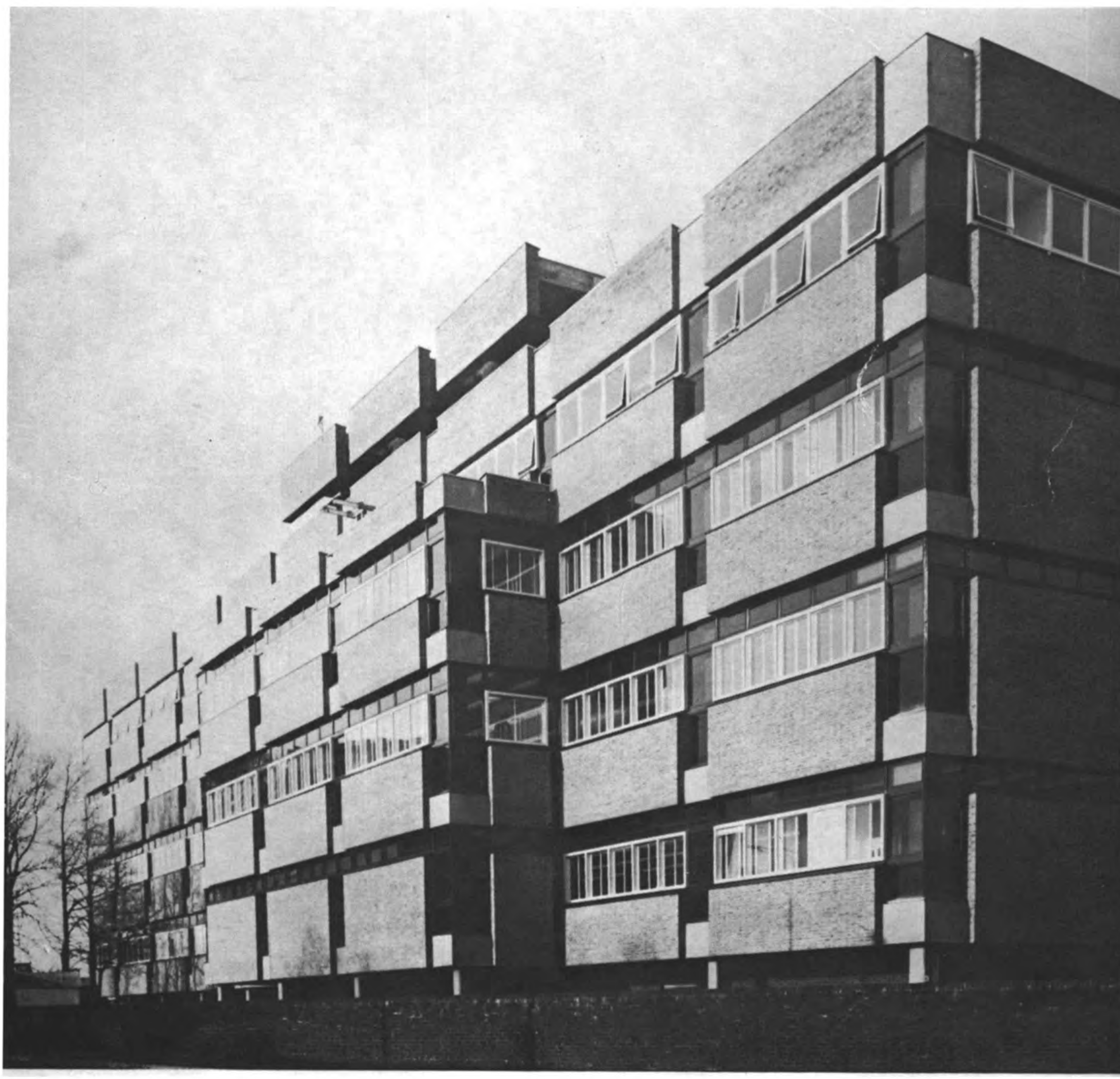
METEOROLOGICAL OFFICE

ANNUAL REPORT 1971



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ANNUAL REPORT
ON THE
METEOROLOGICAL OFFICE

1971

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

LONDON
HER MAJESTY'S STATIONERY OFFICE
1972

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Cover photograph by R. K. Pilsbury

FOREWORD BY THE DIRECTOR-GENERAL

The past year brought tangible evidence of plans formulated five years ago for the modernization and re-equipment of the Office in the shape of three new buildings in or near Bracknell and the installation of important new facilities. The highlight was the installation of the new giant IBM 360/195 computer in the new Richardson Wing (see cover) of the Headquarters building. After delivery of the computer on schedule in mid-October, the installation, testing and acceptance trials were all completed in less than eight weeks and the installation was handed over for operational use on 13 December (see Plate I). It is now being used to test complex mathematical models of the atmosphere that have been developed for operational forecasting and research. The object of one such model is to predict the evolution of major weather systems over the northern hemisphere for several days ahead, while a similar but more refined version aims to provide detailed forecasts, particularly of rainfall, over Europe for up to 36 hours ahead. It is hoped that these two models will replace the much simpler one now in use and provide the main base for operational forecasting in the Office before the end of 1972. The fact that the new computer, which is about 80 times as powerful as our existing machine, has come so quickly and easily into service, owes much to the efficiency and industry of the staff who have worked very hard and successfully to prepare and test our very large and complex programmes on a prototype machine in the United States of America so that they would be ready to utilize our machine from the outset. Some measure of the likely impact of this greatly increased computer power on our work is given by the fact that the research team developing a model of the global circulation of the atmosphere were able to carry out more computations during the first month of the new computer than during the whole of the previous three years.

An important step was also made in modernizing the telecommunications facilities at Bracknell by the completion of the first phase of a long-term programme to install a fully-automated, computer-controlled system for the collection, checking, correction, storage and onward transmission of meteorological data as a part of the global telecommunications system of the World Weather Watch. During the year a computer-controlled message-switching system was installed and accepted to allow a two-way exchange of information between Bracknell, Washington, Paris and Offenbach. Later the system will be extended to deal with other collecting centres in Europe and within the United Kingdom, and will include more-sophisticated methods of error detection and control, automatic selection, editing and compilation of data, but these developments are likely to be spread over about five years.

At last our severe accommodation problems in Bracknell have been alleviated by the completion of new building for instrument research and development at Beaufort Park, Easthampstead (see Plates II and III) and the partial occupation of the newly-completed Richardson Wing. The latter, which already houses the new computer, will also accommodate the new Central Forecasting Office and telecommunications system. It is a fine building and will provide a worthy setting for our responsibilities as a major Regional Meteorological Centre and Telecommunications Hub of the World Weather Watch. It is expected to be ready for full occupation early in 1972. The new Meteorological

Office College at Shinfield Park, near Reading, was also completed during the summer (see Plates IV–VI). Equipped with study-bedrooms for about 100 students and with fine laboratories and lecture rooms, it is expected to play a major role in the future professional and cultural life of the Office and, for the first time, provide accommodation worthy of an institution which has provided training for meteorologists from more than 60 countries. I wish to express my appreciation to the Department of the Environment, not only for providing us with such excellent accommodation but for showing much imagination and skill in overcoming the many problems which have confronted them on difficult sites.

Demand for meteorological information and advice of all kinds continued at a high level although the number of non-aviation inquiries answered by the staff fell slightly from 1·64 million to 1·54 million—the first drop for many years. This can probably be attributed to the weather of 1971 being relatively quiet and to the influence of the postal strike. The number of forecasts for aviation showed little change at 1·4 million.

Turning now to research, another phase in Project Scillonia was completed early in the year when three aircraft, several radars and special radiosonde soundings were used in a detailed study of the cloud structure, rainfall and air motion associated with warm fronts (see Plate III). Analysis of the data is now well advanced and is yielding important information on the banded structure of the rain from these frontal systems. The present technique of determining the wind field with ground-based radars by following sondes dropped from aircraft may be replaced in the future by an airborne tracking system based on the LORAN-C navigational aid.

A new investigation into the physics of the formation and dissipation of fog was initiated at Cardington in the autumn. It is hoped to make progress with this very intractable problem by studying in much more detail than hitherto the correlations between the heat balance, the net radiation, turbulent mixing of the air, and droplet formation on the aerosol particles.

It has been demonstrated in the laboratory that hail particles may become electrically charged by collision with small water droplets in the presence of an external electric field and this provides a promising mechanism of thunderstorm electrification, which was the subject of my Bakerian lecture to the Royal Society in November.

The powerful radar in the 25-metre-diameter steerable reflector at the Royal Radar Establishment, Defford, continues to provide new insight into the structure and dynamics of the optically clear atmosphere (see Plate VII). In particular it has been used to study the production of clear-air turbulence by unstable breaking waves, to investigate waves forming in the lee of the mountains, and to identify regions of preferred thunderstorm development some hours before the first outbreaks of rain.

Measurements of the density of ozone in the high atmosphere were made on a BLACK BRANT rocket launched from Fort Churchill, Canada, and similar experiments were made from a balloon released from White Sands, New Mexico. In a joint experiment with the National Physical Laboratory, measurements of water vapour in the stratosphere up to heights of 30 kilometres were made by a microwave interferometer on a balloon launched from Cardington. A total of 33 SKUA rockets were fired from South Uist and Aberporth to measure winds and temperatures in the high atmosphere.

Work has continued on the development of techniques for measuring the structure of turbulence in the atmospheric boundary layer over both land

and sea, and instruments developed for measuring wind and temperature fluctuations on the cable of a large tethered balloon were used simultaneously with observations of turbulence by the high-powered radar at Defford and with soundings made with a microwave refractometer by the Radio and Space Research Station.

The Geophysical Fluid Dynamics Laboratory has continued its theoretical and experimental studies on the dynamics of rotating fluids and has made considerable progress with the difficult problem of determining the three-dimensional distribution of temperature and motion within the body of the fluid. Dr Raymond Hide's outstanding contributions in this field were recognized by his election to the Fellowship of the Royal Society in March.

In the international field, the Sixth Congress of the World Meteorological Organization, attended by delegates from 133 Member States, was held in Geneva during April. Congress reviewed the structure and functions of the Organization and made a number of important changes in the structure of the technical bodies and the Secretariat. Much attention was given to the planning and implementation of the World Weather Watch and the Global Atmospheric Research Programme. The first phase of World Weather Watch, covering the period 1968–71, though having gone more slowly than some of us had hoped, nevertheless made substantial progress and in some areas, particularly in the field of satellite technology, advanced more rapidly than we expected. The global observational system is still seriously deficient particularly in the oceanic and the tropical regions, and it is to be hoped that remote soundings from satellites will be able to fill the most serious gaps within the next few years. In this regard, the recent decision of the European Space Research Organization to build a European meteorological satellite will be widely welcomed and the Office is making plans to help deal with the large quantities of data that will be produced by this satellite from about 1976. The first major activity planned for the Global Atmospheric Research Programme is an international investigation into weather systems in the tropical Atlantic. This experiment, which is likely to involve ships and aircraft from several nations, is being planned for the summer of 1974. An international Board of Management has been established under my chairmanship and an international group of scientists to plan and manage the experiment is being assembled. The Board has accepted a U.K. invitation to house this group at Bracknell.

After the WMO Congress, the Office acted as host to the Directors of Meteorological Services from 13 Commonwealth countries who came to Bracknell for a week of informal discussions on problems of common interest and concern.

Recruitment at all levels has remained satisfactory with virtually full manning in all grades. The high standard of recruitment into the Scientific Officer class has been fully maintained and there has been a slight increase in the number of graduates in the Experimental Officer class. The large turnover of Scientific Assistants remains a problem, giving rise to a shortage of fully trained staff, but recruitment has been good and by the end of the year the grade was virtually at full strength for the first time for many years.

B. J. Mason

January 1972
Meteorological Office
Bracknell, Berks.

CONTENTS

APPENDICES

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) Provision of meteorological services for the Army, Royal Air Force, Civil Aviation, the Merchant Navy and Fishing Fleets.

(b) Liaison with the Meteorology and Oceanographic Service Division of the Navy Department and provision of basic meteorological information for use by that Service.

(c) Meteorological services to other government departments, public corporations, local authorities, the Press, industry and the general public.

(d) Organization of meteorological observations, including radiation and atmospheric electricity, in the United Kingdom and at certain stations overseas.

(e) Collection, distribution and publication of meteorological information from all parts of the world.

(f) Maintenance of certain British observatories.

(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.

Except for the common services provided by other government departments as part of their normal function (e.g. accommodation by 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 on the Meteorological Office, including that on the common services, was approximately £15·1 million in 1971. Of the amount chargeable to Defence Votes, about £7·6 million represents expenditure associated with staff and £7·2 million expenditure on stores, communications and miscellaneous services. Some £2·6 million was recovered from other government departments and outside bodies in respect of special services rendered, sales 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 1971:

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

Members: Sir Frederic Harmer, C.M.G.
Mr A. F. Hetherington, D.S.C.
Professor J. P. Hudson, M.B.E., G.M.
Professor R. C. Sutcliffe, C.B., O.B.E., F.R.S. (Chairman, Meteorological Research Committee) (*ex-officio*)

Secretary: Mr D. Hanson (Secretary, Meteorological Office)

The Committee met twice in 1971.

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 1971:

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

Members: Professor J. N. Black, F.R.S.E. (University of Edinburgh)
Sir Samuel C. Curran, K.B., F.R.S. (Royal Society)
Professor G. M. Howe (University of Strathclyde)
Dr P. G. Jarvis (University of Aberdeen)
Mr C. Mackay (Department of Agriculture and Fisheries for Scotland)
Mr J. Paton, F.R.S.E. (Royal Society of Edinburgh)
Dr J. M. Rushforth (University of Dundee)
Professor P. A. Sheppard, C.B.E., F.R.S. (Royal Meteorological Society)
Mr J. W. Shiell (Scottish Development Department)
Dr J. H. Steele (Department of Agriculture and Fisheries for Scotland)

Secretary: Mr R. Cranna (Meteorological Office)

The Committee met once in 1971.

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 1971:

Chairman: Professor R. C. Sutcliffe, C.B., O.B.E., F.R.S.

Members: Professor R. L. F. Boyd, F.R.S.
Professor H. Charnock
Professor D. R. Davies
Instructor Captain R. R. Fotheringham, R.N. (Director, Meteorology and Oceanographic Service Division (Naval))
Dr E. R. R. Holmberg (Army Department)
Dr J. T. Houghton
Mr R. F. Jones (Deputy Director, Physical Research, Meteorological Office)
Mr E. Knighting (Deputy Director, Dynamical Research, Meteorological Office)
Dr B. J. Mason, F.R.S. (Director-General, Meteorological Office)
Mr P. J. Meade, O.B.E. (Director of Services, Meteorological Office)
Mr F. O'Hara (Procurement Executive, Ministry of Defence)
Professor R. P. Pearce
Mr J. S. Sawyer, F.R.S. (Director of Research, Meteorological Office)
Mr A. E. Seddon (Natural Environment Research Council)
Professor P. A. Sheppard, C.B.E., F.R.S.
Wing Commander N. E. Wilkins, D.F.C. (Air Force Department)

Secretary: Mr F. E. Dinsdale (Meteorological Office)

The Committee met twice in 1971 and its subcommittees seven times.

PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE

DIRECTOR-GENERAL
B. J. Mason, D.Sc., F.R.S.

DEPUTY TO THE DIRECTOR-GENERAL
P. J. Meade, O.B.E., B.Sc., A.R.C.S.

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PHYSICAL RESEARCH

DEPUTY DIRECTOR	R. F. Jones, B.A.
BOUNDARY LAYER RESEARCH	F. Pasquill, D.Sc.
GEOPHYSICAL FLUID DYNAMICS LABORATORY	R. Hide, Sc.D., F.R.S.
METEOROLOGICAL RESEARCH FLIGHT	D. G. James, Ph.D.
CLOUD PHYSICS	
Assistant Director	P. Goldsmith, M.A.
HIGH ATMOSPHERE	
Assistant Director	R. A. Hamilton, O.B.E., M.A., F.R.S.E.
Special Post	K. H. Stewart, Ph.D.

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SPECIAL POST	R. J. Murgatroyd, O.B.E., Ph.D., C.Eng., M.I.E.E.
SPECIAL INVESTIGATIONS	
Assistant Director	M. H. Freeman, O.B.E., M.Sc.
FORECASTING RESEARCH	
Assistant Director	F. H. Bushby, B.Sc., A.R.C.S.
SYNOPTIC CLIMATOLOGY	
Assistant Director	R. A. S. Ratcliffe, M.A.
Special Post	J. M. Craddock, M.A.
Special Post	H. H. Lamb, M.A.
PUBLICATIONS AND TRAINING	
Assistant Director	K. H. Smith, B.Sc.
DYNAMICAL CLIMATOLOGY	
Assistant Director	G. A. Corby, B.Sc.

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DIRECTOR	P. J. Meade, O.B.E., B.Sc., A.R.C.S.
INTERNATIONAL AND PLANNING	
Assistant Director	D. G. Harley, B.Sc.

FORECASTING SERVICES

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Chief Forecasting Adviser	T. H. Kirk, B.Sc.
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H.Q., Strike Command	E. Evans, M.Sc.
PUBLIC SERVICES	
Assistant Director	L. Sugden, B.Sc.
London/Heathrow Airport	R. E. Farms, B.Sc.

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TELECOMMUNICATIONS	
Assistant Director	E. J. Bell, C.Eng., M.I.E.E.
DATA PROCESSING	
Assistant Director	N. Bradbury, B.Sc.
SYSTEMS DEVELOPMENT	
Assistant Director	E. J. Sumner, B.A.

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DEPUTY DIRECTOR	J. K. Bannon, I.S.O., B.A.
OBSERVATIONAL REQUIREMENTS AND PRACTICES	
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Marine Superintendent	G. A. White, Captain, Extra Master
CLIMATOLOGICAL SERVICES	
Assistant Director	L. Jacobs, M.A., M.Sc.
AGRICULTURE AND HYDROMETEOROLOGY	
Assistant Director	J. Harding, B.A., M.Sc.
Special Post	L. P. Smith, B.A.
OPERATIONAL INSTRUMENTATION	
Assistant Director	M. J. Blackwell, M.A.

SECRETARY, METEOROLOGICAL OFFICE D. Hanson, M.A.

METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION

(at 31 December 1971)

- 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)
    - Deputy Director (Dynamical Research)
      - Met O 20 (Dynamical Climatology)
      - Met O 18 (Publications and Training)
      - Met O 13 (Synoptic Climatology)
      - Met O 11 (Forecasting Research)
      - Met O 9 (Special Investigations)
  - Secretary
    - Met O 10 (Staff)
    - Met O 4 (Equipment)
  - 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)

THE DIRECTORATE OF SERVICES

SPECIAL TOPIC—
THE STANDARDS AND TECHNIQUES OF METEOROLOGICAL OBSERVATIONS

Introduction

The development of meteorological observations obviously followed advances in instrumentation and technology. The early observations were made at, or from, ground level and were relatively simple but progress in engineering and electronics enabled the meteorologist to probe higher and higher in the atmosphere until he can now, with the aid of satellites and television, look down as well as up on the weather and cloud systems. The stage is now being reached where it may become cheaper and more convenient to measure certain parameters by probing the atmosphere from above rather than from below. The development of radar has meant that cloud and precipitation systems can now be studied in detail, both horizontally and vertically.

Meteorological observations are used for a variety of purposes and the requirements of the different users can vary widely; moreover, the responsibility for meeting the user demand is divided among several branches of the Office. For many years, therefore, observational policy was divided among these branches, and this multi-control led to deficiencies and delays in specifying requirements, developing techniques and setting standards. In 1970 this weakness was overcome by the creation of the Observational Requirements and Practices Branch (the new Met O 1) to assume overall responsibility for observational policy. The Branch fills an essential role between instrument development and production on the one hand and forecasting, climatology and hydrology on the other.

Meteorological observations

Meteorological observations are of two types: eye observations which depend mainly on the skill, training and experience of the observer; and observations made by or with the help of one or more measuring instruments. Today there remain only a few meteorological elements which cannot be measured by modern instruments but some of these are very important for certain purposes, for instance cloud amount in fog forecasting. Also, with advances in automation and remoting methods, the comparatively simple measuring devices of yesterday are being replaced by elaborate and sophisticated instrumental systems. These offer many advantages: they are more convenient to use, save manpower, and often provide much more extensive, and in some cases more precise, information than could formerly be obtained. However, it is necessary to ensure that an excess of zeal for the modern does not incur an unacceptable relaxation of standards or degradation of techniques or, on the other hand, lead us to strive for an unnecessary or unrepresentative degree of accuracy.

Meteorological observations are the basic foundation-stones on which are erected the edifices of the theory and practice of meteorology and related scientific disciplines. Should the foundation be faulty, the building will weaken and may fail. Maintenance of the quality of meteorological observations is therefore all-important, and it is necessary to set national and international standards for the training of observers, for the accuracy and exposure of meteorological sensors and instruments, and for quality control.

Required standards of accuracy

The accuracy required of meteorological observations depends on the purpose for which the observations are required. One user may require only a low accuracy but another, using the data for a different purpose, may require much greater precision; a road transport manager or a building supervisor may be content with 'frost' or 'no frost' but to an electricity load engineer a change of only one degree Celsius at that level of temperature is vital. Moreover, user requirements change, often because the user's own technology has advanced and with that advance he is required to work to closer margins. Since past meteorological records are frequently applied to the solution of present and future problems it is necessary, when setting standards of accuracy, to anticipate the refinements that these future problems may require in the basic meteorological data.

Attainable standards of accuracy

No matter what the requirement, there is a limit to the accuracy attainable in an instrumental measurement of a meteorological parameter characterizing the physical state of a sample of the atmosphere at any particular instant in time or position in space. It is limited partly by the instrument itself: a device capable of extreme accuracy, yielding measurements with negligible systematic and random errors, is inevitably costly, sophisticated and not as reliable in the field as in the laboratory. To minimize this difficulty, a single such device may be set up as a national, or international, standard reference instrument. Operational field instruments are then brought in periodically for calibration against this reference. Or, alternatively, an intermediary travelling standard instrument, checked against the reference instrument, is sent out to calibrate the instruments in the field. Standards of accuracy of instruments measuring solar radiation and atmospheric pressure at observing stations are maintained in this way.

Another and more fundamental limit to attainable precision, and one which predetermines a point beyond which further refinement of the measuring system is not worth while, is set by the atmosphere itself, which has its own variability. The air, like the sea, is ever changing, and the same portion of it can never be sampled twice. For instance, at any particular moment a sample may be at a temperature which may be regarded as made up of that value representative in space and time of the environmental air (the measurement required), plus or minus a random departure, characteristic only of that particular sample at that particular time, resulting from natural spatial and temporal variability. This is the concept of 'signal' (the representative value to be measured) and 'noise' (a superimposed random element which must normally be removed from the measurement). It can be shown by developing this concept that there is little to be gained in accuracy by using a measuring system capable of a precision greater than half the amplitude of the naturally occurring 'noise'.

Data on the natural variability of an atmospheric parameter (if available) provide, as does an absolute reference instrument, both a standard against which the accuracy of routine observations of that parameter may be compared and a limit beyond which reduction of random observational error is unnecessary.

Applications of standards

This technique has been applied to the assessment of standards of accuracy of dew-point observations taken by means of a dewcel (a lithium chloride dew-point sensor) instead of by the conventional screen wet- and dry-bulb psychrometer. This latter measures dew-point with a random error of 0·1 degC, whilst the naturally occurring random variations in dew-point over a level piece of grassland at Kew amount to 0·27 degC. Field trials of a dewcel indicate that this instrument measures dew-point with a random error of 0·17 degC. Although this is larger than the screen error, it is still only a little greater than half the naturally occurring variability, and so there is little to be gained by attempting further to reduce the random errors of the dewcel. These figures mean that departures of more than 0·5 degC from the representative value of the dew-point may be expected to occur in nature on about 6 per cent of occasions; they will be noticed by an observer on about 9 per cent of occasions if he uses the conventional screen psychrometer and on about 12 per cent of occasions if he uses a dewcel.

As regards upper air observations of temperature, the limit of random error in the temperature sensing system beyond which a further reduction in observational error is unnecessary is about 0·15 degC. Random errors in the present operational Mk 2B radiosonde, determined from a series of twin flights of these instruments, have been assessed at about 0·8 degC. This radiosonde, first designed a quarter of a century ago, clearly falls far short of the ideal. One of the principal virtues of its successor, the new Mk 3 radiosonde, is that from preliminary trials it is confidently expected to show random temperature errors in the troposphere close to the optimum target of 0·15 degC.

Surface observations—land

Surface observations are needed chiefly for synoptic, climatological and hydrological purposes. Recommendations regarding the density of the various networks of observations are issued by the World Meteorological Organization (WMO) but these are modified to meet national requirements. A committee of the heads of appropriate branches, chaired by the Head of the Observational Requirements and Practices Branch, is responsible for keeping these networks under review and for making recommendations regarding additions or changes. The policy for synoptic observations is to have a skeleton network of 24-hour stations manned by professional staff of the Office while the rest of the network consists of stations open for only part of the time but professionally manned and stations manned by trained auxiliary observers. The distribution of synoptic stations in the U.K. is shown in Figure 1. Spatial quality-control is based to a great extent on the stations manned by meteorologists. The climatological and hydrological networks, which are much denser than the synoptic one, depend to a great extent on voluntary and auxiliary observers. The Office records its thanks to all these voluntary and auxiliary observers for their conscientious and valuable work.

Guide-lines on observational techniques are laid down internationally but these allow considerable national latitude provided world observations remain compatible. As with most other techniques, development is towards a reduction in manpower by automation, and the foreseeable aim is a completely automatic weather-observing system capable of transmitting and recording all its data.

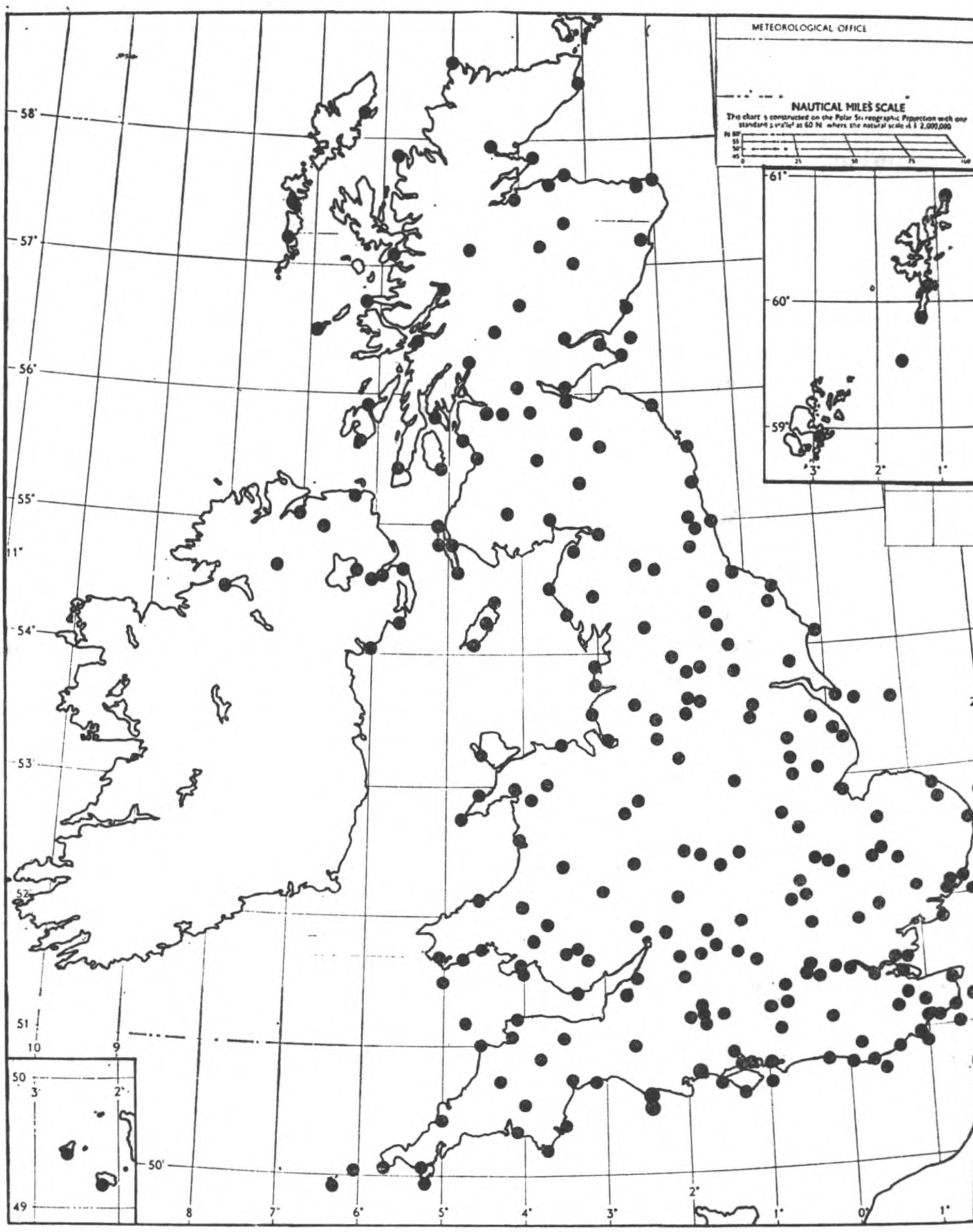


FIGURE 1 — UNITED KINGDOM NETWORK OF SURFACE SYNOPTIC STATIONS

On-the-way developments include cloud-base recorders, transmissometers for measuring visibility, electrical-resistance thermometers, dewcels for measuring humidity and automatic rain-gauges capable of registering rate of rainfall. Some of these instruments are already in operational use, others are on operational trial. The trials ensure that measurements from the new instruments are comparable with those from the instruments which are being replaced.

Upper air observations

The early meteorologists appreciated the importance of exploring the atmosphere and soundings were made by thermometers attached to kites as early as the eighteenth century. The first manned balloon ascents to study conditions in the atmosphere were made about 1784. By the latter half of the nineteenth century systematic soundings were made by recording apparatus carried aloft by both captive and free balloons. In the latter case, several weeks might elapse before the recording apparatus was returned to the station of origin but in those leisurely days observations were not tied to a tight forecasting schedule. Upper winds were measured by a method, devised early this century, which involved following a small free hydrogen-filled balloon by means of a special theodolite, but the method could not be used when cloud was present.

The development of aviation, and the First World War, started the exploration of the atmosphere by aircraft. Between the wars this led to the organization of regular flights by the Royal Air Force to measure temperature and humidity up to the ceiling of its aircraft. These flights, which continued until the establishment of the radiosonde, were of inestimable benefit to meteorology and weather forecasting and the RAF can be proud of its all-weather record.

The radiosonde

Continued advances in aviation and the outbreak of the Second World War increased the urgency for a rapid method of measuring pressure, temperature, humidity and wind in the upper air. This resulted in the introduction of the radiosonde operationally in about 1942. The radiosonde used by the Office is a simple, lightweight (1235 grammes, including the battery) radio-transmitter, designed to operate on a frequency band between 27·0 and 30·0 megahertz. The carrier wave is modulated by an audio-frequency oscillator into whose circuit are switched in turn three variable inductances controlled by the meteorological elements. A 'windmill', driven by the slipstream of the rising balloon, operates the switch. The transmitter is powered by a special lightweight battery. The radiosonde, its aerial and a parachute are suspended from the balloon by string.

The vital parts of the radiosonde are, of course, the meteorological sensor units. They are all similar in construction; each consists of a pair of coils and a movable armature the position of which, relative to the coils, determines the audio-frequency. The movement of the armature is controlled:

(a) in the pressure element by an aneroid capsule,
(b) in the temperature element by a bimetal strip and
(c) in the humidity element by a strip of gold-beater's skin.

The signals from the radiosonde are received by a sensitive short-wave receiver and various methods are available for measuring the audio-frequencies. Currently the Office uses automatic equipment which measures the frequencies and conveniently displays these measurements on a chart record.

Before use each radiosonde is calibrated so that, in simplest terms, readings of audio-frequency can be changed into values of pressure, temperature and humidity by reference to an appropriate graph. However, various errors occur in the readings from the radiosonde and these have to be corrected. They are:

(a) the departure from the original calibration,
(b) the effect of temperature on the pressure element,
(c) the effect of solar radiation on the temperature element and
(d) the lag of the temperature element.

These corrections are made by using techniques and data developed from research into these problems.

During its flight the radiosonde used to be tracked by radio direction from three ground stations, and upper winds could be computed from the data obtained by these stations. This system was replaced by radar wind-finding shortly after the end of the Second World War.

Radiosonde technique

Before each sounding the radiosonde is checked physically and electronically, and any departure from the calibration is evaluated. A sounding balloon is filled with hydrogen and the radiosonde and a parachute are attached, the radiosonde being at least 40 metres from the balloon to minimize the effect of a warm wake from the ascending balloon heated by solar radiation. The balloon and radiosonde are released and automatic recording of the signal from the instrument commences. The balloon is filled so that it should rise at about 6 metres per second; at this rate the windmill-driven switch brings each meteorological element into circuit, in turn, for 6 seconds. Hence temperature is sampled for 6 seconds then there is a break of 12 seconds before the next temperature signal is received. There must, therefore, be a gap of 72 metres without a temperature reading. The record appears as three broken traces, one each for pressure, temperature and humidity. The pressure trace is a smooth curve because of the gradual decrease in atmospheric pressure as the radiosonde ascends. The temperature and humidity traces represent the temperature lapse and the hydrolapse respectively and are subject to sharp changes, often at frequent intervals. These traces are joined by a series of straight pencil-lines in order that sharp changes in lapse rate can be readily identified, often by interpolation. Points of sharp change ('turning points') on the temperature and humidity traces are selected for computation and the pressure values at these points are also extracted. These are values of audio-frequency but are subsequently converted into the normal meteorological elements and corrections are then applied. From the corrected values it is a straightforward task to compile an upper air message in the standard WMO form for transmission to all users.

Radar wind-finding

For wind-finding the Office uses a pulse radar of 10-centimetre wavelength which gives readings of the azimuth, elevation and range of a reflecting target carried by a hydrogen-filled balloon which may also carry a radiosonde at the same time. Readings are taken at one-minute intervals and are used to determine the height and horizontal range of the reflector. In determining the height of the reflector above mean sea level, allowance has to be made for the effect of curvature of the earth. The horizontal ranges are plotted against azimuth, and wind speeds and directions at any height or pressure level can be read off directly by means of a suitably modified drafting machine. Significant wind levels are selected in such a way that from them it is possible to reconstruct the wind profile within specified limits laid down by WMO.

Routine

At present the Office operates eight upper air stations in the U.K. and five overseas and makes upper air ascents from Ocean Weather Ships and other ships at sea. The normal daily programme is a combined radiosonde/radar-wind ascent at midnight and midday GMT and additional radar-wind ascents at 06 and 18 GMT.

Observations at sea

Meteorological observations from neighbouring sea areas are very important, especially to island nations such as the U.K. The replacement of conventional cargo-ships by faster and much larger specialized ships is leading to a smaller mercantile marine. In spite of this, the numerical strength of the Voluntary Observing Fleet has been maintained and their weather reports are much appreciated. Regular surface and upper air observations from the North Atlantic are vital and the introduction of numerical weather forecasting increased rather than decreased the importance of these data; the Ocean Weather Ships in the North Atlantic are therefore of prime importance. Plate VIII shows the launch of a radiosonde from a British Ocean Weather Ship. The recruitment of voluntary ships to make upper air ascents at sea has started but progress is handicapped by lack of suitable ships and staff. The observations are made by a meteorologist who joins the ship's complement for the purpose.

The development of satisfactory observational techniques and the setting of acceptable standards are more difficult at sea than on land. It is obvious that great difficulties are associated with factors such as an unstable travelling observing site, breaking waves and sea spray, absence of visibility objects, ship-generated heat, etc. Work continues on problems such as the exposure of thermometer screens, measurement of rainfall and sea surface temperature, estimation of rain intensity, but many of these problems are proving intractable.

Special observations

This heading covers a wide spectrum of observations, from simple surface-reports to ones made by a Jumbo Jet crossing the Atlantic and to weather-radar observations. Short special surface-reports may come from the AA, RAC, Police and Fire Services, and road engineers. During the war the RAF operated a series of routine weather-reconnaissance flights which continued for some time after the war but have now ceased. Observations continue to be made, however, by the crews of military and civil aircraft during their normal flights. The Office takes advantage of this opportunity to record its gratitude to all the individuals concerned.

The Office operates seven thunderstorm-location stations, four in the U.K. and three in the Mediterranean (Figure 2). The principle is to obtain the bearing of an atmospheric simultaneously at two or more stations by means of cathode-ray direction-finders; the source of the signal can then be located. These observations provide data on thunderstorm activity in western Europe, the eastern North Atlantic and the Mediterranean.

Detailed knowledge of the temperature, humidity and wind profiles in the lowest 2000 feet (600 metres) or so of the atmosphere is required for problems such as fog and low-cloud forecasting, air pollution, and turbulence. These observations can be obtained from instruments carried aloft by tethered balloons, as is done at Cardington. An alternative technique is to install instruments on tall masts, as at Lichfield.

The use of weather radar as an observational network tool in the Office is very much in the development stage but X-band (3-cm) radars have been in

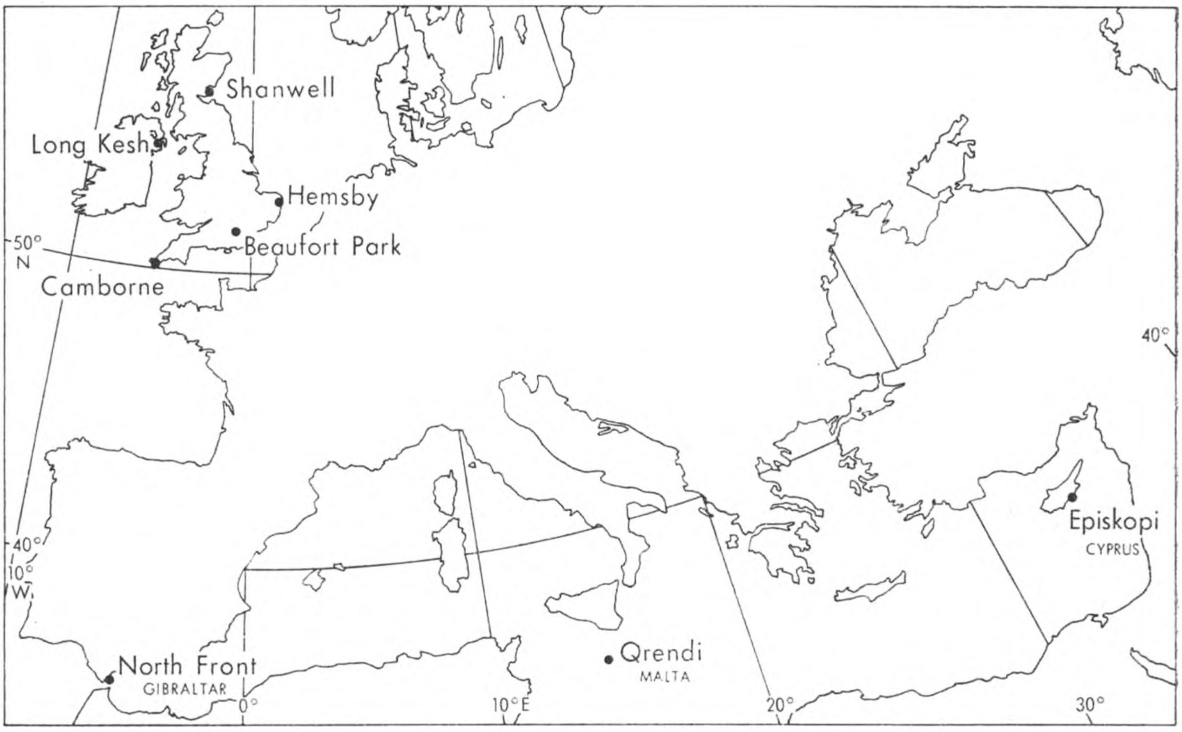


FIGURE 2 — POSITIONS OF STATIONS FORMING THE THUNDERSTORM-LOCATION NETWORK
The control centre is at Beaufort Park, near Bracknell

operation for many years at some home and overseas stations, and an S-band (10-cm) weather radar is working at Gan in the Indian Ocean. The weather radar is designed to display on a cathode-ray tube the precipitation picture within its range. The equipment has been used almost entirely for short-term local forecasting and the technique has been successful although the X-band radars are limited by the marked attenuation of the signal from more distant targets by nearer rain.

Radiation measurements

The measurement of the intensity of solar radiation at the earth's surface is an important meteorological observation because solar radiation is the only appreciable external source of energy for the earth–atmosphere system. Measurements are made at a number of Meteorological Office stations and on Ocean Weather Ships. Kew Observatory acts as the National Radiation Centre and also assists other authorities who make radiation measurements. 'Radiation' from the sun covers electromagnetic radiation of an extremely wide range of wavelengths, from gamma rays to radiation of radio wavelengths, together with particles of various kinds, and all these are important in some respects. However, from the point of view of the energy exchange at the surface of the earth it is possible to restrict attention to electromagnetic radiation in the wavelength range 0·29 to 4 micrometres (μm); 99 per cent of the energy is contained within these wavelengths. Energy units are used to express the observations, i.e. intensities in milliwatts per square centimetre (mW/cm^2) and amounts in milliwatt hours per square centimetre (mWh/cm^2).

The measurement of electromagnetic radiation (hereafter abbreviated to radiation) is not easy and to obtain reliable and accurate results considerable care and attention to detail is necessary; the instruments used have to be checked regularly. The primary standard instruments, which are kept at Kew, are a group of Ångström pyrheliometers, which measure direct solar radiation at normal incidence. Their calibration constant was originally determined by comparison with an absolute instrument of the same type at Stockholm, but one or other of the group is regularly compared with other international standard instruments at intervals (usually 4 years) at meetings organized by WMO. The pyrheliometers at Kew are, of course, intercompared regularly by using the sun as a source of radiation.

