

METEOROLOGICAL OFFICE

ANNUAL REPORT 1968



ANNUAL REPORT
ON THE
METEOROLOGICAL OFFICE

1968

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

LONDON
HER MAJESTY'S STATIONERY OFFICE
1969

FOREWORD BY THE DIRECTOR-GENERAL

This has been another very busy year for the Office and the staff have been fully stretched in coping with a sharp increase in the current activities and in preparing for important future developments.

Much effort has been devoted to the preparation of a detailed Five Year Plan designed to keep the Office in the forefront of meteorological research and practice, to provide weather forecasts of greater reliability and range, to cope with the rapidly increasing demands for services from industry and the general public, and to fulfil our international obligations under World Weather Watch, and this without a significant increase in the total size of the staff. This calls for a major programme of modernization, automation and centralization based on a giant new computer, a new automated telecommunications system, a new radiosonde system, an expansion of basic and applied research, and a major building programme at Bracknell. The Plan has been approved in principle by the Secretary of State for Defence and detailed planning on the individual items is now well advanced.

In particular, detailed discussions have taken place with industry on the design of the new computer and telecommunications systems with a view to making firm decisions within the next few months. The new radiosonde has undergone successful trials, and plans are being made for its introduction into operational service. Estimated expenditure for Air Votes on meteorological research rose from a net £1 million in 1967/68 to £1.2 million in 1968/69. Acquisition of a new building has enabled the stores to be concentrated at Bracknell (with closure of stores at Hayes and Hendon), and works planning is well advanced for a new building at the Experimental Site at Easthampstead, extension of the Headquarters at Bracknell and the move of the Training School to Shinfield Park near Reading. For World Weather Watch, in which we are playing a major role, Bracknell is acting as a Regional Meteorological Centre; the first annual cash contribution of £30 000 has been made to the Voluntary Assistance Programme; equipment worth £100 000 has been offered to developing countries; three overseas meteorologists have been awarded fellowships at Reading University; and improvements are being made in observational coverage, particularly of the upper air in oceanic regions. Further developments in World Weather Watch are planned.

Meanwhile, day-to-day activities have continued to grow. The number of inquiries received from industry and the general public rose by 11 per cent to a new record total of 1.4 million, while the number of forecasts for aviation increased marginally to nearly 1.35 million. Increases in the number of inquiries from the building industry (18 per cent), agriculture (22 per cent) and surface transport (13 per cent) show an encouraging response to our efforts to encourage weather-sensitive industries to make greater use of meteorological advice. Following the experimental trials carried out last year, a routine service for weather-routing of ships across the Atlantic was introduced in March and has been well received. About 100 ships have now been routed and experience has shown that it is often possible to recommend a substantial deviation from the normal route which, by reducing the time spent in heavy seas, may effect considerable savings in time and fuel, and reduce damage to ship and cargo.

There has also been an increased demand for meteorological and climatological investigations in connection with important problems in agriculture, hydrology, civil engineering, building and roads. An investigation into the origin and spread of the recent serious epidemic of foot-and-mouth disease is an interesting example. A detailed analysis of air-mass trajectories for the critical period almost excluded the possibility that the disease entered Britain as an airborne infection from Europe and North Africa. Regarding the internal spread within the country, the evidence indicates that this could have occurred by particles being carried downwind from infected sites and deposited again on the ground by rain. If this be so, it should be possible in future to predict the spread of the disease with greater precision and so allow much earlier identification and isolation of new areas of infection.

The numerical forecasting procedures have undergone several modifications and improvements but we have now almost reached the limit of what can be done with the present computer. Computer methods have led to significant improvements in forecasting the movement and development of the large weather systems and the winds for aviation purposes, and have introduced a greater degree of continuity, consistency and confidence, but have not yet made a marked improvement in forecasting the elements which most affect the man in the street. The present mathematical models are too simplified and coarse-grained to deal with small, rapidly developing systems that can nevertheless produce severe local weather, neither can they forecast rain, snow, fog, etc. These limitations were evident during the Glasgow gales of January, the west-country floods of July and the south-east floods of September. Although strong gales in the first case, and prolonged heavy rain in the last, were correctly forecast well in advance, the maximum intensity of the very localized events that caused most damage could not be predicted. However, the sequence of events leading to the September floods has been reproduced *post facto* by the new sophisticated mathematical model being developed by the research branch, and the fact that location of the zone of heaviest rainfall and the cessation of the rain were remarkably well predicted is most encouraging. It should be possible to put this new model into operational practice soon after the new computer is commissioned.

On two of the occasions just mentioned the Office was criticized, not so much on its forecasts but for not giving sufficient warning to the public. In fact, in both instances, special FLASH warning messages were issued by the BBC at our request more than 12 hours in advance of the peak of the storm but, in order to increase the impact of such messages in the future, their wording has now been strengthened. For the transmission of all such warnings to the public the Office relies very largely on the mass communications media and we are greatly indebted to the BBC, the Independent Television networks and local radio for their help. We are continually seeking ways of improving these services but there is clearly a limit to the number of weather bulletins the broadcasting authorities can accept.

The long-range (monthly) forecasts have shown a small but definite improvement over those issued in previous years. Hitherto, 75 per cent of the forecasts have been in good or moderate agreement with events but this year 80 per cent of the forecasts (19 out of the 24) showed a positive degree of skill compared with what could have been predicted on the basis of climatological statistics.

Turning now to our research activities, the high-atmosphere research programme is selected for special mention this year. The programme of SKUA rocket ascents from South Uist continues to provide evidence for the existence of large 'weather systems' in the high atmosphere and that violent changes in the temperature and winds occur above 30 km in the winter. Similar soundings were made for the first time from Gan in October when seven successful firings showed that quite strong short-period disturbances are present in the equatorial stratosphere and mesosphere. The observations made from the U.K. satellite ARIEL 2 have now been fully processed and indicate that there are broad latitudinal and seasonal trends in the concentration of ozone at levels above 50 km. Analysis of the data from the ARIEL 3 launched in May 1967 has revealed remarkably large longitudinal variations in the concentrations of molecular oxygen at heights of about 200 km, and that the average concentrations were much below expected values, as was also found to be the case at 120 km from our experiments on SKYLARK rockets launched from Woomera.

The first phase of Project Scillonia, whose objective is to study the structure and evolution of frontal cloud systems and the factors that control the duration, intensity and distribution of their rainfall, was implemented with much valuable assistance from the Royal Air Force. This pilot exercise, in which self-opening radar targets were dropped in a predetermined pattern over the front and tracked by a precision radar located in the Isles of Scilly, demonstrated the feasibility of determining the vertical air motions in these clouds, on scales between 10 and 100 km, by a combined use of radar and aircraft. This project and the whole of the cloud-physics programme will be greatly aided by the provision of a Hercules aircraft promised for early 1970. By 1971 this will be equipped as a flying laboratory capable of carrying out a wide range of physical measurements and will be provided with automatic data-processing equipment.

Important investigations of small-scale air motions have been made using an inertial platform fitted to a Canberra aircraft. These studies are yielding unique data on the structure of clear-air turbulence and should help to improve our understanding of this difficult phenomenon and our ability to forecast it. This is one of a number of special studies being made in connection with the operation of supersonic transport aircraft. Another involves the use of newly installed meteorological radars at Singapore and Gan to study the distribution and intensity of cumulonimbus clouds in these tropical areas.

Recruitment into the Scientific Officer class continues to go well and there were almost as many new entrants this year as last. A number of our young scientists have now embarked on courses of study for higher degrees. Both the Scientific Officer and the Experimental Officer classes are up to complement. The long-standing shortage of Scientific Assistants has been slightly eased during the past year.

B. J. MASON

*January 1969
Meteorological Office,
Bracknell, Berks.*

Cover photograph by courtesy of Photus Ltd

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FUNCTIONS OF THE METEOROLOGICAL OFFICE

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

The general functions of the Meteorological Office are:

- (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 on the Meteorological Office, including that on the common services, is approximately £8.5 million. Of the amount chargeable to Defence (Air) Votes, about £5.8 million represents expenditure associated with staff and £2.5 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.

*See page 69 regarding the transfer of Eskdalemuir geophysical laboratory to the Natural Environment Research Council.

METEOROLOGICAL COMMITTEE

Terms of reference:

- (a) To keep under review the progress and efficiency of the Meteorological Service and the broad lines of its current and future policy.
- (b) To keep under review the general scale of effort and expenditure devoted to the meteorological services.
- (c) To ensure the maintenance of adequate contacts between the Meteorological Service and those who use its services.

Membership at 31 December 1968:

Chairman: The Lord Hurcomb, G.C.B., K.B.E.

Members: Mr A. F. Hetherington, D.S.C.

The Rt Hon. Lord Mais, O.B.E., T.D.

Professor J. P. Hudson, M.B.E., G.M.

Professor R. C. Sutcliffe, C.B., O.B.E., F.R.S. (Chairman, Meteorological Research Committee) (*ex officio*)

Secretary: Mr B. M. Day (Secretary, Meteorological Office)

The Committee met twice in 1968.

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 connection therewith.

Membership at 31 December 1968:

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 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)

Mr J. W. Shiell (Scottish Development Department)

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 7 May 1968.

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.

Membership at 31 December 1968:】

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

Members: Instructor Captain J. D. Booth, R.N. (Director, Meteorology and Oceanographic Services (Navy))

Professor R. L. F. Boyd

Wing Commander E. W. Bunkhall

Professor H. Charnock

Professor D. R. Davies

Dr G. E. R. Deacon, C.B.E., F.R.S.

Dr R. Frith, O.B.E. (Deputy Director, Physical Research, Meteorological Office)

Dr E. R. R. Holmberg (Army Department)

Dr J. T. Houghton

Mr E. Knighting (Deputy Director, Dynamical Research, Meteorological Office)

Professor M. J. Lighthill, F.R.S.

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.

Mr J. S. Sawyer, F.R.S. (Director of Research, Meteorological Office)

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

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

The Committee met twice in 1968 and its sub-committees seven times.

PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE

DIRECTOR-GENERAL

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

DEPUTY TO THE DIRECTOR-GENERAL

P. J. Meade, O.B.E., B.Sc., A.R.C.S.

DIRECTORATE OF RESEARCH

DIRECTOR

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

PHYSICAL RESEARCH

DEPUTY DIRECTOR

R. Frith, O.B.E., Ph.D.

SPECIAL POST

F. Pasquill, D.Sc.

GEOPHYSICAL FLUID DYNAMICS

LABORATORY

R. Hide, Ph.D.

METEOROLOGICAL RESEARCH FLIGHT

C. J. M. Aanensen, M.Sc.

OBSERVATORIES AND MICROMETEOROLOGY

Assistant Director

L. Jacobs, M.A., M.Sc.

CLOUD PHYSICS

Assistant Director

P. Goldsmith, M.A.

HIGH ATMOSPHERE

Assistant Director

R. A. Hamilton, O.B.E., M.A.,
F.R.S.E.

Special Post

K. H. Stewart, Ph.D.

DYNAMICAL RESEARCH

DEPUTY DIRECTOR

E. Knighting, B.Sc.

SPECIAL INVESTIGATIONS

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

K. H. Smith, B.Sc.

DYNAMICAL CLIMATOLOGY

Assistant Director

G. A. Corby, B.Sc.

Special Post

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

DIRECTORATE OF SERVICES

DIRECTOR P. J. Meade, O.B.E., B.Sc.,
A.R.C.S.

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

FORECASTING SERVICES

DEPUTY DIRECTOR V. R. Coles, M.Sc.

CENTRAL FORECASTING
Assistant Director R. F. Zobel, O.B.E., B.Sc.
Chief Forecasting Adviser T. H. Kirk, B.Sc.

TELECOMMUNICATIONS
Assistant Director A. A. Worthington, B.Sc.

DEFENCE SERVICES
Assistant Director T. N. S. Harrower, M.A., B.Sc.
H.Q., Strike Command S. E. Virgo, O.B.E., M.Sc.

PUBLIC SERVICES
Assistant Director J. K. Bannon, B.A.
London/Heathrow Airport M. H. Freeman, O.B.E., M.Sc.

OBSERVATIONAL SERVICES

DEPUTY DIRECTOR R. H. Clements, M.A.

MARINE BRANCH
Marine Superintendent C. E. N. Frankcom, O.B.E., R.D.,
Commander R.N.R. (retd)

CLIMATOLOGICAL SERVICES
Assistant Director J. H. Brazell, M.Sc.

AGRICULTURE AND HYDROMETEOROLOGY
Assistant Director J. Harding, B.A., M.Sc.
Special Post L. P. Smith, B.A.

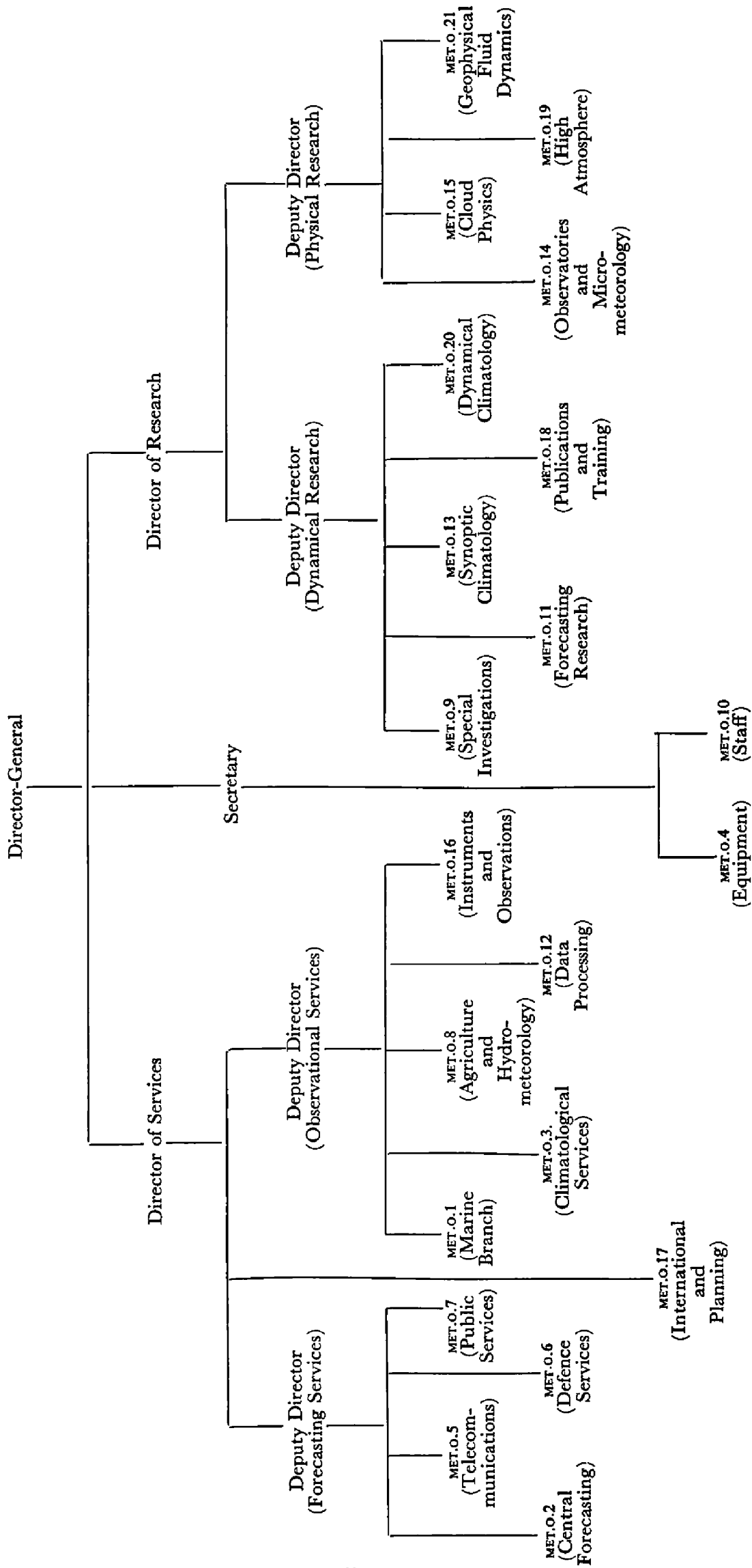
DATA PROCESSING
Assistant Director N. Bradbury, B.Sc.

INSTRUMENTS AND OBSERVATIONS
Assistant Director N. E. Rider, D.Sc.

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

METEOROLOGICAL OFFICE HEADQUARTERS ORGANIZATION

(at 31 December 1968)



THE DIRECTORATE OF SERVICES

SPECIAL TOPIC—OPERATIONAL NUMERICAL WEATHER FORECASTING

Introduction

The usual approach to the preparation of weather forecasts is the prediction of the evolution and movement of the flow patterns both at the surface and in the upper air. When done manually this is a time-consuming process requiring the plotting and analysis of observations for several levels in the atmosphere over a large part of the northern hemisphere and then the prediction of the flow patterns one to three days ahead. All three processes must be done speedily and the analyses and forecasting of the flow patterns call for a high degree of both skill and experience, but at best they are largely subjective.

It is 50 years since L. F. Richardson began to explore the possibility of using the hydrodynamical and thermodynamical equations to compute the future state of the atmosphere. Richardson's experiment failed but even if it had succeeded practical application would have proved impossible until electronic computers provided the means of rapid calculation. Basic research with numerical models of the atmosphere started in the Meteorological Office in the early 1950s but the first computer purchased for the Meteorological Office, in 1959, was neither large enough nor fast enough to be used operationally, and a larger computer was purchased in 1964. Even with that it is possible to achieve the necessary speeds only by employing a simple atmospheric model and rather approximate forms of the mathematical equations. However, the computed flow patterns were found to compare favourably with those produced by experienced forecasters, especially for upper levels, and computed upper air forecasts began to replace hand-drawn products in September 1966. Surface patterns are computed less satisfactorily than upper air patterns and are still modified subjectively before being used as the basis of the national forecasts.

The atmospheric model adopted by the Meteorological Office for operational purposes treats the three-dimensional mass movements in the atmosphere in a simplified fashion. The basic data required for analysis and computation are the heights of three pressure surfaces for a regular mesh of points covering much of the northern hemisphere.

Forecast output is largely confined to the flow patterns at three levels and information must be derived for several intervening levels for aviation. Recent work has shown that this derived information is more reliable if stratospheric flow patterns are known, and a 100-mb forecast has been introduced for this purpose. Five major steps appear in the routine production of forecasts. These steps, which are described below in some detail, are:

- (i) Sorting of observations.
- (ii) Quality control and extraction of the essential elements to perform the required analyses.
- (iii) Analysis of the flow patterns at the standard levels.
- (iv) Forecasting of the flow patterns for periods up to 72 hours ahead.
- (v) Output of analyses and forecasts in the various forms required by users.

Operational forecasts are produced every 12 hours and the routine begins at about 0430 and 1630 GMT, based on observations for 0000 and 1200 GMT respectively. Two additional 12-hour forecasts are produced at about 1130 and 2330 GMT, to form background fields for succeeding analyses; at these times data to support each analysis are as complete as possible.

(i) *Data sorting.* Surface and upper air observations are received in Bracknell by teleprinter (radio or land-line) from most parts of the northern hemisphere. Most surface observations are made every three hours and include pressure, wind, temperature, cloud (type, amount and height), visibility, humidity and weather details. Most upper air observations are made every twelve hours and are confined to heights, winds, temperatures and humidities at various pressure levels up to at least 100 mb. All observations are in figure codes to World Meteorological Organization specifications and are received in the Bracknell telecommunications centre as a series of perforations on paper tapes in Murray teleprinter code. The punched paper tapes are carried by hand from the teleprinters to a reading device on the computer, where a photo-electric cell transforms the patterns of holes into electrical impulses which can be stored in the computer's memory. As each paper tape is read, special programmes 'inspect' it for any abnormal distribution of punched holes which might indicate a faulty reader or a faulty or inverted paper tape, and warning messages are printed at a monitor typewriter when such faults occur. On the tapes there is a wealth of information which must reach the computer for purposes other than numerical forecasting. Therefore, at this stage, all data are preserved but steps are taken to eliminate typical communications errors, such as the transfer of digits from one group to the next in sequence or the transmission of messages in Murray letter code instead of figure code.

(ii) *Quality control and data extraction.* The extraction programme searches for broadcast headings, code indicators and sequences of digits that locate the beginning of an observation. Provision is made for acceptance of number sequences that could occur in partially corrupt messages. A series of operations then examines and sorts the reports according to time and type of observation. The time group is used to form blocks of observations taken simultaneously and land station reports are sorted into an order by reference to a master list of stations. Whenever possible the positions of moving ships are checked against previously reported positions and speeds. Isolated ship reports can be subjected to checks only for gross errors, for example by ensuring that reported positions are not over the land.

The next step is to extract height, temperature and wind data from each upper air report for nine standard pressure levels from 1000 to 100 mb. These data are checked for vertical consistency by means of the hydrostatic equation connecting height, pressure and temperature, and spurious data are replaced where possible. Wind data are also checked for vertical consistency and are accepted only if the vertical shears are plausible. Pressure, pressure change or 'tendency', and temperature are extracted from surface observations. Pressures and tendencies are compared with earlier or later reports from the same station—or with a 12-hour forecast of pressures based on the analysis made 12 hours earlier. If any observations fail to pass a test then duplicate reports, if available from other communications channels, are used to replace spurious data.

When all observations have been examined the checked data are transferred to a magnetic tape which is used by the analysis programme that follows. Lists

of extracted data, including amended and rejected observations, are printed out for examination by a monitoring analyst who can reverse decisions taken in the computer programmes when necessary and cause rejected data to be reinstated or accepted data to be rejected.

(iii) *Analysis of flow patterns.* Analyses are made of the height fields of the standard pressure surfaces from 1000 to 100 mb and also the 1000 to 500-mb thickness field. The analyses are required in their own right to meet the commitments of the Bracknell Regional Meteorological Centre set up under World Weather Watch, but those for 500 mb, 200 mb and 1000 to 500-mb thickness are particularly important because they form the basis of the 600-mb height and 1000 to 600- and 600 to 200-mb thickness fields used in the forecast model. The 100-mb analysis is also important because it provides a means of reducing the height errors in observations at other levels and of generating other height fields which are not directly produced by the forecast model.

The forecast programmes depend on numerical integration of systems of equations by means of the calculus of finite differences and start from a knowledge of the initial values of the variables at mesh points of a grid. Objective analysis, therefore, consists of determining a surface which gives the best fit of the available observations and the reduction of this surface to a set of values at the mesh points of a grid. Apart from the restrictions imposed by maximum and minimum heights and thicknesses and by maximum gradients, contour patterns may assume a multiplicity of shapes in practice. Consequently, simple mathematical surfaces cannot be used to represent actual surfaces except over very small areas. Current practice is to fit quadric surfaces at every one of 1927 grid points in an area covering about half the northern hemisphere. This method allows sufficient freedom for the general shape of the surface given by the grid-point values to correspond to actual situations.

Analyses are made for an area of the earth's surface that forms a rectangle when projected stereographically on to the tangent plane of the North Pole. This area, shown as F in Figure 1, is divided into squares by 47 lines parallel to one side and 41 lines parallel to the other, to form a grid of 1927 points of intersection. The actual distance between grid points varies with latitude from about 325 km (175 n. mile) at the North Pole to about 180 km (97 n. mile) at the most southerly point, near 5°N.

The technique of analysis is broadly similar for all pressure surfaces. Each grid point is dealt with individually and a quadric surface is found, by the method of least squares, which best fits the observed values of contour height and wind at nearby observing stations and also the contour heights in a background field. The background field is a 12-hour forecast from the analysis based on observations made 12 hours earlier. Observations are 'weighted' according to their distances from the grid point. The background field carries about half the weighting of nearby observations but its importance increases as the number of available observations decreases. The presence of the background field ensures reasonable continuity with preceding analyses and also provides grid-point values in areas where no observations are available. At least two analysis 'sweeps' are made at all levels. After the first sweep, height and wind observations are compared with the 'fitted' values obtained in the first analysis at the reporting positions. Observations that depart from the analysis by more than certain values are rejected. The first analysis is also used to compute the curvature of the flow pattern, and reported winds are corrected by this means

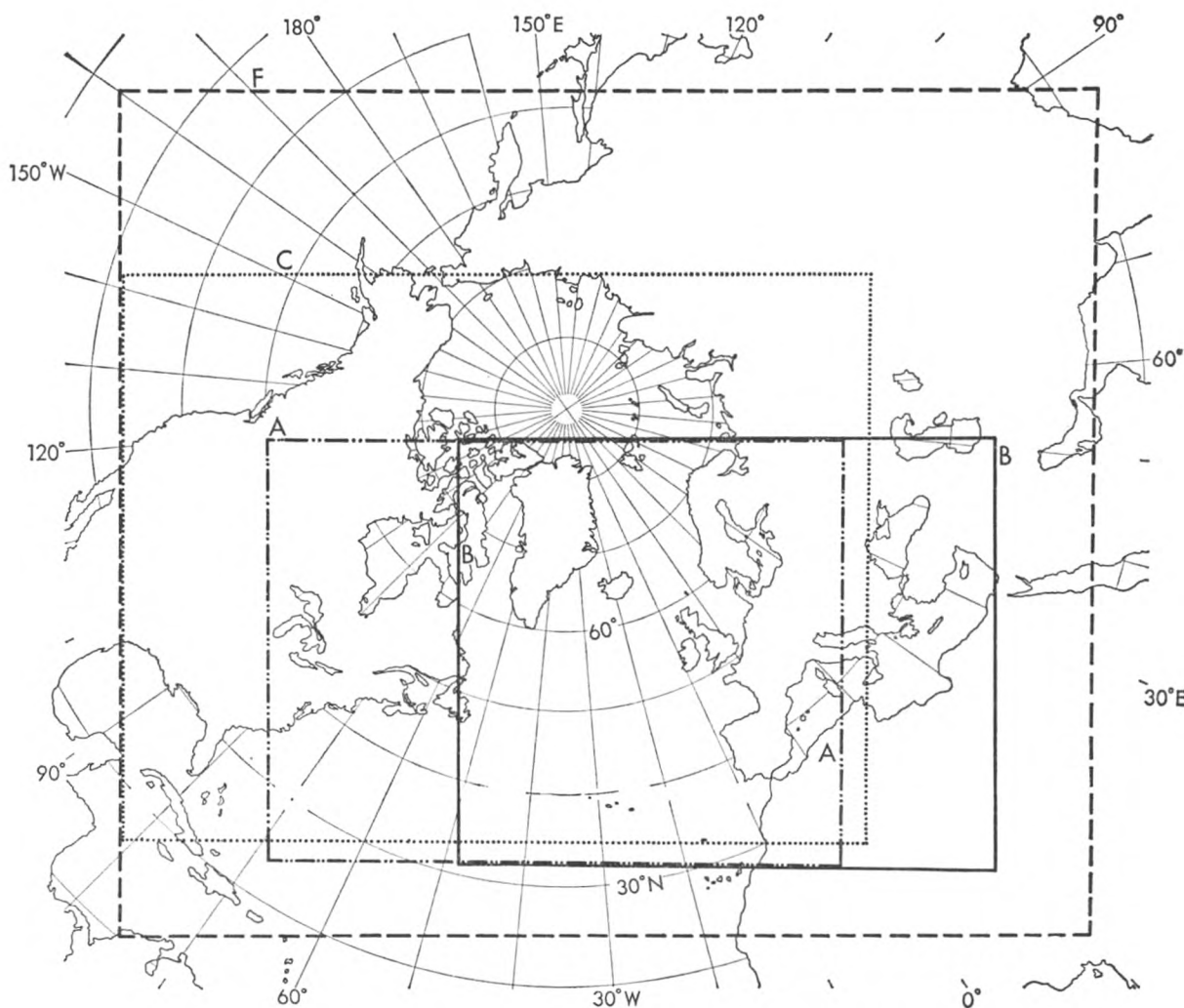


FIGURE 1—THE ANALYSIS AND FORECAST AREAS

F denotes the analysis and forecast area. A, B and C are other areas on which output is produced for particular purposes.

so that they will more closely represent gradients in the contour surfaces. A second analysis is then made, disregarding spurious observations and using winds adjusted for curvature of the flow.

The results are generally good where there is a dense network of observations, but problems arise in areas of sparse data, and facilities are provided for the injection of subjective analysis when necessary. The 100-mb analysis, which is made first, poses special problems. At this level, observed winds are generally light and obey the geostrophic wind equation which relates them directly to the height gradients, but heights are subject to rather large systematic and random errors which render analysis difficult. Therefore a third analysis sweep is made, which is designed to fit the wind observations (which are more reliable than heights) and pay less attention to the reported heights. When the final 100-mb analysis has been made, it is possible to estimate the random height errors at the individual reporting stations. Also, it is known that height errors throughout an upper air ascent are strongly correlated and programmes are being developed to apply varying proportions of the 100-mb height errors to observations for other levels before the remaining analyses are made.

Analysis of the surface pressure field also poses special problems and certain advantages. Depressions, i.e. low-pressure areas at the surface, sometimes have slopes that are too steep to be fitted by a quadric surface which is a paraboloid, bowl-shaped near its vertex, and so a correction known as 'plane-fitting' is introduced to deal with this. The advantages offered at the surface are that there are many more observations than in the upper air and a more detailed analysis is possible. However, in order to retain vertical consistency it is necessary to make adjustments to both the 1000 to 500-mb thickness and the 500-mb height fields after the surface analysis has been modified by means of the data which refer exclusively to that level. An example of a 500-mb (about 18 000 ft (5.5 km)) analysis is shown as Figure 2. The corresponding analysis drawn by hand in the Central Forecasting Office is shown as Figure 3.

(iv) *Forecasting the flow patterns.* If simplifying assumptions are made it is possible to construct equations by using the laws of fluid motion and the law of conservation of mass to describe the fluid state of the atmosphere in terms of the wind components in three dimensions and the forces acting. Various families of differential equations can be formed containing the time and space rates of change of the above variables, or of other more convenient dependent variables and, if the spatial changes can be observed, then the time changes can be calculated.

Two main problems occur. The first is concerned with the selection of an atmospheric model that is realistic and yet simple enough for computations based on it to be completed rapidly. The second problem lies in the solution of the non-linear differential equations. A complete solution is not possible but approximate solutions can be obtained by the method of finite differences. This method effectively reduces the equations to algebraic forms and the new conditions for a short time ahead can be calculated from space changes measured over distances of about 200 to 300 km. The calculations can be repeated in steps of $\frac{1}{2}$ or $\frac{3}{4}$ hour, starting from each set of newly found space conditions, until a forecast for the spatial conditions 24 hours or more ahead has been obtained. However, production of the 24-hour forecast requires about 35 complete sets of computations over the entire grid of nearly 2000 points and can be done quickly ($\frac{1}{4}$ hour) only if a fast computer is used and a simplified model atmosphere is assumed.

