METEOROLOGICAL OFFICE

ANNUAL REPORT 1967

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ANNUAL REPORT
ON THE
METEOROLOGICAL OFFICE

1967

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

LONDON
HER MAJESTY'S STATIONERY OFFICE
1968

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FOREWORD BY THE DIRECTOR-GENERAL

The most important meteorological event of 1967, and one likely to dominate our thinking for many years to come, took place during the Fifth Congress of the World Meteorological Organization when the 122 Member States voted unanimously to support the World Weather Watch and agreed on its implementation during the first four-year period 1968–71. This imaginative programme seeks to establish a global system of improved meteorological observations, communications and data-processing facilities with the object of improving our knowledge and understanding of the global behaviour of the atmosphere and of producing weather forecasts of greater reliability and range. Almost every country is expected to participate and contribute but special responsibility rests with the larger and more-advanced weather services, not only to implement the necessary facilities, but to help developing countries take advantage of the improved data and forecasts that will result. The government has agreed to contribute about £2·5–3 million over the four years to establish up to five new upper air stations outside the United Kingdom, to make radiosonde ascents from up to ten merchant ships, to recruit an additional two hundred ships to our voluntary observing fleet, to provide free training for meteorologists from developing countries, to donate equipment and services to these countries, and to contribute to the WMO Voluntary Assistance Fund. In addition Bracknell will become both a Regional Meteorological Centre and a Regional Telecommunications Hub with major responsibilities for western Europe and the North Atlantic area.

These and other rapidly growing developments in meteorology will call for a major effort from the Meteorological Office over the next few years but, by pressing ahead with our programme of modernization and automation, we should be able to meet our increasing national and international responsibilities, expand our services to industry, and take full advantage of the World Weather Watch without major increases in staff. To this end much effort has been devoted to the preparation of a detailed plan for the Office for the next five years.

Meanwhile our current operational and research activities have continued to grow. During the year under review the number of forecasts issued for aviation rose by 5 per cent to a total of 1·34 million, partly as a result of the Office at London (Heathrow) Airport becoming an Area Forecast Centre responsible for the route forecasting of all flights leaving Europe for North America and the Caribbean. Despite the very mild winter and dry summer the number of inquiries received from industry and the general public rose again to a record total of 1·26 million.

In connexion with the opening of a new Weather Centre in Newcastle, the Central Office of Information arranged for a market survey to assess the potential demand and value of meteorological services to industry in the north-eastern region. Although an interim report revealed many interesting examples of firms using, and profiting financially from, meteorological advice, far too many were not aware that they could obtain services tailor-made to their particular problems. The Office is paying special attention to the need to publicize its services to industry. An experimental trial of a new service, weather-routeing of ships across the Atlantic, was carried out in September. Four ships took part and agreed to follow courses selected by the meteorologist to give the quickest crossing and minimum buffeting from heavy seas. One ship gained 14 hours on its normal route and thereby saved fuel and damage to its cargo. The trial was judged to be very successful and it is hoped to institute a routine service in the near future.

The numerical forecasts produced by integration on the computer of the governing thermo-hydrodynamical equations have now assumed a dominant role in nearly all our operations. Automation was carried a step further this year by the delivery of machines for the automatic plotting of weather symbols and the drawing of lines on weather charts. The computer has led to considerable improvements in forecasting the movement and evolution of the major weather systems, and the winds for aviation purposes, but it is not yet able to help very much with those aspects that most affect the man in the street, i.e. rain, snow and fog, and these still have to be predicted by the human forecaster. However, research in this direction continues to be most encouraging; a very complex model for the numerical prediction of rainfall has now been tested and extended to allow for the influence of Welsh and Scottish mountains and the Alps, and the results suggest that operational forecasts will be possible when a computer many times more powerful than Atlas becomes available. Although the accuracy of current forecasts usually deteriorates rather rapidly beyond 48 hours, computations based on even the present rather crude operational model for periods of up to five days produce coherent atmospheric patterns that retain some reality in their broad features though they may be incorrect in detail. This encourages us to believe that, given adequate observations and computing facilities, it should be possible to produce reliable forecasts of the basic weather patterns for 5–7 days ahead.

These advances will require more extensive and accurate meteorological observations, often from remote land and ocean areas, where automatic weather stations that can be left unattended for months at a time seem the only practical solution. The Office has developed a fully automatic station capable of reporting nine weather parameters and this should be in operational service next year. After several years of development, a new radiosonde system is now undergoing batch trials; it promises to be a great improvement on the current system, which has given good service for over 20 years but is now obsolete. Introduction of the new system, fully automated, will produce considerable staff savings.

Turning now to new developments in research, a new laboratory for geophysical fluid dynamics is being established under Dr Raymond Hide who gave up his professorship at the Massachusetts Institute of Technology to join the Office in September. The new Cloud Physics Branch has been largely concerned with the planning and preliminary stages of a major programme to study the structure and evolution of frontal cloud systems. The project, based on the Isles of Scilly, will use radar, instrumented aircraft, specially designed drop-sondes, satellite photographs and mathematical models to determine the factors that control the intensity and distribution of the rain falling from these clouds as they approach the British Isles. The results should have great practical value in the forecasting of rainfall. Full implementation of the project will depend on obtaining a replacement aircraft for the Meteorological Research Flight but the first attempts to measure the three-dimensional wind field in these clouds will be made early in 1968. Excellent collaboration with the Royal Radar Establishment at Malvern is resulting in a very productive joint programme and the build-up of unrivalled radar facilities for the study of clouds and rain.

Analysis of data obtained from an experiment on the ARIEL 2 satellite has produced very valuable information on the distribution of ozone and dust in the high atmosphere, and a preliminary examination of data received indicates that the experiment designed to measure the vertical distribution of molecular oxygen at heights of about 100 km from the ARIEL 3 satellite was successful. The programme of SKUA rocket ascents from South Uist continues to provide evidence for the existence of large 'weather' systems in the high atmosphere. Soundings made during the Christmas period detected unprecedented changes at the 40-km level; the wind reversed from 350 knots westerly to 100 knots easterly and the temperature fell from +40°C to −30°C within a period of 10 days.

Perhaps the most encouraging and, in the long term, the most important feature of the year was the record level of recruitment into the scientific officer class. Many of our young scientists will now be able to obtain Ph.D.s as internal students of London and Reading Universities while carrying out their research work within the Office under supervisors appointed conjointly by the University and the Office. I very much welcome these closer ties with the universities and also the increasing numbers of foreign scientists who are coming to spend their sabbatical leave in the Office.

After the WMO Congress in May, I had the pleasure of being host to the Directors of Meteorological Services from fifteen Commonwealth countries who came to Bracknell for a week of informal discussions. The Commonwealth is an important force in international meteorology and has a large part to play in the World Weather Watch; this meeting helped to strengthen further the close links that have always existed between our Services.

B. J. MASON

January 1968
Meteorological Office,
Bracknell, Berks.

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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 was, during the period covered by the report, responsible to the Secretary of State for Defence through the Parliamentary Under-Secretary of State for Defence for the Royal Air Force and the Second Permanent Under-Secretary of State (Royal Air Force).

The general functions of the Meteorological Office are:

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

(ii) Liaison with the Directorate of the Meteorological and Oceanographic Services of the Navy Department and provision of basic meteorological information for use by that Service.

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

(iv) Organization of meteorological observations in Great Britain and Northern Ireland, and at certain stations overseas.

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

(vi) Maintenance of certain British observatories, and publication and distribution of geomagnetic and seismological information obtained from them.

(vii) 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 Ministry of Public Building and Works, and stationery by Her Majesty's Stationery Office) the cost of the Meteorological Office is borne by Defence Votes.

The gross annual expenditure by the Exchequer for the Meteorological Office, including that on the common services, is approximately £7·5 million. Of the amount chargeable to Defence (Air) Votes, about £5·5 million represents expenditure associated with staff and £1·9 million expenditure on stores, communications and miscellaneous services. Some £1·9 million is recovered from other government departments and outside bodies in respect of special services rendered, sales of meteorological equipment, etc.

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.

The membership of the Committee was:

Chairman:	The Lord Hurcomb, G.C.B., K.B.E.
Members:	Mr S. Earl
	The Lord Mais, O.B.E., T.D.
	Professor J. P. Hudson, M.B.E., G.M.
	Professor P. A. Sheppard, C.B.E., F.R.S. (Chairman, Meteorological Research Committee) (*ex officio*)
Secretary:	Mr B. M. Day (Secretary, Meteorological Office)

The Committee met three times in 1967.

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 proposals in connexion therewith.

The membership of the Committee was:

Chairman:	Dr B. J. Mason, F.R.S. (Director-General, Meteorological Office)
Members:	Professor J. N. Black, F.R.S.E. (University of Edinburgh)
	Dr S. C. Curran, F.R.S. (Royal Society)
	Mr J. B. Dempster (Scottish Development Department)
	Mr W. O. Kinghorn (Department of Agriculture and Fisheries for Scotland)
	Mr J. Paton, F.R.S.E. (Royal Society of Edinburgh)
	Professor P. A. Sheppard, C.B.E., F.R.S. (Royal Meteorological Society)
	Dr J. Steele (Department of Agriculture and Fisheries for Scotland)
	Dr R. W. H. Stevenson (University of Aberdeen)
	Professor D. W. N. Stibbs, F.R.S.E. (University of St Andrews)
	Professor P. A. Sweet (University of Glasgow)
Secretary:	Mr R. Cranna (Meteorological Office)

The Committee met on 1 June 1967

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 sub-committees, one of which shall be responsible for advising on the usage of monies allocated annually from Air Votes for research projects conducted outside the Meteorological Office. The Committee will be responsible for co-ordinating the work of its sub-committees.

The membership of the Committee was:

Chairman: Professor P. A. Sheppard, C.B.E., F.R.S.

Members:
Professor R. L. F. Boyd
Professor D. R. Davies
Dr G. E. R. Deacon, C.B.E., F.R.S.
Dr E. R. R. Holmberg (Army Department)
Dr J. T. Houghton
Mr E. Knighting (Deputy Director, Dynamical Research, Meteorological Office)
Wing Commander G. Mackie (Air Force Department)
Dr B. J. Mason, F.R.S. (Director-General, Meteorological Office)
Mr P. J. Meade, O.B.E. (Director of Services, Meteorological Office)
Mr D. E. Morris (Ministry of Technology)
Mr J. Paton, F.R.S.E.
Dr G. D. Robinson (Deputy Director, Physical Research, Meteorological Office)
Mr J. S. Sawyer, F.R.S. (Director of Research, Meteorological Office)
Professor R. C. Sutcliffe, C.B., O.B.E., F.R.S.
Instructor Captain J. R. Thorp, O.B.E., R.N. (Director, Meteorology and Oceanographic Services (Navy))

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

The Committee met twice in 1967 and its sub-committees seven times.

Note: On pp. viii to xii the membership of committees, the Meteorological Office Headquarters Organization, and the list of Principal Officers are as at 31 December 1967.

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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DIRECTOR	J. S. Sawyer, M.A., F.R.S.

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SPECIAL POST	F. Pasquill, D.Sc.
GEOPHYSICAL FLUID DYNAMICS	R. Hide, Ph.D.
METEOROLOGICAL RESEARCH FLIGHT	C. J. M. Aanensen, M.Sc.
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Assistant Director	L. Jacobs, M.A., M.Sc.
CLOUD PHYSICS	
Assistant Director	P. Goldsmith, M.A.
HIGH ATMOSPHERE	
Assistant Director	R. Frith, O.B.E., Ph.D.
Special Post	K. H. Stewart, Ph.D.

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Assistant Director	R. F. Jones, B.A.
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	C. J. Boyden, B.A.
DYNAMICAL CLIMATOLOGY	
Assistant Director	G. A. Corby, B.Sc.
Special Post	R. J. Murgatroyd, O.B.E., Ph.D., A.M.I.E.E.

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Assistant Director	D. G. Harley, B.Sc.

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DEPUTY DIRECTOR	V. R. Coles,M.Sc.
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Assistant Director	J. Harding, B.A., M.Sc.
Special Post	L. P. Smith, B.A.
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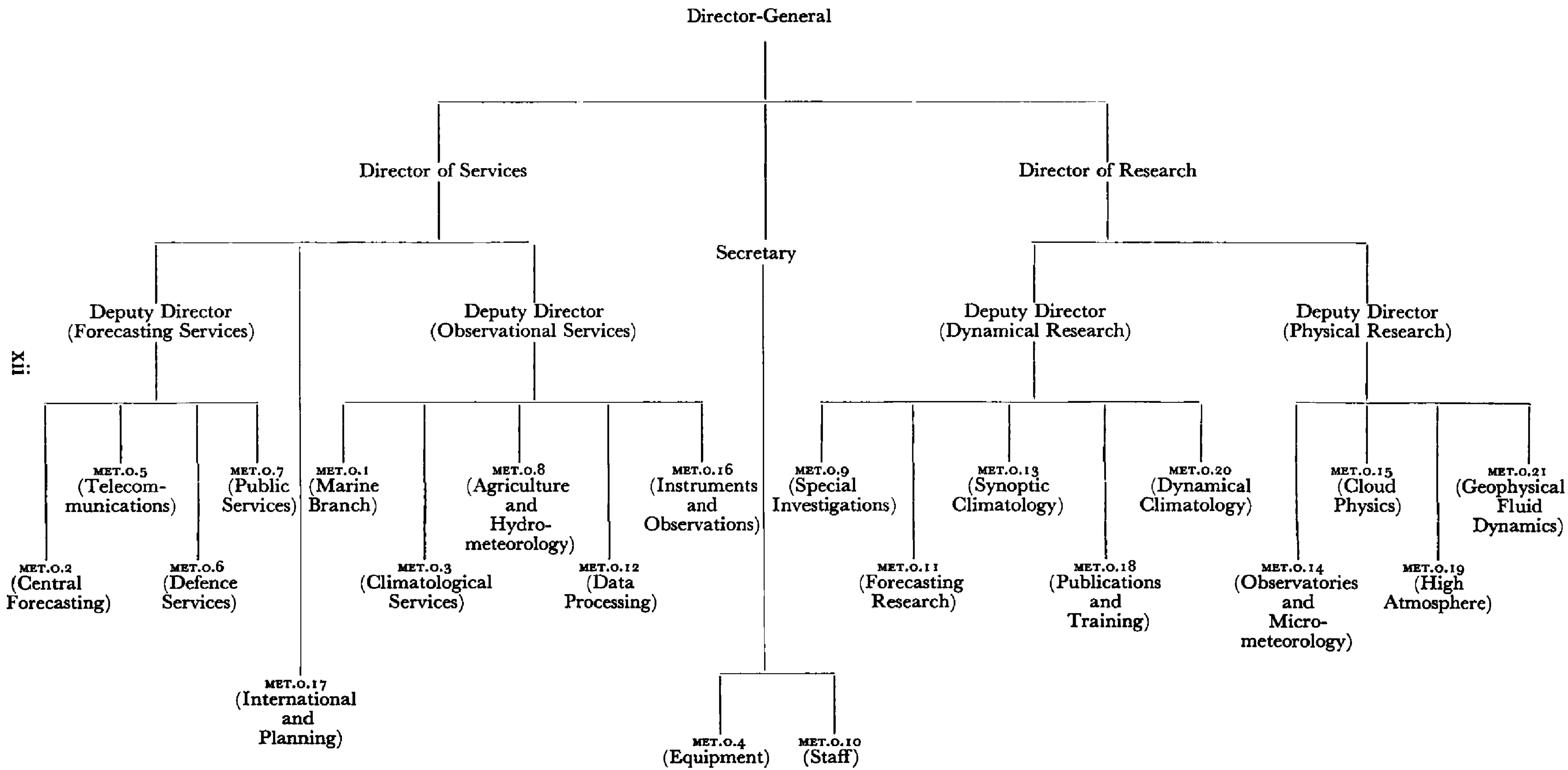
Assistant Director	N. Bradbury, B.Sc.
INSTRUMENTS AND OBSERVATIONS	
Assistant Director	N. E. Rider, D.Sc.

SECRETARY, METEOROLOGICAL OFFICE B. M. Day, B.Sc. (Econ.)

METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION



THE DIRECTORATE OF SERVICES

Special Topic—Hydrometeorology

A difficult problem in hydrometeorology is to find a firm concise definition of the term acceptable to a substantial majority of hydrologists and meteorologists in all parts of the world. In Sweden since 1907 and in the U.S.S.R. since the 1920's there have been central organizations combining the hydrological and meteorological services, and a number of more recently developing countries have decided in favour of a similar basic structure. In such countries, and among those who share the corresponding outlook, hydrometeorology can be taken to mean the whole of hydrology and the whole of meteorology, a vast field of activity which, with all the problems of data collection, services and research, may be in some respects somewhat unwieldy and difficult to unify.

In other countries, by tradition hydrology and meteorology have been, in varying degree, both organizationally and scientifically separate, despite the recognized existence of a large area of overlapping interest and of mutual interaction and interdependence. Moreover, by comparison with meteorology, hydrology itself has been and still is further fragmented in two different ways, occurring separately or together. Firstly, for some countries, whilst there is a central organization for meteorology over a large area covered by politically associated units, some at least of the hydrological services are based on smaller territorial divisions, determined by either administrative or physical boundaries, including natural drainage divides. Secondly, as in the United Kingdom, hydrology may have developed not as a single organizational service and scientific discipline, but as a loose assemblage of a variety of *ad hoc* arrangements arrived at for the solution of specific problems or groups of problems. Thus there may be quite separate organizations, as well as scientific bodies, with responsibilities or interests falling within, or closely associated with, the general field of hydrology, but each operating only in a more or less restricted part of that field. Such separate interests could include, for instance, water resources development, hydroelectric power, inland navigation, control or mitigation of river floods, flood warnings, land drainage, urban drainage, groundwater investigations, snow and ice problems, water pollution, and fresh-water biology and fisheries, as well as nature conservancy, amenities and many hydrological fringe items.

In circumstances where the separation of hydrology and meteorology persists, especially if there is also fragmentation within hydrology, hydrometeorology will tend to take on, in practice, some form of definition such as: 'the common ground between hydrology and meteorology,' or 'that part of meteorology which makes a specific contribution to hydrology.'

It is, however, difficult to determine a precise boundary for this type of definition. The strength and weakness of the form is that it is not static, but carries a significance, not uniform from place to place, which expands as hydrology and meteorology themselves develop and their interdependence becomes ever more apparent. Eventually, perhaps, hydrometeorology will

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acquire all over the world a close approach to the significance which has become well established in Sweden and the U.S.S.R.; but for the U.K., among many other countries, the point at which this may be achieved cannot yet be foreseen. In the meantime, without attempting any very precise wording, it may be said that the appropriate type of definition for the U.K. is the more limited form, embracing all the legitimate activities and interests of the national meteorological service which contribute to the emergence and development of hydrology as a unified field of endeavour and as a scientific discipline in its own right. As an example, a fully-fledged hydrologist must have some sound knowledge of hydrogeology as part of his mental equipment. A hydrometeorologist need not in any sense be also a hydrogeologist, but he should become reasonably well acquainted with the processes through which the combined effects of precipitation and evaporation, and sometimes atmospheric pressure, influence groundwater levels, and be able to understand in some detail the requirements of hydrogeologists for meteorological information.

There are several signs that both internationally and nationally the limited form of definition of hydrometeorology is in fact undergoing, within the present decade, a rapid expansion of its significance. Internationally, a convenient starting point is the formation, as a result of activities during the previous decade, of the World Meteorological Organization (WMO) Commission for Hydrological Meteorology with its first session (CHM–I) in 1961. With a change of name to the Commission for Hydrometeorology there was a definite broadening of the terms of reference by the time of the second session (CHy–II) in 1964.

Only a little later in phase came the preparations for, and formal inauguration of, the International Hydrological Decade (IHD), 1965 to 1974, sponsored by UNESCO with the collaboration of WMO, the Food and Agriculture Organization and other international agencies. From the exhaustive discussions which have taken place annually for several years at UNESCO House in Paris, and from all the documents which have been produced as a result, two things in particular are apparent. Firstly, the different stages of development and differing needs of participating countries are evident in the process of arriving at international agreement on the scope of activities, in order to make the IHD effort sufficiently comprehensive whilst keeping it within reasonable bounds; and secondly, the large part which WMO can play and is indeed anxious to play within the agreed programme has been received with great appreciation generally.

The implication of WMO's effort in the international setting is that most national meteorological services, if not all, have already found themselves in a similar situation with respect to their national hydrological programmes, whether independently developed or deliberately designed within the framework of the IHD. In the U.K., and doubtless in other countries, national developments already in train were broadly in harmony with the outlook stimulating the international developments. For this country, important organizational innovations, offering a more fully integrated structure than that which had previously existed for hydrology, arose as the immediate consequences of two parliamentary acts, the Water Resources Act 1963 and the Science and Technology Act 1965. The first, implementing a Government White Paper of 1962 on Water Conservation in England and Wales (Cmd 1693) led to the establishment on 1 July 1964 of the Water Resources Board (WRB), and to the replacement on 1 April 1965 of the former river boards, covering England and Wales, by the new river authorities, which have greatly increased powers and responsibilities especially in relation to the conservation of water. The second, implementing the Report of the Committee of Enquiry into the Organization of Civil Science (Cmd 2171, 1963) led to the incorporation by Royal Charter on 1 June 1965 of the Natural Environment Research Council (NERC) to assume prime responsibility for research in a number of fields including geology and hydrology and some responsibility in meteorology (prime responsibility remaining with the Meteorological Office), and to take over as component bodies a number of existing research units some of which are concerned with various aspects of hydrological research.

The completely new features of the situation created by these developments, looked at particularly from the standpoint of hydrometeorology, are as follows:

(i) The Water Resources Board, primarily on the management side, and the Natural Environment Research Council, on the research side, can now provide, for the first time at central governmental level, the principal foci for nearly all hydrological activity.

(ii) The river authorities in England and Wales are required by the Water Resources Act to make arrangements 'for obtaining and recording such measurements and other particulars of (*a*) rainfall in the area of the authority, (*b*) the evaporation of water in that area' as may be 'necessary or expedient for the performance of any of their functions'.

It may be noted in passing that the statutory requirement to 'measure' evaporation is perhaps, scientifically, a little premature, though the difficulty may be overcome in the course of time.

Other provisions affecting hydrometeorology, of the Water Resources Act especially, including in particular the duty of river authorities to carry out periodical surveys of water resources, may be taken as the natural extension, under a unifying system, of forms of activity already in being, which however required the stimulus of new forms of organization to bring them to the level required by the circumstances of today.

At present therefore in the U.K. the time is ripe for the development of a comprehensive programme of hydrological activity and research, backed by the authority of the responsible central organizations, to supersede all previous attempts to co-ordinate and harmonize the work of the many separate units still involved. The development is in fact already in hand but it will not be easy and it will take time to arrive at a long-term definitive though flexible programme in a fully satisfactory form. To mark and encourage the advance from the immediate past it could be an advantage if this form no longer reflected the fragmentation of hydrology. As with some of the weaker hydrological texts, both national and international schemes have sometimes over-emphasized, as it were in separate cells, the problems arising with each of the elements of the hydrological cycle, and so overshadowed the essentially dynamical nature of the cycle and of its problems. This is nowhere more evident than in those treatments of the water balance which, in the main, present the balance as an average static situation, even glossing over any actual practical result which may be an apparent imbalance.

If it is possible to identify, for formal presentation in a coherent scheme, the essentially *hydrological* problems, pure or applied, with all the necessary dynamical emphasis, it will then be the task of the contributory disciplines to identify and formulate the associated problems which need to be solved in their particular fields. The reverse approach, to attempt the formulation of hydrology as the sum-total of all contributory disciplines, is bewildering in its complexity and carries the danger of seriously neglecting the vital central core which alone can lead to integration of the science. It is desirable for a fully integrated form to be achieved not so much for each individual country but, as in meteorology, for each important region of the earth's surface possessing major distinctive characteristics resulting from the interplay of natural influences.

As a first step, to counteract the tendency of hydrology to sprawl into many different fields, it is helpful to have, in reasonably compact form, a generalized sketch of its basis and scope, for which the simplest approach is to regard it as an entirely applied science. It is difficult to suggest an alternative which might call into being 'pure hydrology'.

In the applied field, the primary reasons for the existence of hydrological activity—all of them aspects of variability within the hydrological cycle—include the following:

(i) The very uneven distribution in space and time of precipitation amounts (modified by evaporation and associated processes), and therefore of fresh water.

(ii) The existence on parts of the earth's surface of special zones or regions either with permanently extreme conditions (water deficiency or excess), or with significant amounts of water in particular forms (notably groundwater, snow and ice).

(iii) The multifarious effects of variability, deficiency and excess of water on the land itself and on all forms of life on land, with interactions, notably from vegetation on quantity (through transpiration) and from man and his activities on quality (with also sometimes unforeseen effects from modifying the distribution of water).

A sub-heading under the general heading of variability, which is currently receiving increased attention and may become of great importance for many parts of the world, is concerned with climatic change and the effects of very long-period fluctuations or trends on lake levels and groundwater levels, and possibly also on flood and drought frequencies.

Whilst it is not advisable to attempt to draw up a hydrological *programme* based on these suggestions, they have been expanded into an outline scheme of classification, possibly suitable for most problems in the hydrological field. In rather generalized form, which would need to be trimmed to remove irrelevant items for any particular territory, the scheme is given as *Appendix A* (p. 14). Proceeding from this general background of ideas, which may need some reshaping or amendment in detail, the potential contribution of hydrometeorology has next been considered. A scheme in outline form, this time with special reference to the U.K., is given as *Appendix B*. Similar schemes could doubtless be prepared covering contributions from other specialized fields. It is perhaps an inevitable weakness of such contributory schemes that because of at least three factors it is more difficult to outline them in a way which consistently brings out the dynamics and variability inherent in hydrology. They must be taken in conjunction with the parent hydrological scheme, for which this aim can be more fully achieved. The three factors are:

(i) The need for emphasis on basic data collection and all its problems.

(ii) The need at times for concise presentation of rather generalized results in easily assimilable forms.

(iii) The applicability of some of these results, in appropriate forms, to more than one of the hydrologically classified problems; this also demands cross-reference to the parent scheme.

With allowances for its tentative nature and the need which may arise for amendment as the hydrological programme itself takes definite shape, *Appendix B* represents the hydrometeorological background of what the Meteorological Office is doing, or could assist with, as a contribution to British hydrology.

The place of the Meteorological Office in hydrology is based, ideally at least and very largely in fact, on a countrywide system of data collection of a much fuller and more detailed kind than that for any other organization. In the long run in hydrological meteorology, it would be intolerable if any sizable piece of territory, say 50 square kilometres, were kept inadequately sampled or not (at least to some degree) otherwise represented. Moreover, for water resources development especially, the meteorological observations form an important part of the work which should go on for several years, preferably one or two decades or more, before any project is actually pursued. The organization which has been built up to approach this ideal has taken a long time to develop. Though very successful in some ways, because of its very early development it was necessarily based on simple equipment which lent itself extremely well to the voluntary system. The voluntary system flourished, to some degree for all meteorological observations and very much so for rainfall; it is to a large extent still with us and will probably leave its mark for a long time to come. Whilst it remains true that the enthusiastic voluntary observer is among the best of all observers (real excellence would be required from any scheme which could make him altogether redundant) a stage has been reached, almost simultaneously with the new organizational developments, when it is necessary to raise a pertinent question: whether it really suits modern requirements to have data collection dominated, or at least largely influenced, by the old voluntary system. This is the basis of the dilemma which probably affects the Meteorological Office very much more than any other organization in the hydrological field.

A certain strain has already been felt in one particular way during the last few years. Very good progress has been made in eliminating the old subjective hand and eye methods of error detection, particularly for rainfall data. Quality control and further processing of the data for publication and for application to investigations are now done very largely by computer. But the data are still collected in the old way in manuscript or typescript form; a major effort is required each month to convert the information into tape input for the computer, and the troublesome reference of queried observations to the observers is still done, of necessity, in the old traditional way. In this transitional stage, which can be overcome only by new observational techniques, the contrasts between old and new methods within the train of routine procedure are glaring.

New instrumental equipment now under development for recording data automatically in forms which can then be readily dealt with by computer, in large and increasing quantities, could eventually remove these contrasts. But to eliminate them completely for rainfall data on the scale required by installing new equipment at many thousands of stations would be very costly. Expense may not be the only difficulty. Even with the very substantial help of river authority organizations, it will hardly be possible to dispense entirely with the services of part-time observers, so some of the voluntary element will be retained. The function of part-time observers who are required to look after automatic instruments will of course be transformed so that expensive items of equipment, widely distributed and with a good proportion in remote places, can at least be given a measure of protection and some attention from time to time to ensure that they appear to be functioning properly. Whether the new type observers will maintain their interests at the highest pitch without the stimulus of making and handling the observations themselves is the further question which may lead to difficulties. For one reason or another it seems certain that the Meteorological Office, perhaps alone in the field in terms of the intensity of this problem, will have to adapt itself for many years to the maintenance of procedures of a dual (or even more complicated) nature—on the one hand maintaining everything useful, of which there is much, from the earlier system, on the other keeping abreast with all modern developments.

The situation emphasizes one aspect of the differences which arise within hydrology between those investigations which are specially mounted for the solution of specified research items over limited areas and for limited periods, and those activities which contribute to the indefinite extension in space and time of basic knowledge. During any period of intensified development, wherever the latter mode of working is involved, there must be formidable problems, including continuity, and for British hydrometeorology they occur at a time when efforts are being made to improve observational networks very rapidly. From many sides there are insistent demands for a denser network of sampling points in all parts of the country, for more-detailed data from a large proportion of these points (if this is impracticable from all), and for higher standards of verifiable accuracy, especially for rainfall measurement. These demands tend to result from a mixture of two elements. Firstly, hydrological needs for meteorological data are not identical with meteorological needs and in some respects go much beyond them, and secondly, there is a degree of dissatisfaction with what was achieved in the past, and certainly this is justified in relation to present hydrological requirements because the data accumulated are admittedly, for some purposes, of a rather mixed nature and of somewhat limited usefulness. But lest the achievement should be dismissed too easily, there is the question of how else, except by the old standards and procedures, could the product of some 400 000 observer-years of painstaking effort now be available. Though there are weaknesses in the material, the information will long remain an invaluable contribution to hydrological knowledge for which the meteorologists still provide the main custodians and the principal skilled interpreters. Whatever the newer methods may bring for British hydrology, the fuller use of past material must have a part in the hydrometeorological contribution for many years yet.