The Ångström pyrheliometer, however, is not suitable for continuous recording of the flux of solar radiation on a horizontal surface, which is the most useful meteorological measurement, and for this purpose thermopile instruments known as pyranometers are used. These instruments produce an electrical output proportional to the radiation and this output can be recorded in a number of ways. Each pyranometer, however, must be calibrated as an individual and this is done by a two-stage process. A few selected pyranometers (working standards) are calibrated out-of-doors on very clear days by reference to the Ångström pyrheliometer, and these working standard pyranometers are then used to calibrate the routine pyranometers by using an indoor artificial source of diffuse radiation (an integrating sphere). In this way reliable routine calibrations can be carried out in a relatively short time. Calibrations out-of-doors using solar radiation itself can only be carried out when the sky is very clear and the solar radiation is relatively steady; this is not a frequent occurrence in the U.K. In May of this year a working standard pyranometer was taken to Washington, U.S.A., to take part in an international comparison of pyranometers organized by the International Solar Energy Society.

The electrical output from the pyranometers has to be recorded and for the past 9 to 10 years a digital data-logging equipment (MODLE) giving an output on punched paper-tape has been used. It is proposed to replace this in due course with a new system recording on magnetic tape. The output from the MODLE is processed on the Meteorological Office computer and the results are stored on magnetic tapes.

To maintain accuracy, regular checks are made at each station measuring radiation. Each station usually has two pyranometers, one measuring the total flux of solar radiation on a horizontal surface and the other the diffuse component only. These two instruments can be compared on selected clear days, ideally every two months. At yearly intervals a freshly calibrated pyranometer is sent from Kew to the station. This third instrument is intercompared with each of the existing station instruments, and the older of the two station instruments is then sent back for recalibration. In this way a regular and continuing check is maintained on each instrument and any change in performance (due perhaps to corrosion or other deterioration) is detected and remedied quickly. It is also necessary to check the recording system regularly and this is done by standard electrical techniques.

Measurements are also made of illumination; this can be defined as solar radiation evaluated in accordance with its ability to stimulate the human eye, which is sensitive only to wavelengths in the approximate range 0·4 to 0·7 μm. These measurements are expressed in light units, i.e. lux (lx) or lumens per square metre (lm/m^2), and the standard is a collection of tungsten lamps calibrated at the National Physical Laboratory.

Some measurements are also made of net radiation or radiation balance. This is the net difference between the downward or incoming radiation of all wavelengths (solar plus atmospheric thermal radiation) and the upward or outgoing radiation (reflected solar radiation plus thermal radiation from the surface). The instruments used in making these measurements are calibrated by using a laboratory source of radiation, a tungsten filament lamp, which in turn is calibrated by reference to the Ångström pyrheliometer.

It is necessary to carry out the same careful procedures for illuminometers and radiation-balance meters as for solar-radiation instruments, i.e. regular intercomparisons at the stations and recalibrations at Kew, if reliable results are to be obtained.

Automation and the future

A meteorological observation consists partly of eye observations or estimates and partly of readings of various instruments. The subjective eye observations are being replaced more and more by instruments capable of measuring and recording the elements concerned, but a few elements such as weather, sunshine and cloud amount are not as yet amenable to this treatment. However, the stage has been reached where automatic observing systems are within sight.

There are two main types of automatic system:

(a) The automatic climatological station where data can be recorded, and even partly processed, in a form which is computer-compatible, e.g. magnetic tapes, the data being stored and collected as operations demand. This method can also be applied to individual instruments such as rain-gauges and anemographs.

(b) The synoptic automatic weather-observing system where the data are required at the collecting centre almost immediately on request by telephone. These stations will store data for about 10 meteorological elements and these data will be updated every 5 or 10 minutes. Thus the telephone interrogator will receive an up-to-date observation in the form of a printed message which can easily be converted to the standard code for inclusion in normal meteorological broadcasts. The synoptic automatic stations can only supplement, rather than replace, the manned stations until development reaches the stage where the 'missing' elements can be measured by instruments.

The stations are designed with the capability of working from either the public electric power supply or batteries, in order that their use can be extended later to remote land sites and to buoys and unmanned platforms off the coast. However, present plans are to charge the batteries from the public electric power supply because some of the sensors are not yet suitable for prolonged operation from batteries. For really remote use these particular sensors will have to be modified or replaced by more suitable ones.

The introduction of the Mk 3 radiosonde system in about two years' time will also involve automation. At present the radiosonde signals and the radar-wind data are analysed manually, but when the Mk 3 system is in use both sets of data will be fed into an on-line mini-computer for analysis, and the computer will produce both a final coded message ready for transmission to the collecting centre and a magnetic tape of the ascent for archival purposes.

General

The year 1971 was one of sustained activity both in providing services to the wide range of users of meteorological information and in bringing nearer to completion the implementation of plans which had been prepared in earlier years. In many respects 1971 was a year of fulfilment. The giant computer was delivered and installed in the new Richardson Wing on which substantial progress was made, although full occupation was not possible by the end of the year. A new building for the Operational Instrumentation Branch at Beaufort Park was completed and it then became possible to bring together all the various activities of this Branch. Important progress was made in modernizing the telecommunications facilities, but more remains to be done before Bracknell and other important international centres are able to provide the Global Telecommunications System with the operational capability which meteorological services require.

An important milestone on the organization side was the creation of a new Deputy Directorate for Communications and Computing. Within this Deputy Directorate the Data Processing Branch (Met O 12) and the Telecommunications Branch (Met O 5) have been brought together in company with a new Branch (Met O 22) responsible for Systems Development. This structure was seen to be required because the Office's facilities for the reception, processing and transmission of data are being replaced by new systems, which are mutually supporting and based on modern technology, providing speed, flexibility and scope very greatly in excess of anything previously available. With current and future trends in meteorology and in neighbouring disciplines like oceanography and hydrology there is already a high premium upon the efficient utilization of computing and telecommunications facilities. The new Systems Development Branch has therefore important responsibilities over the whole changing field of data handling.

Forecasting Services

Central Forecasting Office

The work of the Central Forecasting Office (CFO) has remained much as in recent years. Its primary task is to provide guidance to the outstations of the Office, mainly by means of charts, depicting actual and forecast synoptic conditions, augmented by advisory texts covering the next two to three days. In providing this service the senior forecaster has the assistance of computed surface-weather charts from the International Computers Limited KDF9 computer in the Meteorological Office and of American computed charts. These charts in no case provide details of the actual weather to be expected, but merely provide the pressure patterns from which the forecaster has to infer the weather. The senior forecaster is at liberty to adopt the computed charts, which of course show variations between themselves depending on the atmospheric models and methods of computation adopted, to any extent he chooses. It is hoped that more objectivity will be possible when new models of the atmosphere are used in conjunction with the new International Business Machines IBM 360/195 computer which was installed late in the year.

All upper air analyses and forecasts, with the exception of those for the 50-mb, 30-mb and 10-mb levels, are made objectively on the KDF9 computer and are produced in chart form by an electro-mechanical line-drawer in most instances ready for despatch to outstations by land-line facsimile. Many of these charts are also broadcast by radio-facsimile.

CFO also assists the outstations by plotting hourly weather charts for the British Isles and three-hourly charts for the western European area. These are transmitted to them by facsimile and thus obviate the necessity for such charts to be plotted at the outstations.

The advisory texts mentioned earlier are augmented in some instances by telephone conferences with staff of some of the major outstations responsible for producing forecasts for all or some part of the United Kingdom. In particular frequent talks are held with the staff of London Weather Centre, which is responsible for extempore television and radio broadcasts for the whole country. Conferences are held regularly also with staff of the offices at Gloucester and Prestwick, in relation to the expected weather over Wales and Scotland respectively.

A second main function of CFO is to provide routine forecast texts for sea and land areas and to issue notifications of expected specified weather such as fine spells, or warnings of hazardous conditions. These are intended primarily for dissemination by the Press and radio, but some are issued direct to public utilities such as the Central Electricity Generating Board (CEGB) and to industry. The hazardous conditions for which warnings are issued include gales for land and sea areas, fog, snow, icy roads, thunderstorms, frost, thaw, strong upper winds and ice accumulation on ship superstructures. Notifications are also issued for expected periods of propitious weather such as fine-spell periods of three days for farmers, or calm seas for delicate towing operations or erection of light-towers.

CFO is also a Regional Meteorological Centre (RMC) within the framework of World Weather Watch (WWW). The latter is a concept, ratified by the Congress of the World Meteorological Organization (WMO), whereby the meteorologically more advanced nations assist those less advanced. This is achieved by the establishment of three World Meteorological Centres; at Washington, Moscow and Melbourne; and by a number of RMCs. CFO has undertaken to meet stated needs of various countries in Europe for certain regional forecasts. This it does by the preparation, for wireless-telegraphy and radio-facsimile transmission, of actual and forecast charts covering a large area of the North Atlantic Ocean, Europe and the Arctic.

Analyses and forecasts of wave heights and directions are produced as routine by computer for the North Atlantic area, for periods up to 48 hours ahead. These are broadcast as a WWW requirement for the benefit of other European maritime nations and of ships at sea. They are also the basis of the ship-routeing service provided by CFO.

Unfortunately it is not possible to report continued progress in the number of ships routed during 1971, the number having fallen from 350 in 1970 to about 220. It is hoped and expected that this decrease will be temporary, as it is due in large measure to reorganization in two large shipping combines. There is no doubt that the object of the routeing is achieved in most instances. The aim of this service is to provide ships with advisory routes or courses to steer, so that the time of crossing will be the least, commensurate with the avoidance of wave conditions liable to cause damage to the ship or its cargo. The speed of the vessel in various states of sea must be known approximately beforehand. To obtain this information a Nautical Officer visits the ship in port prior to its first routed voyage and extracts data from the ship's logs to enable him to draw graphs of the ship's performance in relation to the wave height for various relative directions of approach between ship and waves, i.e. waves from ahead, beam or aft. The speed is then calculated along various possible tracks in relation to the predicted wave-fields, and some regard is paid to the general conditions expected in the outlook period beyond 48 hours ahead. A number of other factors, such as the likelihood of fog or ice and the direction and speed of the ocean current, are considered before advice is offered to the master. He may also have asked for special conditions, which may be important on the particular voyage, to be taken into account. Normally the master is contacted by telephone in port shortly before sailing, and regular advice and forecasts are sent to him thereafter at least as frequently as every 48 hours, through the Post Office Corporation transmitter at Portishead (near Bristol).

The Department of Trade and Industry (DTI) ship *Miranda* was stationed off the Icelandic coast from January to the end of April in order to provide weather information as well as medical and repair services to British trawlers operating in that area. A forecast and warnings service, originated in CFO at Bracknell, was passed by direct radio link from Portishead to *Miranda*. A forecaster on board *Miranda* was responsible for completing the link to the trawlers and also for keeping Bracknell informed of weather conditions encountered by maintaining a regular sequence of weather observations. A similar service is being provided for the winter 1971–72 and *Miranda* has been on station since 29 November 1971.

Cloud photographs from the automatic picture transmission (APT) of the United States ESSA weather satellites have continued to be received by direct interception at Bracknell daily. They are a routine aid in the preparation of surface analyses over the North Atlantic and European areas. Interpretations of the pictures (nephanalyses) have been prepared for issue to outstations by land-line and radio-facsimile. These nephanalyses have been extended to include pictures from all the four orbits from which it is possible to receive. They are of considerable value to the outstations in their day-to-day work and in the briefing of aircrews. In addition some major forecasting outstations and one research outstation receive the APT pictures direct from the Bracknell receiving station by telephone line. The APT unit in CFO is responsible for adding the geographical grid to the pictures and for transmitting it to these selected outstations, so that they can locate the cloud systems geographically.

The plotting and analysis of ice conditions in the northern hemisphere has continued and regular broadcasts are made to assist navigation in waters subject to sea ice, as well as to assist other meteorological services. During the polar spring and summer the APT pictures mentioned above are of considerable value in delineating the edges of the main icefields, though the resolution is insufficient to depict individual icebergs. Unfortunately the U.S.A. satellite from which infra-red pictures had been received in 1970 failed during June 1971, so that insufficient time has elapsed for their full potential to be exploited, especially in relation to sea ice during the dark Arctic winter. The ice charts also show sea temperature isotherms. Separate charts of isotherms are also issued on a daily basis for coastal waters of the British Isles. The temperature data for these purposes are all processed by computer.

Much of the work of CFO has marine applications, as exemplified by the well-known Shipping Forecasts and gale warnings broadcast by the BBC and Post Office. Some of the lesser-known aspects of its work in 1971 included daily forecasts until November for the oil drilling ship *Glomar North Sea* for a position off southern Ireland, the forecasting of the movement of a number of oil slicks off our coast and forecasts for Post Office cable-laying vessels in the Shetlands–Faeroes area and in the South-western Approaches.

Forecasts for a week ahead have continued on a regular basis, but although some success has been achieved it is not yet sufficient to warrant publication of the forecasts. Meanwhile the more promising lines of approach continue to be explored. Forecasts for the Bracknell area for 24 hours are now available on tape and may be obtained by dialling Bracknell 24124. This service has reduced the number of telephone calls to CFO considerably.

Arrangements were made to run the 3-level model operational-forecast programme in KDF9 code on the IBM 360/195 computer whilst the new 10-level model is undergoing its testing trials. This work was developed at the IBM test centre at Croydon, and four visits have been made to Poughkeepsie, U.S.A., to test a simulator programme on the IBM 360/195 computer there, no such facilities being available in the U.K. By September all parts of the KDF9 numerical-forecast programme had been run successfully with the simulator at Poughkeepsie.

Much work has also been done in preparing data required for testing the new 10-level model programmes for running on the new computer. Programmes have been written and tested to retrieve data from the newly developed synoptic-data bank and arrange them in the form required for obtaining analyses at all the standard levels up to 100 mb.

Data sets of monthly sea-temperature, and values of saturation humidity mixing ratio derived from them, have been produced for the grid that is to be used for the extended 10-level forecasting model which is being developed to provide forecasts for aviation and shipping over most of the northern hemisphere.

Programmes have also been written and tested to provide, from the results of the 10-level model forecast, the varied forms of output required for aviation, e.g. spot winds and temperatures at grid points and along chosen routes and at selected airports, contour prints from the line-printer and planning forecasts in digital form, which will be sent direct to airline computers.

A considerable amount of work has been done to improve the verification procedures. Verification can now be made against radiosonde observations of temperature and radar observations of wind, and the error of a comparable persistence forecast is obtained for every forecast element checked. These improvements are being incorporated into the FORTRAN programme which will be used during the field trials of the 10-level model to compare its performance with that of the current operational model. Considerable time has been devoted to devising these field trials.

An experimental scheme to apply a standard correction to heights reported by ocean weather stations on the basis of differences from the norm revealed by the 100-mb analysis was introduced early in the year. The corrections are applied automatically and up-dated each day. The scheme is designed to ensure that when an Ocean Weather Ship of different nationality takes over on a given station in the North Atlantic the correction becomes suitably modified within a few days. Results up to the end of May showed that 80–90 per cent of the systematic error was being removed at each of the five stations in the trial.

In the early part of the year further trials of the proposed WMO 'GRID' code for exchanging meteorological fields by means of digital data instead of using facsimile transmissions of charts were undertaken and a number of recommendations were made.

The work which commenced in 1969 on analysis of meteorological fields by means of orthogonal functions has continued, but the pace has been dictated largely by the inadequacy of the KDF9 computer to handle more than some of the fringe problems. However, a major paper on the subject has been written and is in process of publication. A true four-dimensional analysis system remains an urgent requirement in order to incorporate wind measurements from aircraft and temperatures from satellites, both at non-standard times. The advent of the IBM 360/195 computer should allow this work to make much more rapid progress in 1972.

CFO remains responsible for the publication of the *Daily Weather Report* (*DWR*) with its *Overseas Supplement* and *Monthly Summary* and the *Daily Aerological Record* (*DAR*). Copy for these publications, which are printed locally, is largely extracted by computer methods. An innovation during 1971 was the commencement of a series of correction slips to the *DWR*. Each station (with a few exceptions) appearing in the *DWR* sends to CFO corrections of its own observations as printed and these corrections are subsequently published collectively.

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 a number of other forecasting offices whose primary responsibility is towards aviation, or indirectly through the media of radio and television, the Press and the Post Office Corporation's automatic telephone weather service (ATWS).

The demand for weather information showed some decline in 1971, in contrast to the steady growth exhibited in earlier years. The reason for the decline in demand is not clear but contributing factors were, undoubtedly, the Post Office strike early in the year, which inhibited the use of the telephone, and the relatively quiet nature of the weather for most of the year. Direct calls received at all forecasting offices totalled 1 535 523 compared with 1 633 478 in 1970. Table X gives a breakdown of these inquiries according to purpose and it will be seen that the major decreases occurred in inquiries concerned with the building and road transport industries, both very sensitive to adverse weather conditions which were so little in evidence during the year. Inquiries in connection with holiday pursuits continued to occupy the dominant position in the table and, indeed, took a larger share of the total inquiries than in the previous year. As usual, the demand for information showed considerable fluctuation, dependent mainly on the weather, but with other factors coming into play to a greater or lesser extent; for example, the unseasonable weather in June led to a record number of inquiries for the month—at over 168 000 these were some 20 000 above the previous highest total for June—while in October, despite mainly good weather, the London Weather Centre recorded its highest-ever October total of over 22 000 inquiries, thought, in the main, to have been stimulated by extensive Press comment on the London flood risk during the period of exceptionally high tides.

The dissemination of routine forecast information via the mass communications media continued, but with some important changes in detail. Of particular note were the improvements in the 'Weather Bulletins for Shipping', broadcast on Radio 2; with effect from 3 April the time available for the early evening bulletin was increased to 5 minutes, thus permitting the inclusion of a general synopsis and coastal station reports as with the other bulletins, and also the times of two of the broadcasts were changed to give a more even spacing of bulletins throughout the day. A further improvement in services to yachtsmen was secured in Scotland where, as from 7 May, an extra 30 seconds was allotted for the 'live' broadcasts from Glasgow Weather Centre each Friday morning throughout the summer half of the year to permit the inclusion of forecasts of wind conditions in the Firth of Clyde, the Firth of Forth and the Moray Firth; on Saturday mornings a script was provided to be read by an announcer. To meet a specific request from Scottish east-coast fishermen, arrangements were made for sea area Fisher to be included in the shipping bulletins broadcast by the Post Office coastal radio station at Stonehaven.

Following certain changes in schedules on Radios 1 and 2 in May, the time allowance for all the scripted bulletins (other than shipping bulletins) prepared by CFO was reduced from 1 minute to 15 seconds, thus allowing only a short summary to be given in place of the previous national forecast and outlook. Undoubtedly, the change which excited greatest public interest and comment followed the decision taken by the BBC, in consultation with the Meteorological Office, to modify the practice of including Fahrenheit equivalents for all temperatures given in the regional forecasts on Radio 4. With effect from 1 August, where a forecast included just one value for temperature this was given in degrees Centigrade only, together with a qualitative description in terms of comfort, but where two or more values were given, one carried the Fahrenheit equivalent. The subsequent protests led to a question in the House to which the Minister replied that he would not instruct the Meteorological Office to continue to give temperatures in both the Fahrenheit and Centigrade scales.

The BBC opened 4 more local radio stations early in the year, bringing the total in operation to 20. All were supplied with three or four routine forecasts daily together with warnings of exceptional weather as appropriate. Local station managers showed a quickening interest in personal presentations by meteorological staff and by the end of the year routine 'live' broadcasts were being made from 5 stations. In addition, there were numerous requests for *ad hoc* broadcasts to cover special local events or occasions of unusual weather. Radio Newcastle mounted a series of weekly programmes featuring weather topics, the broadcasts being carried out 'live' from Newcastle Weather Centre.

In the field of television, discussions were continued with the BBC with a view to obtaining a mid-evening 'live' presentation on BBC 2, and consideration was given to the transfer of the television weather presentations, currently carried out at the BBC Television Centre, to London Weather Centre. The situation with regard to the independent television companies was again discouraging; vigorous protest followed a further increase in charges for the meteorological service in April—an increase made necessary by the rising cost of providing the service—and three companies opted out; on a more encouraging note, one of these companies resumed the service in November. A comprehensive account of the techniques employed in the 'weatherman' presentations on

BBC Television was prepared in response to separate requests for advice from the Directors-General of the Egyptian and Polish Meteorological Services.

A number of broadcasts and talks were given by members of the staff on radio and television; most of these dealt with past and current weather. The Office provided facilities for the filming of various aspects of its work by teams from the Central Office of Information, the Open University and the BBC.

Routine services to the Press continued on much the same basis as in previous years. As usual, a large number of requests were received from the national and provincial Press for special interviews or comment on a variety of topics; in answering these inquiries reference was made where appropriate to the Meteorological Office expert in the particular field.

The Post Office's automatic telephone weather service (ATWS) was extended to Bishops Stortford, High Wycombe and Grimsby, and a new recording service for a new forecast area, Norfolk and Suffolk, was opened at Norwich and Ipswich. Mainly as a result of the Post Office strike, which rendered the service non-effective in many areas, the total number of calls made in 1971, at 11 554 411 was substantially down on 1970, at 13 251 614. By local arrangement, a marine sports information service was introduced into the Swansea telephone area as an experiment during the summer months; the Office contributed three forecasts daily for this service. Again by local arrangement, a ski report service was introduced into the Edinburgh telephone area on 1 December and, in this case, the part played by the Office involved the relay of the special snow/ski reports received in the Office from the winter-sports resorts of Cairngorm, Glencoe and Glenshee, and the provision of a forecast for the following day.

Demands for the specialized services provided by the Office continued at a high level. The winter service of 'warnings of certain road dangers due to weather' to local authorities and others attracted 416 registrations for the full service, while 46 Agent Authorities of the Department of the Environment, the Welsh Office and the Scottish Development Department not requiring the full service registered for a limited service comprising warnings of snow between the hours of 1800 and midnight only. The service for pigeon racing again proved very popular and a record number of 1318 'line-of-flight' forecasts were issued during the racing season. Registrations for the 'notification of fine weather spells' showed a further reduction in 1971, but, even so, 265 farmers and others took advantage of this specialized service.

On the industrial and commercial fronts, routine services for the gas and electricity industries, British Rail, London Transport, the North Sea oil and gas exploration and production industries and many smaller concerns were continued. A comprehensive, standardized service, provided by London Weather Centre to meet the joint requirements of the Gas Council, North Thames Gas Board, South-Eastern Gas Board and Eastern Gas Board (in part) was introduced on 1 January and discussions were held with representatives of the Gas Council with a view to extending this standardized service to other areas.

The work of the Weather Centres at London, Glasgow, Manchester and Southampton, in line with the overall trend in the public service field referred to earlier, showed a decrease on the previous year. It is noteworthy, however, that against this general trend, the number of inquiries to the Newcastle Weather Centre continued to grow and the 1971 total represented a 14 per cent increase over 1970 which, in turn, had showed a 14 per cent increase over

1969; the growth of the Newcastle Weather Centre since it opened in April 1967 has been quite exceptional and gives some measure of the gap in the public service sector which previously existed in the north-east. Excluding weather maps provided for shipping at certain major ports, the total numbers of inquiries dealt with by the individual Weather Centres and by the public office at Watnall (near Nottingham) over the past three years are shown below:

	London	Glasgow	Manchester	Southampton	Newcastle	Watnall
1969	338 073	95 223	127 508	77 826	63 903	68 549
1970	335 153	101 549	115 776	95 961	72 603	59 922
1971	303 695	91 430	107 228	79 976	82 654	62 728

Grand totals: 1969, 771 082; 1970, 780 964; 1971, 727 711

There was, as usual, much variety in the services provided. The BBC 'weathermen' gave special television presentations in connection with the flight and 'splashdown' of the Apollo missions; at the request of the Decimal Currency Board, special forecasts were supplied to the Board during the period immediately prior to D-Day, to assist in the planning of the movement by land and air of large amounts of the new currency; London Weather Centre supplied successful three-day forecasts for the final stage of the construction of the Royal Sovereign Light-tower which involved the delicate weather-sensitive operation of towing the cabin platform from Portsmouth and placing it in position on the previously constructed caisson off Beachy Head; Southampton Weather Centre provided special forecasts in connection with safety measures for a visiting nuclear-powered warship.

In an attempt to improve the network of the urban observations which are so necessary for public service work, discussions were held with the Royal Automobile Club (RAC) concerning the routine provision of reports from RAC town offices; the RAC proved most co-operative and it is hoped that the reports will commence in early 1972. With the same objective, arrangements were made locally, with many of the Police authorities, for police reports of road conditions and weather to be sent to an appropriate local meteorological office.

Numerous letters were received at Headquarters. They covered a wide variety of topics ranging from an inquiry into the likely weather in May 1169 during the Anglo-Norman invasion of Ireland to a request for data in connection with a university-sponsored investigation into pollution.

Services for the general public (overseas)

The forecasting offices in Gibraltar, Malta, Cyprus and the Persian Gulf provided services for the general public on much the same lines as those in the U.K. Of particular note was a new television presentation in Cyprus which started in the autumn. A firm of civil engineers constructing a harbour at Salalah (Muscat and Oman) received a tropical-storm warning service, and at Malta inquiries were received regarding the provision of forecasts for oil-drilling rigs nearby in the Mediterranean.

Services for civil aviation

Forecasting services for civil aviation in the U.K. continue to be provided by the Meteorological Office as the agent of the Department of Trade and Industry (Civil Aviation).

For all flights above 5000 ft ($\approx$1500 m), forecast information relating to *en route* weather conditions is provided in chart form by the Principal Forecasting Office at London/Heathrow Airport. These charts are prepared at 6-hourly intervals as routine and cover two main areas of operation: for European flights, over the whole of Europe including the Mediterranean; and for transatlantic flights west-bound from European terminals, over a large area extending to the west coast of North America and to the Caribbean.

Charts of weather likely to affect the safety of a flight are prepared at Heathrow and are supplemented by a series of forecast upper wind and temperature charts for levels up to about 40 000 ft ($\approx$13 000 m). These latter charts are processed from data received from the Meteorological Office computer at Bracknell. Heathrow flight forecast charts are disseminated throughout the U.K. to 14 major airports by facsimile over the Civil Aviation Meteorological Facsimile Network (CAMFAX). The number of airports served in this way was increased over the past year by the addition of East Midlands Airport, near Derby.

The Principal Forecasting Office at Heathrow is also the designated European Area Forecast Centre for all flights to North America and to parts of the Caribbean from European terminals. All transatlantic area forecast charts prepared at Heathrow are disseminated by land-line facsimile to Dublin, Paris, Frankfurt, De Bilt, Copenhagen and thence by further links to other European terminals. These charts are also broadcast by radio-facsimile for reception in the more distant parts of the European area.

Charts received in this manner are copied for use as aircrew documentation with the addition of data, relating to actual and forecast weather conditions at destination and alternate aerodromes, received on Meteorological Operational Teleprinter Network Europe (MOTNE) channels.

Meteorological services for general aviation (private pilots, flying clubs, air taxi services, etc.) are provided by local civil aviation and RAF meteorological offices on request. For flights in this category below 5000 ft ($\approx$1500 m), special flight forecasts are prepared giving more details of cloud, visibility and other phenomena that may be hazardous to light aircraft—details that are not required for flights at higher levels by the major airline operators.

In general, the demand for meteorological services for civil aviation at forecasting offices in the Mediterranean and Persian Gulf has continued to increase and this in turn has put an increasing demand on International Civil

Aviation Organization (ICAO) arrangements in these areas. For example, inquiries for forecasts for direct flights from Cyprus to the U.S.A. were being received towards the end of the year.

The plan to leave a viable meteorological service for civil aviation in a number of independent states in the Persian Gulf, including the existing Flight Information Centre at Bahrain, became effective in December with the handing over at Bahrain of the Main Meteorological Office to International Aeradio Limited (IAL). The hand-over proceeded smoothly. The new Senior Meteorological Officer and his forecasting staff arrived during the last months of the year and, additionally, special training in the U.K. on the Meteorological Office Advanced Synoptic Assistants Course was arranged for four of the more experienced Bahraini assistants to fit them for supervisory duties. Meteorological equipment essential for maintaining the Bahrain office as a going concern was also provided. IAL also took over the meteorological facsimile broadcast to Dubai and they hope to extend this broadcast to other Gulf states. At Sharjah, three Air Traffic Control Assistants were trained in meteorological observing for IAL and they replaced the Meteorological Office staff.

The new Area Forecast Centres in Cairo and New Delhi, together with the Beirut radio-teletype broadcast for operational meteorology (OPMET), will prove invaluable to civil aviation in the Persian Gulf and eastern Mediterranean if satisfactory reception of the facsimile-chart broadcasts can be achieved.

The civil aviation authorities of Malta, Cyprus and Bahrain were advised on meteorological matters as required and additionally, in November, arrangements were made for the Maltese delegation to the ICAO Sixth European Mediterranean Regional Air Navigation (6EUM RAN) Meeting in Geneva to receive technical assistance on meteorology from the U.K. meteorological adviser in attendance.

BOAC has continued to operate its computerized flight-planning service for flights across the Atlantic, both west-bound and east-bound. The meteorological data required, comprising upper winds and temperatures in a grid-point format at about 35 000 ft, are supplied by telex to BOAC at Heathrow from the Bracknell computer twice daily for validity times 00, 06, 12 and 18 GMT. These data now cover flights to the whole of the North American continent including Alaska and to the Caribbean. A similar service of data in grid-point value format is provided to the Air Traffic Control Evaluation Unit at Prestwick, operated by the Department of Trade and Industry (Civil Aviation).

The Principal Forecasting Office at Heathrow, through the Concorde forecasting unit at Fairford, Gloucestershire, has continued to provide special forecasts for Concorde 002 test flying.

A Meteorological Office representative attended the ICAO 6EUM RAN Meeting in Geneva during November as a member of the U.K. delegation. The Meeting was concerned with planning for the oparational needs of civil aircraft in the Region.

Belfast/Aldergrove Airport ceased to be administered by DTI with effect from 1 June 1971 and became the responsibility of Northern Ireland Airports Limited under the Northern Ireland Government. However, DTI continues to be responsible for the provision of technical and meteorological services. Administrative responsibility for Edinburgh/Turnhouse Airport has similarly been transferred from DTI, to the British Airports Authority.

Services for the Royal Air Force

Forecasting services continue to be provided for the RAF by stations 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, are located at convenient centres to control and advise subsidiary offices and enable them to meet the various requirements of aircraft of many types operating in many different roles. At subsidiary stations, a forecaster is on duty at times depending on the requirements of the RAF. A few offices are also maintained where there is no forecaster and the duties comprise the making of weather observations.

A senior officer of the Meteorological Office is located at the various RAF Command Headquarters. This officer acts as adviser in meteorological matters to the Air Officer Commanding-in-Chief and as liaison officer between him and the Director-General of the Meteorological Office.

Overseas, in the Federal Republic of Germany, the Near East, Persian Gulf and Far East areas, services provided for the RAF largely follow the U.K. pattern. However, with the implementation of the 'East of Suez' withdrawal policy, far-reaching changes have taken place in the services provided in the Persian Gulf and Far East, details of which are dealt with later.

Maximum use is made of the technical support provided by the Bracknell CFO and computer. At the Headquarters of both Strike and Air Support Commands a comprehensive 6-hourly routine of area and route forecasts in chart form is prepared, meeting the majority of operational requirements. These routine issues include a forecast surface-analysis and a significant-weather chart in addition to upper air forecasts at standard levels. The charts are distributed by land-line facsimile to subsidiary offices where they are duplicated for issue to aircrews at pre-flight meteorological briefings.

With the establishment of mobile meteorological units within Air Support Command, meteorological support is given to RAF elements participating in field exercises in the U.K. and overseas. Each unit has its own air-transportable meteorological and communications equipment for use at locations far removed from permanent meteorological offices. The facilities include radio-teleprinters and radio-facsimile recording equipment. To supplement these, an additional air-transportable cabin containing apparatus for receiving satellite cloud-pictures will be brought into use shortly. This will provide the mobile weather-forecasters with weather-satellite pictures anywhere in the world and will be a valuable facility in areas where basic routine information is scanty. Forecasters in the mobile units hold C.C. Commissions in the RAF Reserve of Officers. For dealing with the forecasting problems which arise in this type of operation, special techniques have been evolved and these are available in a booklet compiled by the Senior Meteorological Officer in charge of mobile units.

Meteorological Officers continue to give regular courses of meteorological instruction at a number of schools in Training Command and at Operational Conversion Units. Some progress has been made during the year on a study of the suitability of meteorology as a subject for programmed instruction at the schools. Two new RAF instructional films have been prepared in colour for use in RAF schools.

A Runway Visual Range system, based on a count of reference lights visible to an observer positioned near the runway touch-down points, is in the process of being introduced at about 50 RAF aerodromes. The Office continues to co-operate by providing technical advice and calibrating the lights after they have been installed.

A forecast service was provided for the International Helicopter Meet held at West Raynham, Norfolk, from 10 to 19 June. Full briefing facilities were provided at Abingdon for competitors taking part in the London to Vancouver air race held in July to mark the centenary of the entry of British Columbia into the Canadian Federation. The RAF, having been in the Persian Gulf and on Singapore Island for many years, have now withdrawn. With the abolition of a separate RAF Command in the Gulf, it has been possible to transfer the Main Meteorological Office at Bahrain to civil authorities and to close the subsidiary forecasting office at Sharjah. The military function of these offices has been replaced by a new forecasting office at Masirah Island—an RAF staging post off the coast of Muscat and Oman—which has been placed under the command of Near East Air Force, Cyprus.

The five-nation agreement on Singapore Island has enabled the RAF to withdraw their Command from there. Responsibility for meteorological services for military flying has been transferred, by agreement, to the Singapore Meteorological Service which has taken over the meteorological offices at Tengah and Changi. Two U.K. forecasters have been seconded to the Singapore Meteorological Service for a limited period following the hand-over.

Services for the Army

A meteorological office maintained at the Royal School of Artillery, Larkhill, on Salisbury Plain, provided ballistic information, advice on the training of the Royal Artillery Meteorological Section and other meteorological assistance to Army units throughout the Salisbury Plain area and to the Royal Aircraft Establishment (RAE) at its trials site. A special feature of the Army work during the year was the assessment of noise nuisance to the general public. Preliminary reports show that there has been a substantial reduction in the number of complaints received in the six months since the system was introduced.

A review of services provided for the Army Aviation Units based on Salisbury Plain has resulted in a decision to open a subsidiary forecasting office at Netheravon.

An office on the establishment at Aberporth supplied the needs of the RAE there, and three offices were maintained at Proof and Experimental Establishments to provide meteorological advice for trials. Again, at one of these offices, assessments of noise nuisance were supplied as routine.

Liaison with the Navy Department

Close co-operation has continued with the Director of Meteorology and Oceanographic Service Division (Naval) on all aspects of the co-ordination of plans to meet the meteorological requirements of the defence forces both at home and overseas.

International defence services

Within the framework of NATO, CENTO and SEATO, the three international defence organizations associated with treaties to which the U.K. is a signatory, there are meteorological planning committees on which the U.K. is represented. The work of these committees is to co-ordinate the meteorological support needed by the military forces and, as necessary, to study the meteorological problems involved.

The twenty-eighth meeting of the NATO Military Committee Meteorological Group took place in Brussels in May. Mr P. J. Meade, Director of Services, attended as the U.K. member and he was accompanied by Mr E. Evans and Mr D. W. Tann.

The Working Groups of the NATO Military Committee Meteorological Group on Weather Plans and Weather Communications again met twice during the year. Both meetings, in Brussels in March and in Munich in October, were attended by Mr E. J. Bell (Communications) and Mr D. W. Tann (Plans).

The Meteorological Panel (Panel XII) of NATO Group AC/225 met in Brussels in September. Dr P. G. F. Caton was the U.K. representative.

The NATO Nuclear Biological Chemical Interservice Operational Procedures Working Party of the Military Agency for Standardization met in Cologne in May. Mr K. Bryant attended as meteorological adviser to the U.K. delegation.

Services to the Home Office

The meteorological requirements of the Warning and Monitoring Branch of the Home Office have been kept under review and detailed plans for meeting these requirements as effectively as possible in an emergency are maintained and tested in exercises. Lectures were given to the Royal Observer Corps, now part of the Warning and Monitoring organization, who are equipped and trained to make simple meteorological observations in times of emergency.

Services for nuclear establishments

To meet the national requirement for meteorological information under the arrangements to deal with the accidental release of radioactive or toxic material, six Main Meteorological Offices provide information to nuclear establishments. These arrangements are tested twice a year, without notice, with the UKAEA, CEGB and South of Scotland Electricity Board establishments concerned.

Climatological Services

The main function of the Branch is to provide information and advice needed about climate by various sections of the community. The foundation of the service is the national climatological network of about 650 observing stations of various types. The majority of these stations are manned by voluntary observers and the Office takes this opportunity to thank them for their excellent co-operation in helping to maintaining an efficient service. The Branch is responsible for the inspection of the network and for the collection, quality control, publication and preservation of surface and upper air observations made at stations in the United Kingdom. The surface observations are published in the *Monthly Weather Report* (*MWR*) and its *Annual Summary* and in other non-routine climatological publications. Two of the main tables of the *MWR* are now derived by computer processing of the original data; the typed version from the computer is sent to the printers. Work is proceeding on the preparation of programmes for a version of the whole *MWR* to be produced by the new IBM 360/195 computer.

Developments in the application of climatology to industrial, commercial and social planning are continuing and this is leading to an increase in the number of complicated and diverse inquiries, especially from commerce and industry. Most of these inquiries require data to be processed and presented in the special form needed by the user. Thus the demands on computer facilities are continually increasing but problems are being tackled now, the solution of which would have been impracticable, if not impossible, in pre-computer days. An example of this type of work is a study of the best periods for averaging meteorological elements; thus for planning by the Gas Council of weekly consumption needs over the next year it was found that the temperature averages over the last 10 years or so were likely to be the most applicable.

After an increase continuing over many years the total number of inquiries decreased by about 7 per cent this year; the decrease affected proportionally most of the categories listed later in Table XIII. As usual the inquiries covered a wide range and included: many legal ones concerning past weather; the supply of climatological information to aid in the selection of sites for special buildings and structures and for new motorways; wind extremes for buildings, aerials and high-level cranes; and climatological data applicable to the sale of various commercial products.

While most requests are for information relating to the U.K., the Office must also be prepared to answer inquiries about the climate of any other country. Data to meet this requirement are usually collected by means of an international exchange of processed material but there are also some data for British-operated stations overseas. Examples of these inquiries are the consideration of the climate of certain African countries to assist in the planning of microwave radio routes, the incidence of low temperature and the frequency of winds in Sweden and Labrador in connection with mining, the provision of climatological data for France for use as a guide in selecting a site for vineyards in Australia, and full climatological data for the design of a harbour extension in Germany.

The Office continues to collaborate with government or government-associated agencies such as the Building Research Station, the Road Research Laboratory, the National Physical Laboratory and the British Standards Institution (BSI). A senior officer continues to serve on the BSI Committee on Wind Loading and, in the latter part of the year, became a member of the BSI Committee formed to prepare a Code of Practice on lattice towers and masts, and also a member of a Technical Panel, associated with the Royal Aeronautical Society, studying atmospheric turbulence in relation to buildings. The study of wind over and near London continues and a paper on this subject was presented at the Third International Conference on Wind Effects on Buildings and Structures held at Tokyo in September.

Climatological services for Scotland and for Northern Ireland are provided by offices in Edinburgh and Belfast respectively. The Superintendent of the Edinburgh office served on three Scottish Development Department working parties dealing respectively with the requirements for climatological data in Scotland, the performance of windows and other components of buildings, and storm sewerage, and he continued to serve as adviser to the Clean Air Council for Scotland.

In the marine climatology section the collection and processing of ships' observations for the eastern North Atlantic continued for the annual *Marine* *climatological summaries*, which are to be published by the Office by international agreement. The 1964 volume was published in December and work is in hand on the 1965 and 1963 volumes.

Monthly charts were issued as usual showing the distribution of sea ice at the end of each month. Work was completed on the task of submitting all available ocean-current data on punched cards to quality control, covering the years 1929–69 inclusive, and similar work has now been started for the data before 1929. The ocean current and, where applicable, the sea ice sections of five volumes of Admiralty *Pilots* were revised. Two articles describing the nature of ocean currents were written, one for *The mariner's handbook*, and one for *Ocean passages of the world* issued by the Hydrographic Department of the Navy. Inquiries relating to marine climatology, ocean currents and sea ice, were dealt with, among the more interesting being a legal one for information regarding weather and ice conditions alleged to have caused a hold-up in shipping on the Lower Danube and one about extreme wind speeds on certain islands in the West Indies.

The marine climatologist continues to represent the Office on the Working Group on Marine Climatology of the Commission for Maritime Meteorology (CMM) of WMO, and is also co-ordinator of the Group's Polar Panel. He was also nominated as the Office representative on the Working Party on Oceanic Ecology of the new Institute for Marine Environmental Research of the Natural Environment Research Council (NERC), and on the Offshore Installations Technical Advisory Committee of DTI. Work for this last Committee, which meets monthly, included the preparation of a paper on winds and temperatures affecting the design, construction and use of installations that may be employed in offshore areas around the U.K.; this paper is being combined with papers on waves and on sea-bed conditions, prepared by other Committee members, to form a joint paper on environmental factors to be circulated by DTI to those concerned. Another officer in the section is a member of the Working Group on Sea Ice of CMM.