The real atmosphere behaves in a very complicated way; its scales of motion include, in addition to the wavelengths embracing the major depressions and anticyclones which it is desired to predict, disturbances of thunderstorm proportions, sound waves and the smallest gravity waves. Emphasis must be placed on those scales of motion that are typical of the major systems, therefore the model adopted by the Meteorological Office for operational purposes on its existing computer is as follows. The atmosphere is taken to be bounded at 1000 mb (near the earth's surface) and 200 mb (at about 12 km). It is separated into two layers by the 600-mb surface. Pressure is used as the vertical co-ordinate and the vector difference between the 'horizontal' wind blowing in the pressure surfaces at the top and bottom of each layer (the 'thermal' wind) is assumed to be constant in direction but the speed is assumed to vary linearly with pressure through each layer. The vertical velocity, which is defined as the rate of variation with time of the pressure acting on a moving particle of air, is assumed to be zero at 200 mb and to be related at 1000 mb to the 'horizontal' velocity at that level by conditions that depend on ground friction and topography. The

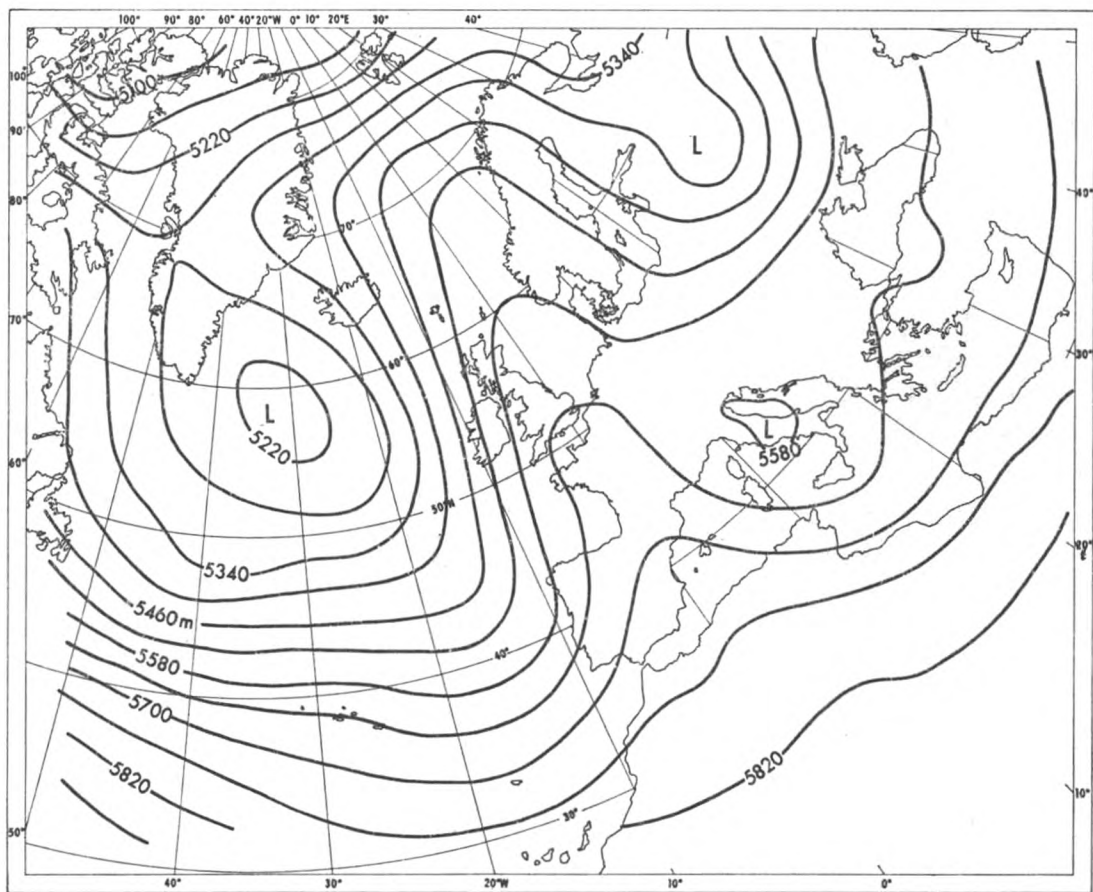


FIGURE 2—OPERATIONAL NUMERICAL 500-MILLIBAR ANALYSIS FOR 1200 GMT, 12 NOVEMBER 1968

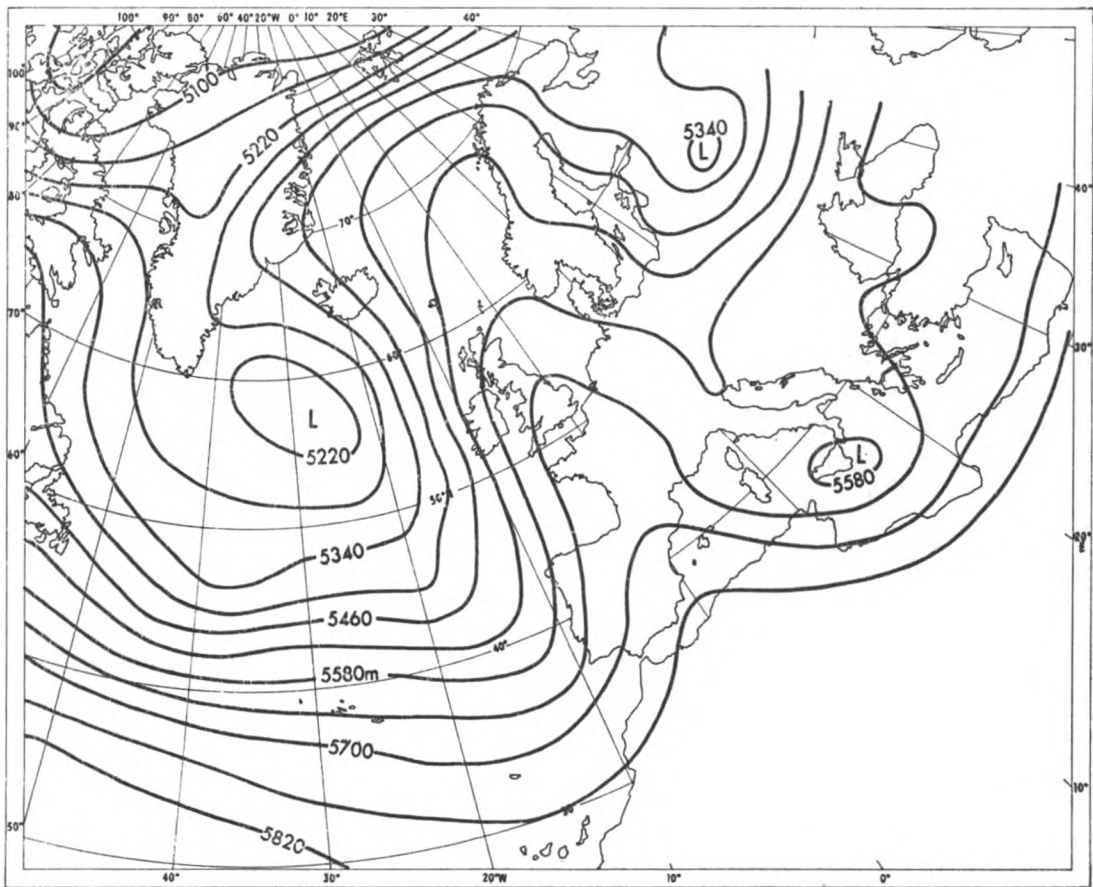


FIGURE 3—SUBJECTIVE 500-MILLIBAR ANALYSIS FOR 1200 GMT, 12 NOVEMBER 1968

effect of surface friction is allowed for by simply assuming that over land the wind blows towards lower 1000-mb heights at an angle of 30° to the 1000-mb contours with 0.35 of the friction-free geostrophic wind speed, and over sea the corresponding values are 3° and 0.85. The effect of ground topography is introduced by assuming that a vertical velocity is generated from the 1000-mb geostrophic wind by the deflexion of the horizontal flow up or down over the ground. The approximate topography is introduced by assigning to each grid point a height equal to the mean height over a symmetrical surrounding square of side equal to one grid length. Within each layer of the model, the vertical velocity varies according to a separate parabolic function of pressure, each function being in two parts. The first part is the same for both layers and has a coefficient which is proportional to the vertical velocity at 1000 mb. The second part has different coefficients in the two layers. The two functions are of course continuous at 600 mb, the common boundary between the two layers. Local heat changes are allowed as a result of both horizontal and vertical advection. In the latter case the changes also take account of the pressure (adiabatic) changes. The only addition or subtraction of heat allowed is that of addition from the sea surface when this is warmer than the air flowing over it. The lapse rates (change of temperature with pressure) are assumed to be constant in each layer of the model and differ from the dry adiabatic lapse rate by about $4.2 \text{ deg C}/100 \text{ mb}$ in the lower layer and $5.1 \text{ deg C}/100 \text{ mb}$ in the upper layer.

Actual atmospheric conditions may vary considerably from those of the model. In particular the temperature lapse rates are rarely simple and marked changes occur frequently in the vertical, especially in the upper layer at the tropopause, which is the zone of separation between the lower part of the atmosphere known as the troposphere and the upper part known as the stratosphere. Other lapse-rate changes also occur within the troposphere. The present model does not incorporate humidity or moisture content, so that no quantitative forecasts of precipitation are made. In spite of the simplicity of the model, quite reliable forecasts of the flow pattern are produced for the three pressure levels 1000, 600 and 200 mb. The flow patterns at other levels and all the temperature fields are derived by regression techniques. However, recent work has shown that the derived fields, especially those near the tropopause which are used for aviation, are greatly improved if the stratospheric flow pattern at 100 mb is also known and forecasts for this level are included in the regression formulae.

The basic dynamical equation used is that for the time rate of change of the vertical component of vorticity (or local spin about a vertical axis) in terms of the vertical variation of vertical velocity. This equation may be integrated with respect to pressure over the depth of the atmospheric model to give the so-called 'equation for mean motion' of the atmosphere, in which the main terms are the time rates of change of the vertical vorticities of the 600-mb wind and of the thermal winds of the two layers. The non-linear partial differential equations used in the computations are of a type that may be solved only by prescribing values on the boundary of the analysis area in advance. The boundary condition used is that there is no change in the heights of the isobaric surfaces on the boundary during the period of the forecast. Full details of the theory and methods of solution have been published in the literature.

(v) *Analysis and forecast output.* The analyses and numerical forecasts are formed as long series of numbers in computer number code, representing values

of heights, temperatures and winds at all the standard pressure surfaces from 1000 to 100 mb for all 1927 grid points in the forecast area. Each field of values is recorded on magnetic tape for forecast times in 6-hour intervals up to 72 hours. The most important direct application is in the planning and control of aircraft operations. These operations fall into two broad categories: (a) the oceanic flights for which airline companies are allowed some choice of track when judicious track selection can lead to important economies in operation, and (b) the flights along fixed airlines with no choice of track but for which winds and temperatures are used in planning the fuel- and pay-loads.

Forecasts can be supplied in digital form, or in the form of charts showing contours of the pressure surfaces, isopleths of wind speed (isotachs), and temperature values. An example is given at Figure 4. This is a forecast of Figures 2 and 3. The corresponding forecast for 300 mb (about 30 000 ft (9 km)) is shown at Figure 5. Most airline companies still select oceanic tracks from such charts, and aircrews often prefer this form of documentation for use in flight. Until recently there were no means of drawing lines automatically by computer, and computer charts had to be produced by means of a digital line-printer, programmed to show patterns of isopleths by filling in alternate intervals with numbers (zebra pattern). An example is shown for 200 mb in Figure 6 for the same time and date as the previous illustrations. More than 400 such charts are produced each day but the combined charts showing contours and isotachs are prepared by hand tracing from separate computer charts of the two patterns. Recently an automatic line-drawer controlled by the computer has been used to produce charts with the two patterns superimposed.

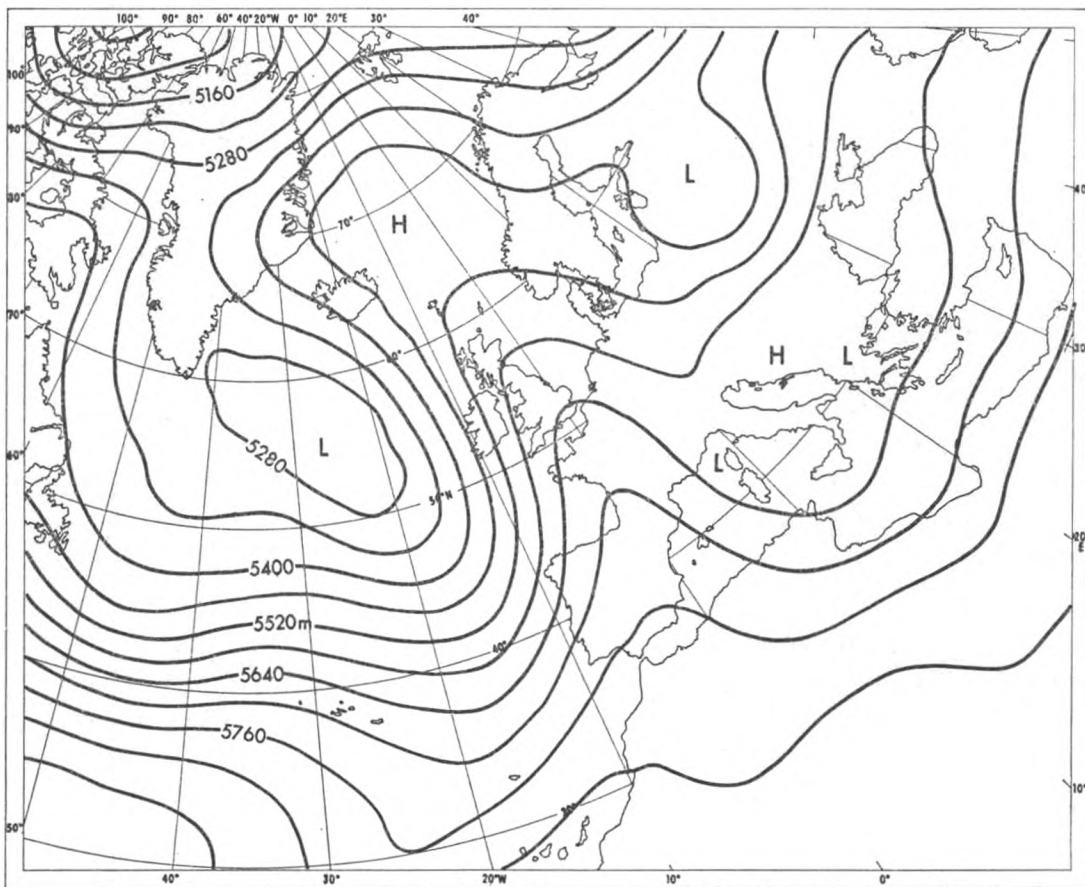


FIGURE 4—OPERATIONAL NUMERICAL 500-MILLIBAR 24-HOUR FORECAST VALID AT 1200 GMT, 12 NOVEMBER 1968

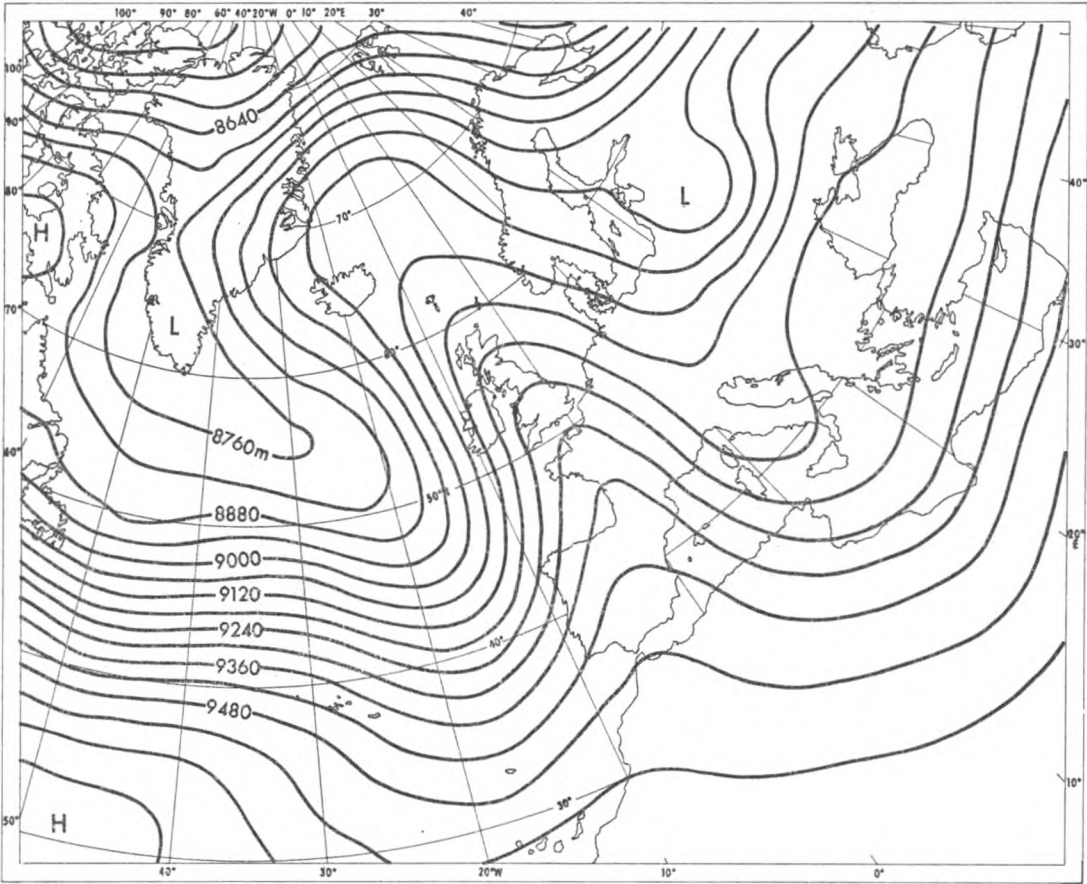


FIGURE 5—OPERATIONAL NUMERICAL 300-MILLIBAR 24-HOUR FORECAST VALID AT 1200 GMT, 12 NOVEMBER 1968

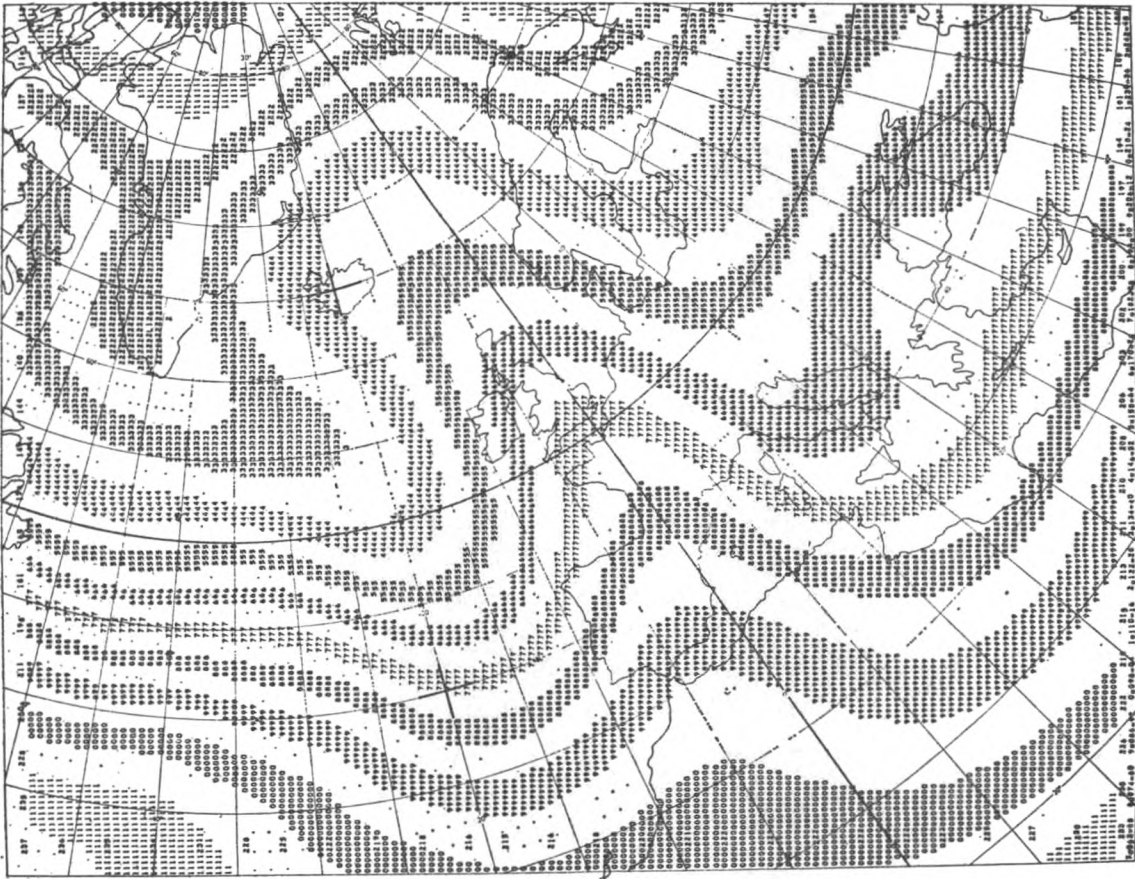


FIGURE 6—OPERATIONAL NUMERICAL 200-MILLIBAR 24-HOUR FORECAST VALID AT 1200 GMT, 12 NOVEMBER 1968 (ZEBRA PATTERN)

Although it is expected that contour/isotach charts will be required for many years, there is a growing demand for digital data, either as numbers printed at fixed points on a chart, giving the wind direction, wind speed and temperature, or as data on tape for teleprinter transmission. These data are received at meteorological briefing centres either as typewritten copy for manual use or, for example at BOAC flight planning centre and at Oceanic Flight Control Prestwick, as punched paper tapes for direct input to the flight planning and flight control computers. Most output is produced to regular schedules but there are limited facilities for producing forecasts of winds along prescribed air routes on request. It is likely that demand will grow for options of this kind.

The forecast flow patterns are used unaltered for the upper air, whilst for the surface they are used in the Central Forecasting Office at Bracknell as a guide in producing the forecast synoptic charts, which are issued every 6 hours for 24 hours ahead, and therefore exert some influence on almost all British Isles forecasts. The guidance provided by the computer charts is reasonably reliable and is particularly helpful in maintaining a consistent approach, especially in the medium-range (three-day) forecasts. Also the provision of computer forecasts of the flow pattern relieves the work load on the forecaster and allows him to concentrate on the all-important weather aspects of the forecast.

The 1000-mb forecast contours are also used to prepare guidance forecasts of sea-wave direction and height for North Atlantic ship-routeing purposes. The wave-height forecasts are computed from a simple formula connecting wave height and 1000-mb wind speed, and further development to improve the results is planned.

Development

A new regression-type technique, incorporating the discontinuities of vertical temperature lapse rate occurring at the tropopause, is under development. The technique yields improved forecasts of the temperature and height fields at all the pressure levels for which regression techniques are used and it is expected to yield reliable forecasts of the height and temperature of the tropopause. Aviation should therefore derive considerable benefit from the application of this new technique. It will also be of value in producing background temperature fields for temperature analysis when increased computer speeds and capacities make it possible to extend the analysis schemes.

Current experiments with objective analysis techniques have shown that sixth- to eighth-power polynomials may be used to fit a single surface for areas of the order of 1000 miles square. Complete evaluation of such complex surfaces is time consuming, but specialized techniques are under development which will provide solutions more quickly than the current quadric-fitting process. The method is capable of extension to fit data in three or four dimensions and will thus make it possible to use data for non-standard levels and times. It will also ensure that the analyses are rigorously consistent and are of the quality required by the more sophisticated forecasting models being developed by the research branches. However, three- and four-dimensional analysis will not be practicable on the present computer.

GENERAL

The year 1968 was one of sustained activity in the Services Directorate both in operational work, which had to cope with increased demands over the whole range of services, and in planning, which entered a more intensive phase of studies and trials in preparation for the acquisition and routine use of more advanced technical equipment and other support facilities. There were no major changes in the organization but, as was indicated in last year's report, the present period extending into the early 1970s is one of transition because increased utilization of modern technology will lead steadily to further streamlining and redeployment of effort.

The value of weather forecasting and warning services to the community as a whole as well as to individual user interests was highlighted by a number of events in which weather of exceptional severity caused loss of life and widespread damage. The gales which affected the Glasgow area in January and the occasions of very heavy rainfall which resulted in floods in the west country in July and in south-east England in September are examples of phenomena which, in their respective areas, may be expected to occur with equal severity once in 100 years or more. Events such as these focus attention on the Meteorological Office from many directions with particular regard to the quality of the forecasting service and to the efficiency of the arrangements for the prompt dissemination of forecasts and, when appropriate, warnings of adverse weather. The Office does not possess the means for communicating weather information to the public at large and for that reason places the greatest value upon the co-operation of the mass media—radio, television and the Press—and of the GPO which provides facilities for the automatic telephone weather service (ATWS). The Office is constantly in touch with all these organizations in order to improve the availability of its services and is making special efforts to have ATWS extended to the whole country and to grasp the opportunities presented by the introduction of local broadcasting.

The Office is co-operating with the Board of Trade in the Trawler Safety Scheme which has been provided in the waters north of Iceland. The control ship is in hourly radio contact with the Central Forecasting Office (CFO) at Bracknell and the ship's complement includes a forecaster who advises the Control Officer on all weather hazards.

In the technical work of forecasting there has been considerable development in the application of numerical methods. This work is described in the Special Topic entitled 'Operational numerical weather forecasting' (p. 1).

As a result of consultations with the building industry, a new service will be introduced early in 1969. This will take the form of a prompt-reply facility for contractors who will be able to obtain an appraisal of the main climatological features of any locality in which they are interested.

In agricultural meteorology a major investigation was carried out into the meteorological aspects of the onset and spread of foot-and-mouth disease. The results were submitted to the Committee of Inquiry which was set up by the Ministry of Agriculture, Fisheries and Food under the chairmanship of the Duke of Northumberland.

Hydrometeorology has been notable for its abundance of both routine work and special projects. Among the latter, much preparatory work has been done in connection with an experimental programme, in the region of the Chester Dee, designed to explore the potentialities of using radar for the accurate measurement of rainfall. A successful outcome of this work would have wide applications although the experiment itself is designed, in conjunction with the Water Resources Board, to help in the operational control of regulating reservoirs. Another major project is a comprehensive study of floods in the United Kingdom. A considerable amount of planning has been done for this project, in which a number of departments and other bodies are involved, so that an early start can be made as soon as resources become available for the work to be carried out.

In the field of basic, indispensable facilities—instruments, communications and data processing—work has continued at a high intensity. Systems design studies of meteorological telecommunications requirements have been carried out by industry as an essential stage in the development of Bracknell as one of the main communications centres in the organization of World Weather Watch (WWW). In data processing, considerable and wide-ranging efforts have been applied in preparing the way for decisions on the very powerful computer system now required by the Office. On the instrument side the Mark 3 radio-sonde has successfully completed its development trials and further progress has been made in automatic observing systems.

On a less formal note, it is pleasing to record that Mr David Houghton, one of the Senior Forecasters of CFO was a member of the British yachting team at the Olympic Games in Mexico. Mr Houghton's efforts as adviser to the team on the important and intricate weather factors for the yacht races earned the highest praise. In the past the Office has been proud at different times to contribute a long-distance runner and a high jumper to the British team for the Olympics. In Mexico the contribution required was meteorological advice and very handsomely it paid off.

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.

Thirdly, CFO is a Regional Meteorological Centre within the concept of World Weather Watch (WWW). In this role CFO undertakes to meet the needs of various countries in Europe for certain regional forecasts. It fulfils this role

by the preparation, for wireless-telegraphy and radio-facsimile transmission, of actual and forecast charts covering a large area of the North Atlantic Ocean, Europe and the Arctic.

Computed forecasts continue to play an increasingly important part in the production of operational forecasts for various purposes and a number of additional numerical forecasts and refinements to existing forecasts have been introduced during the year. Some of these are mentioned in the Special Topic entitled 'Operational numerical weather forecasting' on page 1. It also mentions that there are problems of analysis in sparse data areas, such as the Atlantic Ocean. New methods of dealing with these problems have received much attention and improved analyses will result from experiments carried out during the year.

Experiments have also been made in the objective analysis of frontal zones and in the forecasting of these zones by numerical means. These experiments show considerable promise and are already proving useful in practice.

Forecasts of wave height and direction are now produced as routine by computer for the North Atlantic area, for periods up to 48 hours ahead. These are broadcast as a WWW requirement for the benefit of other European maritime nations and of ships at sea. They are also required by CFO in connection with its ship-routeing service.

Since this service was inaugurated, in March, about 100 ships have been routed across the Atlantic in one direction or the other. The object is to provide the ships with advisory routes or courses to steer, so that the time of crossing will be the least, commensurate with the avoidance of wave conditions liable to cause damage to the ship or its cargo. The method used remains that adopted for the ship-routeing experiment carried out in 1967. The speed of the vessel along various possible tracks is estimated in relation to the predicted wave fields, having regard also to conditions expected in the outlook period beyond 48 hours ahead. However, before offering advice to the master of a vessel it is necessary to consider also a number of other factors, such as fog, icebergs, ocean currents and any special conditions which may be important to a particular vessel on a particular voyage.

An interesting by-product of the routine forecasting of wave and wind conditions on the North Atlantic is the assistance given to the winner of the Single-handed Transatlantic Yacht Race. Forecasts were supplied which enabled the best route or routes to be sailed in the next 24 hours to be computed and sent to the yachtsman, who has stated that they were of considerable assistance to him.

Cloud photographs from the automatic picture transmission (APT) of the United States ESSA weather satellites have continued to be received at Bracknell daily and are a routine aid in the preparation of analyses over the North Atlantic and European areas. 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 during 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.

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 icefields, 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 only the time-honoured reconnaissance methods can be employed. The ice charts also show sea temperature isotherms, and separate charts of isotherms are issued on a daily basis for coastal waters of the British Isles. The temperature data for these purposes are all processed by computer.

CFO remains responsible for the publication of the *Daily Weather Report (DWR)* with its *Overseas Supplement* and *Monthly Summary* and the *Daily Aerological Record (DAR)*. Changes of codes introduced on 1 January 1968 necessitated minor changes of format to the *DWR* and a complete change of format and computer programme for extraction of the data required for the *DAR*. On the whole the new presentation has been well received by the subscribers.

CFO is supported by a computer programming unit which also provides direct assistance to certain major outstations, notably London/Heathrow Airport, Headquarters Strike Command and Headquarters Air Support Command of the Royal Air Force. A number of changes and improvements in this assistance were introduced during the year. The efforts of the programming unit are largely directed to enabling CFO to fulfil its role as a Regional Meteorological Centre, to enabling Heathrow to fulfil its role as an Area Forecast Centre for international civil aviation in the North Atlantic region and to improving the accuracies of the analyses and forecasts required for these purposes.

Services for the general public

Forecasting services for the public—including industry, commerce, public utilities, social and sporting activities—are provided directly from the various weather centres and other forecasting offices or indirectly by means of the mass communications media. These media include the radio and television services of the British Broadcasting Corporation, the companies of the Independent Television Authority, the national and provincial Press, the GPO's automatic telephone weather service (ATWS) and the GPO's coastal broadcasting stations.

Direct calls for weather information received from the public at the various weather centres and forecasting offices during 1968 reached a record total of 1 480 262 compared with 1 264 605 in 1967.

The special efforts made to increase the contribution that meteorology can make to the national economy were reflected in the significant increase in the number of inquiries received from the construction industry, 89 177 in 1968 compared with 73 466 in 1967. Agriculture and transport inquiries showed similar increases.

Studies are continuing of the weather-sensitive features of industrial activities. In particular industries there are close contacts with representative organizations on the industrial side and with appropriate government departments. These contacts encourage a clearer understanding of the meteorological problems within an industry and point the way in which meteorological services can be used for economic benefit.

As a result of contacts with the construction industry the Meteorological Office is developing a new service designed to help those engaged in the estimating and planning stage of a contract. At this stage climatological information for the site is needed at short notice so that allowance can be made in the

tender for the likely effects of adverse weather on the construction programme. The new service will provide assessments of the average frequency of inclement weather in the locality of the contract during the period of construction. Inquiries will normally be dealt with within twenty-four hours of receipt. The service will begin early in January 1969.

Of special interest are investigations now being planned into the effects of weather on the construction industry. These investigations are being financed by the Construction Industry Research and Information Association and guided by the professors of Building Science and Civil Engineering in the University of Sheffield, with the co-operation of the industry, the National Federation of Building Trades Employers and the Meteorological Office. Earlier work on the effects of wet weather on earthworking will be continued and studies will be made to determine the most critical weather factors affecting production in the industry in this country. The value of special meteorological services already developed in conjunction with the industry will be assessed during the investigations and any necessary modifications made to the services.

On the industrial front as a whole, the officer charged with studying the meteorological requirements of industry visited most of the Regional Offices of the Ministry of Technology during the year and had discussions with the staffs there and with some 25 Industrial Liaison Officers. These Officers are responsible for maintaining contact with firms in their areas and encouraging them to make greater use of existing scientific and technical knowledge. They are thus in a special position to advise firms on occasions when meteorological services might be of help.

Further improvements were made in the dissemination of information via the mass media. During the summer week-ends the 'weathermen' augmented the daily forecasts broadcast by the BBC with forecasts for sea crossings and for the major continental resorts. A similar service covering week-end outlooks for British holiday resorts was provided each Friday on BBC Radio 2. Tyne-Tees and Scottish Television continued their personal presentations of week-end forecasts on Fridays; these were undertaken by the officers-in-charge of the Newcastle and Glasgow Weather Centres. Most BBC regions and ITA companies have added close-down forecasts to their other routine issues. They also augmented these routine forecasts with FLASH weather warnings of severe weather. The broadcasting on BBC Radio 2 of warnings of fog on motorways has now been followed by a similar scheme for warning motorists of strong crosswinds.

Local radio stations were quick to recognize the value of forecasting services. Radio Nottingham includes a 'live' presentation with the announcer questioning the forecaster and requesting information of particular interest to the community served by the station. The eight stations now operating make maximum use of routine forecasts and inject all warnings of adverse weather into their programmes as required.

Several broadcasts and talks were given by various members of the staff on both radio and television. The Meteorological Office also collaborated with Associated Television (ATV) in the production of a series of adult educational programmes. The series, entitled 'Working with Weather', was shown on most ITA channels during the spring and summer months. Programmes were televised weekly on Sundays and repeated on the ensuing Saturdays over a period of 13 weeks.

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

The automatic telephone weather service (ATWS) was extended to cover a new area centred about Sheffield. The six services originated by London Weather Centre are now voiced by Meteorological Office staff instead of GPO staff in order to ensure that no delays occur in amending forecasts. The total number of calls made on the ATWS during 1968 was 10 016 877 compared with the 1967 figure of 7 599 241. This year the total exceeded the ten-million mark for the first time.

All direct services to the public continued to expand. A new free leaflet has been published which describes the services available to all sections of the community and strenuous efforts have been made with other government departments concerned to ensure that all road, rail and river authorities are fully aware of the ways in which the Meteorological Office can be of help to them.

In conjunction with the Ministry of Housing and Local Government local authorities responsible for coastal areas were informed of arrangements whereby, when coastal areas are threatened by oil-slicks, they would be provided with forecasts of surface winds for the coastal waters concerned. Arrangements were also made in conjunction with the Ministry of Agriculture, Fisheries and Food for river authorities to receive special warnings when on-shore gales are liable to increase flood hazards.

The routine work of the weather centres at London, Glasgow, Manchester, Southampton and Newcastle, continued to increase, though casual inquiries showed some fluctuations. The Newcastle Weather Centre which opened in April 1967 is steadily gaining the confidence of the community. The initial findings of an independent market survey held to assess the economic value of the centre to the north-eastern counties illustrated the benefits such a centre can bring. The survey is continuing. The absence of weather centres in other areas is still keenly felt.