It is probably true to say that in the pre-computer period the total body of data has never been used to as much as 10 per cent or even 5 per cent of its potential value, so much effort having been necessary for collecting, checking and rather elementary use of any batch before storing it and proceeding to the next incoming batch. Simultaneous operations on any large amount of data have been largely restricted to averages and rather simple related statistics. The situation is changing, but even now there remains an obstacle; it has been estimated that to transfer to tape all past rainfall data which have not yet been converted to computer input form would require 100 man-years of punching effort. Although some small inroads have been made into this mass of material it would be invaluable to have say 25 to 30 per cent of this work done soon, on a well-planned selective pattern, for ready analysis in many hydrological investigations. The existence of this obstacle, together with the urgent task of improving present data and data collection, so that future investigators will have, as soon as possible, a broader and sounder basis for their work, is an essential element of the situation behind any review of current and future activities.

Work with a hydrological bearing done by the Meteorological Office in recent years has included giving some attention to the great majority of individual items, probably 70 to 80 per cent of them, listed in *Appendix B*. It has of course not been possible, with present resources, to take all of them, or even a large proportion of them, forward simultaneously at the desirable rate. Nevertheless performance has not been unimpressive. On the rather elementary though basic and necessary level, most difficulties encountered have been with the sheer volume of material involved. Since the Water Resources Act 1963 became effective, advice has been given to most if not all of the 29 new river authorities covering England and Wales on the improvement of observational networks, and there have already been increases in the numbers of stations reporting directly or indirectly to the Office. For rainfall alone it is likely that the total number of stations in the U.K. will rise within a few years from about 6000 to about 8000. The estimated increase may be on the low side because of the efforts already made, and still continuing, by the Meteorological Offices in Edinburgh and Belfast to secure similar improvements for Scotland and Northern Ireland under different organizational arrangements. It is at present not possible to estimate the corresponding increases for the more intensive collection of other meteorological data, particularly those elements required for estimating evaporation, but they will undoubtedly be large.

Such a rate of growth brings its own problems which would certainly have been more embarrassing but for the progress, already referred to, in the use of the computer for quality control of observations and further data processing, together with all the ancillary arrangements which had to be made with very thorough care. The next stages in the promising development of automatic instruments, including the magnetic-tape rain recorder (see Plate II), will also lead to network improvements, both in spatial density and time-scale detail (and also it is hoped in quality), all of which must be tied in with the further development of computer methods.

Before leaving basic matters behind, there are three areas of investigation which will call for continued attention, perhaps indefinitely. These are concerned with problems of the accuracy of conventional rainfall measurements, the accuracy of estimation of rainfall amounts over areas (fundamental in hydrology) from a scattered and necessarily rather irregular distribution of point measurements and the accuracy of measurement or estimation of evaporation. For the last, the Meteorological Office is collaborating in a series of international comparision trials, guided by WMO, which is now in its early stages. In the U.K. the largest installation of equipment for these trials will be at Kew Observatory; the largest single piece of equipment will be an evaporation tank of 20 square metres (see Plate III), built to a U.S.S.R. specification, which will be compared with smaller and cheaper items of various specifications. At least one of these, it is hoped, will provide a practicable instrument for widespread routine use.

Returning to data processing, the computer has also been brought fully into the picture in the last few years (though further advances can yet be made) in connexion with the supply of areal rainfall estimates for the *Surface water year-book* prepared by WRB, and rather more recently for the preparation of evaporation estimates from meteorological data and the production of the continuous series of soil moisture deficit maps for Britain. The latter takes matters a substantial step beyond the elementary. The series of maps now issued by the Meteorological Office to a variety of users was started experimentally and very tentatively in the autumn of 1962, with the main object of assisting river board engineers (as they then were) to estimate the onset of the most serious flood risk season (with soil moisture deficits approaching zero). The service has been appreciated not only in relation to river flood warning schemes, operated by the river authority engineers, but for other purposes too. Significant improvements have been made in the course of the first five years, though the maps issued are still on a very small scale and are of a rather general nature, which really calls for more detailed checking on a local scale for the best use of the information. Improvements in map scale and detail for the central national service would require, to maintain the work, greater manpower and resources than the present hydrometeorological unit can supply.

Mention of flood warning schemes (or hydrological forecasting in general where other practical problems demanding solution arise under this heading) introduces a promising example of an exercise in hydrology proper, calling for forms of organization specifically hydrological in outlook drawing together, both for research and operational practice, collaborators from all other fields which have anything to offer. It is the hope of the Meteorological Office that in the very near future it will be possible to mount at least a sizable pilot scheme in hydrological forecasting, perhaps for a selected area, to which a hydrometeorological team belonging to the Office would make an important contribution, helping to shape and unify all the local arrangements which provide the nation-wide coverage required. It is from the consideration and development of a group of major items of this kind that a comprehensive national hydrological programme could emerge and there are already a number of other important investigations in being or proposed which could be regarded in a similar way.

The first of these chronologically, certainly as far as Meteorological Office participation is involved, and the one which is outstanding in its implications for the future of water conservation and management in this country, is the River Dee regulating reservoir investigation. Leaving aside discussion of all the economic and other advantages which success would bring, this investigation, under the Dee and Clwyd River Authority at the request of WRB, aims to promote the greatest possible efficiency in the operation of multi-purpose regulating reservoirs. On the one hand, variable spare capacity must be allowed for in the reservoirs to retain a significant proportion of any likely flood flows, according to season. Ideally the requirement calls for very high-performance quantitative forecasting of rainfall on various time scales. Research effort is being made, but unless and until high forecasting standards can be achieved, for hydrological purposes with good quality local detail, the only alternative at the precipitation stage is very efficient and very prompt recording and reporting of rainfall amounts over the relevant drainage areas, sometimes with the inclusion of snowmelt. The problems of automatic recording and transmission of data in very unfavourable weather conditions need not be elaborated in all details; underground cables may become waterlogged, overhead lines may be down, and microwave transmission and radar may be attenuated by heavy rainfall (it has been proposed that radar may offer one means of assessing areal rainfall amounts and, with experience, provide also an aid to quantitative forecasting). On the other hand, at the reverse end of the rainfall variability scale, sufficient water must be stored within the reservoirs to maintain river flows at an acceptable level during deficiency periods, which may be prolonged. Under a regulating reservoir system, water for supply is not drawn off directly from the reservoirs by pipeline, but the natural river channel itself is used as the aqueduct. Supplies are drawn off many miles downstream with benefits for other river users of all kinds, provided that the acceptable flow level can be maintained. Rainfall deficiency investigations (severity, durations, frequencies) and the rôle of evaporation and soil moisture deficits are matters with which hydrometeorologists will be concerned.

Another investigation, with some similarities to the Dee scheme, is the Lambourn valley pilot scheme (see Figure 1) under the Thames Conservancy at the request of WRB. (The Thames Conservancy and the Lee Conservancy Catchment Board, each with a long history before the days of river authorities or the preceding river boards, have functions corresponding to those of river authorities within their own areas.) This scheme may later be extended to a larger proportion of the permeable area of the Thames basin. The object here is, without creating problems for other users depending on groundwater in any way, to take water pumped from the chalk to augment river flow during rainfall deficiency periods, with the prospect that, if successful (that is if the river water does not re-enter the chalk in sufficient quantity to vitiate the effort), spare capacity may thereby be created in the underground chalk 'reservoir' to moderate later high flows at times of excess. The Meteorological Office has already played a small part in the early stages of this scheme (advice on observational networks, arrangements to provide soil moisture deficit estimates) and as the pilot scheme develops, and if it is later extended to other permeable areas, this part will correspondingly grow.

Another form of field work with a bearing on water resources is the responsibility of the NERC Hydrological Research Unit (HRU).* Meteorological Office association with HRU dates from the earliest days of this organization—more correctly from even earlier; the Office provided the Chairman and one other member of the *ad hoc* panel, appointed under a Department of Scientific and Industrial Research (DSIR) committee on hydrological research, which originated the proposal (1960) to form the Unit to investigate the effects of variations in land use on the water relationships of catchment areas. Close

* From 1 April 1968 renamed NERC Institute of Hydrology.

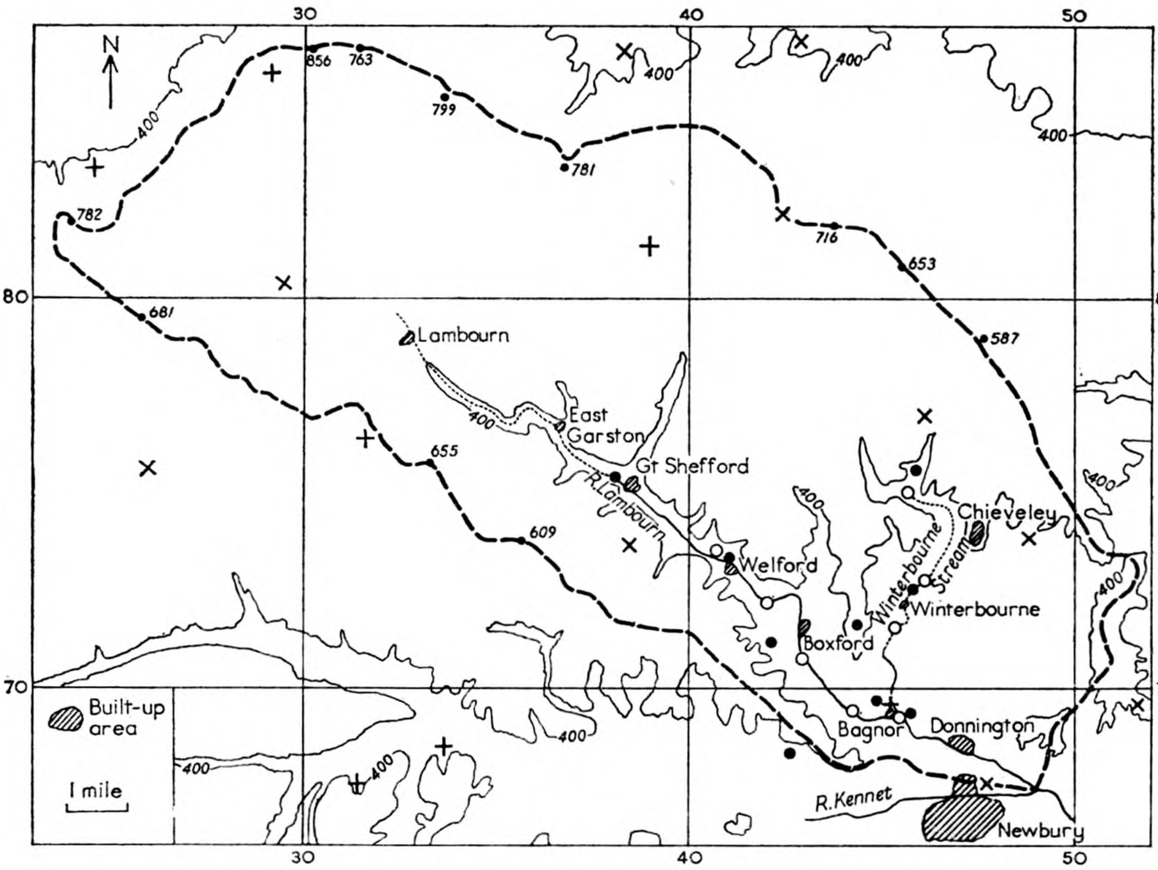


FIGURE 1—LAMBOURN VALLEY PILOT SCHEME—SITES PLANNED

o 36-inch diameter abstraction hole • Observation bore-hole

× Existing rain-gauge station + New rain-gauge station

– – – River Lambourn catchment area boundary

——400—— 400-ft contour. Spot heights in feet thus ·856

The map shows the area of the Lambourn, down to its confluence with the Kennet (about 100 sq. miles), as derived from surface contours. The groundwater divide does not coincide with the surface divide, and therefore the effective groundwater area, though largely overlapping the surface area, is not identical. If the Lambourn pilot scheme is successful the technique of augmenting river flow during deficiency periods by pumping groundwater may be extended to other areas of the Chalk and Limestone which occupy approximately one-third of the Thames Conservancy catchment area of nearly 4000 sq. miles. As part of the Lambourn study it will be necessary to relate the variations of rainfall (and other meteorological conditions) during the period of the pilot scheme to the variability to be expected over much longer periods (see Figure 2, p. 13) (*Appendix B*, item 5.2.).

association has continued and has been strengthened by the secondment of scientific staff for work with HRU at its headquarters or in its experimental areas. The Office attempts to maintain a lively interest in the work in all other experimental areas where meteorological observations are made (in this context with hydrological implications) under river authorities or other bodies. It has been somewhat hindered in this intention by the very rapid growth in the number of such areas in the last few years—a growth influenced in the domestic setting by developments arising from the Water Resources Act, and at international level because of national response to the world-wide interest stimulated by the IHD.

HRU was originally formed as a small semi-independent group within the DSIR Hydraulics Research Station (HRS), and at that time the Meteorological Office was also collaborating with others in HRS, since both organizations contributed to the very successful work of the Road Research Laboratory

(RRL) on the design of urban storm water drainage systems which has since led to routine computer procedures. Urban drainage is not always given a prominent place in a presentation of hydrology, which tends to be regarded as having a predominantly natural rather than a man-made setting. The distinction is highly artificial in modern conditions since it is everywhere becoming more difficult, especially in highly developed countries, to find any area wholly uninfluenced by man. The RRL–HRS–Met.O. collaboration, guided by a committee of the Ministry of Housing and Local Government, was at any rate at the time a very good model of productive joint effort in the hydrological field. This type of model may be superseded if it is found in practice that the present-day centralized organization for hydrological investigations and research does actually cover the entire field. The meteorological contribution to the urban drainage work is by no means complete. Special investigations at Cardington and Winchcombe have provided and are still providing (by further data analysis) useful information about point to area rainfall relationships for short-period intense falls over areas up to 10 or 15 square kilometres, and also typical rainfall-intensity profiles which are being generalized, as far as possible, for use in storm water drainage design. The work constitutes a substantial advance on previous practice, in particular the rather widespread device, to some extent enforced by earlier procedures, of regarding rainfall-intensity profiles as adequately represented by rectangles or triangles. But the country-wide collection of detailed minute-by-minute data from rain recorders must go on for many years, or even decades, before sufficient information will be available about the frequency distributions of heavy falls on an intensity and duration basis, for all parts of the country. Here again the new magnetic-tape rain recorder gives promise for the future. In addition the analysis of point to area rainfall relationships for short-period rainfall over small areas needs to be extended for many purposes, covering both flood studies and water conservation interests, to many different scales both in space and time. As far as resources allow, various sides of this work are being pursued.

A major project is proposed in a report from the Institution of Civil Engineers (ICE), 'Flood studies for the United Kingdom' (February 1967), prepared by a committee of ICE on which the Meteorological Office was represented. In origin, this report and the proposals advanced stem from the situation that for many years the U.K. has, in *some* respects, lagged behind the latest international developments in the field of design studies for engineering structures. British consulting engineers engaged on overseas projects have been ahead in this field, and since 1958 the Meteorological Office has carried out for a widely scattered selection of overseas sites about 12 extreme-rainfall studies to assist in the determination of design floods, especially for the spillways of large dams. Until recently no such study had even been started for any site in the U.K., and indeed there was little British material, readily available for guidance, to show any great advance on the ICE Interim Report: 'Floods in relation to reservoir practice' (1933). After the ICE committee began its work (early 1966) an approach to the Meteorological Office was made by the Trent River Authority for comprehensive extreme-rainfall investigations for the whole of the Trent basin above Nottingham and the investigations were put in hand. Adoption of the ICE proposals would amount to the extension of this hydrometeorological work, with corresponding studies on the hydrological side, to the whole of the U.K.

Finally, to conclude a necessarily incomplete review of some of the more important items governing the hydrometeorological work of the Meteorological Office, it is appropriate to mention again the difficult and perhaps still controversial topic of climatic change. As with instrument development, precipitation forecasting and other topics, this takes matters right outside the routine province of the hydrometeorological section itself, but to a subject in which hydrologists are certainly interested. In relation to water resources, interest has appeared to wax and wane but on the whole to increase. Rather less than a decade ago an isolated inquiry from a water supply engineer in Kent—concerned about a progressive fall in groundwater levels, possibly traceable over four or five decades—was typical of that time. Late in 1966, the Hydrological Group of ICE invited Mr H. H. Lamb to open a discussion on climatic change with special reference to hydrology. Recent findings by Mr Lamb and others associated with him in this field suggest that climatic changes have occurred within historical times, and could occur again, on a scale which could have economic significance in some directions, including water supply. There is room for much more doubt whether long-period fluctuations in rainfall amounts, deduced from a study either of averages or of secondary effects which are by their nature averaged over a lengthy time span, have comparable significance in relation to the rarer short-period conditions, in particular, floods. If they have, until it becomes possible to investigate relationships more fully, it seems at least permissible to suspect that such significance would be linked more with the frequencies of near-extremes than with the magnitude or severity of the absolute extremes which could have occurred or might be estimated as possible during any period.

Work on average rainfall in the U.K., lying more completely within the conventional scope of the hydrometeorologist, has now progressed to the stage at which knowledge of the degree of instability of rainfall averages (for successive periods of a few decades each within the last 100 years) can now almost enter association with conclusions about climatic change on a more extended time-scale. The possibility of ever being able to predict long-period trends, as a contribution to practical hydrology, remains a field of exploration for the future. In the meantime, the best immediate hope may lie in being able to derive from past rainfall data (covering more than 100 years in fair abundance and more than 200 years more sparsely) various forms of probability estimates which would be of valid practical use (see Figure 2). In this respect, provided that a sufficient proportion of past data can be converted to computer input form, the computer opens up prospects which at an earlier stage could never have been thought practicable.

Data deficiencies have played such an important role in the past that they have often dominated methods of work in many sectors of hydrometeorology, and perhaps of hydrology in general. Many problems have seemed problems of insufficient information, and adequate information alone, when it became available, has provided some form of solution. Much effort has been expended, not always with the happiest of results, on devising statistical techniques which might help to fill in gaps in knowledge occurring with respect to either space or time. Whilst good statistical methods might almost be defined as those which extract the maximum of useful valid information from the total available data (and preferably express it in highly condensed forms), there is a limit. They

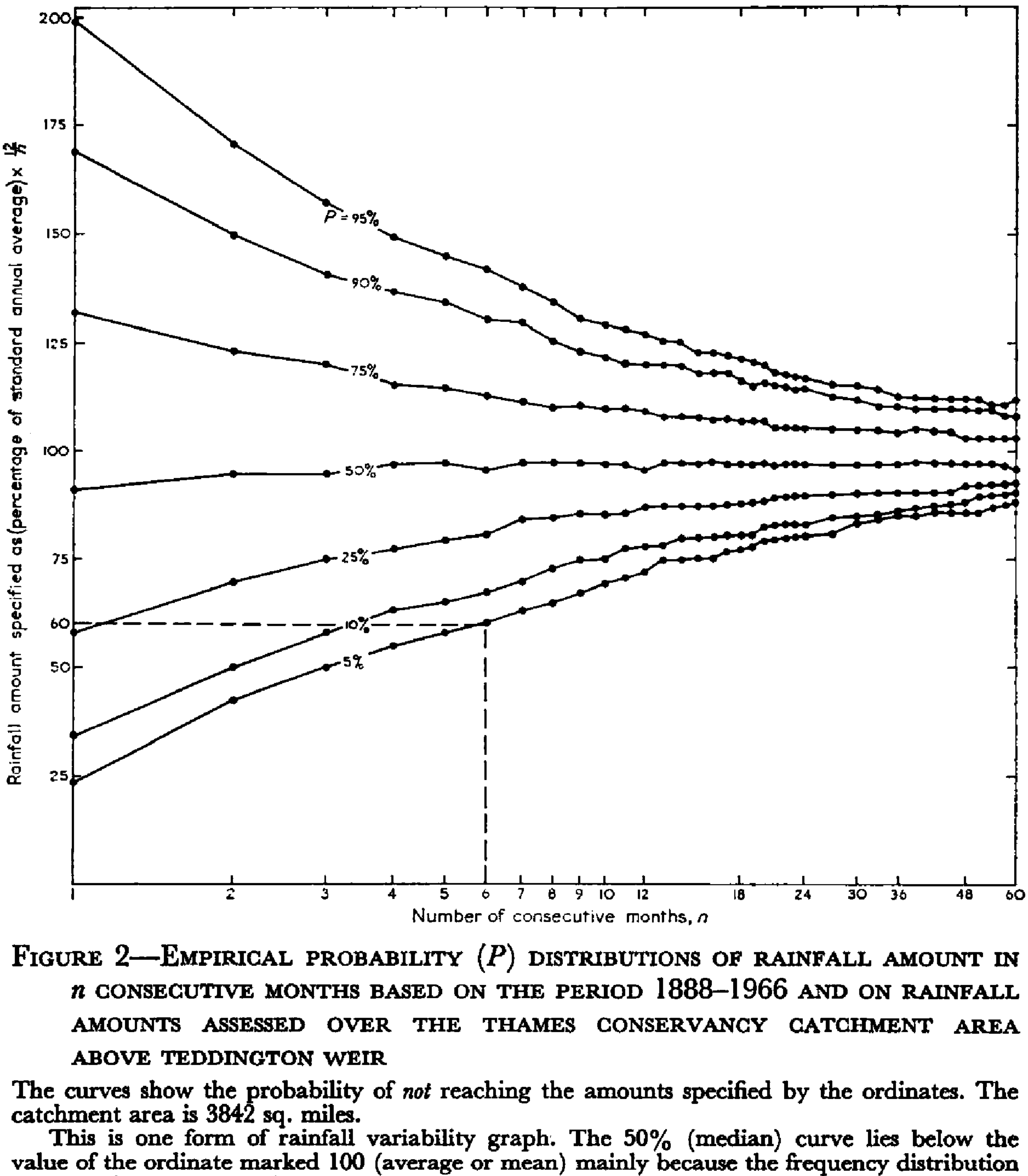


FIGURE 2—EMPIRICAL PROBABILITY (P) DISTRIBUTIONS OF RAINFALL AMOUNT IN n CONSECUTIVE MONTHS BASED ON THE PERIOD 1888–1966 AND ON RAINFALL AMOUNTS ASSESSED OVER THE THAMES CONSERVANCY CATCHMENT AREA ABOVE TEDDINGTON WEIR

The curves show the probability of *not* reaching the amounts specified by the ordinates. The catchment area is 3842 sq. miles.

This is one form of rainfall variability graph. The 50% (median) curve lies below the value of the ordinate marked 100 (average or mean) mainly because the frequency distribution of rainfall amounts is skew. The wettest months (or other periods) depart more from the average than do the driest (decreasingly so as the period lengthens). Also the average rainfall for the whole period 1888–1966 was slightly less (nearly 2%) than the value of 28·9 inches for the standard period 1916–50 now in use. Such graphs, or alternative forms, can be used to estimate the *probabilities* of occurrence of severe conditions for water supply (without of course any information on *when* they may occur). For instance, for rainfall over the Thames Valley as a whole, using 1888–1966 as a guide, there is a 5% (1 : 20) chance that in a 6-month period there may be no more than 60% of the 6-month average, that is 30% of the annual average, or 8·7 inches. The graphs can also be used as an aid in assessing whether the variations of rainfall during an important investigation, such as the Dee investigation (p. 8) and the Lambourn valley pilot scheme (p. 9), differ significantly from expected variability over longer periods (though other forms of graph could be more suitable for this purpose) (*Appendix B*, item 2.5.).

cease to be good methods, unless closely linked with sound physics, if used in themselves to extrapolate incautiously into areas of ignorance. They become speculation and unsound physics.

Paradoxically, along with data deficiencies on a local scale there has often seemed, through sheer volume, to be data abundance on a national scale, and the apparent abundance has had a rather similar effect. In the pre-computer period, and with otherwise limited resources, it was rarely possible to contemplate any advanced forms of analysis on a very large amount of data. Fairly simple and elementary forms of tabulation and mapping predominated on the whole. Rather little physics was attempted, except in the sense that some physical relationships emerge almost spontaneously from good mapping (perhaps more rarely, in hydrometeorology, from other forms of summary, however good). Automated cartography now holds out additional prospects.

At the present stage of development, still somewhat in the shadow of the pre-computer era, it is hardly possible to estimate what advances lie ahead in hydrometeorology (or in hydrology). From the glimpses of future prospects afforded by the most promising developments and the most interesting investigations now in being or proposed, it is certain that not far in the future problems will no longer derive mainly from lack of information, and should certainly not be hindered by lack of means to handle the intensified accumulation of data. The solutions reached will depend on ability to develop and establish the work on a sound scientific footing.

Appendix A

OUTLINE SCHEME OF CLASSIFICATION FOR PROBLEMS IN APPLIED HYDROLOGY

1. Deficiency of water; role of variations of precipitation, modification by evaporation, usually seasonal.
   1.1. Permanent deficiency; arid and semi-arid zones.
   1.2. Temporary, intermittent deficiency; mitigation by storage for water supply, hydro-electric power, inland navigation, etc.
   1.3. Irrigation in areas subject to 1.1. or 1.2.

2. Excess of water with all variations.
   2.1. Permanent excess; marshes, swamps and bogs; drainage.
   2.2. Temporary, recurrent excess.
      2.2.1. Flood warnings; role of evaporation through soil moisture deficits.
      2.2.2. Mitigation or control; design studies for structures (flood frequencies, maxima); land drainage and urban drainage.

3. River flow; seasonal and other changes; multipurpose flow regulation for mitigation of both extremes and for moderation of all variations.
   3.1. Regulating reservoirs.
   3.2. Use of groundwater to regulate river flow.

4. Lakes and reservoirs (where appropriate with rivers in association as part of system); thermal stratification and overturn; seiches; freezing and thawing; fresh-water biology; long-period changes in lake levels.

5. Areas of snow and ice; movement of water, liquid or solid, and processes of change.
   5.1. Irregular, erratic occurrence; problems of assessment, prediction or warnings and clearance; snowmelt floods of irregular occurrence.
   5.2. Regular seasonal occurrence; snow surveys; seasonal run-off from snowmelt; avalanches.
   5.3. Permanent snow and ice; glaciers.
   5.4. Snow-loading on buildings; design studies (frequencies, maxima).

6. Movement of water and processes of change in areas of groundwater and underground streams; infiltration and percolation; role of soil moisture; springs; artesian wells; seasonal variation of groundwater levels and effects on river flow and water resources; long-period changes in groundwater levels; artificial recharge of aquifers.

7. Water quality, variations in space and time, especially with reference to water resources; mineral content, mineral accumulation; pollution; departures from acceptable equilibrium in zones of transition from fresh water to salt.

8. Land forms determined by action of water; processes leading to permanent modifications arising from action of water; changes of natural drainage patterns affecting distribution and disposal of water; sedimentation of reservoirs.

9. Role of vegetation; interception of precipitation followed by evaporation; soil moisture; transpiration.

10. Influence of man's activities, deliberately hydrological or otherwise, on distribution, movement and quality of water; nature conservancy; amenities.

Appendix B

OUTLINE SCHEME OF CLASSIFICATION FOR PROBLEMS IN HYDROMETEOROLOGY WITH SPECIAL REFERENCE TO THE UNITED KINGDOM

1. Primary assessment of precipitation and evaporation.

1.1. Precipitation.

- 1.1.1. Improvement of observational networks and methods, including item 1.1.2.
- 1.1.2. Development of instruments, especially for automatic recording and transmission.
- 1.1.3. Further development of quality control and subsequent processing of data by computer, including improvements in presentation for publication and applications.
- 1.1.4. Accuracy of measurement of point rainfall for all types of site of practical importance:
  - 1.1.4.1. in conventionally acceptable rain-gauge sites;
  - 1.1.4.2. at ground level in very exposed, dissected and rugged terrain;
  - 1.1.4.3. at points well removed from the ground, as above forest canopy.
- 1.1.5. Design of networks and accuracy of assessment of areal rainfall; effects of orography on rainfall distribution.
- 1.1.6. Point to area rainfall relationships and generalization of typical rainfall intensity profiles on various space and time scales; see also item 3.1.
- 1.1.7. Radar assessment of areal rainfall amounts; see also item 2.2.
- 1.1.8. Assessment of snowfall, the water equivalent of snow lying and availability of water from melting snow; see also item 4.2.

1.2. Evaporation.

- 1.2.1. Items equivalent to 1.1.1. to 1.1.5. under precipitation as far as applicable and practicable.
- 1.2.2. Improvement of methods of estimating evaporation for points and areas, including attention to instruments and networks required, and use of computer techniques.
- 1.2.3. Special attention to high ground.
- 1.2.4. Evaporation from snow.
- 1.2.5. Negative evaporation; dew and all other forms of condensation.

2. Forecasting rainfall and analysis of past data with attention to frequencies, periodicities or trends.

- 2.1. Short-term forecasting of rainfall amounts.
- 2.2. Possible eventual use of radar for short-term forecasting of rainfall amounts, following on areal assessment, item 1.1.7.
- 2.3. Medium and long-range forecasting of rainfall in broad quantitative categories.
- 2.4. Analysis of monthly rainfall sequences, especially those following prolonged deficiency or excess periods in the past, to determine the possible prognostic value on a probability basis.
- 2.5. Rainfall averages, variability and long-period fluctuations or trends.

3. Study of maximum rainfall and, on a frequency basis, of near-maximum amounts.

- 3.1. Depth-area-duration analysis of rainfall for smaller and larger areas in relation to urban and river-basin drainage; see also item 1.1.6.
- 3.2. Frequency distributions of near-maximum rainfall amounts for various durations and areas.
- 3.3. Study of individual occasions of notable falls from the past and as they occur; meteorological characteristics and hydrological significance.
- 3.4. Estimation of probable maximum rainfall over drainage basins, for critical periods and rainfall distribution in time as determined by basin dimensions and characteristics.

4. Meteorological contributions to hydrological studies.

4.1. Evaporation and soil moisture deficit investigations including the development of criteria for specifying both meteorological and hydrological drought in terms closely linked with their practical significance.

4.2. Application of soil moisture deficit estimates to the assessment of flood susceptibility, and areal assessment of water equivalent of snow in relation to flood danger; see also item 1.1.8.

4.3. Assessment of areal rainfall and evaporation for investigations of rainfall and run-off relationships in general, as well as for prolonged deficiency periods with low yields or excess periods with high flow and floods.