Hydrometeorology

The hydrometeorological work of the Office falls naturally into three sections: routine, inquiries and investigations. The routine covers regular collection, scrutiny, processing and preservation of rainfall data for the U.K. Most of the data are collected from voluntary co-operating stations maintained by private individuals, water supply undertakings, local authorities and river authorities. Regular inspections are made to ensure the maintenance of required standards of site, instrumentation and observational procedures, and 866 stations were visited during the year. The Edinburgh office administers and inspects stations in Scotland, handles their data and deals with local inquiries, whilst the Belfast office has similar responsibilities for Northern Ireland. Hitherto rainfall data for Scotland and Northern Ireland have been quality controlled subjectively. From the beginning of the year the data have been quality controlled by computer at Bracknell on lines similar to those used for data from England and Wales. Rainfall data are published in the *Monthly Weather Report* and in *British Rainfall*, and from time to time in non-routine publications and branch memoranda. In particular, the year saw the completion of the text of *British Rainfall* for 1966 and 1967 and progress has been made on the 1968 volume. In the inquiries section the number of inquiries handled continued at the high level of recent years. As in former years many of these came from the legal profession, insurance companies and the building and construction industries.

Many of the inquiries had a bearing on water resources. Examples are the assessment of areal rainfall and evaporation over the Pang catchment in connection with Stage 1 of the Thames Conservancy Groundwater Development, assessment of average annual rainfall and evaporation over the river Allen for the Avon and Dorset River Authority, estimates of average monthly rainfall over west-coast streams of Somerset for the Somerset River Authority, and assessments of average annual rainfall for about 115 catchment areas for the Flood Studies Team at the Institute of Hydrology. With most river authorities having completed their seven-year periodical surveys (under Section 14 of the Water Resources Act 1963), there was less emphasis on assessment of areal actual and potential evaporation during the year than in 1970 and it was possible to pay increasing attention to work for the *Surface Water Year-book.* Estimates of average annual and monthly rainfall, and monthly rainfall for individual water years, were prepared for a number of new areas and a start was made on reorganizing station networks and on the preparation of estimates for Scottish areas by computer. Requests were received from a number of river authorities for estimates of areal rainfall in water years (1 Oct.–30 Sept.) for which *Surface Water Year-books* have not yet been published, and there is evidence of a growing demand for such information to be made available currently as soon as data are obtained from the computer.

The inquiries section continues to be responsible for estimating evaporation for a network of stations and for investigations of evaporation problems. The enlarged *Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain* introduced in 1970 continued throughout the year with the addition of a map of deficits under short-rooted vegetation. Assistance was given to river authorities in England and Wales in the current review of the rainfall and evaporation aspects of their hydrometric schemes. In particular, this has included investigation into the types and network densities of climatological stations and evaporation tanks required to provide an acceptable level of accuracy in evaporation estimates and measurements. A hydrological memorandum on the use of the Penman formula in hydrology was produced during the year as a contribution to this work in evaporation, and the Operational Instrumentation Branch of the Office has designed a water-level sensor for use with tanks to ensure high-quality measurements without the need of an equally high degree of observing skill. In addition five investigation memoranda were produced, dealing with the measurement of evaporation from tanks and with data requirements for the calculation of potential evaporation. Most of this work was summarized in a note circulated to river authorities and other interested bodies in August. The causes of errors in potential-evaporation estimates were also summarized as an aid to the establishment of networks of observing stations. Estimates of evaporation were given to consulting engineers and hydrogeologists carrying out ground-water and water-resource investigations in the Persian Gulf, Jamaica and Bermuda.

Good progress was made in assessing end-of-month soil moisture deficits for the period 1941–65 for an enlarged network of stations. The main purpose of the work is to produce much-needed averages but, this year, it has also supported a research project in the Branch. Work was started on the assessment of soil moisture deficits for Scottish stations for the period 1961–70.

Estimates of monthly rainfall representative of Kew, covering the period 1697–1870, have been prepared. The 274-year record is being analysed in terms of aquifer recharge, flooding, rainfall deficiency and other characteristics.

The investigations section has been active in several fields. There are two major computer-handled routine tasks in hydrometeorology, namely rainfall data processing and computations of soil moisture deficits. The change from the KDF9 to the IBM 360/195 computer demands that programmes be rewritten. Furthermore, the opportunity is being taken to utilize the additional features of the new computer to allow much more complete and efficient handling of data. Plans include a more efficient quality-control of rainfall data and the use of the computer to draw rainfall maps and estimate areal rainfalls, thus eliminating manual plotting and analysis of data. Insofar as soil moisture deficits are concerned, the plan is to use the synoptic data bank as the main source of data for the computer calculations. This opens up possibilities of the preparation of a higher frequency of *Estimated Soil Mixture Deficit and Potential Evapotranspiration over Great Britain* bulletins with less staff effort.

Considerable progress has been made in the comprehensive areal rainfall programme (CARP) which was designed to standardize, objectively, assessments of rainfall over areas. Five forms of computer output have been developed—5-km grid-point values of rainfall, isohyetal and isopercentile charts, and areal rainfall in millimetres and as percentages of average annual rainfall—all applicable to any occasion from 1961 and to any area of Great Britain. Studies in synoptic hydrology have led to two papers. The first deals with rainfall averages over England and Wales in different types of weather situation, in which long-term monthly and annual averages of daily rainfall for the period 1950–69 were estimated for each of 27 categories of pressure pattern over the U.K. The accuracy of the results was assessed by calculating individual values of rainfall, for each month, season and year of the period 1861–1949, using frequencies of each type of daily pressure pattern and the synoptic-type averages, and comparing these values with estimates based on data from a large network of stations. The second paper covers the relationship between rainfall in straight westerlies and atmospheric pressure at mean sea level over England and Wales.

Work has continued on the meteorological aspects of the United Kingdom Flood Studies. Daily rainfall records from some 400 stations with an average length of record of 65 years have been assembled, scrutinized and put on magnetic tape. Computer programmes were written to extract seasonal and annual maximum falls in 1, 2 and 30 days for 5000 rainfall stations for the period 1961–70. Hourly rainfall data from a number of recording rainfall stations were gathered, and the microfilming of autographic rainfall-charts from all sources was begun. The analysis of the data of heavy falls of rain has continued and estimates can now be made of the rainfall amounts to be expected at any place in the U.K. within a given return period, for specified durations of from 1 minute to 30 days. A major study was made of heavy areal rainfalls in five different regions and for a wide range of areas and durations of rainfall. From this study reduction factors may now be given to be applied to point rainfall to give the area rainfall with the same return period, for rainfall durations from 2 minutes to 8 days and for appropriate areas from 1 to 10 000 km^2. It is the aim of the project to give a simple display of the final results by means of maps and tables, and preliminary versions of these are being used to answer numerous inquiries for rainfall estimates. The estimates are used in the design of such projects as main-road culverts, urban storm-drainage and sewers, flood balancing tanks and pumping systems.

Co-operation was maintained with the team of hydrologists working at the Institute of Hydrology on the hydrological aspects of the U.K. Flood Studies.

The Dee Weather Radar Project, a joint study by the Office, the Water Resources Board, and Plessey Radar Limited, to investigate the feasibility of using weather radar to measure precipitation, passed from the preparatory to the research and development phase during the year. A project leader, supported by six scientific staff, was established within the hydrometeorological branch and the technical staff was increased at Llandegla Research Station. A network of rain-gauges has been installed by the Dee and Clwyd River Authority on behalf of the Water Resources Board; data from these gauges will be used as a standard with which to compare the radar estimates of precipitation. Towards the end of the year recordings of several periods of rain were made including parts of a lengthy wet spell which eventually resulted in the river Dee flooding. A start has been made in the analysis of data, but significant progress awaits the use of the IBM 360/195 computer from early 1972. The project was featured in several Press, radio and TV reports and was the subject of an exhibit (arranged largely by the Water Resources Board) at the Royal Welsh Show in July. It also attracted the interest of several overseas countries and the radar site was visited by delegations from the Hungarian Hydrological Service and the Cuban Meteorological Service.

The Senior Scientific Officer attached to the Institute of Hydrology has continued his research work on evaporation from forests. Between the end of April and the end of September 1800 hours of data were recorded from about 60 sensors. Temperature and humidity were measured at 8 levels, wind speed at 10 levels and wind direction at 3 levels within and above the forest canopy. Measurements were taken of incoming and reflected solar radiation, diffuse and net radiation and soil heat flux. Manual recordings of leaf wetness and cloud were also made. Preliminary analysis of the data indicates a higher level of recording accuracy than in previous years and programmes are being completed for computer analysis of all the data.

The Office continued its contribution to international hydrometeorology through co-operation with WMO and UNESCO. Members of staff serve on three working groups of WMO's Commission for Hydrometeorology and the Office is represented on the British National Committee of the International Hydrological Decade.

Services for Agriculture

The pattern of services for agriculture continued unchanged. The major effort of staff at Headquarters was devoted to research work to advance the science of agricultural meteorology, together with an element of service to the farming industry. Officers at Cambridge, Bristol, Leeds and Edinburgh continued their work of investigation, and of advice and service to other disciplines in agriculture and to the farming community.

Work continued on many projects: cereal mildew, soil moisture deficits and return to field capacity, days available for using machinery for the cereal harvest, estimation of bean harvesting days, the effects of shelter on meso-climate, seasonal forecasting of the spring growth and flowering of forage crops, forecasting the date of apple blossom, Graminae pollen in London, watercress trials, weather and maize yield, heavy rains and field drainage, to name but a few. The work completed for the Agricultural Advisory Council with respect to soil productivity and soil structure was published by the Ministry of Agriculture, Fisheries and Food (MAFF) as a *Technical Bulletin* on 'The significance of winter rainfall over farmland in England and Wales'. This analysis of winter rainfall presents weather and climate data in terms of their agricultural significance. The bulletin has implications for farming problems concerning drainage, land use, autumn and spring cultivations and fertilizer practice and is potentially useful to soil scientists, hydrologists, agricultural planners and advisers, and to individual farmers. Two members of the staff were responsible for the preparation of a WMO *Technical Note* on 'Protection of plants against adverse weather' and another member for one on 'Weather and animal diseases'.

There were two changes in senior staff during the year, the first due to the sudden death of the Head of Section and the second to the retirement of the Meteorological Liaison Officer at the South-west Division of the Agricultural Development and Advisory Service.

International affairs in agricultural meteorology continued to demand a considerable effort. Mr L. P. Smith continued to serve as President of the WMO Commission for Agricultural Meteorology until the conclusion of the WMO Fifth Session in October, when he completed his term of office covering nine years. He attended the Sixth Congress of WMO in his role as President. The Office was represented at the Commission's Fifth Session by two of the Agricultural Liaison Officers. Contributions to the work of other international organizations have also been made, including that of UNESCO's 'Man and the biosphere' programme.

Lectures were given to many bodies, including agricultural associations of various kinds, to Voluntary Service Overseas courses and university students. Published papers numbered 19 during the year and 68 agricultural memoranda were issued, a significant increase on last year.

As usual, the closest contacts have been maintained with universities undertaking research into agriculture and allied subjects, and with the research stations under both the Agricultural Research Council and MAFF. Many individual inquiries from farmers and research students were answered.

Observational Requirements and Practices

The main responsibility of the Branch is the scientific and technical policy relating to meteorological observations: it is responsible for observational requirements, techniques, standards and accuracy on land and sea, and in the upper air. It operates in close contact with the Operational Instrumentation Branch on the one hand and with the forecasting, climatological and hydrological branches on the other hand. The Marine Division under the Marine Superintendent is part of the Branch.

Observational practices

Work in this field often demands painstaking observations followed by the processing of considerable data which are not amenable to machine methods. Trials to test and evaluate new and modified instruments are under way at Beaufort Park, at the observatories and at other stations. The dewcel, which is an instrument for measuring dew-point and which has the great advantage that it can operate at temperatures below freezing without the attention of a skilled observer, is still under test at Kew, Eskdalemuir and Lerwick and is undergoing operational trials at Brize Norton and Little Rissington. The results so far are very promising.

The main field trials of the newer types of manual and automatic rain-gauges have been concluded, and results establishing the relative accuracy of the measurements have been published. The land trials relating to the problem of measuring rain at sea have now been finished and the next step to be undertaken is the sea trials. The problem is now an engineering one since the prerequisite for sea trials is the development of a suitable gimballed buoy.

The results of a comparison of the performance of mercury-in-glass and electrical-resistance thermometers in the screen at Brize Norton were issued in a branch memorandum and work on establishing the accuracy of the naturally ventilated screen psychrometer is being undertaken at Kew Observatory.

Temperature, humidity and wind observations from the ITA mast at Lichfield are recorded at the mast site and, by means of a telephone interrogation, can also be read off an instrument console at Birmingham Airport. The observations were unsatisfactory and an *ad hoc* committee, consisting of representatives of the interested branches, was set up to look into the problem. Investigations and trials were carried out by the responsible branches, and the committee was able to make recommendations to rectify the trouble. The use of the LORAN-C navigation aid to observe upper winds over the sea is still under consideration; results of an appropriate experiment by the Cloud Physics Branch are awaited.

Observatories

The observatories at Kew and Lerwick and the meteorological section at Eskdalemuir have continued to provide facilities for testing new instruments and techniques; the great advantage is that although the environment approaches operational conditions, skilled attention is nearly always available.

Comparison of evaporimeters at Kew and Eskdalemuir and evaluation of the dewcel at all three places continues. Work on the dewcel and earlier work on the aspirated psychrometer led to the recognition of a small difference between the wet-bulb temperature given by a standard mercury-in-glass thermometer and the value recorded by an electrical-resistance thermometer when both instruments are exposed in a standard screen.

A new gravimetric rain-gauge is being developed at Kew; this instrument involves weighing continuously a 4-ft diameter pan mounted flush with the earth's surface. The design is expected to reduce errors, due to 'splashing' and to wind, to very small quantities, and it is hoped that the instrument will be good enough to act as an 'absolute standard' for checking other standard gauges.

The radiation work at Kew, a Regional Radiation Centre, has continued normally throughout the year. In May, one of the working standard pyranometers (an instrument for measuring the total flux of solar radiation on a plane surface) was taken to Washington, U.S.A., to take part in an international comparison of these instruments organized by the International Solar Energy Society. The results showed good agreement with the North American measurements. During the year a contract was placed for the production of two prototype data-logging systems, recording on magnetic tape, for use with radiation instruments. If successful these systems will replace the existing paper-tape recorders.

Lerwick has been designated as a WMO Regional Sampling Station for the measurement of background pollution. Measurements of several pollutants are already made at Lerwick, and the Cloud Physics Branch is designing equipment and techniques for sampling the others. Measurements of atmospheric turbidity (an assessment of the total aerosol content of the atmosphere as shown by measurements of solar radiation) have just commenced. The routine measurements of solar radiation at Lerwick since 1952 have been examined to evaluate any long-term systematic changes in atmospheric turbidity. Some small but possibly significant increases have been found; the results of this work will be published in due course.

Thunderstorm location

The network of CRDF stations continued to function as in previous years. However, flash selection, hitherto confined to the central station at Beaufort Park for the U.K. network and to Malta for the combined network, was extended on 15 February so that Malta, Gibraltar or Cyprus could act as selector station as required to give a more effective coverage of the area. Data continued to be supplied to specialized users on request.

Surface observations

In the U.K., 60 surface observing stations report in international code and 17 in national code every hour, day and night throughout the year. A further 22 stations report in international and 28 in national code every 3 hours. In addition 24 stations report in international and 112 in national code at various times each day of the year. Of this total of 263 stations, 103 are manned by full-time professional staff and 160 by voluntary observers most of whom have attended a course on observing at the Meteorological Office College.

Reports in plain language at fixed times throughout the year are received from 15 town offices of the Automobile Association, 8 town offices of the Royal Automobile Club, 21 Police or Fire Service offices and 46 road maintenance compounds. Non-routine weather information is also received from AA and RAC road patrols and other sources.

Upper air observations

The normal programme of upper air observations was maintained at the eight stations in the U.K., on four ocean weather stations and at six stations overseas, but the station at Muharraq, Bahrain Island, closed in November following the British withdrawal from the Persian Gulf. Assistance continued to be given to other branches of the Office in support of investigations concerning the upper air. Radiosonde observations continued to be made by a meteorologist aboard a merchant ship and in May a second ship was added to the programme. The high-altitude balloon programme was greatly increased by the introduction of cheaper balloons which had a slightly lower performance. The performance of the standard balloons again improved this year.

To gain experience, staff are co-operating with the Operational Instrumentation Branch in non-routine flights of the new Mk 3 radiosonde.

Runway visual range calibration

Routine six-monthly calibrations of the lights used in the human observer system of measuring runway visual range (RVR) have been continued at the majority of civil airports throughout the U.K. The installation of RVR systems at selected RAF stations at home and overseas is continuing, with planned surveys now complete and the first systems ready to be brought into service. Advice has been given to airport authorities outside the U.K. on the installation and calibration of RVR systems.

Marine Division

The numerical strength of the voluntary observing fleet has barely been maintained during the year and the hoped-for target of an annual increase of 50 ships still seems very far from being realized. At the end of October the total number of ships on the selected list was 526, at the beginning of 1971 it was 531. There were two basic reasons: firstly a shortage of instruments in the earlier part of the year and secondly the overall building programme of the larger shipowners whereby their fleets of conventional cargo ships are being replaced by container ships, bulk carriers and super-tankers. One of these newer types of ship is often able to do the work of six or even eight conventional ships by virtue of its size, its speed, and newer methods of loading and cargo carrying. In one six-month period during 1971, although 34 ships were recruited to the voluntary observing fleet, the total number of ships on the list actually decreased by 12 because 46 ships were withdrawn during the same period, some being sold to a foreign registry, others being laid up, possibly for conversion, or being broken up.

As automation in ships becomes more general, it is probable that shipmasters will be less inclined to undertake the making of weather observations. The year's log-books have shown no deterioration in the quality of the observations made nor in the corresponding number of radio weather-messages sent and the enthusiasm of most officers for observing seems unabated. Nevertheless, the fact has to be faced that the number of officers carried in ships is, in general, being reduced, with a corresponding reduction in crew strength. It has been mentioned in the shipping Press that by the end of the next decade few cargo ships will carry a total crew of more than 15.

A Port Meteorological Officer was appointed to Southampton and commenced duty on 1 September. Before this time urgent commitments had been attended to by officers from the Port Meteorological Office in London or from Bracknell. However, it was not possible to give adequate coverage in this way and all too many observing ships visited Southampton, often as their only port of call in the U.K., without their meteorological requirements receiving attention.

'Excellent' awards were given, as in the past, to the ships which had sent in the most careful and painstaking log-books during the year and tribute must be paid to five distant-water trawlers who figure in the list.

Barographs were presented to four shipmasters for their long and zealous voluntary meteorological work at sea.

The British Weather Ships completed 24 years of service in the North Atlantic during the year. The present four ships, ex 'Castle' class frigates built for the Royal Navy in 1944, have now been operating as weather ships for about 12 years and they continue to give satisfactory service despite their age. They co-operated with the French ships and Dutch ship *Cumulus* in operating station Alfa for about nine months of the year and stations India and Juliett continuously. The operation of station Kilo was shared by the two French ships and the

Dutch ship *Cumulus*. Station Mike was operated continuously by the two Norwegian ships. Stations Bravo, Charlie, Delta and Echo on the western side of the North Atlantic were manned continuously by weather ships operated by the U.S. Coast Guard. All of the weather ships in the North Atlantic are financed internationally through the International Civil Aviation Organization, the operating countries (U.K., U.S.A., France, etc.) bearing the greater part of the cost. All ships made hourly surface and six-hourly upper air observations (see Plate VIII). (For heights reached in upper air ascents see Table V of statistics.)

The following additional observations were regularly made by British Weather Ships: solar-radiation balance, sea temperature and salinity down to the sea bed, magnetic variation, and surface sea-water sampling. The biological sampling programme for the Institute for Marine Environmental Research was intensified during the year with an investigation in which the Longhurst/Hardy plankton sampler was used to determine the vertical distribution of plankton in the upper 500 metres of the ocean at station India throughout the year. For this duty a marine biologist made six voyages to station India. In association with the investigation into vertical plankton-hauls, water samples for phytoplankton analysis were taken and extra net hauls for analyses of toxic organo-chloride residues in the plankton were made.

Communication and navigational facilities were provided for transatlantic aircraft by all the British Weather Ships, and air/sea rescue equipment was kept in a constant state of readiness. Search and rescue exercises were frequently carried out in which RAF Shackleton aircraft sometimes participated.

In May a second ship of the Sugar Line was equipped to take radiosonde soundings and we are much indebted to the Sugar Line management for their help in enabling us to fulfil our obligation to equip a small number of merchant ships for this task as part of the World Weather Watch programme.

The number of marine inquiries, most of them from solicitors, shipping companies, universities and industrial firms, was about the same as for the past two years. The *Marine Observer* was published each quarter as usual.

Operational Instrumentation

For the Operational Instrumentation Branch, the year was dominated by activities associated with the move to new quarters at Beaufort Park. The bringing together of laboratories, workshops and field-station facilities is an important step in helping the Branch to meet its steadily growing responsibilities. These include the design, development, procurement, testing, calibration, installation and maintenance of instruments and data-acquisition systems for routine operational use at home and abroad, on land, at sea and in the air.

Buildings and facilities

Work on the new Branch headquarters at Beaufort Park, some four miles to the south-west of Bracknell, progressed steadily during the first half of the year. Staff and equipment were transferred from the Dines Wing to the new laboratories, workshops, etc., in a phased move during the months of September and October (see Plates II and III (upper)).

Beaufort Park now comprises the original Experimental Site of about 30 acres* plus a further 30 acres lying to the south-east. The original Field Station

*1 acre $\approx$ 4000 m^2.

is now situated at the north-western end of a large, open, graded area with the new headquarters building at the south-eastern end. On the western side of what has become a single, but enlarged, trials ground is the balloon shed. Work has already started on an experimental rotatable balloon-shed, the design of which will be evaluated as a possible replacement for existing balloon sheds at outstations. On the eastern side of the open area is a newly completed operational building, soon to be equipped with a wind-finding radar which will be used to track various types of balloons and radiosondes.

The headquarters building comprises 'surface' and 'upper air' instrument and electronic development laboratories; administrative offices; drawing office; electronic, mechanical and installation workshops; and photographic studio and darkroom. The collocation of the electronic workshop (from Eastern Road) and electronic design and development engineers for the first time should strengthen activities in this field and enable the electronics group to provide a design, development, construction and repair service to the rest of the Branch at first and gradually to 'customers' in other branches.

The new accommodation was planned, often in great detail, in accordance with the specialist requirements of the different sections. It is pleasing to place on record the efforts of the Department of Environment's architects and other staff in realizing our original concepts for the building; equally, there has been unstinting effort by our own staff to ensure that these requirements were correctly specified.

The technical training school is still housed in the Field Station building at Beaufort Park, but as it is now much closer to the administrative offices than hitherto the proximity of the electronics group and associated facilities is expected to benefit students on future courses. It is hoped to move the Regional Servicing Centre from Eastern Road as soon as practicable, and this would provide students with further opportunities to gain practical experience.

The general instrument testing, calibration and standards laboratory is still housed at Western Road, some three miles to the north of Beaufort Park. The radiosonde calibration plant remains at Eastern Road, over four miles to the north-east, and the new semi-automatic calibration plant for the Mk 3 radiosonde will also be installed there. The wind-tunnel remains in the Dines Wing at the London Road site for the time being, but later may be installed near the radiosonde section.

A second, small, mechanical workshop is being set up in part of the area vacated in the Dines Wing when the main workshop moved to the new accommodation; this will specialize in small jobs, particularly for the research branches, when a quick turn-round is often required.

Co-operative projects: national and international

The Dee Weather Radar Project has involved several senior staff in the work of the various committees (steering, planning, operations), in the provision of technical guidance on radar and rain-gauge matters, and in the management of the Research Station at Llandegla. This station has now entered the operational phase, and the technicians there are responsible for the operation and maintenance of the 10-cm radar, the data processing and recording systems, and the calibrating rain-gauge clusters.

Two officers of the Branch have participated in meetings of experts from 15 European countries to discuss possibilities for co-operation in scientific and technical projects in the fields of meteorological instruments and oceanographic /meteorological buoy networks. One officer was additionally involved in informal Dutch/German/Belgian/U.K. talks on the establishment of an oceanographic/meteorological observational network in the North Sea.

As a result of the increasing interest in the use of operational buoys, the Department of Trade and Industry has asked the inter-departmental Committee on Marine Technology to sponsor the design and development of a telemetering oceanographic/meteorological buoy. The Office has agreed to participate in this work.

In spite of difficulties occasioned by the postal strike, arrangements were made for a number of recently developed instruments to be shown at an exhibition held in Geneva at the time of the WMO Sixth Congress. Some of these were shown on the Meteorological Office's own stand, others were displayed by the manufacturers.

Automatic picture transmission (APT) stations were installed for the reception of satellite cloud-pictures in Ethiopia and Jordan under the WMO Voluntary Assistance Programme. Training in operation and maintenance was also given to the local staff.

An active part has been played in the work of a WMO Commission for Instruments and Methods of Observation (CIMO) Working Group which is concerned with the development of an interim reference psychrometer. A theoretical study was made of the effect of natural radiation on the accuracy of the proposed instrument, and staff at Kew Observatory have been co-operating in the construction of a prototype in readiness for field trials. Another officer of the Branch is Chairman of a WMO CIMO Working Group concerned with the standards for, and international comparisons of, interim reference radiosondes.

Development, production and evaluation of new instruments and systems

Effort in the development of instruments for surface observations has, for the most part, been devoted to completing or furthering work on projects which have been mentioned in previous reports.

A contract for the manufacture of the main data-handling equipment for the Mk 2 land automatic weather-observing systems was arranged during 1971 (and finally placed early in 1972). Design and construction of the sensor interfaces is being carried out 'in house'. The trial installation of one of the Mk 1 systems on Lichfield ITA mast last year confirmed the need for the analogue dial read-out at the receiving station to be replaced by a digital read-out (a standard feature of the Mk 2 system).

A preliminary study of a marine version of the Mk 2 automatic weather-observing system was carried out. Such equipment will be needed to provide observations from the automatic light-towers which are steadily replacing the manned light-vessels round our coasts. To gain experience in the use of radio-telemetry links and experimental marine sensors, an air/sea interaction buoy is being modified to telemeter data from a point in Cardigan Bay, 10 kilometres from the coast, to the outstation at Aberporth next year.

Thirty magnetic-tape event recorders, for use with the tipping-bucket rain-gauges, were delivered. The complete systems are undergoing user evaluation trials at 10 outstations, and the custom-built translator is being used to produce computer-compatible tapes for subsequent processing. A contract was placed for 2 magnetic-tape data loggers for evaluation as potential replacements for the existing paper-tape data loggers (now approaching the end of their useful life). Development of a magnetic-tape data logger designed to record the basic wind-statistics currently derived manually from electrical anemographs is nearing completion.

Development of the new Mk 5 electronic anemometer system was completed and field trials are in progress. It is particularly suitable for use over long distances at airports where the number of displays required is large and where the use of telephone lines eliminates the high cost of laying cables.

The automatic, unattended systems described above ultimately depend on the reliability and performance of the sensors where, in the very nature of things, progress is slower.

A new type of digital temperature-indicator has been tested as a possible replacement for the existing Mk 5 temperature bridge. Trials of plastic thermometer-screens for use on ships and buoys have been in progress throughout the year. Experiments have been carried out on new designs of sea-temperature sensors and indicators for use from light-towers and fast-moving ships.

The new precision humidity-generator has been further improved and is regularly used to calibrate a range of hygrometers. The new automatic dew-point hygrometers have been delivered; one is in use at the Royal Greenwich Observatory, Herstmonceux, to detect the likelihood of condensation in the giant Newtonian telescope, and another is being used in fog investigations at Cardington. Field trials of the lithium chloride dew-point sensors were completed.

It has been found in the field that small but systematic differences exist between humidity readings from mercury-in-glass thermometers and those from electrical-resistance wet-bulb thermometers. The effect has been confirmed during wind-tunnel experiments which showed that slightly different psychrometric constants should be applied in the two cases. It will be necessary to establish the general level of ventilation in screens, in typical surroundings, before the correct psychrometric constants can be applied.

A new electrical hygrometer, whose resistance varies with relative humidity, has given encouraging results and appears to be suitable for measuring humidity from buoys. Finally, a new digital water-level sensor was developed, from an idea originating at Kew Observatory, for use with all types of evaporation tanks.

Effort in the development of instruments for upper air observations has been concentrated on preparations for the major task of introducing the Mk 3 radiosonde system into operational use. Radiosondes manufactured from the productions drawings passed successfully the flight-proving-trial stage, and this cleared the way for contract action to be taken for the quantity-production stage.

Work on the necessary ground equipment is nearing completion. Two radiosonde signal loggers were tested and brought into use to facilitate trials; they provide punched paper-tape outputs which have been successfully processed by computer, even when corrupt signals were deliberately injected. It remains to adapt the basic programme for use by the station computers when these are functioning in 'real time' under operational conditions, and to develop programmes for the conversion of the results to the form of message required for international exchange of data.

To provide a measure of protection from the effects of interference, a tracking filter has been developed which searches for and 'locks on' to the radiosonde signals in the presence of interference.

A semi-automatic radiosonde pressure-calibration plant, controlled by the same type of small computer, has been specified to carry out the detailed calibration programme with a reduced work force. Sufficient consistency in the manufacture of temperature elements has been achieved to enable the temperature-calibration procedure to be simplified.

The further use of synthetic-rubber balloons is reflected in the gradual improvement in performance figures shown in Table V. Over 200 experimental balloons were flown to monitor the results of developments in manufacturing processes. The introduction of a cheaper, high-altitude balloon has resulted in a doubling of the number reaching 10 mb.

The generation of hydrogen for balloons by the interaction of steam/methanol appears to have advantages for isolated or mobile units. Prototype equipment, developed by Admiralty Materials Laboratory and Shell Research is now being evaluated.

Technical services

Mention has been made of the setting up of a second mechanical workshop in the Dines Wing, primarily to carry out jobs at the smaller end of the range for some of the research branches. Although the Branch is still the largest user of workshop effort, its requirements make up only 40 per cent of the workload. The two workshops are to be run under unified control. It is pleasing to report that the improved staff position, first noted at the end of the previous year, has been maintained with the result that demands for services have been fully met from within our own resources.

This cannot be said of work in the drawing office where a major portion has again had to be given to outside contractors. There has been, however, an improvement in the staffing position even here, and for the first time in many years there is a prospect of carrying out a much larger proportion of design and drawing work 'in house'. Whereas the mechanical workshop is mainly involved with 'one offs' and protypes, the drawing office is more concerned with specifications and manufacturing drawings for production items.

Both mechanical and electronic workshops are now able to take on repair of equipment again after an extended period of staff shortage, while the Test Room now provides a recalibration service for a restricted range of electrical and electronic measuring instruments. It is intended to expand this service as time permits.

Technical liaison and equipment installation

Technical liaison was maintained with user branches and manufacturers. For most of the period there was a decrease in the work associated with new contracts but, by the end of the year, progression of Mk 3 radiosonde requirements was becoming a dominant activity.

Work concerned with technical inquiries on instrumental systems, often from other Meteorological Services, continued at a high level, as did that involved with the preparation of specifications and the documentation associated with the installation, operation and servicing of equipment.

Installation work and associated planning continued to be a major activity. In addition to projects mentioned under new instruments and international sections, a further 10 cloud-base recorders and 2 transmissometers were installed, and also a set of instruments was installed for the new Meteorological Office College at Shinfield Park. The prototype data print-out equipment for wind-finding radars was installed by the manufacturer for field trial at Crawley.

The increasing complexity of modern instrumentation necessarily involves installation staff in a continuing commitment to deal with the inevitable crop of design faults which are revealed only with the introduction into service of new equipment. The electrolytic hydrogen-generators are an obvious example but although only one more set was installed, to make a total of four to date, there was growing confidence by the end of the year that the worst of our troubles with this equipment lay in the past.

The withdrawal of defence forces from the Far East and Persian Gulf areas meant additional planning for the resiting of radars. Work was begun on the refurbishing of the 10-cm weather radar from Singapore in readiness for its subsequent reinstallation at Watnall. The 10-cm wind-finding radar at Bahrain was dismantled for return to this country; it will subsequently be reinstalled at Beaufort Park.

The post-design services section, set up last year to deal mainly with problems that arise after equipment has been in service for some time, is becoming increasingly active and also more involved with problems *in situ*, an example being the experimental installation of a Mk 1 automatic weather-observing system on the Lichfield ITA mast.

Instrument testing, calibration and standards laboratory

Table XV shows the numbers of instruments or items of equipment which were examined during the year in Test Room. The numbers entered under electrical/electronic instruments and components have dropped some five-fold in recent years because of a decision not to test minor electronic components. Previously published figures are reanalysed here to give the separate totals for electrical/electronic instruments and components, and corresponding figures are given in Table XV for this year.

Year	1966	1968	1970	1971
Electrical/electronic instruments	1 391	1 520	1 003	1 129
Electrical/electronic components	39 731	33 159	7 737	6 523
Total	41 122	34 679	8 740	7 652

This said, there is undoubtedly a real change due to the progressive trend away from simple instruments to more complex systems. These are often required for unattended use and their reliability must be established, beyond reasonable doubt, before the equipments undergo field trials. Testing and/or calibration is undertaken first to confirm that the manufacturer's product is in accordance with his contractual obligations; the next stage is to satisfy those concerned with the evaluation and subsequent use of the equipments in the field that these function correctly over the full environmental range. A temperature-cycling chamber has been acquired to facilitate environmental testing of this sort. Tests of the first magnetic-tape event recorder occupied some three months, and the new chamber proved invaluable in speeding up tests on the main batch of 30 recorders.

Regular comparisons of the Office's pressure standard with that at the National Physical Laboratory have been facilitated by the use of specially selected, precision aneroid barometers; these make excellent substandards and their readings can be interpolated to one or two hundredths of a millibar. The working standards, which are quartz bourdon-tube devices, continue to give satisfactory service. Precision aneroid barometers continue to replace mercury barometers in service; because of the tendency of their calibrations to drift slowly when first manufactured, the barometer checking scheme has been modified slightly so as to ensure the presence of at least one 'low-drift' barometer at each station.

The Mk 2 radiosonde calibration plant continued to function normally and a stockpile of calibrated radiosondes is slowly being accumulated to tide us over the period when staff will be learning to handle the Mk 3 radiosonde calibration apparatus. Plans for the accommodation at Eastern Road to house this new computerized equipment are well advanced.

Regional Servicing Organization

After a brief period in which all vacancies were filled, staff shortages were again in evidence by the end of the year. The basic commitment to provide a complete maintenance and inspection service for meteorological equipment at home and abroad continues to grow as more instrumental systems are introduced into service. In addition to this, technical staff carry out installations of some items of equipment, and they are also involved in the calibration, in the field, of instruments such as anemometers, electrical-resistance thermometers and tipping-bucket rain-gauges.

Staff of the Regional Servicing Organization are also becoming involved in the actual use of equipment, the best example being the operation of the weather radar complex at Llandegla Research Station. Another task, likely to become a time-consuming one in due course, is the changing and collection of tape cassettes for magnetic-tape event recorders. Full technical cover continues to be provided for the various facsimile networks and Meteorological Office telecommunications centres.

The transport of technical staff to fulfil these tasks presents many problems and over 300 000 miles are travelled annually by road alone. Aircraft, helicopters and launches are used when appropriate. The widening range of activities now undertaken has entailed the building of improved servicing centres at Aughton and Upavon.

In co-operation with Marine Division and Port Meteorological Offices, technical staff install and maintain instruments on merchant ships and research vessels. This service has recently been extended to cover the newly commissioned Royal Sovereign Light-tower off Beachy Head.

Training

Overseas students sponsored by the British Council and by WMO are attached to the Branch for varying periods of informal instruction, or attendance at the technical training school at Beaufort Park. A number of university sandwich-course students have gained useful experience in the development laboratories.

The revision and updating of the basic electronics course at RAF Sealand has proved effective, and the trainee technicians now find they are better equipped to tackle the very demanding content of the specialist equipment courses held at Beaufort Park. Ex-members of the Scientific Assistant grade continue to fill most of the very limited places on these courses and demands for trained staff continue to exceed the supply.

Experienced technicians attend selected sections of the courses at Beaufort Park for equipment new to them, while short courses are arranged prior to the introduction of new equipment into service.

Computing and Data Processing

The Data Processing Branch operates the main scientific computers, the punched-card installation and much of the other data-preparation equipment. It is responsible for the software requirements for computer operation and for the programmes necessary within the IBM 360/195 computer for interfaces with the telecommunication systems. It is also responsible for programmes for data extraction, chart plotting and graphical displays required for day-to-day operational tasks.

The main task throughout the year was to prepare for the installation, acceptance and initial use of the IBM 360/195 computer. Much of the requirement for training in computer programming had been completed in 1970 but there was a residual need for additional training in 1971. This was much smaller than that in 1970, and all requirements were met in full and at the appropriate time. By the end of 1971, over 160 staff had been trained in FORTRAN IV and over 70 in the low-level IBM language known as ASSEMBLER. In addition to these languages a number of staff have learnt PL 1 and some work is being coded in PL 1.

Requirements for the testing of programmes under development increased markedly during the year. Much of the testing was carried out on the IBM computers at the Customer Test Centre (CTC) at Croydon. Three main methods were used: some jobs were delivered to CTC at night by a security service van and the work was returned to Bracknell early the following morning, others were performed by means of the remote computer-terminal at Bracknell and, for some types of work, programmers visited CTC for personal submission of jobs. During the year the speed of the remote terminal was doubled and this helped to provide the increased service required. At the beginning of the year the typical number of jobs was about 400 per week, by the middle of the year it exceeded 500 per week and by the autumn of the year it was in the range 800–1000 jobs per week. Testing of some programmes for which the computer configurations at CTC were unsuitable was carried out on other Systems 360 computer installations. Several parties of staff from the Branch visited Poughkeepsie, U.S.A., to test on the IBM 360/195 the operating system and also some key programmes written in the Branch and required for day-to-day operational tasks. For some other work, for which the CTC configurations were unsuitable, programmes were tested at other installations in the U.K. (Rutherford High Energy Laboratory, University College London, and J. Lyons and Company Limited). Their co-operation is gratefully acknowledged.

During the year IBM announced several series of new memory devices and other peripherals suitable for the 360/195. The configuration of the Office's 360/195 was reviewed several times so that the best possible system for meteorological work could be obtained within the price originally quoted. These reviews have involved substantial work but have been worth while because the configuration which was installed in October is right up to date. It incorporates the latest available devices and represents significantly better value than the original configuration. With the exception of the main frame and the punched-card devices, all other parts of the configuration (e.g. fixed-head disc, exchangeable disc units, magnetic-tape units, cathode-ray-tube (CRT) displays and standby operating console) have been changed from the initial tender. In addition the Calcomp device for producing output on microfilm has also been changed from a Model 835 to a Model 1670, thereby incorporating the latest equipment from California Computer Products Incorporated.

In addition to the necessity for formal training of computer programmers, a very substantial task of the Branch has been the formation and training of the operating teams which will be required for the 360/195 computer. The existing KDF9 computer, run 24 hours a day, is an essential part of the operational complex at the Meteorological Office, Bracknell, and it must be kept fully operational until some time after the 360/195 computer has been brought to an acceptable operational state. Hence it has been necessary to form new operating teams for 24-hour rosters for the 360/195 computer whilst retaining the existing KDF9 operating teams at full strength. There have been large problems in manning, organization and training and also in recruiting some auxiliary staff amongst whom there is always a substantial turnover and wastage. In spite of some unavoidable problems in an undertaking of this magnitude, progress has been very good and a good state of readiness was attained at the right time.

A high-speed electronic interface between the 360/195 and the telecommunications computers had been under consideration for some time and, in the earlier part of the year, staff of the Branch, together with Systems Engineers from IBM, carried out further work in specifying the necessary characteristics of the physical interface to the 360/195. The same staff also devised the software which would be required to be resident in the 360/195. Work was also done on specifying and programming for a magnetic-tape back-up for an interface. Work on these projects was halted when it became clear that the fast electronic interface between the 360/195 and the telecommunications computers would not be available until some time after the likely acceptance of the 360/195 computer. Urgent action was then taken, in concert with other branches, to devise systems and programmes which would enable paper-tape produced by the meteorological telecommunication system to be used to provide the necessary input of day-to-day synoptic data to the 360/195 computer. Staff were diverted from other work to provide the necessary effort to produce the programmes in an acceptable time-scale to do these functions. Very good progress has been made and the complex systems were working by the end of the year.

During the latter half of the year some staff in the Branch have been co-operating with staff in the Telecommunications and Systems Development Branches in considering some of the outstanding problems for the automation of meteorological telecommunications.

The introduction of automatic machines for the plotting of meteorological charts and the drawing of isopleths was kept under review during the year and useful progress was made. Towards the end of the year it was decided that for the next year or so some automatic plotters and line drawers would be attached to and driven by the main computer, the IBM 360/195. Active work is now in progress to determine which equipment should be obtained for this limited attack on the substantial problem of automatic charting and line drawing.

Planning of the accommodation, power and air-conditioning requirements for the IBM 360/195, layout of the rooms, detailed disposition of the computer equipment and special fittings, was carried out in co-operation with the Department of the Environment (DOE) and IBM, and satisfactory agreement was reached on all matters. Much of this work was done under pressure because of the limited time available for the necessary construction of the building and for the installation of technical works services. It was a source of satisfaction when, with the co-operation of the several authorities involved, DOE declared on 18 October 1971 that the computer room would be fit for occupation on the 19th. Delivery of the 360/195 commenced early on the 19th and was completed before midday on the 20th. Installation and check out by IBM engineers were carried out in the next five weeks. Site trials of the machine, under the supervision of the Technical Support Unit, commenced on 29 November and were successfully concluded by 13 December. Immediately after the hand-over of the 360/195, the machine was brought into operation and used for testing many parts of the several complex systems and programmes which had been under active development. The acceptance of the 360/195 was a significant episode in a major project which had been active during the last five years. The first stages of the work to obtain this new computer were started as early as 1966. During 1968 the tempo of this work showed a significant and marked increase. There was a further very substantial increase in 1969, and throughout 1970 and 1971 much effort has been directed to the 360/195 project. Morale was at a high level when the 360/195 was handed over to the Office for use, and by the end of the year operating staff were rapidly gaining expertise in using the 360/195. The immediate objective was to achieve a smooth and efficient operating system and this work was tackled with zest and determination.