The total number of inquiries dealt with by the individual centres over the past three years are shown 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
1968	347 267	83 728	108 838	73 433	41 097	60 101
Grand totals: 1966, 581 501; 1967, 614 680; 1968, 714 464.						

The Meteorological Office supported exhibitions sponsored by the RAF (Battle of Britain, Nottingham), Ministry of Public Building and Works (Bristol), and the Scottish Mountain Safety Week (Glasgow). The Battle of Britain exhibition was again well attended and the Meteorological Office pavilion attracted a good share of attention. Visitors were particularly interested to see forecasters at work. The forecasters provided live broadcasts for Radio Nottingham from the exhibition site. The Ministry of Public Building and Works exhibition at Bristol afforded the Meteorological Office the opportunity to display to representatives of the building trades examples of the services it

can provide in the planning and construction phases of major projects. The Glasgow exhibition was aimed at members of the community interested in climbing and in winter sports. The display stressed the variability of weather in time and with height and the need to obtain up-to-date forecasts prior to any planned mountain activity.

The services of the Office were further publicized by a large number of lectures given by members of the staff to chambers of commerce, to professional and scientific institutions and to various societies and associations linked with weather-sensitive activities. A number of articles were also published in scientific, technical and trade journals, and in the national and provincial Press.

Many interesting specialist demands were received for our services. London Weather Centre provided information for the installation of the new Royal Sovereign Light Tower, forecasts of visibility in the Thames estuary required in connection with the movements of the new 200 000-ton tankers, and data to assist in investigations into condensation on the walls of the new Victoria underground. Southampton Weather Centre assisted with information required for the trials of the Mountbatten Class hovercraft, for satellite communications tests being undertaken by the Signals Research and Development Establishment, Christchurch, and for ground-wave radio-propagation trials conducted by the Plessey Company electronics group. Once again a personal briefing was given to the officials and crews competing in the International Power Boat Race for the Wills Trophy. Glasgow Weather Centre provided week-end forecasts for British Rail, Glasgow, for planning of week-end excursions. Manchester Weather Centre provided forecasts for coastal barges being towed from Anglesey to Merseyside.

The services for racing-pigeon clubs reached a new record total of 1157 line-of-flight forecasts.

The routine supply of information to oil rigs drilling in the North Sea, to the power industry (coal, gas and electricity) and to road and rail transport authorities continued. Discussions have been held with the gas and electricity authorities to give them improved services as their own industries progress. Larger computer facilities and the increasing use of North Sea gas are changing the nature of the meteorological requirements.

Each successive year shows an increasing demand for meteorological services. Industry is becoming more aware of the economic benefits that can accrue to them by taking meteorological advice, and the general public are no doubt awakening to the value of forecasts and statistics in planning their own activities. The Office is finding it very difficult to cope with the existing demands. The services are obviously beneficial to the whole community and as such every effort must be made to continue to expand them.

Services for civil aviation

The Civil Aviation Department of the Board of Trade (B. of T.) 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 Meteorological 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 flights operating above 5000 ft (about 1525 m) 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 all major civil airports in the U.K. by land-line facsimile transmission (civil aviation meteorological facsimile—CAMFAX). The Principal Forecasting Office at Heathrow also acts as European Area Forecast Centre for the North Atlantic and is responsible for the supply to European users of forecast weather charts suitable as documentation for flights from European terminals to North America including Alaska and to the eastern Caribbean. Dissemination of these forecast charts in a form suitable for direct use by aviation is by radio-facsimile broadcast on a round-the-clock schedule and by land-line transmission to a limited number of European terminals.

Forecasts of upper winds and temperatures at levels up to 40 000 ft (about 12.2 km) provided by Heathrow are now largely based on computer data from the Meteorological Office computer (COMET) at Bracknell.

For long-range flights to East and West Africa and India use is made of the products of other European Area Forecast Centres at Frankfurt, Paris and Rome. Satellite cloud pictures received at Heathrow also provide a valuable addition to the data received from other sources.

The British Overseas Airways Corporation (BOAC) has now computerized its flight-planning operations, and data in digital form are supplied from the Meteorological Office computer as basic data for flight planning by the BOAC computer; this service commenced in April 1968. Arrangements are also being made on behalf of the Board of Trade for the supply of similar data to their computer at the Prestwick Oceanic Control Centre.

Studies have continued during the year on the meteorological requirements of supersonic transport aircraft. BOAC is carrying out a series of flight-planning exercises for Concorde flights to New York and forecast winds and temperatures and other data for levels up to 60 000 ft (about 18.3 km) are being provided for this purpose at Heathrow. Arrangements have also been made to set up a forecast unit at RAF Fairford to provide meteorological service for flights of the Concorde prototype. Test flights are expected to begin early in 1969.

New codes for aerodrome weather reports and forecasts were introduced on 1 January 1968. These messages are now in a direct-reading format suitable for copying direct to aircrew and airline operators.

Routine six-monthly calibration of lights used in assessing runway visual range (RVR) have continued throughout the year at most civil airports. An operational trial was commenced at London/Heathrow Airport in September 1968 to evaluate a system for the provision of slant visual range to pilots in flight, and approaching to land, whenever the RVR falls below 1100 metres.

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 Strike 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 the Near East, Persian Gulf 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. In order to meet the needs of long-range aircraft of Air Support Command, the Main Meteorological Office was strengthened, and closed-circuit television and an electrowriter were brought into use as a means of transmitting aerodrome reports and forecasts from the meteorological office to the RAF central control room. Changes were also made to meet the requirements of Strike Command. This involved greater centralization of forecasting based on the RAF Principal Forecasting Office and greater use of facsimile as a means of transmitting weather information to offices on aerodromes. Overseas, the most important changes have involved the recruitment, for the first time, of suitably qualified local staff for training, as assistant forecasters in Malta, and in the auxiliary duties of observing and plotting at Bahrain.

Considerable application has come to be made of computerized forecasts for operational use and faster facsimile equipment was installed towards the end of the year in order to speed up the transmission of computer products from Bracknell to some of the larger outstations.

Useful material for preparing operational forecasts over areas where normal data are sparse has continued to be provided by direct reception of cloud pictures from the meteorological satellites being operated by the U.S.A. Reception stations are now operating 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, India, Ceylon and Mauritius, whenever evidence of these phenomena is acquired from the satellite pictures being received at Gan and Changi.

Satellite cloud pictures received at Bracknell are now transmitted simultaneously by land-line to five U.K. offices where timely reception of this information is important.

Meteorological instruction was given at a large number of schools in Training Command and at Operational Conversion Units. A new edition of the RAF meteorological training manual has been drafted and is now with the printers.

Services for the Army

Forecasts required by the Army Aviation Service continued to be supplied.

Four permanent outstations continued to serve the needs of the Army, mainly for ballistic purposes. In addition, two subsidiary stations were manned as necessary for practice firings of both 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

The permanent outstation at Aberporth continued to serve the needs of the Royal Aircraft Establishment.

At South Uist, in the Hebrides, a PETREL rocket programme continued under the direction of the Atomic Weapons Research Establishment. A Senior Experimental Officer from the Meteorological Office continued his seconded service there.

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 U.K. is 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.

North Atlantic Treaty Organization

The twenty-fifth meeting of the Military Committee Meteorological Group took place in Brussels, Belgium, from 1 to 3 May, under the chairmanship of the U.K. member, Mr P. J. Meade, Director of Services. Mr E. Evans was also present.

The Working Groups of the Military Committee Meteorological Group on Weather Plans and on Weather Communications met twice during the year; in Brussels, Belgium, from 18 to 26 April and in Rome, Italy, from 2 to 9 October. Mr E. Evans represented the U.K. at both sessions and he was accompanied by Mr A. A. Worthington at the October meeting.

Mr K. Bryant, as meteorological adviser to the U.K. representative (from the Home Office), attended a meeting of the Warning and Monitoring Working Group of the NATO Civil Defence Committee which was held in Brussels on 21 June.

The Meteorological Panel (Panel XII) held two meetings at the NATO Headquarters in Belgium, the first from 11 to 15 March and the second from 4 to 8 November. These meetings were attended by Mr A. G. Matthewman. A further discussion (prior to a Panel XII meeting due to be held early in 1969) took place in Munich, Germany, on 13 December.

CLIMATOLOGICAL SERVICES

Requests for climatological information may refer to any part of the world, and to meet this requirement the Office collects published data from most parts of the world. However, most of this aspect of the work is concerned with the national climatological network, and one of the major jobs of the Climatological Branch is the collection, examination, analysis, publication and preservation of surface and upper air observations made at stations in the U.K. The surface observations are published in the *Monthly Weather Report (MWR)* and its *Annual Summary*, in the yearly publication *British Rainfall* and in other non-routine climatological publications. Part of the *MWR* is now quality controlled and processed by machine methods and a further extension of this automation is planned; the aim is complete automation of the processing, preparation and publication of the *MWR*. The Office is pleased to record its appreciation of the good work done by voluntary observers in helping to maintain an efficient climatological network.

The Office continues to collaborate with other government agencies such as the Building Research Station, the Road Research Laboratory and the Warren Spring Laboratory. Close liaison was maintained with the meteorologist seconded to the Road Research Laboratory, and plans are well advanced for the secondment of a meteorologist to the Building Research Station. The Head of Branch continues to serve on the Interdepartmental Committee on Air Pollution Research and on the Working Group on Tees-side Mist. The Office is co-operating in the investigation of the composition of Tees-side mists which is being carried out by the Atomic Energy Research Establishment, Harwell.

There was, once again, an increase in the total number of inquiries and an increase in the number of complicated and diverse problems which required machine methods for their solution and reply. One example is the supply of climatological information to the Gas Council for the estimation of future demands in connection with planning the supply of North Sea gas. This computer study involved the calculation of the accumulated temperature deficit for five selected threshold values for each winter half-year at nine stations over periods varying from 40 to 113 years and presentation of the results in ranking order of the magnitude of the deficit. By means of machine methods and a statistical procedure developed in the Office, estimates of the time that could be lost because of low temperatures were prepared in order to answer inquiries from the building and construction industries. These industries will also be interested in a recently started programme of work on driving rain. The aim is to compute and analyse the hourly driving-rain index at each of 21 stations. The frequency distributions of driving-rain index with wind speed, wind direction and hourly rainfall rate have already been computed, but a study of extreme hourly values and frequencies of prolonged periods of driving rain remain to be done. There were many inquiries for design and extreme wind speeds, including one for the design of a new bridge at Woolwich and another for wind data at Meifod, Montgomeryshire, the proposed site of a new radio telescope. The Office

continues to be represented on the British Standards Institution Committee on wind loading; the same member of the staff also serves on a BSI sub-committee on wind loading of bridges and on an Electrical Research Association panel dealing with research into wind loading of lattice masts and towers. Most of the inquiries referred to the U.K. but a substantial number of requests were for information about other countries. For example the British Amateur Athletic Board was supplied with temperature and humidity data for Mexico City, and a committee of the Royal and Ancient, St Andrews, was provided with comparative wind data for the U.K. and the U.S.A. in connection with the size of golf balls.

Climatological services for Scotland and for Northern Ireland are provided by offices in Edinburgh and Belfast respectively. These offices are backed up by Headquarters staff and facilities. The number of inquiries remained high in Scotland and there was an increase in the number of inquiries in Northern Ireland. In Scotland, the severe gale in January and the wet weather in March and May tended to increase inquiries especially those relating to design wind speeds but the fine summer and autumn resulted in a decrease in inquiries, so that the annual total was about the same as last year. The Belfast office continues to work in close accord with Northern Ireland government departments and is co-operating with the new University of Ulster in establishing a climatological station at the University.

The Office has an international obligation to prepare and publish annual marine climatological summaries for the east Atlantic and the North Sea and, to this end, work continues on the collection and processing of ships' observations made in these regions. The marine climatologist continued to serve on the BSI committee dealing with climatic hazards in the transport and storage of goods. Further information was provided for the development of hovercraft services and the Office continued to be represented on the National Physical Laboratory Hovercraft Sea State Committee. At the request of the *Observer* climatological maps were prepared for the Single-handed Transatlantic Yacht Race in June. During the year, the meteorological sections of six Admiralty *Pilots* were brought up to date. A paper entitled 'Icing on trawlers in Arctic waters' was prepared and submitted to the Superintendent of Sailing Directions, Hydrographic Department, for approval and inclusion in the appropriate Admiralty *Pilots*.

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 626 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 appearance of *British Rainfall 1961*. This, the one hundred and first annual volume, marks the introduction of basic changes in the presentation

of data which are in some respects closely linked with the introduction of computer techniques for the quality control and subsequent processing of rainfall data. Changes include the transfer of purely repetitive information to five-year supplements, a big increase in the amount of basic data of the year, and a concise presentation of processed data in the forms of tables, maps and graphs. A memorandum was released, giving monthly and annual rainfalls for 1931–60 for the United Kingdom. The earlier memorandum on rain intensity-frequency relationships in Britain was re-issued with additional information on areal values.

The inquiries section handled about nine per cent more inquiries than in 1967. The substantial increase in the number of inquiries received from the building and construction industries in 1967 was again apparent in 1968, and such inquiries now account for one in four of the total. Inquiries from the legal profession and insurance companies, requesting data concerning accidents of all types and flood damage, were almost as numerous, and inquiries connected with insurance against holiday rainfall continued at a high rate.

Most of the major inquiries of the year are indicative of the growing concern with national water resources. Work for the Water Resources Board included assessment of rainfall and actual evaporation over several sections of the Lincolnshire limestone ridge and over the lower greensand stretching from Letchworth to Cambridge, in connection with the development of ground water resources; a very detailed study of rainfall, evaporation, soil moisture deficits, snowfall and temperature in the basin of the East Anglian Stour, in connection with an inter-departmental study of the water resources of south-east England; assessment of rainfall and evaporation over several chalk areas in the central London basin; and assessment of rainfall over Dartmoor. Work continued on the assessment of rainfall, evaporation and soil moisture deficits as a routine and retrospectively for the Lambourn valley experiment of the Thames Conservancy's plan to exploit the ground waters of the Thames valley. Similar work is to be carried out for major geological strata within the Thames basin. A very detailed study of rainfall and evaporation over catchment areas draining into Morecambe Bay is being carried out for the consulting engineers associated with the Morecambe Bay Feasibility Study. Estimates of the likely monthly evaporation losses from the extensive body of water to be impounded in the bay are also being made. Other requests for assessments of general rainfall over catchment areas as a contribution to water supply schemes have been received in respect of the Tamar, Thrushel and Upper Exe valleys in the south-west, the Wharfe and Dove in the north, Loch Awe and Glenkiln reservoir in Scotland, and Rhymney in Wales. Detailed estimates of actual evaporation have been supplied to the Mersey and Weaver River Authority for their area, and daily rainfall values and estimated soil-moisture deficits were supplied on a weekly basis for a number of places in England in connection with operational procedures for spraying potatoes.

The increasing demand for more-detailed evaporation data has led to more-refined methods of estimation. Hitherto, areal estimates of actual evaporation have been based on the areal means of rainfall, potential evaporation and broad land-use factors. Recent innovations include the use of more-detailed land-use data in estimates, and the estimation of actual evaporation and soil moisture deficits at a network of points in the area determined by the intersections of the major 10-km grid.

The Office continued to issue maps of soil moisture deficits at fortnightly intervals throughout the summer half of the year. Estimates of monthly rainfall were prepared for just over 350 catchment areas for the *Surface water year-book 1966-67*.

The investigational section continued to be actively 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 and river authorities, particularly in respect of rainfall and evaporation networks for river authority hydrometric schemes. In detail, active consideration is being given to requirements for hydrometeorological data, especially from automatic rain-gauges and from automatic climatological stations which measure the physical quantities needed to evaluate evaporation, the development of automatic rain-gauges and climatological stations, the processing of data and the accuracy of point rainfall measurements and evaporation estimates. Further progress was made towards implementing the radar project associated with the Chester Dee regulating-reservoir research project whereby it is hoped to measure areal rainfalls over sub-catchments by means of a 10-cm radar. Associated with this work more progress was made in quantitative rainfall forecasting for the upper Dee catchment area by conventional methods pending the time when quantitative rainfall forecasts will be available as a routine from a computer.

The Office continued to be represented at national level in the work of the International Hydrological Decade (IHD) and contributed to the work of the working group on catchment studies of the Hydrology Committee of the Natural Environment Research Council (NERC). Close liaison was maintained with the Institute of Hydrology, especially on problems concerning the accuracy of point-rainfall measurements, and preliminary work has been done on a snow study planned for a catchment in the Cairngorms. Comparison tests of evaporation tanks have continued as part of a world-wide investigation organized by WMO. Special studies have been made of the rainfalls leading to flooding in Scotland in March, the west country in July, and the south-east of England in September. Contact has been maintained with National Coal Board (NCB) officials following the Office's presentation of rainfall evidence before the Aberfan Tribunal in 1967 and this culminated in the presentation of a paper on rainfall statistics at an NCB conference on coal-tip stability.

The major investigation of precipitation in the Trent area was completed and a report was prepared for the Trent River Authority as a contribution to their flood prevention projects. Experience gained and techniques developed in this work will be valuable in the comprehensive study of river floods in the U.K. proposed by the Institution of Civil Engineers. There has been a considerable increase in inquiries on rainfall intensity/duration frequencies from engineers concerned with motorway and urban storm-water drainage and drainage from factory sites; greater use and analysis of rainfall data from different parts of the country has led to improvements in the conventional method used in handling these inquiries. Analysis of data from the Winchcombe investigation on intense rainfalls has continued and preliminary results suggest some differences from those derived from the similar investigation sited at Cardington some years earlier.

The Senior Scientific Officer attached to the Institute of Hydrology has continued his research work on evaporation from forests. Many of the instruments have been installed and tested at the experimental site at Thetford, Norfolk.

SERVICES FOR AGRICULTURE

There has been little change in the organization, with agricultural meteorologists working at Bracknell, the National Agricultural Advisory Service regional headquarters at Bristol, Cambridge and Leeds, the Grasslands Research Institute of the Agricultural Research Council at Hurley, and the Meteorological Office at Edinburgh. Very varied problems have come under consideration; examples at random include research into the effect of weather on machinery work-days, certain aphid infestations, several animal diseases and quality of crops, and also considerations of spring frosts from several viewpoints. Work has continued on shelter and hill-farming problems. These and other subjects have been described in agricultural memoranda, of which about 50 were issued.

Particularly important research into meteorological factors relating to the spread of foot-and-mouth disease has been carried out as a result of the disastrous 1967/68 outbreak. This has been undertaken by senior members of the staff at Bracknell in conjunction with veterinary research establishments at Weybridge, Pirbright and Tolworth.

Special attention was given to the disease-spreading processes within the country. From an examination of several epidemics it was deduced that meteorological factors, especially wind direction and rainfall, could play a predominant role in the amount of spread. The possibility of spread of the disease from the continent was also examined and a paper was published in the *Veterinary Record*. Papers and oral evidence on this work were presented to the Northumberland Committee.

The very important work of co-operation with the Ministry of Agriculture, Fisheries and Food has continued, and the excellent relations between the branch and various research establishments such as Rothamsted and East Malling and university departments at Long Ashton and Sutton Bonington have continued to flourish. Liaison has been maintained with the Plant Pathology and Veterinary Laboratories in connection with the issue of warnings of potato blight and apple scab, and of liver fluke in sheep.

MARINE BRANCH

As the oceans occupy three-quarters of the world's surface, the value of regular weather observations from oceanic areas is obvious, both for weather forecasting in this country and overseas and for world-wide climatological purposes. The increased attention which is being paid to upper-air observations and satellite photographs has in no way diminished the need for surface observations. With the exception of H.M. ships, Ocean Weather Ships and research ships, these surface observations from the oceans are provided entirely voluntarily by the masters and officers of merchant ships and the organization for obtaining them has, since 1855, been the responsibility of the Marine Branch. Table III on page 43 gives the present strength of the British Voluntary Observing Fleet. These ships, which are supplied with the necessary meteorological instruments on loan, make their observations every 6 hours on a world-wide basis, wherever their voyages take them. The coded results are transmitted by radio to the most convenient coastal radio station, addressed to the relevant meteorological service (e.g. when a ship is in the eastern North Atlantic the messages are addressed to the British service and in the western Atlantic to U.S.A. or Canada) as part of an international scheme arranged by WMO. The map on page 26 shows the distribu-

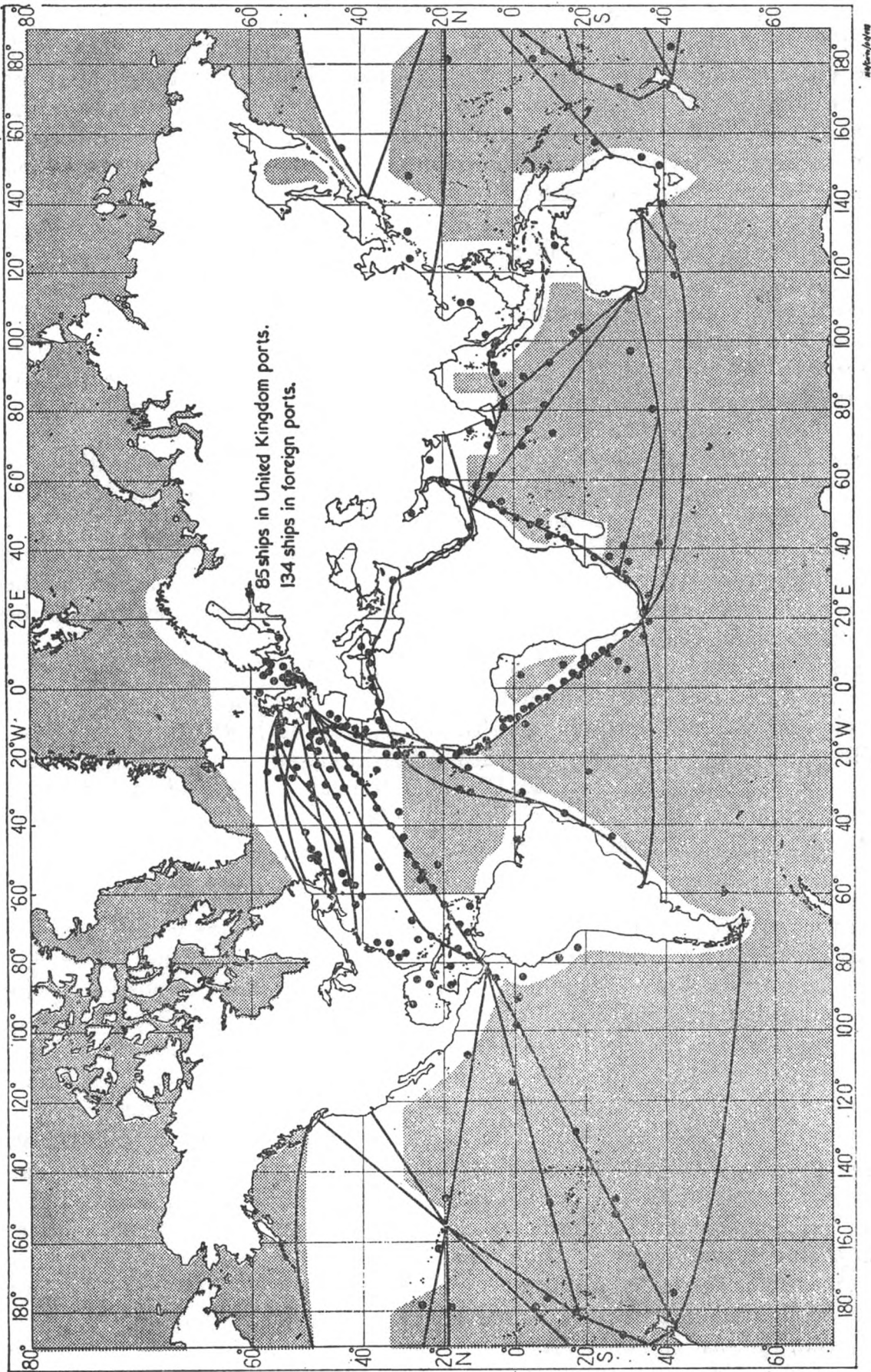


FIGURE 7—THE POSITIONS OF BRITISH SELECTED AND SUPPLEMENTARY SHIPS ON 14 JULY 1967
The shaded areas are those in which shipping is sparse and in which Auxiliary Ships make reports.

tion of these ships on a typical day in 1967 picked at random. The total number of British Voluntary Observing Ships taking part in this scheme represents about 14 per cent of the world total of some 5400 observing ships belonging to various maritime countries. The total British merchant fleet is now about 11 per cent of the world total, so our contribution to this scheme is already appreciable. Nevertheless, in view of the great value of observations from the oceans, endeavour is being made to increase the number of British Voluntary Observing Ships by 50 a year during the next four years as part of the U.K. contribution to WWW. This hoped-for increase in the voluntary observing fleet will not be easy, in view of the tendency for merchant ships to increase in size and speed with consequent reduction in the number of ships needed. For example, during the year several ships were withdrawn from the North Atlantic trade and were replaced by larger and faster ships. One new ship often replaced two or more smaller ones. This tendency has been accelerated by the increasing use of container ships, which are replacing the conventional cargo ship. These ships are able to carry considerably more cargo during a year than conventional ships can because containers are so easy to load and discharge and thus the ships' turn-round time in port is very much less. During the years ahead it seems likely, therefore, that there will be a reduction in the number of ships plying the trade routes of the world.

The British Voluntary Observing Fleet comprises all types of ships, from passenger ships to the humblest coaster and the distant-water trawler. The direct administration of this work, including the recruitment of the ships and the supply and replenishment of instruments and instructions, is carried out by Port Meteorological Officers and Merchant Navy Agents at the major ports in the U.K. These are all master mariners with experience of voluntary observing at sea, who maintain personal contact with the shipmasters, deck and radio officers as often as possible, ideally every three months. Wider administrative contact is maintained by the Marine Branch at Bracknell where every meteorological log-book or form which is received becomes the subject of a personal letter to the master. Personal record cards are kept and visits by voluntary observers on leave from their ships are encouraged. There can be little doubt that the personal touch, bringing goodwill on both sides, has been a major factor in maintaining the high quality of this service during its long history.

Throughout their voyages, the officers aboard voluntary observing ships record their observations in log-books, in addition to transmitting them by radio, and at the end of the voyage these are returned to the Marine Branch for scrutiny and extraction of the data. During the year, 1099 meteorological log-books were received from the regular observing ships. In addition, records were received from Auxiliary ships of weather events in areas where shipping is very sparse.

Observations from all types of ships continued to be of a high standard and often went into considerable detail not actually called for by the meteorological code, e.g. time of wind shift, time and duration of precipitation, etc. It is obvious that there is considerable enthusiasm for this work among ships' officers. Though the majority of British merchant ships carry only one radio officer, the number of radio weather messages cleared to coastal stations in various parts of the world is very creditable. Most ships' officers seem now to be aware that a late transmission can nevertheless be of very considerable use to a forecaster and in consequence it is not uncommon for all four synoptic observations to be included

in one or two transmissions from a 'single operator' ship, where the radio office is manned for only 8 hours a day. Many such messages have indeed been transmitted during a radio officer's off-duty time, whilst observations are frequently made and transmitted at the intermediate synoptic hours during tropical-storm conditions.

As an additional contribution to WWW during the next four years the Meteorological Office aims to install in up to 10 merchant ships the necessary equipment for making radiosonde observations. The first of these ships, the Sugar Line's bulk carrier *Sugar Exporter* carried two meteorologists on two voyages between mid-January and mid-June, during which over 130 successful radiosonde observations to an average height of nearly 70 000 ft (21 km) were made. One meteorologist, assisted by a seaman, is now making similar observations aboard the same ship on a round-the-world voyage. The Meteorological Office is grateful to the Sugar Line for providing this facility.

Awards of books were, as customary, made to the masters and officers of the 100 ships who had sent in the most carefully kept meteorological log-books during the year, and barographs were presented to the four shipmasters whose long record and consistently good service were considered as deserving special recognition.

The British Weather Ships completed 21 years service in the North Atlantic during the year; the existing four ships have been in operation for about nine years and continue to give good service. These ships co-operate with French, Netherlands and Norwegian vessels in maintaining five ocean 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 (radiosonde and radar wind) to an average height of about 65 000 ft (19.5 km) are transmitted by radio. In addition the British ships make observations of solar and total radiation, of sea temperatures and salinity at various depths down to the sea bed, and of magnetic variation, make deep 'echo soundings' and do some biological work, including plankton sampling and fishing for squid. All four ships are now fitted with wave recorders.

Communication facilities and routine navigational aids were provided for transatlantic aircraft by all the weather ships and air/sea rescue equipment was kept in a constant state of preparedness. Comprehensive search and rescue exercises were frequently carried out, in which RAF aircraft sometimes participated. On 29 March *Weather Reporter*, while on station 'K' in the Bay of Biscay, rescued the American pilot of a single-engined aircraft, on route from Gander, Newfoundland, to the Azores, who was blown off course and because of shortage of fuel and instrument trouble was advised to ditch. The rescue was carried out in darkness with a 23-kt (11 m/s) wind and 15-ft (5 m) swell.

During February and March the British Weather Ship on duty at station 'A' had a Control Officer on board and provided special advice by radio to British trawlers fishing north of Iceland. This facility was provided at the request of the Board of Trade, as a result of the earlier loss of the two British trawlers *Ross Cleveland* and *Kingston Peridot* in the same area during exceptionally severe gales and freezing conditions.

At the sixth International Civil Aviation Organization (ICAO) conference on North Atlantic Ocean Stations, held in Paris in March, it was decided that

the present nine-station network should be maintained for a further period of at least five years. A meeting of experts subsequently met in London, at the invitation of the U.K. Government, to consider the most economical method of replacing one of the Netherlands Weather Ships which will have to be withdrawn in 1970.

The Marine Branch has worked closely with CFO throughout the year in connection with the scheme for providing weather-routeing facilities for North Atlantic ships, and in the production of ice charts.

The Marine Observer was published each quarter as usual. Other publications included revised reprints of both the *Ships' Code Cards*, the *State of Sea Card* and the *Ships' Code and Decode Book*. The 9th edition of the *Marine observer's handbook* is in the press.

Revision of the ocean-current and sea-ice sections of six volumes of the *Admiralty Pilot* was completed during the year and the extraction and processing of ocean-current data continued.

There was a substantial increase in the number of marine inquiries dealt with during the year. Most of these were from solicitors, brokers and insurance companies. Meteorological evidence was prepared for the official inquiry into the tragic loss last February of the three trawlers *St Romanus*, *Ross Cleveland* and *Kingston Peridot*.

INSTRUMENTS AND OBSERVATIONS

The Instruments and Observations Branch has maintained its services of instrument development, specification, installation and maintenance throughout the year. These are essential functions as no meteorological service can operate without observations and these, with few exceptions, cannot be obtained without instruments. It is also necessary that these aids be used in the most appropriate and economical way, and considerable attention has been devoted to these aspects.

Instrument development and operational assessment

The automatic weather observing system, known as MOWOS Mk 1, was transferred to London/Heathrow Airport for an extended trial and assessment of accuracy against conventional instruments. As a result, modified specifications were prepared for a Mk 2 model; these have been accepted as a basis for introducing a preliminary chain of MOWOS into operational service. A further Mk 1 equipment has been installed to telemeter wind, temperature and humidity data from the Belmont TV mast to the meteorological office at Manby.

A contract for 50 magnetic-tape event recorders is expected to be placed, following the preparation of a revised specification for a Mk 2 model. This will be introduced into operational service with the tipping-bucket type rain-gauges. This recorder is intended to be the first of a family of magnetic-tape devices, and the second may well be equipment for processing and recording wind statistics which, until now, have been derived manually from the standard electrical-anemograph records. A common translator for these recorders is expected to be provided as an interface with the new computer system.

Instruments, together with suitable interfaces and a magnetic-tape recorder, were manufactured for mounting on a small toroidal buoy to be used during the international air/sea interaction 'Atlantische' expedition early in 1969 (see

Plate I). This marks the start of the development of automatic marine weather-observing systems in co-operation with the Meteorology and Oceanographic Services of the Navy Department.

Trials of the Mk 3b radiosonde were completed and the instrument was accepted for introduction into operational service at an early date. A system of automatic computation will be installed at the same time to realize the potential accuracy and resolution of the new sonde and to reduce staff numbers at operational stations. Improved synthetic-rubber balloons are now being used, on a selective basis, to meet data requirements to greater heights in the atmosphere and these will also utilize the capability of the new sonde to provide satisfactory data to about twice the present heights. The performance of the standard natural-rubber balloons (see Table V) deteriorated during the year, and necessitated an extensive investigation of manufacturing techniques.

In addition to the various automatic systems so far described, work continued on a number of individual instruments including the laser cloud-base recorder, fluidic anemometers, automatic dew-point hygrometers, heated anemometers for use in icing conditions, and sensing-transducers for sunshine, rainfall intensity and pressure. Installation of the new transmissometers (some with telemetry attachments) was started, and the Mk 5 indicator for remote-recording of temperature is beginning to give good service. A routine checking scheme for outstation barometers has been initiated.

Equipment installation and technical liaison

Two 10-cm radars have been installed at Gan. One is a windfinder and the other a weather radar (Plate II). Both the latter set and a similar one at Changi are now being used for investigational work as well as routine forecasting aids.

Plans are being made for other radar installations at home and abroad; it has now become general policy for installation of all major equipment of this type to be carried out by our own technical staff.