4.4. Meteorological aspects of hydrological forecasting in general, as problems of practical significance arise.

5. Meteorological contributions to special investigations involving repetition of several of the above items.

5.1. Regulating reservoir investigations (contribution to work of WRB and river authorities).

5.2. Use of groundwater for regulating river flow (contribution as in 5.1.).

5.3. Effects of land management on water relationships in catchment areas (contribution to work of HRU).

5.4. Representative and experimental areas in general (contribution to work of other investigators, especially collaboration with WRB, HRU, river authorities and university departments).

6. Other studies.

6.1. Physical chemistry of rainfall, as part of the international programme now guided by WMO and specifically mentioned in UNESCO documents on the IHD.

6.2. Physics of snow accumulation, changes and melting.

6.3. Depth of frozen soil.

ORGANIZATION OF THE SERVICES DIRECTORATE

During 1967 no major changes were made in the organization of the Services Directorate. This was to be expected since in November of the previous year a full-scale structural regrouping had been completed and the past year has shown that the new, largely functional, organization conferred many advantages. However, the present organization should be regarded as more transitional than static since the new division or allocation of responsibilities together with increased flexibility have been designed to pave the way for greater utilization of modern technology—more powerful computers, faster and more adaptable communications, automatic observing systems—and, as progress is achieved, opportunities will become available for further streamlining and redeployment of effort.

An important milestone for all national meteorological services was the acceptance of the plans for a World Weather Watch by the Congress of the World Meteorological Organization which was held in Geneva last April. The fulfilment of these plans, at least in their operational context, will result in the co-ordinated aggregation of all the separate national meteorological services throughout the world, full advantage being taken of any special or highly organized elements of each service. The proposed functioning of the Central Forecasting Office at Bracknell as a Regional Meteorological Centre and of the communications establishment as a Regional Telecommunications Hub will be among the highlights of the participation of the U.K. The plans for World Weather Watch are providing a strong impetus to all services to modernize their forecasting, communications and data-processing organizations. This provides an additional spur to meteorological services to accelerate the installation of new facilities which in any event are required in order to meet purely national responsibilities.

In forecasting services there were a number of new and important developments. In civil aviation the Principal Forecasting Office at London (Heathrow) Airport became the Area Forecast Centre for all westbound Atlantic flights starting from any aerodrome in Europe. Considerable experimental work has been carried out in the applications of numerical forecasts to meet the different requirements of the Royal Air Force and of civil aviation.

Forecasting for industry, commerce and the utilities as well as for the general public continued to expand and to present fresh problems. All forecasting offices, whether at Weather Centres, on RAF stations or at civil airports, participate in this work and, although the load may be manageable when the weather is good, days of adverse weather, notably fog or snow, give rise to a sustained stream of inquiries which stretch the staff to the utmost at all offices.

A Principal Scientific Officer was assigned the task of studying the meteorological requirements of industry. There are many industrial activities which are recognized as weather-sensitive but the nature of the meteorological problems and the resulting requirement for forecasts are imperfectly understood. Close contacts with industry are therefore being developed and are already proving beneficial. New types of service for the building industry have been arranged and studies of the requirements of food manufacturers are well under way. A promising new service that has been tried out experimentally after much pioneer work by the Marine Branch is the weather-routeing of ships, a forecasting technique designed to enable shipping to avoid severe conditions of wind and waves.

The work in applied meteorology reveals the existence of several growth areas. In climatological services generally and also in hydrometeorology and in agricultural meteorology there has been a considerable increase in investigations and in consultancy. Work in these fields is of great and lasting importance to the community, offering enormous returns as can readily be demonstrated in the light of cost effectiveness.

There has been quite remarkable activity in the branches which provide the basic facilities—instruments, data processing and communications. The operational efficiency of the Office is greatly dependent upon these facilities and it is gratifying to report that these branches have responded well to ever increasing demands and display in their planning a modernity of outlook which is particularly important at the present time when there is an urgent need for more up-to-date equipment of all kinds. The present computer, a powerful one, is fully used but is no longer adequate either for research or for operational forecasting. The work of modernizing the communications system has begun and, on the instrument side, the final trials of a new radiosonde and of automatic weather stations are proceeding well.

Forecasting Services

Central Forecasting Office

The Central Forecasting Office (CFO) has three primary forecasting objectives. The first of these is the provision of guidance for outstations, mainly by means of charts depicting actual and forecast synoptic conditions, augmented by advisory texts covering the next 2–3 days.

Secondly, CFO is responsible for routine forecasts for sea and land areas and for the notification of expected specified weather such as fine spells or warnings of hazardous conditions. The forecasts are mainly intended for dissemination by the Press, broadcasting and television, but some are issued direct to public utilities such as the Central Electricity Generating Board 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 and strong upper winds. CFO is also the co-ordinating authority for the issue on BBC Radio 2 of 'FLASH' messages which warn the public of the occurrence of weather conditions likely to cause serious inconvenience to a large number of people.

Thirdly, CFO is a Master Analysis Centre as designated by the World Meteorological Organization. It fulfils this role by the preparation for wireless-telegraphy and radio facsimile transmission of series of actual and forecast charts covering a large area of the North Atlantic Ocean, Europe and the Arctic. This function will take on a new significance with the inauguration of World Weather Watch (WWW) on 1 January 1968. Under this concept CFO will become a Regional Meteorological Centre (RMC) serving the needs of various countries in Europe. A good deal of planning on a national and international basis has taken place during the year so that the changes called for may be introduced gradually and smoothly during the first period of WWW (1968–71).

During the year further progress has been made in the application of computer techniques to analysis and forecasting procedures. Forecasts for 72 hours ahead are now produced once daily in addition to the normal programme, twice daily, which provides forecasts for levels from the earth's surface up to 200 millibars extending to 48 hours ahead. Direct analyses and forecasts are at present produced by the computer for three levels only, the earth's surface, 500 millibars and 200 millibars, and statistically based programmes are used to derive forecasts for levels required by aviation, namely 850, 700, 400, 300 and 250 millibars. At some altitudes this method does not provide the accuracy required, so further work has been started to improve the accuracy by the use of a more refined method. Most of the computer-produced upper air forecast charts are distributed by the land-line and radio facsimile services. There is still a need for the forecaster to check the accuracy of the objective analyses produced by the computer and he also continues to predict the 100-millibar contour field in a subjective manner.

Much work has been devoted to perfecting a programme to analyse the contour fields of any standard level up to 30 millibars. This will obviate the necessity to derive by statistical methods analyses for levels other than the surface, 500 millibars and 200 millibars. At present such analyses are not broadcast since subjectively drawn analyses are somewhat superior. The new programme will make it possible to dispense with the subjective upper air analyses and to produce sound objective analyses in a shorter time.

Cloud photographs from the automatic picture transmission (APT) of the United States weather satellites ESSA and NIMBUS (see Plate V) have continued to be received at Bracknell daily and are now a routine aid in the preparation of analyses over the North Atlantic and European areas. With effect from April, interpretations of the pictures (nephanalyses) have been prepared for issue to outstations by land-line facsimile and radio facsimile. These nephanalyses are made from pictures received from the two orbits nearest to the British Isles. They are of considerable value to the outstations in their day-to-day work and in the briefing of aircrews.

In September an exercise was carried out in which CFO gave advice to the masters of four British merchant ships before they sailed and during the west-bound voyage on the North Atlantic. The object was to provide the ships with advisory routes or courses to steer, so that the time of the crossing was the least, commensurate with the avoidance of wave conditions liable to cause damage to the ship or its cargo. The wave conditions were predicted on the COMET computer for periods up to 72 hours ahead and these were used with some subjective adjustments to route the ships along least-time tracks, having regard to the known performance of the ships in various wave conditions. In deciding on the advice to be offered to the master of a ship it is necessary also to have regard to other conditions, such as fog, icebergs and oceanic currents. There must necessarily be a measure of judgement and subjectivity in such an exercise, but nevertheless substantial savings of time were made by the ships, estimated as up to 14 hours on the Liverpool–New York crossing, and the ships were also subjected to less severe wave conditions than would have been experienced on the normal great-circle courses. Plans are being drawn up with the object of providing a regular ship routeing service in the near future.

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 summer the APT pictures mentioned above are of considerable value in delineating the edges of the main ice-fields, though the resolution is insufficient to depict individual icebergs. The APT satellites in operation do not at present produce infra-red photographs, so that in winter the time-honoured reconnaissance methods must be employed alone. It is of interest that the ice-fields off the east Greenland coast at the beginning of December were more extensive than at any time since regular records were begun about 90 years ago. Hand plotting of sea isotherms, valuable to the fishing industry amongst others, has now ceased as the data are now extracted and analysed by the computer.

An automatic synoptic plotter was delivered in June and brought into use for the plotting of hourly weather charts of the British Isles for issue on land-line facsimile to outstations. The advantages will be economy of time and increase of legibility, both factors of importance to the recipients. The plotter is operated from incoming teleprinter tapes and transcribes the weather reports to a 35-mm microfilm at the rate of about one a second. After development, which is automatic, the microfilm is used to produce enlargements for transmission by facsimile. The entire process (tape sending, microfilm recording and automatic processing, and fixing the final print) takes about 10 minutes from receipt of the teletapes to the production of the synoptic map (on a Mercator projection) of about 105 stations in and around the British Isles. Charts produced by the automatic plotter are now being substituted for some of the hand-plotted charts transmitted to outstations by facsimile.

A link with the past was broken when the CFO daily forecasting conference was discontinued on 31 March 1967. As a substitute, a personal briefing service is provided from 1230–1300 hours Monday to Friday inclusive, in the entrance hall of the Headquarters building, a forecaster being in attendance to explain and discuss both charts and forecasts.

CFO continues to be responsible for the publication of the *Daily Weather Report* with its *Overseas Supplement* and *Monthly Summary* and the *Daily Aerological Record.* Changes of codes, to be introduced on 1 January 1968, have necessitated only minor format changes to the *DWR*, but a complete change of format and of computer programme for extraction of the data has been required for the *DAR.*

CFO is supported by a computer programming element which also provides direct support for certain major outstations, notably London (Heathrow) Airport, and Headquarters Bomber Command* and Headquarters Air Support Command of the Royal Air Force. Many changes and improvements in this support were introduced during the year and further extensions to the numerical analysis and forecast procedures are in hand. These are largely directed to three main objectives, namely to enable CFO to fulfil its role as a Regional Meteorological Centre, to enable Heathrow to fulfil its role as an Area Forecast Centre for international civil aviation in the North Atlantic region and to improve the accuracies of the analyses and forecasts required for these purposes.

Services for the general public

Forecasting services for the public—including industry, commerce and public utilities such as electricity, gas and transport—are provided either

* Strike Command from 30 April 1968.

directly from the various weather centres and other forecasting offices or indirectly using the mass media of communication. The mass media include the British Broadcasting Corporation, the Independent Television Authority, the Press, the GPO's automatic telephone weather service, and the GPO's coastal broadcasting station. Inquiries for weather information during 1967 reached a total of 1 264 605 compared with 1 204 921 in 1966.

Special efforts have been made to increase the contribution which meteorology can make to the national economy. Information provided through the mass media has of necessity to be general in character. It cannot take into account all user interests and cannot include any detailed advice on the weather-sensitive aspects of individual industries, of local authorities, of public utilities, of sporting organizations, etc. These call for tailor-made advice based on a full knowledge of the users' problems.

A special service has been introduced for the construction industry which offers meteorological advice for major civil engineering and building sites throughout the country. This service provides forecasts tailor-made to meet the particular circumstances at each site in the light of local peculiarities of the site and of the weather factors of importance as construction progresses. Use of this service is increasing. Following recommendations made by the joint working parties of the National Federation of Building Trades Employers and the Meteorological Office, lectures to civil engineers and builders have been given at a number of centres, with the co-operation of the Ministry of Public Building and Works. Discussions are now taking place with the Ministry of Agriculture, Fisheries and Food on the ways of developing meteorological services for the manufacturing, distributing and retailing sections of the food industry.

In co-operation with the Ministry of Technology and through its Regional Organization and Liaison Centres, steps have been taken to ensure that knowledge of the services that the Meteorological Office provides reaches all sectors of industry. A series of lectures by Meteorological Office staff is planned at the Regional Offices of the Ministry of Technology.

Improvements have been made in the dissemination of forecasts through the mass media. Last year's experiment of establishing a weatherman at the BBC's Television Centre, Shepherds Bush, has now become accepted practice. Following many complaints from the public the BBC has agreed to the reintroduction of actual as well as forecast weather charts in the television presentations by the weatherman. Special presentations were introduced during the summer months to inform the public of week-end weather prospects at British and continental holiday resorts, and occasional presentations were made to cover special events such as the return of Sir Francis Chichester and the *Torrey Canyon* disaster. The independent television companies have also shown a lively interest. Most of the companies readily agreed to schemes for including FLASH weather messages in their programmes whenever there was an imminent threat of weather causing serious inconvenience to a large conurbation. Tyne Tees Television was also quick to make use of the new weather centre opened at Newcastle to serve the north-east. The officer-in-charge has made personal presentations on Tyne Tees Television each Friday to discuss the week-end prospects. Rediffusion, Anglia and Southern Television have continued with their own schemes for personal presentation by members of their own staffs, based on information supplied by the Meteorological Office, and the remaining companies read out scripted forecasts and/or display caption charts also supplied by the Meteorological Office.

The changes in BBC (Sound) to their new Radio 1, 2, 3 and 4 programmes were discussed in detail with the BBC. It was agreed that the Meteorological Office would provide short scripted forecasts for Radio 1, which would be read by the news announcer. Radio 2 took over the mantle of the Light Programme. Some changes were made in the times of broadcast of the shorter national forecasts and additional forecasts were introduced in the evening programmes. The times of broadcast of Shipping Bulletins remained unchanged except that as from 6 November, an additional minute was allowed for the 1758 local-time broadcast bringing it forward to 1757. Forecasts for Radio 3 and Radio 4 followed closely the arrangements which previously existed for the Third Network and the Home Service respectively. All the main national forecasts, i.e. those broadcast at 0655, 0755, 1255 and 1755 local times on Radio 4 are now presented live from the London Weather Centre and are followed by live broadcasts of regional forecasts for the South-east. Other regions continue to be provided with scripted regional forecasts issued to them by the appropriate regional meteorological office.

Perhaps the most exciting new outlet in providing forecasts for the public, is the network of local radio stations now being introduced on an experimental basis. Each of the new stations will be provided with its own local forecasts. The forecasts will pay particular attention to the varying needs of the community. So far eight local radio stations are either operational or will shortly become so and specified meteorological offices have been negotiating with the station managers on ways and means of providing the public with detailed weather information. The service should prove to be of considerable value to the community both socially and economically.

A variety of short broadcasts and talks were given by various members of staff on television and sound. Most of these dealt with past and current weather. Preliminary work is in hand for a new series of broadcasts on meteorology and meteorological services to be televised in 1968 by the Independent Television Authority in their Adult Educational Programme.

The BBC and the responsible independent television company also co-operated with the Meteorological Office in making special arrangements for forecasts for major sporting events to be available to their production units and through them to the millions of viewers and listeners. The events included the cricket test matches, the All-England tennis championships at Wimbledon, the Derby and Royal Ascot.

The major changes in the provision of information to the Press were at the provincial rather than the national level. More provincial papers now obtain their forecasts directly from the nearest meteorological office thus reducing the time lag between the time of issue of the forecast and the time it is on sale in the streets. The forecasts can also be more closely related to the area of distribution of the newspaper. The *Western Mail* has a large farming interest and to meet this they are now being provided with an extended forecast aimed at the general trends expected in the weather. This is an experimental stage with its real value to farmers still to be assessed.

The automatic telephone weather service was introduced into two new areas, one serving the south-west Midlands and the other the area within 40 miles radius of Bedford. The GPO is also ready to introduce this service to the industrial areas of the West Riding with centres in Leeds and Sheffield. The total number of calls made on the various automatic telephone weather services now established was 7 599 241 during 1967 compared with 8 701 169 in 1966.

The work of the weather centres at London, Glasgow, Manchester and Southampton continued to expand. A new weather centre was established in Newcastle as from 27 April to assist with the provision of information to the north-eastern counties and a market survey is being conducted by an independent firm to assess its economic value to the community. The absence of a weather centre in the Midlands is still keenly felt. Some improvement has been possible by continuing the existence of the Watnall Meteorological Office after transferring its remaining aviation commitments to other meteorological offices. Watnall continues to provide most of the public services for which it previously had responsibility and has been able to undertake a limited amount of additional public service work such as the provision of the new Bedford automatic telephone weather service, and the forecasts required for the local radio stations at Leicester and Nottingham. The total number of inquiries dealt with by the weather centres in 1966 and 1967 are given in the table below.

	London	Glasgow	Manchester	Southampton	Newcastle	(Watnall)
1966 ..	299 312	74 495	83 915	63 916	—	59 863
1967 ..	304 907	84 298	95 098	63 937	16 037	50 403

Throughout the year London Weather Centre dealt with most of the needs of the south-east for weather information and in addition dealt with the requirements of oil companies and consortia drilling in the North Sea. British Petroleum Development Ltd, have now joined the list of such companies who are all provided with routine information, special forecasts for towing etc., and warnings. The Centre dealt with a record number of inquiries for each month from May through to September. The highest ever monthly total of 33 457 was recorded in August, but both May and July inquiries also exceeded 30 000. In addition to supplying these needs, London Weather Centre also undertook the parentage of the Watnall Office with effect from 15 May. As the Watnall office has no forecaster coverage at night, the responsibility for forecasts and warnings for the Midlands has then to be undertaken by the London Weather Centre.

Glasgow Weather Centre held a Press conference on 12 January to introduce a new officer-in-charge to the Press and public. A Press conference was also held on 27 April to inaugurate the Newcastle Weather Centre. The Newcastle Press conference was attended by representatives of BBC and Tyne Tees Television. The Director of Services and the officer-in-charge of the Centre were both interviewed and appeared on television programmes that evening.

All the weather centres have been actively engaged in publicizing the services they can provide. This has been done by circular letters, by interviews with the Press, by visits to various authorities and organizations, by lectures and by exhibitions. The Meteorological Office again took a large part in the 1967 Battle of Britain Exhibition which was held in Birmingham and which was attended by some 100 000 visitors. A complete forecast office was installed in the meteorological pavilion. Captions, photographs and a display of instruments served to show the diversity of the work of both the service and research directorates. The Office also assisted at Swansea with a display for the Swansea Air Day, at the Southampton Show with a display in the marquee organized by the Chamber of Commerce, at the Leeds meeting of the British Association for the Advancement of Science with a daily display of weather charts and forecasts, and at a number of career conventions organized by local schools.

The provision of fog warnings for motorways has been extended to cover new motorways. The officers-in-charge at Manchester and Watnall have visited the new sites and have made local arrangements to help solve the problems. Warnings of snow for the Ministry of Transport, and of snow and ice on roads for local authorities were organized as in previous years. Services for public utilities—gas, electricity, railways and river boards—were continued with only minor changes designed to meet the users' revised requirements. The services for racing pigeon clubs reached a new record demand of 1037 line-of-flight forecasts.

There were as usual a variety of interesting special demands for our services. Forecasts and warnings to cover the launching of the *Queen Elizabeth II* were provided by Glasgow Weather Centre; a personal briefing was provided by the officer-in-charge of Southampton Weather Centre for the competitors in the International Power Boat Race for the Wills Trophy; the manager of a region of British Rail obtained week-end forecasts in order to plan his excursion trains; wind-raised sand in the Moray Firth called for an explanation of the phenomenon on BBC (Scotland) Television.

The year has been one of expanding demand with new groups of customers making their needs more strongly felt. There has already been a very large growth in the number of in-shore forecasts supplied to coastguards, and discussions are taking place to find ways and means to make more weather information available to yachtsmen and to privately owned cruising vessels. As existing demands become more numerous and new requirements present themselves, the Office finds increasing difficulty in providing services to meet all individual needs. These problems raise difficult questions of organization which are being urgently examined.

Services for civil aviation

The Civil Aviation Department of the Board of Trade is responsible for providing technical services for civil aviation. The provision of meteorological facilities is a technical service and is undertaken by the Meteorological Office as the agent of the Board of Trade.

The meteorological organization for civil aviation in the U.K. consists of a Principal Forecasting Office at London (Heathrow) Airport, Main Offices at Air Traffic Control Centres and in Northern Ireland, subsidiary offices at other civil airports and observing offices at some minor civil aerodromes. Subsidiary offices are also maintained at four research and development aerodromes under the Ministry of Technology.

Meteorological services for civil aviation overseas are provided at a number of joint-user aerodromes (i.e. RAF and civil) in the Mediterranean area and also at Bahrain and Sharjah.

In the U.K. the provision of forecasts for medium and long-range flights operating above 5000 feet is the responsibility of the Principal Forecasting Office at London (Heathrow) Airport. Weather documentation for flights throughout Europe and the Mediterranean area and for transatlantic flights to North America is disseminated from Heathrow to 17 major civil airports by land-line facsimile transmission (civil aviation meteorological facsimile—CAMFAX).

Forecasts of upper winds and temperatures at levels up to 40 000 feet are now largely based on computed data from the Meteorological Office computer (COMET) at Bracknell.

The Principal Forecasting Office at Heathrow assumed the responsibilities of the European Area Forecast Centre for the North Atlantic on 1 October 1967. Forecast charts suitable for direct use by aviation for flights over a wide area including the North Atlantic, North America and much of the polar basin are now being disseminated by radio facsimile broadcast on a round-the-clock schedule; the same material is also transmitted by land-line to Frankfurt, Paris, De Bilt and Copenhagen.

Satellite cloud pictures are now regularly received at Heathrow and provide a valuable addition to the data received from other sources.

The meteorological requirements of supersonic transport aircraft, in particular the Concorde, have continued to be studied during the year and preparations have been made to provide the meteorological service for Concorde prototype flying in 1968.

The British Overseas Airways Corporation is planning to computerize its flight planning operations, and discussions have taken place during the year on a programme to relay the relevant output of the Meteorological Office computer to the BOAC computer for this purpose.

Assistance has been given to the Board of Trade (Civil Aviation Department) in planning and executing alterations and extensions to the Meteorological Operational Teleprinter Network Europe (MOTNE). In this Phase 3 of MOTNE, which came into effect on 30 November 1967, the single loop for the international exchange of weather information for aviation throughout Europe, North Africa and the Near East, has been replaced by two loops which accommodate half-hourly weather reports and routine forecasts for an increased number of aerodromes. In addition, aerodrome forecasts for civil airports in North America and Greenland are now inserted in the loops by the London (Heathrow) MOTNE centre and so are distributed to more than 150 European aerodromes connected to the loops.

Preparations have been made for the installation of nine cloud-base recorders on the approaches to runways at certain civil airports where significant differences in the height of the cloud base are known to occur between the approach area and the observing site.

Routine calibrations of lights used in making runway visual range (RVR) observations are now being carried out at six-monthly intervals at major British airports. Special investigations were made at Bournemouth (Hurn) and Stansted Airports, to study the effects of variations in lamp output and visual acuity of the observers on the RVR observations.

To investigate instrumental methods of assessing RVR, trials of the Mk II transmissometer are continuing at Birmingham Airport. The Meteorological Office has co-operated with the Blind Landing Experimental Unit (BLEU) in carrying out experiments concerned with slant visual range measurement at the Royal Aircraft Establishment, Bedford, and at Heathrow.

Services for the Royal Air Force

Forecasting services are provided for the Royal Air Force by outstations which are distributed largely in conformity with the RAF organization. There is a Principal Forecasting Office at Headquarters Bomber Command, and Main Meteorological Offices, functioning throughout the 24 hours, are located at the Headquarters of some of the RAF Groups to control and advise subsidiary offices at RAF stations in the Group. At these subsidiary offices a forecaster is available at times which depend on the needs of the RAF. Some observing offices are maintained where there is no forecaster and the duties comprise the making and issue of weather observations. At RAF Command Headquarters the meteorological unit usually consists of a senior officer of the Meteorological Office who acts as adviser to the Air Officer Commanding-in-Chief and as liaison officer between him and the Director-General of the Meteorological Office. The same general pattern applies in the U.K. and overseas in the Federal Republic of Germany and in the Mediterranean, Middle East and Far East areas.

Outstation meteorological services continued to meet the various requirements for the operation of RAF aircraft of all types ranging from those flying at high speed and high level to those with many hours endurance at low levels. There has been some increase in the demands at stations in the U.K. caused by units withdrawn from overseas. Plans were prepared to meet the meteorological requirements of the new RAF Command structure. Overseas, the most important changes in organization have involved the withdrawal of Meteorological Office facilities from Borneo and south Arabia, and the augmentation of facilities in the Persian Gulf area. An upper air station was established on Masirah Island.

There has been a continuation of the trend towards greater centralization of forecasting and greater use of facsimile documentation. A new radio facsimile broadcast was established in Cyprus to serve stations in the Mediterranean and Middle East areas.

Considerable application has come to be made of computerized forecasts for operational use.

Useful material for preparing operational forecasts over areas where normal data are sparse is now provided by direct reception of cloud pictures from the meteorological satellites being operated by the U.S.A. Reception stations were established during the year at Changi (Singapore), Gan, Muharraq (Bahrain) and Episkopi (Cyprus) to exploit this modern aid. Information on the position and movement of cyclones in the Indian Ocean area is being passed to the meteorological services of Australia, Ceylon and Mauritius whenever evidence of the existence of these phenomena is acquired from the satellite pictures being received at Gan and Changi.

Services for the Army

As in previous years forecasts were provided for the Army Aviation Services.

For ballistic operations, four permanent outstations continued to be maintained at Army establishments. In addition, two subsidiary stations were manned during periods of practice firings of guided weapons and conventional artillery.

Assistance and guidance were given in the training of Royal Artillery meteorological sections.

Liaison with the Navy Department

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

Services for the Ministry of Technology

A permanent outstation is maintained at the Royal Aircraft Establishment, Aberporth.

At South Uist in the Hebrides, some assistance was given in the launching of PETREL rockets on behalf of the Science Research Council. A Senior Experimental Officer from the Meteorological Office was seconded to the Atomic Weapons Research Establishment to lead a team to carry out the meteorology and tracking of these rockets from South Uist.

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.

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 meteorological services of the member states are represented. The work of these committees is to co-ordinate the meteorological support needed by the military forces in accordance with joint defence plans and, as necessary, to study the meteorological problems involved. Members of the Meteorological Office play an active part in the committees of all three organizations.

North Atlantic Treaty Organization

The annual meeting of the Military Committee Meteorological Group (which has superseded the former Standing Group Meteorological Committee) took place in Bonn, Germany, from 12 to 14 June. Mr P. J. Meade, Director of Services, attended as U.K. member of the Committee and he was accompanied by Mr E. Evans.

The Working Groups of the Military Committee Meteorological Group on Weather Plans and on Weather Communications met twice, in Izmir, Turkey, from 7 to 16 March and in The Hague, Holland, from 3 to 12 October. Mr R. A. Buchanan was present as U.K. member of both groups at the Izmir meetings and Mr E. Evans attended the Hague meetings.

At the beginning of the year, there was a general reorganization of the Groups of Experts formerly under the Armaments Committee, and the work of the meteorological groups and subgroups concerned with ballistics and measuring techniques and equipment was reconsidered. A new Meteorological Panel has been formed provisionally. Its first meeting in Paris, 4 to 6 September, was attended by Mr A. G. Matthewman. Unanimous proposals were made to the new Armaments Groups regarding the organization and tri-service tasks of the Panel.

Mr K. Bryant, as meteorological adviser, accompanied the U.K. representative (from the Home Office) to the meeting of the Warning and Monitoring Working Party of the NATO Civil Defence Committee which was held in Paris from 28 to 30 June.

Climatological Services

Weather affects most of our activities to some extent, and there is an increasing awareness of the importance of climatological studies in many aspects of economic and social planning. As a result, inquiries are becoming more complicated and diverse, and they are received from an ever-widening field of industries, public utilities and government departments and organizations. Thus, the Office has to be prepared to process and present climatological data in the form required to meet the design or planning problem of the particular industry or authority. The increasing use of the computer has helped considerably to meet this requirement and some of the more complicated inquiries could not have been tackled before the machine era. The Office continues to collaborate with other government agencies such as the Building Research Station, the Road Research Laboratory and the Warren Spring Laboratory. A meteorologist has been seconded to work at the Road Research Laboratory and similar arrangements are being made with the Building Research Station. The Office continues to be represented on the Interdepartmental Committee on Air Pollution Research and on the Working Group on Tees-side Mist.

One of the basic jobs of the Climatological Branch is the collection, examination, analyses, publication and preservation of surface and upper air observations which are the raw data used to answer inquiries. Data for the U.K. are published in the *Monthly Weather Report* and its *Annual Summary*, in the yearly publication *British Rainfall* and in other non-routine climatological publications. The maintenance of a satisfactory network of climatological stations depends to a great extent on the voluntary co-operation of private individuals, local authorities, river authorities, private firms, schools, public utilities, etc., and the Meteorological Office records its appreciation of the work done by these individuals and organizations.

The total number of inquiries continued to increase during 1967, and there was also an increase in the inquiries demanding machine methods. For instance, the frequency and severity of cold weather at three long-term stations were determined for various gas boards. On request from one of the major ice-cream manufacturers, an investigation was commenced to find out which weather factors affected ice-cream sales. A project, code word 'Jumbo', was launched to produce complete climatological statistics by computer for a network of hourly reporting stations. The results of 'Jumbo' will help to answer inquiries from industry and commerce, the building industry, public utilities, town and country planners, etc., and the visibility data are already being used by the Road Research Laboratory in a review of the problems relating to fog and road accidents. Advice on probable maximum wind speeds for the design of various structures, including a North Sea oil rig, and for building components was supplied to many organizations; many of these inquiries resulted from the publication in 1966 of a new *British Standard Code of Practice—Glazing and fixing of glass for buildings*. Further work was done for a British Standards Institution Committee on wind loading. After discussions, the Central Electricity Generating Board was supplied with information which could be used for estimating probable maximum wind speeds in a form suitable for the design of cooling towers. In a lighter vein, the author of a book on Dick Turpin was provided with information on the winter of 1734–35. Most of the inquiries were for the climate of the U.K., but a substantial number referred to other countries. For instance, upper winds over Algeria were supplied for research into the migration of birds, and data for East Africa were supplied in connexion with an investigation into water levels and fish catches in lakes and rivers.