COMET computing laboratory

The ICL KDF9 electronic computer (COMET), which was installed in 1965, continued as the main operational computer. It is run 365 days a year, 24 hours a day. The work-load has remained at a very high level. Until the late autumn the computer was fully loaded but from October there has been a slight decrease in the work-load and there have been a few hours a week during which some work could be done on the back-log of processing meteorological synoptic data to form a good library of data in synoptic order. Serviceability and reliability of the KDF9 have been good throughout the year.

Punched-card installation

The installation is equipped with a range of punched-card machines, including automatic punches and verifiers, sorters, collators, tabulators, and tape-to-card converters. Since it was set up in 1920 a library of almost 60 million standard 80-column punched-cards containing surface and upper air data from land and marine stations and surface data from voluntary observing ships has been accumulated. The present punching rate of British data is about one and a third million cards per year and about a further three-quarters of a million cards of selected foreign data are obtained through international exchange.

During the year work was started on plans for some re-equipment of the punched-card installation. The main objective is to replace some of the punching equipment for cards and paper-tape, by keyboard systems which record the data on magnetic media, thereby facilitating the keying of data, their subsequent correction, and also their processing on computers. A considerable proportion of the processing of punched cards is already performed on the computer, but there remains some residual direct punched-card machining on which the introduction of a keyboard–magnetic-medium system will have some consequential effects.

Systems Development

The overall objective of the Systems Development Branch is the more effective application to the functions of the Office of systems ideas and of actual working systems, in practice mainly electronic data-processing (EDP) systems. This entails keeping abreast of new developments in the electronic and telecommunication fields and appraising all known systems plans and requirements of meteorological users, both nationally and internationally.

One of the more immediate concerns of the Branch is the efficient utilization of the IBM 360/195 computer in its work, particularly the build-up of a comprehensive bank of good-quality meteorological data in machine-readable forms and the devising of means to make them readily accessible to all users. The ultimate size of the bank is expected to amount to at least one hundred thousand million (10^{11}) decimal digits, involving a wide variety of data sources (ships, upper air, land surface, satellite, aircraft, etc.) and comprising all the usual weather elements (pressure, temperature, humidity, wind, cloud, etc.) as well as some special elements such as radar-intensity values, cloud brightness, raindrop sizes, etc. The period of the record usually starts with the present day and extends back for several years, in some cases for more than a century. Quite a large proportion already exists in machine-readable form although some conversion will be necessary from the present media ($\frac{3}{4}$-inch magnetic tape, punched cards and paper-tape) to the two main media that will be used on the new computer, viz. $\frac{1}{2}$-inch magnetic tape and exchangeable magnetic discs.

Good progress has been made in designing the formats and file layouts of the various classes of data within the bank, in cataloguing the files involved and in programming input and retrieval routines. More precise codification and classification of the attributes of these data files will be required than ever before, especially as one of the aims is to introduce the maximum automation into the retrieval of data via computer programmes or via the remote terminals that are being attached to the new computer. Data banking has international implications, particularly in the design of data formats and catalogues, since data files are often exchanged with other Meteorological Services and international standards are already laid down or are being developed for this.

Most of the present staff of the Branch are occupied with the data-bank function. However, as other posts are filled more effort will be devoted to systems studies and future planning. The senior staff are already involved in advice on such matters as the automation of Meteorological Office telecommunications and the introduction of a new system of data entry and verification to replace the present punched-card methods. Other projects on which advice is being given to user branches include the specification of mini-computers for particular uses such as the automation of radiosonde calculations, the conversion of field data (e.g. rainfall, radiation, etc.) logged on non-computer-compatible tape into data on computer tape, the digitization and transmission of radar information for various purposes, etc. Consideration is also being given to the problems involved in the further automation of library functions.

One system of special interest is a computer-controlled flying-spot CRT scanner, designed and working in the Nuclear Physics Laboratory, Oxford University, which shows great promise for the possible automatic analysis of the pen-and-ink traces which are available for many kinds of meteorological data (pressure, rainfall, temperature, humidity and wind), and from which only small amounts have been extracted by hand, in the past. The Oxford equipment has shown itself capable of analysing even the most complicated traces (viz. of wind and rainfall fluctuations) with high precision and may make it worth while to reclaim much back-log data.

METEOROLOGICAL TELECOMMUNICATIONS

Throughout the year the meteorological telecommunication services and facilities generally have been maintained at approximately the same level as in 1970, with national and international operational requirements being met mainly by conventional telecommunication methods. National requirements in this context include those of offices located in the U.K. associated with military and civil aviation, public services and shipping, as well as those of British meteorological offices supporting military establishments and formations overseas, such as those located in Germany, the Mediterranean area and the Indian Ocean. International aspects fall chiefly within the field of WMO, though there is a definite impact on meteorological telecommunication services through the needs of the International Civil Aviation Organization (ICAO). So far as the WMO field is concerned, the U.K. requirements for meteorological information have a global basis, but with emphasis on data related to the northern hemisphere. Telecommunication services of course reflect these factors, though there are, as one might expect, more clearly defined telecommunication links between the U.K. and North America to the westward, and with the European Regional Meteorological Telecommunication Network to the eastward, than is readily apparent farther afield.

The main Meteorological Office Telecommunications Centre (Met TC) is located at the Headquarters at Bracknell. It forms the hub of the extensive, exclusive, land-line network in the U.K., a network composed of teleprinter and facsimile systems. Linked with the network are certain radio-communication services, including collection of observational data from Ocean Weather Ships in the North Atlantic, and pictorial read-out from meteorological satellites. Met TC, Bracknell, maintains two radio-facsimile broadcasts and a radio-teleprinter broadcast, each broadcast being made simultaneously on a family of four frequencies in the high-frequency band, designed to provide reliable reception by other meteorological services and by ships located within a radius of approximately 2000 miles.

The maintaining of basic, conventional telecommunications services is an essential task, demanding skill and constant effort from the staffs associated with them. Another task which has demanded perhaps even greater knowledge and effort during 1971 from the specialist staff directly concerned, is that of implementing the first phase of telecommunications automation at Met TC, Bracknell, while at the same time moving forward on planning the following phases. These other phases will eventually extend automation to most (perhaps all) of the meteorological offices in the U.K., and those supporting the RAF in Germany. Although in the longer term automation will pay out greater and greater dividends within the national area, circumstances have dictated that initially the benefits will accrue more in the area of international meteorological information exchanges.

Within WMO, Bracknell has been designated both a Regional Meteorological Centre (RMC) and a Regional Telecommunications Hub (RTH). As an RTH it will be one of the nodes in the Global Telecommunication System (GTS), responsible for receiving and retransmitting all of the observational data in alpha-numeric form and processed information in pictorial form that is scheduled to be passed on the Main Trunk Circuit (MTC) of the GTS between Europe and North America. In accordance with WMO resolutions and recommendations, an RTH in this nodal position must be an automated centre capable of: effecting data transmission at rates of 1200 and 2400 bits per second, handling characters of both 5-unit and 7-unit alphabets, error control covering both error detection and correction, and coping with pictorial information in analogue form. The automated centre must be of high integrity and reliability, and is required to operate on-line 24 hours a day, 7 days a week. Should a breakdown occur, its length must be of minimum duration, and recovery to normal service should be possible without loss of data.

The first phase of automation within the Bracknell RTH will fully meet the various criteria agreed by Members of WMO. The heart of the automated complex comprises two Marconi Myriad II computers working in dual mode, both of them accepting all data arriving at the complex in alpha-numeric form and cross-checking with each other for accuracy, with the lead computer being responsible for the output of correct characters. This kind of computer control, together with error detection and correction techniques, is directed towards the achievement of integrity. The reliability factor is based on such things as the ability of the system to maintain full service with only one computer in action, and a no-break local power supply which can keep the whole system in operation even if the public electricity power supplies are interrupted for a long period. Quite a number of the computer peripherals, such as disc drives, disc packs (backing store), paper-tape punches and readers, are also duplicated.

The hardware for the first phase of automation of Met TC, Bracknell, was delivered to the Napier Shaw Building on 23 June 1971. This was installed by the contractor in a specially prepared room having an environment air-conditioned to prescribed standards of temperature, relative humidity and dust filtration. It was hoped that the software writing and testing could be completed by the contractor soon after installation of the hardware, and that the first phase of an automated system would be handed over to the Office by the end of August 1971. Unfortunately this hope was not realized. Although this was a slight setback, it was not entirely a surprise to the specialist telecommunication staff of the Office. The automated system, although fundamentally a computer-controlled message-switching system, has a number of special features which are peculiar to meteorological telecommunications, and also peculiar to the technical and operational characteristics evolved and agreed within WMO for application to the GTS. Therefore some of the technology involved and some of the operational requirements to be met are quite new, and the Bracknell RTH in this respect has been involved in a kind of pioneering effort. Only three other major meteorological telecommunication centres have advanced as far as Bracknell towards the common goal, namely Washington, Paris and Offenbach, and they too have found the path of progress both difficult and frustrating.

It so happens that the hubs on the GTS main trunk immediately to the west and east of Bracknell are respectively Washington World Meteorological Centre (WMC) and Paris RTH. Offenbach RTH is connected to Bracknell RTH by a European Main Regional Circuit. Each of these centres, in developing its automated complex, has introduced computer hardware produced by a national company of its own country. This has meant that in order to enable the centres to work operationally as an integrated system, it was essential to ensure that computers produced by completely different manufacturers were correctly 'taught' the common procedures (software aspects in particular) agreed within WMO, and that they could 'converse' fluently with each other. In order to achieve this common understanding and to check that a reliable operational system has been achieved, a number of meetings (bilateral, three-centre and four-centre) have been held during the year for the purposes of checking compatibility in hardware and software design and of deriving operational trials programmes. Limited operational trials were carried out with Paris RTH for about two weeks from 28 April 1971, while the Bracknell system was still in the contractor's works at Chelmsford. Evidence obtained during those trials indicated that the automated centres of Bracknell and Paris were substantially correct in basic design and largely compatible in operation.

Full-scale operational trials of automated telecommunication centres were planned to begin between Washington WMC and Bracknell RTH on 1 September 1971. An important and essential facility for the trials (and indeed for future operations) was the establishment of a high-quality telephone-type transatlantic circuit between the centres, and for certain technical reasons the Post Office had been requested to provide the circuit through commercial satellite routeing. Owing to an industrial dispute in the U.S.A., this circuit was not provided until October. By that time the high-grade circuit connecting Bracknell RTH to Paris RTH had been established. It is expected that a similar high-grade circuit will be provided between Bracknell RTH and Offenbach RTH early in 1972, possibly during January. The telecommunication specialists concerned with the design and implementation of these four major centres are making every effort to complete the operational trials, and to establish as an integrated operational system by mid-January 1972 the complex of the four centres and the three interconnecting main trunk segments. When this has been achieved, it will place Bracknell RTH effectively as the 'gateway' centre between North America and Europe for the exchange of meteorological information—a very responsible and key position, the importance of which has been recognized by the Meteorological Office in the design and build-up of the automated component of Met TC, Bracknell.

For many months of 1971 the telecommunication planning staff have been very much concerned with another large task, and one containing an acute problem for which there are few reference sources as an aid to finding the answers. The overall task is to move Met TC, Bracknell, without any interruption in service, from its present location in the Napier Shaw Building to the new Richardson Wing, so that it can be collocated with the new scientific computer (IBM 360/195) and the Central Forecasting Office in the new Wing. This task is both complex and difficult. It needs careful detailed planning, and it requires considerable co-operation by other parties such as the Department of the Environment (DOE) and the Post Office. However, the job of moving the whole of the Telecommunication Centre from one location to another, without any break in service, has been done before; the Centre was moved from Dunstable to Bracknell in the late summer of 1961, so the overall task is not new. The acute problem is to move the newly automated system and at the same time maintain continuity of service. A number of possible solutions have been studied, but most have included the procurement of more computers and associated hardware, as well as additional software. These are very costly items, and usually cost has been the main factor in deciding against such solutions. Although a measure of operational risk is involved, it has been decided to take advantage of the duality in the design of the system and first reduce to single-mode working in the present location, then build up for single-mode working in the new location and cut-over the services to that, and finally restore dual-mode operation but in the new Wing. This description over-simplifies both the problem and the agreed solution, but perhaps it provides a general picture of what is being done. As regards the time scale, the automated system is intended to be moved some time ahead of Met TC, Bracknell, as a whole, because of inter-operation with the automated RTHs at Washington, Paris and Offenbach. This part of the move should be effected early in the New Year. The move of the whole Centre should be completed during the first few months of 1972.

As already mentioned, further phases of telecommunication automation are intended to follow the first phase. Indeed a second phase has already been planned, designed, and is under contract for supply of hardware and software. This second phase will provide a larger and more sophisticated system than the first phase, and will supersede it.

Some planning had been done in respect of a third phase, but changes in user requirements and in technology, as well as increasing knowledge and expertise in the subject of applying computerized automation to telecommunication facilities and services, have indicated the wisdom of carrying out further and more extensive studies before the composition of phases three and four is decided. Towards this end, a comprehensive document was produced in November, entitled 'Meteorological Office Telecommunications Operational Requirement up to 1980'. The intention is that this document will form the basis for further studies, policy decisions, planning and possibly contractual action during 1972. Perhaps it should be explained that any reference here to possible contractual action in 1972 implies nothing more than a current line of thought. During 1971 the Office has built up a team of professional engineers in the Telecommunications Branch, and both they and certain scientific officers within the Office have acquired much valuable specialist knowledge on the hardware and software associated with computer-controlled automation of telecommunications. Some of this knowledge has been acquired through formal training given by the Marconi Company Limited under special contract. Further training of this type is planned. The Office is therefore much better equipped at the end of 1971 to deal with matters of hardware and software systems design and implementation than, say, a year ago.

Although, as already stated, conventional telecommunication services and facilities have been maintained at approximately the same level as in 1970, there were certain significant happenings in the area of facsimile services. In January a direct land-line facsimile service was introduced from Bracknell to Dublin Airport and Shannon Airport, the main part of the transmission programme consisted of charts for civil aviation purposes produced by the Principal Forecasting Office at London/Heathrow Airport. A similar service was opened in July over a direct land-line circuit which was established between Bracknell and Copenhagen Airport. During September, international trials of facsimile transmissions at 240 rev/min (double the normal upper limit of 120 rev/min) were mounted between a number of major meteorological offices in Europe. Existing international land-line circuits were used during the trials. Bracknell acted as co-ordinator of the trials and provided the transmitting centre; receiving centres included Offenbach, Zurich, Rome, Shannon and Copenhagen. Facsimile transmission at 240 rev/min introduce a number of technical problems, most of which are demonstrated by poor-quality recorded pictures. The trials were directed towards testing the feasibility of transmitting more information in the form of facsimile charts, and faster, without unacceptable loss of definition in the received pictures. The analysis of the trials results shows that there is a general desire for a 240-rev/min service, that to provide it is probably a practical proposition within the limits of existing land-line circuits and available facsimile equipment, but that a few technical troubles have yet to be eliminated and further international trials are needed before an unequivocal answer can be given.

Meteorological offices in the U.K., and those at locations abroad equipped with suitable receiving equipment, have continued to make the fullest possible use of pictorial information obtained from available meteorological satellites. During the latter part of 1971, only one U.S.A. meteorological satellite (ESSA 8) continued to provide an operational service, and this has daylight automatic-picture-transmission (APT) by vidicon cameras only. Night-time satellite observations, as well as APT, were obtained from the U.S.A. satellite NOAA 1 (also known as ITOS-2) as long as it was in service. A number of other U.S.A. meteorological satellites either ceased to provide a service or, in the case of NOAA 2 (also known as ITOS-B), failed to go into orbit during the year. It is thought that ESSA 8 will be the last U.S.A. observational satellite to carry the daylight APT system, and any that are put into service during 1972 will provide read-out based on scanning-radiometer techniques. To meet this situation action is in hand to procure suitable ground recording-equipment.

INTERNATIONAL AND LONG-TERM PLANNING

The international character of meteorology necessarily leads to a number of international conferences each year. Many of those with which the Meteorological Office is concerned are held under the auspices of one or other of three intergovernmental organizations. The World Meteorological Organization

(WMO) deals with the international aspects of the organized practice of meteorology and its applications to human activities. Many of the meetings of the International Civil Aviation Organization (ICAO) are concerned directly or indirectly with the meteorological aspects of civil aviation. Aspects of meteorological support for the armed forces of the North Atlantic Treaty Organization (NATO) are discussed at meetings of committees and working groups set up for that purpose. There are also meteorological committees associated with the other international military organizations in which the U.K. is concerned.

A number of other meetings are organized by one or other of the constituent bodies of the non-governmental International Council of Scientific Unions (ICSU). The various bodies included in ICSU are each concerned, especially as regards international requirements, with the promotion of a science or sphere of scientific interest, such as outer space, the oceans, or the Antarctic. Meteorology has a part to play in several of these, and the Office is represented on the related British National Committees.

Delegates and representatives from the Office at these meetings are drawn from all branches according to the subjects to be discussed. An account of the principal meetings attended will be found in the 'International Co-operation' section (page 99).

The Director-General is Permanent Representative of the U.K. with WMO. As such, he represents also Dependencies of the U.K. other than those which, having their own meteorological services, are Members of WMO on their own account (Bahamas, Hong Kong, British Caribbean Territories). The Director-General continues to be an elected member of the WMO Executive Committee. The Assistant Director (International and Planning) assists him in this work, and acts as the usual channel of communication with WMO on behalf of the Permanent Representative. Much of the work of WMO is carried out by the Members, so that as the international aspects of meteorology continue to develop so the volume of work falling to the Members expands.

In the preparation for the 4-yearly session of the WMO Congress in April 1971 most branches of the Office were involved, as well as the Directorate of Meteorology and Oceanographic Services (Navy), the Water Resources Board, the Institute of Hydrology and the Foreign and Commonwealth Office. The Congress studied the implementation to date of the World Weather Watch (WWW), revised the plan and reshaped the structure and functioning of the Organization around WWW. The system of Technical Commissions was reorganized, necessitating subsequent changes in our representation on the various Commissions. Operational hydrology was at last accepted as the responsibility of WMO. The accelerating development of the Global Atmospheric Research Programme (GARP) was studied, and the plans for its first international tropical experiment in the eastern Atlantic, GARP Atlantic Tropical Experiment (GATE), in 1974 were endorsed. The Scientific Management Group for this experiment is to be located at the Meteorological Office Headquarters in Bracknell.

The increasing involvement of meteorology in other environmental problems (e.g. the study and exploitation of the oceans, airborne and waterborne pollution) was a major preoccupation of Congress. The budget of WMO, which is mainly concerned with the work of the Secretariat in planning and co-ordinating the work of the Members, was reduced to the minimum compatible with the work to be done. Expenditure on technical assistance is met almost entirely from outside the budget. In this connection Congress decided to continue the Voluntary Assistance Programme to help ensure the adequate implementation of WWW.

The United Kingdom's own plans for implementing WWW were further developed during the year. The New Hebrides upper air station, jointly established and financed by France and the U.K., should become operational early in 1972. The planning of two more U.K. upper air stations, in the Gilbert and Ellice Islands Colony (GEIC), was completed, following agreement and understanding reached with New Zealand and the GEIC Administration. Construction work should start soon. Once established, these projects will be placed under the administrative and technical control of the New Zealand Meteorological Service as agent of the U.K. Planning work was begun on further WWW projects in the Seychelles and British Indian Ocean Territories.

Through the Voluntary Assistance Programme (VAP) of WMO, APT equipment, which gives direct reception of meteorological satellite pictures, was provided to Ethiopia and Jordan. Equipment installation and staff training were carried out by a Meteorological Office technician. At the end of the year 10 other VAP equipment-projects were in train, of which 9 are due to be completed in the first quarter of 1972. Other VAP requests for equipment were studied as a basis for deciding which ones U.K. should offer to supply.

After the WMO Congress the Office was, as usual, host to the Conference of Commonwealth Meteorologists. The Under-Secretary of State for Defence (RAF), Mr Antony Lambton, M.P., opened the Conference on Tuesday, 11 May, and there was a reception at Lancaster House the next evening. The Director-General's address, and papers by nine staff of the Office introduced discussions on recent developments in meteorology. The overseas participants visited several branches of the Office and also had a number of individual discussions with staff.

The U.K. acted as host country for a 'Technical Conference on the Uses of Meteorological Radar' organized by WMO with the support of the United Nations Development Programme (UNDP). The Conference was held in Church House, Westminster, 1–10 September 1971, and all supporting services were organized by the Office. The Conference was an inter-regional project supported by UNDP and was restricted to participants from countries in Europe and Africa. Its purpose was to provide practising meteorologists with information and instruction on basic principles and modern methods and techniques for the application of radar to meteorological activities related to hydrology, agriculture, aviation and other human interests. Meteorologists from 46 countries attended. During the Conference many of the participants took advantage of the excursions to places of scientific interest which were arranged with the support of manufacturers of radar equipment. Several participants also took the opportunity to visit Meteorological Office Headquarters, Bracknell, for technical discussions.

The planning of the first large international observational experiment of the Global Atmospheric Research Programme in the tropical eastern Atlantic commenced under the supervision of the Tropical Experiment Board. A climatological study of the area of the experiment was prepared for the Interim

Scientific Management Group, and the capabilities of shipborne and airborne systems were discussed. Preliminary arrangements were made for accommodating the Group in Bracknell.

The construction and equipping of the new Richardson Wing of the Headquarters building at Bracknell was almost completed. In advance of completion, the new computer was installed in October and November, and installation of telecommunications equipment began in November. Plans were made to begin using each area of the new building as soon as it became available, and the whole building should be in operational use early in 1972. For the entrance hall a mural intended to be both informative and artistically interesting has been commissioned. The completion of the Richardson Wing and of the Beaufort Park building afford much-needed relief to the growing pressure and complex requirements for work space. The efficient matching of these requirements with the expected accommodation continued to be the responsibility of a high-level committee. A special review of the situation as planned for early 1973 was begun in co-operation with DOE, as a basis for further planning.

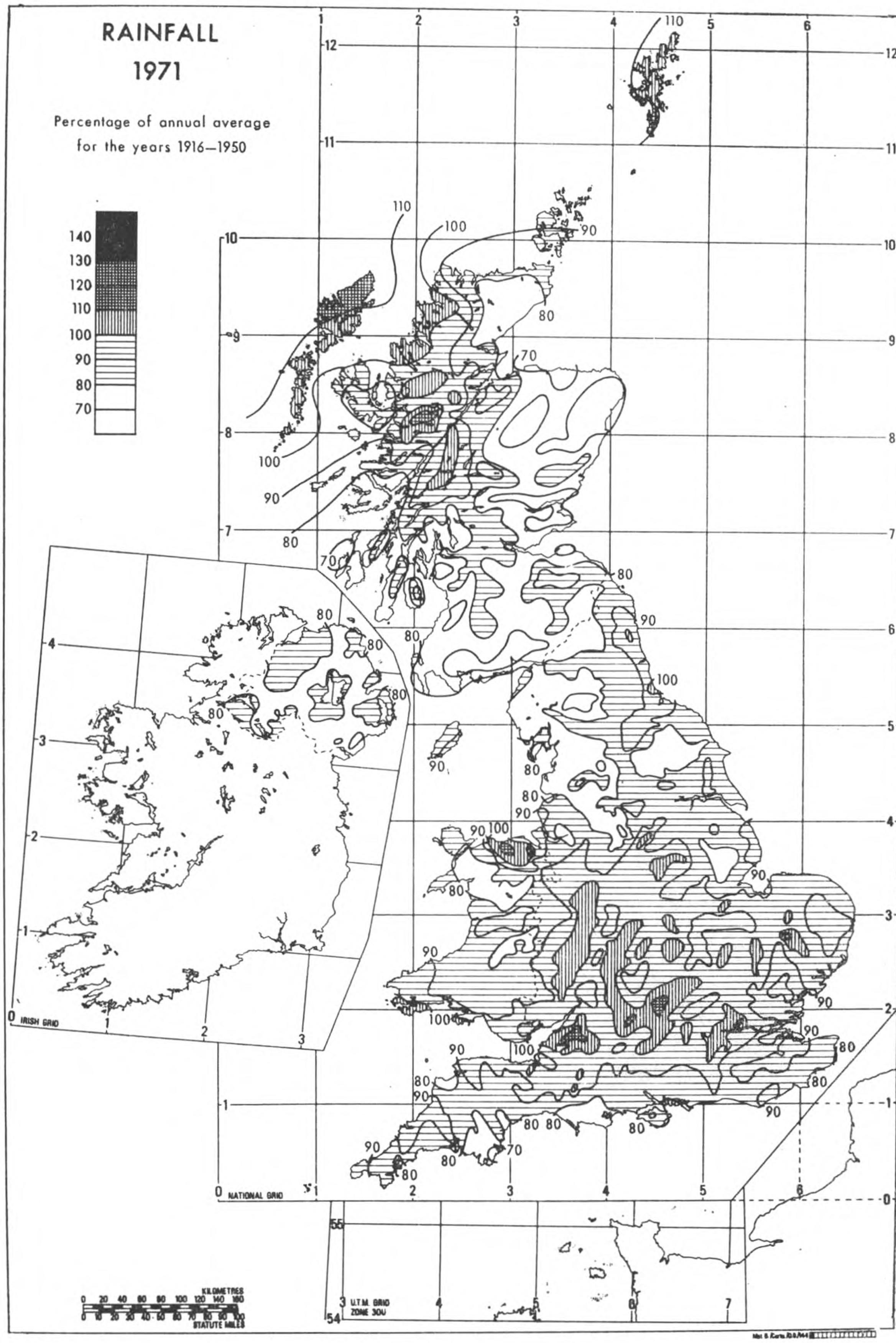
Advice on meteorological subjects was provided as necessary to the Foreign and Commonwealth Office including the Overseas Development Administration. There was discussion with the new Seychelles Meteorological Service on a number of technical matters, including the proposed upper air station there. In the Falkland Islands the Office's technical responsibility in meteorology ended when, under an agreed rearrangement, the forecast service became entirely the responsibility of the Governor instead of being shared with the British Antarctic Survey.

P. J. MEADE
Director of Services

SUMMARY OF THE WEATHER OF THE YEAR (1971)

Prominent features of the weather in the United Kingdom during 1971 included the following: a mild January and early February in which some unusually high temperatures were recorded including a new record for the country in January; spells of dry or almost dry weather over large regions in the spring; the contrast between a cool and dull June with heavy rain at times and a sunny July with dry spells, and a similar contrast between August (which also included a damaging hailstorm in the East Riding of Yorkshire) and September; a very sunny November in many areas; a mild and generally very dry December.

January. The year began cold with a little snow or sleet (rain or drizzle and snow) in the north and east, and the snowfall of late December in southern England lay on the ground until about the 6th. However, on the 6th, mild changeable weather spread north-eastwards across all areas, with heavy rain in the west and north, and during the next few days there was further heavy rain, especially in the west. It was very mild from the 7th to 10th and unusually high temperatures occurred on the 9th and 10th in the north and west. On the 9th a temperature of 16·7°C at Lairg (Sutherland) equalled the highest January air temperature recorded in Scotland since 1889, and very high temperatures



RAINFALL 1971

PLATE I

The computer room in the new Richardson Wing at the Meteorological Office Headquarters at Bracknell, showing the IBM 360/195 configuration specified by the Office

The staff member farthest from the camera is operating the machine from the main console. The chequered frame behind him identifies part of the central processing unit and high-speed store. The floor area of the room is 8220 ft^2 and allows for some expansion of the configuration.

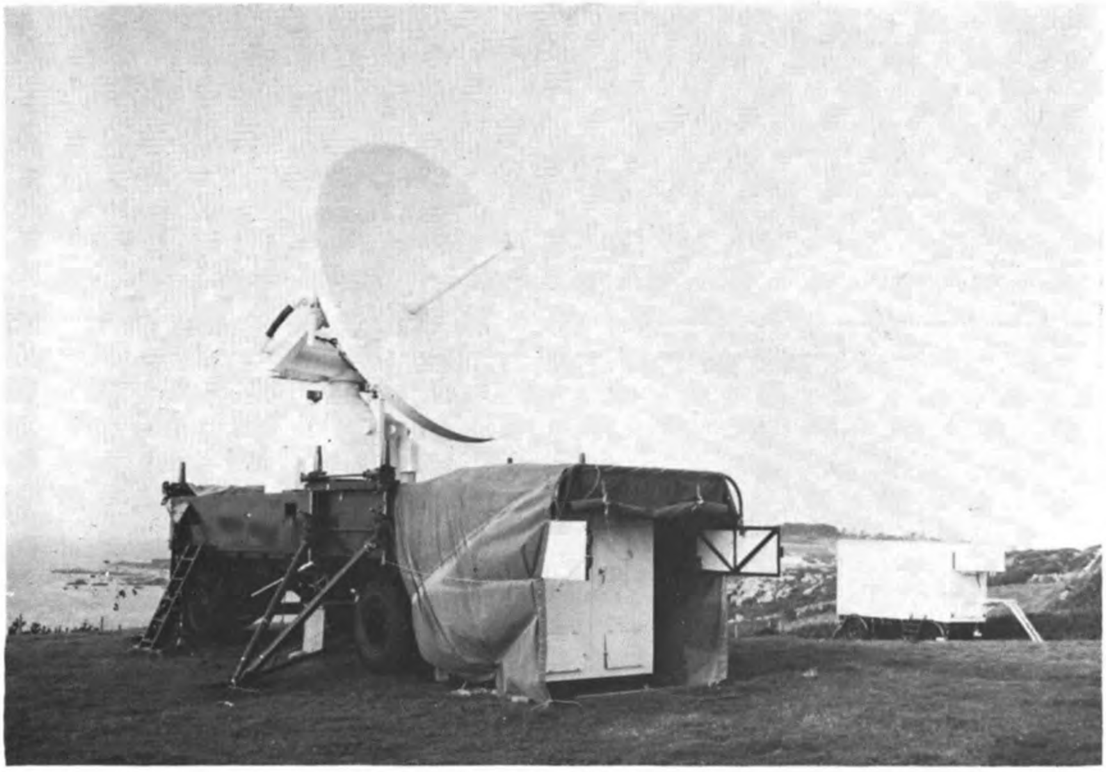
(See page 42.)

PLATE II

The new headquarters building for the Operational Instrumentation Branch at Beaufort Park

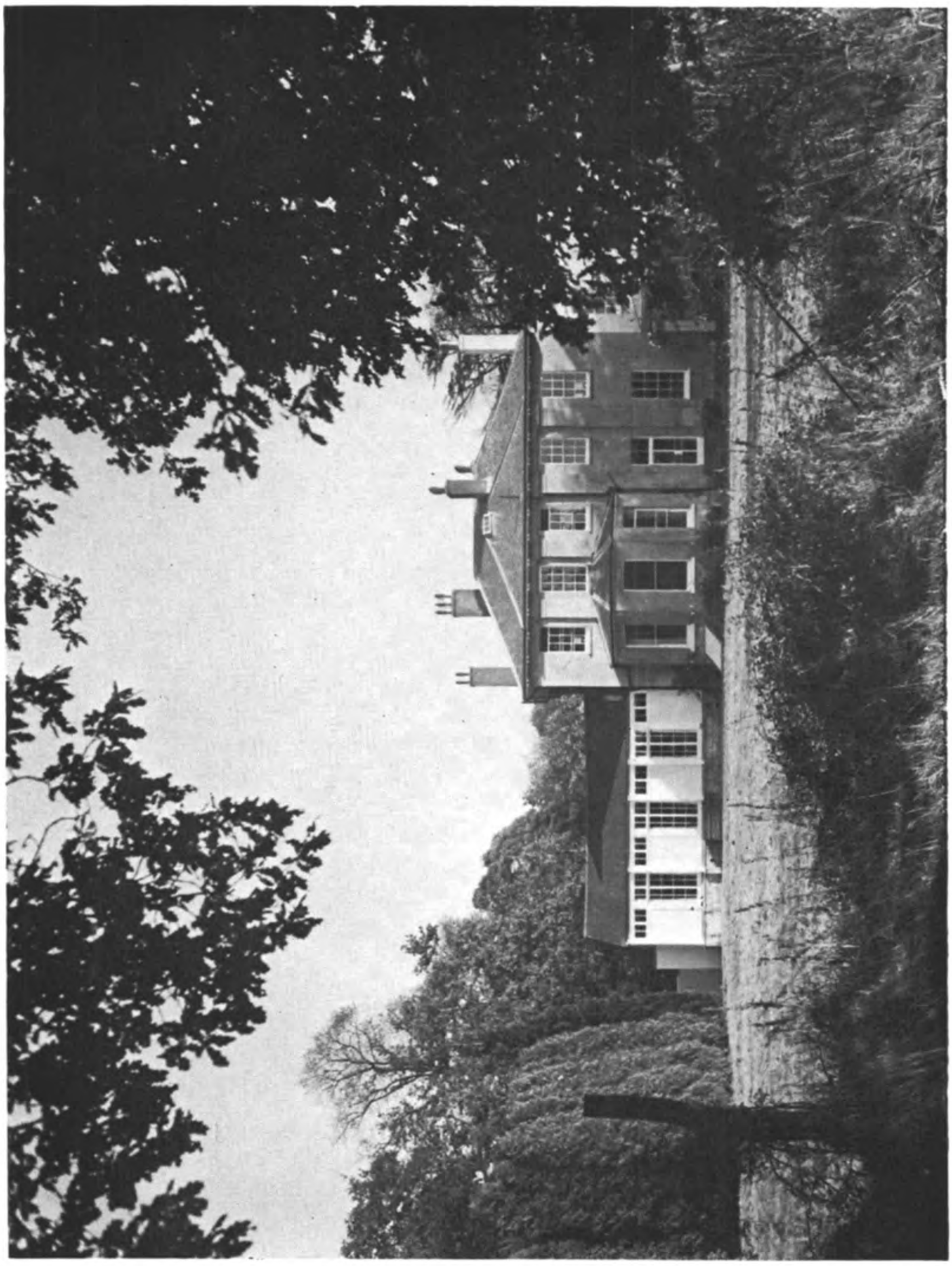
(See page 33.)

PART OF THE EXPERIMENTAL SITE AT BEAUFORT PARK
The photograph shows the new operational building (right centre) and the original Field Station (left background). (See page 33.)



PROJECT SCILLONIA — 43S PRECIPITATION RADAR INSTALLATION ON ST MARY'S, ISLES OF SCILLY
(See page 79.)

PLATE IV

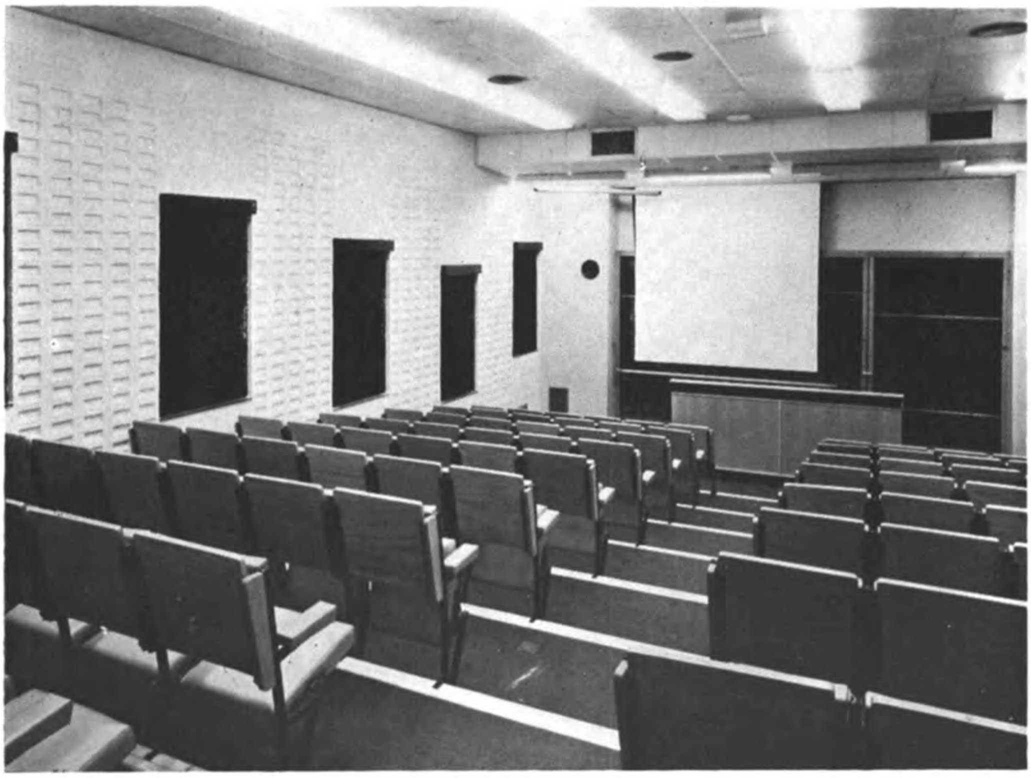


METEOROLOGICAL OFFICE COLLEGE AT SHINFIELD PARK NEAR READING
The Lodge in its parkland setting.
(See page 94.)

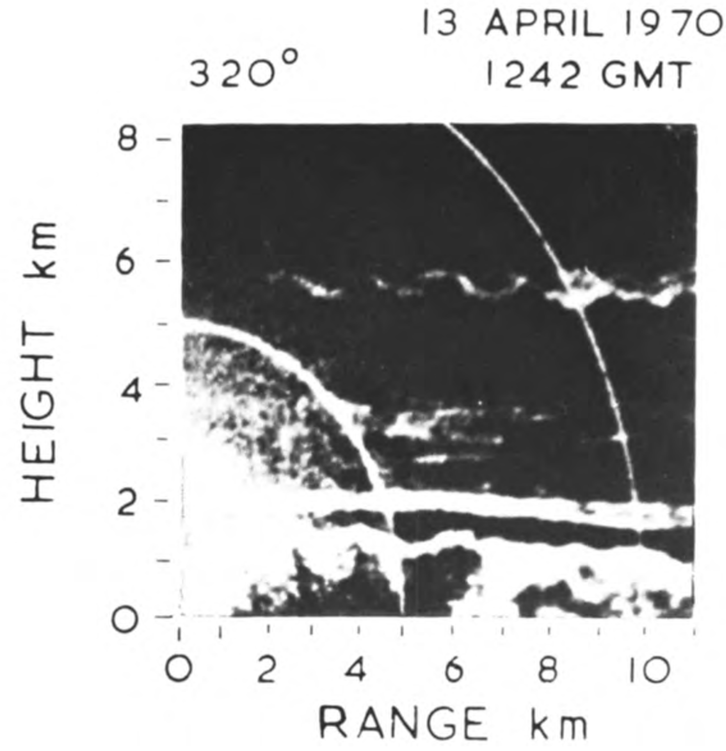
PLATE V

METEOROLOGICAL OFFICE COLLEGE AT SHINFIELD PARK NEAR READING
Meteorological assistants being trained to plot weather maps.
(See page 94.)

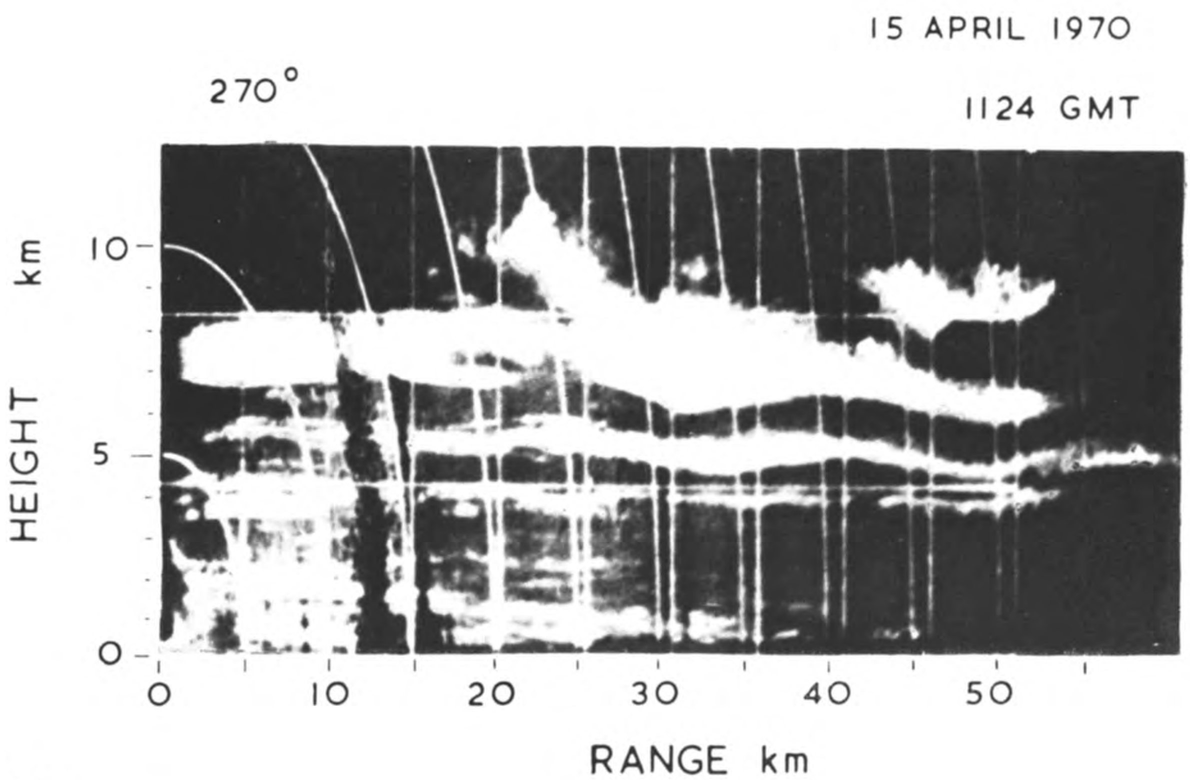
PLATE VI



METEOROLOGICAL OFFICE COLLEGE AT SHINFIELD PARK NEAR READING
Upper photograph: The dining hall in the Lodge.
Lower photograph: The interior of the cinema.
(See page 94.)