The first cloud-base recorders Mk 3a from the latest contract were accepted after some manufacturing delays. Some of these recorders will be used, where cable runs are excessive (mainly at civil airports), with a new telemetry attachment. The earlier sets from the previous contract have now been in operation for six years and have proved to be very reliable.

A contract was placed on our behalf for ten electrolytic hydrogen-generators for use at upper air stations. These are designed to a new concept by the manufacturer with whom liaison continues.

The design and construction of established equipment is being studied, as time allows, in accordance with the principles of value engineering.

Advice has again been given to the Ministry of Overseas Development on weather radar installations for CENTO countries. Some of these radars will be installed by staff of the Office if the receiving country so requests.

Instrument testing and calibration

Table XV shows the number of instruments tested or calibrated. The routine testing of precision aneroid barometers and the ordinary sheathed thermometers has now largely been taken over from the National Physical Laboratory. For the first time members of a new staff grade, known as Laboratory Attendant, have been employed in the Test Room where they have received

extensive training in routine tasks during the year. Final assembly and calibration of Mk 2 radiosondes have continued and considerable thought has been given to the design of a new calibration plant which will be needed for the Mk 3 sonde. Work for outside authorities has been at a higher level than in the previous few years. A number of foreign visitors have received instruction in various aspects of instrument testing and calibration.

Thunderstorm location

The CRDF thunderstorm location network, with a central control station at Easthampstead, has continued to function throughout the year. In addition to routine location work, co-operation has been extended to a number of other bodies (both at home and overseas) in the provision of data, and in the mounting of special observations.

Surface observations

In the United Kingdom, 81 surface observing stations report in international code every hour, day and night, throughout the year. A further 46 stations report every three hours. In addition 134 stations report at various times during each day of the year. Of this total of 261 stations, 114 are manned by full-time professional staff and 147 by voluntary observers most of whom have attended the Meteorological Office Training School course on observing.

Reports in plain language are received from 16 town offices of the Automobile Association, 25 Police or Fire Service Stations and 32 Road Maintenance Depots located alongside motorways.

Upper air observations

The upper air network fulfilled its normal programme of observations throughout the year. In addition, special ascents were made from a few stations to provide support for investigational work undertaken by other sections.

As mentioned previously, the performance given by standard natural-rubber balloons used to carry the radiosondes aloft has been disappointing. This is reflected in the figures given in Table V. However, extensive trials of synthetic-rubber balloons have given highly promising results and the Office looks forward to an increasing use of this type.

Regional servicing organization

The work undertaken by the organization continues to expand. This is a direct consequence of the increasing use and diversity of equipment throughout the Office. The major part of the Telecommunications Technical Officer class within the Office is engaged in this organization, and the future, in terms of staff recruitment and training, is giving rise to some anxiety.

Training

Students, including a number from overseas countries, have been trained in various facets of instrumental work. In particular, the Instruments and Observations Branch has continued to staff and run the radiosonde training school at Hemsby and the technician school at Easthampstead.

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 throughout 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). Its high-speed random access memory consists of 24K (48 bit)* words and to enable more efficient use to be made of the multiprogramming a magnetic drum provides a further 40K words of backing memory. 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 40K words and one punched-card reader. A variplotter, manufactured by Electronic Associates Limited, has been installed a 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 and rather better than in previous years.

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 immediate access and magnetic-drum backing stores and also keep the central processor busy for much of the run. Nevertheless, by a judicious choice of suitable programmes to mix with the forecast run it is possible 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 6500 stations in the U.K.) and the preparation of tabular material for certain publications, e.g. *British Rainfall*. During the year a revised computer programme for the automation of the *Daily Weather Report* was introduced to deal with changes in international

* $K=2^{10}=1024$, 1 bit=1 binary digit.

codes which were made on 1 January 1968. At the same time other computer routines were introduced to provide for the automatic preparation of the tabular sections of the *Daily Aerological Record*. 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 to produce automatically isopleths on meteorological charts from values at grid points computed by the numerical forecast routines continued and a first version is now operational. Titles of charts and numerical values of isopleths are written under programme control. The on-line operation of the line drawer was beset with difficulties for a considerable time but an acceptable mode of operation has been attained. The line drawer is being progressively introduced into the operational routines. Plans are being made for its wider use in the Office.

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 50 million standard 80-column punched cards containing surface and upper air data from land and marine stations and surface data from voluntary observing ships has been accumulated. The present punching rate of British data is about one and a half million cards a year and about a further one million cards of selected foreign data are obtained through international exchange. The Office has continued to utilize spare capacity at other governmental punching installations which unexpectedly remained available. Arrangements which were being made for all punching to be done at Bracknell were temporarily deferred.

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

Some limited experimental and development work continued on the prototype automatic plotter for producing weather charts.

The specification of a very much more powerful computer system needed by the early 1970s was completed. Approval in principle for the acquisition of such a system was obtained and for the latter half of the year the senior staff were heavily committed to a series of discussions with potential manufacturers. These activities were intense and absorbed much of the time of senior staff who were strengthened by an additional scientist in midsummer. Teams of specialists have visited establishments of computer manufacturers both in the U.K. and in the U.S.A. The initial phase of discussions with manufacturers was completed by the end of the year.

TELECOMMUNICATIONS

The effectiveness of meteorological services is very dependent on adequate and efficient supporting telecommunication services. Every country is expected to contribute basic observational data, for the benefit of all, and it is only through the telecommunication services that these necessary basic data can be collected

and made available to meteorologists. Also, over the years, the processing of meteorological data in the sense of analyses and forecasts, has become more and more centralized. Such centralization cannot be worthwhile 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 co-ordinated by WMO so that the needs of all its Members, for both basic and processed data, can be met to the best advantage. In this context the U.K., as a Member of WMO, has certain specific international responsibilities for the collection and distribution of basic and processed data. The organization of meteorological telecommunication services in relation to national needs has to be complementary to that of the international system.

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.

The Meteorological Telecommunications Centre at Bracknell is one of the eight 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 United Kingdom, the Republic of Ireland, Iceland and Greenland, to collect reports made by three ocean weather stations in the North Atlantic, to collect reports from merchant ships received via British coastal radio stations and then to transmit all these reports into the network for international dissemination. The Centre also has the responsibility to provide a radio-teleprinter broadcast of observational data relating to the European Region. The area of required reception embraces the European Continent, North America, the northern half of Africa and western Asia. Much has depended and will continue to depend on the reliability of this broadcast and the sound work of the staff of the transmitting station contributes in no small way to that reliability.

Processed meteorological information is normally in pictorial format, such as charts of isopleths. Transmission is based on an analogue facsimile mode of operation. Internationally, the U.K. has a responsibility to provide radio facsimile broadcasts of pictorial information. There are two such broadcasts which carry between them processed data from the WMO Regional Meteorological Centre at Bracknell and from the ICAO North Atlantic Area Forecast Centre at London/Heathrow Airport. Additional international requirements for processed data from the U.K. are met through land-line facsimile facilities connecting Bracknell to Offenbach, Paris, De Bilt and Copenhagen.

As regards national requirements the Telecommunications Centre at Bracknell is responsible for the collection and distribution of data (both observational and processed) to meet the needs of the meteorological services centred at Bracknell and the needs of the meteorological offices throughout the country. The coverage of observational 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 of these observational data is largely by data-telegraph systems. The distribution of processed data in pictorial format is by land-line facsimile facilities.

Clearly, meteorological telecommunications must be planned and organized so that meteorological services are not conditioned by any failure to take full

advantage of telecommunications technology. Higher speeds of operation have been and continue to be brought into use in respect of not only alpha-numeric data but also pictorial data. As from September 1968, transmissions at drum speeds of 240 rev/min as opposed to 120 rev/min were introduced operationally for certain analogue facsimile land-line services.

A systems design study of meteorological telecommunications has been carried out by industry, under the auspices of the Ministry of Technology and the Meteorological Office. The study was over the three-month period September to November 1968. Planning is now progressing for automation of the meteorological telecommunications system. The establishment of the Meteorological Telecommunications Centre, Bracknell, as a Regional Telecommunications Hub of the WMO Global Telecommunications System is planned to be operational by 15 January 1970.

The fullest use has been made of meteorological satellite facilities. Half-tone pictures from the ESSA orbital satellites, using the VHF automatic picture transmission (APT) system, are now supplied in real time through the Bracknell Telecommunications Centre receiving system, to the Central Forecasting Office at Bracknell, the Principal Forecasting Office at London/Heathrow Airport and to four other important outstation meteorological offices. The U.K. has taken an active part in a weather-facsimile experiment (WEFAX) conducted by the U.S.A. using the geo-stationary ATS3 satellite, with its sub-point at the mouth of the Amazon.

As to the future, there is no doubt that satellite facilities, both as telecommunication relay and interrogating stations and as meteorological observation platforms, will be taking their place in the meteorological telecommunications organization and the Office is actively preparing for this advance.

INTERNATIONAL AND LONG-TERM PLANNING

The international character of meteorology inevitably leads to a number of international conferences each year. Many of those in which the Meteorological Office is concerned are held under the auspices of one or other of three inter-governmental 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. In addition, 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 several of these, and the Meteorological Office is a member of several 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 74).

The Foreign and Commonwealth Office, the 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 (Hong Kong, 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 organization of the WMO Scientific and Technical Conference on Aeronautical Meteorology, to which the U.K. was host, was carried out by the Meteorological Office, assisted by the Foreign Office and other departments. The Conference was held in Church House, Westminster, from 18 to 29 March, and was attended by 224 participants from many countries including, besides meteorologists, representatives from many parts of the world of aviation. The Conference was successful in its purpose of providing scientific discussion of the many important problems of aeronautical meteorology.

Plans are being made to set up new upper air observing stations on certain Pacific islands in implementation of the World Weather Watch (WWW) plan for 1968-71. Offers have been made, to the Voluntary Assistance Programme of WMO, of equipment and help in installing it, to help other Members implement important elements of the WWW plan. Several offers were also made of training fellowships by which students are financially supported through appropriate university courses. Three such fellowships were taken up, for study at Reading University.

The growing importance of ocean islands as observation platforms caused the U.K. to join Regional Association I (Africa) of WMO in respect of the Seychelles and some other U.K. Dependencies not represented in the Association.

The increasing interest internationally in the resources of the sea led to much discussion on the means by which international co-ordination could best be achieved. Meteorologists have a long-standing interest and experience in this subject and WMO has set up a Panel on Meteorological Aspects of Ocean Affairs, on which the U.K. is represented.

Further work was done on the first comprehensive five-year plan for the Office.

A statement was prepared, showing the co-ordinated accommodation requirements for the projected new computer and those branches of the Office most closely associated with it.

P. J. MEADE,
Director of Services

SUMMARY OF THE WEATHER OF THE YEAR (1968)

The year 1968 had many noteworthy features. Among them were: the severe storms in Scotland and the record gust of 116 kt at Great Dun Fell, Westmorland, during January; the heavy snowfall in the Midlands in February; the unusually heavy rainfall in north-west Scotland during March; and the fine warm summer and early autumn in Scotland and north-west England compared with the unsettled weather in the south of England. There were widespread floods in south-west England in July and in south-east England in September.

January began rather cold with snow at times. The extreme north of Scotland had heavy falls on the 3rd but south-west England, where weather was somewhat milder, suffered widespread flooding following heavy rain from the 6th to the 9th. Most districts were very cold with snow and severe night frosts, and by the 10th much of the Midlands was under 30 cm of snow while parts of northern England reported depths of up to 50 cm. Nearly a week of mild stormy weather began on the 13th. Winds reaching storm force in the north on the 14th and 15th caused extensive structural damage in Scotland; Glasgow, where gusts of 90 kt were recorded, was particularly badly hit. A gust of 116 kt at Great Dun Fell, Westmorland, on the 15th was the highest confirmed wind speed ever recorded in England and Wales. The 19th to the 22nd was a mild, dry period with overnight fog persisting well into the following days, but from the 23rd to the 27th it was showery. The last two days were exceptionally mild.

February. After the 2nd February the first half of the month was cold with heavy falls of snow in many districts. During a blizzard in Scotland on the 4th, the wind reached 75 kt in gusts, and deep snow-drifts blocked many roads. A fall of 30–35 cm during a heavy snowstorm on the 6th virtually brought traffic to a halt in the Birmingham and Manchester areas. After a night of severe frost, freezing fog persisted in many parts of central and north-west England throughout the 8th. The second half of the month was even colder, especially at night, but mainly dry and sunny, except from the 19th to the 21st when there was rain at times in Scotland and along the south coast of England, and widespread fog in the Midlands. Northern districts became somewhat milder on the 29th as rain reached western Scotland.

March was mainly dry in the south but wet in the north with stormy periods. The month began cold and dry but became milder on the 3rd. Gales in Scotland on the 5th spread to eastern coastal districts of England on the 6th and a gust of 92 kt was recorded at Whitby. On the 13th Chivenor, Devon, had its first measurable rain for 28 days, and this rain was the beginning of about 12 days of very unsettled weather. Widespread gales on the 17th and 18th were accompanied by snow and hail in the north where snow-drifts blocked many roads. From the 24th to the 29th weather was fine and dry in southern England but generally unsettled with heavy rain in Scotland, Northern Ireland and the extreme north of England. The wettest day was the 26th when rainfall in these areas exceeded 100 mm locally; in north-west Scotland, Glen Etive recorded 164 mm and Kinlochewe 159 mm. In southern England afternoon temperatures reached unusually high levels for the time of year; East Dereham reported a maximum of 24.9°C on the 29th, almost equalling the highest previously recorded March temperature in the United Kingdom.

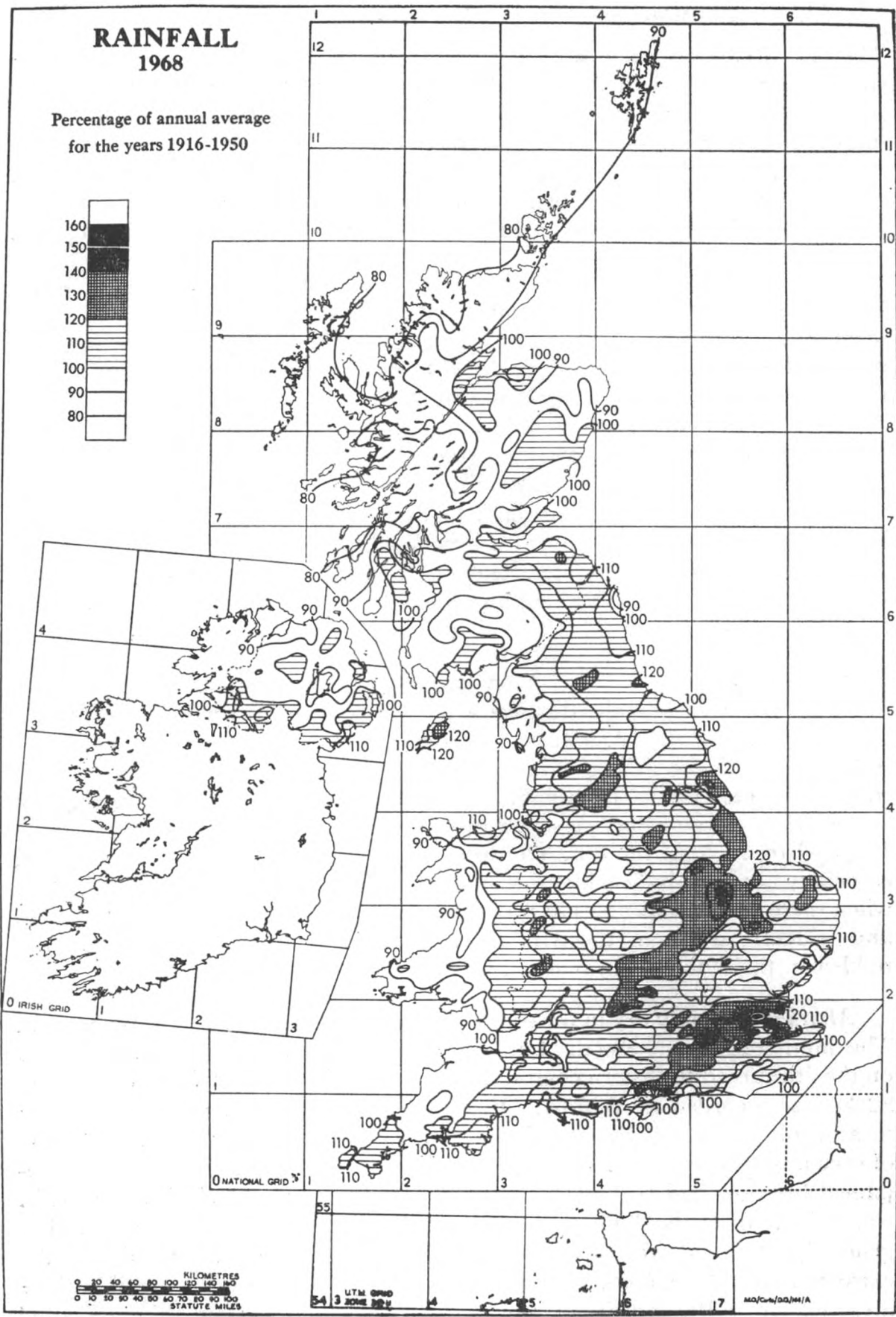


FIGURE 8—RAINFALL 1968

April began dull and wet with snow in the north, but northerly gales on the 2nd brought cold weather and snow showers to most of the country. Northerly winds, wintry showers and scattered thunderstorms continued until the 6th when weather became dry and sunny over most of the country with light and variable winds. Rain spreading in from the Atlantic on the 15th commenced a week of mild unsettled weather. The rain was frequently heavy and there were scattered thunderstorms in a general southerly airstream. The 21st was the warmest day with temperatures reaching 25°C at a number of places in East Anglia. Weather continued mild from the 22nd to the 26th and it was generally dry with light variable winds. The 27th and 28th were two rather wet days but the last two days of the month were cooler and showery with scattered thunderstorms.

May. The first week was mostly dull, cold and wet with northerly winds. Thunderstorms occurred daily, and rainfall in Scotland exceeded the monthly average during the first few days. On the 5th, Blackford Hill, Edinburgh, recorded 35 mm of rain, its highest daily total for 30 years. Parts of south-west England, on the other hand, enjoyed 10 hours of sunshine on most days. The second week was rather less cold, especially over the southern half of the country where northerly winds had given place to moist southerlies. Patches of sea fog formed in the English Channel and persisted for much of the 14th and 15th. The weather in western districts was fine and sunny during the third week with daily sunshine exceeding 14 hours at many places, but northerly winds brought a sharp fall of temperature to eastern districts on the 17th and kept temperatures generally well below normal until the 23rd. Rain from the Atlantic reaching western districts on the 24th was followed by a few days of rather mild weather with outbreaks of heavy rain on the 25th and 26th and widespread thunderstorms on the 27th, but the last four days of the month were warm and sunny.

June began warm, sunny and mainly dry but thunderstorms broke out on the 2nd and 3rd. Sea fog patches affected some coastal areas. Rain spread to all districts on the 4th and weather remained generally unsettled and cool until the 8th. The 9th, with 15 hours of sunshine in some western districts, was the beginning of a fine, dry spell, especially in Scotland where afternoon temperatures exceeded 25°C. Thunderstorms broke out over southern England on the 14th and 15th but over most of the country weather remained dry and sunny until the 17th. The fine spell was followed by ten days of generally cool, unsettled weather with rain, often heavy and prolonged, alternating with showery periods. Widespread floods were reported in the Midlands, eastern and southern England on the 27th and 28th. The 29th was a fine day with rapidly rising temperatures and the last day of the month was very warm in southern England with temperatures reaching 27°C in the afternoon, but thunderstorms broke out during the evening.

July. Early on the 1st, a fine multicoloured dust, which probably originated in Spain or north Africa and which was carried north by high-level winds, was brought down by rain over an area extending from Cornwall to Essex in the south and to Derbyshire in the north. The afternoon of the 1st was very hot in south-east England with temperatures at many places exceeding 30°C. In the south-west, on the other hand, frequent thunderstorms were accompanied by

torrential rain which led to widespread flooding. Hailstones, reported to be as large as tomatoes (see Plate III), added to the damage to crops and property. The worst storms, however, were on the 10th and 11th when seven people are known to have been killed in the resulting floods, and more than a thousand bridges were washed away by swollen and overflowing rivers. Almost every town and village in Devon was flooded, and the damage in south-east Devon amounted to a major disaster. The occasion was remarkable for the large area covered by heavy rain, and floods were reported from places as far apart as Exeter, Birmingham and Peterborough. There was further flooding on the 14th in the Midlands and East Anglia. From the 18th until the end of the month, weather was mainly fine and dry apart from some rain in Scotland on the 20th and 21st which spread to many other districts on the 22nd and 23rd, and heavy thunderstorms on the 31st which led to local flooding.

August was dull and wet in the south-east but sunny in Scotland and Northern Ireland. This pattern of weather was maintained for the first 11 days of the month, with periods of heavy rain and local thunderstorms in the south from the 7th until the 10th. On the night of the 12th/13th rain spread from the Atlantic to Scotland and from then until the 17th rain, heavy at times, and scattered thunderstorms alternated with showery periods in all areas. The 18th was a generally sunny day but rain spread to western and northern districts on the 19th, 20th and 21st. A fine, warm spell began on the 22nd with afternoon temperatures rising to 28°C at places as far apart as Cleethorpes and Ross-on-Wye. From the 24th, however, north-easterly winds brought cooler weather and some rain to eastern districts. Thunderstorms developed in south-east England on the 27th, and weather became generally cooler in the south but remained fine and warm in Scotland until the 29th. Rain from the Atlantic reached north-western districts on the 30th and spread to the remainder of the country on the 31st.

September was cool and rather wet during the first twelve days with showers and scattered thunderstorms, except from the 6th to the 9th which were warm and mainly dry. Rain from the Atlantic reached south-west England on the 13th, and 50 mm were reported from the Isles of Scilly on the 14th. Exceptionally heavy rain and thunderstorms broke out in south-east England and continued in many areas throughout the 14th, 15th and 16th. During these three days large areas of Kent, Surrey and Essex had between 150 and 200 mm of rain, while Purleigh, Essex, recorded 57 mm in 42 minutes on the 14th. The rain led to widespread and disastrous flooding in Kent, Essex, Surrey, Sussex and East Anglia, the floods being particularly prolonged in the East Molesey area of Surrey. In contrast to the heavy rain in south-east England, weather was fine and dry in Scotland, Northern Ireland and north-west England from the 14th to the 16th, and although heavy rain returned to Kent on the 17th, most of the country was fine and dry on the 17th and 18th. The remainder of the month was very unsettled, all districts having frequent showers alternating with periods of rain and scattered thunderstorms. Rain was widespread and locally heavy on the 25th and 27th.

October began with two rather wet days, but the rain gradually died out on the 3rd, and from then until the 7th weather was mainly dry and very mild. The next few days were rather unsettled with heavy rain at times, and with wind reaching gale force in the north on the 11th. The rain cleared southern England on the 12th and was followed by five days of showery weather with temperatures a little below normal. The showers gave place to longer periods of rain on the 18th and 19th, and temperatures rose rapidly. The 20th to the 23rd was a rather foggy spell with light variable winds. As winds freshened on the 24th occasional rain spread first to southern England and then to the whole country with moderate to heavy falls in all districts during the last four days of the month.

November. The very mild wet weather at the end of October continued over most of England and Wales until the 2nd, but gave place to wintry showers on the 3rd as northerly winds spread from Scotland to all districts. The next two days were mainly dry, but by the 6th a strong south-easterly airstream had become established over the British Isles, and rain from the continent spread north-westwards over most of the country on the 6th and 7th. Winds continued mainly between south and east until about the 20th, and weather during this time was generally cloudy, cold and dry. There was, however, occasional rain or drizzle in the south and east on some days and temperatures approached average in some western districts around the 17th. Winds veered to south-west on the 21st and temperatures in all areas rose rapidly. Most of the remainder of the month was very wet and mild but northerly winds brought temperatures to near normal in many districts on the 29th and 30th.

December. South-westerly winds during the first ten days of the month maintained generally dull weather with occasional fog and drizzle, and with periods of more continuous rain in western districts. Temperatures were above average in the west but below average over the eastern part of the country. Winds became light and variable on the 11th, and during the next few days weather became progressively colder with fog persisting all day in many places. On the 14th temperatures over much of England and Wales failed to rise above freezing-point. Winds freshened from the west on the 15th as rain, preceded by snow in the north, spread in from the Atlantic. By the morning of the 16th snow lay 5–7 cm deep in many parts of Lancashire. This was the beginning of an unsettled period with heavy rain at times, which led to flooding in parts of central and southern England on the 17th and 20th. Heavy rain in southern England on Christmas Eve turned to snow during the evening, and on Christmas morning snow lay 5–10 cm deep in parts of Wales and southern and central England. Winds remained north-westerly for most of the rest of the month and snowfall was heavy in parts of Norfolk, Lincolnshire and the East Riding of Yorkshire. Whitby, which was isolated for several days by snow-drifts, recorded a gust of 80 kt on the 27th. At High Mowthorpe, Yorkshire, level snow lay 40 cm deep on the 30th and 31st; high winds caused considerable drifting and many roads near the east coast were blocked by deep snow-drifts.

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 1968

	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	43	11
Observing offices associated with the RAF	7	5
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 1968 for the British Ocean Weather Ships are shown below.

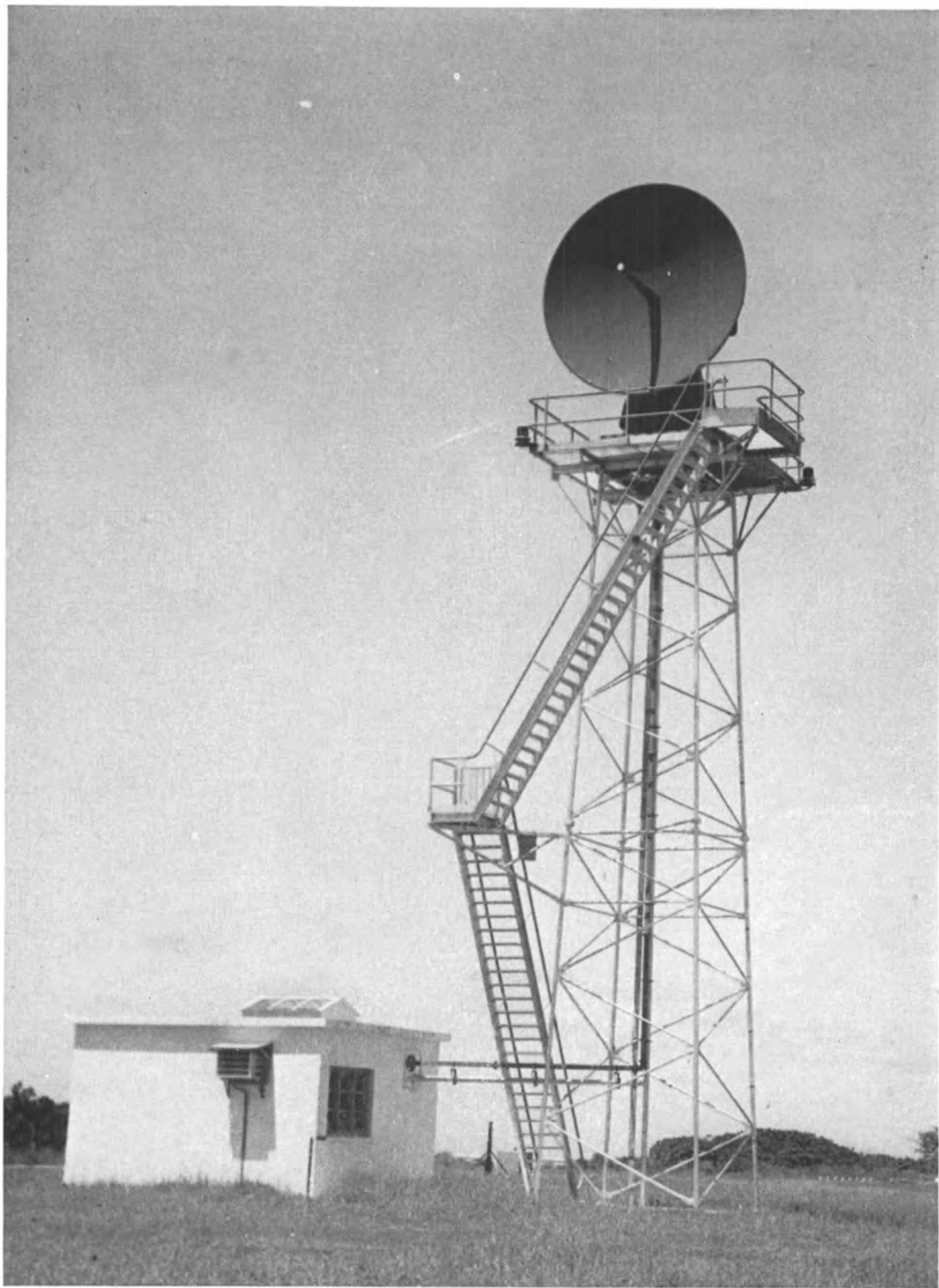
Total number of days on station ..	729.7			
Total number of days on passage ..	164.2			
	Station A	Station I	Station J	Station K
	<i>average number per voyage of 24 days</i>			
Aircraft contacted	241	603	1433	320
Radar fixes to aircraft	985	6530	12 676	576
Weather messages to aircraft ..	382	419	1262	—



INSTRUMENTAL BUOY FOR USE DURING THE ATLANTISCHE EXPEDITION

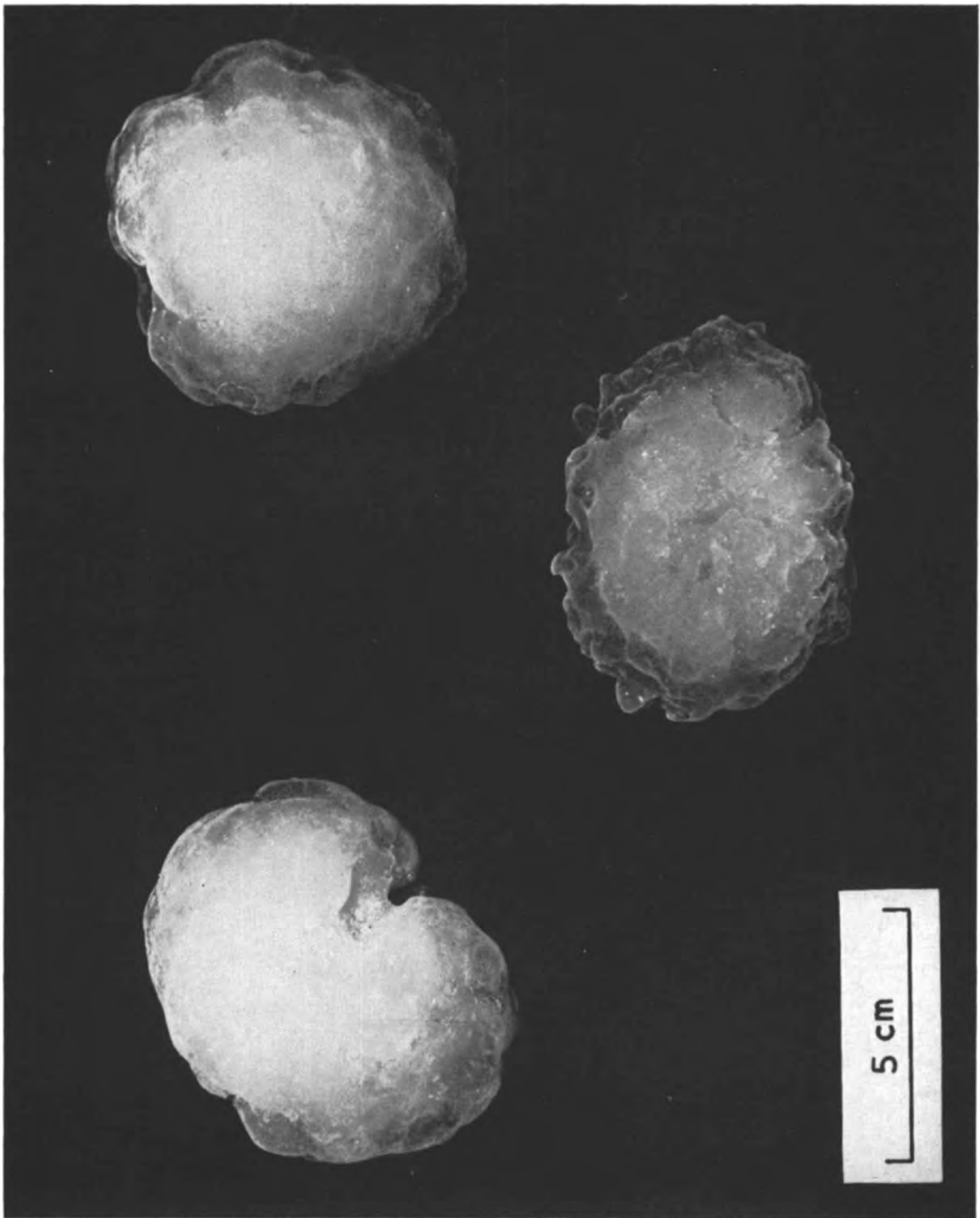
Final assembly of an instrumental buoy which is to be deployed in the southern North Atlantic during the forthcoming Atlantische Expedition. The buoy carries sensors to record air and sea temperature, wet-bulb temperature, wind speed and pressure: the recording package is carried at the centre of the lattice mast and the recording medium is $\frac{1}{4}$ -inch magnetic tape. (See page 29.)