An office in Edinburgh provides climatological services for Scotland and an office in Belfast carries out a similar function for Northern Ireland. Both offices are supported by the machine facilities available at Headquarters at Bracknell. The number of inquiries at both Edinburgh and Belfast continued to increase during 1967 especially in the building and construction fields. In Scotland, closer contact was established with university departments in architecture, town planning and allied subjects, and the Belfast office continued to work in close accord with the Ministry of Development (Northern Ireland).

In marine climatology, work continued for a British Standards Institution Committee on climatic hazards in the transport and storage of goods. Information was provided for the development of hovercraft services, and the Office was represented on the National Physical Laboratory Hovercraft Sea State Committee. A working group of the Ministry of Transport was advised on the meteorological aspects of using an immersed tube method of constructing the Channel Tunnel, as a possible alternative to a bored tunnel. A great deal of work was done on the preparation of annual marine climatological summaries for the World Meteorological Organization. During the year, the meteorological sections of a number of *Admiralty Pilots* were brought up to date.

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 771 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. 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 publication of the Ordnance Survey '10 miles to the inch' rainfall map of Great Britain, depicting annual averages for the standard period 1916–50, and of an explanatory text supplemented by monthly rainfall maps. A memorandum on monthly and annual averages of rainfall for Northern Ireland for the World Meteorological Organization period 1931–60 has been released and similar maps and tables for Great Britain have been prepared. This work has been done at the request of WMO for inclusion in their climatological atlas of Europe. At the request of the Central Statistical Office, areal averages of rainfall, 1916–50, have been computed for nine areas of England for use in tables of monthly and annual rainfall to be included in annual volumes of *Abstract of regional statistics* from 1964 onwards. Increasing use is being made of the computer COMET in processing data for publication.

The inquiries section handled over a third more inquiries than in 1966. As usual, the category of inquiries for which most requests for data were received was the legal and quasi-legal. In this category inquiries were mainly straightforward requests for data concerning accidents, motoring offences, damage to property and requests for data arising out of claims against insurance brokers. In this connexion mention should be made of the increasing number of inquiries concerning 'pluvius' insurance, insurance against bad weather whilst on holiday. A noteworthy feature of inquiries in 1967 has been the increased number from the building industry. Many of these inquiries have been concerned with time lost on contracts due to bad weather but a number have related to tendering and forward planning of contracts. A number of requests for assessment of general rainfall over catchment areas have been received, particularly with regard to proposed water supply schemes. Among these have been assessments of general rainfall over three areas in the Tamar basin (for a proposed water supply scheme for Plymouth Corporation Waterworks) over Lake Ennerdale (for the South Cumberland Water Board) in the Foyers area (in connexion with a hydroelectric scheme) over areas on Dartmoor (for the North Devon Water Board) and over Meggett and Yarrow Waters (for Edinburgh Corporation Waterworks). For this last inquiry, estimates of monthly general rainfall in the driest three years 1887–89 were also supplied together with estimates of monthly areal evaporation in the dry three years 1955–57. In connexion with the Chester Dee regulating reservoir project, estimates of general rainfall for a period of more than 50 years were supplied to the Water Research Association for a number of catchment areas in the upper Dee basin. Estimates of general monthly rainfall for the water year October 1965–September 1966 have been prepared for more than 350 catchment areas in Great Britain for publication in *Surface water year-book 1965-66*. The amount of work concerned with evaporation and soil moisture has grown considerably during the year and some of the biggest inquiries involving many weeks work have been in this field. Examples are assessments of average annual rainfall, potential evaporation and actual evaporation over chalk areas on the Chiltern Hills and North Downs for the Water Resources Board, similar data for the Lincolnshire River Authority and advice to the Kent River Authority on the calculation of percolation into chalk areas of north Kent. The amount of effective infiltration into three chalk areas in Lincolnshire for specified catchment conditions has been calculated for the Water Research Association. One of the most important investigations in which the Office is concerned arises from the proposal by the Thames Conservancy to pump underground water from the chalk and limestone hills into the Thames in order to supplement summer flow, it is hoped by up to 270 million gallons a day, the extracted water to be replaced by percolation of winter rainfall. The Meteorological Office is supplying estimates of rainfall and evaporation for the initial experimental area in the Lambourn valley, retrospectively and month by month for the duration of the scheme. Rainfall, evaporation and soil moisture deficit data were supplied to the Water Resources Board for publication in a *Groundwater year-book.*

The Office continued to issue maps of soil moisture deficit at intervals throughout the summer and autumn to river authorities, water engineers and similar interests.

The investigational section was increasingly involved in the expansion of effort being put into the science of hydrology, both nationally and internationally. It maintained its close liaison with the Water Resources Board, continuing its advisory work on networks for river authority hydrometric schemes and participating in the planning stage of the Chester Dee regulating reservoir research project as well as carrying out statistical analyses of monthly and seasonal rainfall sequences. The Office continued to be represented in the work of the International Hydrological Decade, both at the national level and at the meeting of the Co-ordinating Council in Paris in June. The Winchcombe investigation on intense rainfalls continued throughout the summer half of the year and data for 30 storms were collected. Sufficient data are now available for analysis and significant comparison with the results of the Cardington investigation, and the observational sites have been dismantled. Liaison was maintained with the Road Research Laboratory on the systematic design of urban storm water sewer systems and on problems of precipitation patterns over small catchment areas. Participation continued in the planning stages of the Institution of Civil Engineers' proposals for a comprehensive study of river floods in the U.K., whilst a major investigation of precipitation in the Trent area, including determination of probable maximum precipitation, is being carried out for the Trent River Authority as a contribution to their flood prevention projects. Two short studies were completed relating to Jamaican rainfall; the first was in connexion with an examination of groundwater resources in the Kingston area and the second a study of the famous 1909 storm. A probable maximum rainfall study was undertaken of the catchment area of the Legadadi dam near Addis Ababa and a map of long-term average rainfall was prepared as a contribution to a feasibility study of the possibility of further dam construction in the Aberdare Mountains in Kenya. Rainfall evidence was submitted before the Aberfan Tribunal in April. This took the form of a comprehensive study of the rainfall régime of the area. Special reference was made to outstanding occasions of very heavy rainfall during the last 100 years, and the degree to which heavy rainfall during the past three decades could be considered relevant to the series of landslides in the area, culminating in the Aberfan disaster. Work continues on the accurate measurement of rainfall at a point and on development of new rain-gauge systems. More work has been done on measurement of rainfall in a gauge on a mast 30 feet above the ground with a view to developing a satisfactory method of measuring rainfall at sea. Comparison tests of evaporation tanks are being carried out as part of a world-wide investigation organized by WMO. The section was represented on a Ministry of Housing and Local Government working party set up to advise on the technical aspects of the change to the metric system in relation to water supply and sewerage.

The Senior Scientific Officer attached to the Hydrological Research Unit has completed his survey of the previous work on evaporation from forests and has formulated proposals for comprehensive research into outstanding problems.

Services for Agriculture

A wide variety of problems involving the interaction of meteorology and agriculture have been dealt with during the year. Staff at headquarters in Bracknell, and at Bristol, Cambridge, Leeds and Edinburgh have carried out investigations into such subjects as shelter problems with reference to both crops and animals, the effects of weather on milk and crop yields, the selection of glasshouse sites, the incidence of frost particularly in the spring, and analysis of dry spells. A Senior Scientific Officer has been detached to Hurley to work with the Grassland Research Institute on problems of mutual interest. Further study has been made of methods of predicting the number of work-days possible on the land using various criteria of temperature and rainfall. Airborne movements of insects and spores have been assessed using trajectory and plume methods of calculation. About 25 branch memoranda have been issued dealing with these topics.

A very important aspect of the work is the degree of co-operation and consultation which exists between the meteorologists and research and advisory workers in agriculture. Many inquiries are received from research stations, experimental farms, universities and farm institutes, and experiments have been mounted in co-operation with them. Liaison has been maintained with the Plant Pathology and Veterinary Laboratories in connexion with the issue of warnings of potato blight, apple scab, and liver fluke in sheep. An officer was sent to Oswestry in November to participate in the investigations into the spread and control of the epidemic of foot-and-mouth disease.

Marine Branch

Regular weather observations from the oceans are necessary for weather forecasting in this country and for marine climatological purposes. Most of these observations are provided by merchant ships and the organization for obtaining them, which has been in existence for well over a century, is the responsibility of the Marine Branch. Table III on page 47 gives the present strength of the British Voluntary Observing Fleet. These ships make their observations on a world-wide basis wherever their voyages take them and transmit the relevant messages by radio to the appropriate meteorological service, e.g. when in the eastern North Atlantic to the British service, as part of an international scheme arranged by the World Meteorological Organization. The total number of British Voluntary Observing Ships taking part in this scheme represents about 1/6th of the world total of some 4500 observing ships belonging to various maritime countries.

During the year, 1013 meteorological log-books were received from selected and supplementary ships and 149 forms from auxiliary ships voyaging through oceanic areas where shipping is sparse. Valuable observations and radio weather messages continue to be received by radio from trawlers of the distant-water fishing fleets. The willingness of the owners and skippers of these ships to add our instruments to the many others they have in their small chartrooms is noteworthy; trawlers' meteorological log-books are almost invariably of a high standard despite the obvious difficulty of doing this work in such small ships in the frequent bad weather which they experience.

All this work is done entirely voluntarily by the ships' officers; recruitment of the ship and the supply of instruments and instructions is done by Port Meteorological Officers and Merchant Navy Agents, who maintain personal contact with the observing officers by 3-monthly visits. 'Excellent Awards' in the form of books were presented to the officers of 100 ships which were judged to have sent in the most useful and consistent observations during the year.

The greater freedom now allowed to the radio officer aboard a merchant ship in choosing the station through which he may clear a radio weather message resulted in more messages being received. A random sample of observations made during the period 1–7 June 1967 showed that out of 749 radio weather messages sent by 50 ships only 43 messages, less than 6 per cent, had to be broadcast as the remaining 706 were cleared point-to-point to specific radio stations ashore. This is an appreciable improvement compared with previous years. Most merchant ships only carry one radio officer who generally makes strenuous efforts to get the maximum number of weather messages transmitted.

The closing of the Suez Canal in June 1967 and the consequent rerouteing round the Cape of Good Hope of all ships on the Persian Gulf, India, Far Eastern and Australian trades improved the observational network from ships in the Indian Ocean but there were consequently fewer observations from the Red Sea and Mediterranean.

Valuable observations have been received during the year from H.M. ships, particularly the Hydrographic Survey ships, as well as from the Research ships *Discovery*, *Shackleton*, *John Biscoe* and *Ernest Holt*.

The British Weather Ships completed 20 years service in the North Atlantic during the year; the existing four ships have been in operation for about eight years and continue to give good service. These ships co-operate with French, Netherlands and Norwegian vessels in maintaining five weather stations in the eastern North Atlantic while a number of other countries make financial contributions towards the cost; weather ships of the U.S. Coastguard similarly man four stations in the western Atlantic. All these ocean weather stations are constantly manned, and hourly surface and 6-hourly upper air observations (to an average height of about 65 000 feet) are transmitted by radio. In addition the British ships make observations of solar and total radiation, of sea temperature and salinity at various depths down to the sea bed, and of magnetic variation, make deep soundings and do some biological work, including plankton sampling and fishing for squid. All four ships are now fitted with wave recorders.

All the weather ships provided routine navigational aids, communication facilities and air/sea rescue potential for transatlantic aircraft. Comprehensive air/sea exercises were carried out frequently both in harbour and at sea. RAF aircraft took part in some of these exercises and on four occasions they dropped, in watertight containers, urgently needed spare parts for the ship's electronic equipment, in addition to mail.

During the summer months the British ships on stations 'I', 59°N 19°W, and 'J', 52°N 20°W, embarked parties of Naval personnel to carry out a special series of bathythermograph soundings; during this period some 10 000 bathythermograph and 3000 temperature soundings were taken. In connexion with this exercise, the ships on duty at station 'J' maintained constant visual and radar contact with an oceanographic buoy for two months—a unique experiment in mid-Atlantic. This buoy enabled special ocean current observations to be made.

Since the transfer to the Central Forecasting Office last year of the day-to-day responsibility for sea ice work, more time has been devoted to the study of ice development. The Marine Branch retains responsibility for the production and issue of monthly ice charts. New recipients during the year include McGill University, the University of British Columbia, the Free University of West Berlin and Tokyo University. Permission was given to the American Geographical Society to display our ice charts in their New York headquarters.

The Marine Branch co-operated with the Central Forecasting Office in providing experimental weather-routeing during September for four merchant ships on westbound passages across the Atlantic.

A new edition of the ocean current atlas for the South Pacific was published during the year and publication of *The Marine Observer* each quarter continued as usual.

A considerable amount of time and effort had to be given to the revision of ships' meteorological codes, guides, log-books and other publications supplied to the Voluntary Observing Fleet in consequence of the changes in codes, authorized by WMO, which came into force on 1 January 1968.

Revision of the ocean current and sea-ice sections of six volumes of the *Admiralty Pilot* was completed during the year and the computer programming for the processing of all ocean currents data, much of which have already been put on punched cards, proceeded steadily.

There was an increase in the number of marine inquiries dealt with during the year, most of which were from solicitors, brokers and insurance companies. Amongst other technical questions, advice was given about various aspects of hovercraft and hydrofoil operation, cable laying in the North Sea, and the probable spread of oil during the *Torrey Canyon* incident.

Instruments and Observations

Robust instruments, able to withstand storage and transport hazards, suitable for quantity production and giving a uniform standard of performance from sample to sample, are necessary for the Office to obtain, with the required accuracy, the regular weather observations it needs to fulfil its national and international roles. Moverover the observational techniques have to be clearly specified and developed so that appropriate data to the required accuracy are obtained.

The Office is by far the largest user of meteorological instruments in the United Kingdom. The Instruments and Observations Branch is responsible for development and/or selection of instruments and observational techniques, drawing up specifications for manufacturing contracts, the technical progressing of these contracts, acceptance testing and calibration of instruments, installation of equipment or arrangements for this and for maintenance in service.

Instrument development and installation

Automatic recording on magnetic tape of temperature, humidity, wind run, rainfall, radiation, etc., as available from appropriate sensors, would overcome difficulties in obtaining data from remote sites (or from other sites at inconvenient times) for climatological and research purposes, and also the time-consuming task of hand analysis of autographic records. The development of such recorders has continued and encouraging results have been obtained with these devices in association with components of the new standardized rain-gauges and with radiation measuring instruments. The first operational systems have been installed.

Further work has been done on automatic observing systems to yield, on interrogation from a distant point, observations for use in forecasting. The automatic weather station at White Waltham was tested throughout the year and plans are being made for a more extensive trial of the system.

Cloud picture transmissions from U.S. satellites are a significant aid in weather analysis and thus in forecasting both at home and overseas. Five equipments for the reception of these pictures were installed during the year, including four overseas.

Three additional weather and wind-finding radars have been installed and brought into use and progress towards the completion of the installation of a further three has been made. The new 10-cm wind-finding radars, of which nine are now in service, are proving very satisfactory. Work continued on the new Mk 3b radiosonde and flight trials of the pre-production models are in progress.

The development of a number of individual instruments has continued. Among these are the laser cloud-base recorder, sonic anemometers, transmissometers and automatic dew-point hygrometers. Installation of a variety of observational instruments continued throughout the year and telemetry attachments are now available for conventional cloud-base recorders and anemometers. The Branch continued to give physical help and advice to other branches of the Office and to outside organizations.

Instrument testing and calibration

Table XV shows the number of instruments tested or calibrated. Although the total number of items shows a slight reduction, amounting to about 5 per cent, compared with 1966, there was an increase of over 50 per cent in the number of electronic and electrical instruments and components. This reflects the changing nature of meteorological instrumentation and the trend is expected to continue. Some work continued to be undertaken for outside authorities and a number of foreign students received training.

Thunderstorm location

The four U.K. based and three Mediterranean stations of the CRDF thunderstorm locating network continued to operate throughout the year. There was collaboration with the Radio and Space Research Station, Slough, and the Winkfield Tracking Station in experiments devoted to ionospheric research. Data were supplied to research workers at universities in the U.K. and overseas.

Surface observations

In the U.K. 85 surface observing stations report in international code every hour, day and night, throughout the year. A further 50 stations report every three hours. In addition 134 stations report at various times during each day of the year. Of this total of 269 stations, 120 are manned by full-time professional staff and 149 by voluntary observers most of whom have attended the Meteorological Office Training School course on observing.

Reports in plain language are received from 17 town offices of the Automobile Association, 25 police or fire service stations and 27 road maintenance depots located alongside the motorways.

Upper air observations

Upper air stations were maintained at eight locations in the U.K. and on four Ocean Weather Ships. Seven upper air stations were maintained overseas, all at RAF stations. One of the stations, at Aden, was closed in October but a new station opened in September at Masirah. A short sea trial was carried out to test the feasibility of carrying out radiosonde ascents from merchant ships. Table V summarizes the heights achieved by upper air ascents.

Regional servicing organization

This has continued to expand during the year to keep up with the increase in installed facilities. It is working at full stretch. In particular it has been necessary to set up a small section to deal solely with routine equipment, mostly employed in the communications role, in the Bracknell Headquarters building. The overall staffing situation has been considerably improved by the successful class-to-class transfer and subsequent training of a number of Scientific Assistants to become Radio (meteorological) Technicians.

International collaboration

Foreign students have continued to be trained in various aspects of instrument work, and advice has been supplied to Commonwealth and some foreign countries. In addition various equipments of U.K. manufacture have been accepted on behalf of Commonwealth countries.

Computing and Data Processing

Computing and data-processing services are centralized in one branch, Met.O.12, which operates the computing laboratory and punched-card installation and also provides a programming and consultancy service for all other branches of the Office. Training courses in computer programming are provided for a wide range of staff from many branches so that the writing of the necessary programmes for operations and research may be accomplished and also so that knowledge of machine methods of computing and data processing shall become more widespread through the Office. Computing and data processing continue to be fields in which the rate of technological advance is very high and it is an important responsibility of the Assistant Director in charge of the Branch to keep abreast of developments in equipments and techniques which may be of value to the Office.

COMET computing laboratory

The laboratory is equipped with an English Electric KDF9 electronic computer which was installed in the summer of 1965. Within the Office the computer is known as COMET. The computer is able to run up to four programmes simultaneously (i.e. it has a multiprogramming facility) and in 1967 the high-speed random access core store was increased from 16 384 to 24 576 words to enable more efficient use to be made of the multiprogramming facility so that the increased computer service which branches have demanded could be met. The standard peripheral equipment of COMET consists of six magnetic-tape units, three paper-tape readers, three paper-tape punches, one high-speed line printer, one magnetic-drum backing store containing 40 960 words and one punched-card reader. During the year an automatic line drawer, manufactured by Electronic Associates Limited, was installed as a special 'on-line' peripheral device. The laboratory also contains ancillary rooms with a range of tape editing equipment for punching of data and programme tapes and for 'off-line' printing from paper tape.

Throughout the year the computer has been operated round-the-clock except for periods of routine maintenance which currently aggregate 16 hours a week. On the whole, serviceability has been good but the air conditioning and power supply plants have been subject to some unserviceability which has hampered operations from time to time.

One of the main tasks carried out on the computer comprises operational numerical forecasting runs at fixed times. Between seven and eight hours a day are devoted to this work during four periods of intense computer activity. These numerical forecast runs consist of large programmes which occupy substantial parts of the core and drum backing stores and also keep the central processer busy for much of the run. Nevertheless, because of the increase of core store installed during the year and by a judicious choice of suitable programmes to mix with the forecast run it is possible now to use the computer in the multiprogramming mode throughout much of the forecast runs. Other important tasks are computations for research projects and for parts of the long-range weather forecasting routine, routine data processing (e.g. checking and processing rainfall data from about 5000 stations in the U.K.) and the preparation of tabular material for certain publications, e.g. *British Rainfall*. During the year the computer programme for the automation of the *Daily Weather Report* was recast and it is being further amended to deal with changes in codes due to be introduced on 1 January 1968. Good progress has been made with work to automate the *Daily Aerological Record* with effect from 1 January 1968. Work has continued on the build-up of a comprehensive general-purpose library of meteorological data on magnetic tape. Programming work to control the line drawer producing isopleths automatically on meteorological charts from values at grid points computed by the numerical forecast routines has made good progress. Because of delays encountered by the manufacturers in making the equipment work 'on-line' to COMET, site trials did not commence until the end of the year and it has been possible to make only limited tests of the computer programmes. Further testing will be required before the charts produced by the line drawer can be introduced operationally.

During the year two programming courses were given in the use of KDF9 Usercode language.

Punched-card installation

This installation is equipped with a range of modern punched-card machines, including automatic punches and verifiers, sorters, collators, tabulators, tape-to-card converter, etc. Since it was set up in 1920, a library of over 45 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 rate of punching British data is over a million cards a year and a selection of foreign data is obtained through international exchange. For some years the Office has utilized spare capacity at other governmental punching installations but this spare capacity will shortly cease to exist. Plans are being made for all punching to be done at Bracknell.

Punched-card machines are used for the simpler jobs of data processing which do not involve much calculation, such as frequency distributions, listing and tabulation of data, whereas the larger computing tasks from data on punched cards are programmed for and carried out on COMET.

Other activities—present and future

The prototype automatic plotter for weather charts which had been much delayed was delivered during the summer. Early experience with the plotter is encouraging and its experimental use is continuing. Plots of the weather over the British Isles produced on this machine are being sent by facsimile to outstations. Some modifications are being designed to improve the clarity of some plotted symbols. This is a pioneering effort and development is expected to continue.

Further planning of the specification of a more powerful computer system needed by the early 1970's was carried out and by midsummer the overall specification had been largely determined. Some planning of the computer requirements for the automation of meteorological communications was accomplished but the final computer requirements for meteorological communications could not be settled until further work on the redesign of the communications systems had been carried out. During the year a review of the needs of the Office for automatic data-processing (ADP) staff and of the policy best suited to meet those needs was commenced. In the latter half of the year representatives of several manufacturers of the largest scientific computers gave presentations of their existing large computers and some indications of their production plans for the near future.

TELECOMMUNICATIONS

The effectiveness of meteorological services is dependent on adequate and efficient supporting telecommunications services. It is only through the telecommunication services that the necessary basic data, such as observational data, can be collected and made available to meteorologists. Every country is expected to contribute data, particularly observational data, for the benefit of all and in turn there is a need to make data available to all.

Over the years the processing (analysing and forecasting) of meteorological data has become more and more centralized. Such centralization would not be possible without well-organized telecommunication services to disseminate the centrally processed data to places where it is required and where it can be translated into meteorological service of one kind or another.

The organization of meteorological telecommunications in relation to international aspects is a matter for WMO who balances the international and national meteorological telecommunication services so that the needs of all its Members, for both basic and processed data, are met to the best advantage.

The organization of meteorological telecommunications services in relation to national needs has to be complementary to that of the international organization.

The U.K., as a Member of WMO, has certain specific international responsibilities for the collection and distribution of basic and processed data.

Telecommunication facilities required by the Meteorological Office to meet both international and national responsibilities are normally obtained through the Director of Signals (Air), Ministry of Defence.

With the agreement of WMO the U.K. sub-regional high-frequency radio teleprinter broadcast, which has been in operation for many years, ceased with effect from 30 September 1967 and the regional broadcast is now the only meteorological radio teleprinter broadcast made by the U.K. This regional broadcast contains reports of weather observations over Europe and the North Atlantic. The change has been made in order to convert the radio teleprinter facility to facsimile working to cover the international demand for processed data from the Central Forecasting Office at Bracknell. When this facsimile broadcast becomes operational early in 1968 there will be two U.K. meteorological radio facsimile broadcasts, carrying between them processed data from the WMO Master Analysis Centre at Bracknell and from the North Atlantic Area Forecast Centre at London (Heathrow) Airport.

The Meteorological Communication Centre at Bracknell is also one of the seven European Centres of the International Meteorological Teleprinter Network of Europe. As such, it has a commitment to collect reports of weather observations made in the U.K., the Republic of Ireland, Iceland and Greenland, to collect reports made by three ocean weather stations in the North Atlantic and reports from merchant ships received via British coastal radio stations, and to transmit these reports into the network.

As regards national requirements, the Centre at Bracknell is responsible for the collection and distribution of data to meet the needs of the meteorological services centred at Bracknell and the needs of the meteorological offices throughout the country. The coverage of data collected is the whole of the northern hemisphere, the depth of coverage being greatest over the U.K. and adjacent areas. Collection and distribution are largely by teleprinters and land-line facsimile networks.

On 16 August 1967, the Weyhill transmitters for meteorological radio teleprinter broadcasts, under the control of the Director of Signals (Air), were transferred to Edlesborough. Much has depended and will continue to depend on the reliability of the meteorological radio teleprinter broadcasts, and the sound work of those staff at the transmitting stations contributes in no small way to that reliability.

A radio facsimile broadcast from Episkopi (Cyprus) was established on a routine operational basis on 1 November 1967.

The Aden territorial broadcast ceased with effect from 13 August 1967 and the Aden shipping broadcast ceased with effect from 30 September 1967.

Planning is now in hand for an automated meteorological telecommunications system, a system making greater use of modern telecommunication techniques, particularly in the direction of higher speeds of operation. An important development in this direction is the reception of North American observational data, transmitted at a speed of some 1200 words per minute (as compared with normal teleprinter working of 66 words per minute) via a cable/land-line telephone-type circuit Washington–Offenbach–Bracknell. This reception commenced in November 1967.

In 1956 the pressing need for a direct exchange of meteorological data between the meteorological offices of Canada and the U.K. was recognized and a cable circuit linking the meteorological telecommunications centres of the two meteorological services was agreed. The telecommunication service provided by this cable facility has proved of inestimable benefit to the Meteorological Office. However, with the opening of reception of data over the Washington–Offenbach–Bracknell circuit, it was decided to terminate the Montreal–Bracknell cable circuit with effect from 31 December 1967. This decision was reached with some considerable reluctance for it involved not only parting with an old and proven facility but parting with a direct link with the Canadian Meteorological Service.

International and Long-term Planning

The international character of meteorology inevitably leads to a number of international conferences each year. Most, but not all, of those in 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. The International Civil Aviation Organization (ICAO) deals with international questions affecting civil aviation and many of its meetings are concerned directly or indirectly with the meteorological aspects of civil aviation. Thirdly, various 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 with the promotion of one or other of the sciences or spheres of scientific interest, such as outer space, the oceans, the Antarctic, especially as regards international requirements. Meteorology has a part to play in many of these, and the Meteorological Office has membership of the corresponding British National Committees.

Delegates and representatives from the Meteorological Office at these various meetings are drawn from all parts of the Office according to the subjects to be discussed. An account of the principal meetings attended will be found in the 'International Co-operation' section (see page 71).

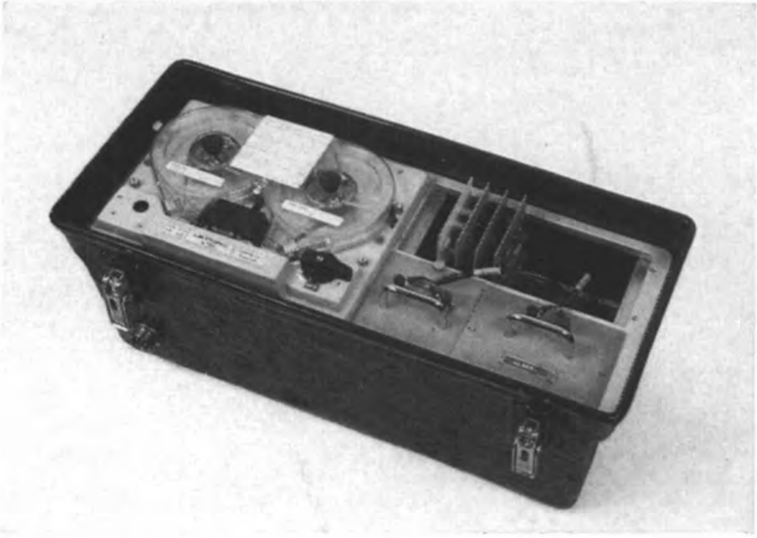
The Foreign Office, Commonwealth Office and Ministry of Overseas Development and other government departments regularly require advice or comment on administrative, financial and technical aspects of meteorological matters which arise in the general international field, particularly with respect to United Nations and WMO activities.

The Director-General is Permanent Representative of the U.K. with WMO. U.K. dependencies are included with the U.K. except for those which, having their own meteorological services, are Members of WMO on their own account

DELEGATES AT THE EIGHTH CONFERENCE OF COMMONWEALTH METEOROLOGISTS IN MAY 1967

Standing, left to right: Mr R. H. Clements (United Kingdom), Mr L. A. D. I. Ekanayake (Ceylon), Cdr R. K. Alcock and Mr J. S. Sawyer (United Kingdom), Mr E. G. Davy (Mauritius), Mr P. M. A. Bourke (Ireland, attending as an observer), Mr C. M. Taylor (East Africa), Mr R. Frost (Zambia), Mr G. J. Bell (Hong Kong), Mr K. V. W. Nicholls (the Caribbean), Mr V. R. Coles (United Kingdom), Dr G. O. P. Obasi (Nigeria), Mr G. M. D. Rudder (Barbados), Mr P. J. Meade (United Kingdom), Mr R. J. F. Andersson (Botswana). *Sitting, left to right:* Dr L. S. Mathur (India), Dr J. F. Gabites (New Zealand), Mr N. A. Akingbehin (Nigeria), Dr B. J. Mason (United Kingdom), Mr W. J. Gibbs (Australia), Mr J. R. H. Noble (Canada), Mr K. Rajendram (Singapore). (See page 71.)