(a)



(b)

RANGE HEIGHT INDICATOR (RHI) RECORDING SHOWING ECHOES

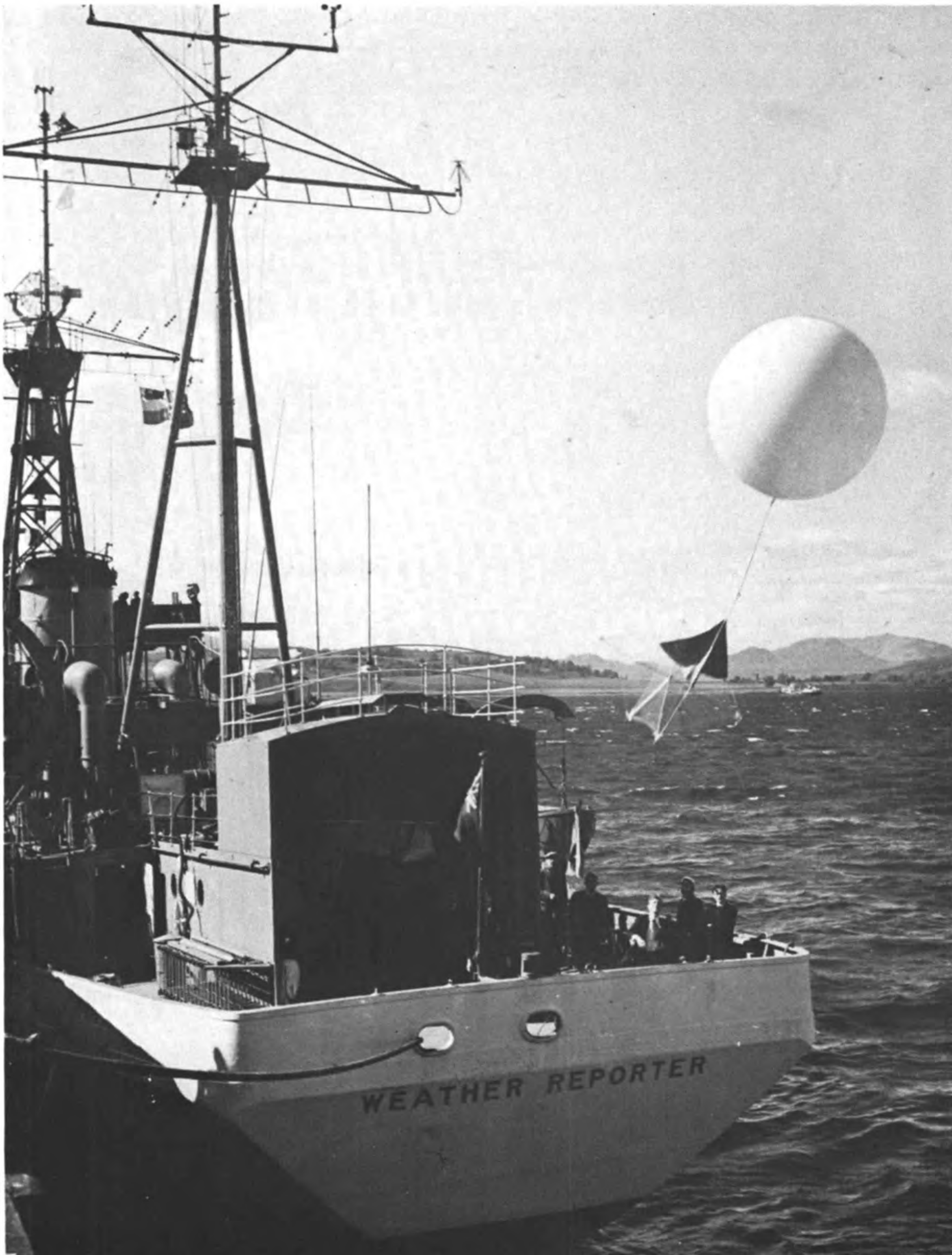
(a) From clear-air turbulence billows at a height of about 6 kilometres.

(b) From clear-air layers and cirrus clouds.

The normally horizontal scattering layers have been distorted by lee waves generated by the Welsh mountains.

Echoes from stationary targets have been removed by coherent processing. (See page 80.)

PLATE VIII



RADIOSONDE BALLOON BEING RELEASED FROM OCEAN WEATHER SHIP WEATHER REPORTER AT GREENOCK

(See page 33.)

occurred in the Scottish Highlands. The föhn effect over the Welsh mountains led to exceptionally high temperatures on the north coast of Wales on the 10th. Aber (Caernarvonshire) recorded 18·3°C and an almost identical temperature occurred at nearby Llandudno—this is the highest air temperature on record for January in the U.K. On the same day central Manchester had its mildest January day since records became available in 1877 and several long-established stations also recorded their highest ever January temperature, among them Rhyl (Flintshire) and Bradford (West Riding of Yorkshire) where records began in 1905 and 1908 respectively. The mild weather continued until the last few days of the month and resulted in an unusually snow-free January. The incidence and amounts of snow were very low and during the period 7th to 17th much of the snow lying in the mountains melted, even in the Highlands of Scotland. A wet period in the south during the fourth week led to local flooding from swollen rivers, and on the 25th violent winds, associated with a number of whirlwinds, occurred in east London and adjacent areas of Essex and Kent and caused local damage to buildings, uprooted trees and overturned motor vehicles. It was a dull month nearly everywhere and Ross-on-Wye (Herefordshire) had its lowest January sunshine total since records began in 1915.

February. It was generally mild during the first half of the month and unusually so on the 3rd and 4th; a temperature of 15·0°C was recorded at Scarborough (North Riding of Yorkshire) on the 3rd and 14·2°C occurred in Falkirk and Stirling on the next day. This period was also virtually dry, especially in the east and south of England; no measurable rainfall occurred at Cleethorpes (Lincolnshire) until the 13th or at Sandown (Isle of Wight) until the 14th. However, from the 11th to 18th, although amounts of rain elsewhere continued to be mostly small, there were some heavy falls in western and northern areas. The Lake District had a particularly wet spell and in the 48 hours commencing 09 GMT on the 11th, Seathwaite Farm (Cumberland) recorded 162·1 mm of rain and, in the same period, Long House, near Langdales (Westmorland) had over 132 mm of rain. Seathwaite Farm recorded a further 57·1 mm of rain in the 24 hours from 09 GMT on the 14th. Strong, gusty winds occurred in many areas overnight on the 12th/13th. They recurred on the 15th and later that night snow spread into Northern Ireland and south-west Scotland and reached most of England and Wales during the following day. At the same time it became cold for a few days and the air temperature at Lanark fell to −11·7°C on the morning of the 16th and at Shawbury (Shropshire) it fell to −10·0°C on the 17th. Although a little rain fell in the west during the last 10 days or so, many eastern areas of the country had only very small amounts. After a mild interlude from the 19th to 25th it became cold again and snow or sleet occurred in southern Scotland and northern England on the last 2 days. The dry spells resulted in below average rainfall nearly everywhere, notably in eastern districts; it was the driest February at Gordon Castle (Moray) since records began in 1865. The northern half of the country also had little sunshine and Tiree (Hebrides) had its dullest February since 1940.

March. The weather was generally changeable and, except in a few areas in southern England and central Scotland, it was less sunny than average. Many parts of the U.K. had more rainfall than average and West Baldwin reservoir (Isle of Man) and Forglen House (Banffshire) had their wettest March since records began in 1899 and 1901 respectively. Snow fell in many areas on the 1st and snow occurred again in the southern half of England (and also in the Channel Islands) on the 5th. In contrast to the weather in England on the 5th, the air temperature at Rothesay (Buteshire) on the same day reached 15·0°C. Much of the second week was mild, except in the extreme north of Scotland where it was also very windy at times, with gusts over 50 knots* in places on the 10th. In southern England on the 15th widespread snow, which quickly turned to rain, heralded a wet and windy spell in most districts, particularly from the 17th to 20th. During the period 09 GMT on the 17th to 09 GMT on the 21st a total of 209·4 mm of rain fell at West Baldwin reservoir. The extent of the heavy rain during this wet period is illustrated by the following selection of rainfalls recorded in the 24 hours from 09 GMT on the dates stated: 75·6 mm at St Clears (Carmarthenshire) on the 17th; 60·3 mm at Sourhope (Roxburghshire) on the 18th; 112·5 mm at Hopes reservoir and 110·7 mm at Hungry Snout (both in East Lothian) on the 19th; 60·1 mm at Llangwyfan (Denbighshire) on the 20th. From the 18th to 20th much of the precipitation fell as heavy snow over high ground in the Isle of Man and in northern England and southern Scotland. Strong winds and high gusts during this period, including one of 63 knots at Hunterston (Ayrshire), resulted in snowdrifts 2–3 metres deep in the mountains. Strong winds, which occurred in many areas on the 25th, reached gale force in places and these strong winds recurred in north-west Scotland on the 28th.

April. Apart from widespread heavy rain on the 23rd and 24th, many areas had long, almost dry spells during the month and rainfall was below average nearly everywhere. This was especially so in parts of Scotland where overall it was the driest April since 1957; the town of Nairn had only 8 mm of rain during the entire month making it the driest April there since records commenced in 1866. Persistent easterly winds during the first fortnight contributed largely to a cold and dull month. Ground frost was a frequent occurrence in Scotland. Sheffield and Huddersfield (both in the West Riding of Yorkshire) recorded their lowest April sunshine since 1920 and 1941 respectively, and some stations in north and west Scotland had their dullest April for over 20 years. The first half of the month was cold and air frost occurred in Scotland, although it was mostly slight. Although on the first few days snow fell on high ground from north Wales northwards, the first two weeks were virtually rainless but it was wet on the 9th in southern England. Mainly dry weather continued in the south for another week but snow fell in northern areas on the 16th and 17th. After a very warm day away from coasts on the 22nd, the weather became wet in many districts. Throughout the 23rd and at first on the 24th all areas, except parts of extreme south-west England and north Scotland, had continuous rain which was heavy and thundery in places and led to large rainfalls over a very wide area. In the 24-hour period commencing 09 GMT on the 23rd a number of stations had their wettest April 'day' on record, including Watnall (Nottinghamshire) where records began in 1941. On the 26th snow in south Wales and the West Country, and sleet in southern England, heralded a return to cold, though mainly dry weather, and air frost occurred in many areas during the last few nights.

*1 knot $\approx$ 0·5 m/s.

May. The month was sunnier than average in most areas and unusually so in east Scotland and north-east England; Durham had its sunniest May since records began in 1886 and Marchmont (Berwickshire) equalled its sunniest May (in 1901) since records commenced in 1881. Other stations in these districts, and in the Midlands also, recorded their highest May sunshine total for over 20 years. Although the weather in the northern half of the U.K. was often changeable with rain at times, some areas in the south had spells of almost dry weather. Much of the rainfall during the month was showery in nature and most of the rain recorded in the south occurred in a few thundery outbreaks. The first 5 days were dry almost everywhere but on the 6th outbreaks of rain with local thunderstorms occurred in many places from south Scotland southwards. On the next day south and east England had prolonged rain which was sometimes heavy and thundery and there were reports in the Press of large numbers of hailstones 'the size of new pennies' (2 cm in diameter) at Ilkley (West Riding of Yorkshire). The period from the 8th to 14th was mainly dry but sea fog affected areas near the North Sea coast. After a changeable spell from the 15th to 17th, with slight snow showers on the peaks in the Scottish mountains, many southern and eastern areas again had very little rain until the 23rd when rain occurred over much of the country with thunderstorms in the Midlands, West Country and east Scotland. Overnight on the 24th/25th rain and thunderstorms in the Midlands and southern England led to local flooding, and houses in the London area were damaged by lightning. Early on the 25th a rainfall of 34 mm occurred in 35 minutes at Honeycroft Nursery in Uxbridge (Greater London); a rainfall of this intensity is classified as 'remarkable'. Over the month some areas in the west had less than half the average rainfall and Teignmouth (Devon) with only 17 per cent of average (9·9 mm) recorded the driest May there since continuous records began in 1910.

June. Frequent winds between north and east, which were particularly persistent during the first half of the month, resulted in what is estimated to have been the coolest June generally since 1927 and 1928. Ross-on-Wye recorded its lowest monthly mean temperature for June since 1916 and in most parts of the U.K. day-time temperatures were lower, on average, than those in May. Another feature of the month was the heavy frontal rainfall in the south of England, notably on the 10th and 11th, which contributed to over four times the average rainfall for the month near Eastbourne (Sussex) and on the Isle of Wight. The first week was dry generally and it was warm away from the North Sea coast; a temperature of 25·6°C was recorded at Littlehampton (Sussex) on the 3rd. It then became changeable and very cool; on the 9th the temperature at Watnall reached only 8·5°C which is the lowest recorded on a June day there since 1953. On the 10th a complex area of low pressure near the English Channel became increasingly active and during the next 2 days it moved slowly north-westwards. Rainfall during this period was heavy and prolonged, and the greatest amounts occurred in the southernmost counties of England. The 10th, with 53·4 mm of rain during the 24 hours commencing 09 GMT at Mayflower Park in Southampton, is estimated to have been the wettest June 'day' in that area since 1905, and other heavy rainfalls in the same period included 82·7 mm recorded at Inkpen (Berkshire). Further frontal rain fell in the southern half of England and Wales on the 14th and 54·2 mm occurred in 5½ hours at East Hoathly (Sussex). Periods of heavy rain occurred again on the 18th and 19th, this time particularly in Wales where 90·0 mm was recorded at Cwmystwyth (Cardiganshire) in the 24 hours from 09 GMT on the 18th. It was the wettest June in Ryde (Isle of Wight) since at least 1870 and at Beaminster (Dorset) since records began in 1900. Sunshine during the month was below average, except in one or two places in north and west Scotland.

July. In contrast to the previous month, July was sunnier than average almost everywhere; Cornwall and Devon were particularly sunny and Plymouth Hoe with 296·2 hours of sunshine had its sunniest July since 1911. Again unlike June, it was drier than average in most places, especially in England where it was the driest July generally since 1955. The Exmouth (Devon) area had its lowest July rainfall since 1898 and Cleethorpes (Lincolnshire) had its driest July since 1935. It was sunny and very warm at times until mid-month although it was cooler near coasts, and the sunny weather continued for another week in most areas. Many places in southern England had no measurable rainfall until the 22nd and other areas had very little rain despite thunderstorms here and there on a few days. Thunderstorms or thundery rain in the west and north on the 3rd contributed to large rainfall totals in the 24 hours beginning at 09 GMT, for example 97·0 mm at Loggerheads (Denbighshire) and 85·2 mm at Drumloist (Perthshire). On the same day 56 mm of rain fell in 1 hour at Bleasdale (Lancashire) and flooding occurred in many areas, particularly in north Wales where the River Gele overflowed in Abergele. The 4th was thundery also; a boy was killed by lightning in Oxfordshire and a 24-hour rainfall of 68·4 mm was recorded at Papplewick (Nottinghamshire). During the second week day-time temperatures rose well above average in many districts. On the 7th Edinburgh/Turnhouse Airport had its warmest July day (27·6°C) since records began in 1948 and on the 8th Newquay (Cornwall) recorded 27·1°C which is the highest air temperature there in July since 1949. On the 9th thunderstorms occurred in south Wales and south-west England; 44 mm of rain fell in about 2 hours at Sturminster Newton (Dorset). On the 11th several places in England had high temperatures and at St James's Park in London the temperature reached 30·0°C. On the same day thunderstorms broke out in East Anglia but then it became virtually dry until the 21st, although rain and gales affected north Scotland on the 15th with high gusts as far south as Worcestershire. The last 10 days were changeable with heavy thundery rain at times in many areas. Notable rainfalls during this period included the following: 81·5 mm at Newcastleton (Roxburghshire) in the 24 hours from 09 GMT on the 24th; 40 mm in 14 minutes near Watchet(Somerset) on the 27th; 88·2 mm at Gorleston (Norfolk) in the 24 hours commencing 09 GMT on the 27th; 90·2 mm at Kidwelly (Carmarthenshire) in the 24 hours from 09 GMT on the 30th.

August. With the exception of a few days during the third week the month was dominated by changeable weather, more especially in the southern half of the U.K. In general, rainfall was below average in the north and above average in the south where rainfall varied widely because of its thundery character. Over England and Wales as a whole it was the wettest August since 1960 but at Oxford (Radcliffe Observatory) the rainfall total of 133·2 mm was the second highest recorded there in August since records began in 1815 (it was just exceeded in 1879). During the first week there was heavy rain at times in many areas. In a thunderstorm at Creggan reservoir (Co. Londonderry) on the 4th a rainfall of 63·4 mm in about 78 minutes occurred; a fall of this intensity is classified as 'very rare'. Overnight on the 4th/5th heavy rain fell in south-east England and London Weather Centre had its heaviest 24-hour rainfall since records began in 1940. On the 7th a whirlwind in Haverhill (Suffolk) caused, according to an estimate in the Press, damage to crops and farm buildings amounting to £10 000. It became very cool in northern districts towards the end of the first week and on the morning of the 8th the air temperature at Carnwath (Lanarkshire) fell to −1·9°C. A series of mobile depressions crossed England and Wales from the 10th to 14th resulting in a very wet and windy 5 days. The following selection of 'daily' rainfalls (i.e. in the 24-hour period from 09 GMT) illustrate well this stormy spell: 86·6 mm at Llyn Fawr (Glamorgan) on the 9th; 77·5 mm at Threapwood (Cheshire) on the 10th; 104·9 mm at Ballypatrick Forest (Co. Antrim) and 86·1 mm at Smiddy Shaw reservoir (Co. Durham) on the 13th; 65·7 mm at Tophill Low (East Riding of Yorkshire) on the 14th. On the 13th and 14th flooding occurred in cities as far apart as Bristol, Durham, Londonderry and York. On the 14th a boy was killed by lightning in Cardiff and hailstones about 2 cm in diameter fell at Rugby (Warwickshire). On the afternoon of the same day a devastating hailstorm in the neighbourhood of Beverley (East Riding of Yorkshire) did costly damage to buildings and growing crops. One farmer near the village of Walkington in the same locality lost 193 out of 200 acres of cereal in addition to losses in potato crops. At the end of the storm hailstones were in piles up to 3 feet (≈ 1 metre) in depth against the sides of some buildings. Although the latter half of the month was generally less changeable the last week was rainy in the west and north. On the 18th the temperature at Writtle (Essex) rose to 28·2°C and thunderstorms occurred in southern England. Thunderstorms recurred in this region on the next day and a man was struck and killed by lightning in Gloucestershire. Sunshine was below average almost everywhere, the exceptions were in north and east Scotland.

September. The changeable weather of late August continued into September with gales in parts of Scotland and gusts of gale force as far south as Kent on the 1st. However, the changeable weather soon came to an end and the main feature of the month was the long dry, often sunny, spell in parts of east Wales and eastern and southern England where many places had no measurable rainfall until the 22nd. This spell itself was a continuation of the type of weather which predominated in nearly all areas during the first fortnight and these dry spells resulted in many places recording their driest September for over 40 years. Notable among these stations were the following where it was the lowest September rainfall since the year quoted: Durham since 1910 (although it was equally dry in 1941), St Andrews (Fife) since 1920 and Sidmouth (Devon) since 1929 when records began. Parts of Devon, Dorset and Somerset had less than one-tenth of the average rainfall and over England and Wales as a whole and over Scotland it was the driest September generally since the memorable year of 1959. Vivary Park in Taunton (Somerset) and Thorney Island (Sussex) recorded only 1·8 mm and 2·3 mm respectively during the whole month while Littlehampton (Sussex) had rain on the 24th and 26th only, totalling 4·6 mm. Other features of the sunny, dry, first 3 weeks were recurrent overnight fog, especially in central and southern England, and the generally above average day-time temperatures which, however, contrasted with occasionally cold nights. In the Cairngorms on the 8th the temperature at Glenmore Lodge (Inverness-shire), height 341 metres, reached 27·1°C which is the highest there since 1951. Gales in north Scotland on the 23rd heralded changeable weather for the last 7 days. Snow or sleet showers fell on the peaks of the Cairngorms on the 23rd/24th with air frost in central and southern Scotland and northern England. Air frost occurred again in these areas on the next 2 nights and the air temperature at Carnwath (Lanarkshire) fell to −4·5°C on the morning of the 24th. On the 23rd thunderstorms occurred in Wales, the Midlands and East Anglia. Widespread rain on the 26th included thunderstorms in central and eastern England; violent winds in Cheshire, Derbyshire and Yorkshire, associated with thunderstorms, caused much structural damage in a number of localities. It was the warmest September at Buxton (Derbyshire) since at least 1908 and it was the sunniest September at Springburn Park in Glasgow and at Perth since 1914 and 1919 respectively.

October. Temperatures everywhere were generally above average (except notably from the 11th to 16th) and this resulted in the seventh successive October with monthly mean temperature above average over England and Wales as a whole. The month began very warm with a temperature of 25·0°C in parts of central Wales on the 2nd and subsequently day-time temperatures remained mostly above average until the 12th. This period was generally dry and sunny but morning fog occurred in places, mainly in the south and east. Many parts of southern England had no measurable rainfall until the 13th but farther north the first appreciable rainfall of the month occurred on the 9th and 10th in west and central Scotland. On the 11th and 12th cold weather spread southwards and snow settled briefly in the West Country on the unusually early date of the 13th. During the next night the air temperature fell to −8·3°C at Grantown-on-Spey (Moray) and Crawfordjohn (Lanarkshire). From the 15th to 22nd it was generally windy but it again became warm. In the 24 hours from 09 GMT on the 18th a rainfall of 112·0 mm was recorded at Cowlyd, near Dolgarrog (Caernarvonshire); the same 24-hour period was the wettest October 'day' recorded in the Manchester area since records began in 1877. By the 19th seas around all coasts had become very rough. Generally dry weather returned to the south on the 20th but heavy rain, accompanied by strong winds, fell in north and west Scotland on the 21st and 22nd. Exceptional rainfalls in the 24 hours beginning 09 GMT on the 21st were 162·0 mm at Dalness (Argyll) and 158·2 mm at Cassley power station (Caithness) and on the next day a gust of 93 knots was recorded at Cairngorm (Inverness-shire), height 1090 metres, with a mean wind speed of about 60 knots. The last week or so in many areas saw a return to the kind of weather with which the month began but further heavy rain fell in north Scotland on the 30th. It was a sunny month everywhere and Sheffield (West Riding of Yorkshire) had its sunniest October since records began in 1898.

November. The month was much sunnier than average, except in parts of Scotland and Northern Ireland. New high record November sunshine totals occurred at many stations in the southern half of England, some of them long-established stations. Record-breaking sunshine totals included 103·3 hours at

Kew (Greater London) and 128·7 hours at Torquay (Devon) where records began in 1880 and 1891 respectively. Cambridge had its sunniest November since at least 1884 when monthly sunshine totals for the city were first published. On the 1st an air temperature of 17·5°C at Falmouth (Cornwall), the highest there in November since 1869 when available records began, heralded 5 very warm days in many places. However, during this period in Scotland rainfall was sometimes heavy and on the 3rd there were several 'daily' rainfalls in excess of 100 mm in the north-west, including 133·5 mm at Kinlochourn (Inverness-shire). On the 5th heavy rain fell in many parts of the U.K. and flooding occurred in parts of Fife. On the next day it became cold everywhere; wintry showers occurred in the north on the following 4 days and snow or sleet fell on high ground farther south on the 8th and 9th. Nevertheless, by the 11th parts of south-east England had recorded more sunshine than the monthly average. Gales in the north on the 16th coincided with the beginning of a wintry spell which spread to the south on the 18th and lasted everywhere until the 24th. During this period night frost was sometimes widespread; overnight on the 19th/20th the temperature at Carnwath fell to −11·7°C following a day when the air temperature in some areas in Scotland remained below 0°C. Amounts of snow were generally small except on high ground, where strong winds led to drifting. On the 22nd, 6 members of a school party were found dead in the snow in the Cairngorms after blizzards. The weather remained changeable but despite some further heavy rain in places, large regions of England and Scotland had below average rainfall.

December. Most parts of the U.K., except north Scotland, were drier than average and many areas had considerably less rainfall than average. This was especially so in Northern Ireland; at Armagh the total of 16·4 mm of rain was the lowest recorded there in December since 1844, and some areas in Co. Down had only about 10 mm of rainfall during the whole month. It was also a very mild month everywhere and it is estimated that the areas around Glasgow, Edinburgh and Forres (Moray) had their mildest December since 1868, 1876 and 1888 respectively. On a notably mild day on the 20th, Manchester had its mildest December day this century. The first half of the month was generally dry in many southern areas but farther north the weather was mainly changeable with rain at times. During this period overnight fog was a frequent occurrence in parts of England where occasionally it persisted throughout the day in places. Although the month began cold with night frost, temperatures gradually rose and during most of the month it was very mild. From the 14th to 22nd the changeable weather in the extreme north spread to all areas; rainfall was occasionally heavy in north and west Scotland and everywhere was very windy. On the 19th gales occurred widely; gusts exceeding 90 knots were reported along the English Channel coast and there were numerous reports of minor damage to buildings. On the 20th it was very mild everywhere; the temperature reached 16°C along the coast of north Wales and 15°C was reported on the coast of Moray. Although colder weather with wintry showers affected north Scotland from the 21st to 23rd, it remained mild elsewhere until the 27th when north-east winds became established over all areas. On the last 4 days of the year there were sunny spells in most districts but snow or sleet showers fell in eastern and southern England.

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 1971

	Within U.K.	Overseas
Principal Forecasting Offices associated with the RAF	1	—
Main Meteorological Offices associated with the RAF	7	5
Subsidiary offices associated with the RAF	36	7
Observing offices associated with the RAF	7	3
Principal Forecasting Offices associated with civil aviation	1	—
Main Meteorological Offices associated with civil aviation	4	—
Subsidiary offices associated with civil aviation	11	—
Observing offices associated with civil aviation	6	—
Upper air observing offices	8	5
Public service offices	6	—
CRDF offices	5	3
Port Meteorological Offices	5	—
Offices associated with the Agricultural Development and Advisory Service	3	—
Other offices	27*	3

* Five of these stations are administered by D.R.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

To meet its obligation under the ICAO North Atlantic Ocean Station Agreement the United Kingdom operates four Ocean Weather Ships which work in rotation with two ships from France, one ship from the Netherlands and two ships jointly operated by Norway and Sweden. The British ships serve at four of the five ocean weather stations in the eastern North Atlantic; each vessel makes, on average, eight voyages a year and spends an average of 24 days on station during each voyage. Some statistics for 1971 for the British Ocean Weather Ships are shown below.

Total number of days on station	726·6
Total number of days on passage	165·7

	Station A	Station I	Station J	Station K*
		average number per voyage		
Aircraft contacted	159	204	366	—
Number of aircraft given one or more radar fixes	105	153	264	—
Weather messages to aircraft	17	20	22	—

* During 1971 Station K was operated by France and the Netherlands.

Table III—merchant navy ships

A total of about 6700 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 1971 the numbers of British ships reporting were:

Selected ships	517
Supplementary ships	42
	including 13 trawlers
Coasting vessels	64
Lightships	15
Trawlers	30
Auxiliary ships	36
Total	704

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

U.K. to Australasia	93
U.K. to Far East	94
U.K. to Persian Gulf	36
U.K. to South Africa	50
U.K. to West Indies	27
U.K. to Atlantic coast of North America	91
U.K. to Pacific coast of North America	7
U.K. to South America	13
U.K. to European ports	36
U.K. to Falkland Islands and Antarctica	3
U.K. to distant-water fishing grounds	16
World-wide tramping	93

During two typical days, one in June, the other in December, the numbers of reports from ships received at Bracknell were as follows:

	Reports	
	June	*December*
Direct reception from:		
British ships in eastern North Atlantic	84	77
Foreign ships in eastern North Atlantic	32	43
British trawlers in North Sea	13	15
British merchant ships in North Sea	32	46
Total	161	181
Reception via other European countries:		
Ships in eastern North Atlantic	304	357
Ships in Mediterranean	52	49
Ships in North Sea	88	131
Ships off north Russia	17	14
Ships in other European waters	18	6
Ships in Pacific	39	22
Total	518	579
Reception via U.S.A. and Canada:		
Ships in North Atlantic	421	377
Ships in North Pacific	596	667
Ships in other waters	12	21
Total	1029	1065

TABLE IV—CLASSIFICATION OF STATIONS RENDERING CLIMATOLOGICAL RETURNS

A large amount of meteorological data is obtained for climatological purposes from stations which are not part of the Meteorological Office organization. The following table shows how the sources of climatological information in the United Kingdom (including Meteorological Office stations) were distributed on 31 December 1971.

	Stations					Autographic Records		
	Observatories	*Synoptic*	*Agrometeorological*	*Climatological*	*Rainfall**	*Sunshine*	*Rainfall*	*Wind*
Scotland, north..	1	9	0	30	332	28	10	15
Scotland, east	0	10	8	63	596	53	19	11
Scotland, west	1	13	1	54	545	29	20	14
England, north-east	0	10	4	25	515	27	16	10
England, east	0	11	14	20	571	29	18	11
England, Midlands	0	13	17	46	1311	60	32	15
England, south-east (including London)	1	19	18	43	870	63	33	18
England, south-west	0	13	8	33	562	33	10	6
England, north-west	0	5	3	24	507	24	12	14
Wales, north	0	2	3	16	291	11	4	2
Wales, south	0	7	9	15	383	22	4	4
Isle of Man	0	2	0	1	19	3	1	2
Scilly and Channel Isles	0	3	0	3	21	7	0	2
Northern Ireland	0	7	7	49	308	25	28	9
Total	3	124	92	422	6831	414	207	133

* 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 balloons 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 U.K.	5830	94·2	79·9	53·2	9·8	46·2
Six stations overseas	4013	96·0	77·0	39·7	8·0	70·3
Four Ocean Weather Ships	1490	94·5	81·8	51·3	2·4	—

(b) Observations of wind

	Number of observations	Percentage of all balloons reaching				Percentage of largest balloons 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 U.K.	11 556	90·1	67·8	32·9	4·6	43·2
Six stations overseas	7 567	91·2	71·0	35·4	4·9	76·6
Four Ocean Weather Ships	2 972	91·1	70·3	36·6	1·0	—

TABLE VI—THUNDERSTORM LOCATION

Number of thunderstorm positions reported by CRDF network:

In 1971	67 322

TABLE VII—METEOROLOGICAL COMMUNICATIONS 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 90 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 through the Meteorological Office Telecommunications Centre for one typical day (24 hours) taken near the end of December 1971 and, for comparison, some corresponding figures are given for one day near the end of 1970.

	In	Out	Total	Total in 1970
Coded messages		*number of groups in one day*		
Land-line teleprinter	500 059	378 091	878 150	841 624
Radio	167 836	235 975	403 811	419 593
Facsimile charts		*number of charts in one day*		
Land-line	104	747	851	693
Radio	65	134	199	211

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is no need for forecasts of a special type at certain seasons. These are described in Met O Leaflet No. 1 (1970). The numbers receiving such specialized services are as follows:

	Year	No. of customers	Year	No. of customers
Fine-spell notifications (a summer service primarily for farmers)	1970	336	1971	265
Week-end temperature forecasts (a winter service primarily for industrialists) ..	1970–71	32	1971–72	27
Winter road danger warnings (primarily for local authorities)	1970–71	404	1971–72	416

TABLE IX—FORECASTS FOR AVIATION

Forecasting for aviation constitutes the primary function of many of the offices. The Central Forecasting Office is mainly concerned with analysis of the weather situation, the issue of guidance in outline to other offices and the issue of forecasts to the BBC and the national Press. Thus the volume of work in the Central Forecasting Office shows little variation from year to year. The following figures indicate the numbers of forecasts issued for aviation and the numbers of meteorological briefings that took place during 1970 and 1971. They do not include warnings and routine general forecasts.

	1970	1971
Number of meteorological briefings for		
aviation in the U.K.	405 346	395 537
aviation at overseas stations	48 853	40 266
Number of aviation forecasts issued for		
aviation in the U.K.	1 158 974	1 110 115
aviation at overseas stations	310 642	289 411

TABLE X—NON-AVIATION INQUIRIES

Non-aviation inquiries are handled by five Weather Centres, in London, Manchester, Glasgow, Southampton and Newcastle, and one other 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. (The *Post Office Guide* lists 37 offices providing forecasts for the general public.) These inquiries, most of which refer to current or future weather, are listed below according to the purpose of the inquiry.

	1970	1971
Total number of non-aviation inquiries	1 633 478	1 535 523
Percentage relating to		
agriculture	9·1	9·3
building	6·0	5·3
commerce, industry	5·0	4·7
holidays	20·2	21·0
marine matters	15·1	15·9
Press	9·4	10·1
public utilities	8·8	8·2
road transport	11·7	9·8
other known purposes	6·7	6·9
unknown purposes	8·0	8·8

TABLE XI—FLASH WEATHER MESSAGES

FLASH weather messages are passed to the BBC for broadcast on radio, and to the BBC and most Independent Television Companies for inclusion in their programmes 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 1971.

Area	Dense fog	Moderate or heavy snow	Heavy rain	Glazed frost or icy roads	Severe inland gales	Wind in coastal waters
Edinburgh and south-east Scotland	—	—	—	—	4	—
Glasgow and south-west Scotland ..	1	—	1	—	4	—
Belfast and Northern Ireland ..	—	1	1	—	1	—
Industrial north-east England ..	—	—	—	—	—	—
Industrial Lancashire and Merseyside	1	—	2	1	—	—
Industrial Midlands	4	—	3	—	—	—
Bristol and Bath	1	1	9	—	2	—
South Wales..	1	1	10	—	3	—
London and south-east England ..	1	1	4	—	—	—
Plymouth and south-west England	—	—	1	—	5	1
Yorkshire	2	—	1	—	—	—
Southampton and Portsmouth ..	—	—	1	—	—	—
Total	11	4	33	1	19	1

Table XII—Automatic telephone weather service forecasts

The total number of calls made on the service during 1971 showed a decrease of 12·8 per cent over the previous year, the major part of the decrease being attributable to the Post Office strike in the first quarter. A sharp recovery took place in the second half of the year when calls exceeded the 1970 total for the same period by some 140 000. Forecasts were made available at 5 more Post Office Information Service Centres bringing the total of such Centres to 54. The number of forecast areas was increased from 24 to 25.

Information Service Centre	Forecast area	Number of calls 1970	1971
London	London	3 202 724	2 747 974
London	Essex coast	188 547	155 622
London	Kent coast	179 303	160 377
London	Sussex coast	303 266	307 773
London	Thames Valley	152 836	159 366
London	40 miles radius of Bedford	89 753	73 975
Colchester	Essex coast	202 070	189 136
Brighton and Hove	Sussex coast	458 558	471 658
Birmingham	Birmingham	578 768	444 799
Coventry	Birmingham	83 059	80 235
Liverpool	South Lancashire and north Cheshire	264 615	191 089
Liverpool	Lancashire coast	79 294	65 055
Liverpool	Chester and north Wales coast	58 430	52 194
Manchester	South Lancashire and north Cheshire	375 397	269 765
Manchester	Lancashire coast	77 561	68 551
Manchester	Chester and north Wales coast	46 733	49 445
Cardiff	Cardiff	322 323	278 793
Belfast	Belfast	211 904	143 991
Glasgow	Glasgow	456 765	362 490
Edinburgh	Edinburgh	251 545	222 365
Bristol	Bristol	789 259	560 070
Swindon	Bristol	24 254	30 946
Portsmouth	South Hampshire	270 306	257 842
Southampton	South Hampshire	214 848	259 074
Canterbury	Kent coast	195 434	157 497
Blackpool	Lancashire coast	180 430	136 604
Southport	Lancashire coast	62 040	41 385
Plymouth	South Devon and east Cornwall	153 643	135 892
Exeter	South Devon and east Cornwall	108 670	95 857
Newcastle	Tyne, Tees	241 862	216 258
Blackburn	Central Lancashire	160 831	110 026
Blackburn	Lancashire coast	74 381	52 792
Bournemouth	South Hampshire	340 183	158 331
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	487 380	410 221
Leicester	Nottinghamshire, Derbyshire, Leicestershire	243 427	224 830
Middlesbrough	Tyne, Tees	102 619	96 609
Oxford	Thames Valley	148 906	167 563
Colwyn Bay	Chester and north Wales coast	61 628	48 547
Gloucester	South-west Midlands	112 920	98 698
Cheltenham	South-west Midlands	63 052	61 868
Tunbridge Wells	London	60 456	45 540
Southend	Essex coast	103 080	117 716
Chelmsford	Essex coast	68 725	76 663
Bedford	40 miles radius of Bedford	157 681	115 340
Reading	Thames Valley	181 726	227 334
Hereford	South-west Midlands	45 217	35 752
Bradford	Leeds, Bradford, Huddersfield	78 300	70 218
Leeds	Leeds, Bradford, Huddersfield	201 322	196 809
Torquay	South Devon and east Cornwall	61 281	55 999
Sheffield	Sheffield, Chesterfield, Doncaster, Barnsley	191 404	192 347
Doncaster	Sheffield, Chesterfield, Doncaster, Barnsley	26 570	28 137

TABLE XII (*continued*)

Information Service Centre	Forecast area	Number of calls 1970	Number of calls 1971	Date of opening
Medway	Kent coast	57 842	72 133	
Chester	Chester and north Wales coast	95 512	86 476	
Guildford	London	76 833	75 979	
Peterborough	40 miles radius of Bedford	48 574	47 658	
Huddersfield	Leeds, Bradford, Huddersfield	51 242	39 024	
Derby	Nottinghamshire, Derbyshire, Leicestershire	67 173	98 356	January 1970
Luton	40 miles radius of Bedford	52 246	67 083	February 1970
Lincoln	North Lincolnshire and Retford area	6 906	20 864	November 1970
Bishops Stortford	40 miles radius of Bedford		10 197	April 1971
Grimsby	North Lincolnshire and Retford area		17 187	May 1971
High Wycombe	Thames Valley		14 849	July 1971
Norwich	Norfolk and Suffolk		18 331	September 1971
Ipswich	Norfolk and Suffolk		8 856	September 1971
Total		13 251 614	11 554 411	

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.

	1970	1971
Total number of climatological inquiries	14 498	13 553
Percentage relating to		
agriculture (farming, forestry, market gardening)		12·1
building and design (including siting)		19·3
commerce (sales, marketing, advertising)		4·0
drainage		2·0
education and literature		6·2
flooding		0·6
heating and ventilation		2·1
industrial and manufacturing activities		5·5
law (damage, accident, insurance)		14·3
medical and health		1·4
Press and Information Service Centres		3·3
research		7·5
sport, hobbies, holidays		1·5
transport and communications		1·6
water supplies		8·7
miscellaneous (purpose known)		4·0
miscellaneous (purpose unknown)		5·9

TABLE XIV—DATA PROCESSING

(a) Punched-card installation

Number of cards punched by the Meteorological Office installation	1 559 736
Number of cards punched elsewhere on behalf of the Meteorological Office ..	87 973
Number of cards converted from paper tape	271 557
Number of non-routine investigations completed..	205

(b) Computer installations

(1) The KDF9 computer (COMET) was used for computing during 7535 hours.

(2) The 360/195 was used for 146 hours (15–31 December 1971).

TABLE XV—INSTRUMENT TESTING AND CALIBRATION

The numbers include those of instruments tested or calibrated for outside authorities on repayment.

	Number of tests or calibrations
General meteorological instruments	62 201
Balloons	51 838
Radiosonde batteries	7 660
Radar reflectors	25 272
Electrical/electronic instruments..	1 129
Electrical/electronic components	6 523
Radiosondes, calibrated	15 615
Total	170 238

In addition, 2435 radiosondes were recovered after flight and 59 per cent of these were repaired and recalibrated for further use.

THE DIRECTORATE OF RESEARCH

Special Topic—Cloud Physics

Introduction

Rain and snow are two of the main conversational topics of the average resident in the United Kingdom. It is hardly surprising, therefore, that one of the more important aspects of the weather forecasters' output in these islands is concerned with the likelihood, or otherwise, of rainfall. Needless to say, these forecasts are also of profound concern to management in many spheres, such as the construction and transport industries, agriculture, and water resources, to mention but a few. In some other countries the sparsity of rainfall and the consequent drought conditions are of greater national concern and in those countries meteorologists are not so much concerned with the forecasting of precipitation as with the possibility of modifying cloud systems in such a way as to increase it. In other parts of the world, where crops suffer considerable damage from the fall of giant hailstones, there have resulted major programmes to modify hailstorm clouds so as to reduce the size of the hailstones and so the amount of damage. Such a programme, for which a high degree of success is claimed, has now been operational over large areas in the south of the U.S.S.R. for some years.

The common factor in all these facets of the meteorologist's work is cloud physics. This is concerned not only with the dynamics of the air motions which lead to the condensation of part of the atmosphere's water vapour, but also with the microphysical processes whereby that condensate forms and the resulting ice or water particles grow to such a size that they can fall to the earth's surface by gravitational settling. Research in the Cloud Physics Branch is concerned with the extension of knowledge and understanding of these dynamical and microphysical processes and their interaction. The practical objective of such research in the Office is to improve the quantitative forecasting of rainfall. To do this, the knowledge gained must be used ultimately to improve, where necessary, the mathematical treatments of cloud systems which are basic to any method of quantitative rainfall forecasting. The mathematical representation of the microphysical processes within clouds is in itself a major problem, and the degree to which such schemes must be injected into any realistic dynamical model describing the air motions which produce rainfall is a matter requiring further study. It is also by such sophisticated mathematical models that the practicability of any precipitation or hail modification scheme will be made amenable to a real scientific assessment.