PLATE II



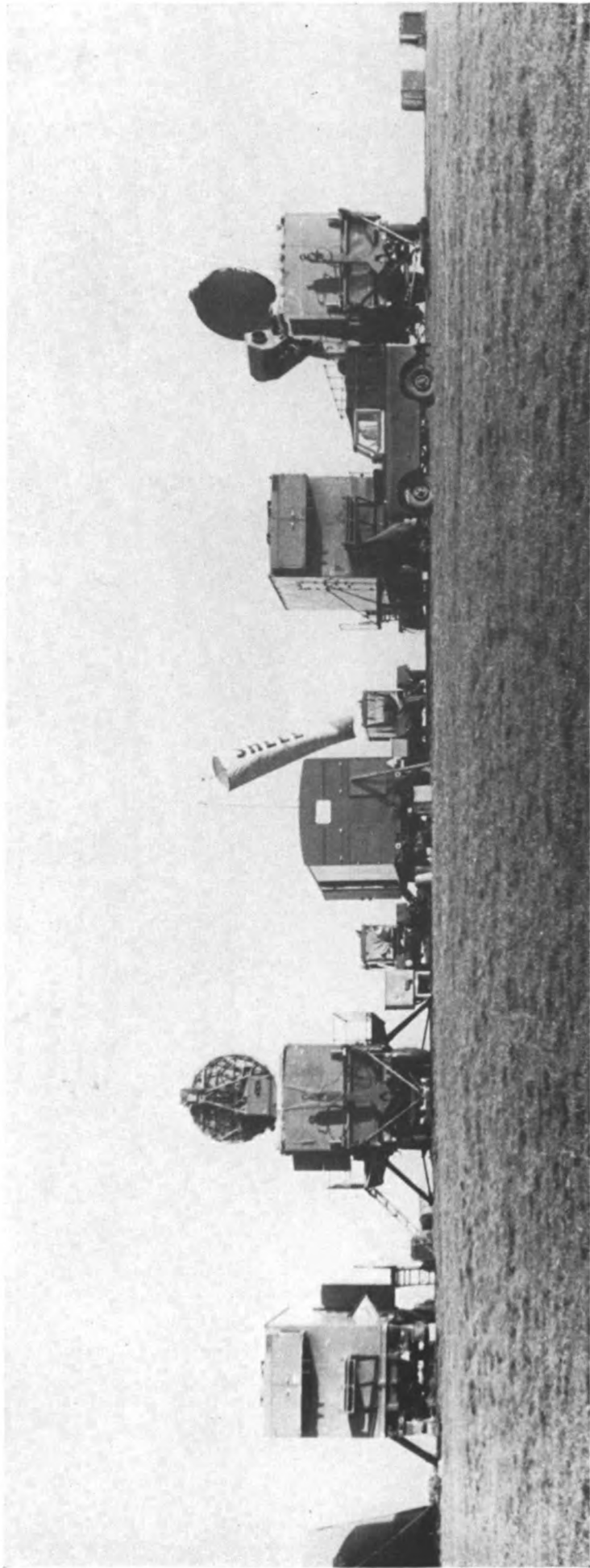
WEATHER RADAR AT GAN

The antenna tower and transmitter/receiver building of the 10-cm weather radar at Gan, an island in the Indian Ocean. This equipment was put into operational use in July 1968. (See page 30.)



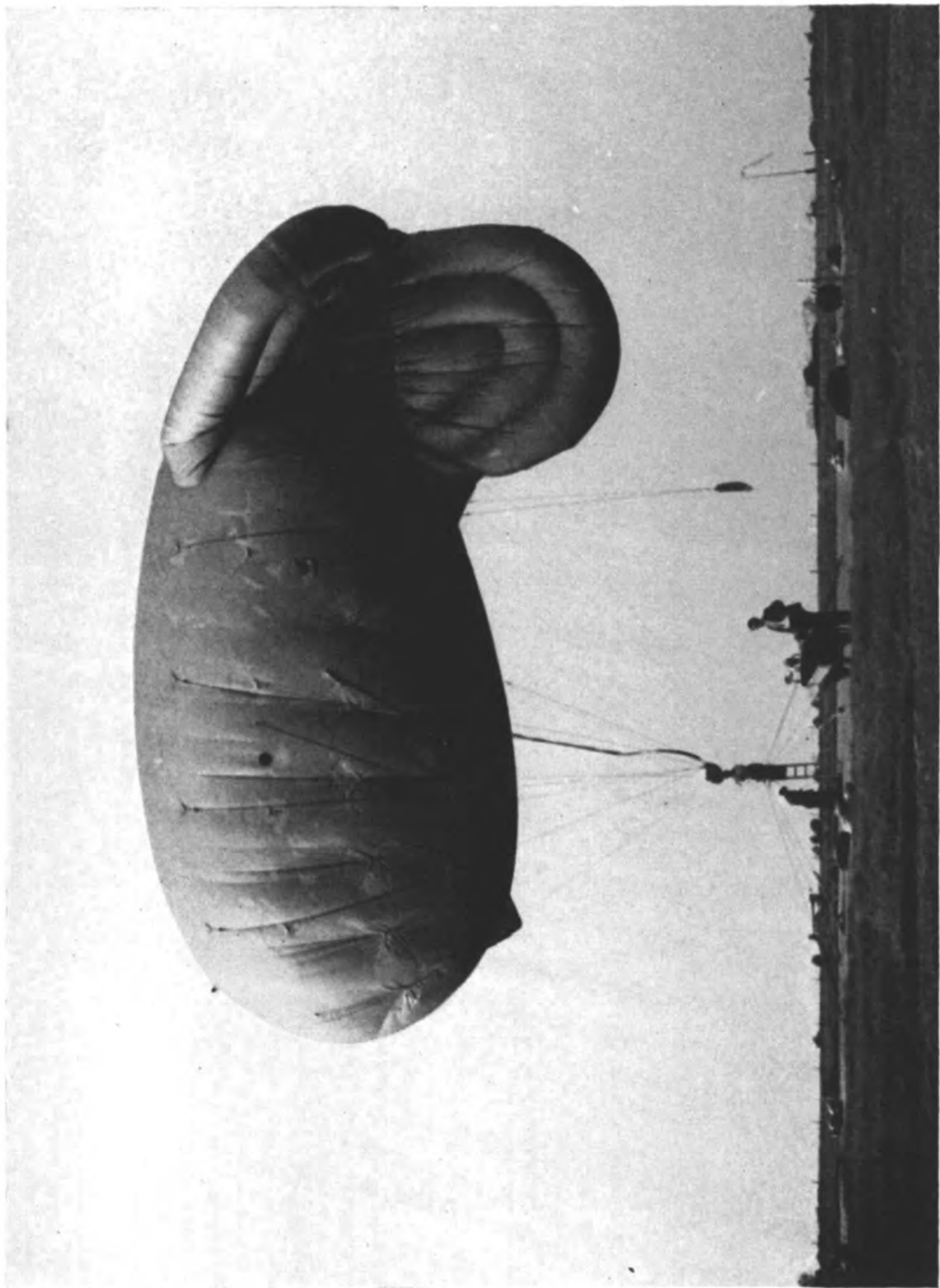
GIANT HAILSTONES WHICH FELL NEAR CARDIFF ON 1 JULY 1968

The largest hailstone was nearly 8 cm in diameter. (See page 40.)



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

This equipment is used in Project Scillonian, whose objective is to study the structure and evolution of frontal cloud systems and the factors that control the duration, intensity and distribution of their rainfall. (See page 61.)

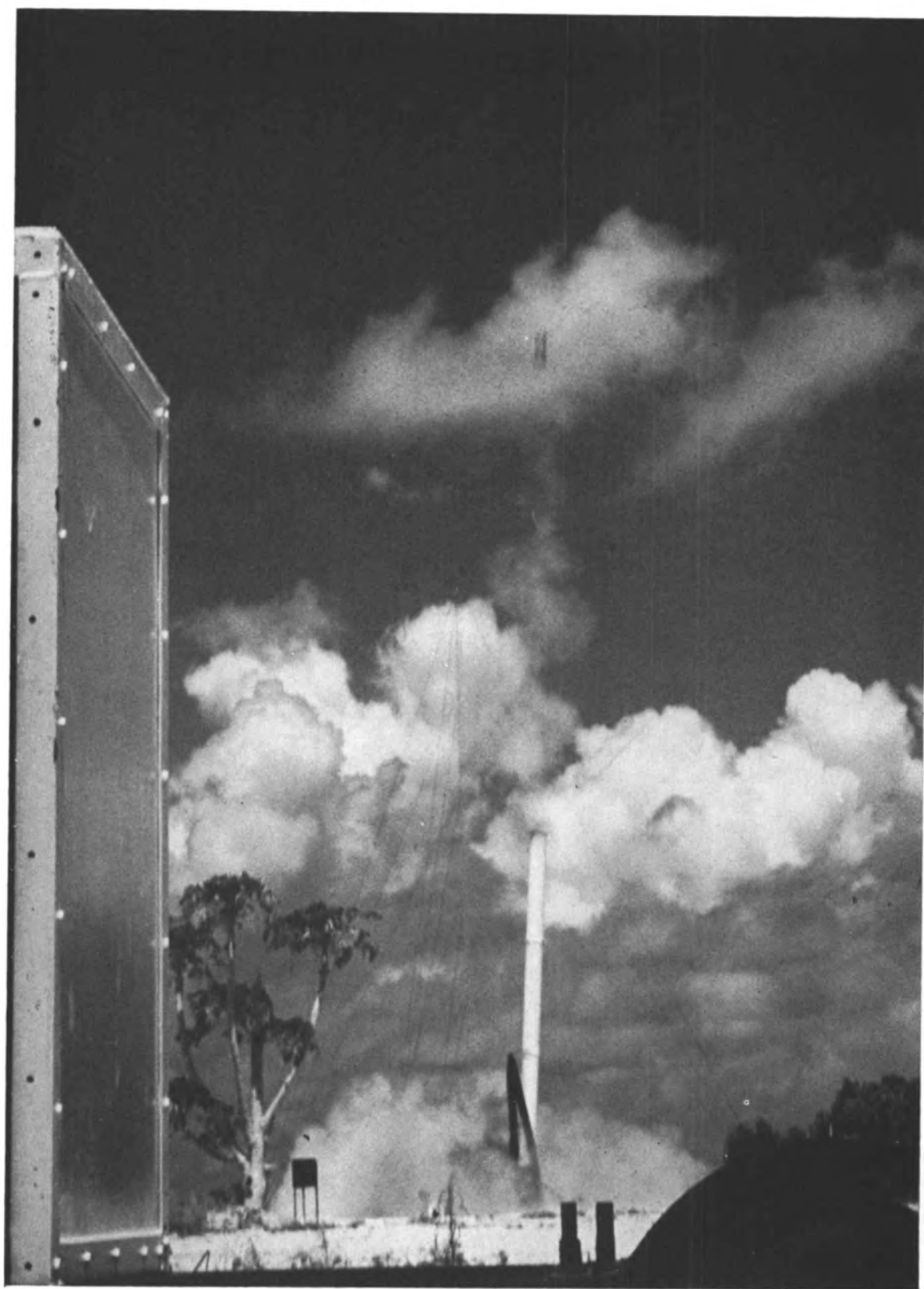


Photograph by courtesy of the Stevenage News

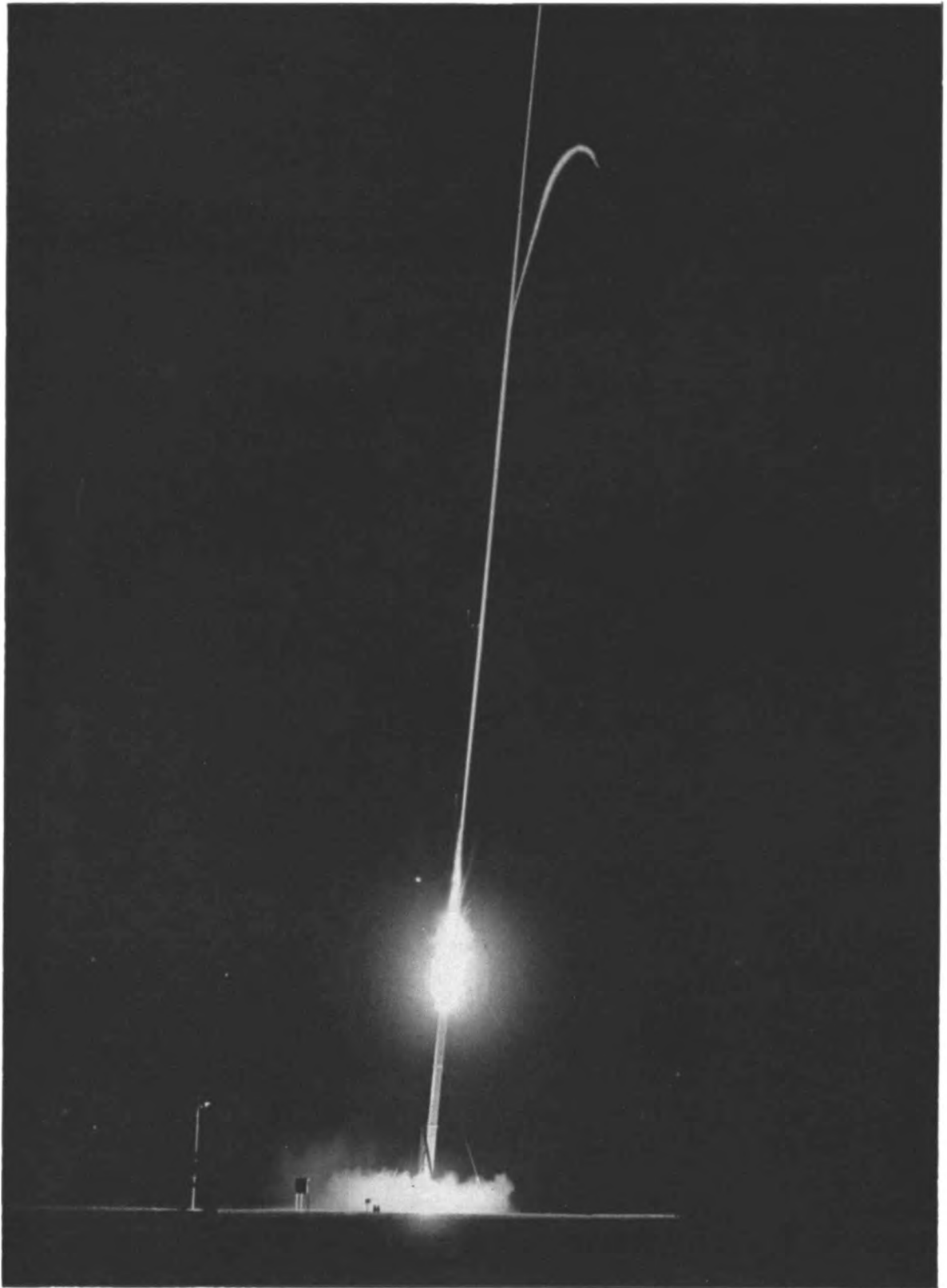
TETHERED BALLOON USED AT CARDINGTON IN BEDFORDSHIRE

The balloon is used to raise instruments for the measurement of wind, temperature and turbulence at heights up to 1 km (about 3000 ft). (See page 63.)

PLATE VI



DAY-TIME LAUNCH OF SKUA ROCKET AT GAN
Separation of boost has just taken place. (See page 63.)



NIGHT-TIME LAUNCH OF SKUA ROCKET AT GAN

Shows trail of rocket and boost (boost apogee about 150 ft). (See page 63.)

TABLE III—BRITISH VOLUNTARY OBSERVING FLEET

A total of about 5300 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 1968 the number of British ships reporting, and constituting the British Voluntary Observing Fleet, was:

Selected ships	497
Supplementary ships ..	58 including 18 trawlers
Coasting vessels	92
Lightships	15
Trawlers	31
Auxiliary ships	55
Total	748

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	93
U.K. to Persian Gulf	33
U.K. to South Africa	32
U.K. to West Indies	36
U.K. to North America	96
U.K. to South America	19
U.K. to Pacific coast of North America	12
U.K. to European ports	49
U.K. to Falkland Islands and Antarctica	2
World-wide tramping	84

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	
								<i>June</i>	<i>December</i>
Direct reception from:									
British ships in eastern North Atlantic	..	..	..	..	..	..	71	90	
Foreign ships in eastern North Atlantic	..	..	..	..	..	..	8	12	
British trawlers in North Sea .. .. .	..	..	..	..	..	..	7	9	
British merchant ships in North Sea ..	..	..	..	..	..	..	21	28	
Total .. .. .	..	..	..	..	..	..	107	139	
Reception via other European countries:									
Ships in eastern North Atlantic	..	..	..	..	..	..	401	280	
Ships in Mediterranean .. .. .	..	..	..	..	..	..	42	72	
Ships in North Sea .. .. .	..	..	..	..	..	..	104	124	
Ships off north Russia .. .. .	..	..	..	..	..	..	23	40	
Ships in Pacific .. .. .	..	..	..	..	..	..	73	94	
Ships in other European waters	..	..	..	..	..	..	14	146	
Total .. .. .	..	..	..	..	..	..	657	756	
Reception via U.S.A. and Canada:									
Ships in North Atlantic	..	..	..	..	..	..	561	407	
Ships in North Pacific .. .. .	..	..	..	..	..	..	511	432	
Ships in other waters .. .. .	..	..	..	..	..	..	25	19	
Total .. .. .	..	..	..	..	..	..	1097	858	

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 1968.

					STATIONS					AUTOGRAPHIC RECORDS		
					Observatories	Synoptic	Agrometeorological	Climatological	Rainfall*	Sunshine	Rainfall	Wind
Scotland, north	..	..	..	..	1	10	0	27	330	26	8	12
Scotland, east	..	..	..	..	0	10	9	67	589	49	16	11
Scotland, west	..	..	..	..	1	13	2	53	516	34	17	13
England, north-east	..	..	..	..	0	11	4	24	450	27	16	9
England, east	..	..	..	..	0	11	15	18	554	32	26	13
England, Midlands	..	..	..	..	0	14	19	49	1344	61	26	12
England, south-east (including London)	..	..	..	..	1	18	20	51	828	64	86	17
England, south-west	..	..	..	..	0	11	8	32	591	31	10	6
England, north-west	..	..	..	..	0	5	4	25	482	26	15	13
Wales, north	..	..	..	..	0	2	3	17	273	10	4	1
Wales, south	..	..	..	..	0	5	10	16	368	22	4	6
Isle of Man	..	..	..	..	0	2	0	1	20	3	1	2
Scilly and Channel Isles	..	..	..	..	0	3	0	4	23	7	1	2
Northern Ireland	..	..	..	..	0	9	6	44	310	25	24	10
Total	..	..	..	..	3	124	100	428	6678	417	255	127

* 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 observa- tions	Percentage of all balloons reaching				Percentage of largest balloons reaching
			<i>100 mb 16 000 m (approx.)</i>	<i>50 mb 20 000 m (approx.)</i>	<i>30 mb 24 000 m (approx.)</i>	<i>10 mb 30 000 m (approx.)</i>	<i>10 mb 30 000 m (approx.)</i>
Eight stations in the U.K.	..	5809	82.5	52.1	22.3	7.4	54.4
Seven stations overseas	..	4757	94.2	73.7	36.0	4.9	55.7
Four Ocean Weather Ships	..	1574	78.8	44.9	14.8	0.2	—

(b) Observations of wind

		Number of observa- tions	Percentage of all balloons reaching				Percentage of largest balloons reaching
			<i>100 mb</i> <i>16 000 m</i> <i>(approx.)</i>	<i>50 mb</i> <i>20 000 m</i> <i>(approx.)</i>	<i>30 mb</i> <i>24 000 m</i> <i>(approx.)</i>	<i>10 mb</i> <i>30 000 m</i> <i>(approx.)</i>		10 mb 30 000 m (approx.)
Eight stations in the U.K.	..	11 603	77.8	44.5	14.7	3.9	54.6
Seven stations overseas	..	8134	87.2	62.4	25.2	3.3	60.3
Four Ocean Weather Ships	..	3090	73.0	39.6	10.8	0.2	—

TABLE VI—THUNDERSTORM LOCATION

Number of thunderstorm positions reported by CRDF network:

In 1967 70 262 In 1968 73 456

TABLE VII—METEOROLOGICAL COMMUNICATIONS TRAFFIC

Almost all the national and international exchanges of meteorological data, which are used in the construction of synoptic charts and the production of forecasts, are effected by coded messages. The coded messages are composed of groups of five figures and there may be from 5 to 90 such groups in one message. The messages are exchanged by radio and land-line facilities. In addition there is an exchange, both nationally and internationally, of meteorological information in pictorial format. This information is largely analyses and forecasts derived from processing observational data. The transmission method is analogue facsimile by either radio or land-line.

The following figures give an analysis of the traffic through the Meteorological Office Telecommunications Centre for one typical day (24 hours) taken near the end of December 1968 and, for comparison, some corresponding figures are given for one day near the end of 1967.

						In	Out	Total	Total in 1967
Coded messages							<i>number of groups in one day</i>		
Land-line teleprinter	..	..	..	..	..	415 874	324 201	740 075	750 777
Radio	..	..	..	..	..	198 539	259 105	457 644	411 344
Facsimile charts							<i>number of charts in one day</i>		
Land-line	..	..	..	..	..	93	492	585	499
Radio	..	..	..	..	..	80	136	216	189

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is a need for forecasts of a special type at certain seasons. These are described in Met. O. Leaflet No. 1 (1968). 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)	1967	519	1968	505
Week-end temperature forecasts (a winter service primarily for industrialists) ..	1967-68	38	1968-69	35
Snow and icy-road warnings (primarily for local authorities)	1967-68	296	1968-69	354

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 that took place during 1967 and 1968. They do not include warnings and routine general forecasts.

	1967	1968
Number of meteorological briefings for aviation in the U.K.	365 534	394 217
aviation at overseas stations	52 042	55 907
Number of aviation forecasts issued for aviation in the U.K.	1 039 703	1 073 364
aviation at overseas stations	295 632	272 004

TABLE X—NON-AVIATION INQUIRIES

Non-aviation inquiries are handled by five weather centres in London, Manchester, Glasgow, Southampton and Newcastle and one other office in Nottingham (Watnall) whose function is to meet the needs of the general public for forecasts for special purposes. Many other forecast offices, established primarily to meet the needs of aviation, also answer telephone requests for forecasts and other weather information, from the general public, Press, public corporations, commercial firms, etc. (*The Post Office Guide* lists 39 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.

							1967	1968
Grand total of inquiries (all figures)							1 264 605	1 480 262
Percentage of inquiries connected with								
agriculture, etc.	..	..	..	..	..	..	10.4	11.1
building	..	..	..	..	..	..	5.8	6.0
commerce, industry	..	..	..	..	..	..	5.5	5.3
holidays	..	..	..	..	..	..	18.3	19.0
marine matters	..	..	..	..	..	..	17.6	14.4
Press	..	..	..	..	..	..	9.3	8.9
public utilities	..	..	..	..	..	..	8.2	8.5
road transport	..	..	..	..	..	..	9.6	10.0

TABLE XI—BBC FLASH WEATHER MESSAGES

FLASH weather messages are passed to the BBC for broadcast on Radio, and to the BBC and most Independent Television companies for inclusion in their programmes at a convenient break. They are, effectively, warnings of the actual occurrence of weather conditions which might cause considerable inconvenience to a large number of people. The following table shows the kind of weather and areas of the country for which FLASH messages are broadcast and the number issued in 1968.

Area				Dense fog	Moderate or heavy snow	Heavy rain	Glazed frost or icy roads	Severe inland gales	Wind in coastal waters
Edinburgh	..	..	..	—	—	2	—	—	—
Central Clydeside	..	..	..	2	2	3	1	—	—
Belfast	..	..	..	1	1	—	—	—	—
Tyneside and Tees-side	..	..	..	4	—	4	1	1	—
Merseyside and south-east Lancashire	..	..	..	4	1	6	1	—	1
Industrial Midlands	..	..	..	2	2	18	2	—	—
Bristol	..	..	..	3	1	9	—	—	—
Industrial south Wales	..	..	..	—	—	7	—	—	1
London and Home Counties	..	..	..	1	—	15	1	—	—
Southampton/Portsmouth	..	..	..	—	—	4	—	—	—
Plymouth	..	..	..	—	—	1	—	1	—
West Riding	..	..	..	3	—	7	1	—	—
Total	..	..	..	20	7	76	7	2	2

In addition more-general warnings of heavy rain (5 occasions) and icy roads (1 occasion) were issued.

TABLE XII—AUTOMATIC TELEPHONE WEATHER SERVICE FORECASTS

The total number of calls made on the service during 1968 showed an increase of 32 per cent over the previous year. Forecasts were made available at 7 more GPO Information Centres bringing the total of such Centres to 43. The number of forecast areas was increased from 22 to 23.

Information Service Centre	Forecast area	Number of calls		Remarks
		1967	1968	
London	London	2 553 294	3 360 216	
London	Essex coast	141 171	177 796	
London	Kent coast	138 472	184 516	
London	Sussex coast	208 765	288 441	
London	Thames Valley	75 468	103 300	
Colchester	Essex coast	144 411	161 206	
Brighton and Hove	Sussex coast	274 738	313 170	
Birmingham	Birmingham	430 022	523 466	
Liverpool	South Lancashire and north Cheshire	220 917	258 702	
Liverpool	Lancashire coast	68 746	70 818	
Liverpool	Chester and north Wales coast	54 747	57 141	
Manchester	South Lancashire and north Cheshire	277 511	284 243	
Manchester	Lancashire coast	56 157	54 573	
Manchester	Chester and north Wales coast	32 495	34 860	
Cardiff	Cardiff	218 771	293 182	
Belfast	Belfast	207 665	221 781	
Glasgow	Glasgow	317 938	374 348	
Edinburgh	Edinburgh	268 553	261 422	
Bristol	Bristol	273 374	344 042	
Portsmouth	South Hampshire	150 897	179 299	
Southampton	South Hampshire	176 154	206 058	
Canterbury	Kent coast	110 598	136 662	
Blackpool	Lancashire coast	144 261	153 010	
Southport	Lancashire coast	49 502	55 863	
Plymouth	South Devon and east Cornwall	105 175	134 789	
Exeter	South Devon and east Cornwall	58 332	74 951	
Newcastle	Tyne, Tees	185 450	190 467	
Blackburn	Central Lancashire	75 370	86 454	
Blackburn	Lancashire coast	40 246	40 146	
Bournemouth	South Hampshire	77 387	106 124	
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	135 564	242 428	
Leicester	Nottinghamshire, Derbyshire, Leicestershire	84 732	138 186	
Middlesbrough	Tyne, Tees	57 585	70 573	
Oxford	Thames Valley	58 708	110 195	
Colwyn Bay	Chester and north Wales coast	25 438	46 155	<i>Opened</i> May 1967
Gloucester	South-west Midlands	23 249	57 679	May 1967
Cheltenham	South-west Midlands	11 420	31 025	May 1967
Tunbridge Wells	London	6914	22 907	May 1967
Southend	Essex coast	12 981	52 317	August 1967
Chelmsford	Essex coast	7 881	28 553	August 1967
Bedford	40 miles radius of Bedford	15 246	79 910	September 1967
Reading	Thames Valley	14 931	106 218	October 1967
Hereford	South-west Midlands	1238	14 870	November 1967
Bradford	Leeds, Bradford, Huddersfield	1285	19 955	December 1967
Leeds	Leeds, Bradford, Huddersfield	5482	97 481	December 1967
Torquay	South Devon and east Cornwall		38 472	March 1968
London	40 miles radius of Bedford		25 183	May 1968
Sheffield	Sheffield, Chesterfield, Barnsley		53 065	June 1968
Medway	Kent coast		11 026	July 1968
Chester	Chester and north Wales coast		13 129	August 1968
Guildford	London		9547	August 1968
Peterborough	40 miles radius of Bedford		6186	September 1968
Huddersfield	Leeds, Bradford, Huddersfield		10 771	October 1968
Total		7 599 241	10 016 877	

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.

	1967	1968
Total number of climatological inquiries	12 533	13 610
Percentage relating to		
agriculture (farming, forestry, market gardening)		12.2
building and design (including siting)		20.4
commerce (sales, marketing, advertising)		3.5
drainage		1.4
education and literature		5.8
flooding		0.6
heating and ventilation		1.9
industrial and manufacturing activities		5.6
law (damage, accident, insurance)		14.9
medical and health		1.5
Press and Information Centres		3.6
research		5.9
sport, hobbies, holidays		1.9
transport and communications		1.4
water supplies		7.2
miscellaneous (purpose known)		6.1
miscellaneous (purpose unknown)		6.1

TABLE XIV—DATA PROCESSING

(a) Punched-card installation	
Number of cards punched by the Meteorological Office installation	1 132 325
Number of cards punched elsewhere on behalf of the Meteorological Office	348 753
Number of cards converted to paper tape	2260
Number of cards converted from paper tape	178 316
Number of non-routine investigations completed	172
(b) Computer installation	
The electronic computer COMET was used for computing during 7402 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	50 988
Balloons	88 242
Radiosonde batteries	17 270
Radar reflectors	17 824
Electrical/electronic instruments and components	34 679
Radiosondes, calibrated	14 779
Total	223 782

In addition 1999 radiosondes were recovered after flight and 74 per cent of these were repaired and recalibrated for further use.

THE DIRECTORATE OF RESEARCH

SPECIAL TOPIC—SOUNDING THE HIGH ATMOSPHERE WITH METEOROLOGICAL ROCKETS

Ninety-nine per cent of the earth's atmosphere and all clouds (with the exception of noctilucent clouds) are contained within the first 30 km above the earth's surface. Soundings to this level, using balloons, are now achieved with some regularity and provide the basic data for ordinary day-to-day weather forecasting. But the atmosphere does not stop at 30 km; there is considerable, indeed sometimes violent, meteorological activity at much higher levels. This activity is brought about by the absorption, at these higher levels, of solar ultra-violet radiation by ozone.

The absorption, at the surface of the earth, of visible and infra-red solar radiation leads to the weather systems which are a familiar feature of the lower atmosphere. It is of considerable theoretical and practical interest to compare the behaviour of the atmosphere in the two layers where solar heating occurs: the lower atmosphere, where energy is derived from the absorption of visible and infra-red radiation at the surface; and the higher atmosphere, where energy is derived from the absorption of ultra-violet radiation by ozone. Balloons cannot be used for soundings much higher than 30 km; to make observations at higher levels rockets must be used.

Rockets designed specifically for meteorological soundings were being used from a few rocket ranges in North America in the late 1950s. However the rocket used, the ARCAS rocket, had too large a wind dispersion* for use in this country, where winds are strong and where range areas are necessarily small.

It was therefore decided that a new meteorological rocket should be developed suitable for use in this country. The task was undertaken by the Ministry of Aviation (now the Ministry of Technology) and in 1963 the first flight trials of the rocket now known as SKUA were carried out.

The SKUA rocket, developed jointly by Bristol Aerojet Limited, of Banwell, and the Ministry of Aviation Rocket Propulsion Establishment, Westcott, carries a temperature-measuring sonde and a large metallized parachute. These are ejected from the rocket at a height of about 70 km (230 000 ft). The metallized parachute, with sonde attached, is tracked by radar throughout its subsequent descent. From its motion winds are calculated (the system moves with the wind from a height of about 60 km down). The same radar measurement gives the height of the sonde, which continuously transmits measurements of air temperature as it descends.

* Wind dispersion. The trajectory of a simple rocket of this type is very much affected by wind. With the British SKUA rocket an error of 4 kt (2 m/s) in the predicted 'ballistic wind' leads to an impact of the expended rocket motor 8 miles from the aiming point. With the ARCAS rocket, as it then was, the dispersion was two to three times as great.

There are two ranges in the British Isles from which the SKUA rocket can be launched: the Ministry of Technology range at Aberporth in south Wales, and the Ministry of Defence range at South Uist in the Outer Hebrides. Some of the early proving rounds were launched from Aberporth but apart from these all SKUA rocket launchings in Great Britain have been made from South Uist. A small number have been launched from the island of Gan, in the Indian Ocean. About 220 rounds have so far been launched with an overall success rate close to 90 per cent.

The earth's atmosphere

The various gases which make up the earth's atmosphere are effectively transparent to solar radiation at wavelengths longer than about 0.3 micrometres (μm): visible radiation extends from about 0.4 μm (violet) to about 0.7 μm (red). All radiation of wavelength shorter than 0.3 μm is absorbed in the atmosphere.

Far ultra-violet radiation—radiation of wavelength shorter than 0.2 μm —is absorbed by molecular oxygen. Much, but not all, of this absorption takes place at very high levels in the atmosphere, levels well above 100 km, leading to temperatures in excess of 1000°C at these high levels. Some far ultra-violet radiation penetrates to lower levels. It is this radiation, the far ultra-violet radiation which penetrates to lower levels, which reacts with molecular oxygen to form ozone, and so creates a shell of ozone round the globe, extending from the tropopause up to a height of about 70 km. This shell of ozone is of fundamental importance in the meteorology of the high atmosphere.