PLATE II



MAGNETIC-TAPE RAIN RECORDER

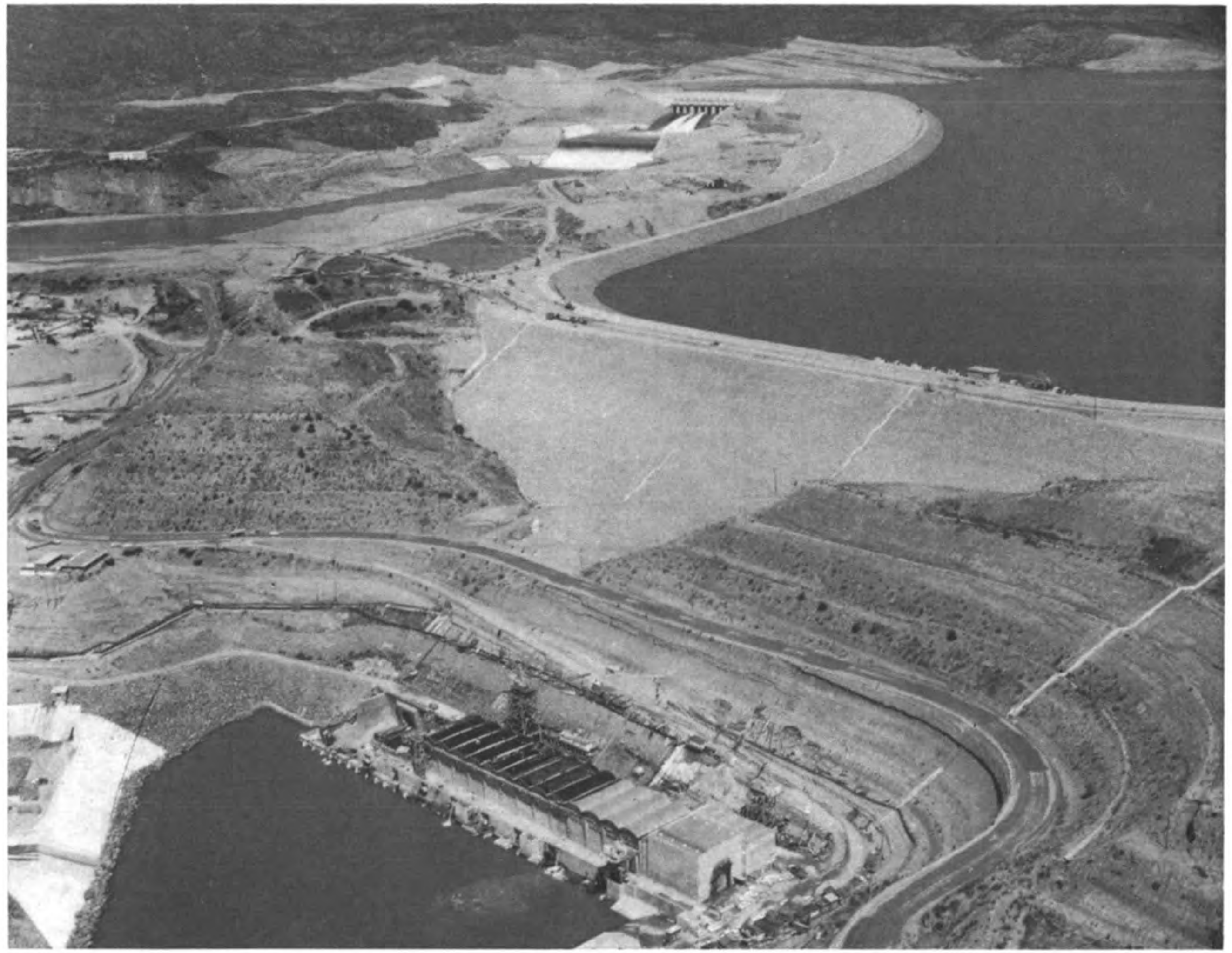
The top photograph shows the rain-gauge and the bottom photograph is of the tape recorder which is housed in a separate watertight box nearby.

Instruments of this kind are at present undergoing field tests in the Bracknell area prior to tests in more exacting sites. They will provide very detailed rainfall information (down to 2-minute intervals) in a form suitable for very rapid computer analysis, to supersede the old type of recorder with charts which require very slow and laborious manual analysis. Unlike the conventional rain recorder they will be usable in remote areas where frequent and regular visits are not possible (see pages 6, 7 and 11). (*Appendix B*, items 1.1.2., 1.1.6., and 3.1.)

INSTALLATION OF AN EVAPORATION TANK OF 20 SQUARE METRES AT KEW OBSERVATORY

The use of this large evaporation tank of a U.S.S.R. specification at Kew Observatory will form part of a series of international comparison trials under WMO. At Kew there will also be the smaller U.S.S.R. tank (3000 cm^2), the U.S.A. W.B. Class A pan, and the British standard tank. There will be more than one of each of the smaller tanks and the results of various methods of installation or exposure will be compared. Evaporation estimates will also be made from meteorological data (see page 8). Scientific staff seconded to the Hydrological Research Unit will take part in the work at Kew Observatory, and similar work (without a 20 square metre tank) will be carried out at HRU Wallingford (see page 9), Cardington and Eskdalemuir. (*Appendix B*, items 1.2.1. and 1.2.2.)

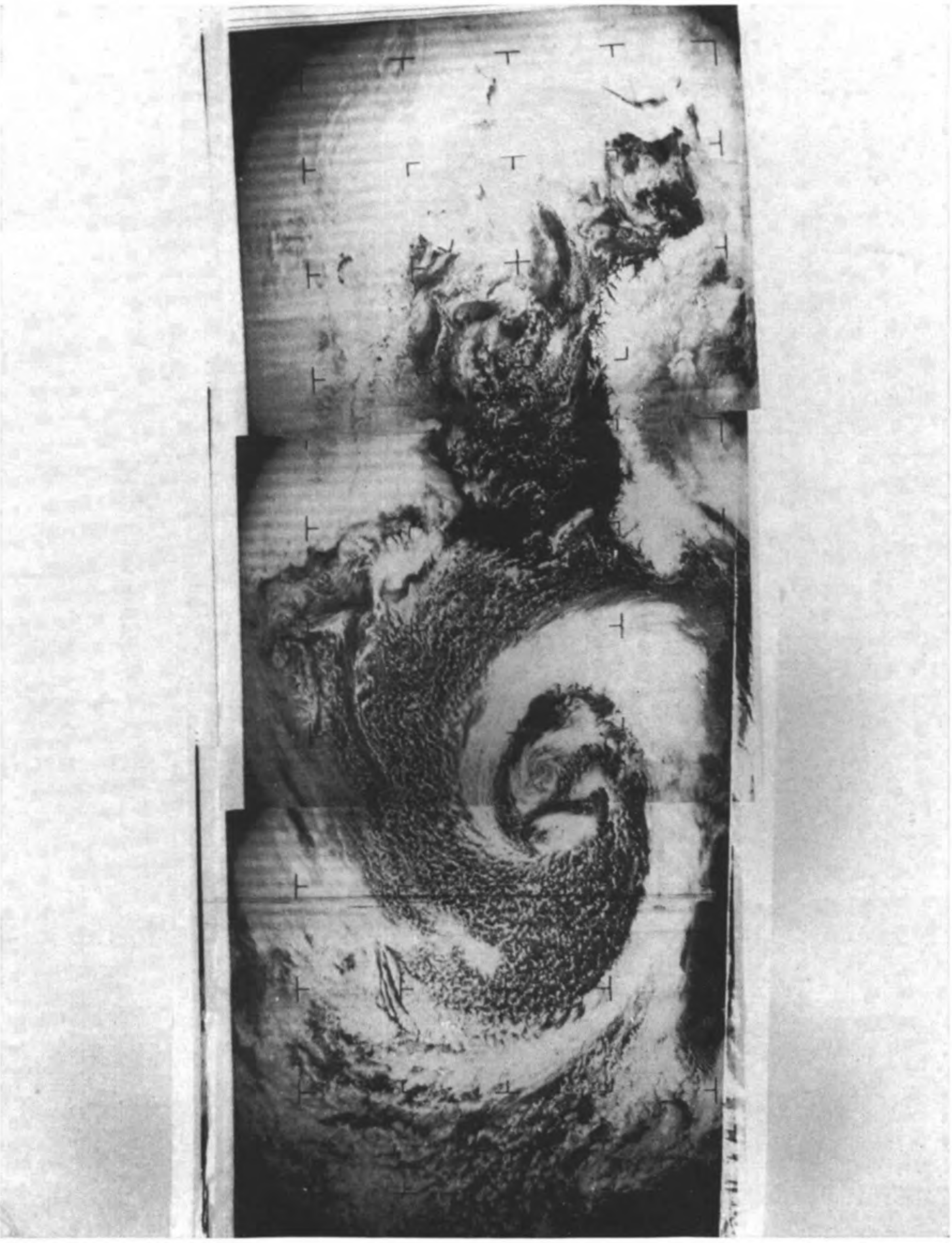
PLATE IV



Photograph by courtesy of Binnie & Partners

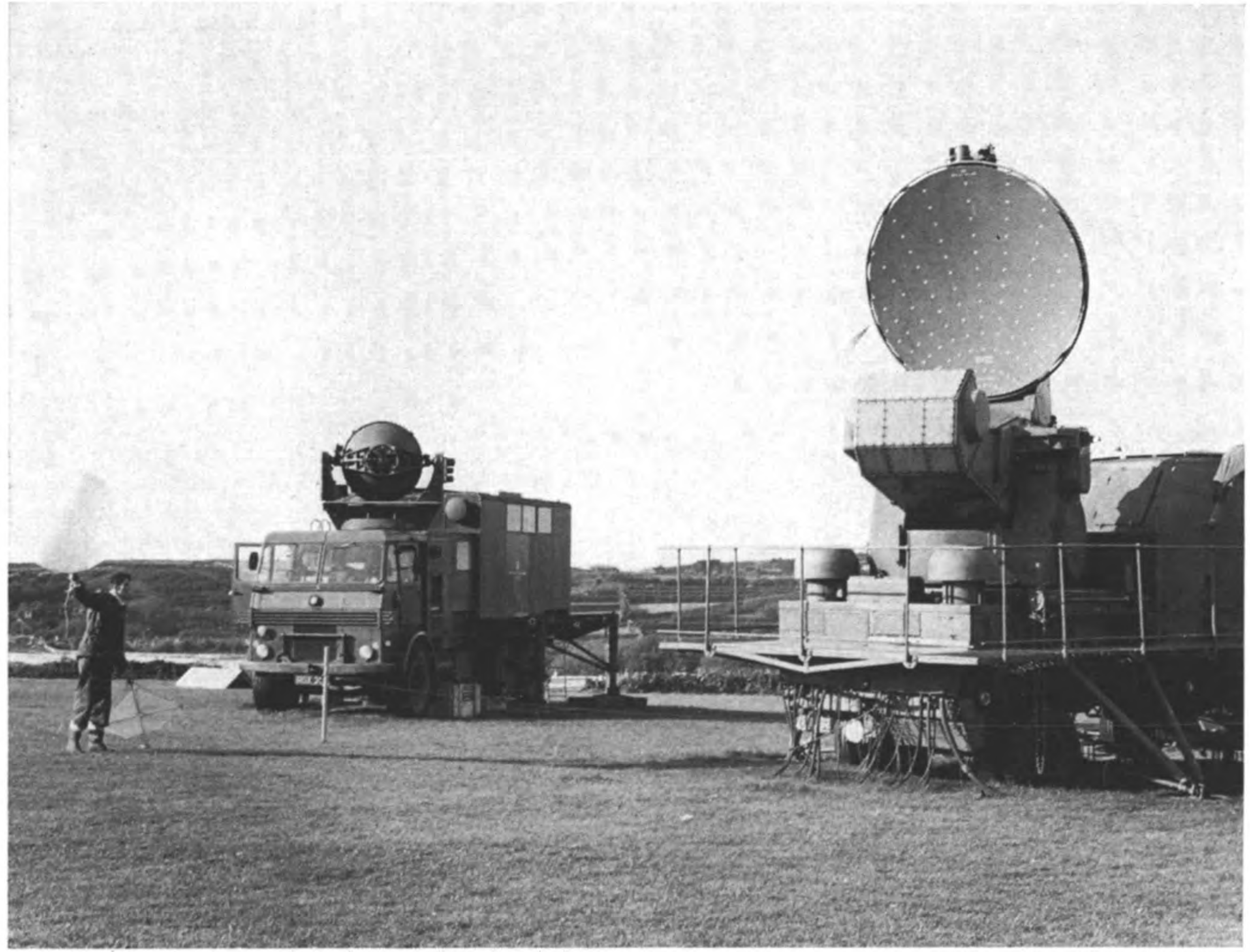
MANGLA DAM, PAKISTAN

On 23 November 1967 at Mangla, the President of the Republic of Pakistan formally inaugurated Phase I of the Indus Basin Project of the West Pakistan Water and Power Development Authority. The works inaugurated at this ceremony, including the dam, associated barrages and link canals for irrigation, form one of the largest civil engineering projects ever undertaken at one time. The photograph shows a view of the dam with the power station in the centre foreground and the main spillway (length 444 feet) near the centre background. In 1958 a scientist of the Meteorological Office working with a Consulting Engineers' hydrologist carried out studies on the probable maximum precipitation and the probable maximum flood as a basis for spillway design at Mangla. This was the first major study of the kind in which the Meteorological Office was involved (see page 11).



CLOUD PHOTOGRAPH FROM A WEATHER SATELLITE

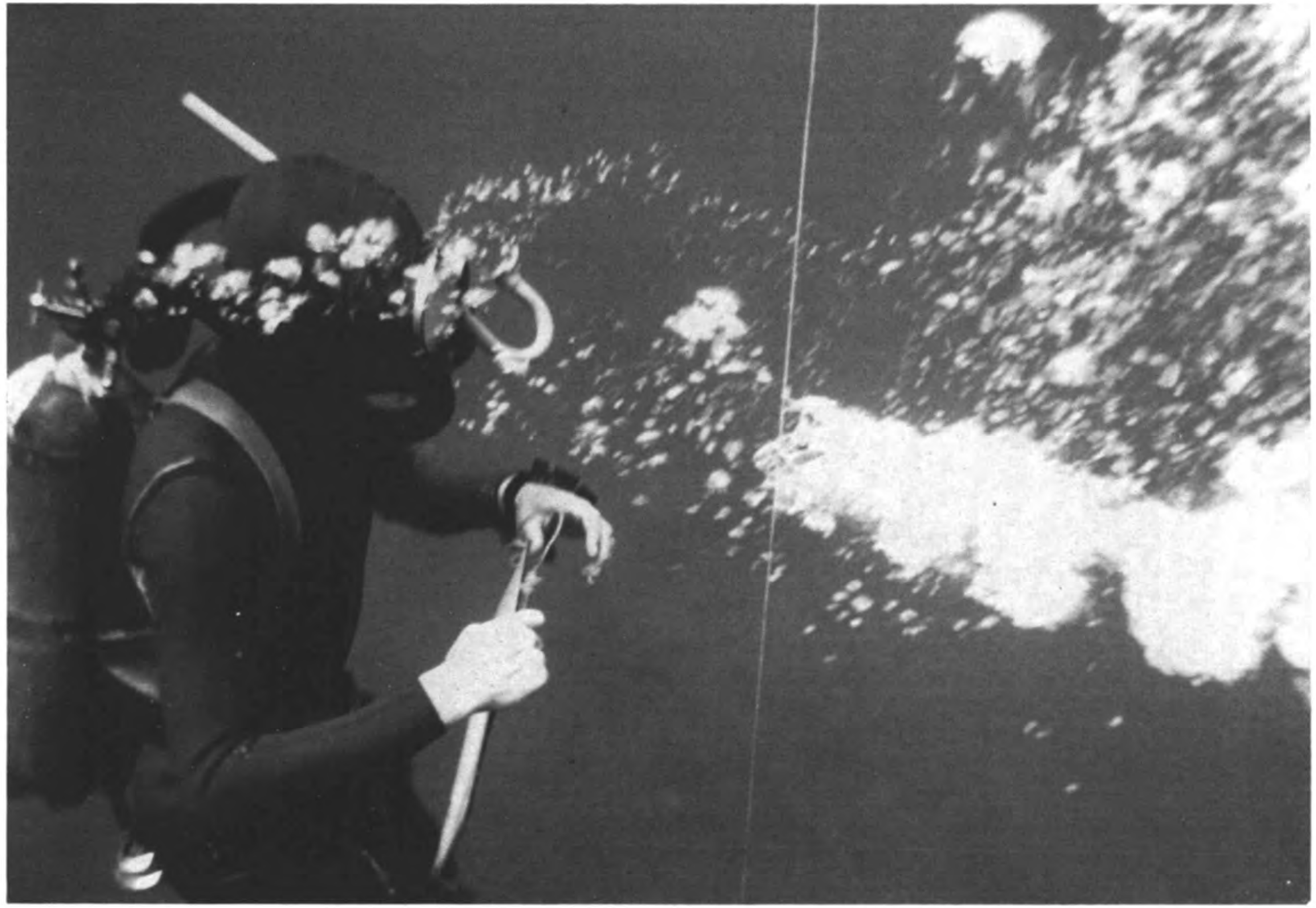
A complex depression and the associated frontal system lie over the British Isles. The North Pole is near the top left corner of the photograph and Scandinavia and Iceland are plainly visible. The picture was received at Bracknell Meteorological Office at 0922 GMT on 4 May 1967 from the automatic picture transmission of the U.S. weather satellite ESSA II on orbit 5452 (see page 19).



Photograph by K. A. Browning

RADAR AT ST MARY'S AIRPORT IN THE ISLES OF SCILLY

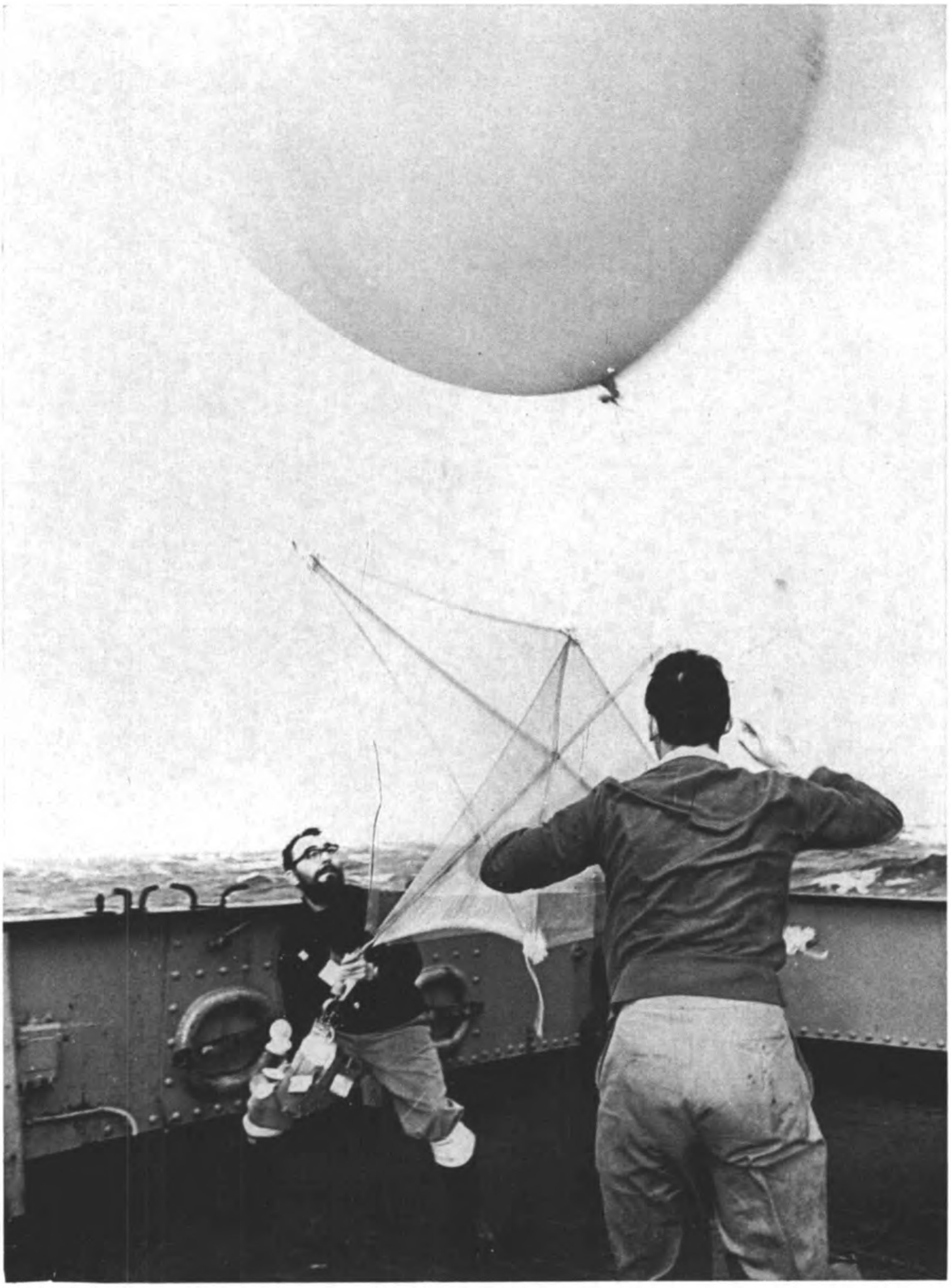
The radars will be used in a major project to study the structure and evolution of warm-frontal cloud systems (see page 62).



UNDERWATER STUDIES IN THE MEDITERRANEAN

A diver watches the turbulent plume emitted from a dye packet tied to a vertical shot line at a depth of 20 metres under the Mediterranean Sea off Malta. Photographs of these dye plumes provide a valuable insight into transport processes associated with internal waves in the sea and, by analogy, with similar processes in the atmosphere (see page 64).

PLATE VIII



Photograph by R. H. Brass

LAUNCHING A METEOROLOGICAL BALLOON FROM AN OCEAN WEATHER SHIP

Attached to the balloon is a radar target, used in the measurement of upper winds, and a radiosonde for the measurement of temperature, humidity and pressure to a height of about 60 000 feet (20 000 m).

(Hong Kong, Mauritius and British Caribbean Territories). The Director-General is an elected member of the WMO Executive Committee in a personal capacity. 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, the Secretariat acting as co-ordinator, so that as the international development of meteorology continually expands so the volume of work falling to the Members also expands.

The early part of the year was dominated by preparations for the Fifth World Meteorological Congress held in Geneva in April, and for the Conference of Commonwealth Directors held at Bracknell afterwards. The follow-up from Congress, while involving many matters arising from other Congress decisions, was in turn dominated by planning the activities to be undertaken by the U.K. as part of the World Weather Watch plan decided on by Congress. These activities include sharing in the necessary increase of observations from data-sparse areas of the globe, by providing more observations, both surface and upper air, from merchant ships and from land stations; offering the services of Bracknell as a Regional Meteorological Centre (forecasting and data processing) and as a Regional Telecommunications Hub on the planned main trunk circuit round the globe; and contributing both in cash and in kind to help set up necessary similar facilities in developing countries.

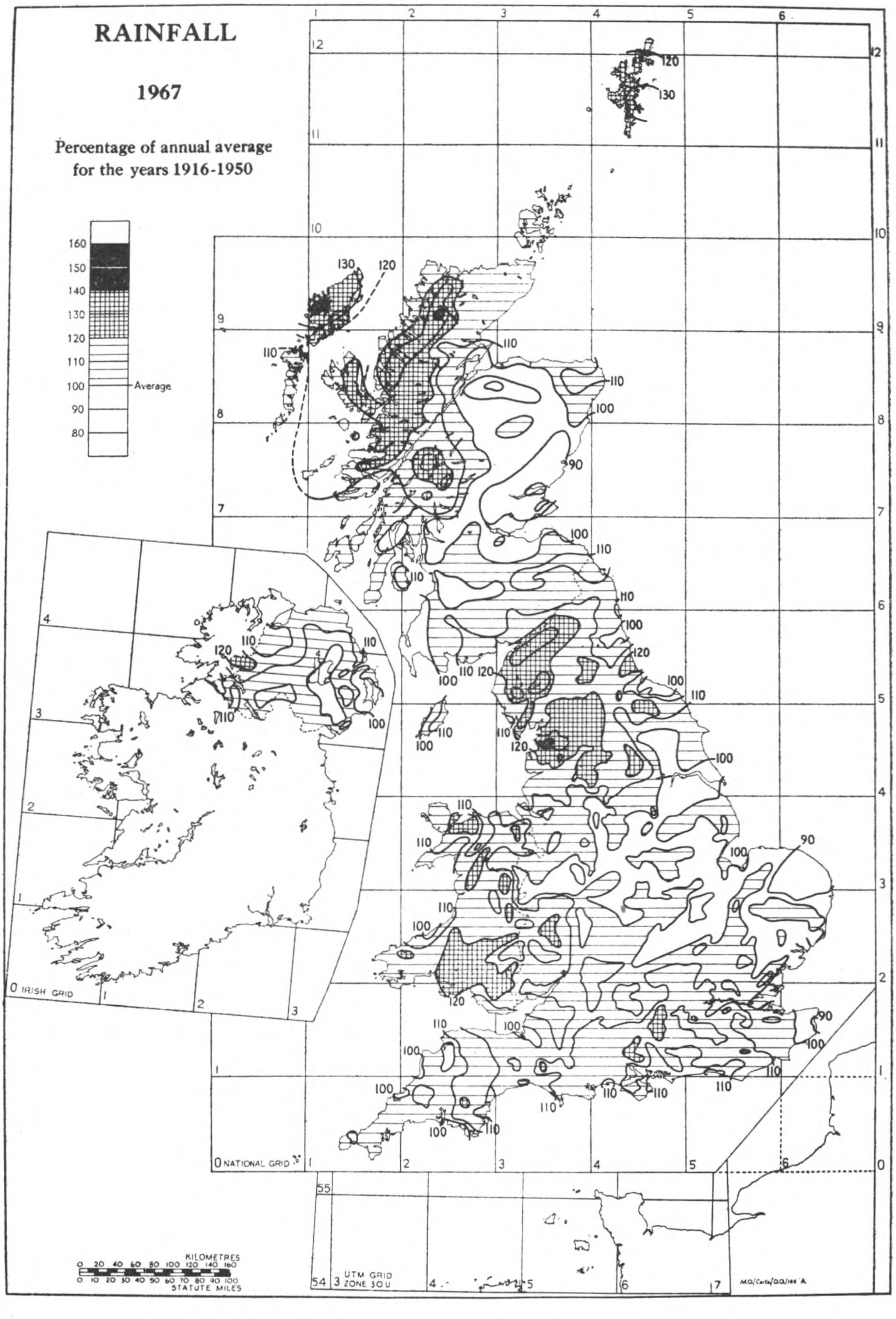
The selection of places for new upper air stations on some of the many ocean islands which are dependencies of the U.K. began with studies of costs and feasibility, and discussions with other interested parties, which continued until the end of the year. Other planning activities undertaken included the preparation of a comprehensive plan for the Office for the next 5 years, and the preparation of estimates of the accommodation needed in 10 years' time at the Headquarters in Bracknell.

Planning progressed for the WMO Scientific and Technical Conference on Aeronautical Meteorology to be held in London, 18–29 March 1968. A number of staff will contribute papers, and otherwise participate in the Conference.

P. J. Meade
Director of Services

Summary of the Weather of the Year (1967)

January opened with 10 days of cold northerly winds. Snow was fairly widespread in eastern districts on the 6th and 7th, and lay 5–7 cm deep in parts of East Anglia and Kent, but the coldest days were the 8th and 9th when much of Lancashire and Cheshire were blanketed by freezing fog. Temperature was above average for most of the rest of the month and weather became exceptionally mild during the last few days; in parts of southern England afternoon temperatures reached 13°C on the 27th, 28th and 29th. It was a generally dry and sunny month; rainfall was mainly less than the average



RAINFALL 1967

except in counties bordering the English Channel, and sunshine was above the average, except in northern Scotland where Forres had its dullest January since records began there in 1933.

February was mainly dry with good sunny periods at first, but became unsettled and stormy after about mid-month. The very mild weather at the end of January continued during the first two or three days of February, but was slowly replaced by colder conditions. Fog and frost were fairly widespread around dawn from the 11th to the 14th and there were some snow showers. Mild, unsettled weather during the second half of the month brought both temperature and rainfall above the average for the month. The 22nd, 23rd and 27th were particularly stormy days with periods of heavy rain; wind reached 70 kt in gusts on the 27th at places as far apart as the Lizard and Benbecula.

March was the third successive month with temperatures above the average in nearly all districts. The warmest periods were during the first 8 or 9 days and around the 20th, but temperatures were generally below average during the last week. The stormy weather of late February continued in Scotland for much of the first week of March, though in England and Wales weather was mainly sunny and dry. However, heavy rain and gales were widespread in southern England for a time during the second week, then it was sunny and dry again over most of England and Wales from the 13th to the 23rd, although weather in Scotland was unsettled with wind reaching gale force at times. Snow showers were reported around the 11th and between the 26th and 31st in England and Wales, and on most days, except during the third week, in Scotland. A feature of the month was the exceptionally stormy weather in north-west Scotland where parts of Inverness-shire and Wester Ross had four times their usual amount of rain. Over most of England and Wales, however, rainfall was below the average, except in the north-west, and south of a line from Bristol to London.

April was generally cool and dull with rainfall below the average except in eastern England. However, there were three warm spells, one around mid-month, another towards the end of the month and a third, which was mainly confined to southern England, around the 4th and 5th when afternoon temperatures reached 16°C at places near the south coast. Weather was mainly sunny and dry in Scotland during the second week, and over most of the British Isles from the 13th until the 21st, although northerly winds on the 18th brought a sharp fall of temperature and wintry showers. Weather was rather changeable from the 22nd, and there were long sunny periods in south-west England during the last week of the month.

May was an exceptionally wet month with frequent thunderstorms. Over England and Wales as a whole it was the wettest May since 1773, and rainfall was more than three times the average over large areas of northern England. At Manchester 86 mm (about 3·4 inches) of rain fell in 6 hours on the 11th. Sunshine and mean temperature were both below the average. In Scotland it was the coldest May since 1961, and many places from Braemar southwards recorded their lowest May sunshine for 30 years. There was a warm spell, however, over most of England during the second week when afternoon temperatures in parts of the south-east reached 26°C.

June was the third successive month with mean temperature below the average, and during all three months the deficit was greatest in east and north-east England. A warm, dry spell over northern districts which lasted from about the 10th to the 18th, was preceded and followed by two or three rather cold days. Most of the month's rainfall, which was below average in most districts, was confined to the last week. Sunshine was generally above the average except for a few areas near the east coast and in the extreme south-east of Cornwall. Some northern districts of Scotland had their sunniest June for more than 20 years.

July was a rather warm month generally over England and Wales, the excess over average temperature being greatest in the east Midlands and in east and south-east England. In Scotland, Northern Ireland and the extreme north of England, weather was unsettled for most of the month, but over most of the rest of the country it was generally warm, dry and sunny, apart from scattered thunderstorms, until the last week. On the 17th, the warmest day, temperature rose to 30°C (86°F) at places as far apart as London and Doncaster; this was also the warmest July day at Ross-on-Wye since 1959. Heavy thunderstorms caused widespread flooding in central and north-east England on the night of the 13th/14th, and in southern England on the night of the 22nd/23rd, when nearly 100 mm (4 inches) of rain were recorded in parts of west London. Over most of Sussex and Kent the month's rainfall was less than 25 per cent of the average. Sunshine was generally above the average except in western and northern Scotland.