In any outline of the broad philosophy of cloud-physics research in the Office it must be pointed out that at present meteorologists do not fully understand some of the more basic aspects of cloud microphysics and they are only just beginning to have more than a primitive appreciation of the structure of, and airflow patterns within, real cloud systems. Clearly, before great advancement can be made on the modelling problems, priority must be given to the elimination of these limitations to basic knowledge. There are, therefore, two broad areas into which the work of the Branch can be divided. One is concerned with the outstanding microphysical problems of the growth of water droplets, ice crystals, rain, snow and hail, and the other with observational and dynamical studies of clouds and cloud systems, especially the measurement of the patterns of vertical air motion which, by controlling the movement of water vapour, determine the environment in which the microphysical processes take place. The following sections illustrate some of the work currently under way in the Branch.

Cloud microphysics

Coalescence. The early stages of droplet nucleation and growth may be critical in deciding whether rain, snow or hail can form within the lifetime of a cloud. One of the most important of the unresolved microphysical problems concerns the initial stages of rain formation by the coalescence of water droplets. Cloud droplets can grow both by condensation and by collision and coalescence processes. The problem is, however, that on one hand the rate of growth of small droplets by condensation in conditions typical of a cloud becomes very small, compared with the lifetime of a typical cumulus cloud cell, when droplet radii exceed about 15 μm, whilst on the other hand the growth by collision and coalescence of droplets smaller than about 20 μm is very slow because they do not readily amalgamate with other drops. Once a few droplets of about 25-μm radii at concentrations of about 1 per litre appear in the cloud then calculations show that there is no difficulty in accounting for their growth to raindrop size (1000 μm) in reasonable time. Thus there is an apparent gap between the effectiveness of the condensation and the coalescence mechanisms as they are currently understood.

Attempts to account for this apparent paradox have been twofold. In one, a theoretical study was made of the effect that fluctuations in the supersaturation due to turbulence within the cloud would have on the growth by condensation. The outcome of this study was to show that such an effect was small. In the second, it was argued that the turbulent motions in a typical cumulus cloud may significantly increase the number of collisions and amalgamations of droplets with radii within the critical range of 15 to 20 μm. It was argued that the microstructure in clouds could be represented, as far as small-droplet interaction is concerned, by a region of linear sheared airflow. Experiments were therefore carried out to measure the collection efficiencies of small droplets in such flow. Some of the results of these experiments are illustrated in Figure 3. This shows the experimentally determined collection efficiencies of larger droplets (10 to 40-μm radii) for small droplets of 9-μm radius in a number of different linear sheared flows. (The collection efficiency is defined for a pair of droplets of radii R and r as $A/(\pi(R+r)^2)$, where A is the cross-sectional area of the column in which the centre of the smaller droplet must lie if it is to coalesce with the larger, faster falling, droplet.) The solid line is the theoretical curve for droplets falling in still air and represents the data upon which most of the growth calculations to date have been used. It is seen that there is a dramatic increase in the collection efficiencies for droplets in the critical size range. Because of experimental evidence of this type, it can now be argued that microshears in a turbulent cloud may have a profound influence on the efficiency of the coalescence process. However, so far it has not been possible to account for this increase theoretically.

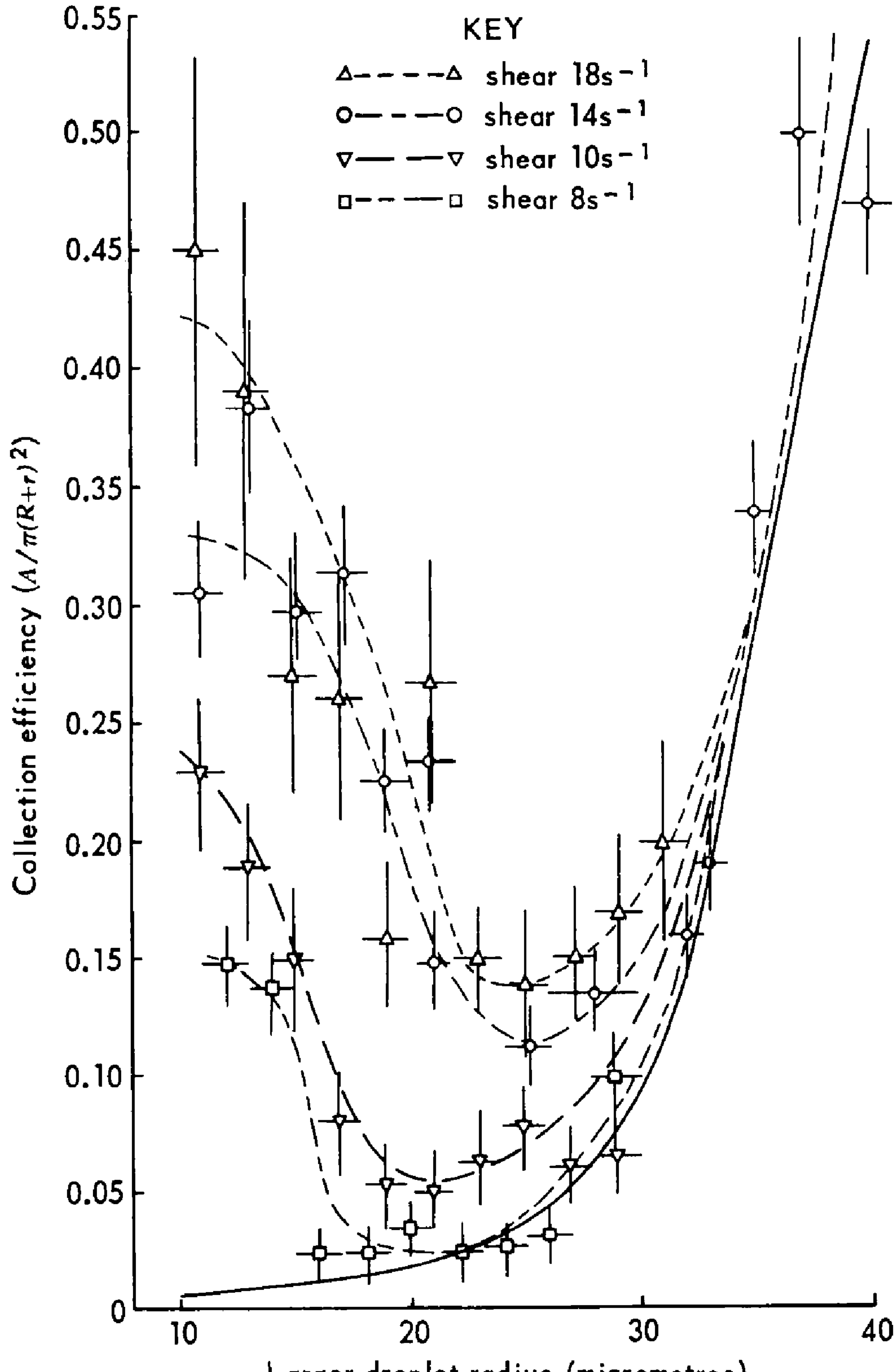


FIGURE 3 — COLLECTION EFFICIENCIES OF LARGER DROPLETS FOR DROPLETS OF 9-MICROMETRE RADIUS IN A SELECTION OF SHEARED HORIZONTAL AIRFLOWS

———— Theoretical collection efficiencies for droplets falling in still air

Ice crystal processes. In temperate and high latitudes most precipitating clouds extend to heights where the temperature is below 0°C. Under these circumstances, it has long been known that the ice phase has a strong influence on the development of precipitation. This is because pure water in the form of small droplets does not freeze spontaneously until temperatures as low as −35°C to −40°C are reached, depending upon the droplet size. Thus clouds at temperatures somewhat below 0°C are composed predominantly of supercooled water droplets. However, there are some small particles in the atmosphere which can initiate freezing at much higher temperatures than those required for spontaneous ice nucleation. The existence of these natural 'freezing nuclei' means that supercooled clouds generally contain a few ice crystals in an environment which is slightly supersaturated with respect to water. Now, since the equilibrium vapour pressure over ice is lower than that over water by approximately 0·9 ΔT per cent, where ΔT is the degree of supercooling, any ice crystals can grow rapidly by sublimation. In this way it is not difficult to account for the initial growth of ice crystals in clouds containing a mixture of water droplets and ice. The subsequent growth is of course by collision and coalescence with other ice crystals or supercooled water droplets. It is this latter 'riming' process which in cumulonimbus clouds leads to the formation of hailstones.

Another fundamental problem in cloud microphysics concerns this initiation of the ice phase, and the role that it plays in thunderstorm electrification. It is on the assumption that there is a shortage of natural freezing nuclei in the atmosphere that most attempts to modify precipitation processes have been based. Clearly then, it is necessary to know the concentration of freezing nuclei in the atmosphere, and their mode of action, i.e. whether they: (a) act as sublimation nuclei, (b) are attached to condensation nuclei and so act by condensation followed by freezing, or (c) are small enough to be captured by the supercooled droplets by means of diffusive processes and so act as contact nucleators. Much work has been carried out on all these and many other factors, but the evidence now is that the measurements of freezing nuclei at cloud base generally indicate concentrations much lower (often by a factor of over 100) than those to be expected from the concentration of ice crystals in the clouds and those required for realistic precipitation rates. There seem to be two possible explanations of these observations: (a) that the methods of measurement of freezing nuclei are inadequate, and (b) that there is a secondary process of ice-crystal production.

Much laboratory work in the Branch has been and is devoted to these areas of interest. The membrane filter method of measuring freezing nuclei, in which the atmospheric particles are captured on a special filter which is later developed under strictly controlled temperature and humidity conditions to allow growth of ice crystals on the nuclei, has been improved to give a high degree of reproduceability. Measurements at Bracknell and Eskdalemuir show that the concentration of nuclei in air of continental origin is much greater than in that of maritime origin. The results also indicate that local industrial sources are important at Bracknell.

Recent laboratory work has demonstrated that artificially produced freezing nuclei of silver iodide, of such small size (0·01 μm) that they can be captured effectively by small droplets due to Brownian diffusion, are capable of nucleating small droplets by contact, with an efficiency of a few per cent at −11°C increasing to 100 per cent at −15°C. It has also been demonstrated that these small particles are not effectively detected by the membrane filter technique, which detects only about 1 in 10^4 of these 0·01-μm particles at −18°C. This poses the question whether there are in the atmosphere any natural submicrometre particles with characteristics similar to those of silver iodide particles in this respect. So far no other artificial nuclei having a contact nucleation ability similar to that of silver iodide have been discovered.

As far as the importance of a secondary process of ice-crystal production in natural clouds is concerned, the main effort in the Branch has been devoted to the possibility of ice splinters being produced by freezing droplets. For instance, a series of experiments designed to detect ice splinters and the associated electric charging when supercooled water droplets impact and freeze on an ice substrate has been carried out. Although in certain artificial conditions charged ice splinters were observed, there was no evidence of charging or splinters in circumstances which simulated in most respects those in which ice crystals grow by accretion in real clouds. As a result of this work, it was concluded that the splintering of freezing droplets is a much rarer phenomenon than was once thought and is not an important factor in the ice-nucleus economy of clouds. However, the experimental methods adopted in this study were such that small ice splinters ($\leqslant 10\ \mu m$) would not have been detected. The experimental methods are therefore being currently modified to allow the detection of sub-micrometre ice particles if they are ejected during freezing.

These results also imply that conditions in clouds are quite unfavourable for the operation of a mechanism of electrical charge separation based on the charging of rime during the splintering of freezing droplets in thunderstorms, as was once thought to be the case. However, recent experiments in the cloud-physics laboratory have provided evidence for a new process which enables the electric field in thunderstorms to be accounted for by induction. In these experiments, supercooled water droplets with diameter 20 to 100 μm and speed 10 m/s were allowed to impact on an ice pellet in the presence of an electric field in a small wind-tunnel. A proportion of the incident drops (about 1 to 10 per 1000 drops accreted) were found to hit the edge of the pellet in such a way that part of the drop froze on the pellet whilst the remainder broke away and continued on its way with reduced velocity. The ice pellet and an induction ring downstream of the pellet were connected to electronic circuits which measured the charges on the pellet and on the departing drop respectively. Genuine charge-separation events were selected by a coincidence circuit and displayed on an oscilloscope with the charge on the pellet (Q_p) on the y-axis and that passing through the ring (Q_{r_2}) on the x-axis. Figure 4(a) shows the result of such an experiment with 100-μm diameter drops, in which the pellet acquired positive charge and an equal negative charge was carried away by the departing drop. The variable magnitudes of the charges are probably due to the different electric field strengths at the point of interaction, which differs for each drop. Figure 4(b) shows the effects of reversing the electric field when the sign of the charge separation is also reversed. No charging was observed in the absence of an electric field. The nature of the interaction was confirmed by collecting drops downstream of the pellet. Most drops were of uniform diameter, having missed the pellet completely, but there were some which were significantly smaller, agreeing in number with the recorded electrical events.

In a thundercloud, charging by induction is a field-dependent process which increases the electric field until leakage currents balance the rate of generation. Preliminary calculations show that the partial coalescence process is efficient enough to generate, within half an hour or so, fields strong enough to initiate a lightning flash in a thundercloud.

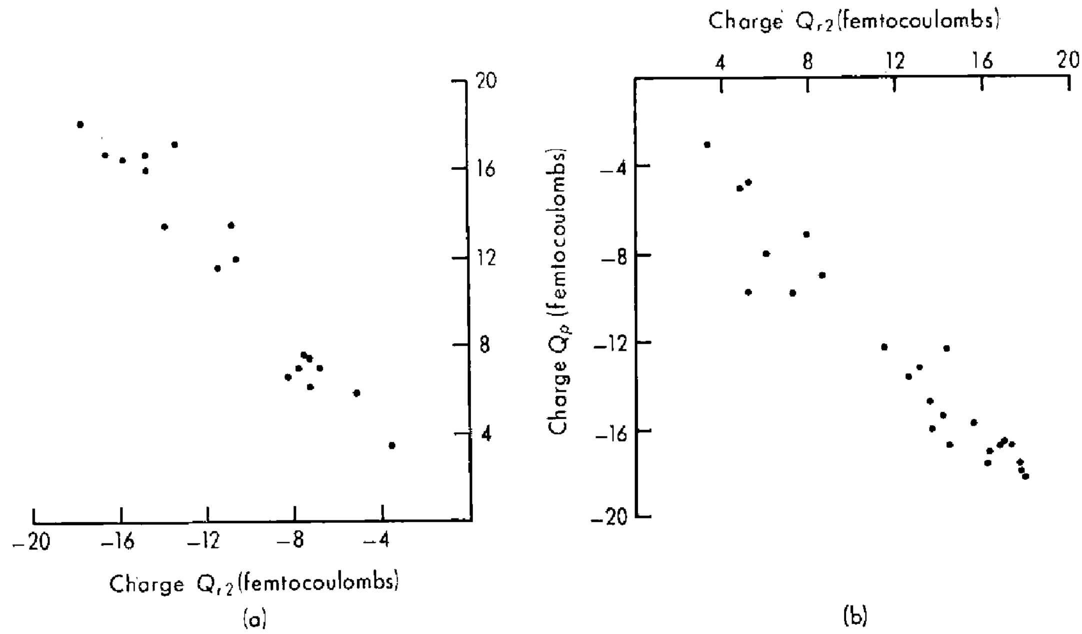


FIGURE 4—RESULTS OF WIND-TUNNEL EXPERIMENTS IN WHICH SUPERCOOLED WATER DROPLETS WERE ALLOWED TO IMPACT ON AN ICE PELLET IN THE PRESENCE OF AN ELECTRIC FIELD

Charge Q_p on ice pellet correlated with charge Q_{r2} on departing drop when drops 100-μm diameter graze pellet at 10 m/s.
(a) Negative charge induced on pellet, positive charge on departing drop.
(b) Electric field reversed, direction of charge separation also reverses.
The prefix femto signifies 10^{-15}.

The dynamics of clouds and cloud systems

General. So far the microphysical aspects of the growth of the hydrometeors within clouds have been discussed largely from a theoretical and laboratory experimental point of view. However, one of the principal factors controlling the growth of precipitation is the dynamical structure of clouds, in particular the vertical air motion. The intensity, duration and extent of regions of vertical motion, by controlling the rate of condensation, determine the environment within which the microphysical processes take place. The main reason for the relatively under-developed state of knowledge concerning precipitation production within clouds in the real atmosphere is that very little is known about the patterns of vertical air motion. This deficiency is of course due to the great difficulty of measuring vertical air motion in the atmosphere. Indeed this is one of the major problem areas in the overall field of meteorology and, whereas various ingenious methods have been devised for inferring the magnitude of large-scale fields of vertical air motion, until recently there have been few successful attempts to measure vertical air motion on the relatively small scales which are important for the production of precipitation. Accordingly one of the principal tasks of the Branch has been to develop techniques for measuring vertical velocity both on the scale of individual convective shower clouds and on the scale of the regions of gently rising motion which occur in association with fronts. Although the rising motion in these latter regions may extend over many hundreds of kilometres and may be measurable on the basis of observations from the existing synoptic scale, there are embedded within these regions smaller areas of more vigorous ascent which produce important variation in rainfall intensity over areas with horizontal dimensions of order tens of kilometres.

A number of radar techniques have been developed for measuring the patterns of small-scale air motion and foremost amongst these is the application of pulsed Doppler radar. By measuring the Doppler shift of the radar echo returned from natural targets, such as raindrops and snowflakes, it is possible to measure the velocity of these hydrometeors along the line of sight and to build up a quite detailed picture of the three-dimensional field of air motion in the region within which the precipitation targets are embedded. It is not proposed to describe the measurement technique in detail here. Suffice it to say that different modes of operation have been developed, by means of which it is possible, by using one mode, to measure the pattern of updraughts and downdraughts within individual convective shower clouds and, by using another mode, to infer the much weaker but more extensive regions of vertical air motion associated with fronts. At the same time it is often possible to infer from the Doppler-radar data the concentration and sizes of the precipitation particles. Some examples of the results obtained with these techniques are now described.

The structure of shower clouds. The ideal requirement is to measure the time evolution of the three-dimensional pattern of air motion within natural shower clouds at the same time as observing the location and rate of growth of the population of cloud particles from the time of the first appearance of the cloud up to and beyond the time of initiation of precipitation. A start has been made by using Doppler-radar techniques to infer the pattern of airflow and the distribution of hydrometeors within a mature shower cell, and a simplified representation of this is shown in Figure 5. This figure shows that hydrometeors were being grown within a bubble of rising air some 2 km in diameter within which the vertical air motion was close to 1 m/s. The updraught maintained a concentration of supercooled cloud droplets sufficient to enable soft hail (graupel) particles to grow. These hail particles reached the ground after falling several kilometres within a region of weak downdraughts.

More-comprehensive studies of the structure of shower clouds are planned, during which direct measurements of the cloud particles will be made from an instrumented aircraft at the same time as the cloud is being observed by the radar. Additional radar techniques are also being developed in which a highly sensitive 10-cm radar is used to detect the cloud boundaries. The radar actually detects back-scatter from refractive-index irregularities associated with humidity gradients and such radar echoes can be detected from the edges of convective elements even before the development of any cloud within the rising air. Another radar, operating at a millimetric wavelength (instead of at the centimetric wavelength of most other radars) is being developed to detect the early development of precipitation particles whilst they are still much smaller than drizzle droplets.

The highly sensitive 10-cm radar referred to above is also being used to map the height of the upper limit to convection as a function of time over areas with horizontal dimensions of about 100 km. The intention is to identify and study the development of areas of relatively deep clear-air convection which form preferred sites for later outbreaks of showers and thunderstorms. (This topic is referred to later under the section entitled 'Radar studies of the optically clear atmosphere', p. 80.)

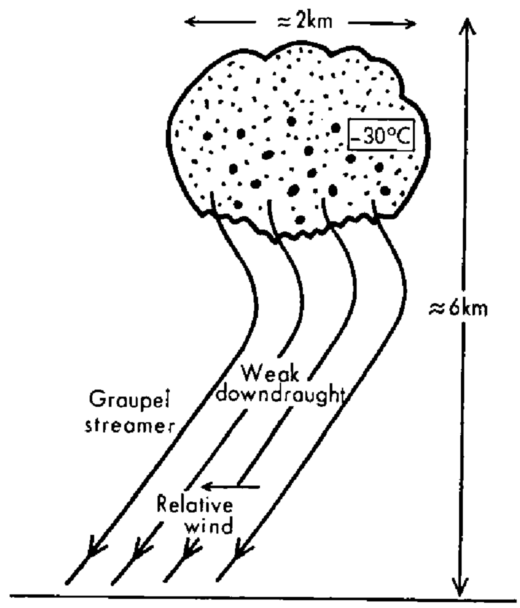


FIGURE 5 — SIMPLIFIED MODEL OF A SHOWER ON 2 MAY 1967 IN VERTICAL SECTION

In the generation region (boldly outlined) horizontal and vertical air velocities relative to the shower were ≈ 1 m/s, liquid-water content ≈ 1 g/m^3.

Small stipple represents ice crystals (balanced by updraught). Large dots represent graupel; maximum diameter 6 mm, mean density ≈ 0·05 to 0·2 g/cm^3.

Shower is moving from left to right at 8·5 m/s. The whole of the cloud is not shown.

Air motion and precipitation in frontal regions. The generalized pattern of precipitation and air motion in mid-latitude depressions as described half a century ago by the Norwegian school of meteorologists has been broadly accepted for many years. Nevertheless, it is well known that there are significant features in the precipitation distribution which have dimensions of 100 km and less and which lead to far more complicated precipitation patterns than those associated with the generalized model. By numerically integrating the primitive equations using a grid length of 50 km, Bushby and his co-workers in the Office have successfully predicted, in some situations, rainfall amounts on a grid scale of 100 km, but the actual rainfall distributions show far more irregularities than were predicted even by these calculations.

Although it is recognized that effects due to latent heat, friction, small-scale convection and orography are amongst the factors contributing to the irregular distribution of rainfall in frontal regions, little is known about the role of these mechanisms in relation to the large-scale dynamical structure of depressions. Consequently their effects have not yet been adequately incorporated in any numerical treatments. Indeed, at the present time surprisingly little is known, even on a purely descriptive plane, about the kinds of small-scale patterns of precipitation and air motion that occur in depressions. The Branch has, therefore, set out to make simultaneous measurements by using radar and other, more conventional, observations of the precipitation patterns and the associated air motion.

The frequent occurrence of rain bands has emerged as one of the most striking features of the frontal precipitation. The distribution of precipitation encountered in one particular depression is portrayed in Figure 6. This shows

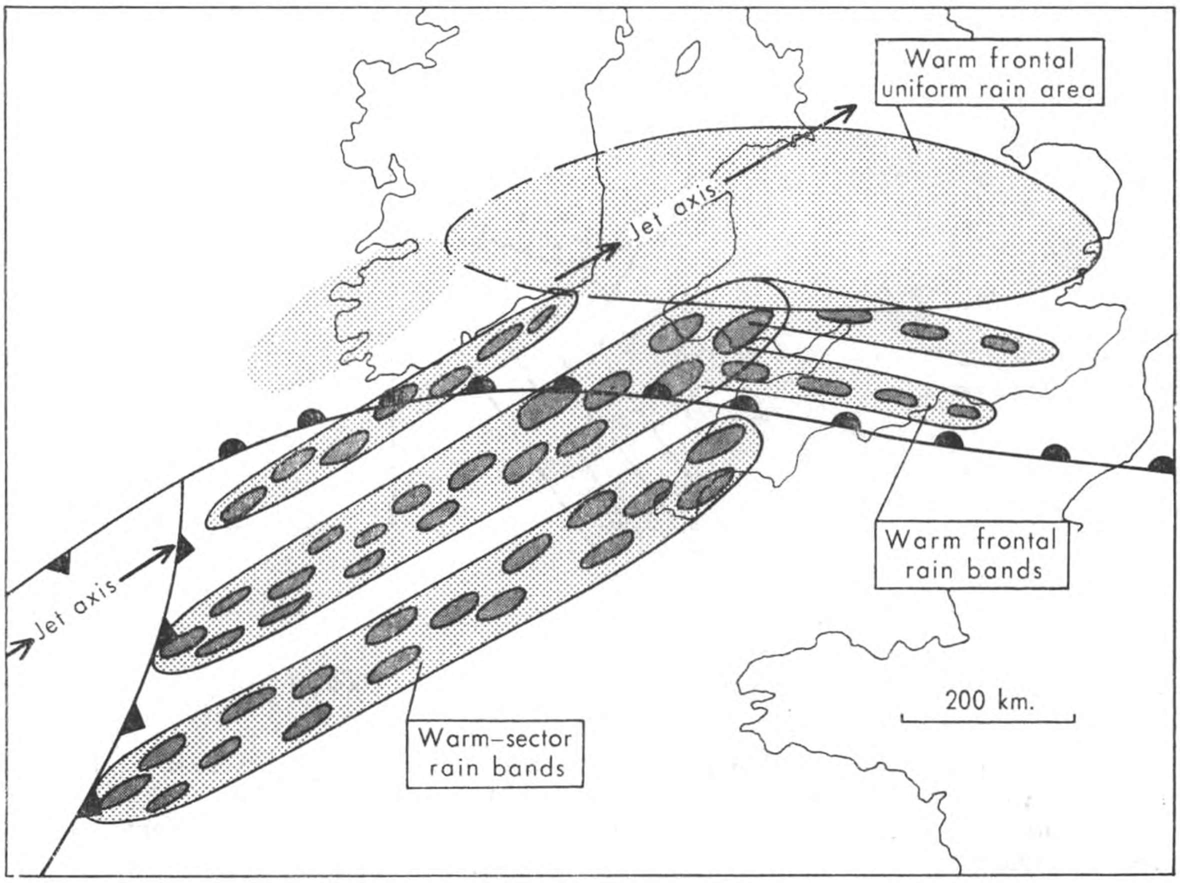


FIGURE 6 — COMPOSITE DIAGRAM SHOWING SCHEMATICALLY THE DISTRIBUTION OF RAINFALL RÉGIMES WITHIN THE DEPRESSION OF 16 OCTOBER 1967

The position of the depression at 12 GMT is shown relative to the land to give an indication of scale. The diagram is based upon observations over land; the warm-sector rain bands were orographically enhanced and may not have been major features over the sea.

Light stipple represents moderate rain, heavy stipple represents heavy rain.

that areas of heavy rain were aligned in bands which occurred both ahead of the warm front and within the warm sector. Other studies have revealed similar patterns. The bands appear to be associated with convective instability, and there is evidence that the convection is sometimes triggered preferentially over major hills to give enhanced falls of rain over and along a swath to lee of the hills, as depicted in Figure 7.

Measurements of airflow in the regions of frontal precipitation have been made, as already mentioned, by Doppler-radar techniques and these have been accompanied by wind measurements made by radar tracking specially designed targets dropped from aircraft. The latter measurements have the advantage of giving information on air motion in regions outside the area of precipitation and also over a much larger area than that which can be surveyed by a single Doppler radar, although the information they provide is less detailed. Because of the complicating effects of hills on the nature of the airflow and precipitation patterns, many of the observational studies have been undertaken over the sea, from a base on the Isles of Scilly. It is intended that some later projects shall be centred over the mainland, so as to study the influence of topography in some detail and to find out to what extent the modification of the precipitation patterns over land can be predicted from a knowledge of the thermodynamic structure of the approaching systems.

An example of the kind of detailed airflow pattern which can be derived

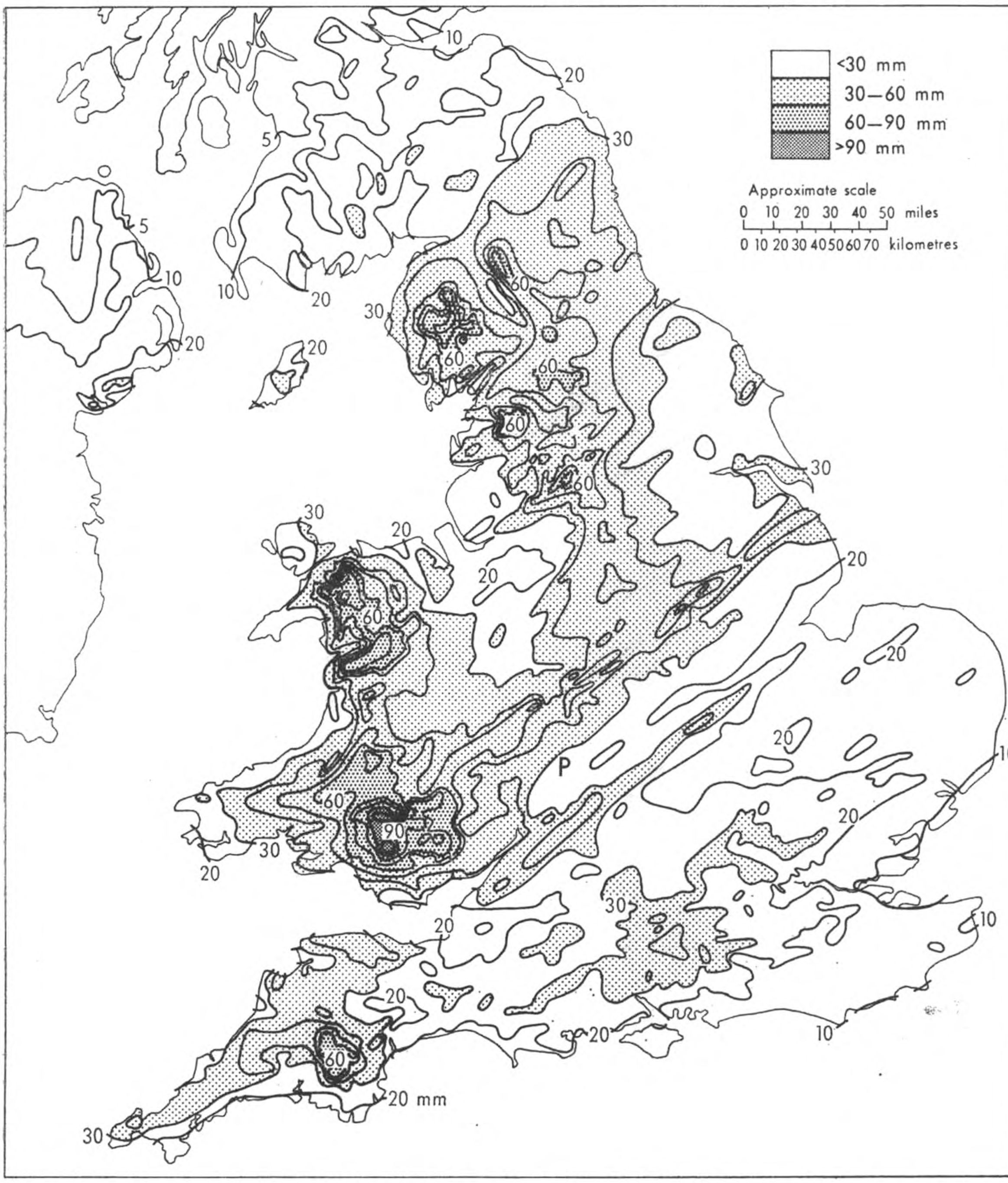


FIGURE 7 — TOTAL RAINFALL FOR 24 HOURS, 16 OCTOBER 1967

The measurements were obtained from about 2000 rain-gauges. P marks the position of Pershore.

is shown in Figure 8. This is a time/height section obtained during the passage of an active cold front, and the speed of travel of the frontal system was such that each hour on the time scale corresponds to 40 km. Thin solid lines are streamlines of flow relative to the system. Thick lines denote the boundaries of the cold frontal zone and other stable layers inferred from radiosonde data. Crosses denote the base of the main frontal-cloud deck. Hatched shading indicates a region of strong stretching deformation normal to the section and stippled shading indicates strong vertical wind shear. All of the data have been derived from the Doppler-radar measurements. As is usual in active fronts, there is a well-defined direct solenoidal circulation (i.e. one in which warm air rises and cold air sinks). Almost all of the precipitation growth took place within

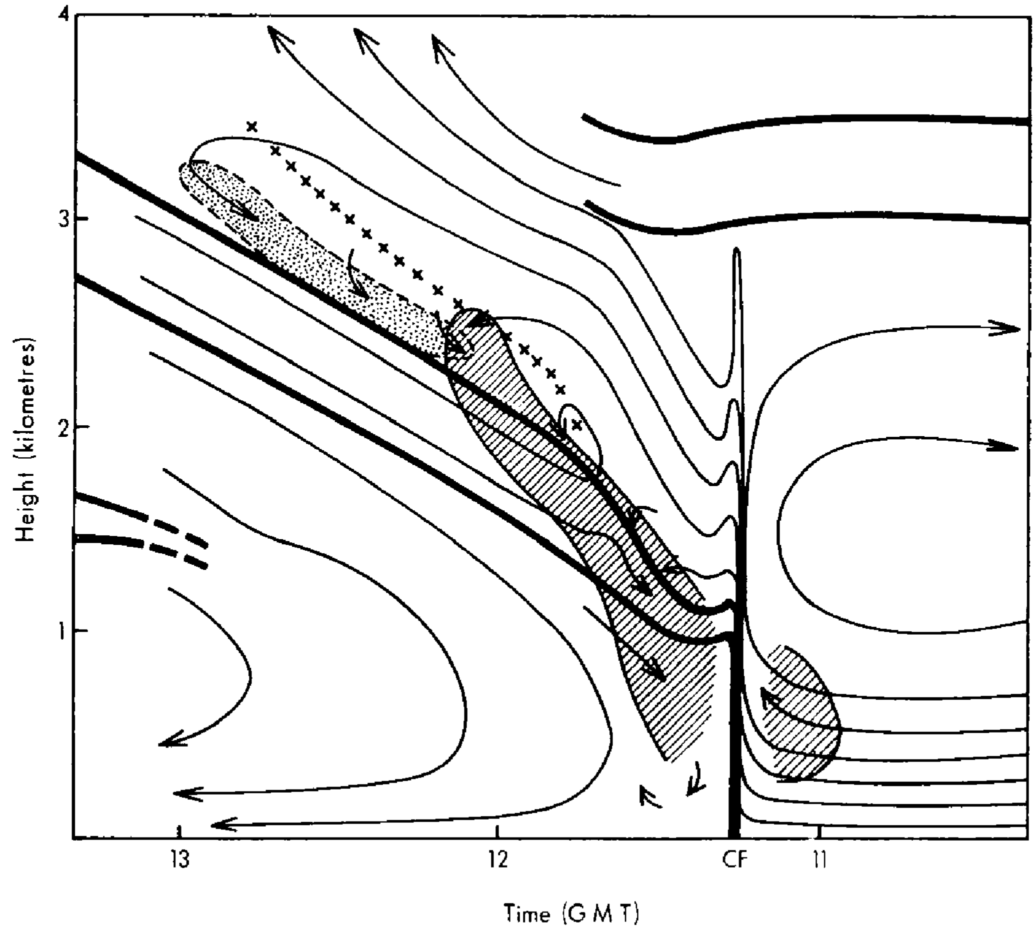


FIGURE 8 — TIME/HEIGHT SECTION SHOWING THE DETAILED AIRFLOW PATTERN IN THE VICINITY OF THE COLD FRONT OF 6 FEBRUARY 1969 AS IT PASSED OVER PERSHORE

Thin solid lines are streamlines of flow relative to the system. Thick lines denote the boundaries of the cold frontal zone and other stable layers inferred from radiosonde data. Crosses denote the base of the main frontal-cloud deck. Hatched shading indicates a region of strong stretching deformation normal to the section, and stippled shading indicates strong vertical wind shear. CF = cold front.

a shallow (1 km) layer of air which originated in the surface friction layer just ahead of the front. The air ascended in two stages; first abruptly at the surface cold front as nearly vertical line-convection at up to 8 m/s, and then gently as shallow slope-convection above the frontal zone. The rate of ascent above the frontal zone reached about 40 cm/s. The maximum downdraught, of about 20 cm/s, occurred within the cold frontal zone. Although the intensity of the convection at the cold-front nose was rather unusual in this case, the values of vertical velocity in the regions of shallow-type convection are fairly typical of the magnitudes which have been observed within other intense fronts, both warm and cold.

Attempts to model the growth of the rain and hail, given this air motion structure, have demonstrated that the hydrometeors must have made two vertical traverses of the cloud to grow to their final size in the time available.

Physical Research

Structure of clouds and cloud systems

A major field study in the early part of the year was directed to the study of the cloud structure, rainfall and air motion as fronts approach south-west England. This completed the data acquisition of Phase III of the project known as Project Scillonia.

The most comprehensive data were obtained on 18 January 1971 during the passage of a warm front in process of occlusion. The two Meteorological Research Flight aircraft, a Varsity and a Canberra, were used together with an Argosy from RAF Benson. During the four hours of continuous rain four radars operated simultaneously on St Mary's Island, Isles of Scilly. One radar recorded the distribution of rain both in the horizontal and in the vertical, a second radar operating in the Doppler mode enabled vertical air motion to be assessed on the 10-km scale and two tracking radars were employed to measure winds by following targets ejected from the Varsity and Argosy aircraft. The Canberra aircraft was directed to the areas of high-level radar echo where it was used to measure the small-scale motions directly. (Photographs of the radar installations appear in Plate III.)

The subsequent development of the precipitation over the mainland was monitored by a 3-cm radar specially set up at Camborne and by the weather radars at Bracknell, Manchester, Malvern, Boscombe Down, etc. Sequential balloon radiosonde soundings were made at Camborne, Larkhill and Aberporth during the passage of the frontal system and extra radiosonde ascents were made at all radiosonde stations in England and Ireland.

The processing and study of these extensive data are now well advanced and are beginning to yield important information on the occurrence of the banded structure of precipitation in these frontal systems.

The possibility of determining upper winds from the motion of the radiosondes dropped from the aircraft, by means of the navigational aid (LORAN-C) signals, is being studied with a view to use in future field programmes. The radiosonde would carry a LORAN receiver and transmit the signal to the aircraft ejecting the radiosondes.

Cloud physics

Theoretical and laboratory work on the growth of cloud droplets continues. Recent experiments have confirmed that the coalescence of small water droplets is very much more efficient in a horizontal airstream the speed of which varies with height than it is in still air. This fact may go some way towards accounting for the observed distribution of drop sizes in real clouds which always contain irregular air motions.

The airflow revealed by radar measurements at a cold front has been used to calculate the movement and growth of ice crystals on this occasion. There are indications that after their initial growth ice crystals were lifted and subsequently made a second descent through the cloud before reaching their final size.

Studies of the cloud electrification processes are being extended to include measurements in the atmosphere as well as in the laboratory. In order to do this a programme of instrument development has been initiated with a view to equipping the Meteorological Research Flight aircraft for these studies. This work is being carried out in co-operation with the University of Manchester Institute of Science and Technology.

Fog

An investigation into the physics of the formation and dissipation of fog was initiated at Cardington late in 1971. The principal aim is to study the correlations between the various relevant meteorological factors such as the heat balance, radiation, mixing, droplet microphysics and the aerosol content of the atmosphere. The Office is collaborating with the Atomic Energy Research Establishment (AERE), Harwell, and the Clarendon Laboratory, Oxford, in this work.

Radar studies of the optically clear atmosphere

The high-power radar using the 25-metre diameter parabolic reflector at the Royal Radar Establishment (RRE), Defford, first mentioned in the 1969 *Annual Report*, has continued to provide new insight into the structure and dynamics of the optically clear atmosphere.

One phenomenon being studied is clear-air turbulence (CAT). Theoretical and observational studies strongly suggest that CAT is due to unstable waves, known as Kelvin-Helmholtz billows, which break in much the same way as sea waves. Billows which produce intense CAT develop within layers of strong static stability (temperature increasing rapidly with height) in the presence of sufficiently strong wind shear (wind velocity changing rapidly with height). Plate VII (a) is a photograph, obtained with the Defford radar, showing billows in clear air at a height of about 6 km. The radar signal shown in the photograph is reflected from a layer containing small-scale temperature inhomogeneities. Similar photographs have been obtained for some time by American workers, but recent observations made with the Defford radar have, for the first time, revealed the life cycle of individual billows. These observations, interpreted in the light of sequences of vertical temperature soundings, have confirmed theoretical predictions about the nature of CAT by showing that the breaking billows gave rise to a splitting of the layer of strong static stability.

The Defford radar has been used to identify a large number of occurrences of large-amplitude Kelvin-Helmholtz billows over a total period of 176 hours. Hourly radiosondes have been released from the radar site and tracked by precision radar to study the fine-scale structure of the atmosphere in the vicinity of these events. All of the events were found to be associated with well-defined local maxima in the vertical wind shear which usually persisted for longer than an hour. The large shears were associated with large static stabilities in such a way that the minimum value of the Richardson number fell mostly within the narrow range of 0·15 to 0·3.

It is already known from joint radar/aircraft studies in the U.S.A. that the detection of an echo from the clear air at high altitudes is in itself indicative of a perceptible degree of CAT. Most clear-air echoes are found to be diffuse and featureless; billows with an amplitude as large as those in Plate VII (a) are observed only occasionally. However, it is precisely these large-amplitude billows that in certain circumstances can be expected to produce the most intense occurrences of CAT. This was confirmed when moderately intense turbulence was encountered by an instrumental aircraft from the Royal Aircraft Establishment (RAE), Bedford, during a flight through an area of large-amplitude billows which were at the same time being detected by the Defford radar.

The CAT studies with the Defford radar are being continued, with two main aims. The first aim is to improve the capability of ground-based radar to assess quantitatively the intensity of turbulence, and to this end steps have been taken to derive Doppler velocity information from the radar signal. The second aim is to study CAT in relation to the meteorological factors leading to its development in the hope that conventional meteorological observations can be used to forecast the likely regions of CAT more accurately.