The importance of this shell of ozone stems from the fact that ozone absorbs radiation in a waveband which, as it happens, directly adjoins the molecular oxygen absorption band: molecular oxygen absorbs from 0.1 to 0.2 μm ; ozone absorbs from 0.2 to 0.3 μm . Thus there are three distinct regions where absorption of solar radiation is important:

- (i) *The high atmosphere.* Above 100 km where far ultra-violet radiation is absorbed by molecular oxygen. Very high temperatures prevail at levels above 200 km.
- (ii) *The middle atmosphere.* From 15 to 70 km, where near ultra-violet radiation is absorbed by ozone. Maximum temperatures occur at about 50 km.
- (iii) *The low atmosphere.* Where solar radiation in the visible and in the infra-red is absorbed. Maximum temperatures are found at the surface.

In all these regions the tilt of the earth's axis to the ecliptic results in a heat input which varies greatly with latitude. When a fluid is heated more in one place than in another the fluid is set into motion and when the fluid is a gas on a rotating sphere and the variability of the heat input is great these movements are complex and variable, and at times violent. So in each of these three regions complex, variable and at times violent air movements are to be expected. The wind and pressure systems, which develop from these air movements, may take quite different forms at different levels, and what goes on at one level may be affected by, in some cases perhaps largely controlled by, what goes on at some other level. The 'small meteorological rocket' project is concerned with studying

the wind systems and the general behaviour of the middle atmosphere, and with seeking to explain its behaviour in terms of the properties of the atmosphere as a whole. The following sections describe some of the more important features of the middle atmosphere, as recorded by meteorological rocket soundings. The first section discusses average winds, and especially how and why these average winds vary, as they do, with longitude.

Average winds. In the lower atmosphere the irregular distribution of oceans, continents and mountain ranges leads to marked climatological differences between places at the same latitude. This effect is well known at the surface (the climate of London is quite different from the climate of Newfoundland) and it has long been known that these differences can persist up to quite high levels, in some cases, indeed, up to the highest levels reached by balloons. Figure 9 shows average winds, for summer and for winter, at two meteorological rocket stations at nearly the same latitude: South Uist ($57^{\circ} 21' \text{N}$, $07^{\circ} 22' \text{W}$.) and Fort Churchill ($58^{\circ} 44' \text{N}$, $93^{\circ} 49' \text{W}$.). For levels up to 20 km the average winds were computed from very large numbers of balloon ascents. For the higher levels average winds were computed from relatively small numbers of rocket ascents so, for these levels, wind roses are also given.

Although these two stations are at nearly the same latitude, there are clear differences in the average winds. The differences are less strong in summer than in winter, and the summer differences are very small indeed at levels above 25 km. It seems probable that at these levels in summer the mean airflow is very nearly easterly and uniform round the globe. It may be noted also, from the wind roses, that in summer the winds are relatively steady, with little variability, so that quite a small number of measurements suffice to give a good mean value.

The situation is entirely different in winter. In winter there is enormous variability—on one occasion at South Uist the wind changed in 10 days from 350 kt (about 175 m/s) westerly to 100 kt (about 50 m/s) easterly. So a very large number of observations over a period of many years will be needed to determine 'seasonal means'. Nevertheless it is clear, even from the limited data in Figure 9, that there is a real climatological difference at all levels in winter between South Uist and Fort Churchill. It must be concluded that the geographically induced asymmetry in the lower atmosphere flow-pattern extends, in winter, up to 50 km and indeed, since the asymmetry is so great there, that it must persist up to much higher levels—perhaps up to the mesopause, at a height of about 85 km.

Some of the variability shown by the wind roses in Figure 9 is probably caused by local disturbances of the flow, for example wave motions similar to sea waves, but much of it is undoubtedly caused by travelling 'synoptic scale' systems, 1000 km or more in extent, analogous to the depressions and larger systems of the lower atmosphere.

Synoptic-scale systems. For a proper study of synoptic-scale systems, frequent soundings from a network of stations, sufficiently close for the systems to be delineated, are needed. Meteorological rocket stations are typically 3000 km or more apart, and the nearest one to South Uist is 5000 km away. Obviously only extremely large meteorological systems would be identified on charts constructed from such a network of observations. To identify smaller systems meteorologists must rely on time cross-sections, constructed from soundings made at a single

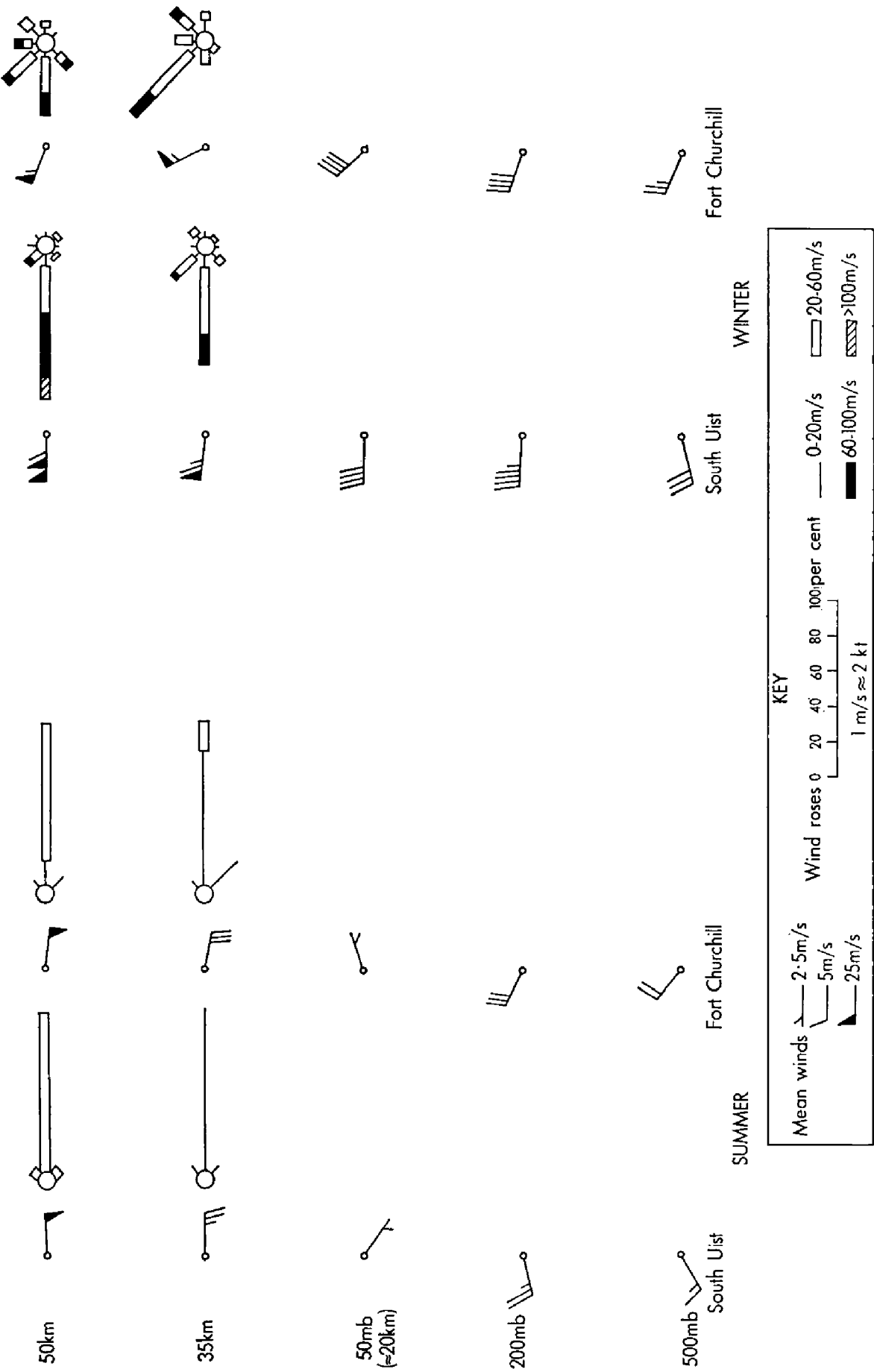


FIGURE 9—AVERAGE SEASONAL WINDS AT SOUTH UIST AND FORT CHURCHILL

station. Of course a time cross-section at a single station cannot indicate how large any recorded disturbance is, but time cross-sections do indicate the intensity of disturbances and how long they take to pass a fixed station.

It has already been remarked that conditions in the middle atmosphere, at South Uist, are much less disturbed in summer than in winter (Figure 9). Nevertheless, there do appear to be, even in summer, clear synoptic-scale disturbances—disturbances typically lasting a few days. Figure 10 is a plot of the height of the 0.7-mb surface, as measured on 15 rocket soundings from South Uist, between 1 June and 16 July 1967. There is some scatter but, superimposed on the seasonal trend, there are clear signs of synoptic-scale disturbances with an amplitude of 0.2 km. (A similar oscillation in the height of an isobaric surface near the ground would correspond to a change of about 20 mb in the surface pressure.) These variations were caused almost wholly by middle atmosphere processes; throughout the period pressures and temperatures at the 30-km level were almost constant.

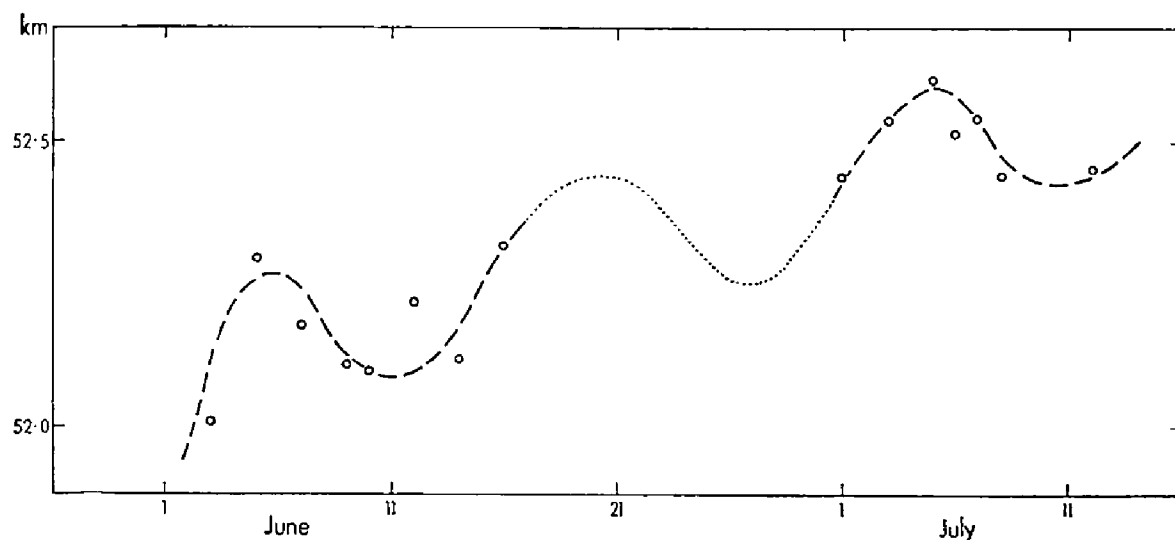


FIGURE 10—HEIGHT OF THE 0.7-MILLIBAR SURFACE AS MEASURED ON FIFTEEN ROCKET SOUNDINGS FROM SOUTH UIST IN 1967

There have been two good winter campaigns at South Uist. On both occasions the really outstanding feature was a quite enormous oscillation in the zonal (west to east) wind component taking about 30 days (Figure 11). (Similar oscillations, though less intense, are observed at Fort Churchill.) There was a corresponding pressure oscillation which, at 55 km, caused the height of individual isobaric surfaces to vary through a total range of 4 km (a similar oscillation in the height of isobaric surfaces near the ground would correspond to a pressure change of 400 mb!). Superimposed on these very large wind and pressure changes are smaller, shorter-period fluctuations which seem to have, as in summer, a typical period of 10 days.

There are occasions when these shorter-period fluctuations seem to be linked with disturbances in the lower atmosphere. Figure 12 shows such an occasion. Three continuous curves, constructed from balloon radiosondes, show heights of the 850, 200 and 50-mb surfaces; five dashed curves connect points showing heights of the 10, 3, 0.7, 0.3 and 0.2-mb surfaces as measured by rocket

soundings. There is a pronounced contour height minimum at all levels from the surface to the highest level reached, 60 km. Twice-daily balloon soundings permit accurate timing of this contour height minimum up to the 50-mb level—it occurred on 27–28 March 1967. The time cannot be as precisely defined at higher levels; but it does appear to have occurred, at all levels, one or two days before 29 March. Linkages of this sort, if they are real, are of considerable meteorological interest and it would be especially interesting to know the slope of the axes of maximum and minimum pressure—to know, for example, whether the pressure minimum at 60 km occurred before, or after, the pressure minimum at the surface. This cannot be determined on the occasion illustrated; there were too few rocket ascents. More closely spaced soundings are needed, but it is just in these circumstances—the passage of a deep depression—that rocket soundings are most likely to be interrupted by weather.

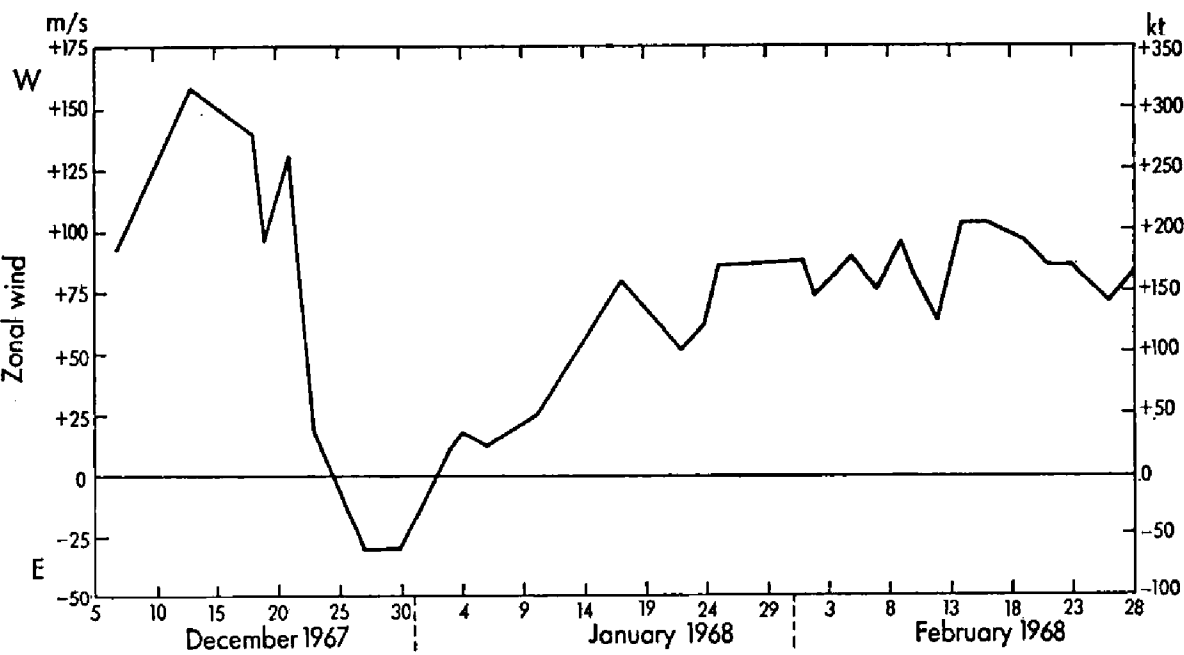


FIGURE 11—ZONAL WINDS OVER THE 45 TO 55-KILOMETRE LAYER AT SOUTH UIST DURING THE WINTER 1967/68
Westerly winds are positive.

Stratospheric warmings. One of the most interesting synoptic features of the lower stratosphere is the stratospheric warming. This is a winter phenomenon, marked by a rapid rise of temperature—by as much as 30 degC in 24 hours. In extreme cases temperatures reach their summer value, leading to a complete breakdown of the winter polar vortex—westerly winds in the lower stratosphere being replaced by easterlies. It is not yet known how or where these warmings originate but the warming is usually first noted, from balloon soundings, at high levels. It then usually descends, at a rate of about 3 km/day, becoming less intense as it does so and becoming insignificant by the time the tropopause is reached. Rocket soundings might provide answers to the questions: are stratospheric warmings even stronger, and do they occur even earlier, at still higher levels?

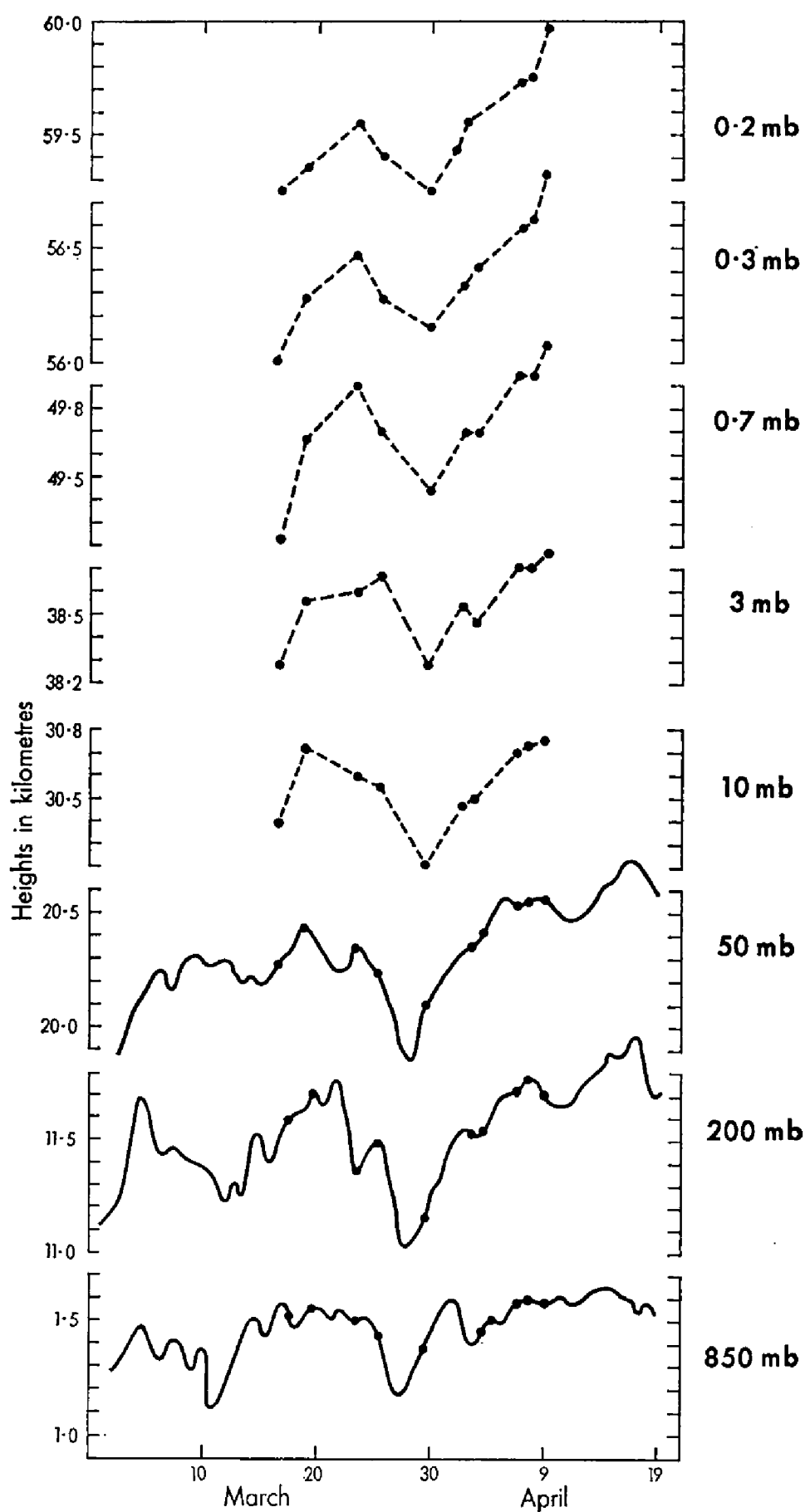


FIGURE 12—HEIGHTS OF A SELECTION OF PRESSURE SURFACES AT STORNOWAY (850 TO 50 MILLIBARS) AND SOUTH UIST (10 TO 0.2 MILLIBARS) DURING MARCH AND APRIL 1967

—— Stornoway radiosonde

---- South Uist rocket soundings.

Strong warmings are quite rare so it is fortunate that one of the most intense warmings in recent years occurred during the 1967/68 South Uist rocket campaign.

Figure 13 shows time cross-sections of temperatures at 5-km levels from 20 to 60 km, determined from a series of rocket launches at South Uist—the temperatures being expressed as differences from a standard reference atmosphere. The slanting lines on the diagram seem to indicate the more or less steady progression downwards of a stratospheric warming. The average descent rate from 60 to 20 km seems to have been about 2 km/day, and the level of greatest intensity seems to have been 40 to 45 km. However it is possible that even more intense warmings occurred at higher levels before the series began.

Equatorial soundings. High-level balloon ascents are scarce in tropical and sub-tropical latitudes but what ascents there are suggest that tropical monsoon circulation systems do not extend far into the stratosphere. This means that, although there is considerable *day-to-day* variability at all levels, the *average* values of pressure, wind and temperature, i.e. the climatology, at levels above perhaps 30 km will be the same at all points round a latitude circle.

There are now three meteorological rocket stations in tropical latitudes: United States stations at Fort Sherman (9° 20'N. 79° 59'W.) and Ascension Island (7° 59'S. 14° 25'W.) and a Meteorological Office station at Gan (0° 41'S. 73° 10'E.). Fort Sherman and Ascension Island have been operating for a number of years and the climatology for 14°N. and for 9°S. may be regarded as beginning to be reasonably well established. Monthly means of zonal winds for these two stations are shown in Figure 14. The quasi-biennial cycle is fairly evident at the 30 to 35-km level but at other levels there seems to be little systematic variation from year to year. (It should be noted that these are monthly means. There are quite large synoptic-scale variations at both stations. There may also be variations, e.g. with the solar cycle, yet to be determined.)

The meteorological rocket station at Gan became operative in 1968 and there has so far been only one short campaign, from 27 September to 10 October, during which seven successful soundings were made. The average values of the zonal winds measured on these occasions are shown on Figure 14. It is noteworthy that the Gan winds, at all levels, fall outside the envelope of the Ascension Island and the Fort Sherman winds. However the variability of the winds is such that this may not be significant.

Although no conclusions can yet be drawn about climatological differences between Gan and the other two tropical stations, there is clear evidence for the existence in the tropics, as at higher latitudes, of synoptic-scale disturbances. Figure 15 (upper diagram) shows winds averaged over the 50 to 55-km layer for each of the seven launchings at Gan. These seven points present a coherent pattern indicating, almost certainly, the passage during this period of a synoptic-scale disturbance. The same figure shows winds determined from a series of rocket launchings from Ascension Island for the previous year. There seems little doubt that the systematic variability shown, both at Gan and at Ascension Island, must arise from fairly large travelling disturbances.

Figure 15 (lower diagram) shows the pressures at the 50-km level measured at Gan during this series of soundings—corrected for seasonal drift. The two curves, for pressure and for wind, are noticeably similar. (A time cross-section

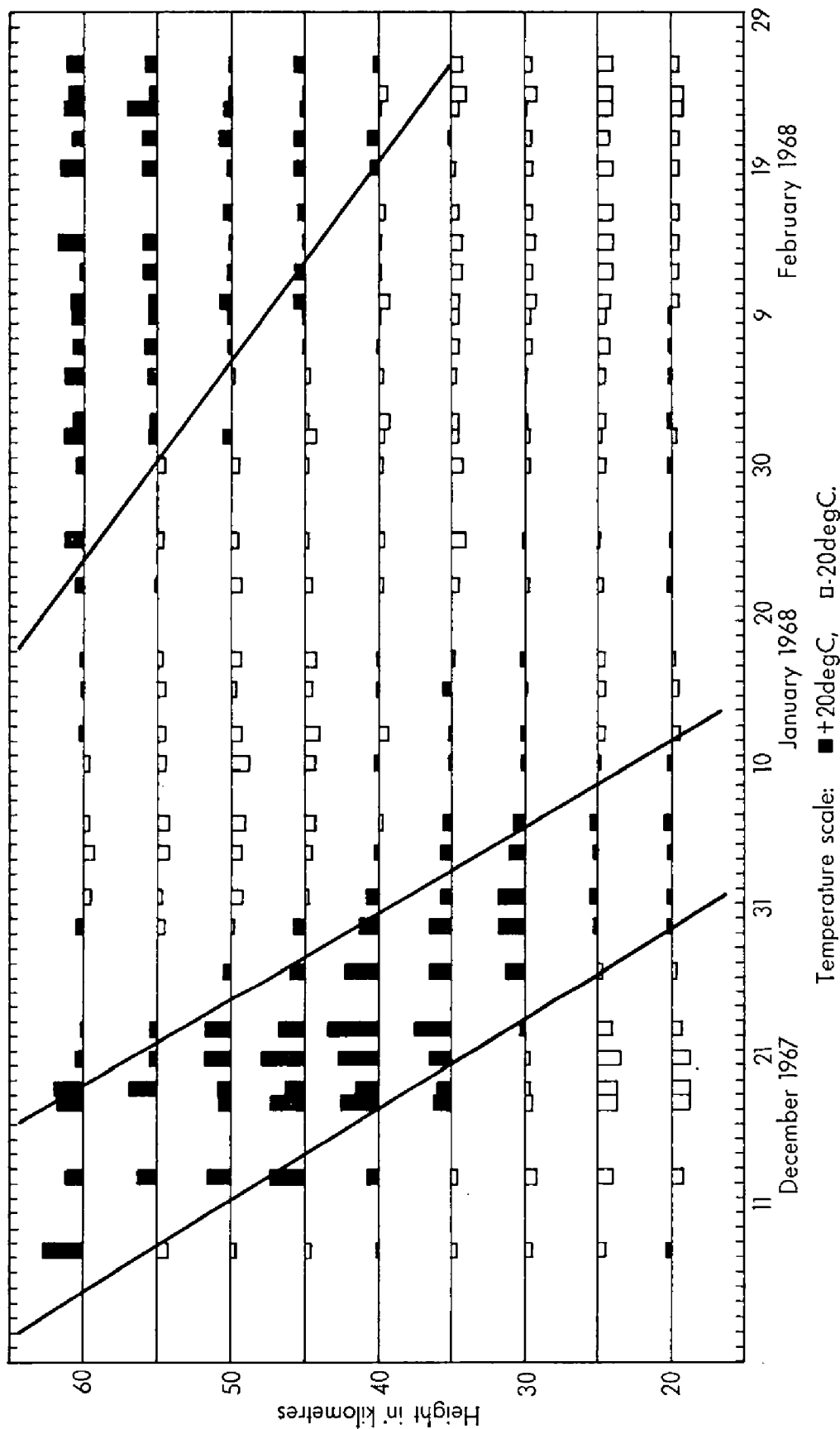


FIGURE 13—TIME CROSS-SECTION OF TEMPERATURES FOR NINE LEVELS AT INTERVALS OF FIVE KILOMETRES AT SOUTH UIST SHOWING DEPARTURES OF TEMPERATURES FROM ASSUMED REFERENCE VALUES DURING WINTER 1967/68

The slanting lines seem to indicate the downwards progression of a stratospheric warming.

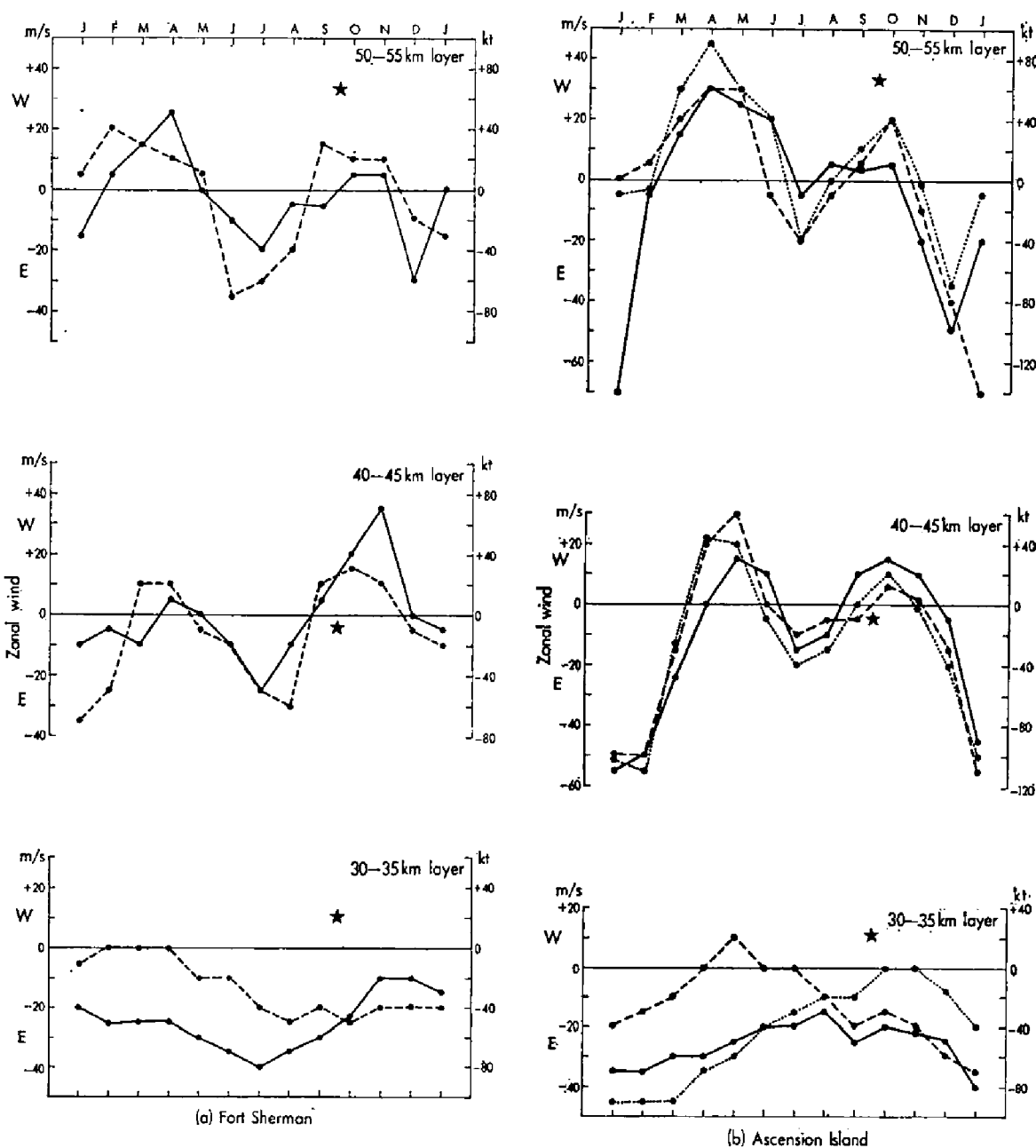


FIGURE 14—MONTHLY MEAN ZONAL WINDS OVER 5-KILOMETRE LAYERS AT FORT SHERMAN AND ASCENSION ISLAND

The average values from seven soundings at Gan between 27 September and 10 October 1968 are shown by stars.

●.....● 1965 ●---● 1966 ●——● 1967

of pressure, arising from the passage of a synoptic-scale disturbance, need not, of course, resemble at all closely the corresponding time cross-section of wind, but some relationship between them is to be expected.)

Diurnal variations. Something should be said about diurnal variations in the middle atmosphere. Diurnal variations of temperature are difficult to measure because measurements by day are much affected by radiation errors—the temperature element itself is heated, to an unknown extent, by direct and reflected solar radiation.