August was unsettled and rather wet until the 19th, and then mostly fine. Mean temperatures were a little below the average but afternoon temperatures exceeded the average for a few days around the 9th and from about the 20th to the 28th. Rainfall was below the average over most of Scotland and over central and southern England, but above the average over England north of a line from about the Mersey to the Wash. A feature of the month was the thunderstorms, accompanied by torrential rain, in Lancashire on the 8th, 9th and 10th. Widespread flooding caused great havoc in the Downham/Burnley area, and damage in the Rossendale Valley was estimated at half a million pounds. On the 8th, Hornby, Lancashire, recorded 75 mm of rain in 115 min. Generally sunny weather from the 20th was insufficient to bring the sunshine up to the normal for the month, except in some coastal districts of Scotland and eastern districts of England.

September was an unsettled month and, in spite of a spell of mild weather during the last week, mean temperature was below the average. There was also a mild period of 4 or 5 days in northern districts around the middle of the month. Rainfall was below the average in eastern districts north of the Thames, but elsewhere it was above the average, particularly in the south-west; around Torquay and Bath it was twice the average. The second week was the driest in England and Wales, and there was little rain in Scotland between the 12th and 15th. Sunshine was mainly below the average, especially in the east and north; in the Shetlands, Lerwick had its dullest September since records began there in 1923.

October was very wet and frequently stormy. Rainfall was above average in all districts and more than twice the average over south-west Scotland, north-west England and over much of the Midlands. Heavy falls on the 9th led to flooding in south-west Scotland and the Lake District; Great Langdale (Westmorland) recorded 146 mm (5¾ inches) of rain in 24 hours. North Wales suffered considerable flood damage on the 10th, and also, together with parts of the Midlands, on the 16th, which was one of the wettest and stormiest days of the month; a gust of about 90 kt was reported from Whitby (Yorkshire). By the 25th, Morecambe (Lancashire) had already recorded its wettest October since 1896. Temperatures were mostly above average, the nights being particularly mild from the 7th until the 11th, but snow fell as far south as the Lake District on the 18th. Sunshine was also above average over most of Scotland and northern England where much of the rain fell at night. Glasgow had its sunniest October since 1881 in spite of it being the wettest October there since rainfall records began in 1886.

November was rather cold generally. The unsettled, stormy and rather cold weather of late October continued until 6 November. Rainfall was frequently heavy and wind reached gale force on most days during this period; 50 mm of rain fell at Brighton on the 4th and a gust of 73 kt was recorded at Whitby on the 6th. During the second week, after a foggy day on the 8th, troughs in a generally mild westerly airstream brought gales and periods of heavy rain to northern districts, but in the south rain was mainly slight. Northerly winds on the 15th and 16th brought a general fall of temperature, and from the 17th until the 24th weather was quiet, cold and dry with fog night and morning. Widespread rain on the 25th heralded a return of milder, unsettled weather which continued until the end of the month. Despite wet periods, the total rainfall of the month was below average except in northern Scotland and Northern Ireland. Sunshine was above average except in the extreme north of Scotland.

In *December* cold spells alternated with milder periods. Fog was widespread and locally dense on the mornings of the 1st and 2nd, and was slow to clear in the Midlands. Frontal rain and freshening wind in northern Scotland during the evening of the 2nd were associated with a deep depression near Iceland; during the night a rainbelt moved south-eastwards across the country and the 3rd was mainly fine. Winds over the British Isles then veered to north-west, reaching gale force at times on the 4th and 5th. A belt of rain moving southwards cleared southern England on the morning of the 6th. The rain was followed by five days of cold northerly winds which brought snow to all areas. From the 8th until the 11th temperature at one place or another remained below freezing all day. Rain was widespread on the 11th and continued for much of the 12th in south-east England. Temperature was about normal during the next two days and weather was mainly dry apart from some coastal drizzle and overnight fog. Rain was again widespread on the 15th and an area of snow extended southwards over the country on the 16th and 17th. Rain occurred in the south on the 18th but otherwise weather was generally sunny and cold from the 17th until the 20th with snow showers and night frosts. On the 21st south-westerly winds extended across the whole country and weather became mild again and rather wet and remained so until the 27th. A deep trough of low pressure moving slowly eastwards across the British Isles brought Kew its wettest Christmas Day for 20 years. During the last four days of the month winds were mainly north-easterly and weather became cold again with snow at times.

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 METEOROLOGICAL OFFICE STAFF AND OPERATING ON 31 DECEMBER 1967

	Within U.K.	Overseas
Principal Forecasting Offices associated with the RAF	1	—
Main Meteorological Offices associated with the RAF	8	6
Subsidiary offices associated with the RAF	42	13
Observing offices associated with the RAF	7	4
Principal Forecasting Offices associated with civil aviation	1	—
Main Meteorological Offices associated with civil aviation	3	—
Subsidiary offices associated with civil aviation	11	—
Observing offices associated with civil aviation	6	—
Upper air observing offices	8	7
Public service offices	6	—
CRDF offices	5	3
Port Meteorological Offices	5	—
Offices associated with the National Agricultural Advisory Service	3	—
Other offices	27*	7

*Eight of these stations are administered by D.R.Met.O.

Notes

A Principal Forecasting Office meets the needs of aircraft flying over very 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 U.K. operates four Ocean Weather Ships which work in rotation with two ships each from France, Netherlands and Norway/Sweden jointly. The British ships serve at four of the five ocean weather stations in the eastern North Atlantic; each vessel makes, on an average, 8 voyages a year and spends 24 days on station during each voyage. Some statistics for 1967 for the British Ocean Weather Ships are shown below.

Total number of days on station	722·1
Total number of days on passage	172·2

	Station A	Station I	Station J	Station K
	average number per voyage of 24 days			
Aircraft contacted	274	576	1418	315
Radar fixes to aircraft	269	503	1039	360
Weather messages to aircraft	40	100	144	0

TABLE III—MERCHANT NAVY SHIPS

A total of about 4500 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 these, 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 1967 the number of British ships reporting was:

Selected ships	479	
Supplementary ships	60	including 11 trawlers
Coasting vessels	95	
Lightships	13	
Trawlers	16	
Auxiliary ships	62	
Total	725	

The British Voluntary Observing Fleet includes ships of over 100 shipping companies; the numbers on the various routes are as follows:

U.K. to Australasia	99
U.K. to Far East	79
U.K. to Persian Gulf	35
U.K. to South Africa	33
U.K. to West Indies	40
U.K. to North America	90
U.K. to South America	21
U.K. to Pacific Coast of North America	11
U.K. to European ports	44
U.K. to Falkland Islands and Antarctica	2
World-wide tramping	85

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

	Reports	
	June	*December*
Direct reception from:		
British ships in eastern North Atlantic	112	104
Foreign ships in eastern North Atlantic	13	19
British trawlers in North Sea	12	10
British merchant ships in North Sea	10	17
Total	147	150
Reception via other European countries:		
Ships in eastern North Atlantic	581	337
Ships in Mediterranean	61	98
Ships in North Sea	97	113
Ships off North Russia	47	41
Ships in Pacific	143	135
Ships in other waters	123	86
Total	1052	810
Reception via North America:		
Ships in North Atlantic	554	342
Ships in North Pacific	520	494
Ships in other waters	93	46
Total	1167	882

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 U. K. (including Meteorological Office stations) were distributed on 31 December 1967.

	STATIONS					AUTOGRAPHIC RECORDS		
	Observatories	*Synoptic*	*Agro-meteorological*	*Climatological*	*Rainfall**	*Sunshine*	*Rainfall*	*Wind*
Scotland, north	1	11	0	26	326	24	8	11
Scotland, east	0	10	9	66	579	49	16	11
Scotland, west	1	13	3	50	509	32	17	13
England, north-east	0	11	4	24	430	27	15	10
England, east	0	12	13	19	516	29	27	10
England, Midlands	0	13	19	48	1292	61	44	8
England, south-east (including London)	1	18	20	50	818	65	94	17
England, south-west	0	12	8	31	554	32	10	5
England, north-west	0	5	4	25	483	25	20	13
Wales, north	0	2	3	16	282	10	4	2
Wales, south	0	4	9	15	348	21	8	6
Isle of Man	0	2	0	1	18	3	1	2
Scilly and Channel Isles	0	3	0	4	20	7	0	2
Northern Ireland	0	9	6	43	318	24	24	9
Total	3	125	98	418	6493	409	288	119

* 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.	5636	90·9	67·5	33·9	8·2	54·6
Seven stations overseas	4602	95·3	77·3	45·8	4·2	31·4
Four Ocean Weather Ships	1410	85·8	54·8	20·4	0·4	—

(*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.	11 325	85·5	58·4	21·2	3·9	48·5
Seven stations overseas	8190	87·2	62·3	28·8	2·8	32·2
Four Ocean Weather Ships	2783	73·8	40·4	13·1	0·4	—

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 either coded messages or facsimile charts. The coded messages are composed of groups of five figures and there may be from five to ninety such groups in one message. The messages are exchanged by radio and land-line. The following figures give an analysis of the traffic through the Meteorological Office Communications Centre for one typical day (24 hours) taken near the end of December 1967 and, for comparison, some corresponding figures for one day near the end of 1966.

	In	Out	Total	Total in 1966
Coded messages		*number of groups in one day*		
Land-line teleprinter	437 192	313 585	750 777*	606 587
Radio	177 809	233 535	411 344†	356 853
Facsimile charts		*number of charts in one day*		
Land-line	108	391	499‡	174
Radio	67	122	189	183

* Increase due to the reception of North American data via the medium-speed cable link Bracknell–Offenbach–Washington.

† Increase due to the relay of North American data via Birdlip to Iceland. An increase due to the relay of Bracknell Regional RTP broadcast (GFL) to Gibraltar was offset by the closure of the Bracknell sub-regional RTP broadcast (GFA).

‡ Increase due to three causes:
(i) The relay of numerical forecast charts to London (Heathrow) Airport, Bomber Command and Air Support Command.
(ii) The relay of London Airport area forecast system products to De Bilt, Paris and Offenbach.
(iii) The receipt of Washington products via the cable link Bracknell–Offenbach–Washington.

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is a need for forecasts of a particular type at certain seasons. These are described in Met.O. Leaflet No. 1. 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)	1966	566	1967	519
Week-end temperature forecasts (a winter service primarily for industrialists) ..	1966–67	39	1967–68	38
Snow and icy road warnings (primarily for local authorities)	1966–67	261	1967–68	290

TABLE IX—FORECASTS FOR AVIATION

Forecasting for aviation constitutes the primary function of many of the offices. The Central Forecasting Office is almost solely 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 which took place during 1966 and 1967. They do not include warnings and routine general forecasts.

	1966	1967
Number of meteorological briefings for		
aviation in the U.K.	347 648	365 534
aviation at overseas stations	69 537	52 042
Number of aviation forecasts issued for		
aviation in the U.K.	979 659	1 039 703
aviation at overseas stations	302 278	295 632

TABLE X—NON-AVIATION INQUIRIES

Non-aviation inquiries are handled by five weather centres specially established in London, Manchester, Glasgow, Southampton and Newcastle 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 telephone requests for forecasts and other weather information, from the general public, public corporations, Press, commercial firms, etc. (The *Post Office Guide* lists 40 offices providing forecasts for the general public.) Most of these inquiries refer to current or future weather and are listed according to the purpose of the inquiry in the figures below. Climatological inquiries are dealt with in Table XIII.

	1966	1967
Grand total of inquiries (all figures)	1 204 921	1 264 605
Percentage of inquiries connected with		
agriculture etc.	11·1	10·4
building, commerce, industry	10·3	11·3
holidays	18·3	18·3
marine matters	16·6	17·6
Press	8·9	9·3
public utilities	8·6	8·2
road transport	10·4	9·6

TABLE XI—BBC FLASH WEATHER MESSAGES

FLASH weather messages are passed to the BBC for broadcast on Radio 2, 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 1967.

Area	Dense fog	Moderate or heavy snow	Very heavy rain	Glazed frost	Icy roads
Edinburgh	2	—	—	1	—
Central Clydeside	2	—	—	1	—
Belfast	—	1	—	—	—
Tyneside	2	—	1	—	—
Merseyside and south-east Lancashire	6	—	1	1	—
Industrial Midlands	1	1	3	—	—
Bristol	—	—	2	—	—
Industrial south Wales	—	1	5	—	—
London	—	1	1	—	1
Southampton/Portsmouth	—	—	1	—	—
Plymouth	—	1	2	—	1
West Riding	1	—	1	—	—
Total	14	5	17	3	2

In addition one warning of heavy rain of a more general nature was issued.

TABLE XII—AUTOMATIC TELEPHONE WEATHER SERVICE FORECASTS

The total number of calls made on the service during 1967 showed a decrease of 13 per cent over the previous year. Forecasts were made available at 11 more GPO Information Centres bringing the total of such Centres to 36. The number of forecast areas increased from 19 to 22.

Information Service Centre	Forecast area	Number of calls 1966	Number of calls 1967	*Opened*
London	London	3 585 999	2 553 294	
London	Essex coast	192 330	141 171	
London	Kent coast	180 800	138 472	
London	Sussex coast	247 593	208 765	
Colchester	Essex coast	137 244	144 411	
Brighton and Hove	Sussex coast	255 007	274 738	
Birmingham	Birmingham	510 967	430 022	
Liverpool	South Lancashire and north Cheshire	243 713	220 917	
Liverpool	Lancashire coast	80 748	68 746	
Liverpool	Chester and north Wales coast	56 335	54 747	
Manchester	South Lancashire and north Cheshire	302 536	277 511	
Manchester	Lancashire coast	57 302	56 157	
Manchester	North Wales coast	31 098	32 495	
Cardiff	Cardiff	272 877	218 771	
Belfast	Belfast	311 684	207 665	
Glasgow	Glasgow	367 858	317 938	
Edinburgh	Edinburgh	318 596	268 553	
Bristol	Bristol	304 494	273 374	
Portsmouth	South Hampshire	165 895	150 897	
Southampton	South Hampshire	194 675	176 154	
Canterbury	Kent coast	118 396	110 598	
Blackpool	Lancashire coast	153 227	144 261	
Southport	Lancashire coast	55 290	49 502	
Plymouth	South Devon and east Cornwall	61 359	105 175	
Exeter	South Devon and east Cornwall	46 699	58 332	
Newcastle	Tyne, Tees	195 660	185 450	
Blackburn	Central Lancashire	58 634	75 370	
Blackburn	Lancashire coast	25 656	40 246	
Bournemouth	South Hampshire	43 281	77 387	March 1966
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	51 586	135 564	March 1966
Leicester	Nottinghamshire, Derbyshire, Leicestershire	30 732	84 732	March 1966
Middlesbrough	Tyne, Tees	24 301	57 585	June 1966
London	Thames Valley	10 026	75 468	October 1966
Oxford	Thames Valley	8841	58,708	October 1966
Colwyn Bay	North Wales coast		25 438	May 1967
Gloucester	South-west Midlands		23 249	May 1967
Cheltenham	South-west Midlands		11 420	May 1967
Tunbridge Wells	London		6914	May 1967
Southend	Essex coast		12 981	August 1967
Chelmsford	Essex coast		7881	August 1967
Bedford	40 miles radius of Bedford		15 246	September 1967
Reading	Thames Valley		14 931	October 1967
Hereford	South-west Midlands		1238	November 1967
Bradford	Leeds, Bradford		1285	December 1967
Leeds	Leeds, Bradford		5482	December 1967
Total		8 701 169	7 599 241	

TABLE XIII—CLIMATOLOGICAL INQUIRIES

Most of the inquiries dealt with by the offices outside Headquarters refer to current weather or to forecasts. 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 arising from various categories.

	1966	1967
Total number of climatological inquiries	11 006	12 533
Percentage relating to		
agriculture (farming, forestry, market gardening)		12·9
building and design (including siting)		16·3
commerce (sales, marketing, advertising)		4·1
education and literature		6·4
industrial and manufacturing activities		6·4
law (damage, accident, insurance)		16·9
Press and Information Centres		3·8
research		5·4
water supplies		7·9

TABLE XIV—DATA PROCESSING

(*a*) Punched-card installation

Number of cards punched by the Meteorological Office installation	1 073 800
Number of cards punched elsewhere on behalf of the Meteorological Office	227 700
Number of cards converted to paper tape	1230
Number of cards converted from paper tape	400 837
Number of non-routine investigations completed	153

(*b*) Computer installation

The electronic computer COMET was used for computing during 7117 hours.

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	55 506
Balloons	57 365
Radiosonde batteries	20 940
Radar reflectors	33 323
Electrical/electronic instruments and components	64 802
Radiosondes	15 992
Total	247 928

In addition 2333 radiosondes were recovered after flight and 86 per cent of these were repaired and recalibrated for further use.

THE DIRECTORATE OF RESEARCH

Special Topic—The General Circulation of the Atmosphere

An observer out in space studying the movement of cloud systems over the earth would soon discover that our atmosphere moves in a highly organized manner in fairly well-defined patterns. He would observe systems which have a life history of a few days, these being the disturbances which provide most of the day-to-day weather, at least in middle latitudes, but careful observation over a period would indicate that these disturbances are superposed on a basic flow which changes only slowly. In discussing this basic flow we speak of the 'general circulation of the atmosphere'. This term may be defined in various ways if we wish to be more specific, but for the purpose in hand we may regard it as the long-term average global circulation together with some specification of its annual evolution and variability. The long-term average circulation determines the distribution of climate over the earth, the annual cycle gives rise to the seasons, and the short-term variability provides the day-to-day weather.

The average motions and their annual evolution are remarkably stable in the sense that the coming of winter after each summer can be predicted with certainty. However, the motions of the atmosphere are subject to fluctuations on all time scales. For example, the differences between the winter of one year and that of another can properly be regarded as due to fluctuations of the general circulation about its average state; it is not essential that an external cause of these differences should be looked for, such as a change in the output of energy from the sun. It may well be that even the ice-ages of the past were the result of extreme but nonetheless natural fluctuations without specific extraterrestrial cause.

The broad division of the circulation zones of the globe into equatorial doldrums, subtropical trade winds, mid-latitude westerlies, etc., will be recalled by many as a part of the school geography syllabus but this is, of course, a very crude and incomplete description. To make possible a more fundamental understanding we require a much fuller description of the circulation and, in particular, one which treats the circulation three dimensionally. A great deal of diagnostic and descriptive work has been carried out since World War II, making use of considerable observational data, both surface and upper air, over the whole globe. The major effort of this kind undertaken by the Meteorological Office was the production of material illustrating the monthly mean flow of the atmosphere over the globe at several levels from 3 km to 16 km for each of the four seasons. This has proved to be invaluable descriptive material, both for research purposes and for various airline planning activities on a world-wide basis. However, because of the large and sudden changes which take place between April and July in certain tropical regions subject to monsoonal influences, it is not possible to interpolate successfully between the seasonal mean flow charts. Additional charts have therefore been prepared for much of the tropics and sub-tropics for 10-day periods during May and June in order to study in detail how these changes take place and how they differ from year to year. These have shown that a large and rapid northward movement of the subtropical westerly jet stream takes place each year over Asia, usually about the end of May or early June, whilst at the same time the equatorial easterly current in the upper troposphere expands northwards and increases markedly in strength. This large-scale change is accompanied by changes in the lower troposphere; the most marked and well known of these is the onset of the south-west monsoon over India. Associated effects are observed over Africa and the west Pacific but elsewhere over the globe such effects are generally small.

Another important extension of the original work has been the production of charts describing the climatology of the 50-mb (approximately 20 km) level, mainly in order to meet the modern needs of aviation for descriptive material about the lower stratosphere. These charts have proved very useful in portraying features of the general circulation which are either specially evident in, or are principally confined to, the stratosphere. Among these are the winter system of strong westerly winds over middle latitudes, known as the polar-night vortex, and its breakdown in spring which often leads to a complete change in the wind system over a few days together with a remarkable warming exceeding 40 degC in some areas. Also of interest are the persistent Aleutian warm area and the mid-latitude warm belt in winter, the polar high in summer, the change-over from stratosphere westerlies in winter to easterlies in summer (and the reverse in autumn) and the so-called '26-month' fluctuation in tropical stratospheric winds in which easterly winds one year are replaced by westerly the next. Although some of these features have now been very fully described, much remains to be done in determining how each fits into the overall scheme of the general circulation. The bi-modal nature of stratospheric winds generally, necessitates special treatment in devising a statistical description of the flow properties. Further work now in progress is directed towards extending the work to the 30-mb (approximately 24 km) level over the northern hemisphere and, in addition, studies are being made which attempt to link events in the stratosphere with those in the troposphere.

The International Geophysical Year (1958) resulted in the accumulation of additional meteorological data over the globe, and as its contribution to the analysis of these data the Meteorological Office undertook to prepare aerological cross-sections depicting the spatial distribution of wind, temperature and humidity from the surface of the earth to an altitude of about 30 km and around the entire latitude circle at 30°N. The cross-sections have been prepared for each day of the months March, June, September and December 1958 and the first three volumes have already been published. These detailed and carefully analysed maps form a unique series which presents the data in a form suitable for a variety of dynamical or climatological studies, and a number of such investigations have already been conducted using these data.

The analytic and descriptive studies of the general circulation, of which the foregoing provide examples, have now established a fair qualitative, and to an increasing extent quantitative, description of the circulation; but this alone leaves unanswered many fundamental questions. Thus, having established that the global circulation is organized in a certain fashion it is a proper scientific question to inquire *why* it is so organized, and one of the main aims of present-day research is to achieve a mathematical description and theory. Thus we may pose the question: can we predict from the laws of classical physics, as applied to the atmosphere, that the average circulation is necessarily organized as it is? This is not merely an intriguing academic question, because, if we can succeed in predicting the average circulation, there might be some hope of predicting, say, the general character of the next month or the fluctuations about the average state which give rise to the marked differences between corresponding seasons of different years. Moreover, a quantitative understanding of the atmospheric circulation is an essential prerequisite if we are to form a realistic assessment of the effect of any action proposed to control weather or climate—and with man's developing technical resources such proposals are now being seriously made.

Clearly unless the side effects and repercussions of such an interference could be assessed with complete confidence it would be highly dangerous to permit experiments in climate modification; it would clearly be useless to improve the climate of one area if the penalty were to convert fertile areas elsewhere into deserts. However, although this is an exciting justification for research into the general circulation, it is the potentially rich pay-off in the field of long-range forecasting which provides the immediate practical stimulus.

What drives the general circulation? It is of course the heat energy from the sun. The earth, being a warm body floating in space, is continuously losing heat by radiation, mostly in the infra-red region of the spectrum, and in the long term there must be a balance between this loss and the incoming solar energy, otherwise the earth would become steadily hotter or colder. The earth's atmosphere behaves as a vital buffer in this process—it is nearly transparent to the sun's radiation but it prevents most of the earth's long-wave radiation from being re-radiated directly to space. Were this not so, the average surface temperature of the globe would be below freezing instead of about +15°C as it is. (In contrast the average surface temperature of the moon, which has no atmosphere, is near freezing with a range of about 250 degC.)

Although there is a global long-term balance between incoming and outgoing radiation there is in fact an excess of incoming radiation in the zone from the equator to about latitude 40° and a deficit from there to the poles. Why then do the tropics not become even hotter and the polar regions colder? The answer is provided by the general circulation itself which is organized so as to convey to higher latitudes heat accumulated in the tropics; it provides the means for stirring up the global atmosphere on a grand scale and so preventing the differences in climate from equator to poles being even greater than they are.

In our latitudes the familiar depressions play a major part in performing this essential mixing-up process. At any one time there may be a dozen or so depressions in each hemisphere acting in concert to transport billions of tons of mild air towards high latitudes and polar air equatorwards. At the same time the depressions provide much of the rainfall of temperate latitudes.

In low latitudes the mechanism is more subtle. The excess heating in the equatorial zone gives rise to irregular thundery rains and indeed there may be 1000 or more major thunderstorms in progress at any one time over the globe, most of these being in the equatorial or tropical regions. These storms convey heat to the upper atmosphere; in fact the average vertical motion of the air near the equator is a gentle rise. In consequence of this upward trend the air moves towards the equator at low levels and away from it at high levels. The rotation of the earth exerts its influence on these horizontal currents, giving the low-level equatorward current an easterly component and the upper current a westerly component. The low-level easterlies so formed are the trade winds and the upper westerlies constitute the subtropical jet stream. The circulation described is completed by a gently descending average current in latitudes 30° to 40°. This is known as the Hadley cell, after the 18th century scientist who first suggested it as an explanation of the trade winds. Most of the earth's deserts occur in the region of the descending branch of the Hadley cell, for descending motion warms the air and results in an absence of clouds and rain.

To some extent the large-scale motions of the atmosphere may be studied by means of laboratory experiments in which a fluid contained in a rotating vessel is differentially heated. Clearly the extent to which such a model can simulate realistically the behaviour of the atmosphere under the control of gravity, rotation and differential heating is limited. Nevertheless in the hands of shrewd experimentalists useful insight into the properties of atmospheric motions can be gained and a fluid dynamics laboratory is in process of being set up in the Office under the direction of one of the foremost experts in this field, Professor R. Hide, who has recently joined the staff.

An alternative line of attack, which is now being actively pursued by a number of research groups throughout the world, is to set up the mathematical equations governing the motion and heat balance of the atmosphere and to solve the system numerically on an electronic computer. This is the line being followed by the Dynamical Climatology Branch of the Office. In essence one attempts to calculate the behaviour and evolution in time of the atmosphere starting from prescribed initial conditions; such studies have come to be known as numerical simulation experiments because, in a sense, the computer is analogous to a laboratory with the system of equations taking the place of a physical model and indeed frequently being described as a mathematical model of the atmosphere. Some extremely successful work of this kind has already been carried out by research groups in the U.S.A. but there are so many opportunities for differing treatments in the design of a model and so many variants of the possible experiments that may be conducted with it that there is little likelihood of simply duplicating the work. Furthermore, independent approaches by different research groups are desirable to ensure that the success (or failure) of some experiment does not depend on some arbitrary assumption adopted within the formulation of the model without realization of its significance.

The equations for such a model are usually solved at an array of discrete points arranged over the area of interest and the variables which specify the state of the atmosphere at these points are continually updated during the period of the prediction until a forecast for some future time is obtained. Typically the points are a few hundred kilometres apart because such resolution is adequate to define the meteorological systems in which we are generally most interested. For short-period numerical forecasting, i.e. for forecasts up to 24 or 36 hours ahead, tolerably good results can be obtained without taking any account of the energy sources which drive the atmospheric circulation against the various processes, such as friction, which dissipate the energy. For such periods the atmosphere behaves largely as an inertial system with its evolution almost entirely determined by its state at the beginning of the period. For longer periods however, it becomes necessary to introduce into the equations many complex physical processes which are justifiably ignored in the short term. Thus, in forecasting for more than a day or so ahead, the heating brought about by the release of latent heat of condensation becomes relevant and must be accounted for. This means that the amount of moisture in the atmosphere must be carried as a full variable of the model and predicted from the appropriate conservation equation. Furthermore, if we so treat the moisture we must predict also the evaporation from the surface, both land and ocean, by means of which the moisture lost from the atmosphere by precipitation is replenished; in other words we must simulate in our model the hydrological cycle.

For several of these complicated physical processes there are no known exact laws or if known they are too involved for direct use in a numerical model of the atmosphere. The effects must therefore be represented by some other means, e.g. empirically, statistically or even climatologically. The shrewdness with which this empirical representation is carried out has an important bearing on the success and realism of the model.

In recognition of the fundamental scientific importance and high promise of numerical simulation experiments, the Committee on Atmospheric Sciences set up by the International Council of Scientific Unions (ICSU) has proposed an ambitious global atmospheric research programme (GARP) in which many nations will participate, and has recommended that high priority be given to it. The programme is now taking shape and includes a variety of studies directed towards specific physical problems. It will culminate, probably around 1976, in an attempt to make observations of the global atmosphere up to about 30 km on a much more comprehensive scale than is currently done as routine. This will allow a variety of numerical experiments based on a truly global coverage of observations and it is of course desirable that the Office should be in a position to take advantage of, and profit by, this elaborate programme.

Naturally, very powerful computing facilities are required to make long-period predictions with an ambitious model and the model under development in the Meteorological Office makes use of the Science Research Council Atlas computer. The model is being made as flexible as possible in order to permit a wide variety of numerical experiments to be conducted. Thus it will be possible to perform calculations for the hemisphere or the complete globe; also both the lateral resolution in the model and the number of levels in the vertical are variable at will. Typically, however, it is the intention to use the model in five-level form over the hemisphere with a lateral resolution of 5° of latitude/longitude. This involves operating with about 30 000 variables which are the wind, temperature and moisture at about 1300 points for each of 5 levels, together with various surface parameters.

In order to integrate the equations over long periods, namely to simulate the evolution over, say, many months, it is necessary to employ mathematical techniques that provide a solution which is stable and sufficiently accurate. Indeed, the mathematical procedures used are crucial to the success of numerical simulation experiments. Separate experiments were therefore conducted using equations applicable to a much simpler physical system, namely an incompressible ocean without density variations; nevertheless, these experiments contain the essential mathematical ingredients of the atmospheric system of equations. In this way a satisfactory technique for treating the equations was established and is being carried over to the atmospheric model.

Amongst the several physical processes which must be represented in the model, transfer of heat by radiation is one of the most difficult to deal with adequately. This is because the net radiative flux at any level in the atmosphere depends on the temperature and concentration of the radiatively active constituents at *all* levels as well as on the presence of cloud layers. Thus, although radiation theory has now reached an advanced state of development, it is exceedingly complicated and the full exploitation of the theory in numerical simulation experiments carries a very heavy computational penalty. Computer limitations make it impracticable for us to tolerate this penalty but at the same time it was considered inadequate to employ climatology for the specification of radiative effects as this would omit the desirable feed-back aspects of these processes. Fortunately, workers at the Clarendon Laboratory, Oxford, have suggested a promising alternative treatment and have devoted substantial efforts to developing the method. Briefly, highly detailed radiation calculations have been carried out for a sample of soundings from many parts of the globe and the net cooling rates so obtained at various levels have been correlated with the relevant parameters which will be available in the model calculations, namely the temperatures and humidities at the data levels of the model. This provides a statistical basis for estimating radiative changes in terms of the state at the time in question. It is hoped that in some sense the effect of clouds will be at least partially included since the cloud structure must itself be highly correlated with the temperature and humidity structure.