Defford radar is also being used to study the atmospheric waves forming in the lee of mountains. Defford is situated 70 km east of the Welsh mountains and lee waves are common. Wavelengths of up to 30 km and crest-to-trough amplitudes of up to 1 km have been observed. The radar detects the lee waves as a result of their effect in distorting echoes which otherwise would lie in horizontal layers. Plate VII (b), for example, shows lee waves observed while the radar was scanning a vertical section towards the west. Echo layers can be seen at many altitudes, being associated mainly with humidity and temperature laminations. Above 6 km, however, the radar echo is from cirrus ice-crystals and, although the upper parts of the cirrus are complicated by convection, the base of the cirrus is sharp enough to serve as a useful indicator of wave motion. Long lee waves, with a crest-to-trough amplitude of 500 m, are evident between heights of 5 and 7 km; the layer at 4 km, however, shows little sign of waves. The wind on this occasion was blowing from the west and the wave crests were oriented north–south. Successive photographs of the radar display showed that the wave pattern maintained a fixed position while smaller identifiable echo features travelled through it.

The Defford radar has also been used as a means of identifying likely areas of thunderstorm development. The high-power radar is capable of detecting the humidity gradients at the edges of convective elements even before they have risen high enough to produce cumulus clouds. Studies using the Defford radar have shown that the height of the upper limit of convection varies considerably from one place to another several hours before the development of showers. Moreover, it has been found that the regions of relatively deep convection preceding the development of showers or thunderstorms are persistent and can be tracked. As a result it has been found possible to identify regions of preferred thunderstorm development three hours before the first outbreaks of rain. The range to which the clear-air convection can be detected with the Defford radar varies considerably, but in highly convective summer-time situations it can be as great as 100 km. Consequently during thundery situations high-power radar appears to offer promise as a practical means of making short-term predictions of the preferred areas for thunderstorm outbreaks.

The Defford radar was upgraded at the beginning of 1971 so as to provide Doppler velocity information. This has enabled vertical wind measurements to be made in the absence of clouds. The first application of this has been to study the air motion and turbulence characteristics within an inversion at the top of the planetary boundary layer at a time when the inversion was being strongly disturbed by rising air currents from below. The radar was scanned to observe a region adjacent to that being probed by turbulence sensors developed by the Meteorological Office Unit at Cardington, the sensors being suspended at the level of the inversion by means of a tethered balloon.

Oceanography

Investigations into the detailed structure of fronts in the seasonal thermocline have continued, with the object of discovering the physical mechanisms by which the multi-layered structure of the ocean is established. During a six weeks' expedition to Malta (the seventh and last in the present series), detailed measurements of the thermocline microstructure were made from HMAFV *Sea Otter*. A special 0·1-μs LORAN-C navigation system, which gave the ship's position, allowed the team to calculate the precise position of the microstructure instrument as it slowly descended through the sea. This improvement in navigation allowed a far higher density of sampling than has hitherto been justified in thermocline investigations. The results of the expedition have revealed how stable layers are formed by fronts. This mechanism is an important contribution to a comprehensive model of vertical mixing in the thermocline. Work is proceeding on theoretical studies directed at the construction of a quantitative model of the physical processes which lead to the observed structure of the thermocline.

Air pollution

With the co-operation of the Government Chemist, measurements of the chemical composition of air and rain continue to be made at Lerwick, Eskdalemuir and Bracknell. Lerwick has been designated a Regional Sampling Station of the WMO network for monitoring the background pollution in the atmosphere. Arrangements are in hand to modify and extend the sampling measurements at this station to make sure they are truly representative of the background pollution in that area.

Some consideration has been devoted to the study of possible effects which the pollution from aircraft might have on the chemical and radiation balance of the stratosphere. Contrary to suggestions which have appeared in the scientific literature, preliminary studies suggest that effects produced even by the large number of supersonic aircraft projected for the next decade will be barely detectable. However, relevant monitoring of the stratosphere and further theoretical studies are being planned.

Meteorological Research Flight (MRF)

The Canberra aircraft was withdrawn from service early in February for a major inspection. While it was out of service, provision was made for the installation of the digital data-recording system which was being built by the British Aircraft Corporation. This digital recording system has been designed to handle up to 48 data channels and to record them on magnetic tape at a rate of 640 samples per second. The data recorded in this way are not in a format suitable for immediate use on the large computer of the Meteorological Office or on that of RAE. Hence the airborne tape must be replayed through a smaller computer at MRF, so that the required data blocking, etc., can be provided. This small computer, a PDP8/I, can, of course, also be used to process small amounts of the data directly. A new wing has therefore been added to the MRF building in order to house their new computer, and also to provide office accommodation for the programmers and maintenance staff who will be closely associated with the new system.

The Varsity aircraft has again been used on a variety of projects. During January and February it was involved in Project Scillonia. Later, several flights were undertaken in co-operation with the Health Physics Division, Atomic Energy Authority, Harwell, in order to measure some aspects of low-level pollution introduced into the atmosphere from the industrial Midlands. The experience of these flights has led to a modification of the techniques and requirements, and a further series of flights is envisaged. During August the aircraft was detached for two weeks to Malta to participate in the oceanographical studies, by the Meteorological Office, in the sea area to the east of Malta. During this detachment more than 60 hours flying time was achieved on task. Considerable data were collected relating to the occurrence, movement and magnitude of sea surface temperature discontinuities.

It has now been agreed that the Varsity aircraft, which is nearing the end of its useful life, will be replaced by a C-130 Hercules. This is a well-proven long-range transport aircraft capable of operating up to 35 000 ft ($\approx$11 km), and with a wide range of airspeeds. The task of modifying the aircraft to MRF specifications is being conducted by Marshall's Engineering Company of Cambridge. The modifications are extensive; the addition of a 22-ft nose-boom entails not only major structural alterations at the nose of the aircraft, but also the repositioning of the precipitation radar. Delivery of the aircraft is expected in the spring of 1973.

High atmosphere

Measurements of wind and temperature at levels from 20 to 60 km above the ground were made at two places in the British Isles by SKUA rockets at the same time that similar measurements were being made at Kiruna, Sweden. The measurements were carried out in the winter 1970–71. The aim was to study the spatial structure of the disturbances of the winter stratosphere and mesosphere. A large-scale warming of the stratosphere occurred during the period of the measurements, and the radiation measurements made by the Heriot Watt and the Oxford University Selective Chopper Radiometer on the U.S. satellite NIMBUS-4 are being studied in conjunction with the rocket measurements. A total of 33 SKUA rockets were fired from South Uist and Aberporth.

Measurements of the density of ozone in the high atmosphere were made on a BLACK BRANT rocket launched from Fort Churchill, Canada, on 13 January (a joint experiment with the University of Saskatchewan). Similar measurements were made on a balloon, released at White Sands, New Mexico, on 2 August, which reached a height of 40 km (a joint experiment with Queen's University, Belfast).

An experiment was carried out in November in which ozone sondes were launched at 4 radiosonde stations at 12-hour intervals for 3 days to study the variations in space and time of the vertical profile of the ozone mixing ratio.

In a joint experiment with the National Physical Laboratory a balloon was launched, at Cardington, on 2 October carrying a microwave interferometer for measuring the density of water vapour in the stratosphere; measurements were made up to a height of 30 km.

Work is progressing on the construction of a dye laser for determining the air density and dust concentration in the stratosphere by measuring the Rayleigh and Raman back-scattering of the laser beam.

Construction is now complete of the Doppler radar for measuring winds in the 80–100-km range from the motion of meteor trails, and some measurements have been made. Some progress has been made in the design to automate the equipment.

The results of the experiment on the ARIEL 3 satellite, for measuring the density of molecular oxygen in the thermosphere, are being prepared for publication. A comprehensive discussion of the results of the ozone experiments on the satellite ARIEL 2 is being prepared. This will include the results of ozone measurements from rockets fired subsequently.

Boundary layer research

The observational facilities for the study of the atmospheric boundary layer have been further developed at Cardington. The equipment for measuring turbulent fluctuations of wind and temperature from a balloon cable is being converted for radiotelemetry of the results to the ground, and improved facilities are planned for the recording and analysis of the data. The development of equipment for measuring fluctuation in wind direction is nearing successful completion. This will enable all three components of the turbulent air motion to be recorded.

An exhaustive series of comparisons has been carried out between the sensors mounted on the cable of the tethered balloon and simultaneous measurements of sensors on a high tower. The main object was to obtain a direct assessment of the errors arising from balloon movement, and the data obtained are now being studied. Preliminary results from these and other experiments are encouraging. These comparisons were arranged in Florida in the autumn in conjunction with the U.S. Air Force Cambridge Research Laboratories. The instrumentation on the tower was provided by the U.S. Air Force Cambridge Research Laboratories.

The Cardington captive-balloon system for studying turbulence was also used simultaneously with turbulence observations by the high-power radar at Malvern and with soundings made with a radio-refractometer developed and operated by a team from the Radio and Space Research Station. The object is to assign velocity components and temperatures to identifiable features of the flow, e.g. waves on an inversion layer. Early analysis suggests that quantitative interpretations of hitherto qualitative descriptions will be possible.

Analysis of the structure of the boundary layer has continued with particular application to problems of diffusion.

Studies of the relation between sulphur-dioxide concentration at certain stations in central London and meteorological conditions have provided a promising basis for forecasting day-to-day variations in pollution concentration.

Analysis has been completed of the turbulence measurements made during 1970 from a captive balloon carried on a ship during project Jasin. These analyses indicate the need for servo-stabilization at the tethering point of the balloon cable. If this is not done, useful data on the turbulent fluxes will not be achieved when the wind speed exceeds about 10 m/s.

An investigation has been started into the importance of spray in evaporation over the sea. Simple calculations suggest that the process may contribute significantly to vertical moisture fluxes in high wind-speeds.

Measurements of evaporation, soil moisture and related meteorological variables were maintained at Cambridge during the growing season of a crop of barley. This work is carried out in conjunction with the Plant Breeding Institute which is studying the water requirements of the crop. This will be the last season of such measurements at Cambridge.

Geophysical fluid dynamics

The main features of the behaviour of the earth's atmosphere on the global scale arise because the atmosphere is a fluid envelope rotating with the earth and responding to the temperature changes resulting from the heat received from the sun and radiated to space. The very complex behaviour of the atmosphere makes it difficult to test ideas regarding the way in which the earth's rotation and other factors determine the behaviour of the atmosphere. Some of these ideas can however be tested in simpler dynamical systems such as are provided by rotating-fluid systems in the laboratory. For this purpose experimental studies of rotating fluids are carried out in the Geophysical Fluid Dynamics Laboratory of the Meteorological Office.

During the year a large, rotatable, annular tank was brought into use. The external diameter of the tank is 76 cm and fluid motions in it can be maintained by temperature differences between inner and outer cylindrical boundaries of the annulus. The temperature distribution within the fluid is an important indicator of the motion and can be determined by an array of thermocouples. The fluctuations are recorded on paper tape for subsequent computer processing.

Other experiments are carried out by using a smaller tank. A new technique has been introduced for measuring the motion within the fluid at several levels. This is based on streak photography of small neutrally buoyant particles illuminated by a horizontal light beam. A laser method of measuring velocities is also being developed.

Among the important questions investigated, both theoretically and experimentally, was that regarding the factors which control the vertical distribution of temperature in a rotating fluid in which heat is being transported radially by the fluid motion, by analogy with the atmospheric heat flow from pole to equator. The onset of unstable wave motions has been studied and the effect of the latitudinal variation of the Coriolis parameter on the earth (an effect of the spherical shape of the earth) has been simulated by using a rotating vessel with a sloping base (and upper surface). The results show that the stabilizing effect of the sloping boundary is partially offset by internal temperature readjustments associated with changes in the flow pattern.

Experiments also show that, even when the flow in a rotating fluid in the laboratory appears to become irregular, spectral analysis demonstrates that the flow consists of only a few components, with amplitude fluctuations making a much bigger contribution to the variability than fluctuations of phase. The extent to which this conclusion is applicable to the atmosphere is as yet unknown.

The effects of large-scale topography on the atmosphere can also be simulated in the laboratories by irregularities placed on the base of the rotating tank.

The behaviour of flow under these circumstances has been studied both theoretically and experimentally, particularly in relation to the so-called 'spin up' of a rotating system, which is the period of adjustment of the fluid motion to a change in rotation rate of the tank.

Theoretical studies of rotating systems have also been extended to conditions under which magnetic and electrical effects may become important. Such studies are particularly relevant to the understanding of motion in the earth's core and of variations in the earth's magnetic field.

Dynamical and Synoptic Research

Research related to short-range weather forecasting

One of the major tasks of the Office is the routine provision of weather forecasts for short periods up to a day or two ahead both for the public, through Press, radio and television, and for more specialized purposes, such as use by aviation interests. Once again a considerable research effort has been devoted to improving the accuracy of these forecasts and extending them to cover longer periods and larger areas. It is generally recognized that the most promising way of achieving improvement is to develop those methods which are loosely called 'numerical weather prediction', in which the atmospheric motions are represented in mathematical form through the equations of motion and energy for a compressible fluid. The resulting set of partial differential equations is in principle capable of predicting the developing pattern of wind, temperature, pressure and humidity, provided that these are well enough known to begin with from the routine meteorological observations. However, the equations are complex and highly non-linear with no simple analytical solutions and their integration has to be carried out by arithmetical methods. The arithmetical burden is great—more than ten thousand million arithmetical operations are required in the computation of a 24-hour forecast using the recently developed technique—and calls for very powerful computers. As the mathematical treatment of the problem is extended so that it represents more closely the behaviour of the real atmosphere, the computations become more complex and are likely to tax the even more powerful computers that are now becoming available.

The principal research effort has been directed to developing an operational version of the numerical prediction scheme which has been the focus of much research over the last few years and which is designed to give greater detail in the weather forecasts than does the present operational model. The basis for the improvement lies in recognizing, and taking account in the computations of, more of the physical processes which determine the evolution of weather systems. The computations as now developed take account of the effects of water vapour and water in the atmosphere, also of topography, friction at the earth's surface, convective overturning of the atmosphere, large-scale diffusion and of the diurnal radiation processes near the earth's surface. Further research is directed towards the inclusion of the snow and ice phases in precipitation and the presence of clouds. Two versions of the computation have been designed: the first gives predictions of temperature, moisture and wind at 10 levels in the vertical and at grid points on a square mesh which are approximately 100 km apart, over an area covering much of the North Atlantic Ocean, North America and Europe; the second gives predictions at the same levels over most of the northern hemisphere but at points about 300 km apart. Both computations predict the rainfall at each grid point.

The development of the operational numerical prediction scheme has been accomplished through monthly visits to the IBM installation at Poughkeepsie, U.S.A., where there is an IBM 360/195 computer, similar to that installed at Bracknell at the end of the year. The first few visits confirmed the provisional estimates which had been made of the computer time necessary to carry out the integrations, and subsequent visits led to the assembling of the programmes in an operational form ready for field trials. Some useful forecasts were obtained during these visits, mostly for the fine-mesh area, and some changes were introduced into the programmes as a direct result of examination of these forecasts. Two suites of programmes were available at the end of the year for extensive testing: one embracing the objective analysis, initialization and prediction programmes for the fine-mesh model, and the other consisting of similar programmes for the coarser-grid hemispherical area. Field trials were planned to commence early in 1972.

The intensive development of these suites of programmes led naturally to much further research work on the analysis of the initial observations, on the derivation of a self-consistent set of initial values and on the prediction itself, as earlier formulations were corrected and improved. The objective analysis programmes have been designed to make use of the forecast from earlier data as a preliminary analysis to be altered in the light of the new observations which become available, and to allow for a small amount of human monitoring and intervention. The initializing procedure, which is necessary to ensure that the prediction computation runs smoothly without undue interference from meteorologically unimportant features, has been extensively recast in its mathematical detail, and experiments are being carried out into the use of actual or predicted pressure-tendencies to shorten the settling down period of the prediction computation. A number of changes have been made in the formulation of the prediction computation in light of the experience gained from the computations carried out at Poughkeepsie. For example, the detailed treatment of friction at the surface was altered after the computations indicated spurious anticyclonic developments near Greenland when the forecast period was extended beyond 24 hours. In so complex a model it is often difficult to isolate the area of computation which is causing trouble and the diagnosis requires a nice balance between mathematical and physical insight.

Attention has also been paid to the impact of the new computational scheme on the forecasting service. The investigation started with the evaluation of the rainfall forecasts and involved studies of actual rainfall on a scale comparable with that predicted numerically; it has now been extended to the interpretation of the predictions in terms of other weather, for example cloud amount and type.

Experiments have continued in 7-day forecasting and a limited number of forecasts have been prepared in association with the 30-day forecasts. The weekly forecasts have been based partly on the numerical predictions for 72 hours ahead and partly on analogue techniques. It has been found that if there is a good analogue for the synoptic situation over most of the northern hemisphere for a few days prior to the day of issue of the forecast, then this provides good guidance as to the weather to be expected over the ensuing 5–7 days. It seems necessary for the analogue to attain its closest resemblance to the current weather situation in the European–Atlantic sector on the day of issue. Several computer-based methods of selecting such analogues have been developed and the first 100 test forecasts show that about half would have given good guidance over 5 days or more.

Further attention has been paid to those problems of weather forecasting which depend upon the local terrain and can best be understood and solved by the forecasting staff at outstations. The investigations have covered a wide variety of problems such as the forecasting of minimum temperature at road surfaces, the use of data from several levels on tall television masts and the variation of precipitation with wind direction, hour and season. A small team at Headquarters co-ordinates the research carried out at outstations, giving advice and assistance, especially in the sorting of data by machine methods. The team also engages in associated investigations and is reviewing the empirical formulae used as a basis for forecasting visibility at London/Heathrow Airport where there has been a change in fog climate over the last decade.

Research related to long-range forecasting

Throughout the year, weather forecasts for a month ahead have been prepared at the beginning and middle of each month and have been made available to the public through radio, television and the Press. The detailed forecast, along with statistics of the weather of the month in question, has been available at a small nominal charge to subscribers, who number more than 2000. It is not possible to predict over long periods in the same detail as is attempted in forecasts for a day or two ahead and the monthly forecasts are not intended to provide information relating to specific days. The forecasts indicate the expected mean monthly temperature anomaly in one of five categories and the mean rainfall anomaly in one of three. The expected broad weather sequence is also described and mention is made of any expected outstanding weather-features, such as an unusual number of gales or frosts. The forecasts for the summer months of 1971 were disappointing, especially that for June which was entirely wrong—a warm, dry month being forecast for almost all districts. Such errors in forecasts are to be expected from time to time, since the forecasting system is based on identifying periods in the past when somewhat similar weather sequences occurred along with somewhat similar surface conditions, especially over the oceans. During the summer one of the most reliable forecasting tools, the sea surface temperature anomalies over the North Atlantic, provided little guidance because the anomalies were too small to form a sensible pattern. The weather sequences in the summer were highly unusual within the experience of recorded weather events, with a warm and fairly dry May, a very cold and very wet June and a warm, dry July. This June–July sequence last occurred in 1769.

Despite the unsatisfactory forecasts for the summer months, much consolidating research was carried out. Work was continued on trying to uncover the relationship between sea surface temperature anomalies and the ensuing atmospheric anomalies. A study of the relation between anomalies in the Pacific Ocean and the subsequent weather in north-west Europe is nearing completion, but the Pacific data may well be inadequate to provide results as useful as those obtained from the previous Atlantic Ocean study. A considerable effort has been directed towards determining areas for which there is a significant relationship between their pressure anomaly and the temperature and rainfall over the U.K. between one and three months ahead, and some promising predictors using the pressure anomalies in these key areas have been developed. This work is only at an early stage but shows considerable promise. A similar technique using anomalies of the contour heights at 500 mb to distinguish between wet and dry, and warm and cold, periods to follow has shown greatest success when the 15-day 500-mb anomalies are used to predict the temperature and rainfall for the next 15 days. A number of special studies have been made, such as one which summarizes all the methods known to us for predicting the mean temperature and rainfall in March.

Experimental seasonal forecasts have been made for each of the seasons and the associated research has been concentrated on completing objective procedures for predicting winter weather by using pressure anomalies over the northern hemisphere in the preceding September, October and November, and spring weather by using the amount of Arctic and Baltic ice and the sea surface temperature of the North Atlantic Ocean.

The ability to carry out the research directed towards improving the forecasts and to make the monthly and seasonal forecasts depends very largely upon having readily available a vast bank of data in a form suitable for use in a computer. The total data bank, with additions during the year, now contains a very high proportion of all the meteorological data over the last 100 years which are likely to prove of value in long-range forecasting. The surface pressure data are now complete over much of the northern hemisphere for every day since 1873 and are readily available on magnetic tape; this is probably a unique data set.

The research and preparation of forecasts, so dependent upon the examination of large quantities of data, have been considerably aided over the last few years by the use of the specially designed computer language for the COMET computer. Considerable effort has been spent during the year in modifying this language to a form suitable for use on the new IBM 360/195 computer installed late in the year, and in extending it to include more-sophisticated quality-control techniques. Further progress has also been made in the use of techniques of analysis which depend on the natural characteristic patterns of the fields of atmospheric pressure and temperature, both in selecting analogues and in processing data. Mr J. M. Craddock has acted as consultant to WMO in devising a computer scheme for the cataloguing and retrieval of meteorological data and the scheme is in trial use. Further developments in statistical theory applied to meteorology were reported by publication.

Climatic changes

There has been continued interest in the study of climatic changes at both national and international levels both because of the economic value of predictions far into the future and of the considerable discussion centring on the possible influence of human activity on our climate. The natural climatic variations that have occurred, presumably without any interference from man-made effects, need to be established so that other effects may be measured against them. Substantial work was carried out on the climatic changes in the Arctic regions during the last 10 000 years and a paper was presented at a conference on this subject held in Finland. Other substantial papers were prepared for a

WMO Working Group on Climatic Fluctuations and for a special publication on Palaeoclimatology. Direct observational evidence for these studies is available only after the invention of the thermometer and barometer, and then on a routine basis over only limited areas from the mid-nineteenth century. Indirect evidence is inferred from botanical, archaeological and oceanic studies using modern dating methods. The daily register of circulation patterns over the British Isles from 1861 to 1971 is almost ready for the press and a comparison of the averages of the mean-sea-level pressure over the northern hemisphere for the periods 1900–39 and 1951–66 is about to be published. Work has continued on the association of sunspots with average pressure for different times in the cycle, and on the frequency of westerly types in the last few years.

General circulation of the atmosphere

The study of the general circulation of the atmosphere is one of the major tasks facing meteorology, and research groups in several countries have been set up to investigate the factors which govern the circulation and which determine changes in it. The importance of the study lies in the attractive prospect of forecasting for long periods and a challenging problem is the determination of the length of time over which weather forecasts will ultimately be possible. This is one of the central goals of the international Global Atmospheric Research Programme (GARP). The importance of the research is emphasized by the prospect that ultimately there may be changes of world climate resulting inadvertently (or even deliberately) from man's activity. The activities of mankind are growing at such a rate that it has become necessary to consider whether in decades to come the addition of pollutants to the atmosphere, the changes in land use or even the waste heat from industrial activity may have a significant effect on climate. A thorough understanding of the reaction of the atmosphere to such changes in the environment is essential if the extent of the modification of climate and weather is to be assessed before the event. When atmospheric models are sufficiently well developed they should provide a valuable tool for such research, but at present they are not good enough to warrant high confidence in their prediction.

It is generally recognized that the most effective way of attacking the problems of the general circulation is by developing numerical methods akin to those used for short-range forecasting but especially adapted for prediction over a long period of time. Work has continued during the year on developing a mathematical model which takes into account those physical processes which are thought to be most important in affecting the atmospheric motions over a long period of time. They are the hydrological cycle, and the effects of radiation and topography and also of the small motions which cannot be treated explicitly in the model; included in these smaller-scale motions are those responsible for frictional dissipation of energy and turbulent-transfer processes. (See Special Topic—The general circulation of the atmosphere, *Annual Report on the Meteorological Office*, 1967.)

The associated computations were carried out, on the Science Research Council's Atlas computer, for grid points in the northern hemisphere which are 5 degrees of longitude and 3 degrees of latitude apart and for five levels in the vertical, and the results of an integration for 60 days have now been analysed in some detail and papers describing this substantial experiment are being prepared for publication. The results show that the model reproduces well many of the features of the real atmosphere's general circulation; in particular, sequences of realistic depressions form in the model computations in mid-latitudes, there are subtropical anticyclones of about the right intensity and the hydrological cycle in the model atmosphere has much in common with that of the real atmosphere.

During the year computational facilities similar to those to be provided by the Meteorological Office's new computer, the IBM 360/195, became available at Poughkeepsie, U.S.A., and the opportunity was taken to redevelop the original model incorporating a number of improvements which had been indicated by the initial computations; in particular a new grid of more nearly constant grid-length was adopted. Thus at the end of 1971 the Office has the ability to carry out useful experiments to further understanding of the atmosphere's general circulation at the particularly opportune time when the new computer is installed.

Some of the shortcomings of the model can be attributed to inadequacies in the representation of the physical effects, especially the treatment of the radiative transfer of heat, and some to mathematical errors mainly due to excessive truncation error because of the limited resolution. The increased facilities offered by the new computer should make it possible to improve the model in both respects and also to develop further models with finer resolution in the vertical, with horizontal extension to the whole global area and with more-elaborate representations of the physical effects. These further developments should put the Office in a good position to take full advantage of the greatly increased meteorological data coverage expected during the first Global Experiment to be conducted in the GARP programme, at present scheduled for 1976.

The work has a considerable mathematical content and calls for an awareness of all advances in mathematical techniques which might be applicable. The potential value of finite-element methods in solving the model equations is being explored and their use may lead to solutions more accurate than those obtainable by currently available methods for the same computational effort. The possibility of integrating the equations by using variable space and time grids so that attention can be focused on the areas of greatest interest is being studied, as is the use of semi-implicit methods of integration with respect to time. The awkward problem of initialization, i.e. obtaining at grid points a definition of the state of the atmosphere in a form suitable for starting the integration, has been studied and a promising method is being evolved in which the subtle adjustments between the pressure and wind fields, necessary to render the initial state suitable for integration, are effected by the model equations themselves. A study has been continued of the effect on the general circulation of changes of sea surface temperature in a limited tropical region.

Attempts to develop a numerical model of the stratosphere on a global basis have continued and experiments have been conducted using a version extending to the mesosphere, with eight levels in the vertical above 100 mb. The uppermost level is at about 80 km where it is known that gravity waves and tidal motions dominate the flow. As expected, new problems, not encountered in investigations using models reaching to more modest heights, have been encountered and are far from being resolved. The work has been hampered by lack of computing facilities but should progress more quickly in 1972.

Charts of mean wind, temperature and contour height at the 30-mb level over the northern hemisphere for January and July were published; a similar set of charts for February and March (for areas north of 45°N only) and for April has been completed and is being prepared for publication. Work on charts for October is well advanced. A study has been made of the spring and autumn reversal of 30-mb winds over Scotland.

Special investigations

Meteorological advice is sought on numerous topics not covered by the main stream of research, and special investigations have to be made to provide the information required. Often suitable data are scanty and scientific judgement is needed in framing the reply.

Work in relation to the Concorde aircraft has included studies of temperature measurements from the aircraft, storm avoidance techniques, estimates of the probabilities of encountering heavy rain or hail, and meteorological aspects of incidents involving sonic bangs. Investigations into the mechanism of clear-air turbulence have continued and the characteristics of giant cumulonimbus clouds (especially in north-east India) have been studied. Photographs of cloud echoes on radars at Gan and Singapore are being digitized for analysis by computer, and estimates of the likelihood of aircraft entering echo areas have been made.

Research into tropical meteorology has included the investigation of regular oscillations in the large-scale equatorial wind-patterns, and the preparation of a detailed climatological report on the tropical eastern North Atlantic to assist in the planning of the WMO GARP Atlantic Tropical Experiment (GATE).

Work started on the complete revision of *Handbook of weather forecasting*.

Other work undertaken has included: the estimation of temperatures and humidities for standard atmospheres in different latitudes; answering inquiries covering atmospheric pollution; the preparation of route appreciations for various special aircraft flights including Miss Sheila Scott's polar round-the-world flight; advice on helicopter icing, on fog dispersal and on airport siting problems; and the production of rainfall intensity statistics in connection with effects on radio and laser communications.

General Activities of the Research Directorate

The scientific staff continued to take an active part in the development and co-ordination of research programmes of national and international concern extending beyond the direct responsibility of the Meteorological Office. Several scientists of the Office are members of international working groups and committees, set up under WMO, the International Association of Meteorology and Atmospheric Physics (IAMAP), the European Space Research Organization (ESRO) and other bodies. The meetings which they attended are listed in the International Co-operation section.

During the year particular effort had to be devoted to consideration of international programmes of meteorological observation from satellites. The formulation of a meteorological satellite programme within ESRO received particular attention and was the subject of several meetings, and the proposal for a geostationary meteorological satellite based on the French METEOSAT programme received critical evaluation. Direct discussions with the U.S. authorities led to proposals for the inclusion of British observing equipment on American operational meteorological satellites due for launch in the late 1970s. These proposals are likely to be finalized early in 1972.

Forward planning of the research activities of the Office are substantially influenced by the very large international programme known as GARP. This envisages a major effort to observe the world's atmosphere as completely as possible in 1976, a special effort to carry out a study of tropical weather systems in the Atlantic in 1974 and the co-operative development of numerical methods of extended weather prediction. Plans are being prepared for Meteorological Office participation in the GARP Atlantic Tropical Experiment (GATE). Officers of the Research Directorate serve on several of the international groups responsible for planning the programme.

A close liaison is maintained with the Natural Environment Research Council (NERC) and the Royal Society on matters concerning research in meteorology, and several members of the Office staff serve on committees of these bodies. Contact is also maintained with meteorological research in the universities. Six small research projects in the universities are directly supported by grants from the Meteorological Office and nine others are assisted through the Gassiot Committee of the Royal Society.

The scientific research of the Office was reviewed by the Meteorological Research Committee and its subcommittees during the course of nine meetings.

Library and Publications

The National Meteorological Library forms part of the Meteorological Office Headquarters at Bracknell. It is used mainly by staff of the Office but almost one-third of the loans of publications were to professional users from outside the Office or to members of the general public.

The library provides a comprehensive coverage of the literature of meteorology and associated subjects. An indication of the activities of the year is contained in Table XVI on page 97. Despite the reduced number of loans during the postal strike the total for the year (16 769) was above average.

Students from library schools have visited the Library in groups or individually as part of their programme of practical training. Library staff of the Office have continued to take advantage of the facilities offered by the Association of Special Libraries and Information Bureaux (ASLIB) and the Circle of State Librarians.

The number of journals regularly received was increased by 16 additional specialist journals in mathematics and computing, and a microfiche reader has now been added to the microviewing equipment of the Library.

Meteorological observations in manuscript and other original documents of the Meteorological Office are kept, in accordance with the Public Records Act of 1958, in special repositories in Bracknell, Edinburgh and Belfast. The material in these Archives is being consulted by an increasing number of users.

The Editing Section works in close co-operation with HMSO and is responsible for preparing for printing the official publications listed in Appendix III.

These include the *Meteorological Magazine*, a valuable medium for the publication of short scientific papers of interest and importance to the scientific staff of the Office in their day-to-day work.

The Cartographic Drawing Office prepares diagrams for Meteorological Office publications, for internal memoranda and for reports in scientific journals of research by Meteorological Office 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.

Training

The conversion and extension of the former Royal Air Force buildings at Shinfield Park, near Reading, to provide accommodation for the new Meteorological Office College, was completed in October (see Plates IV–VI). Courses were held until the 15th of that month in the old wartime buildings at Stanmore, which had housed the Meteorological Office Training School since 1950, and after 15 October courses were held at the new site without a break in the programme.

Skilful conversion minimized the limitations imposed by the need for adaptation of existing buildings. The seven spacious classrooms of the Main Building are equipped with light-tables and projection facilities for practical instruction in weather analysis and forecasting. Five of them are housed in a system-built extension to the original building and are grouped around an instruments lobby from which the meteorological elements are continuously monitored. Also within the Main Building is a lecture theatre, the library and the administrative offices. School House, formerly an airmen's dormitory block, is used largely for training in the use of meteorological instruments, weather observing and the preparation of weather messages and weather charts. In addition to classrooms, workshops, communications rooms, offices and a students' common-room, there is a small lecture-room and a cinema to seat 94. The cinema, a new extension to the existing building, is well equipped for lecturing as well as for showing the instructional films which are an important part of the curricula. This addition to the training facilities will allow the semi-annual staff colloquia which have hitherto taken place in rather unsatisfactory circumstances at Bracknell, to be held at the College.

At Shinfield Park the courses have become fully residential, the College being designed to accommodate 110 students each of whom has a compact but well-furnished study/bedroom which allows for quiet evening work. Social activities centre upon the Lodge, a small nineteenth-century residence with extensions housing the dining room, games room and bar. Squash and tennis courts within the park land have been retained. The grounds themselves allow adequate room for the field-work which has formed an important part of courses in recent years. In addition to the equipments found normally in standard enclosures and at observatories there are in course of installation at Shinfield Park a number of instruments encountered by staffs in their daily work but not available at Stanmore owing to the restricted space. These include a cloud-base recorder, a full set of solar and terrestrial radiation recorders, a transmissometer and visibility lights.

In the early weeks of their courses students are taught to plot past weather-data and to analyse past weather-situations. As the courses develop however, it becomes necessary, in simulating operational working conditions, for current weather-information to be available. The communications facilities installed in the Main Building and in School House allow for the quick reception of meteorological data from operational networks serving all parts of the globe. These data are raw material for courses in analysis and forecasting not only for the Atlantic and European areas but also for the Mediterranean countries, the Middle East, the Far East and many parts of the tropics. Cloud and radiation pictures are received at the College via the ground station at Beaufort Park, near Bracknell, soon after their transmission from the orbiting satellites.

The benefits of the new facilities have quickly been felt. Proximity to the Headquarters at Bracknell has facilitated the participation, in the College lecturing programmes, of specialists working in the various branches of the science at Bracknell. There have been exploratory contacts with the University authorities at Reading regarding joint training projects of potential mutual benefit to the Geophysics Department of the University and to the College. An increasing amount of evening work has been done. Previous dependence upon lodging accommodation in the vicinity of Stanmore meant that some students were hampered in their studies by unsatisfactory working and living conditions. Overseas students in particular had complaints of unheated rooms, inadequate diets and lack of sympathy in health problems. These difficulties are of the past. Course members are now getting through more work with greater success and less stress.

Changes in the curricula and in the College staff were kept to a minimum during the year. The second of the four-week courses in Advanced Dynamical and Physical Meteorology was held at Bracknell. These take place in March immediately following the post-graduate course for newly entered Scientific Officers. The special topics in 1971 were: Cloud Physics, the Higher Atmosphere, Long-range Forecasting, and Modern Climatology. Twenty-four members of the staff of the Meteorological Office and 5 members of overseas Meteorological Services attended. Numbers are expected to increase with the transfer to Shinfield Park.

The Basic Meteorology Courses for Experimental Officers which provide grounding for those taking up non-forecasting posts were very well attended. The reduction in the annual rate of recruitment into the Experimental Officer grade led to fewer staff taking the Initial Forecasting Courses in 1971. Amongst the 17 members of the Initial Forecasting Course which began on 13 September were staff from the Meteorological Services of Antigua, Barbados, Ethiopia, Jersey, Jordan, Mauritius and Thailand. A member of the Department of Geophysics, University of Reading, also attended to gain practical experience in weather analysis. The Advanced Forecasting Courses, designed for those with several years' experience, were extended to include a limited amount of management training, including syndicate work, covering subjects of special interest in the Meteorological Office. Overseas participation in the Extension and Senior Meteorologists' Courses has been increasing and in 1971 they were attended by experienced staff of the Royal Observatory, Hong Kong, and of the Air Forces of Belgium and the Netherlands.

The revised programme of training for newly entered Scientific Assistants became firmly established and in addition to the four-week Initial Synoptic

Assistant Courses a full programme of Advanced Synoptic Assistant Courses was held for the first time. These too are attracting overseas students and were successfully completed by observers from Bahrain and Kuwait.

Courses in Management at the Civil Service College, or at the Management Studies and Civilian Training Centres of the Ministry of Defence, were attended by 83 members of the staff. One Principal Scientific Officer attended the first National Defence College Course at the Joint Services College, Latimer.

Twenty-four new-entrant Technicians took the course in basic electronics at RAF Sealand and later, during a 6 months' course at Beaufort Park, received practical instruction in the servicing of equipments in use in the Meteorological Office. Part of the Beaufort Park course was attended by Technicians from Nigeria and Trinidad. Training in radiosonde operation is provided in the School attached to the upper air station at Hemsby, on the coast of Norfolk. The regular Initial, Advanced and Refresher Courses attracted students from Malaysia and Nigeria. A special course of instruction in the operation of the GRAW radiosonde was provided for staff of the British Antarctic Survey.

An overseas student sponsored by the United Kingdom under the Voluntary Assistance Programme of WMO successfully completed his Ph.D. studies at Reading University; eight entered the third year and two began the second year of the B.Sc. degree course in Meteorology, Mathematics and Physics. One student continued with his higher-degree studies. There were three new awards under the programme in 1971; two were for higher-degree studies at Reading University and one was for a postgraduate course at the Meteorological Office College to be followed by practical training.

The number of staff given release for part-time study, mainly at technical colleges rose to 299 during the year. In addition, some members of the staff received assistance under the further education scheme, a number taking advantage of the facilities of the Open University.

J. S. SAWYER
Director of Research

STATISTICS OF THE RESEARCH DIRECTORATE

TABLE XVI—LIBRARY AND ARCHIVES

Library

Items received, including duplicates but excluding daily weather reports	6 511
Individual books, pamphlets, articles and microfilms classified and catalogued	7 375
Transparencies acquired	506
Publications lent (excluding daily weather reports and internal 48-hour loans)	16 769
New agreements for exchange of publications	1
Total number of exchange agreements	375
Number of pages translated by Library translators	
Russian	2 311
German	410
French	118
Bulgarian	10
Spanish	9
Hungarian	8
Italian	6
Dutch	4
Icelandic	4
Number of pages translated by freelance translators	342
Total	3 222

Archives

Number of loans	2 310

TABLE XVII—TRAINING

The following figures give details of courses completed during 1971 at the Meteorological Office training establishments at Stanmore (and at Shinfield Park from 15 October), Hemsby, and Beaufort Park.

	Number of courses	Length of course in weeks	Number of students
Scientific Officers	1	28	13
Initial Forecasting	2	15	35
Advanced Forecasting	4	6	46
Extension Course	2	4	22
Senior Meteorologists	1	3	11
Basic Meteorology	2	4	38
Climatology	1	4	8
Tropical Meteorology	2	3	17
Mediterranean Meteorology	2	3	10
Advanced Instruments	3	2	30
Auxiliary and Voluntary Observers	3	1	49
Basic Assistants	2	4	11
Initial Assistants	10	4	108
Advanced Assistants	4	6	35
Radiosonde (Initial)	4	9	19
Radiosonde (Refresher)	1	5	4
Radiosonde (Advanced)	3	4	7
Radiosonde (British Antarctic Survey Special)	1	4	8
Radiosonde (GRAW-sonde Special)	3	1	6
Radiosonde (Overseas Postings Special)	2	2	2
Electronics (Beaufort Park)	1	23	12
Total			491

Students from the following territories attended courses which terminated during 1971.

	Number of students
Afghanistan	1
Antigua	1
Bahrain	6
Barbados	2
Belgium	2
Channel Islands	1
Cyprus	3
East Africa	8
Ethiopia	3
Fiji	1
Gibraltar	1
Greece	4
Hong Kong	7
Jordan	4
Malaysia	4
Malta	3
Mauritius	1
Netherlands	3
Nigeria	2
Singapore	1
Switzerland	3
Thailand	1
West Indies	3
Total	65

INTERNATIONAL CO-OPERATION

At the Sixth World Meteorological Congress which met in Geneva from 5 to 30 April 1971 Dr B. J. Mason, Director-General of the Meteorological Office, led the U.K. delegation, which included Mr D. Hanson, Secretary of the Meteorological Office, Mr D. G. Harley, Assistant Director (International and Planning), and Mr G. Needham, Met O 17, as well as Instructor Captain R. R. Fotheringham, DMOS(N), and representatives of the Water Resources Board and the Institute of Hydrology and of the United Kingdom Mission in Geneva. Mr J. S. Sawyer, Director of Research, attended as President of WMO's Commission for Atmospheric Sciences (CAS) and Mr L. P. Smith as President of the Commission for Agricultural Meteorology (CAgM). The Congress reviewed the general policies of the Organization and decided on its budget for the following 4 years.

During the first week of the Congress an international exhibition of meteorological instruments was mounted in the Palais des Nations. There were several British displays, including one from the Office staffed by Messrs D. G. Wilkinson and J. E. Wright of the Operational Instrumentation Branch.

The 23rd Session of the Executive Committee of WMO took place in Geneva from 3 to 7 May and was attended by Dr B. J. Mason accompanied by Mr D. G. Harley. The newly elected Committee was mainly concerned with the follow-up action on the decisions of Congress.

Following Congress a Conference of Commonwealth Meteorologists was held at Bracknell in the Meteorological Office Headquarters from 11 to 14 May. It was attended by 15 meteorologists, mostly Directors, from 12 Commonwealth countries and the Republic of Ireland. The Conference consisted of informal discussions on meteorological matters of common interest. Dr B. J. Mason, Mr P. J. Meade, Mr J. S. Sawyer and a number of staff took part. The Government gave a reception to delegates at Lancaster House.

Dr B. J. Mason took part in discussions of meteorological satellites with the directors of meteorological services in Europe and the U.S.A. in Washington in February and in Amsterdam in March. In February he took part in Geneva in the first session of the Tropical Experiment Council and the Tropical Experiment Board (TEB), being elected Chairman of the Board. He also presided over the second session of the TEB in Geneva in December. Mr R. F. Jones, Deputy Director (Physical Research), accompanied him at these meetings on the Tropical Experiment.

The XVth General Assembly of the International Union of Geodesy and Geophysics (IUGG), held in Moscow from 5 to 12 August, was attended by Dr B. J. Mason, Mr J. S. Sawyer, Dr R. Hide, Mr P. Goldsmith and Dr R. J. Murgatroyd.