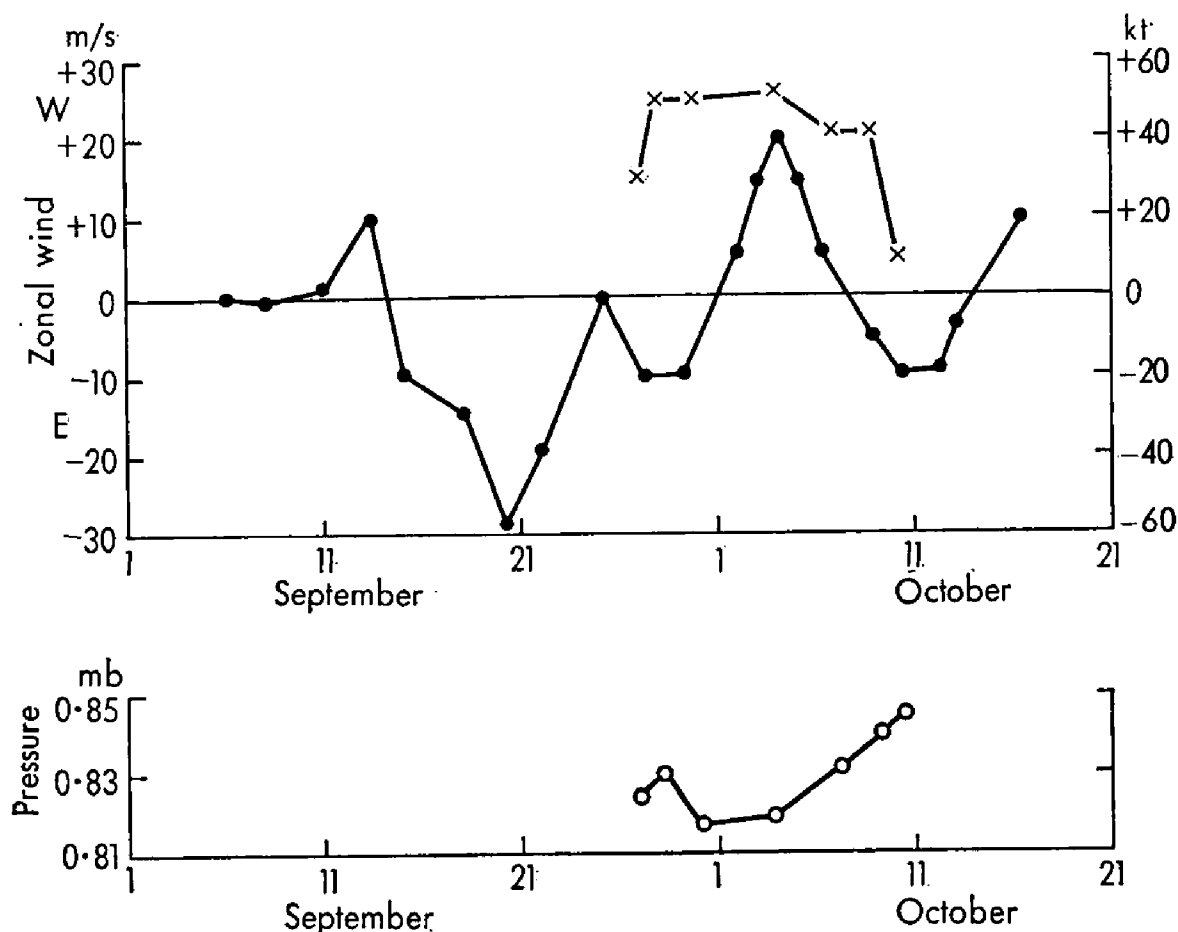


FIGURE 15—SYNOPTIC-SCALE PATTERNS REVEALED BY TIME CROSS-SECTIONS OF ZONAL WINDS OVER THE 50 TO 55-KILOMETRE LAYER AND OF PRESSURES AT 50 KILOMETRES

- Zonal winds, Ascension Island, 1967
- X—X Zonal winds, Gan, 1968
- Pressure, Gan, 1968.

Wind measurements are free from this error. At high-latitude stations in winter the inherent variability of the wind makes the determination of a relatively small diurnal variation difficult. Soundings in the summer, however, both at South Uist and at high-latitude American stations, indicate a very regular variation in the north-south wind component; at 55 km, for example, the meridional component is always south, about 10 kt (≈ 5 m/s), by day and always north, also about 10 kt, by night. It is not yet certain whether or not there is a similarly significant diurnal variation in the east-west component.

Diurnal variations at low latitudes are certainly less strong and their magnitude is not yet well established.

Airglow. The chemical and photo-chemical reactions which lead to the dissociation of molecular oxygen and to the creation of the ozone layer in the middle atmosphere, lead also to the phenomenon known as airglow. Airglow is the emission of radiation by atoms or molecules which have been put into an excited state, directly or indirectly, by the absorption of solar ultra-violet radiation. Analysis of the intensity and of the spectral distribution of airglow radiation reveals much about the chemical and photo-chemical reactions taking place in the atmosphere.

The Meteorological Office is co-operating with Oxford University in a project to measure certain airglow emissions from molecular oxygen in the 50 to 70-km region. The observations of radiation required for these studies will be made at levels from 70 km downwards using SKUA rockets to launch the equipment.

As was stated earlier, the small meteorological rocket project is concerned with studying and seeking to explain the behaviour of the middle atmosphere. These airglow measurements, together with measurements of molecular oxygen and ozone concentrations obtained from satellites and large rockets, provide essential additional data.

PHYSICAL RESEARCH

Cloud dynamics

The first phase of Project Scillonia (the Isles of Scilly project) took place during March 1968, when two warm fronts were investigated. Self-opening radar targets, dropped in a predetermined pattern over the fronts from the Varsity aircraft of the Meteorological Research Flight, were tracked by a high-precision radar located on the airfield at St Mary's, Isles of Scilly (see Plate IV). The fields of horizontal wind were determined at heights between 15 000 and 3000 feet (approx. 4570 and 915 metres) over an area 80 km by 100 km in extent. The Canberra of the Meteorological Research Flight was used to provide further wind data at 1000 ft (approx. 305 m) over the same area. From these measurements the field of mean vertical air movement on scales of 40 to 80 km was computed. The mobile Doppler radar, also located at St Mary's airfield, was used to obtain simultaneous wind measurements in precipitation to yield the fields of vertical air motion on a smaller scale (10 to 20 km).

This pilot exercise has demonstrated the feasibility of obtaining data on vertical air motion on scales between 10 and 80 km in frontal conditions by a combined use of radar and aircraft. In the second phase of this project additional observations will be made of the amount and the nature of precipitation, both inside and below the clouds, using conventional weather-radar.

The first few days of July 1968 were characterized by widespread outbreaks of thunderstorms which were exceptional for both their violence and the nature and size of the precipitation particles. An extensive study has been undertaken to investigate these outbreaks with particular reference to the dynamical processes that caused the exceptional violence, to the origin and composition of the dust washed out by the rain, and to the distribution and structure of the giant hail (up to 7 cm diameter) which fell in some places.

Doppler radar, conventional radar, balloon-borne radiosonde and surface observations of rainfall were used in an intensive study of the dynamics and precipitation of a wave depression as it affected the area around Malvern on 16 October 1967. The results suggest that the rainfall was of two distinct types: a uniform frontal area of rain produced by widespread slow ascent, and a separate distinctive banded structure caused by organized overturning of the air to the rear of the uniform rain band.

Cloud physics

One way in which precipitation grows in natural clouds is by each falling ice-crystal gathering up supercooled water droplets which lie in its path. This process is called riming. Controlled experiments are being conducted in a refrigerated laboratory to simulate this riming process with a view to determining the importance of the associated ejection of ice splinters. The ejected ice splinters act as centres on which new ice crystals can grow, thus providing an important multiplication process in precipitation growth. Furthermore, because the splinters are often electrically charged, it is possible that this process may contribute to the charge separation in thunderstorms. The first results of this study indicate that splintering is a much rarer phenomenon than was once thought.

Theoretical studies have been directed to the effects of turbulence on the spectrum of droplet sizes in a cloud. The turbulent updraught has been simulated mathematically, incorporating random velocity fluctuations into the calculations. Preliminary results indicate that mixing of the cloud with its environment is probably an essential factor affecting the spectra which exist in real clouds.

Meteorological Research Flight

It was decided during the year that the Hastings aircraft could not be used again and the aircraft of the Flight now consist of a Canberra and a Varsity. It is planned to replace the Hastings in 1970 by a modern aircraft with a long range and capable of operation through a wide range of altitude.

Detailed consideration has been given to a digital data-recording system for the new aircraft and for the Canberra. The urgent need for such a system is illustrated by the fact that with the present system of reading data directly by eye from the output of the recording equipment on the aircraft it may take as long as four man-weeks to extract the information from four minutes of flight recordings.

This work is particularly lengthy and tedious in respect of investigations of small-scale air motions made using the inertial platform fitted to the Canberra aircraft. Such studies are yielding unique data on the structure of clear-air turbulence and it is hoped that these data will lead to a proper understanding of the phenomenon and ultimately to improved forecasting of it. Some 20 flights were made to study small-scale atmospheric motions in 1968. Analysis of about half of these, and of all flights made in earlier years, is now complete.

Both aircraft of the Flight were used in support of the studies of rain areas off south-west England (Project Scillonia) and continue to be used (in co-operation with the Cloud Physics Branch) to obtain samples of the nuclei on which ice crystals form in the atmosphere. The aircraft were also used to collect botanical spores for study by the Rothamsted Experimental Station and airborne dust particles for examination by the Atomic Energy Research Establishment (AERE), Harwell.

The Varsity aircraft is now equipped with an infra-red radiation thermometer for measuring the effective temperature of the sea or land surface, and flights have been made over the waters around the U.K. and Malta in order to study the patchiness of the sea surface temperature distribution, which has important meteorological consequences.

High atmosphere

The observations made from the U.K. satellite ARIEL 2 during May, July and August 1964 have now been fully processed. These data indicate that there are broad latitudinal and seasonal trends in the concentration of ozone in the atmosphere at levels above 50 km which follow the latitudinal and seasonal trends in air density at these levels. However, it appears that the ozone variations are larger than those of density.

Analysis of data from satellite ARIEL 3 launched in May 1967 is almost complete. Perhaps the most remarkable result has been the discovery that there are large longitudinal variations in the concentrations of molecular oxygen at the levels investigated (around 180 km)—the concentration varying by a factor as much as 1.5 over a distance of a few hundred miles. Even the highest value found is much below the value given in the COSPAR Reference Atmosphere.

Molecular oxygen concentrations lower than those given in the COSPAR atmosphere have also been found at a lower level, about 120 km, from experiments carried out from SKYLARK rockets launched from Woomera.

Instruments are being built for two co-operative rocket projects; one from Fort Churchill, in co-operation with the University of Saskatchewan, is planned to make simultaneous measurements of airglow (University of Saskatchewan) and ozone concentration (Meteorological Office) in the mesosphere; the other, on European Space Research Organization (ESRO) rockets from Sweden, will make measurements of molecular oxygen and ozone concentrations in the mesosphere (Meteorological Office) simultaneously with mass spectrometer measurements by other experimenters.

The SKUA rocket campaign from South Uist, which started in December 1967, continued until 29 February 1968. During this period 32 temperature and 35 wind profiles were obtained. A most remarkable development was observed during the period 21 December to 1 January when the temperature at 44 km fell from $+40^{\circ}\text{C}$ to -36°C and at 24 km rose from -86°C to -44°C . At the same time the winds at about 44 km changed from 350 kt* westerly to 100 kt easterly.

Ten SKUA rockets were launched from Gan (a small island on the equator in the Maldives group) between 25 September and 11 October (see Plates VI and VII). Temperatures, pressures and winds were, as expected, all fairly close to the values given in the COSPAR Reference Atmosphere; but even this short series was sufficient to show that quite strong short-period disturbances are present in the stratosphere and mesosphere producing coherent changes in the average temperature of a deep layer over periods of a week or two.

Work continues jointly with Oxford University on a project to measure certain infra-red airglow emissions which are believed to come from excited oxygen molecules. These arise during the dissociation of ozone molecules by solar ultra-violet radiation. The measurements will be made from South Uist, using SKUA rockets.

Micrometeorology

As reported last year, computation of the fluxes of momentum and heat on three anticyclonic days in 1965 showed a lack of local balance between the production and decay of the energy of turbulent flow. In view of the importance of this result, if it is generally true, a study in depth is being made of sources of error in the whole chain of measurement and data reduction involved in the computation of fluxes of momentum and heat using eddy correlation methods.

At Cardington, field trials of techniques for the measurement of the spectra of high-frequency fluctuations of wind inclination and of temperature have continued. These trials have provided preliminary information on the variability and decay, with height, of the intensity of wind and temperature fluctuations.

At the same time studies on the theoretical aspects of vertical transfer in the planetary boundary-layer have begun. Extension of the theoretical work is planned in conjunction with the programme of turbulence and flux measurements at Cardington described above (see Plate V).

* 1 knot = 0.515 m/s.

Equipment similar to that used on tethered balloons at Cardington is being modified with a view to its use on tethered balloons at sea. A short series of sea trials of the performance of a tethered balloon was made from HMS *Hydra* in November. A balloon filled with 3000 ft³* of helium was successfully flown with a 10-kg load to a height of 500 m in a 20-kt wind.

Work continues on the fine structure of the temperature and current distribution in the top 100 metres or so of the ocean. It has been established that turbulence in the thermocline occurs in discrete, rather short-lived, patches—as is the case with some types of clear-air turbulence. With the object of relating this microstructure to synoptic-scale oceanic structures the programme at Malta this year included mapping of the sea surface temperature from aircraft of the Meteorological Research Flight, using a radiation thermometer.

Soundings made in the Loch Ness thermocline in September have confirmed that the water there exhibits a microstructure similar to that found off Malta. This suggests that salinity gradients are not a necessary factor in producing the small-scale layering in the ocean.

The Office again collaborated with the National Plant Breeding Institute, Cambridge, in a study on the effects of drought conditions (artificially induced) on a field of barley. The study was complicated in 1968 by the 'drought' crop suffering an attack of mildew.

Geophysical fluid dynamics

Although much handicapped by shortages of laboratory accommodation and staff, the new Geophysical Fluid Dynamics Branch is now firmly established.

Geophysical fluid dynamics is a term now given to the systematic study of fluid motions on planets and stars and it aims to provide an understanding and interpretation of fluid movements fundamental to meteorology, oceanography and astrophysics.

There are some aspects of geophysical fluid dynamics that can be simulated by means of laboratory models. Processes important in the global-scale motions in the oceans and in the atmospheres of the earth and other planets have close parallels in the motions of water in a rotating pan. Detailed investigations of such motions are being conducted in the Geophysical Fluid Dynamics laboratory, both experimentally and theoretically. Phenomena which have been produced and are being studied are (i) waves comparable in dimensions with the rotating pan having many features in common with the large planetary waves in the atmosphere, (ii) boundary layers with frictionally controlled flow towards lower pressure as in the lowest kilometre of the atmosphere, (iii) detached shear layers within the fluid and (iv) columns of fluid with a remarkable tendency to resist dispersion but which remain parallel to the axis of rotation (Taylor columns).

An important class of phenomena which cannot be paralleled in the laboratory is that in which electromagnetic forces play a significant part in the behaviour of a rotating fluid which is a good conductor of electricity. Such effects are being studied theoretically. They are relevant to the properties of the earth's core (where the geomagnetic field originates), to the behaviour of the

* About 85 m³.

sun and stars and possibly to the properties of the lower atmosphere of Jupiter and other major planets. Geomagnetic and gravitational data from artificial satellites are being used to provide data on the earth's deep interior for comparison with theory.

DYNAMICAL AND SYNOPTIC RESEARCH

Research related to short-range weather forecasting

One of the main research efforts has continued to be directed to improving and extending short-range weather forecasts. The most promising line of research, and one which has received most attention, is that in which the physical causes of weather processes are expressed in mathematical terms through the equations of motion and of energy; these equations are solved numerically, by means of a high-speed electronic computer, to calculate the changes in the developing weather systems that take place over a period of a day or two. Routine computations of this kind are now performed and are the basis on which forecasts are made of the broad distribution of temperature, pressure and wind in the atmosphere. The success of these computations has stimulated research into the possibilities of forecasting in more detail for a day or two ahead and of extending the forecasting period to several days.

During the year much progress has been made with the development of a computational scheme which is designed to give more detail in the prediction. The quality of these predictions depends to a large extent upon the success with which the basic physical processes in the atmosphere are accounted for and in these computations account is taken of the effects of water and water vapour in the atmosphere as well as of surface friction, topography, convective overturning and large-scale diffusion. Temperature, wind and humidity are forecast at 10 levels in the vertical at the intersections of a square grid of about 100-km grid length, and the rainfall reaching the ground is also computed. The computations are so extensive as to require the full power of Science Research Council Atlas computer for 8 hours in order to produce a 24-hour forecast and a considerably more powerful computer would be required to make the computations on an operational basis. Several calculations have been made over 24-hour periods and the results are very promising. They indicate that computation may be possible in considerably more detail than in the present routine. Many further test computations will be necessary before the scheme can be made ready for operational use. An ancillary problem is that of preparing the observed data in a suitable form for the computation. In an operational system this preparation must be done automatically on the computer; it is also economic to use the computer when preparing data for test cases, and methods of objective analysis of observations have been developed for the 10-level model.

Work has continued on the extension of the forecast period to several days by means of methods similar to those used in the routine forecast. The extension requires that the forecast area be extended to at least a hemisphere and that more attention be paid to the energy transformations. Changes have been introduced into the methods of calculating the effects of heating by the sea and also into the method of solution of some of the equations; this work has had repercussions on the routine numerical forecasts, shortening the computational

time. Attention has also been paid to the formulation of the release of latent heat and of radiational cooling and to the development of an objective analysis scheme for preparing the initial data in a suitable form.

Work was started on forecasting for up to seven days ahead. It was based on the empirical study of the mid-level pressure distributions of the previous five days, recognizing especially the patterns which precede wet and dry spells. By using, in addition, the numerical predictions for 72 hours ahead, about 30 experimental seven-day forecasts have been made and the results show an encouraging degree of success.

Research has also continued into methods of forecasting which are less mathematical and seek to distil our experience of past weather events in order to provide a guide to the future weather. Case studies of some occasions of heavy rainfall indicate some of the prerequisite conditions, and the work has been discussed with the Water Resources Board in connection with river-regulating experiments. Further studies have been made of the wind, temperature and humidity structure in frontal regions.

The staff at outstations have continued to make important contributions to the study of those forecasting problems which are best understood and pursued locally. The problems range from those connected directly with flying, such as the variation of visibility with wind direction at an airport, to those more directly concerned with the general public, such as the prediction of night minimum temperatures. New studies include the use of observations recorded at different heights on tall television masts and an investigation of the behaviour of road surface temperatures in connection with icy conditions in winter. All these studies lead to a revaluation of current methods of forecasting the local weather and often to the introduction of superior methods.

Research related to long-range forecasting

Throughout the year weather forecasts for a month ahead have been prepared at the beginning and middle of each month and they have been made available to the public through the Press and broadcasting media. More than 2000 subscribers receive, for a small charge, a more detailed copy of each forecast together with other relevant information about the month in question. These monthly forecasts do not attempt to give a day-by-day sequence of the expected weather in the detail found in shorter-period forecasts but indicate, on a regional basis, the expected monthly mean temperature anomaly in one of five equally likely categories and the expected mean rainfall in one of three categories. The broad sequence of the expected weather types is also described, particular reference being made to the first week, and mention is made of any expected outstanding weather features such as a more than usual number of foggy days or days with thunder. There was a slight improvement in the average standard of success during the year, mainly in respect of the general description of the broad weather sequences and the outstanding weather features. A number of oil companies have shown considerable interest in long-range forecasts of temperature, particularly for the winter months, using the forecasts as an aid in estimating fuel demands. Confidence limits are now available for each region; they indicate that in most regions three-quarters of the temperature forecasts are correct within 1 to 1.5 degrees Celsius.

The method of making monthly weather forecasts was described in the *Meteorological Office Annual Report 1965* (pp. 47–54) and remains unchanged in principle. Briefly it consists of examining weather records to identify periods in the past when the weather was similar to that for the few weeks preceding the forecast period and then basing the forecast on the known sequels of the analogue periods. The success of the method depends upon acquiring a long and reliable record of past weather data and in the past few years there have been many additions to the data library, notably upper air data at 500 mb and sea surface temperatures. Many of these data are now being analysed and new statistical relationships between weather patterns and their sequels are being revealed. As a result the facility for identifying analogue periods has been considerably extended; e.g. 500-mb charts have been inferred for each month back to 1873. Studies of more-recent 500-mb patterns have established statistical rules between the position and spacing of the troughs and ridges in one month with the rainfall over England and Wales in the succeeding month and also between the trough positions in April and the subsequent summer rainfall. Studies have also revealed statistical relationships between the sea surface temperature anomalies over the Atlantic Ocean in one month with the surface pressure anomalies near Great Britain in the succeeding month; these relationships vary from month to month and probably hold best when the patterns are strongly marked. As a result of these investigations analogues are now selected additionally on the basis of the similarity of sea surface temperature anomaly and of 500-mb pattern.

Attempts to extend the approach of the monthly forecasts to seasonal forecasting have continued and a number of useful statistical relationships have been discovered. Trial forecasts were prepared in November 1967 for the winter 1967–68 and in May for the summer of 1968. The winter forecast was successful and provided further confirmation of previous research on that type of winter. The summer of 1968 followed an unusual course, not matched for at least 80 years and it is not surprising that the analogue type of forecast failed to reveal the true course. A detailed study is being made of the summer's peculiarities.

The computer language designed to deal with the data problems arising in synoptic meteorology and climatology has been developed to the point where further elaboration seems unnecessary and the descriptive documentation has been thoroughly revised. One valuable application has been in the determination by statistical methods of the characteristic patterns which arise in the distribution of pressure over the northern hemisphere at sea level and 500 mb. Such work enables the main features of the pressure field to be characterized by the minimum number of variables.

Climatic change

Studies were continued of both ancient and recent climatic changes. The daily weather classification of day-to-day weather in the vicinity of Britain into 27 types has been extended backwards to 1861 and is ready for publication; an accompanying text has been written and includes a brief survey of other comparable daily classifications for all or part of the earth's surface. Daily and monthly averages, frequencies and other statistics derived from the classification have been computed. Some computations using 5-day values have been made of wavelength averages and frequencies for the flow at 500 mb around different

sectors of the northern hemisphere; the results have been of immediate value in discussions of the physical processes that affect the atmosphere during the period of the monthly forecasts.

General circulation of the atmosphere

The importance of studies of the world-wide circulation of the atmosphere is recognized in many countries. It is realized that man's ability to modify the earth's surface and discharge artificial substances into the atmosphere is growing to the extent that the climate of the earth might be affected accidentally or, possibly, by design. It is essential therefore that an understanding of the atmosphere should be acquired from which the extent of any possible modifications can be assessed quantitatively prior to the event.

Studies of the general circulation of the atmosphere are also necessary to determine the length of time over which weather forecasts will ultimately be possible and to assess the observational network which would be needed to achieve them. Work has continued throughout the year on the setting up of mathematical models of the atmosphere suitable for simulation of atmospheric motions on a hemispheric or global scale, as described in a Special Topic article in the Meteorological Office Annual Report 1967 (pp. 53–59). The computations require the whole power of the Science Research Council's ATLAS computer and, even so, two hours computing time is required to advance the forecast by 24 hours. A larger, faster computer will clearly be required when large-scale testing is envisaged. The physical processes judged to be important and which have been included in the computations are the hydrological cycle (the evaporation and condensation of water and the consequent latent-heat transfers), the effects of topography, the effect of small-scale air movement not treated explicitly within the model, friction between the atmosphere and the surface of the earth and radiative transfer within the atmosphere. Trial calculations have been carried out at each introduction of a new physical process. In the course of the development work the numerical procedures used to solve the mathematical equations have been substantially revised in the light of experience and the work has now reached the stage when meteorologically meaningful numerical experiments can be carried out. The treatment of radiative transfer in the atmosphere is complex, and valuable co-operation and help has been received from the workers of the Clarendon Laboratory, Oxford, who are in the process of designing a more ambitious and realistic treatment than the interim scheme originally devised. During the year a Senior Scientific Officer was based at the Geophysical Fluid Dynamics Laboratory of the Environmental Science Services Administration (ESSA) in Washington where similar work is being undertaken and the opportunities so provided for frequent exchanges of views on the problems arising in this type of work proved extremely useful.

The studies of the transfer of heat and momentum in the upper troposphere and lower stratosphere have continued and papers on eddy diffusivity and on the mean latitudinal circulation await publication. The work has been extended by means of a three-dimensional mathematical model of the stratosphere and preliminary work on its formulation and programming for computation has begun.

A study of the mean seasonal temperatures, contour heights and winds over the northern hemisphere at 50 mb was completed and awaits publication as a Geophysical Memoir. A similar study for the 30-mb level continues. A study of

the flux of angular momentum and energy across latitude 30° N during the extended period of the International Geophysical Year (IGY) was also made and will be published.

Tropical meteorology

The nucleus of a small team charged with the study of tropical meteorology was appointed in April. It has begun on a systematic study of cloud systems in the sector of the tropics between West Africa and the Philippines using American satellite data.

Storm surges in the North Sea

Further refinements have been made to the empirical formulae for forecasting dangerously high tides at east-coast ports using the basic data for over 150 cases of surges. These data have been put on magnetic tape for easy reference. Consideration has been given to the construction of empirical formulae for use in the provision of early preliminary warnings and a study has also been made of the timing of very high waters at Southend. Throughout the work there has been close collaboration with the Storm Tide Warning Service, Liverpool Tidal Institute and National Institute of Oceanography.

Special investigations

A number of special investigations were required for the preparation of advice on meteorological problems which were not treated in the main stream of research. Special studies have been made of the meteorological aspects of supersonic transport flying. In particular the distribution of cumulonimbus clouds in the vicinity of Singapore and over the Indian Ocean has been studied; use is being made of the meteorological radars at Singapore and Gan to carry out the investigation.

Theoretical and practical investigations have also been carried out into the physical mechanism of clear-air turbulence, analyses being made of flight reports by civil aircraft and by the Meteorological Research Flight. As part of an investigation into the landing problems of large aircraft an array of anemometers has been set up at Cardington to measure wind fluctuations along a typical approach path and a preliminary report should be ready next year. Calculations have been made of the position and amplification of the sonic boom under different meteorological conditions.

There has been an increased demand for meteorological information referring to possible sites for a third London airport and for other new airports in England. Meteorological advice was also given through membership of various departmental and inter-departmental committees.

GENERAL ACTIVITIES OF THE RESEARCH DIRECTORATE

Responsibility for the geophysical observatory at Eskdalemuir was transferred from the Meteorological Office to the Natural Environment Research Council (NERC) on 1 April 1968. The Meteorological Office will maintain a small staff at Eskdalemuir to continue the meteorological observations. No other changes in the organization of the Research Directorate were made during the year.

Close liaison is maintained with meteorological and other geophysical research conducted elsewhere in this country and abroad. This contact is provided by representation on a number of related committees of NERC and

of the Royal Society. Several members of the Meteorological Office staff also play an active part on commissions and working groups of the World Meteorological Organization (WMO) and the International Association of Meteorology and Atmospheric Physics.

The scientific research of the Office was reviewed by the Meteorological Research Committee and its sub-committees on several occasions and the Meteorological Office received thereby valuable advice from members of other government departments and the universities. The Meteorological Research Committee also advises on the arrangement of a number of small contracts with university groups for meteorological research. These provide a valuable link with university research groups which is further encouraged by the invitation of university staff to serve at the Meteorological Office as consultants for short periods during the vacations. Six members of university staffs acted as consultants during 1968.

The international plan for a major research programme to study the global circulation of the atmosphere by means of two major observation efforts in the 1970s began to take more definite shape during the year. The programme is now known as the Global Atmospheric Research Programme (GARP) and an organizing committee has been established jointly by WMO and the International Council of Scientific Unions. Mr J. S. Sawyer of the Meteorological Office has been appointed a member of this committee.

Mr G. W. Brier of the Environmental Science Services Administration (ESSA) of the U.S.A. worked in the Meteorological Office, Bracknell, from 16 October 1967 to 1 October 1968 on problems concerned with long-term fluctuations in the atmosphere and their association with gravitational tides. His attachment was part of the scheme, for exchange of scientists with ESSA, under which a Meteorological Office scientist was working with the ESSA general circulation research group in Washington (see p. 68).

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 72. The figure of 17 152 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 include a series of photographs of the activities of representative outstations of the Office, and a collection obtained from members of the Office staff as a result of a Meteorological Office competition. A noteworthy addition to the library was a set of microfilm reels giving daily cloud photographs over the world by ESSA satellites during 1967.

Two translators on the library staff were fully occupied during the year and work was also sent to freelance translators.

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

The Editing Section is responsible for preparing the official publications for printing and it 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.

The Cartographic Drawing Office undertakes the preparation for printing of all diagrams for Meteorological Office publications including the many charts and diagrams required by forecasters as background upon which meteorological observations may be plotted.

TRAINING

Basic professional training required by staff in each of the three Scientific classes is provided by means of courses at the Meteorological Office Training School, Stanmore. In these courses a sound basis of meteorological theory is laid, and particular emphasis is placed on practical aspects of the subject. The formal instruction at the School is then supplemented by means of post-course operational experience at Headquarters or outstations. The School also runs a number of specialist and background courses, mostly for members of the Experimental Officer class.

New arrangements for the training of the Scientific Assistant class were introduced during the year. As the majority of new entrants are employed in the synoptic field, these staff now receive a four-week Initial Assistants' Course of an almost entirely practical character; the aim here is to equip the newcomer to carry out useful work under supervision at an outstation. After a few years' experience the assistant returns to the School at age 20 or 21, for a six-week Advanced Assistants' Course; at this stage a thorough theoretical foundation is provided, and observing and instrument work receives special treatment. A four-week course in Basic Meteorology has also been planned for assistants at Headquarters who are employed on non-synoptic work; this combines a theoretical background with appropriate practical work. Unfortunately owing to the staff situation in the Assistant Class it has not yet been possible to post Meteorological Office staff on to Advanced Assistant or Basic Courses.

The basic training for the Experimental Officer Class has also been widened during the year to include a special four-week course of general meteorology for non-forecasting officers at Headquarters. Professional training for forecasting has now been split into three stages instead of two, and includes fourteen-week Initial, six-week Advanced, and four-week Extension Courses. Forecasters will spend some five to ten years in an operational post between courses at the School. Older members of the Class who require a broader approach not restricted to forecasting alone are catered for by a three-week Senior Meteorologists' Course; most of the lectures on this course are given by expert staff from Meteorological Office branches outside the Training School.

A review of training for the Scientific Officer class, is in hand. For the time being, all new Scientific Officers continue to spend six months at the School, but the post-course training period at outstations has been reduced to three months.

Training in radiosonde operation is provided at the Meteorological Office Training School at Hemsby. The Initial Course there lasts for nine weeks and there is also an Advanced Course of four weeks for staff experienced in the basic operations. Attendance at this is sometimes preceded by a Refresher Course.

TABLE XVII—TRAINING

The following figures give details of courses completed during 1968 at the Meteorological Office Training Schools at Stanmore, Hemsby and Easthampstead.

	Number of courses	Length of of course in weeks	Number of students
Scientific Officers	1	22	20
Senior Meteorologists	1	3	12
Basic Meteorology (Experimental Officer Class) ..	1	4	7
Forecasting (Preliminary)	1	4	4
Forecasting (Initial)	2	17	45
Forecasting (Advanced)	5	4	42
Tropical Meteorology	2	3	12
Mediterranean Meteorology	1	2	9
Climatology	1	4	7
Instruments (Advanced)	4	2	31
Assistants	6	9	78
Assistants (Initial)	5	4	50
Assistants (Advanced)	1	6	2
Auxiliary Observers	2	1	31
Voluntary Observers (Climatological)	1	1	16
Voluntary Observers (Agrometeorological)	1	1	19
Antarctic Observers	1	8	4
Radiosonde (Initial)	5	9	29
Radiosonde (Refresher)	3	5	3
Radiosonde (Advanced)	4	4	11
Technicians	2	14	21
Total			453

Students from the following territories attended courses which terminated during 1968:

	Number of students
Barbados	1
Belgium	2
British Antarctica	4
Burma	1
Cameroons	2
Cyprus	1
East Africa	11
Ethiopia	1
Ghana	1
Greece	2
Hong Kong	1
Israel	1
Jordan	1
Malaysia	2
Malta	3
Mauritius	3
Netherlands	1
Switzerland	2
Thailand	1
Total	41

INTERNATIONAL CO-OPERATION

The U.K. was host to the first Scientific and Technical Conference on Aeronautical Meteorology, of the WMO Commission for Aeronautical Meteorology, held in London from 18 to 29 March. The Director-General, Dr B. J. Mason, spoke at the opening and closing sessions and, with Mr. J. S. Sawyer, Director of Research, chaired the first symposium, on aeronautical meteorological problems in the vicinity of aerodromes. The other two symposia were on similar problems in the troposphere and lower stratosphere, and on meteorological information for supersonic transport operations, respectively. Meteorological Office staff presented several papers and took part in discussion. The substantial number of staff who attended included Mr P. J. Meade, Director of Services, and Mr J. K. Bannon, Assistant Director (Public Services).

Mr P. J. Meade, Director of Services, Mr V. R. Coles, Deputy Director (Forecasting Services), and Commander C. E. N. Frankcom (Marine Superintendent) attended the 6th ICAO Conference on North Atlantic Ocean Stations, in Paris, from 5 to 22 March. The Conference decided that the existing scheme will be maintained and that ICAO will continue to administer it for at least the next 5 years.

The 20th Session of the WMO Executive Committee was held in Geneva from 30 May to 13 June. Dr B. J. Mason was accompanied by Mr B. M. Day, Secretary, Meteorological Office, and Mr D. G. Harley, Assistant Director (International and Planning). Mr J. S. Sawyer attended as President of the Commission for Atmospheric Sciences, and Mr L. P. Smith as President of the Commission for Agricultural Meteorology. Major topics discussed included the progress in implementation and the further planning of World Weather Watch (WWW); the first report of the Joint Organizing Committee for the Global Atmospheric Research Programme (GARP); meteorological training; and WMO's role in developments in the international organization of marine scientific and technical activities. On this last point the Committee set up a Panel on Meteorological Aspects of Ocean Affairs, on which 10 countries including U.K. will be represented. The 13th IMO Prize, for outstanding work in meteorology and in international collaboration in this field, was awarded to Sir Graham Sutton, formerly Director-General of the Meteorological Office.

The Director-General, accompanied by Mr P. Goldsmith, Assistant Director (Cloud Physics), Dr J. T. Bartlett, Dr K. A. Browning and Dr J. C. Drake, Mr T. W. Harrold and Mrs C. M. Stevenson of the Cloud Physics group attended the IUGG (International Union of Geodesy and Geophysics)/WMO International Conference on Cloud Physics in Toronto from 26 to 30 August. Dr Browning and Mr Harrold also attended the 13th Radar Meteorology Conference in Montreal from 20 to 23 August. Six papers from the Cloud Physics branch, and two by the Director-General, were presented at these conferences. The Director-General attended the Commission on Cloud Physics, International Association of Meteorology and Atmospheric Physics (IAMAP), in Toronto on 25 August.