Another vital matter which raises thorny problems is concerned with the exchanges of heat and moisture between the atmosphere and the ocean or land surface, and of course the frictional drag. The difficulties spring from two causes. Firstly, in the ultimate these exchanges take place at the molecular scale whereas in the model the state of the atmosphere is only defined at points some hundreds of kilometres apart laterally. Secondly, no exact physical laws governing these exchanges are known. Once again, therefore, it is necessary to resort to empiricism and make use of the considerable body of existing meteorological data. In the Meteorological Office model the exchange rates at the surface are represented in a manner which is equivalent to use of a surface drag coefficient in association with the low-level vertical wind shear and the gradients of the quantities being exchanged.

In addition to the surface exchanges, we must take account of the internal exchanges due to turbulent eddies and free convection. These constitute a range of motions having too small a scale to be resolved explicitly in the model but which have too large a cumulative effect to be neglected. These effects are simulated by diffusive type terms in the equations which for the vertical exchanges are designed to account for free convection in depth as well as forced turbulent mixing through the lowest layers of the atmosphere.

It will be appreciated from what has been said that the design of a realistic model for numerical simulation experiments embraces the whole of meteorology.

The success of the model depends on many things, but of undoubted importance is the shrewdness with which effects requiring empirical representation are treated. In the course of developing the Meteorological Office model, therefore, some sideline trials have been conducted to ensure that so far as possible terms representing such effects will behave in the manner intended when operating in the full model. At the time of writing, about two-thirds of the development has been completed, and at various stages limited trial integrations of the incomplete model have been computed from both real and synthetic situations. These trials have thrown up additional problems, mostly of a mathematical nature, but no insuperable difficulties have emerged which throw doubt on the suitability of the model for numerical simulation experiments.

What kinds of experiments can be carried out when the development of the model is complete? Naturally there are many kinds but broadly they fall into two main categories. Thus one can study the general character of the evolution predicted over some long period and appraise how closely the world climatology implied by the model is like that of the real atmosphere. Such predictions may commence from some arbitrary initial state, or alternatively one may start from a condition of zero wind and uniform temperature everywhere and allow temperature gradients and winds to develop as a consequence of the solar heating and other physical effects simulated in the model. If the observed features of the general circulation are predicted successfully one could repeat the calculations with selected parameters judiciously modified and so seek to discover the significance of the role they play.

Other experiments can be aimed more specifically at some form of direct prediction. Thus one might explore the possibility of forecasting useful detail for, say, a week ahead. Here we come up against the difficult question of the ultimate determinism or predictability of the atmosphere. It might be assumed that if the current state of the atmosphere were precisely known then a perfect model would be capable of accurate prediction indefinitely. However, this is a somewhat academic question as the practical answer is determined both by the lack of precision with which the current state is known as well as by inevitable shortcomings of the model. The latest work and the best opinion at the present time suggest that the practical limit for forecasts containing useful detail is likely to lie somewhere between one week and one month, but much work remains to be done before prediction over that time scale can become routine.

Another interesting question of predictability is whether the calculated evolution, beyond the period containing valid detail, contains anything useful for long-range forecasting about the general character of the ensuing period. There are good grounds for expecting that the general character of the régime may be predictable with reasonable success for a much longer period ahead than that at which one can hope to predict the detailed state within the régime. An exploration of this question is one of the primary aims of the Meteorological Office numerical simulation programme for which the model is being developed. Another important aim will be to investigate the extent to which ocean temperature anomalies exert a controlling influence on the general character of the large-scale régime, because, owing to the very large thermal inertia of the oceans, there is a real hope that this controlling influence may be of great importance and therefore a potentially valuable predictor of long-term changes.

ORGANIZATION OF THE RESEARCH DIRECTORATE

No major changes were made in the organization of the Research Directorate during the course of the year. Research in the Meteorological Office continues to be organized under two Deputy Directors, one responsible for the physical aspects of meteorology and the other for research concerned with the dynamical and synoptic aspects. The responsibility of the latter includes the control of training within the Office and responsibility for the Meteorological Office publications and library.

In September Dr R. Hide gave up his post as Professor at the Massachusetts Institute of Technology (MIT) in order to join the Meteorological Office. Dr Hide had built up at MIT one of the world's leading laboratories for the study of the motions of rotating fluids. Such a laboratory is now being established in the Meteorological Office at Bracknell under Dr Hide's direction. The aim is to simulate with laboratory models those aspects of the motion of the atmosphere and oceans which arise from the effects of the rotation of the earth, and to learn from rotating models in the laboratory the fundamental laws which control the behaviour of the fluid envelope (and interior) of rotating planets.

The Meteorological Research Committee and its sub-committees met on a total of nine occasions to consider the research work of the Meteorological Office including a number of small projects carried out under contract at the universities. A close liaison was maintained with university departments which have interests in meteorological physics and dynamics both through the activities of the Meteorological Research Committee and through many other contacts between the Meteorological Office scientists and their colleagues in the universities. Joint projects are being developed with the Department of Physics at Oxford University for the measurement from SKUA rockets of airglow and for the study of the absorption of radiation by water vapour in the atmosphere by means of balloon-borne instruments. Three members of the university staffs spent periods at Bracknell during the year as consultants on various topics.

The exchange of research scientists with the Environmental Science Services Administration (ESSA) of the U.S.A. continued during the year. Dr F. B. Smith of the Meteorological Office completed a profitable year at the Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee, and was followed by Mr P. R. Rowntree who will spend a year at the Geophysical Fluid Dynamics Laboratory in Washington, which is the centre for the ESSA studies of the general circulation of the atmosphere. Dr Lester Machta returned to America in August after a year of active co-operation with scientists at Bracknell. Continuing the exchange, Mr Glenn Brier of ESSA came to Bracknell and will be working on statistical studies of meteorology.

PHYSICAL RESEARCH

Meteorological Research Flight

The Hastings aircraft remained unserviceable throughout the year and it now looks unlikely that it will be suitable for further use. An extensive review has been made of the suitability of possible replacement aircraft but no decision has yet been made.

The Canberra aircraft has been successfully fitted with a Ferranti stable platform. Flight tests have determined the practical accuracy of the system (which is high) and a start has been made on a series of flights through regions of clear-air turbulence to measure detailed air movement relative to the stable base-line provided by the platform. The usefulness of this aircraft has been increased by continuous recording of temperature and by Doppler radar determinations of drift angle and ground speed, but the full potential of the aircraft and its equipment will only be realized when a comprehensive digital recording system becomes available. The provision of suitable equipment is being actively explored.

An infra-red thermometer has been fitted to the Varsity aircraft. This will be used to determine the effective surface temperature of sea and ground.

The Meteorological Research Flight co-operated with the French Meteorological Service during the latter's research project 'COLOMBE' (a study of the influence of the Pyrenees on air movement and cloud development) in September by making four flights at high level over France to aid in the charting of temperature, wind, turbulence and cloud disposition.

Cloud physics

The new cloud physics laboratories continued to operate successfully in Ocean House adjacent to the Meteorological Office Headquarters building. A number of studies into microphysical aspects of clouds have been initiated. These include work on the mode of operation of freezing nuclei in the atmosphere, on the freezing and electrification of supercooled water drops when accreted on a small ice crystal, and the efficiency of coalescence of water drops in a field of linear wind shear.

New instrumentation for direct measurement of the droplet size spectrum and the ice-crystal concentration of clouds, and the humidity around them, is being constructed and an improved technique for the direct measurement of the concentration of atmospheric freezing nuclei has been developed.

Theoretical investigations on the glaciation in cloud and the growth of drops by coalescence are being pursued in parallel with these experimental studies.

Radar meteorology

A mobile Doppler radar has been made available to the Meteorological Office unit at the Royal Radar Establishment (RRE), Malvern, for meteorological use on a limited basis during development and testing by RRE staff and it is expected to be more continuously available in the future. It has been used in conjunction with a similar fixed installation at Pershore to obtain horizontal and vertical velocity components of winds. The handling of the large quantity of data from the mobile Doppler is a major problem and the construction of special analogue computing equipment has been postponed in favour of possible use of digital computer techniques.

The Isles of Scilly project

A major project is planned to study the structure and evolution of warm-frontal cloud systems. This project, in which the Meteorological Research Unit of RRE, Malvern, and the Meteorological Research Flight co-operate actively, will be a central feature of the research effort of the Cloud Physics Branch for the next few years. One of the principal aims of the work is to try to determine the field of vertical air motion on the same scales as those on which the structure, constitution and development of the clouds and precipitation will be observed by the radars and instrumented aircraft, and to relate these observations to the larger-scale developments as revealed by synoptic analyses, satellite pictures and the predictions of numerical models. The Isles of Scilly have been chosen as the base for the study because of the desirability of examining the cloud systems before they undergo rapid modification by the orography and surface heating of a variable land terrain and because of the relative freedom of the surrounding airspace from traffic control restrictions.

Initial experiments took place at the end of the year and will continue into 1968. The main features are the operation of the mobile Doppler radar from St Mary's Airport (see Plate VI) and a feasibility study on the measurement of the wind field and its convergence on the 100-km scale by the accurate tracking of a series of free-falling radar reflectors ejected from the Varsity aircraft of the Meteorological Research Flight in a predetermined pattern around the Isles of Scilly.

High atmosphere

An experiment to measure the amount of molecular oxygen in the atmosphere above 100 km and to investigate some aspects of its distribution was included in the payload of the satellite ARIEL 3, which was launched successfully on 5 May 1967. Measurements are made as the satellite passes into the earth's shadow and good results were obtained from launch until the satellite entered all-sun phase on 12 May, except that there is a fairly small spurious signal, believed to be caused by the charging of the ionization chambers by ionospheric electrons and ions. This will reduce accuracy somewhat unless the effect can be removed by analysis, and this is at present somewhat uncertain.

Similar experiments to measure molecular oxygen, were conducted on SKYLARK rockets launched from Woomera. SKYLARK 406 carrying an oxygen experiment was launched on 14 March 1967 and gave valuable data on solar ultra-violet intensity, which was the main purpose of the experiment, as well as reasonably good measurements (not yet fully worked out) of molecular oxygen at a height of about 120 km. A similar experiment was carried on SKYLARK 407, successfully launched on 2 November. Preliminary indications are that this experiment will also give good data.

Analysis still continues of the records obtained from the experiment to measure the distribution of ozone above 30 km which was mounted on the satellite ARIEL 2. Various refinements have been added to the treatment of the data to reduce the error of the results but there is still no sign of any really significant deviation of individual measurements from the mean of all results.

The computation of ozone distribution continued from the results of observations on SKYLARK rockets. Analysis of the most successful flight is now practically complete but there is still work to do on earlier flights. The difficulties are mainly connected with the complex motion of the rockets.

A plan to measure ozone at night by observations from SKYLARK rockets of the absorption of moonlight was abandoned in view of the limited scientific effort available.

There were three series of firings of SKUA rockets from South Uist in 1967:

(i) 8 February to 22 April.

(ii) 31 May to 16 June.

(iii) 29 June to 30 July.

The first campaign was much handicapped by unusually bad weather which continued until early April. From 25 firings, 20 temperature and 21 wind records were obtained. The weather was excellent for the second and third campaigns and from 26 firings, 21 temperature and 22 wind records were obtained. During these campaigns there were in all 5 daylight firings which confirmed the existence of a strong diurnal variation of the meridional wind component at levels above 40 km which had already been detected. Evidence for a diurnal temperature variation or a diurnal component in the zonal wind was vague.

Two SKUA rockets were fired for the Science Research Council; these carried experiments by Aberystwyth University making direct measurements of atmospheric pressure. Assistance was also given for the firing of two PETREL rockets for the Science Research Council, also from South Uist.

Radiation

The processing of radiation data in the Meteorological Office network has steadily become more automated, with the improvement in the reliability of the Meteorological Office data-logging equipment (MODLE) and the development of computer programmes to handle the necessary amendments to the magnetic tapes on which the data are finally stored. Computer processing is now used to prepare the data for publication in the *Monthly Weather Report* and in the scheme sponsored by the World Meteorological Organization and operated by the Hydrometeorological Service of the U.S.S.R.

A complete year's recording has now been obtained at Bracknell from the apparatus for the measurement of the spectral intensity of solar radiation in 15 bands.

One of the new magnetic-tape recorders for solar radiation has been installed on board a Naval survey vessel for further testing.

Micrometeorology

Computation of the fluxes of momentum and heat was completed from data for wind inclination and temperature fluctuation collected at a height of 600 m, using a captive balloon, on three anticyclonic days in May 1965. The results clearly show a lack of local balance between production and dissipation of the energy of turbulent flow. If this is a general feature of the atmosphere at these heights it greatly complicates certain problems of estimating transfer of heat and momentum through the planetary boundary layer; this transfer is important in the theory of the general circulation.

An important addition to the existing captive-balloon system is under development in the form of a system for measuring fluctuations of wind direction. It is proposed to use a gyroscopic system, which has given encouraging performance in tests, the precession rate being less than $1 \cdot 5^{\circ}$ per hour, and assembly of the gyroscope with the vane and potentiometer is under way.

In connexion with the problem of exchange of momentum, heat and moisture with the ocean, a second summer season of underwater studies has just been completed off Malta, by a small unit directed by a Senior Research

Fellow in collaboration with the Admiralty Research Laboratory. These studies have the object of further elucidating the form and fine structure of the thermocline. The programme has included modified and extended measurements of the motion of the water using underwater photography of streaks and patches of dye (see Plate VII), together with supporting measurements of the vertical profile of temperature.

An extended programme of investigation of the transfer processes over the sea is now under serious consideration. A principal aim is to carry out turbulence measurements at heights well above the surface, say up to 1000 m. Accordingly consideration is first being given to the design of a suitable captive-balloon-borne system for operation on a ship. It is proposed to use wind inclination and temperature sensors similar to those already in use at Cardington but with a frequency-modulating telemetering system for transmitting signals to suitable ground equipment. A specification has been prepared.

In collaboration with the National Plant Breeding Institute, Cambridge, experiments were conducted on the effects of artificially induced drought on a field of barley. Measurements of soil moisture, radiation, heat flux, evaporation and rainfall were carried out between April and August, after which the trial plots were harvested. The results are now being processed. The Nuffield Foundation has provided a grant which will enable the National Plant Breeding Institute to continue the investigation for a further three years.

Dynamical and Synoptic Research

Research related to short-range weather forecasting

Considerable effort has been devoted during the year to research into methods of improving short-range weather forecasting. Once again emphasis has been largely on those methods which have been loosely described as 'numerical weather prediction'; in them the important physical effects in the atmosphere are expressed through the mathematical equations describing the motion and heat balance and these equations are then solved numerically to give the changes in the atmospheric variables that follow from the observed conditions on a specific occasion. Such numerical predictions of the pressure and wind fields are now in daily use for forecasting the broad-scale synoptic features for a day or two ahead. Research has been continued towards extending the prediction method to compute rainfall distribution on a much smaller scale as a first step towards predicting actual weather conditions by numerical methods. The computations are so extensive that the full power of the Science Research Council Atlas computer is required to carry them out; even then 8 hours of computing time are required to make a 24-hour prediction and when the method is used operationally a considerably more powerful computer will be needed. The main developments during the year have been concerned with introducing the effects of topography, ground friction and convective overturning of the atmosphere and with ensuring the self-consistency of the data upon which the computations are based. Several forecasts have been made for periods up to 24 hours ahead and the results are encouraging.

The problem of extending the current routine numerical forecast period from two to five or more days ahead has been actively pursued; preliminary forecasts for five days ahead have been computed and show promising results but further improvements are expected when the non-adiabatic effects of heating and cooling and the release of latent heat are better taken into account. Investigations have also been made into the compatibility of the analyses of the wind and pressure fields which are used as a basis for numerical prediction.

Attention has also been focused on research into methods of forecasting which depend upon the collation of experience of weather events in order to provide forecasting rules which are statistical in character. For example, during the year, work was successfully completed on an objective technique for forecasting hail and thunderstorms over south-east England; it is designed to make use of computed forecasts of the large-scale weather situation so that it could be integrated into a future numerical forecasting procedure to give routine forecasts of the likelihood of thunderstorms.

Increasing attention has been paid to those problems which can best be understood and solved locally and the forecasting staff at outstations have continued to play an important part in these studies. Increased emphasis is being laid on problems of direct importance to the general public, such as the variation of shower frequency and intensity from place to place as a result of topography, and the variations of visibility within a foggy area. New empirical forecasting relations have been tested at the outstations and the results compared with previous forecasting methods. Diagrams have been produced for the objective forecasting of visibility at London (Heathrow) Airport for three and six hours ahead in the winter months and attention has been turned to producing similar diagrams relating to the summer months.

Research related to long-range forecasting

Throughout the year, weather predictions for a month ahead have been made at the beginning and middle of each month and have been made available to the public through the Press and broadcasting media as well as to over 2000 subscribers who receive, for a small charge, a more detailed copy of each forecast along with other relevant information about the month in question. These forecasts do not strive to give the detail normally found in shorter-period forecasts and are content to indicate on a regional basis the probable monthly mean temperature anomaly in one of five categories and the probable mean rainfall in one of three; the broad succession of weather types is also predicted with mention of any expected outstanding weather features such as an increase in the number of frosty days or in the monthly sunshine total. The average standard of success showed a slight improvement during the year, mainly as regards rainfall and miscellaneous information.

The method of making these forecasts was described in the *Meteorological Office Annual Report 1965* (pp. 47–54) and has not materially changed since then; it consists of identifying periods in the past when the weather was similar, over a large area, to that of the past few weeks and then basing the forecast on the sequels which followed the analogue periods. The success of the method depends largely on the availability of past data records and during the year there have been several additions to the data library, notably upper air data at 500 mb from Germany, sea temperature anomaly charts for the North Atlantic south of 50°N back to 1880, and northern hemisphere surface data from the U.S.A.

A careful examination of the data at our disposal reveals new statistical associations between the synoptic situations at different times of the year; these associations are not usually well defined but may play their part in the selection of analogues and in the monthly weather prediction. Classification of the weather régime of the months according to the bias towards progressive westerly, meridional, or cyclonic weather situations has proved valuable in selecting analogues; also the acquisition of the German data has stimulated research into the selection according to upper air pattern.

Attention has also been directed to longer-period forecasting, and trial forecasts were prepared for both the winter of 1966/67 and the summer of 1967; that both were disappointing indicates the difficulty of finding a suitable method of forecasting and progress is likely to be slow.

The computer language designed to deal with the data problems of the type arising in synoptic meteorology and climatology has proved very effective and a number of inquiries about its use have been made by outside bodies. It has also proved valuable in investigating the statistical problems which were thrown up by the work, including the generation of random numbers and extensions of both the chi-square and Sherman's statistics. The analysis of data by principal component analysis (or in terms of empirical orthogonal functions) has reached a satisfactory stage and a general practical method for dealing with the analysis of time series has been devised.

Climatic change

The study of the past climate of the British Isles is an essential basis for advice on the weather conditions which should be allowed for in all matters of long-term planning and development. The daily weather type classification extending back to 1861 was checked for publication and an accompanying text is being written. Charts are being compiled for each January and July back to 1550 and many additional observational data became available during the year.

General circulation of the atmosphere

A survey of the Meteorological Office work on the general circulation of the atmosphere is given as a 'Special topic' on pages 53–59. The main effort at present consists in the simulation of the large-scale air motions of the world by mathematical calculations on the Atlas computer of the Science Research Council. About two-thirds of the programme has been written and testing has commenced. There are a number of physical effects which cannot be represented in the model by exact laws, because either the laws have not been properly formulated or the effect, although important, acts on a scale too small to be explicitly treated by the mathematical methods that are used; examples are the exchanges of heat, moisture and momentum at the surface and the effect of free convection on the larger-scale motions. A number of subsidiary studies have been carried out to test possible methods of introducing these effects by empirical methods. The treatment of radiative transfers in the atmosphere is extremely complicated and substantial help in the development of a system which introduces these radiational effects and which is computationally acceptable has been received from workers at the Clarendon Laboratory, Oxford.

Numerical studies of the mechanisms by which heat and momentum are transported in the upper troposphere and lower stratosphere have continued and further understanding has been gained of the relative roles of the mean circulation and the large-scale turbulent eddies. Attention has also been focused on the transfer of ozone and radioactive particles in this region of the atmosphere. Dr L. Machta, who completed his year of detachment from the Air Resources Laboratory, Institute for Atmospheric Sciences, ESSA, U.S.A., collaborated in this work, paying special attention to the large-scale transfer of ^{14}C in the stratosphere.

Studies of the mean seasonal flow at 50 mb and 30 mb have continued and will be published in due course. The final set of aerological cross-sections at 30° N based on International Geophysical Year (IGY) data was completed for publication and a study of the meridional transports up to about 30 km has started. Some mean charts covering the monsoon period over a substantial area of the tropics have been prepared with a view to publication.

Storm surges in the North Sea

Investigational work has continued, leading to the establishment of further improved empirical formulae for the forecasting of dangerously high tides at east-coast ports. A study has been made of the interaction of surge and tide on the east coast with particular attention to the Thames estuary. Collaboration has been maintained with the Storm Tide Warning Service, the National Institute of Oceanography and the Liverpool Tidal Institute.

Special investigations

A number of requests for meteorological information and advice were received from government departments and other bodies, which could not be met from routine sources or from the main stream of research and so called for special investigations. Many of these requests called for answers in a short time and some involved considerable work. The provision of meteorological advice and information for projected supersonic aircraft led to considerable investigations into problems such as the accuracy of temperature forecasts for both the flight levels and the terminals and the frequency of airframe icing in the approaches to selected international airports. Studies have been made of severe storms, mountain waves and high-level turbulence with aviation needs in mind, and close contact has been maintained with the Royal Aircraft Establishment and the Ministry of Technology. Meteorological Office scientists have taken part in the tripartite committees of France, the United Kingdom and the U.S.A. studying problems of supersonic flight. Meteorological advice was also given on a number of other topics through membership of departmental and interdepartmental committees.

Library and Publications

The National Meteorological Library forms part of the Meteorological Office Headquarters at Bracknell. It is used mainly by the staff of the Office but is also available to the professional user from outside the Meteorological Office and to members of the general public. It provides an exceedingly comprehensive coverage of the literature of meteorology and associated subjects. An indication of the activity of the library is contained in Table XVI on page 69. The figure of 15 287 for publications lent is the highest since records began in 1924. The library holds photographs and transparencies suitable for the illustration of lectures, books, etc., and these were augmented during the year by a series of photographs of the activities of representative outstations of the Office.

The library provides an information and translation service. One of the translator posts became vacant at the beginning of the year and was not filled until November. In the interim period work was sent to freelance translators.

The Editing Section is responsible for preparing the official publications for printing and works closely in co-operation with HMSO. The official publications are listed in Appendix III and include the *Meteorological Magazine* which provides 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. Work of the Cartographic Drawing Office includes not only the preparation of diagrams for Meteorological Office publications and internal memoranda and for reports of scientific research by Meteorological Office staff published in other journals, but also the many charts and diagrams for various areas of the world required by forecasters as background maps upon which meteorological observations may be plotted.

Training

The Meteorological Office Training School at Stanmore provides meteorological training at four different levels. In addition to providing the training necessary for newly appointed staff of the Meteorological Office, the Training School accepts students from meteorological services of other countries. The courses are aimed to give the student a sound and adequate basis in meteorological theory, but there is an emphasis on the practical aspects of the subject and its application to forecasting. The formal instruction is normally followed by work at a forecasting office where practical experience is gained over a period from a few weeks to several months.

The course for Scientific Assistants lasts 9 weeks and covers basic meteorology as well as the practical aspects of their duties at a forecasting office. For the Experimental Officer class the first stage of the training is a 17-week course together with some training in the duties of the Assistant class. After some years the forecasting officer returns for further, more-advanced training lasting 4 weeks during which he is introduced to the latest developments in the subject. The highest level of training is given to the Scientific Officer class who spend 6 months at the school and up to a further 6 months mainly at forecasting offices. This training ensures that the young Scientific Officer has a broad appreciation of the problems of the Office before he undertakes a specific and usually specialized research task.

A thorough review of training for the Experimental Officer class has been carried out during the year, and new arrangements will be introduced in the autumn of 1968. Similar reviews of training for the Scientific Officer and Scientific Assistant classes are in progress, and it is hoped that any necessary changes can also be implemented at the beginning of the next training year.

The training in radiosonde operation, provided at Hemsby, is given to staff who, if they are in the Meteorological Office, will be engaged on full-time radiosonde duties at a land station or on an Ocean Weather Ship. The initial course lasts for 9 weeks and there is an advanced 4-week course for staff experienced in basic operations; if necessary the latter is preceded by a 4-week refresher course.

Compared with 1966, there has been a marked increase in total training largely due to the maintenance of a full programme of Assistant courses, and the holding of two special courses for those assistants recruited during 1966 but not trained on entry. It has not yet been possible to restart the background courses for more-experienced assistants. The officer-in-charge courses given in conjunction with the Civilian Training and Education Branch of the Air Force Department were restarted in November 1967; the course content has been redesigned to give greater emphasis to management aspects including staff reporting.

The number of students from overseas shows a drop from the 1966 figures, but there are no signs that this indicates a significant trend. A number of overseas students were given 'on-the-job' training either following courses at one of the schools, or without having taken any formal training.

External training facilities continue to be made available to large numbers of staff. In July more generous provisions for sponsored study at external colleges and institutions were announced by the Treasury; these have been applied to all applications for the 1967–68 academic year, but it is too early yet to assess the effect of the changes. The number of students on sandwich courses at City University remains at seven.

J. S. Sawyer
Director of Research

STATISTICS OF THE RESEARCH DIRECTORATE

Table XVI—Library

Items received including duplicates but excluding daily weather reports	6727
Individual books, pamphlets, articles, and microfilms classified and catalogued	6174
Transparencies acquired	456
Publications lent (excluding daily weather reports and internal 48-hour loans)	15 287
New agreements for exchange of publications	2
Total number of exchange agreements	417
Number of pages translated by Library translators*	
Russian	1183
German	23
Total	1206

* One, only, in post from 9 January to 1 November 1967.

Archives

Number of loans	1379

TABLE XVII—TRAINING

The following figures give details of courses completed during 1967 at the Meteorological Office Training Schools at Stanmore, Hemsby and Easthampstead.

	Number of courses	Length of course in weeks	Number of students
Scientific Officers	1	22	7
Senior Forecasters	1	3	11
Forecasting (Preliminary)	2	4	34
Forecasting (Initial)	2	17	56
Forecasting (Advanced)	5	4	48
Tropical Meteorology	2	3	13
Mediterranean Meteorology	1	2	6
Climatology	1	4	8
Instruments (Advanced)	3	2	13
Assistants	11	9	158
Assistants (backlog)	2	5	21
Auxiliary Observers	2	1	30
Voluntary Observers	1	1	20
Antarctic Observers	1	8	10
Radiosonde (Initial)	5	9	31
Radiosonde (Refresher)	2	5	4
Radiosonde (Advanced)	5	4	11
Technicians	2	14	20
Total			501

Students from the following territories attended courses which terminated during 1967:

	Number of students
Austria	3
Barbados	1
British Antarctica	16
Burma	2
Channel Isles	1
East Africa (Kenya, Uganda and Tanzania)	11
Hong Kong	5
Isle of Man	1
Jamaica	1
Jordan	2
Libya	1
Malaysia	4
Mauritius	2
Pakistan	1
Sierra Leone	2
Total	53

INTERNATIONAL CO-OPERATION

The Fifth World Meteorological Congress was held in the Palais des Nations, Geneva, from 3 to 28 April. The United Kingdom delegation was led by the Director-General, Dr B. J. Mason and included Mr C. W. G. Daking, Mr B. M. Day and Mr D. G. Harley from the Meteorological Office, Instructor Captain G. P. Britton, Director of Meteorology and Oceanographic Services (Navy) and two members of the United Kingdom Mission in Geneva. Of the U.K. dependent territories, Hong Kong, Mauritius and British Caribbean Territories were separately represented as Members.

The main business was the completion and approval of the plan for World Weather Watch for 1968–71, and for its implementation. World Weather Watch is the first comprehensive internationally agreed plan for a global network of meteorological observations, a system of world and regional data-processing centres to deal with the data in support of national centres, and a global telecommunications plan to carry both raw and processed data. Education and training, and supporting research programmes are included.

Dr B. J. Mason was re-elected to the Executive Committee of WMO, in a personal capacity. Seven of the 24 members of this Committee are directors of meteorological services of Commonwealth countries. The Committee had a short session in the week after Congress.

Immediately after this, the eighth Conference of Commonwealth Meteorologists was held at Bracknell from 9 to 12 May. The directors of meteorological services of 14 Commonwealth countries and Ireland attended. As in 1963, the proceedings were informal, with discussions on several meteorological topics of current importance, in particular the problems of implementing the World Weather Watch plan. Staff of the Meteorological Office participated in most of the discussions.

In his capacity as Chairman of the British National Committee for Geodesy and Geophysics, Mr J. S. Sawyer was the principal British delegate to the XIV General Assembly of the International Union of Geodesy and Geophysics which was held in Switzerland from 23 September to 7 October. The Meteorological Office delegation also included Dr B. J. Mason, Dr G. D. Robinson, Mr F. H. Bushby, Mr R. F. Jones, Dr K. H. Stewart who attended the meetings of the International Association of Meteorology and Atmospheric Physics (IAMAP) in Lucerne and Mr J. Harding who attended the International Association of Scientific Hydrology (IASH) in Berne. Other members of the Meteorological Office who attended some of the meetings by private arrangement or with the support of other bodies were: Dr R. Hide, Dr J. D. Woods, Dr K. A. Browning, Mr M. K. Miles and Dr J. T. Bartlett.

In addition to taking an active part in the meetings described above, the Director-General together with other meteorological experts attended a meeting in Paris on 5 October of the Advisory Committee on Programmes of the European Space Research Organization. There was unanimous agreement among the experts on the desirability and importance of including meteorological satellites as an important component of any European programme on applications satellites.

In October, while on a lecture tour of Scandinavia, the Director-General had discussions with the directors of the state meteorological services of Denmark, Sweden and Norway.