The 100th anniversary of the Canadian Meteorological Service, now the Atmospheric Environment Service of Canada, was celebrated in Toronto in October with a symposium 'A history of meteorological challenges' and the opening of the new headquarters of the Service. Dr B. J. Mason, Mr J. S. Sawyer, Mr E. Knighting and Dr R. J. Murgatroyd took part. Earlier in October, Dr B. J. Mason attended in Lisbon the 25th anniversary of the National Meteorological Service of Portugal.

Mr J. S. Sawyer, Director of Research, is a member of the Joint Organizing Committee (JOC) for the Global Atmospheric Research Programme (GARP) and attended its 5th session in Bombay in February, and its 6th session in Toronto in October. He also represented the JOC at a two-day meeting in London in January of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU).

Several projects in the field of meteorology have been discussed between the members of the European Economic Community (EEC) and other European countries within the general scheme for Co-operation in Science and Technology (COST). Staff of the Office have served on the international groups studying these projects, which have met at the headquarters of the Commission for the European Communities in Brussels. The most important of these projects is that for the establishment of a European Medium Term Weather Forecasting Centre. The main functions of this International Centre would be to carry out research into techniques for preparing weather forecasts up to 10 days ahead and, when reliable techniques have been developed, to issue them to national meteorological services. Mr P. J. Meade, Director of Services, visited Brussels in June, August, October and December for the study of this project. Visits about other COST projects are listed below.

A number of staff from the Office took part in the WMO Technical Conference on the Uses of Meteorological Radar held at Church House, Westminster, from 1 to 10 September. The participants came from 46 countries. The Technical Director of the Conference was Mr R. F. Jones, Deputy Director (Physical Research), and the Executive Secretary was Mr G. Needham, Met O 17.

Two Technical Commissions of WMO met during the year, both in Geneva. The Commission for Aeronautical Meteorology (CAeM) met from 4 to 16 October. The U.K. delegation was led by Mr L. Sugden, Assistant Director (Public Services), and included Mr A. L. Johnson. Important topics discussed included the further development of the area-forecast system, the observation and forecasting of phenomena affecting aircraft landing, and future trends in the provision of meteorological services for aviation. The Commission for Agricultural Meteorology (CAgM) met from 18 to 30 October. Mr L. P. Smith attended as President of the Commission and the U.K. delegation was led by Dr R. W. Gloyne and included Mr C. V. Smith. The Commission paid particular attention to the economic aspects of its subject, in its influence on diseases of plants and animals, and in its importance in planning.

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*
CIMO Working Group on Satellite Instrumentation for Meteorology	Geneva February	Dr K. H. Stewart (Met O 19)
CMM Working Group on Sea Ice	Geneva March	Mr B. F. Bulmer (Met O 3)
Executive Committee Panel on Meteorology and Economic Development	Tunis May	Mr R. A. Buchanan (Met O 7)
CBS Meeting of Experts on GRID code form	Geneva May	Mr T. H. Kirk (Met O 2)
Assistance to GARP Joint Planning Staff	Geneva May	Mr G. A. Corby, Assistant Director (Dynamical Climatology)

Subject	*Place and date*	*Attended by*
CAgM Advisory Working Group	Geneva June	Mr L. P. Smith (Met O 8)
CHy Working Group on Hydrological Aspects of WWW	Geneva June	Mr J. Harding, Assistant Director (Agriculture and Hydrometeorology)
Consultant to the Interim Scientific Management Group of GATE	Geneva July	Mr D. H. Johnson (Met O 18)
Joint Organizing Committee of GARP Study Group Meeting	Norfolk, U.S.A. August	Mr G. A. Corby, Assistant Director (Dynamical Climatology)
WMO/IAMAP Symposium on Physical and Dynamical Climatology	Leningrad August	Mr A. Gilchrist (Met O 20)
CAS Working Group on Climatic Fluctuations	Geneva August–September	Mr H. H. Lamb (Met O 13)
Executive Committee Panel of Experts on Collection, Storage and Retrieval of Data for Research—Second Session	Geneva September	Mr E. J. Sumner, Assistant Director (Systems Development) Mr J. M. Craddock (Met O 13)
Informal Planning Meeting on the Use of Ship Radar during GATE	Oberpfaffenhofen, Germany September	Mr T. W. Harrold (Met O 15)
Fifth Session of Commission for Aeronautical Meteorology	Geneva October	Mr L. Sugden, Assistant Director (Public Services) Mr A. I. Johnson (Met O 7)
CBS Working Group on the Global Data Processing System	Geneva November–December	Mr T. H. Kirk (Met O 2)

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*
Republic of Ireland National Committee for Geodesy and Geophysics and IGOSS Study Group on Oceanographic Observations	Dublin January, March, May, November and December	Mr W. G. Durbin (Met O 7) (observer)
NATO Study Group	Washington January	Mr D. W. Tann (Met O 6)
Integration and launching of rocket payload	Canada January	Dr P. Ryder (Met O 19)
Symposium on Tropical Meteorology	Trivandrum, India January	Mr J. S. Sawyer, Director of Research
EEC COST Study Group on Oceanographic/Meteorological Buoys	Brussels January and February	Mr M. J. Blackwell, Assistant Director (Operational Instrumentation)
EEC COST Study Group on Meteorological Instruments	Brussels January and April	Mr G. A. Clift (Met O 16)
Republic of Ireland National Study Group on Evaporation and Evapotranspiration	Dublin February	Mr S. J. G. Partington (MetO 7) (observer)
SEATO Orientation Course	Bangkok February	Mr J. C. Gordon (MetO 6)
19th Meeting of the NATO AFCENT Meteorological Committee	Brunssum, The Netherlands February	Mr W. G. Harper (Met O 6) Mr F. J. Burton (Met O 6)

Subject	*Place and date*	*Attended by*
EEC COST Working Party on Meteorology and Oceanography	Brussels February and May	Mr M. J. Blackwell, Assistant Director (Operational Instrumentation)
EEC COST Study Group on Telecommunications for a European Centre for Medium Term Weather Forecasts	Brussels March	Mr R. A. Buchanan (Met O 7)
EEC COST Study Group on Economic Benefits of a European Centre for Medium Term Weather Forecasts	Brussels March, July and December	Mr R. A. Buchanan (Met O 7)
International Colloquium on the Exploitation of the Oceans	Bordeaux March	Mr P. J. Meade, Director of Services (representing WMO)
NASA 'Workshop on Satellite-Rocket Comparisons'	Wallops Is, U.S.A. March	Dr K. H. Stewart (Met O 19)
NOAA Discussions on TIROS N Project	Washington March	Dr K. H. Stewart (Met O 19)
NATO Advanced Study Institute—Mesoscale Dynamics	Exeter March–April	Mr J. S. Sawyer, Director of Research Dr D. J. Carson (Met O 14) Mr J. F. Keers (Met O 2) Mr A. Woodroffe (Met O 2) Dr D. G. James (MRF) Dr M. N. Hough (Met O 8) Dr A. J. Gadd (Met O 11) Dr P. W. White (Met O 11)
NATO Working Groups on Weather Communications and Weather Plans	Brussels March	Mr E. J. Bell (Met O 5) Mr D. W. Tann (Met O 6)
Meeting on Telecommunications Arrangements Copenhagen/Bracknell	Copenhagen March	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met O 5)
First European Earth and Planetary Physics Colloquium	Reading University March	Dr R. Hide (Head of Met O 21) Dr D. J. Acheson (Met O 21) Mr P. J. Mason (Met O 21) Mr H. A. Douglas (Met O 21) Mr E. J. Hinch (Met O 21)
Course on Fluid Mechanical Aspects of Pollution	Brussels March	Dr F. Pasquill (Head of Met O 14)
Symposium on the Biology of the Indian Ocean (Sponsored by SCOR/ICSU)	Kiel March–April	Mr D. H. Johnson (Met O 18)
Symposium on Four-Dimensional Data Assimilation for GARP	Princetown, U.S.A. April	Mr P. Graystone (Met O 11) Mr R. Dixon (Met O 2)
NATO Advanced Study Institute on Radio Meteorology	Norway April	Dr C. J. Readings (Met O 14)
Working Congress on Forecasting for Gliding	Zell-am-See, Austria April–May	Mr T. A. M. Bradbury (Met O 2)
NATO Nuclear, Biological and Chemical Prediction Systems Meeting	Hilversum April	Mr K. Bryant (Met O 6)
ESRO Study Groups for Ground Facilities for a Meteorological Satellite	Paris April, May, July, August, September and October	Mr D. E. Miller (Met O 19)
NATO Advisory Group on Meteorology	Brussels May	Mr J. S. Sawyer, Director of Research (Chairman)
Radiometer Intercomparison, International Conference of the Solar Energy Society	Washington, U.S.A. May	Mr R. H. Collingbourne (Met O 1)

Subject	*Place and date*	*Attended by*
RAeS/CASI/AIAA Conference on Atmospheric Turbulence	London May	Mr R. F. Jones, Deputy Director (Physical Research) Dr K. A. Browning (Met O 15) Dr W. T. Roach (Met O 9) Mr J. M. Nicholls (Met O 9) Mr D. N. Axford (MRF)
ICAO European Advisory Committee on North Atlantic Ocean Stations	Paris May	Captain G. A. White (Marine Superintendent)
Environmental Symposium of the International Commission for Northwest Atlantic Fisheries	Dartmouth, Canada May	Mr H. C. Shellard (Met O 3)
ESRO Interim Applications Programme Committee Meeting	Paris May	Dr K. H. Stewart (Met O 19)
NATO NBC Operational Procedures Inter-service Working Party	Cologne May	Mr K. Bryant (Met O 6)
NATO Military Committee Meteorological Group	Brussels May	Mr P. J. Meade, Director of Services Mr E. Evans (Met O 6) Mr D. W. Tann (Met O 6)
EEC COST Atlantic Regional Group on Oceanographic/Meteorological Buoys	Paris May	Mr G. A. Clift (Met O 16)
COSPAR 14th Plenary Meeting	Seattle June–July	Mr E. Knighting, Deputy Director (Dynamical Research)
Symposium on the Development of the Resources of Ireland	Dublin June	Mr W. G. Durbin (Met O 7)
Discussions on Pollution Aspects of SST Operation	Paris June	Mr P. Goldsmith, Assistant Director (Cloud Physics)
OECD Planning Group on Long-range Transport of Air Pollutants	Paris June	Dr F. Pasquill (Head of Met O 14)
ESRO *ad hoc* Group on Satellite Meteorology	Zurich June	Dr K. H. Stewart (Met O 19)
ESRO Sub-Group on Meteorological Requirements	Rome June	Dr K. H. Stewart (Met O 19)
NOAA Conference on Modelling Urban Boundary Layer Dynamics	Oak Ridge, U.S.A. June	Dr F. B. Smith (Met O 14)
NATO *ad hoc* Working Party on Weather Communications	Cologne June	Mr E. J. Bell, Assistant Director (Telecommunications)
Symposium on Grain Storage	Winnipeg June	Mr C. V. Smith (Met O 8)
Informal U.K./German/Dutch/Belgium Working Group on North Sea Ocean Data Stations	De Bilt, The Netherlands June	Mr M. J. Blackwell, Assistant Director (Operational Instrumentation)
NATO Summer School in Geophysical Fluid Dynamics	Bangor June	Mr P. J. Mason (Met O 21)
NATO Advanced Study Institute—Geophysical Fluid Dynamics	Bangor July	Dr P. White (Met O 11)
Meeting on Implementation of Main Trunk Circuit, Washington/Bracknell Segment	Washington August	Mr R. K. Pilsbury (Met O 5) Mr R. Ross (Met O 5)
3rd International Conference on Wind Effects on Buildings and Structures	Tokyo September	Mr N. C. Helliwell (Met O 3)
ICAO SST Panel	Montreal September	Mr A. I. Johnson (Met O 7)
ESRO Interim Applications Programme Committee — Presentation on METEOSAT	Toulouse September	Dr K. H. Stewart (Met O 19)

Subject	*Place and date*	*Attended by*
Meeting on Implementation of Main Trunk Circuit, Bracknell/Paris Segment	Paris September	Mr E. J. Bell, Assistant Director (Telecommunications) Mr R. Ross (Met O 5)
NATO AFCENT Meeting on Meteorological Telecommunications	Wiesbaden September	Mr C. E. Goodison (Met O 5)
Meeting on Telecommunications Arrangements Offenbach/Bracknell	Offenbach September	Mr C. E. Goodison (Met O 5)
UNESCO Panel on Hydrological Information	Paris September	Mr A. Bleasdale (Met O 8)
Automation of Weather Communications	Wiesbaden September	Mr C. E. Goodison (Met O 5) Mr F. J. Burton (Met O 6)
NATO Meteorological Panel	Brussels September	Dr P. G. F. Caton (Met O 6) Mr C. V. Else (Met O 16)
9th Meeting of NATO ACEWEX Working Group	Wiesbaden September	Mr W. G. Harper (Met O 6) Mr F. J. Burton (Met O 6)
NATO Long-term Scientific Study on Arctic Conditions	Oslo October	Mr J. Briggs (Met O 9) Mr D. W. Rhead (Met O 6)
7th Regular Session of the Intergovernmental Maritime Consultative Organization	London October	Captain G. A. White (Marine Superintendent) (WMO Representative)
ESRO Sub-Group on METEOSAT	Frankfurt October	Dr K. H. Stewart (Met O 19)
Symposium on Climatic Change in the Arctic during the Last 10 000 Years	Oulu, Finland October	Mr H. H. Lamb (Met O 13)
NATO Working Groups on Weather Plans and Weather Communications	Munich October	Mr E. J. Bell, Assistant Director (Telecommunications) Mr D. W. Tann (Met O 6)
Meeting on Implementation of the Four Centres Washington/Bracknell/Paris/Offenbach on the Main Trunk Circuit	Bracknell October	Mr E. J. Bell, Assistant Director (Telecommunications) Mr R. K. Pilsbury (Met O 5) Mr C. E. Goodison (Met O 5)
NATO Weather Sub-Group Meeting	London October	Mr D. W. Tann (Met O 6)
NATO Technical Weather Network Meeting	Hilversum October	Mr W. G. Harper (Met O 6) Mr F. J. Burton (Met O 6)
Installation of APT set, provided through VAP	Addis Ababa October	Mr P. Bradley (Met O 16)
EUROCON 71. Conference on information processing in large systems	Lausanne October	Mr N. Bradbury, Assistant Director (Data Processing)
ICAO 6th European Mediterranean Navigation Meeting	Geneva November	Mr C. Hinkel (Met O 7)
International Standards Organization Working Group on Standard Atmospheres	London November	Mr J. Briggs (Met O 9)
NATO North Sea Science Conference	Aviemore November	Mr H. H. Lamb (Met O 13)
Survey of Computer-driven Chart Plotters and Line Drawers	Washington November	Mr R. F. Zobel, Assistant Director (Central Forecasting) Mr N. Bradbury, Assistant Director (Data Processing)
NATO Planning Conference	Rheindahlen November	Mr M. K. Miles (Met O 2) Mr W. G. Harper (Met O 6) Mr F. J. Burton (Met O 6)
NATO NBC Prediction System Meeting	Bracknell November	Mr K. Bryant (Met O 6)
Installation of APT set, provided through VAP	Jordan November	Mr P. Bradley (Met O 16)
NATO Civil Defence Meeting	Copenhagen December	Mr K. Bryant (Met O 6)

Subject	*Place and date*	*Attended by*
Meeting on Temperature Measurements by Concorde	Toulouse December	Mr M. H. Freeman, Assistant Director (Special Investigations)
Meeting on Telecommunications Arrangements Offenbach/Bracknell	Offenbach December	Mr R. K. Pilsbury (Met O 5) Mr R. Ross (Met O 5)
NATO MCMG Working Group Weather Communications *ad hoc* Working Party	Porz Wahn (Cologne) December	Mr E. J. Bell, Assistant Director (Telecommunications)

Visits abroad to give lectures were made by Dr R. Hide to U.S.A. in February and October, and by Mr A. Gilchrist to Canada and U.S.A. in October.

The following members of the staff were released during the year to take up international appointments overseas:

Mr E. P. Ward	Telecommunications Technical Officer II	Seconded in January to Scientific Research Council, Slough, and in March proceeded to Falkland Islands
Mr B. Dyson	Higher Scientific Officer	Seconded in January to East Africa, through Overseas Development Administration
Mr G. V. Clark	Higher Scientific Officer	Seconded in February to East Africa, through Overseas Development Administration
Mr J. C. R. Kidd	Higher Scientific Officer	Seconded in February to East Africa, through Overseas Development Administration
Mr M. G. Waller	Higher Scientific Officer	Seconded in February to East Africa, through Overseas Development Administration
Mr M. J. Kerley	Higher Scientific Officer	Seconded in March to East Africa, through Overseas Development Administration
Mr J. Findlater	Senior Scientific Officer	Seconded in March to East Africa, through Overseas Development Administration
Mr B. J. Burton	Telecommunications Technical Officer II	Seconded in July to New Hebrides, through Overseas Development Administration
Mr G. Nicholl	Higher Scientific Officer	Seconded in September to the Singapore Meteorological Service
Mr M. H. Lloyd	Higher Scientific Officer	Seconded in September to the Singapore Meteorological Service
Mr G. Hunt	Senior Scientific Officer	Released in October to Jet Propulsion Laboratory, U.S.A.
Mr R. Williams	Higher Scientific Officer	Released in December to International Aeradio Limited, Bahrain
Mr J. S. Parsons	Scientific Officer	Released in December to International Aeradio Limited, Bahrain

The following staff returned to the Office from appointments overseas:

Mr. B. Ramsey	Senior Scientific Officer	from East Africa
Mr H. W. Jones	Scientific Officer	from Zambia
Mr R. F. Johnson	Higher Scientific Officer	from the Falkland Islands
Mr F. D. Wilmot	Higher Scientific Officer	from the Bahamas
Mr L. S. Birch	Senior Scientific Officer	from the Bahamas

STAFF

GENERAL

The names of the principal officers of the Meteorological Office are listed on pages x–xi and the organization of the Office is shown in the diagram on page xii. At the end of 1971 the total number of posts of all grades was 3710, an increase of 2 over the year. The actual strength at the end of the year, including Research Fellows, was made up as follows:

Science Group	
Chief Scientific Officers	3
Deputy Chief Scientific Officers	8
Senior Principal Scientific Officers	25
Principal Scientific Officers (includes former Chief Experimental Officers)	108
Principal Research Fellows	2
Senior Scientific Officers (includes former Senior Scientific Officers and Senior Experimental Officers)	285
Higher Scientific Officers (formerly Experimental Officers)	484
Scientific Officers (includes former Scientific Officers, Assistant Experimental Officers and Senior Scientific Assistants)	536
Assistant Scientific Officers (formerly Scientific Assistants)	1067

The new structure for Civil Service scientists was introduced on 1 October 1971. The above 'Science Group' now includes staff formerly graded under the Scientific Officer Class, the Experimental Officer Class and the Scientific Assistant Class.

Administration Group	
Assistant Secretary	1
Principal	1
Executive Grades	25
Clerical Grades	159
Marine Staff	
Marine Superintendent	1
Nautical Officer Grades	10
Ocean Weather Ships and Base	
Officers and non-industrial grades	98
Crew	109
Technical and Signals Grades	319
Typing and miscellaneous non-industrial grades	187
Industrial employees	99
Locally entered staff and employees overseas	139

Full manning has continued in the Scientific Officer and Experimental Officer classes throughout 1971 and there has been no difficulty in replacing the normal wastage. The high standard of recruitment into the Scientific Officer class has been more than maintained and there has been a slight increase in the number of graduates in the Experimental Officer class. As always, there has been a large wastage of Scientific Assistants but it was noticeable that during the autumn losses fell off markedly while applications for appointment increased by some 25 per cent. This has resulted in our reaching the best manning position for many years and by the end of 1971 the grade was virtually at the full allowed strength.

The technician class remained comfortably manned throughout 1971.

During the year, 7 college-based Sandwich Course students spent their extra-college periods working in the Office. Study concessions at various levels were enjoyed by 282 members of the staff, their time totalling 1715 course hours per week. A total of 6 university undergraduates were chosen to work in the Office during the long vacation while 2 'vacation consultants' from universities contributed to the work of the Office during the year.

HONOURS AND DISTINCTIONS

Mr A. A. Worthington was awarded the O.B.E.

Dr R. Hide was elected a Fellow of the Royal Society on 18 March.

The L. G. Groves Memorial Prize for Meteorology was awarded to Mr H. H. Lamb.

The Director-General gave the Bakerian Lecture to the Royal Society on 18 November.

Mr J. S. Sawyer received the Symons Memorial gold medal for 1971 from the Royal Meteorological Society.

The 1971 L. F. Richardson prize was awarded jointly to Dr A. J. Gadd and Mr J. F. Keers and the 1971 Darton prize was awarded to Dr W. T. Roach by the Royal Meteorological Society.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

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PARKER, B. N., *see* LAMB, H. H. and PARKER, B. N.

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RITCHIE, W. G., *see* PARREY, G. E., RITCHIE, W. G. and VIRGO, S. E.

RUMNEY, R. P., *see* HURST, G. W. and RUMNEY, R. P.

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SPACKMAN, E. A., *see* DIXON, R. and SPACKMAN, E. A.

SPARKS, W. R. and KEDDIE, BARBARA, B.Sc.; A note on the optimum averaging time of wind information for conventional aircraft landings. *Met Mag, London,* **100,** 1971, pp. 129–134.

STUBBS, M. W., *see* WRIGHT, P. B. and STUBBS, M. W.

TAYLOR, A. P., B.Sc., *in* LIMBERT, D. W. S. and TAYLOR, A. P.; An evaluation of the phosphorous pentoxide electrolytic hygrometer. *J Phys, E, J Scient Instrum, London,* Ser 2, **4,** 1971, pp. 571–574.

TIMPSON, MARGARET S., *see* BENWELL, G. R. R., GADD, A. J., KEERS, J. F., TIMPSON, MARGARET S. and WHITE, P. W.

TYLDESLEY, J. B., B.A.; Fifty years at Lerwick Observatory. *Met Mag, London,* **100,** 1971, pp. 173–179.

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WRIGHT, P. B., B.Sc.; Early reversal of the Indian Ocean circulation in 1956. *Met Mag, London,* **100,** 1971, pp. 187–188.
WRIGHT, P. B., B.Sc.; An erroneous use of the chi-square test. *Met Mag, London,* **100,** 1971, pp. 301–303.
WRIGHT, P. B., B.Sc.; Spatial and temporal variations in seasonal rainfall in south-western Australia. *Misc Publ, Univ West Aust, Inst Agric, Agron Dep, Perth,* 71/1, 1971.
WRIGHT, P. B., B.Sc., and STUBBS, M. W., B.Sc.; Circulation patterns at 850, 700, 500 and 200 millibars over the eastern hemisphere from 40°N to 40°S during May and June. *Geophys Mem, London,* **15,** No. 114, 1971.

APPENDIX II

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

ACHESON, D. J., M.Sc., Ph.D.
Slow hydromagnetic waves and critical layers. *First European and Planetary Physics Colloquium, Reading University.* 31 March.
Some aspects of hydromagnetic waves in rapidly rotating fluids. *Imperial College, London.* 26 November.

ADAMS, R. J., M.Sc.
Development of a holographic technique for sizing particles in moving aerosols. *Inter/Micro 71 Conference, Imperial College, London.* 20 September.

BANNON, J. K., I.S.O., B.A.
Measuring rainfall by radar. *Conference of River Authority Engineers, Cranford.* 22 September.

BARTLETT, J. T., Ph.D.
Cloud physics. *The Physical Society, Queen Mary's College, London.* 28 January.
Cloud physics. *Course of 20 lectures to 2nd year undergraduates and M.Sc. students, Department of Geophysics, University of Reading.* October 1970 to March 1971.

BENWELL, G. R. R., M.A.
Numerical weather prediction.
Honeywell Users Association (U.K.), Killarney. 1 May.
Cheltenham Branch of the British Computer Society. 16 November.
Weather forecasting. *Edinburgh Branch of the British Computer Society.* 6 October.

BORRETT, P. D.
Use of radar in forecasting. *WMO Technical Conference on the use of meteorological radar, London.* 6 September.

BROWNING, K. A., Ph.D., D.I.C.
Studies of lee waves, clear-air turbulence and convection by high-power radar.
Electronics Research Committee at the Royal Radar Establishment, Malvern. 3 January.
Imperial College, London. 18 March.
Royal Society Conversazione, London. 6 May.
Radar measurements of airflow in the vicinity of fronts. *NATO Advanced Study Institute, University of Exeter.* 30 March.
Observations of shearing and other instabilities in the atmosphere. *NATO Summer School on Geophysical Fluid Dynamics, Bangor.* 6 July.
Studies of clear-air echoes using the Defford radar. *WMO Technical Conference on the use of meteorological radar, London.* 7 September.
Radar measurements near fronts. *WMO Technical Conference on the use of meteorological radar, London.* 7 September.
Studies of the structure and motion of the clear atmosphere using the high-power Defford radar.
Royal Radar Establishment, Physics and Electronics Department Seminar, Malvern. 14 October.
Department of Geophysics, Reading University. 15 October.

BROWNSCOMBE, J. L., Ph.D.
Ice accretion on parked aircraft. *Atmospheric Environment Committee of the Aeronautical Research Council, London.* 19 October.

BRYANT, K.
Effect of meteorological parameters on nuclear fallout. *Royal Observer Corps, Blackpool,* 13 February; *and Lancaster,* 4–5 September.
Effect of meteorological parameters on nuclear and biological prediction. *Home Office (Sector Scientists), Bath.* 13–14 March.

BUCHANAN, R. A., M.A.
Weather forecasting for industry. *University College of Wales, Aberystwyth, Symposium on Weather Forecasting for Agriculture and Industry.* 17 March.

BUSHBY, F. H., B.Sc.
Numerical methods of weather forecasting. *The Archimedeans, Cambridge University Mathematical Society.* 29 January.

COLGATE, M. G., B.Sc.
Some aspects of long-range rainfall forecasting. *Meeting of local statisticians, Reading University.* 22 September.

CRADDOCK, J. M., M.A.
Urban development and its effects on the local temperature régime. *Annual Conference of the Institute of Statisticians, Nottingham.* 10 July.
The use of a digitized data bank in statistical meteorology. *Edinburgh group of the Royal Statistical Society.* 16 November.

DALTON, F.
Meteorology. *Course of* 12 *lectures to the Workers Educational Association, High Wycombe.* 29 September–15 December.

DEEKS, P. H. G.
Meteorology for mariners. *School of Navigation, Poplar Technical College, London.* 15 July.
Meteorology for the construction industry. *South-East London Technical College.* 14 July.

DIXON R., B.Sc.
The global analysis of meteorological data using orthogonal base functions. *International Symposium on Four-dimensional Data Assimilation for GARP, Princeton, N.J.*, 20 April.

DORRELL, A. T. and MACKIE, G. V.
Weather routeing of ships. *Royal Meteorological Society, Welsh Centre, Cardiff.* 18 November.

DURBIN, W. G., B.Sc.
Meteorological services for the construction industry. *Federation of Building Trades Employers of Northern Ireland, Dunmurray, Co. Antrim.* 19 October.

EBDON, R. A.
Equatorial stratospheric winds. *Symposium on Equatorial Currents in Atmospheres and Oceans, London.* 21 May.

EVANS, D. C.
Forecasting for North Atlantic flights. *Royal Aeronautical Society, Glasgow Branch.* 12 January.

FOORD, H. V.
*Contribution to BBC*1 *TV programme 'War on the Weather'.* 7 April.

FREEMAN, M. H., O.B.E., M.Sc.
Developments in weather forecasting. *Guildford Forum.* 10 March.

GADD, A. J., Ph.D.
Mathematics in meteorology.
Mathematics course at Thames Polytechnic, London. 10 March.
6th Form Careers Conference at Bath University of Technology. 6 July.
Prediction problems in meteorology. *Numerical Fluid Dynamics Course at University of Reading.* 21 May.
Some aspects of the 10-level model. *Department of Geophysics, University of Reading.* 10 June.

GILCHRIST, A., M.A.
General circulation research in the Meteorological Office. *Clarendon Laboratory, Oxford.* 17 June.
Lectures on general circulation research. (NATO lecture tour.)
Canadian Meteorological Society, Montreal. 5 October.
McGill University, Montreal. 7 October.
Air Force Cambridge Research Laboratories, Bedford, Mass. 13 October.
Massachusetts Institute of Technology, Cambridge, Mass. 14 October.
Geophysical Fluid Dynamics Laboratory, Princeton University, N.J. 18 and 19 October.
National Meteorological Center, Washington, D.C. 22 October.
National Center for Atmospheric Research, Boulder, Colorado. 28 October.

GOLDSMITH, P., M.A.
Cloud, rain and rainmaking. *The Ulster Society, Oxford.* 14 April.
Stratospheric pollution and supersonic transport.
Atmospheric Environment Committee of the Aeronautical Research Council, London. 21 July.
Fluid Dynamics Panel of AGARD, NATO, London. 9 September.
The role of air pollutants in cloud and precipitation processes. *International Commission on Atmospheric Chemistry and Radioactivity, IAMAP meeting in Moscow.* 11 August.
Physics of rain formation. *Blackheath Scientific Society, London.* 26 November.
Cloud particle growth. *Department of Meteorology, Imperial College, London.* 2 December.
Current problems in cloud physics. *Wills Physics Society, Bristol University.* 13 December.

GRAYSTONE, P., B.A.
Computational and mathematical aspects of weather forecasting. *Joint meeting of the Hull and East Riding Branch of the British Computer Society, the Hull University Centre for Computer Studies and the Hull Branch of the Mathematical Association.* 8 December.

HAMILTON, R. A., O.B.E., M.A., F.R.S.E.
Rocket and satellite observations of stratospheric warmings. *Discussion meeting of the Royal Astronomical Society and the Institute of Physics, London.* 26 November.

HARROLD, T. W., B.Sc., D.I.C.
The quantitative measurement of precipitation using radar. *WMO Technical Conference on the use of meteorological radar, London.* 9 September.

HAWSON, C. L., B.A.
Weather and supersonic transport. *Bristol Branch of the Royal Aeronautical Society.* 23 November.

HELLIWELL, N. C., B.Sc.
Weather loading of structures. *Institution of Structural Engineers, Northern Ireland, Belfast.* 5 January.
Wind over London. *Third International Conference on Wind Effects on Buildings and Structures, Tokyo.* 6 September.
Wind loading on buildings. *Brixton School of Building, London.* 17 November.
Meteorological aspects of wind loading. *Building Research Station Educational Seminar, Garston.* 7 December.

HIDE, R., Sc.D.
Dynamics of planetary atmospheres. *Lowell Observatory, Flagstaff, Arizona.* 3 February.
Planetary magnetic fields.
Royal Society Planetary Sciences Study Group, London. 16 February.
Oxford University. 12 October.
Motions in planetary atmospheres.
University of Surrey, Guildford. 4 March.
Scottish Centre of the Royal Meteorological Society. 10 December.
(1) Baroclinic waves, (2) The giant planets, (3) Motions in the Earth's core, (4) Geostrophic motions of a non-homogeneous fluid, (5) Novel correlations between the Earth's gravitational and magnetic fields. *First European Earth and Planetary Physics Colloquium, Reading University.* 30 March–2 April.
Magnetohydrodynamics of rotating fluids. *Leeds University.* 21 April.
Jupiter, the other magnetic planet. *BBC1 TV programme 'The sky at night'.* 27 April.
The rotation of the Earth and Jupiter. *Manchester University.* 5 May.
Planetary atmospheres. *Hull University.* 6 May.
Baroclinic waves.
Atomic Energy Research Establishment, Culham Laboratory, Abingdon. 12 May.
NATO Study Institute, Bangor. 14 July.
Imperial College, London. 21 July.
Equatorial currents on Jupiter and Saturn. *Royal Astronomical Society, London.* 21 May.
(1) Dynamics and structure of the Earth's deep interior, (2) The interiors of the giant planets, (3) Motions in planetary atmospheres, (4) Recent work on correlations between the Earth's gravitational and magnetic fields. *IUGG General Assembly, Moscow.* 9–14 August.
Meteoroids and the Moon's magnetism. *Lunar Geophysics Conference, Houston, Texas.* 21 October.
The Earth's core-mantle interface.
Massachusetts Institute of Technology, Cambridge, Mass. 22 October.
Cambridge University. 26 November.

JAMES, D. G., Ph.D.
Mesoscale motions near a warm front over the sea. *NATO Advanced Study Institute, University of Exeter.* 31 March.

JENKINSON, A. F., I.S.O., M.A.
Rainfall analysis for the United Kingdom flood studies. *Conference of River Authority Engineers, Cranfield.* 22 September.

JOHNSON, D. A., Ph.D.
Charge separation due to riming in thunderstorms. *Department of Meteorology, Imperial College, London.* 4 March.
Charge separation associated with riming in an electric field. *Royal Meteorological Society, London.* 16 June.

JOHNSON, D. H., M.Sc., D.I.C.
The value of satellite data in tropical meteorology. *Bristol University.* 23 February.
Recent satellite studies. *Symposium on the Biology of the Indian Ocean, Kiel.* 31 March.
The GARP Tropical Experiment. *Reading University.* 25 August.

JONAS, P. R., Ph.D., D.I.C.
The numerical simulation of particle motion in a homogeneous field of turbulence. *Institute of Physics, Computational Physics Group, London.* 15 December.

KEERS, J. F., B.Sc.
Computers in meteorology. *Leicester Branch of British Computer Society.* 12 January.

KIRK, T. H., B.Sc.
Extraordinary weather conditions in Italy, 5–9 March 1971. *Broadcast on Radio Italiana.* 9 March.

KNIGHTING, E., B.Sc.
Weather forecasting, satellites and computers. *Hull Physics Centre, Hull University.* 25 March.

LAMB, H. H., M.A.
The changing climate of Britain. *Wokingham Natural History Society.* 2 February.
The new look of climatology. *Cambridge University Geographical Society.* 17 February.

LEAF, G. G., B.Sc.
Contribution to BBC Radio 4 programme 'How we do the Weather Forecast'. 2 January.

McKELLER, H. A.
Contribution to BBC Scotland Radio 4 programme 'Weather over Scotland'. 22 January.

MASON, B. J., D.Sc., F.R.S.
Weather forecasting in the satellite and computer age.
School Scientific Society, St Paul's School, London. 22 January.
Natural Philosophical Society of the Manchester Literary and Philosophical Society, Manchester University. 27 January.
Closing Session of DATAFAIR, Albert Hall, Nottingham. 2 April.
Future developments in meteorology: an outlook to the year 2000. *Royal Meteorological Society (Manchester Branch) and the Geographical Association (Manchester Branch), Manchester.* 28 January.
Numerical weather prediction. *Cambridge Branch of the Mathematical Association, Cambridge.* 12 February.
Global Atmospheric Research Programme. *First European Earth and Planetary Physics Colloquium, Reading University.* 30 March.
Use of Computers in research and weather forecasting. *London Branch of the British Computer Society, University College, London.* 20 May.
The future of weather forecasting and meteorological services to the public. *Public Lecture, County Museum, Lerwick.* 15 June.
The interaction of microphysical and dynamical processes in clouds. *Fifteenth General Assembly of the International Union of Geodesy and Geophysics, Moscow.* 10 August.
The physics of clouds and precipitation (in retrospect and prospect). *Special Symposium 'A history of meteorological challenges' to mark the 100th Anniversary of the Canadian Meteorological Service, Toronto.* 26 October.
The Global Atmospheric Research Programme and the United Kingdom's participation. *A Meeting for Discussion, organized jointly by the Royal Society and the Royal Meteorological Society, Royal Society, London.* 17 November.
The physics of the thunderstorm. *The Bakerian Lecture, Royal Society, London.* 18 November.

MASON, P. J., B.Sc.
Effects of rotation on natural convection. *Symposium on Natural Convection and Crystal Growth, University of Birmingham.* 5 April.
Experiments on thermal convection due to a moving internal heat source. *First European Earth and Planetary Physics Colloquium, University of Reading.* 30 March.
Sloping convection in a container with sloping end walls. *NATO Summer School in Geophysical Fluid Dynamics, Bangor.* 29 June.

MAULE, A. G.
Weather routeing procedures in the United Kingdom. *WMO Ship's Routeing Symposium, Olympia, London.* 16 July.

MEADE, P. J., O.B.E., B.Sc.
Meteorology for industry. *Margary Lecture, Royal Meteorological Society, London.* 3 November.

MILLER, D. E., B.A.
Attitude behaviour of a parachute-sonde deployed from SKUA 2. *South Uist Colloquium, Southampton University.* 25 May.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.
Equatorial currents in the atmosphere. *Joint meeting Royal Meteorological Society/Royal Astronomical Society, London.* 21 May.
Upper atmosphere meteorology. *Symposium on a History of Meteorological Challenges, Centenary of Canadian Meteorological Service, Toronto.* 27 October.

NICHOLASS, C. A., B.Sc.
Dee Weather Radar Project. '*Wales Today*' *BBC1 TV interview.* 5 July.

NICHOLLS, J. M., B.Sc.
Measurements of stratospheric airflow and clear-air turbulence up to 63 000 ft over and downwind of mountainous terrain. *RAeS/AIAA/CASI International Conference on Atmospheric Turbulence, London.* 18 May.

OGDEN, R. J., B.Sc.
Weather forecasting. *Junior British Association, University of Sussex.* 15–16 July.
The work of the London Weather Centre. *Recorded interview for the External Service of Finnish Radio.* 11 January.
Physics and meteorology. *Sir John Cass Physical Society, City of London Polytechnic.* 8 February.

PARKER, G. H., B.Sc.
Contribution to BBC1 TV programme on tornadoes. 25 January.
Meteorology. *Course of 13 lectures to Adult Evening Institute, Chiswick.* September–December.

PASQUILL, F., D.Sc.
The application of meteorology to air pollution problems. *The von Kármán Institute of Fluid Dynamics, Brussels.* 22 March.
Atmospheric dispersion of pollution. *Presidential address to the Royal Meteorological Society, London.* 21 April.

PETTIFER, R. E. W., B.Sc.
Meteorology for the layman. *Six lectures, Adult Education Course, South-East Berkshire College of Further Education, Bracknell.* 20 September–1 November.

READINGS, C. J., Ph.D., D.I.C.
Atmospheric probing using a tethered balloon. *NATO Advanced Study Institute, Skeikamten, Norway.* 21 April.
Some comments on making measurements of wind and temperature in the atmosphere. *NATO Advanced Study Institute, Skeikamten, Norway.* 22 April.

ROACH, W. T., Ph.D., D.I.C.
The influence of synoptic development on the production of clear-air turbulence. *Royal Aeronautical Society Conference on Atmospheric Turbulence, London.* 19 May.

SAWYER, J. S., M.A., F.R.S.
Problems and promise of numerical dynamics applied to mesometeorology. *NATO Advanced Study Institute, University of Exeter.* 29 March.
Effect of man's activity on climate.
Canadian Meteorological Society, Toronto. 20 October.
Clean Air Conference, Folkestone. 5 November.
Discussion meeting of the Royal Meteorological Society on Man's Effect on the Atmosphere, London. 15 December.
The strategy of the GARP programme as seen in 1971. *Royal Society/Royal Meteorological Society joint meeting on U.K. contribution to GARP, London.* 17 November.

SPALDING, T. R.
Course of six lectures on elementary meteorology. *Workers Educational Association, Wokingham.* September–October.
STARR, J. R., Ph.D., D.I.C.
Why does it rain?
South Worcestershire Teachers Association, Worcester. 5 January.
Dyson Perrins High School, Malvern. 17 February.
Malvern University Women's Association, Malvern. 22 March.
Twenties Club, Worcester. 24 March.
University College of Wales, Aberystwyth. 2 November.
Understanding the weather. *Six evening classes, Technical College, Worcester.* March–May.
STEWART, K. H., Ph.D.
Meteorological satellites. *University Extension Lecture at Croydon.* 2 February.
Royal Aeronautical Society Symposium, London. 13 October.
WHITE, P. W., Ph.D.
Initialization problems in meteorology. *Numerical Fluid Dynamics Course, University of Reading.* 21 May.
WOODS, J. D., Ph.D.
Divers in physical oceanography. *University of Cambridge.* 29 January.
Oceanography. *Science Society of Ranelagh School, Bracknell.* 22 February.
Fronts in the thermocline as a factor in sonar propagation. *Admiralty Underwater Weapons Establishment, Portland.* 24 May.
Diffusion as a factor in pollution models. *International Conference 'Pacem in Moribus', Malta.* 2 July.
Weather under the sea. *Woods Hole Oceanographic Institution, Woods Hole, Mass.* 31 August.
The diver's role in physical oceanography. *Science Symposium of the World Underwater Federation, Santiago, Chile.* 9 September.

APPENDIX III

PUBLICATIONS

The publications prepared by the Meteorological Office are generally issued by Her Majesty's Stationery Office as official publications. A complete list, showing the prices at which they can be purchased through any of the sales offices or usual agents of Her Majesty's Stationery Office, is sent free to any applicant.

The following publications were issued during the period of this Report:

PERIODICAL

Annual Report on the Meteorological Office 1970.
Daily Aerological Record containing information in respect of meteorological conditions in the upper air for the British Isles (to 22 December 1971).
Daily Weather Report containing weather maps for the northern hemisphere, British Isles, etc., and data (to 31 December 1971).
Daily Weather Report, Overseas Supplement containing surface and upper air data (to 20 October 1970).
Monthly Summary of the *Daily Weather Report* (to November 1971).
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 (to 15 December 1971).
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 (to 16 December 1971).
Monthly (coloured) Ice Maps (to January 1971).
Ten-day Ice Maps (to 31 December 1971).
Meteorological Magazine (monthly) (to December 1971).
Monthly Weather Report (to March 1971).
Marine Observer (quarterly) (to October 1971).

SERIAL

Geophysical Memoirs:
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