An International Conference on Water for Peace, organized by the U.S. government on the personal initiative of the President of the U.S.A., was held in Washington from 23 to 31 May. Two papers, *Weather modification* by Dr B. J. Mason and *Weather forecasting and related aspects* by Mr P. J. Meade, were presented by Mr R. H. Clements, Deputy Director (Observational Services).

Two Technical Commissions of WMO met during the year. The Commission for Agricultural Meteorology, whose President is Mr L. P. Smith of the Meteorological Office, met in Manila, Philippines, from 15 to 29 November. Mr W. H. Hogg led the U.K. delegation, which also included Mr C. V. Smith. The Commission for Aeronautical Meteorology (CAeM) met in Montreal from 14 November to 13 December, mostly in simultaneous session with the 5th Air Navigation Conference (ANC) of ICAO. Mr J. K. Bannon, Assistant Director (Public Services) represented the U.K. in CAeM, and Mr L. Sugden was one of the U.K. delegation to 5th ANC.

The South Pacific Air Transport Council had its 18th session in Suva, Fiji, from 6 to 16 November, attended by Mr G. Needham. Meteorological subjects discussed included the setting up of a regional meteorological service in the south-west Pacific. Opportunity was taken also to discuss with representatives of Australia, New Zealand and governments of U.K. island territories the implementation of World Weather Watch plans for more upper air stations on British territories in the Pacific.

Dr R. Frith took an active part in organizing an international seminar on stratospheric circulation which was held in London from 31 July to 4 August in connexion with the annual meeting of the Committee on Space Research (COSPAR) which immediately preceded it. Many of the delegates visited Bracknell.

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

Subject	*Place and date*	*Attended by*
CAeM Working Group on Met. Aspects of the Area Forecast System	Geneva March	Mr L. Sugden (Met.O.7)
Fifth WMO Congress	Geneva April	Mr L. P. Smith (Met.O.8)
Symposium on Containment and Siting of Nuclear Power Plants and Joint WMO/IAEA Meeting on Met. at Nuclear Establishments	Vienna April	Dr R. J. Murgatroyd (Met.O.20)
Working Group on Marine Climatology	Geneva May	Mr J. G. Cottis (Met.O.3)
Working Group on Air Pollution and Atmospheric Chemistry	Geneva June	Dr A. G. Forsdyke, Assistant Director (Climatological Services)
CAgM Working Group on Guides and Technical Regulations	Geneva August	Mr L. P. Smith (Met.O.8)
International Symposium on Floods (UNESCO/IASH/WMO)	Leningrad August	Mr F. Singleton (Met.O.8)

Subject	*Place and date*	*Attended by*
COSPAR WGII Panel and WMO Seminar on Stratospheric Circulation	London August	Dr R. Frith, Assistant Director (High Atmosphere) Dr E. L. Simmons Messrs R. Almond, D. E. Miller and S. F. G. Farmer (Met.O.19)
Informal Planning Conference on Quality Control of Met. Data	Geneva September	Mr R. H. Clements, Deputy Director (Observational Services)
WMO Working Group on Sea Ice	Geneva September	Mr G. A. Tunnell (Met.O.1)
WMO Informal Planning Meeting on Output Products of Regional Met. Centres	Geneva October	Mr A. A. Worthington, Assistant Director (Telecommunications)
WMO Informal Planning Meeting on the Routeing of the Moscow–Washington Portion of the Main Trunk Circuit of WWW	Geneva October	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
WMO RA.VI Working Group on Telecommunications—Seventh Session	Geneva October	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
Informal Planning Meeting on Utilization and Distribution of Meteorological Satellite Data	Geneva October	Mr R. F. Zobel, Assistant Director (Central Forecasting)
Informal Planning Meeting on Output Products of Regional Met. Centres Affecting Europe	Geneva October	Mr R. F. Zobel, Assistant Director (Central Forecasting)
WMO Working Group on Machine Processing of Hydrometeorological Data	Geneva November	Mr A. Bleasdale (Met.O.8)

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*
RAE investigation of mountain waves and associated turbulence	Washington/ San Francisco (Moffat AFB) January–February	Mr J. M. Nicholls (Met.O.9)
Inter-Governmental Maritime Consultative Organization (IMCO) 2nd Session of Sub-Committee on Radio Communications	London January–February	Commander C. E. N. Frankcom (Marine Superintendent), as WMO Observer
European Space Research Organization (ESRO) Ionosphere and Auroral Phenomena (ION) Group Meeting	Paris January	Dr R. Frith, Assistant Director (High Atmosphere)
Supervision of Met. Office equipment in SKYLARK rocket SL406, and its pre-launch calibration checks	Woomera, Australia January–March	Mr M. S. Shaw (Met.O.19)
Informal MOTNE Phase 3 Implementation Meeting	Paris February	Mr L. Sugden (Met.O.7)

Subject	Place and date	Attended by
ICAO Informal Meeting on the Area Forecast System	Paris February	Mr L. Sugden (Met.O.7)
Fifth FAUSST (French-Anglo-U.S.A. Talks on Supersonic Transport Operations)	Washington February	Mr M. H. Freeman (Met.O.7)
ESRO Launching Programme Advisory Committee (LPAC) Meeting	Paris February	Dr R. Frith, Assistant Director (High Atmosphere)
Meeting of COSPAR WGVI with the IUGG Committee on Atmospheric Sciences	Geneva February	Dr R. Frith, Assistant Director (High Atmosphere)
To prepare Met. Office experiment for launching in U.K. 3 satellite	Vandenburg AFB Western Test Range, California February–March	Dr P. J. L. Wildman and Mr G. P. Carruthers (Met.O.19)
XVth Session of Maritime Safety Committee (IMCO)	London March	Commander C. E. N. Frankcom (Marine Superintendent), as WMO Observer
ICAO Informal Meeting on Runway Visual Range	Copenhagen March	Mr L. Sugden (Met.O.7)
North Atlantic Systems Planning Group (ICAO)	Paris April	Mr C. H. Hinkel (Met.O.7)
Society for General Microbiology 17th Symposium on Airborne Microbes	London April	Mr G. W. Hurst (Met.O.8)
To prepare Met. Office experiment for launching in U.K.3 satellite	Vandenburg AFB Western Test Range, California April–May	Dr K. H. Stewart (Met.O.19)
Annual Meeting of Advisory Committee of European Operating States on North Atlantic Ocean Stations	The Hague May	Commander C. E. N. Frankcom (Marine Superintendent)
Discussion with Irish Government on U.K. method of runway visual range assessment by human observer	Dublin May	Mr D. P. Smith and Mr G. Wind (Met.O.7)
ESRO Meeting on Atmospheric Structure and Meteorology (ATM)	London May	Dr R. Frith, Assistant Director (High Atmosphere)
Third Session of Sub-committee on Radio Communications (IMCO)	London June	Commander C. E. N. Frankcom (Marine Superintendent), as WMO Observer
Global Atmospheric Research Programme (GARP) Planning Conference	Stockholm June–July	Dr G. D. Robinson, Deputy Director (Physical Research)
Co-ordinating Council of the International Hydrological Decade (3rd Session)	Paris June	Mr A. Bleasdale (Met.O.8)
ESRO ATM/ION Meeting	London June	Dr R. Frith, Assistant Director (High Atmosphere)
Conference on Tropical Meteorology (U.S. Army)	Miami June	Mr D. H. Johnson (Met.O.6)
Symposium on Meteorological Investigations above 70 km	Miami June	Dr R. J. Murgatroyd (Met.O.20)

Subject	*Place and date*	*Attended by*
Joint CSIRO/Commonwealth Weather Bureau Colloquium	Melbourne June	Mr D. H. Johnson (Met.O.6)
Joint IQSY Assembly/COSPAR Scientific Symposium	London July	Mr J. S. Sawyer, Director (Research)
Anglo-French meeting on Concorde	Paris July	Mr L. Sugden (Met.O.7)
International Quiet Sun Year/COSPAR Assemblies	London July–August	Mr R. F. Jones, Assistant Director (Special Investigations) Mr C. L. Hawson (Met.O.9)
	London July	Dr R. Frith, Assistant Director (High Atmosphere) Mr H. H. Lamb (Met.O.13) Drs K. H. Stewart, E. L. Simmons, P. J. L. Wildman; Messrs R. Almond, A. P. Taylor, D. E. Miller, S. F. G. Farmer (Met.O.19)
GARP Conference	Stockholm July	Mr F. H. Bushby, Assistant Director (Forecasting Research)
International Colloquium on Scientific Use of Balloons	Paris July	Mr P. Goldsmith, Assistant Director (Cloud Physics)
ESRO Summer School on Dynamics of the Stratosphere, Mesosphere and Lower Thermosphere	Frascati, Italy August	Mr P. Goldsmith, Assistant Director (Cloud Physics) Dr R. J. Murgatroyd (Met.O.20)
NATO Structure of Lower Atmosphere and Electromagnetic Wave Propagation	Aberystwyth September	Dr W. T. Roach (Met.O.9)
National Research Council of Canada Seminar on Wind Effects on Buildings and Structures	Ottawa September	Mr H. C. Shellard (Met.O.3)
Third South American/South Atlantic Regional Air Navigation Meeting (ICAO)	Buenos Aires September	Mr B. F. Westwater (Met.O.7)
XIVth International Union of Forestry Research Organization	Munich September	Mr J. B. Stewart (Met.O.8)
International Association of Physical Oceanography	Berne September–October	Dr J. D. Woods (Met.O.14)
Supervision of Met. Office Equipment in SKYLARK Rocket SL407 and its pre-launch calibration checks	Woomera September–November	Mr M. J. Kerley (Met.O.19)
Commonwealth Research Activities on Aeronautical Aspects of Atmospheric Turbulence (Commonwealth Advisory Aeronautical Research Council)	RAE, Bedford October	Mr C. J. M. Aanensen and Mr D. N. Axford (Met. Research Flight)
Fifth Session of the IMCO Assembly	London October	Commander C. E. N. Frankcom (Marine Superintendent), as WMO Observer
Informal Planning Meeting on North Atlantic Ocean Stations	Geneva November	Mr P. J. Meade, Director (Services)
NATO Advisory Panel on Meteorology	Brussels November	Mr J. S. Sawyer, Director (Research)

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

Mr J. T. Frampton Mr D. P. Cullum Mr W. E. J. Newton Mr A. B. Turner	Senior Experimental Officers	All seconded in January to the Libyan Government in Idris
Mr W. N. Burton Mr K. M. Sutherland Mr R. S. Whalley Mr J. Lomas Mr W. E. Tozer	Senior Scientific Assistants	
Mr H. B. Cawthorne	Chief Experimental Officer	Seconded in March to the Libyan Government in Idris
Mr N. Lynagh	Scientific Assistant	Released in June to the Australian Bureau of Meteorology
Mr H. W. Jones	Senior Scientific Assistant	Seconded in August to the Zambian Meteorological Service under arrangements made with the Crown Agents
Mr H. G. E. Hills	Senior Scientific Assistant	Seconded in September to the Zambian Meteorological Service under arrangements made with the Crown Agents
Mr P. R. Rowntree	Senior Scientific Officer	One-year exchange visit from October, to the Geophysical Fluid Dynamics Laboratory, Washington, U.S.A.
Mr H. C. Shellard	Principal Scientific Officer	Released in November to the WMO Caribbean Special Fund Project in Barbados

The following staff returned to the Office from appointments overseas:

Dr R. W. Gloyne	Principal Scientific Officer	From WMO, Turkey, in February
Miss J. H. Winscom	Senior Scientific Assistant	From WMO, Geneva, in March
Mr P. A. Canning	Senior Experimental Officer	From Libya in June
Mr M. J. Batstone Mr K. J. Smith	Experimental Officers	From Trinidad in August
Dr F. B. Smith	Principal Scientific Officer	From Oak Ridge, Tennessee, U.S.A., in September
Mr J. Findlater	Senior Experimental Officer	From secondment to the Kenya Ministry of Defence, in October

1967

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 1967 the total number of posts of all grades was 3818, an increase of 44 over the year. The actual strength at the end of the year, including Research Fellows, was made up as follows:

Scientific Officer Class	
Chief Scientific Officers	3
Deputy Chief Scientific Officers	6
Senior Principal Scientific Officers	26
Principal Scientific Officers	68
Principal Research Fellows	3
Senior Scientific Officers	24
Senior Research Fellows	3
Scientific Officers	32
Junior Research Fellow	1
Administrative Class	
Assistant Secretary	1
Experimental Officer Class	
Chief Experimental Officers	24
Senior Experimental Officers	236
Experimental Officers	414
Assistant Experimental Officers	222
Scientific Assistant Class	
Senior Scientific Assistants	324
Scientific Assistants	1129
Marine Staff	
Marine Superintendent	1
Nautical Officer Class	7
Ocean Weather Ships and Base	
Officers	71
Crew	116
Technical and Signals Grades	280
Executive and Clerical Grades	179
Typing and miscellaneous non-industrial grades	146
Industrial employees	84
Locally entered staff and employees overseas	179

Recruitment to the Scientific Officer class during the year has exceeded all recent records for the Office. There were 17 new entrants into the class, one being at Deputy Chief Scientific Officer level. The number of inquiries from undergraduates has continued at a high level. Recruitment to the Experimental Officer class was lower than over the previous five years but manning has improved. The Scientific Assistant class, however, continues to give concern. During 1967 there was an average recruitment, and wastage was lower than usual but these factors were more than counterbalanced by a high promotion rate and the net result over the year was a loss of nearly forty. There may be some improvement during 1968 following acceptance of the recommendations of a departmental committee which examined all scientific assistant posts at Headquarters and at some large outstations. This has led to the deletion of some posts and the regrading of others. In the Technician classes good recruitment has enabled us to fill all the present posts.

Nine Assistant Experimental Officers from the Office who were taking Sandwich Courses leading to a degree, split the year between the Office and their college. Three college-based Sandwich Course students spent their extra-college periods with the Office. A new departure in 1967 was the nomination of a Radio Meteorological Technician for a Sandwich Course at the Reading College of Technology leading to a Higher National Diploma. One Assistant Experimental Officer was granted a Treasury Bursary for degree studies at Queen's University, Belfast. Another was allowed full time release for similar studies. A further 288 members of the staff took advantage of study concessions. Twenty-four university undergraduates were chosen from among many applicants to work in the Office as vacation students. Three 'vacation consultants' from the Universities contributed to the work of the Office during the year.

CHANGES IN SENIOR STAFF

Dr R. Hide was appointed to the Office in the grade of Deputy Chief Scientific Officer as Head of the Geophysical Fluid Dynamics Laboratory.

Mr P. Goldsmith, M.A., was appointed Assistant Director (Cloud Physics).

Mr J. H. Brazell, M.Sc., succeeded Dr A. G. Forsdyke as Assistant Director (Climatological Services).

Mr D. G. Harley, B.Sc., succeeded Mr C. W. G. Daking, B.Sc., as Assistant Director (International and Planning).

Dr N. E. Rider succeeded Mr A. L. Maidens, B.Sc., as Assistant Director (Instruments and Observations).

HONOURS AND DISTINCTIONS

Dr A. G. Forsdyke was awarded the I.S.O., Mr Haig Paroyian was awarded the B.E.M., and Messrs E. S. Pearce, R. F. Relf and V. E. Vaughan were awarded the I.S.M.

The L. G. Groves memorial Prize for Meteorology was awarded to Dr W. T. Roach; Mr T. W. Harrold, B.Sc., received the Second Meteorological Award and Mr A. M. Dunning received the Meteorological Observer's Award.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

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TIMPSON, Margaret S., see BUSHBY, F. H. and TIMPSON, Margaret S.

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WOODROFFE, A., see LAMB, H. H., LEWIS, R. P. W. and WOODROFFE, A.

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WRIGHT, P. B., B.Sc.; Changes in 200 mb circulation pattern related to the development of the Indian south-west monsoon. *Met. Mag., London*, **96**, 1967, pp. 302–315.

APPENDIX II

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

ALMOND, R., B.Sc.
The Meteorological Office rocketsonde system. *COSPAR/WMO seminar, Imperial College, London.* 31 July–3 August.
The rocketsonde station, South Uist. *COSPAR/WMO seminar, Imperial College, London.* 31 July–3 August.

ANDREWS, J. B., Ph. D.
Rainfall statistics. *Road Research Laboratory, Crowthorne.* 12 April.
Studies on small catchments. *Conference of River Authority Engineers, Cranfield.* 19 July.
The Cardington rainfall experiment. *Water Research Association, Medmenham.* 19 September.
The results of rainfall studies at Cardington and Winchcombe. *Hydrological Group of the Institution of Civil Engineers, London.* 16 November.
Rainfall: distribution of raindrop sizes and other related parameters in several types of rainfall. *Physicochemical and Biophysical Panel of the Society of Chemical Industry, London.* 5 December.

BARTLETT, J. T., Ph.D.
Clouds, rain and rainmaking. *Junior British Association, Cardiff.* 20 March.
Some optical effects in deformed single crystals of ice. *IASH meeting of XIV IUGG General Assembly, Berne.* 28 September.

BRADBURY, N., B.Sc.
Automatic mapping of some meteorological information. Discussion meeting on 'Automated cartography, scientific needs and technical possibilities'. *Institute of Electrical Engineers, London.* 20 March.

BROWNING, K. A., Ph.D.
Radar study of hailstorms. *IAMAP meeting of XIV IUGG General Assembly, Lucerne.* 26 September.

BRYANT, K.
Synoptic meteorology and applications to civil defence. *Scientific Intelligence Officers, Regional Civil Defence Headquarters, London.* 4 March.
Meteorology for fallout. *Home Office Warning Officers, Midland Sector, Norwich.* 23–24 September.
Effects of weather and terrain on radioactive fallout. *Home Office (Sector Scientists) Conference, Civil Defence Staff College, Sunningdale.* 12 November.

BUCHANAN, R. A., M.A.
Meteorological services for industry. *Sheffield Exchange.* 27 October.

BUSHBY, F. H., B.Sc.
A ten-level atmospheric model and frontal rain.
Royal Meteorological Society, London. 5 February.
Mathematics Society, University College of North Wales, Bangor. 4 May.
IAMAP meeting of XIV IUGG General Assembly, Lucerne. 29 September.

CRABTREE, J., B.A.
The earth's atmosphere. *Slough Astronautical Society, Slough.* 28 July.

CRADDOCK, J. M., M.A.
Computational and statistical aspects of weather forecasting. *Department of Computation and Statistical Science, Liverpool University.* 26 January.
Long-range weather forecasting. *University of Kent.* 7 March.
Uses of the electronic computer and weather forecasting. *Ranelagh School, Bracknell.* 10 October.
General problems of pattern recognition. *Institute of Electrical Engineers, Portsmouth College of Technology.* 15 November.

EVANS, G. J., B.Sc.
Meteorological services to the public. *Royal Meteorological Society Popular Lecture, County Hall, London.* 28 and 29 November.

FARMER, S. G. F., M.A.
Recent rocket measurements in the mesosphere and upper stratosphere. *Royal Meteorological Society Summer Meeting, Belfast.* 20 September.

FLOOD, C. R., B.A.
Long-range weather forecasting. *Oxford University Scout and Guide Group, Oxford.* 29 May.
The chi-squared statistic in contingency tables with small cell expectancies. *Royal Statistical Society, North Eastern Group, Newcastle upon Tyne.* 18 October.

FREEMAN, M. H., O.B.E., M.Sc.
Weather forecasting for the supersonic transport. *British Airline Pilots Association Symposium, London.* 30 November.

FRITH, R., O.B.E., Ph.D.
The international publication of rocketsonde data. *COSPAR/WMO seminar, Imperial College, London.* 31 July–3 August.

GILCHRIST, A., M.A.
The general circulation. *Scottish Branch of the Royal Meteorological Society, Edinburgh.* 27 October.

GOLDSMITH, P., M.A.
Water vapour and radioactivity in the stratosphere. *ESRO Summer School, Frascati, Rome.* 24 August.
Stratospheric humidity. *Royal Meteorological Society Summer Meeting, Belfast.* 19 September.

GOODISON, C. E., C.Eng., M.I.E.R.E.
The impact of electronics on meteorology. *Institution of Electronic and Radio Engineers, Portsmouth.* 28 November.

GRIMMER, M., B.Sc.
The use of numerical models in the study of the general circulation. *Atomic Weapons Research Establishment, Aldermaston.* 2 April.

HARLEY, D. G., B.Sc.
Discussion on meteorology in the Caribbean. *For Central Office of Information, London, recorded newsletter.* 15 March.
Service and industry. *BBC Overseas Service, sound broadcast on 'World Weather Watch'.* 25 May.

HAWSON, C. L., B.A.
Winds and temperatures in the stratosphere. *Royal Meteorological Society Summer Meeting, Belfast.* 20 September.

HAY, R. F. M., M.A.
Sea temperature variations, their meteorological causes and possible effects. *Challenger Society, London.* 26 January.
Long-range forecasting. *Nicholas Scientific Society, Aspro Nicholas Research Institute, Slough.* 5 October.

HIDE, R., Ph.D.
The dynamics of the earth's interior. *IASPEI meeting of XIV IUGG General Assembly, Zurich.* 26 September.

HOGG, W. H., M.Sc.
Horticultural meteorology. *Horticultural Department, Bath University of Technology.* Five lectures in February.
Application of meteorology to agriculture and horticulture. *Meteorological Society of Wales, Cardiff.* 19 April.

HUNT, B.
Meteorology for gliding. *RAF Gliding and Soaring Association Air Day, Bristol.* 16 March.

JOHNSON, D. H., M.Sc., D.I.C.
Meteorological problems of the Far Eastern tropics. *Conference on Tropical Meteorology, University of Miami.* 5–13 June.

Special problems of tropical meteorology.
CSIRO Commonwealth Weather Bureau Colloquium, Melbourne. 22 June.
Weather Bureau, Perth. 26 June.
Weather Bureau, Brisbane. 28 June.
Weather Bureau, Darwin. 30 June.

JONES, R. F., B.A.
Meteorological problems of supersonic transport aircraft. *BBC Overseas Service sound broadcast.* 27 January.
BBC Overseas Service sound broadcast on 'lightning discharges'. 7 September.

KNIGHTING, E., B.Sc.
The use of computers in weather forecasting. *British Computer Society, London.* 20 November.

LAMB, H. H., M.A.
Climatic variations. *Institute of Civil Engineers, London.* 23 February.
Climatic history and climatic change; contributions to knowledge from recent meteorological work. *University of Newcastle upon Tyne.* 3 March.
Climate, a modern view of its behaviour and changes. *Oundle School.* 17 March.
Britain's climate, its history and development. *Leeds University Geographical Society.* 12 October.
Britain's climate, its variability and some of its extremes.
Kingston upon Thames College of Advanced Technology. 16 October.
Institute of Mechanical Engineers, London. 1 November.

LEWIS, R. P. W., M.Sc.
Long-range weather forecasting. *Luton Scientific Society.* 12 April.
Alternating direction implicit method of solving the Dirichlet problem over a circular area. *St Andrews University.* 29 June.

MASON, B. J., D.Sc., F.R.S.
Recent developments in cloud physics.
Physics Department, Queen Mary's College, London. 20 January.
CERN, Geneva. 6 April.
University of Oslo. 17 October.
The generation of electricity in thunderstorms.
Institution of Electrical Engineers, London. 26 January.
Royal Radar Establishment, Malvern. 7 December.
The physics of clouds, rain and snow.
Oxford University Scientific Union. 3 February.
Department of Natural Philosophy, Glasgow University. 31 May.
'Who Knows?'
BBC Home Service. 9 February.
BBC Home Service. 16 February.
THE JAMES FORREST LECTURE: Recent developments in weather forecasting and their application to industry. *Institution of Civil Engineers, London.* 14 February.
The physics of thunderstorms and lightning. *University of Leeds Public Lecture.* 27 February.
A talk on the work of the Meteorological Office. *Physics Department, Imperial College, London.* 17 March.
Weather forecasting by computer.
British Association, Birmingham Branch. 20 March.
University of Sussex Scientific Society. 31 October.
'Dateline'. *Independent Television.* 8 May.
World Weather Watch—A new era in weather forecasting. *Civil Defence Staff College, Sunningdale.* 24 May.
New developments in weather forecasting and World Weather Watch. *Ninth London International Science Fortnight.* 1 August.
THE EVENING DISCOURSE: Weather forecasting by computer. *British Association Annual Meeting, Leeds.* 1 September.
Thunderstorms and lightning. *British Association Annual Meeting, Leeds.* (The 'York Lecture'.) 4 September.
Recent developments in the physics of clouds, rain and snow. *Danish Society of Natural Sciences, Copenhagen.* 12 October.

Physics of the thunderstorm.
Meteorological Institute, Stockholm. 13 October.
Department of Physics, Exeter University. 20 October.
Physical Society, Southampton University. 14 November.

Recent developments in forecasting and research in the Meteorological Office. *Geophysical Association, Oslo.* 16 October.

Recent developments in weather forecasting and their application to various branches of industry. *Radio and Space Research Station, Slough.* 13 December.

McKellar, H. A. and Plant, J. A.

Meteorological services for the construction industry. *Scottish National Trades Federation (Employers), Glasgow.* 27 September.

Meade, P. J., O.B.E., B.Sc.

Meteorological services for the construction industry. *URWICK Management Centre, Slough.* 6 April.

Economic benefits of meteorological services. *Industrial Marketing Research Association, London.* 13 April.

Murgatroyd, R. J., O.B.E., Ph.D., A.M.I.E.E.

Temperature, density and pressure variations in the stratosphere and mesosphere. *American Meteorological Society symposium, Miami, Florida.* 31 May.

Five lectures and one seminar on the dynamics and circulation of the stratosphere and mesosphere. *ESRO Summer School, Frascati, Rome.* 21–25 August.

Transfer processes in the upper troposphere and lower stratosphere. *Royal Meteorological Society Summer Meeting, Belfast.* 19 September.

Parrey, G. E., B.Sc.

Meteorological services for the construction industry. *MPBW Technical Information Lectures, Midland Region.* Derby 20 November, Birmingham 27 November.

Pothecary, I. J. W., B.Sc., A.Inst.P.

The interpretation of meteorological satellite data. *Luton and Stevenage branch of the Royal Aeronautical Society, Stevenage.* 1 April.

Robinson, G. D., Ph.D., F.Inst.P.

Meteorological observations over the oceans. *British National Conference on the technology of the sea and sea-bed, Atomic Energy Research Establishment, Harwell.* 7 April.

Some current projects for global meteorological observation and experiment. *Presidential address to the Royal Meteorological Society, London.* 19 April.

Some meteorological aspects of radiation and radiation measurements. *The Eppley Laboratory Inc., Newport, Rhode Island.* 4 August.

Transmission of solar radiation by polluted atmosphere. *National Center for Air Pollution Control, Cincinnati, Ohio.* 7 August.

Some elementary aspects of atmospheric dynamics.
Department of Earth Sciences, State University of New York, Albany, New York. 15 August.
Mathematics Society, University College of North Wales, Bangor. 9 November.

Sawyer, J. S., M.A., F.R.S.

BBC Overseas sound broadcast on 'weather control'. 18 January.

The future of weather forecasting. *ICI (Merseyside) Scientific Society, Winnington.* 2 February.

Shellard, H. C., B.Sc.

Wind records and their application to structural design. *Symposium on 'Natural draught cooling towers—Ferrybridge and after', Institution of Civil Engineers, London.* 12 June.

Results of some recent special measurements in the United Kingdom relevant to wind loading problems. *'International research seminar on wind effects on buildings and structures', Ottawa, Canada.* 13 September.

Singleton, F., B.Sc., D.I.C.

Probable maximum precipitation and rainfall frequency studies. *Postgraduate hydrology students, Imperial College, London.* Three lectures in February.

The estimation of probable maximum precipitation in the U.K. *Conference of River Authority Engineers, Cranfield.* 19 July.

SMITH, L. P., B.A.
The weather factor in agriculture. *Clive Behrens lectures (5), University of Leeds.* January–March.
Weather and agriculture. *WMO Congress, Geneva.* 12 April.

STANSFIELD, R.
Heavy rain and flood warnings. *British Spelaeological Association, Birmingham.* 10 September.

STEWART, K. H., Ph.D.
Satellite techniques for measurement of ozone height profile. *IAMAP Meeting of XIV IUGG General Assembly, Lucerne.* 28 September.

WICKHAM, P. G., M.A.
Practical meteorology. *Teacher's vacation course, College of Aeronautics, Cranfield.* 28 July.

WILLIAMS, W. T.
Weather forecasting. *Royal Aeronautical Society, Coventry Branch.* 8 November.

WOODROFFE, A., B.Sc.
Use of computers in weather forecasting. *Welsh College of Advanced Technology, Cardiff.* 11 January.

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, with 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 official publications were issued during the period of this Report:

PERIODICAL

Daily Aerological Record, containing information respecting meteorological conditions in the upper air over the British Isles (to 14 December 1967).

Daily Weather Report, containing weather maps for the northern hemisphere, British Isles, etc., and data (to 31 December 1967).

Daily Weather Report, Overseas Supplement, containing surface and upper air data (to 19 July 1967).

Meteorological Magazine (to December 1967).

Monthly Weather Report (to August 1967).

Seismological Bulletin. A diary of seismological disturbances recorded at Eskdalemuir, Dumfriesshire, on the standard American World-wide Seismograph System, together with observations from a short-period vertical seismograph at Kew Observatory (to October 1966).

Marine Observer (quarterly) to October 1967.

Monthly Weather Survey and Prospects, a monthly publication containing climatological data for Britain, the weather of the past month, a general survey and inference, and weather prospects for the coming month in Britain; a supplementary document, containing survey, inference and prospects only, is published in mid-month (to 15 December 1967).

Estimated soil moisture deficit 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 December 1967).

SERIAL

Scientific Papers:

26. A study of vertical air motion and particle size in showers using a Doppler radar. By P. G. F. Caton, M.A., Ph.D.
27. The determination of the extraterrestrial constant of a Dobson spectrophotometer. By R. A. Hamilton, O.B.E., M.A. and J. M. Walker, M.Sc., D.I.C.

OCCASIONAL

Daily aerological cross-sections at latitude 30°N during the International Geophysical Year period—June 1958.

Daily aerological cross-sections at latitude 30°N during the International Geophysical Year period—September 1958.

Meteorology for mariners, with a section on oceanography.

Ships' code and decode book. 7th Edition, 1967.

Quarterly surface current charts of the South Pacific Ocean. 2nd edition, 1967.

Handbook of weather messages—Part II. 5th edition, 1967.

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