Other visits abroad by the Director-General included attendance in Geneva of sessions of the Executive Committee Panel on WMO Voluntary Assistance Programme in February and May, a tour of RAF stations in Germany from 2 to 5 April, visits to the Canadian Meteorological Service and the National Center for Atmospheric Research at Boulder, Colorado, in September, and a meeting of European meteorologists, to discuss a European meteorological satellite programme, in Stockholm in November.

Experts from the European Operating States and Prospective Operating States of North Atlantic Ocean Stations met in London from 10 to 11 September to consider possible methods of manning stations 'A', 'I', 'J', 'K' and 'M' after 1 July 1970. Commander C. E. N. Frankcom was elected Chairman of the meeting. Meteorological Office representation included Mr J. K. Bannon and Mr H. Maggs.

Two Technical Commissions of WMO met during the year. The Commission for Maritime Meteorology met in Rhode Island, U.S.A., from 19 to 31 August. The U.K. delegation, led by Commander C. E. N. Frankcom, included Mr J. H. Brazell, Assistant Director (Climatological Services), and Mr G. A. Tunnell, from the Meteorological Office and Instructor Captain J. D. Booth, RN, Director of Meteorology and Oceanographic Services (Navy). Discussions covered among other things the effects of new developments in ship operation both on ships' requirements for meteorological service and on observing methods and methods of reporting sea-ice and ice-accretion on ships. The Commission for Hydrometeorology met in Geneva from 9 to 20 September. Mr J. Harding, Assistant Director (Agriculture and Hydrometeorology), led the U.K. delegation, which also included Mr A. Bleasdale, Dr J. Ineson from the Water Resources Board and Dr J. C. Rodda and Dr J. S. G. McCulloch from the Institute of Hydrology, NERC. The important topics discussed included WMO's role in the International Hydrological Decade and a long-term plan of action in hydrology.

On a visit to U.S.A. in April and May, Mr J. M. Nicholls (Met.O.9) visited the Air Resources Laboratory of the Environmental Science Services Administration (ESSA), the University of Texas and the National Severe Storms Laboratory, to discuss problems of sonic bangs, studies of lee waves, and studies of severe storms.

A WMO seminar on Operation and Maintenance of Meteorological Telecommunications in Africa, held in Geneva from 7 to 18 October, was attended by representatives of most meteorological services in Africa. A demonstration of some British equipment was mounted, with the co-operation of the manufacturers concerned, for the instruction of the participants. Mr J. Paine (Met.O.5) conducted the demonstration and also lectured in the seminar.

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

<i>Subject</i>	<i>Place and date</i>	<i>Attended by</i>
WMO Informal Planning Meeting on telecommunication operational procedures and standards of technical characteristics	Geneva January	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
CIMO Working Group on Instruments and Methods of Observations at Aerodromes	Bracknell April	Mr L. Sugden (Met.O.7)

<i>Subject</i>	<i>Place and date</i>	<i>Attended by</i>
Inter-Agency Co-ordinating Group on Agricultural Biometeorology	Geneva April	Mr L. P. Smith (Met.O.8)
Joint ICSU/WMO Organizing Committee for GARP	Geneva April	Mr J. S. Sawyer, Director of Research
Regional Training Seminar on Methods of Hydrological Forecasting	Wageningen, Holland May	Mr G. W. Hurst (Met.O.8) Mr W. H. Hogg (Met.O.8) (Member of WMO Panel)
Symposium on Data Processing for Climatological Purposes	Asheville, U.S.A. May	Mr E. J. Sumner (Met.O.12)
Joint IUGG/WMO Symposium on Radiation including Satellite Techniques	Bergen August	Dr K. H. Stewart (Met.O.19) Mr R. H. Collingbourne (Met.O.14)
RA VI Working Group on Radiation	Bergen August	Mr R. H. Collingbourne (Met.O.14)
CIMO Working Group on Radiation Instruments and Observations for General Use	Bergen August	Mr R. H. Collingbourne (Met.O.14)
IUGG/WMO International Symposium on Ozone	Monaco September	Dr E. L. Simmons (Met.O.19)
CSM Working Group on Telecommunications—IV	Geneva September–October	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
CAeM Working Group on Meteorological Aspects of an Area Forecast System	Geneva October	Mr L. Sugden (Met.O.7)
CAeM Working Group on Briefing and Documentation Practices	Geneva October	Mr L. Sugden (Met.O.7)
RA VI Regional Training Seminar on Methods of Hydrological Forecasting	Bratislava, Czechoslovakia October	Mr J. Harding, Assistant Director (Agriculture and Hydro-meteorology)
WMO/WHO Symposium on Urban Climates and Building Climatology	Brussels October	Mr J. H. Brazell, Assistant Director (Climatological Services)
Informal WWW Planning Meeting on Collection, Archiving, Retrieval and Quality Control of Meteorological Data	Geneva November	Mr J. M. Craddock (Met.O.13)
CCI Working Group on Climatological Summaries	Geneva November	Mr J. G. Cottis (Met.O.3)
Regional Training Seminar on Forecasting of Heavy Rains and Floods	Kuala Lumpur November	Mr M. W. Stubbs (Met.O.6)
WMO/IUGG Symposium on Numerical Weather Prediction	Tokyo November–December	Mr E. Knighting, Deputy Director (Dynamical Research) Mr F. H. Bushby, Assistant Director (Forecasting Research)

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

<i>Subject</i>	<i>Place and date</i>	<i>Attended by</i>
Sixth FAUSST (French-Anglo-U.S.A. Talks on Supersonic Transport Operations)	London February	Mr L. Sugden (Met.O.7)
Meeting on Commonwealth Synoptic Rocket Programme	Colombo February	Dr R. Frith, Assistant Director (High Atmosphere)
Dedication Ceremony and Seminar of the Indian COSPAR	Trivandrum, India February	Dr R. Frith, Assistant Director (High Atmosphere)
Meetings on meteorological telecommunications between Washington, Offenbach, Paris	Washington March	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
U.K./Ireland Working Group on Telecommunications	Dublin and Shannon March	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
Symposium on Wind Effects on Buildings and Structures	Loughborough April	Mr N. C. Helliwell (Met.O.3)
Joint Scientific Meeting of Royal Meteorological Society, American Meteorological Society, Verband Deutscher Meteorologischer Gesellschaften and Deutsche Geophysikalische Gesellschaft	Hamburg April	Dr J. D. Woods (Met.O.14) Mr T. H. Kirk (Met.O.2) Mr J. F. Keers (Met.O.11)
Automatic plotting and line drawing at Deutscher Wetterdienst	Offenbach May	Mr R. F. Zobel, Assistant Director (Central Forecasting) Mr N. Bradbury, Assistant Director (Data Processing)
Liaison visit to National Meteorological Center to discuss automation and data processing	Suitland, Maryland, U.S.A. May	Mr E. J. Sumner (Met.O.12)
Eleventh Plenary Meeting of COSPAR	Tokyo May	Dr R. Frith, Assistant Director (High Atmosphere)
Symposium on Ariel 3 Results	Washington May	Dr K. H. Stewart (Met.O.19)
Symposium on Turbulence in the Ocean	Vancouver June	Dr J. D. Woods (Met.O.14)
European Space Research Organization (ESRO) Symposium	Munich July	Dr P. J. L. Wildman (Met.O.19)
Special Committee on Antarctic Research (SCAR) Conference on Quaternary Studies (ICSU)	Cambridge July	Mr H. H. Lamb (Met.O.13)
International Congress of Plant Pathology	London July	Mr G. W. Hurst and Mr W. H. Hogg (Met.O.8)
Consultation on Laser Holographic Technique for Sampling Cloud Droplets	Bedford, Mass. August	Dr J. T. Bartlett (Met.O.15)

<i>Subject</i>	<i>Place and date</i>	<i>Attended by</i>
International Cereal Rusts Conference	Oeiras, Lisbon August	Mr W. H. Hogg (Met.O.8)
Consultations on Cloud Physics	University of Virginia August	Dr J. T. Bartlett (Met.O.15)
NATO Panel on Meteorological Telecommunications	Brussels August	Mr A. A. Worthington, Assistant Director (Telecommunications)
UN Conference on the Peaceful Uses of Outer Space	Vienna August	Mr J. S. Sawyer, Director of Research
First Congress of Singapore National Academy of Sciences	Singapore August	Mr S. C. Mason and Mr M. W. Stubbs (Met.O.6)
International Symposium on Physics of Ice	Munich September	Dr D. A. Johnson (Met.O.15)
Consultations on cloud physics	Swiss Institute for Snow and Avalanche Re- search, Davos September	Dr D. A. Johnson (Met.O.15)
UNESCO Intergovernmental Con- ference of Experts on Scientific Basis for Rational Use and Conservation of Resources of the Biosphere	Paris September	Mr L. P. Smith (Met.O.8)
U.K./Ireland/Netherlands Working Group on Telecommunications	Dublin September	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
Meeting on meteorological telecom- munications between Washington, Offenbach, Paris and Bracknell	Geneva September	Mr A. A. Worthington, Assistant Director (Telecommunications) Mr E. J. Bell (Met.O.5)
SCAR Symposium	Hanover, U.S.A. September	Mr D. W. S. Limbert (Met.O.19)
IMCO Sub-Committee on Revision of Simla Rules	London September	Commander C. E. N. Frankcom (Marine Superintendent)
Discussion on objective analysis prob- lems	National Meteorolo- gical Center, Washington September	Mr R. F. Zobel, Assistant Direc- tor (Central Forecasting)
Third Aeronomy Conference on Meteorology and Chemical Factors in D Region Aeronomy	Illinois September	Dr R. J. Murgatroyd (Met.O.20)
Meteorological research flights in U.S.A.	Boulder, Nevada, Miami, Washington, Cambridge, Woodshole September- October	Mr D. N. Axford (MRF)
NATO Working Group on Meteorolo- gical Telecommunications	Rome October	Mr A. A. Worthington, Assistant Director (Telecommunications)

<i>Subject</i>	<i>Place and date</i>	<i>Attended by</i>
Meeting of COSPAR Working Group VI (Application of Space Experiments to Meteorology)	London October	Dr R. Frith, Deputy Director (Physical Research) Mr E. Knighting, Deputy Director (Dynamical Research) Mr G. A. Corby, Assistant Director (Dynamical Climatology)
Sixth FAO Regional Conference Europe	Malta October	Dr P. G. F. Caton (Met.O.6) (As representative of WMO)
Sixth Meeting of ICAO/MOTNE Panel-Area Forecast System	Paris October	Mr B. F. Westwater (Met.O.7)
Fifth Antarctic Treaty Consultative Meeting	Paris November	Mr D. G. Harley, Assistant Director (International and Planning)
ICAO MID/SEA (1968) Regional Air Navigation Meeting	Manila November–December	Mr P. Graystone (Met.O.6)
NATO <i>ad hoc</i> Advisory Committee on Meteorology	Brussels December	Mr J. S. Sawyer, Director of Research

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

Mr L. A. Nixon	Chief Experimental Officer	Released in January to WMO Secretariat, Geneva, to conduct WWW planning study
Mr D. Davidson	Scientific Assistant	Released in February to British Antarctic Survey, Falkland Islands
Mr R. M. Perry	Senior Scientific Assistant	Released in April to WMO Secretariat Geneva
Mr W. McKay	Senior Experimental Officer	Seconded in May to Board of Trade for service at the South Pacific Air Transport Council's meteorological station at Nandi, Fiji
Mr D. McFarlane	Senior Experimental Officer	Seconded in July to Board of Trade for service at the South Pacific Air Transport Council's meteorological station at Nandi, Fiji

The following staff returned to the Office from appointments overseas:

Mr W. E. J. Newton	Experimental Officer (now retired)	} From Idris, Libya, in January
Mr R. S. Whalley	Scientific Assistants	
Mr J. Lomas		
Mr J. T. Frampton	Experimental Officer	From Idris, Libya, in February
Mr W. N. Burton	Senior Scientific Assistants	} From Idris, Libya, in April
Mr W. E. Tozer		
Mr K. M. Sutherland		
Mr L. A. Nixon	Chief Experimental Officer	From WMO, Geneva, in April
Mr M. T. Hulbert	Senior Scientific Assistant	From British Antarctic Survey, Falkland Islands, in May
Mr H. B. Cawthorne	Senior Experimental Officer	From Idris, Libya, in June
Mr D. M. Selway	Scientific Assistants	} From British Antarctic Survey, Falkland Islands, in June
Mr G. W. Pugh		
Mr D. P. N. Cullum	Experimental Officers	} From Idris, Libya, in July
Mr A. B. Turner		
Mr T. D. D. Jennings	Experimental Officers	} From British Antarctic Survey, Falkland Islands, in July
Mr P. A. Richards		
Mr F. J. Smith	Experimental Officer	From Nigeria, in September
Mr P. R. Rowntree	Senior Scientific Officer	From Geophysical Fluid Dynamics Laboratory, Washington, in October

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 1968 the total number of posts of all grades was 3696, a decrease of 122 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	...	...	...	...	...	...	4
Senior Scientific Officers	...	...	...	...	...	...	26
Scientific Officers	...	...	...	...	...	...	34
Junior Research Fellows	...	...	...	...	...	...	1
Administrative Class							
Assistant Secretary	...	...	...	...	...	...	1
Experimental Officer Class							
Chief Experimental Officers	...	...	...	...	...	...	30 + 6
Senior Experimental Officers	...	...	...	...	...	...	236 --
Experimental Officers	...	...	...	...	...	...	428 + 14
Assistant Experimental Officers	...	...	...	...	...	...	196 - 26
Scientific Assistant Class							
Senior Scientific Assistants	...	...	...	...	...	...	336 + 12
Scientific Assistants	...	...	...	...	...	...	1067 - 62
Marine Staff							
Marine Superintendent	...	...	...	...	...	...	1
Nautical Officer Class	...	...	...	...	...	...	9
Ocean Weather Ships and Base							
Officers	...	...	...	...	...	...	93
Crew	...	...	...	...	...	...	108
Technical and Signals Grades	...	...	...	...	...	...	281
Executive and Clerical Grades	...	...	...	...	...	...	184
Typing and miscellaneous non-industrial grades	...	...	...	...	...	...	162
Industrial employees	...	...	...	...	...	...	92
Locally entered staff and employees overseas	...	...	...	...	...	...	177

Recruitment to the Scientific Officer class during the year continued at the high level set in 1967 with 14 new entrants to the class. There were fewer new entrants than usual to the Experimental Officer class but the overall manning was satisfactory. The Scientific Assistant class remained under strength. Recruitment was sufficient to offset wastage during the year and a little progress was made in cutting back the shortfall which existed at the beginning of the year. Recruitment into the Technician class was good and all posts were filled, with a small surplus available against training and future expansion needs.

In common with other Departments, the Meteorological Office was required to accept limitations on both complement and strength during the year. At 31 December 1968 the strength was 10 below that of twelve months previously, and 122 posts had been cut from the complement.

Three Senior Scientific Officers were sponsored by the Office to work towards Ph.D. degrees in a special scheme which has been introduced in conjunction with Imperial College, University of London. Eight Assistant Experimental Officers have been taking Sandwich Courses leading to degrees, while two Radio Meteorological Technicians have been attending similar courses aimed at the Higher National Diploma. One Assistant Experimental Officer who was awarded a Treasury Bursary in 1967 has continued his degree studies at Queen's University, Belfast. One Experimental Officer has been allowed full time release with pay to work towards a degree at the Plymouth College of Technology. In addition, 228 members of the staff took advantage of study concessions at various levels and a further 27 attended special short courses. Sixteen university undergraduates were chosen from among many applicants to work in the Office as students during the long vacation, while seven 'vacation consultants' from the universities contributed to the work of the Office during the year.

CHANGES IN SENIOR STAFF

Mr K. H. Smith, B.Sc., succeeded Mr C. J. Boyden, B.A., as Assistant Director (Publications and Training).

Dr R. Frith, O.B.E., succeeded Dr G. D. Robinson as Deputy Director (Physical Research).

Mr R. A. Hamilton, O.B.E., B.A., F.R.S.E., succeeded Dr Frith as Assistant Director (High Atmosphere).

HONOURS AND DISTINCTIONS

Sir Graham Sutton, formerly Director-General of the Office, was awarded the 13th IMO Prize.

Mr S. E. Virgo was awarded the O.B.E., and Mr P. A. Warn was awarded the B.E.M.

The L. G. Groves Memorial Prize for Meteorology was awarded to Mr A. H. Hooper. The Meteorological Observers' Award was received by Mr W. J. Cox.

Dr K. A. Browning received the 1968 L. F. Richardson Prize from the Royal Meteorological Society.

Dr J. D. Woods was awarded the Back Grant of the Royal Geographical Society for services to underwater exploration. He also received the L. G. Groves Second Memorial Award.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

- ATKINS, J. E.; Changes in the visibility characteristics at Manchester/Ringway Airport. *Met. Mag., London*, **97**, 1968, pp. 172–174.
- AXFORD, D. N., M.A., M.Sc., A.I.E.E.; An example of a vector error distribution derived from a routine upper wind forecasting test. *Met. Mag., London*, **97**, 1968, pp. 361–368.
- AXFORD, D. N., M.A., M.Sc., A.I.E.E.; On the accuracy of wind measurements using an inertial platform in an aircraft, and an example of a measurement of the vertical mesostructure of the atmosphere. *Jnl appl. Met., Boston, Mass.*, **7**, 1968, pp. 645–666.
- BEIMERS, J. G. D., see BROWNING, K. A., HARROLD, T. W., WHYMAN, A. J. and BEIMERS, J. G. D.
- BENWELL, G. R. R., M.A. and TIMPSON, Margaret S., B.Sc.; Further work with the Bushby-Timpson 10-level model. *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 12–24.
- BENWELL, G. R. R., M.A. with BRETHERTON, F. P.; A pressure oscillation in a 10-level atmospheric model. *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 123–131.
- BIRD, L. G. and RIDER, N. E., D.Sc.; The laser cloud-base recorder. *Met. Mag., London*, **97**, 1968, pp. 107–115.
- BLACKBURN, M. R., see BLACKWELL, M. J. and BLACKBURN, M. R.
- BLACKWELL, M. J., M.A. and BLACKBURN, M. R.; Crop environment data acquisition. WADSWORTH, R. M. (editor); The measurement of environmental factors in terrestrial ecology. *Br. ecol. Soc. Symp., Reading, March 1967*. Oxford, Blackwell Scientific Publishers, 1968, pp. 213–224.
- BOOTH, R. E.; The severe winter of 1963 compared with other cold winters, particularly that of 1947. *Weather, London*, **23**, 1968, pp. 477–479.
- BRAZELL, J. H., M.Sc.; North Sea drilling operations—wind and wave problems. *Mar. Obsr, London*, **38**, 1968, pp. 84–91.
- BRAZELL, J. H., M.Sc.; Wind and wave problems. *Inst. Petrol., Rev., London*, Aug. 1967, pp. 249–255.
- BRIGGS, J.; Estimating the duration of high-intensity rainfall. *Met. Mag., London*, **97**, 1968, pp. 289–293.
- BROWNING, K. A., Ph.D., D.I.C.; The organization of severe local storms. *Weather, London*, **23**, 1968, pp. 429–434.
- BROWNING, K. A., Ph.D., D.I.C., HARROLD, T. W., B.Sc., D.I.C. and JOHNSON, D. A. with HALLETT, J.; The collection and analysis of freshly fallen hailstones. *Jnl appl. Met., Boston, Mass.*, **7**, 1968, pp. 603–612.
- BROWNING, K. A., Ph.D., D.I.C., HARROLD, T. W., B.Sc., D.I.C., WHYMAN, A. J. and BEIMERS, J. G. D.; Horizontal and vertical air motion and precipitation growth, within a shower. *Proc. 13th Conf. Radar Met., Montreal, Aug. 1968*. Boston, Mass, American Meteorological Society, 1968, pp. 122–127; also published in *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 498–509.
- BROWNING, K. A., Ph.D., D.I.C., HARROLD, T. W., B.Sc., D.I.C., WHYMAN, A. J. and BEIMERS, J. G. D.; Study of showers using two Doppler radars. *R.R.E. News. Res. Rev., Malvern*, No. 7, 1968, pp. 1–3.
- BROWNING, K. A., see HARROLD, T. W. and BROWNING, K. A.
- BROWNING, K. A., see HARROLD, T. W., BROWNING, K. A. and NICHOLLS, J. M.
- BRYANT, D.; An investigation into the response of thermometer screens—the effect of wind speed on the lag time. *Met. Mag., London*, **97**, 1968, pp. 183–186.

- BUCHANAN, R. A., M.A.; Weather services for the builder. *Bldg Technol. and Mgmt, London*, **6**, 1968, pp. 244–245.
- BUSHBY, F. H., B.Sc.; Numerical weather prediction. *Mar. Obsr, London*, **38**, 1968, pp. 80–83.
- CARRUTHERS, G. P.; see WILDMAN, P. J. L., CARRUTHERS, G. P. and ELSE, C. V.
- CLARK, D. J.; Pressure jump lines in the Persian Gulf. *Met. Mag., London*, **97**, 1968, pp. 368–372.
- COCKRELL, P. R.; The Meteorological Society of London 1823–1873. *Weather, London*, **23**, 1968, pp. 357–361.
- CORFIELD, G. A., B.Sc. and NEWTON, W. G.; A recent change in visibility characteristics at Fittingley. *Met. Mag., London*, **97**, 1968, pp. 204–209.
- CORNFORD, S. G., M.Sc.; Fluctuations of temperature and humidity in clear air over the North Sea around sunset on a winter's day. *Met. Mag., London*, **97**, 1968, pp. 353–361.
- CORNFORD, S. G., M.Sc.; The measurement of shower rainfall using an airborne foil impactor. *Jnl appl. Met., Boston, Mass*, **7**, 1968, pp. 956–957.
- CORNFORD, S. G., M.Sc.; Sampling errors in measurements of particle size distributions. *Met. Mag., London*, **97**, 1968, pp. 12–16.
- CRADDOCK, J. M., M.A.; An experiment in the analysis and prediction of time series. *The Statistician, London*, **17**, 1967, pp. 257–268.
- CROSSLEY, A. F., M.A. with PARKINSON, I. N., B.A.; Distribution of jet streams at 200 mb in the Middle East. *Jnl Inst. Navig., London*, **20**, 1967, pp. 397–404.
- DAVIS, N. E., M.A.; An optimum summer weather index. *Weather, London*, **23**, 1968, pp. 305–317.
- DE LA MOTHE, P.D.; Middle-latitude wavelength variations at 500 mb. *Met. Mag., London*, **97**, 1968, pp. 333–339.
- DINSDALE, F. E., B.Sc.; Fog frequencies at inland stations. *Met. Mag., London*, **97**, 1968, pp. 314–317.
- DURRANS, K. L., see KEMP, A. K. and DURRANS, K. L.
- EBDON, R. A.; Lower stratospheric wind and temperature distributions. *Met. Mag., London*, **97**, 1968, pp. 97–107.
- EBDON, R. A., see WRIGHT, P. B. and EBDON, R. A.
- ELSE, C. V., see WILDMAN, P. J. L., CARRUTHERS, G. P. and ELSE, C. V.
- FOORD, H. V.; An index of comfort for London. *Met. Mag., London*, **97**, 1968, pp. 282–286.
- FREEMAN, M. H., O.B.E., M.Sc.; A general-purpose computer-programme for statistical work. *Met. Mag., London*, **97**, 1968, pp. 209–214.
- FREEMAN, M. H., O.B.E., M.Sc.; The role of numerical forecasts in the provision of meteorological information for civil aviation at London/Heathrow Airport. *Met. Mag., London*, **97**, 1968, pp. 177–181.
- FREEMAN, M. H., O.B.E., M.Sc.; Visibility statistics for London/Heathrow Airport. *Met. Mag., London*, **97**, 1968, pp. 214–218.
- FREEMAN, M. H., O.B.E., M.Sc.; Weather forecasting. *Brit. Airline Pilots Ass. Symp., Nov. 1967, The SST. Harlington*, 1968, pp. 133–138.
- FRITH, R., O.B.E., Ph.D.; The earth's higher atmosphere. *Weather, London*, **23**, 1968, pp. 142–155.

- GILL, D. S.; The diurnal variation of the sea-breeze at three stations in north-east Scotland. *Met. Mag., London*, **97**, 1968, pp. 19–24.
- GLOYNE, R. W., Ph.D.; Final report on agricultural meteorology in Turkey. *Wld met. Org., Geneva*, WMO RP. TC.6, 1967, pp. 1–44.
- GOLDIE, E. C. W. and HEIGHES, J. M.; The Berkshire halo display of 11 May 1965. *Weather, London*, **23**, 1968, pp. 61–69.
- GOODISON, C. E., C.Eng., M.I.E.R.E.; Satellites in the service of meteorology. Space communications symposium, London, June 1968. London, Northern Polytechnic, 1968 (unpublished).
- GORDON, J., B.Sc. and VIRGO, S. E., O.B.E., M.Sc.; Comparison of methods of forecasting night-minimum temperatures. *Met. Mag., London*, **97**, 1968, pp. 161–164.
- HARDMAN, M. E., B.Sc.; The Wiltshire hailstorm, 13 July 1967. *Weather, London*, **23**, 1968, pp. 404–415.
- HARROLD, T. W., B.Sc., D.I.C. and BROWNING, K. A., Ph.D., D.I.C.; Low-level airflow at a cold front. *Proc. 13th Conf. Radar Met., Montreal, Aug. 1968*. Boston, Mass, American Meteorological Society, 1968, pp. 222–225.
- HARROLD, T. W., B.Sc., D.I.C., BROWNING, K. A., Ph.D., D.I.C. and NICHOLLS, J. M., B.Sc.; Rapid changes in the height of the melting layer. *Met. Mag., London*, **97**, 1968, pp. 327–332.
- HARROLD, T. W., B.Sc., D.I.C. and NICHOLLS, J. M., B.Sc.; An investigation of air motion in frontal precipitation. *Scient. Pap. met. Off., London*, No. 29, 1968.
- HARROLD, T. W., see BROWNING, K. A., HARROLD, T. W. and JOHNSON, D. with HALLETT, J.
- HARROLD, T. W., see BROWNING, K. A., HARROLD, T. W., WHYMAN, A. J. and BEIMERS, J. G. D.
- HAY, R. F. M., M.A.; Relations between summer and September temperature anomalies in central England. *Met. Mag., London*, **97**, 1968, pp. 76–90.
- HAY, R. F. M., M.A.; Relationships between autumn rainfall and winter temperatures. *Met. Mag., London*, **97**, 1968, pp. 278–282.
- HEIGHES, J. M., see GOLDIE, E. C. W. and HEIGHES, J. M.
- HIDE, R., Ph.D.; Jupiter's great red spot. *Scient. Am., New York*, **218**, No. 2, 1968, pp. 74–82.
- HIDE, R., Ph.D.; On source-sink flows in a rotating fluid. *Jnl Fluid Mech., London*, **32**, 1968, pp. 737–764.
- HIDE, R., Ph.D. and HORAI, K.; On the topography of the core-mantle interface. *Phys. Earth Planet. Interiors, Amsterdam*, **1**, 1968, pp. 305–308.
- HIDE, R., Ph.D. with IBBETSON, A.; An experimental study of 'Taylor Columns'. *Icarus, New York*, **5**, 1966, pp. 279–290.
- HIDE, R., Ph.D. with IBBETSON, A.; On slow transverse flow past obstacles in a rapidly rotating fluid. *Jnl Fluid Mech., London*, **32**, 1968, pp. 251–272.
- HOGG, W. H., M.Sc.; The cost of weather. *Agriculture, London*, **75**, 1968, pp. 518–521.
- HOGG, W. H., M.Sc. with HIRST, J. M. and STEDMAN, O. J.; Long-distance spore transport: methods of measurement, vertical spore profiles and the detection of immigrant spores. *Jnl gen. Microbiol. Cambridge*, **48**, 1967, pp. 329–355.
- HOLLAND, J. D., M.A.; Evaporation. *Br. Rainf. 1961, London*, 1967, Pt. III, pp. 5–34.

- HOOPER, A.; Meteorological instrumentation II: routine instruments for upper air observations. *Jnl scient. Instrum., London*, Ser. 2, **1**, 1968, pp. 272-277.
- HORAI, K., see HIDE, R. and HORAI, K.
- HURST, G. W., B.Sc., D.I.C.; Foot-and-mouth disease. The possibility of continental sources of the virus in England in epidemics of October 1967 and several other years. *Vet. Rec., London*, **82**, 1968, pp. 610-614.
- HURST, G. W., B.Sc., D.I.C. with HIRST, J. M. and STEDMAN, O. J.; Long-distance spore transport: vertical sections of spore clouds over the sea. *Jnl gen. Microbiol. Cambridge*, **48**, 1967, pp. 357-377.
- JOHNSON, D. A., see BROWNING, K. A., HARROLD, T. W. and JOHNSON, D. with HALLETT, J.
- JONAS, P. R. and MASON, B. J., D.Sc., F.R.S.; Systematic charging of water droplets produced by break-up of liquid jets and filaments. *Trans. Faraday Soc., London*, **64**, 1968, pp. 1971-1982.
- JONES, R. F., B.A.; Radar detection of rain. HUGHES, L. E. G. and HOLLAND, F. W. (editors); Electronic engineer's reference book, 3rd edn. London, Heywood Books, 1967, pp. 1306-1309.
- JONES, R. F., B.A. with McINTURFF, R. M. and TEWELES, S.; Meteorological problems in the design and operation of supersonic aircraft. *Tech. Notes Wld met. Org., Geneva*, No. 89, 1967.
- KEMP, A. K. and DURRANS, K. L.; Expedition to Tibesti. *Weather, London*, **23**, 1968, pp. 331-338.
- LAMB, H. H., M.A.; Britain's changing climate. *Geogr Jnl, London*, **133**, 1967, pp. 445-468.
- LAMB, H. H., M.A.; Britain's climate, its variability and some of its extremes. *London, Instn mech. Engrs, Symp., Nov. 1967*, Heating and ventilation for a human environment. London, 1968, pp. 1-27.
- LAMB, H. H., M.A.; The climatic background to the birth of civilization. *Advmt Sci., London*, **25**, 1968, pp. 103-120.
- LAMB, H. H., M.A.; Climatic changes during the course of early Greek history. *Antiquity, Cambridge*, **42**, 1968, pp. 231-233.
- LAMB, H. H., M.A.; On climatic variations affecting the far south. *Tech. Notes Wld met. Org., Geneva*, No. 87, 1967, pp. 428-453.
- LAMB, H. H., M.A.; Glacier variation and weather: comments on Professor Hoinkes' paper. *Jnl Glaciol., London*, **7**, 1968, pp. 129-130.
- LAMB, H. H., M.A.; Volcanic dust, melting of ice caps, and sea levels. *Palaeogeogr., Palaeoclim., Palaeoecol., Amsterdam*, **4**, 1968, pp. 219-222, pp. 223-226.
- LAWRENCE, E. N., B.Sc.; Changes in air temperature at Manchester airport. *Met. Mag., London*, **97**, 1968, pp. 43-51.
- LAWRENCE, E. N., B.Sc.; The development of low-level midday air temperature inversions. *Met. Mag., London*, **97**, 1968, pp. 270-277.
- LOVE, D. M., B.Sc.; April temperatures and the following summers in Southampton, 1901-62. *Weather, London*, **23**, 1968, pp. 214-216.
- LOWNDES, C. A. S.; Forecasting large 24-hour rainfall totals in the Dee and Clwyd River Authority Area from September to February. *Met. Mag., London*, **97**, 1968, pp. 226-235.
- LUPTON, G.; Estimation of monthly mean wind speeds. *Met. Mag., London*, **97**, 1968, pp. 58-60.

- McFARLANE, D. with SMITH, C. G.; Remarkable rainfall in Oxford. *Met. Mag., London*, **97**, 1968, pp. 235–245.
- MARSHALL, N. B., B.Sc., B.Mus., F.R.C.O.; The icefields round Iceland in spring 1968. *Weather, London*, **23**, 1968, pp. 368–376.
- MASON, B. J., D.Sc., F.R.S.; Automation in weather forecasting. *Computer Wkly, London*, **4**, 1968, No. 71, pp. 6–7.
- MASON, B. J., D.Sc., F.R.S.; Development of meteorological observing techniques in the satellite and computer age. *Jnl scient. Instrum., London*, Ser. 2, **1**, 1968, pp. 257–264.
- MASON, B. J., D.Sc., F.R.S.; Developments in weather observing and forecasting. *The Hawker-Siddeley Review, London*, **5**, 1968, No. 4, pp. 9–14.
- MASON, B. J., D.Sc., F.R.S.; Forecasting the weather by computer. *Advm Sci., London*, **24**, 1968, pp. 263–272.
- MASON, B. J., D.Sc., F.R.S.; Initiation of the ice phase in the atmosphere and The generation of electric charges and fields in precipitating clouds. *Proc. Int. Conf. Cloud Phys., Toronto, August, 1968*. Toronto, 1968, pp. 162–173, 657–662.
- MASON, B. J., D.Sc., F.R.S.; The new age of weather forecasting. *Air Force Dep. Soc Jnl, London*, No. 7, 1967, pp. 1–7.
- MASON, B. J., D.Sc., F.R.S.; Recent developments in meteorology and the World Weather Watch. (The fifty-ninth Kelvin lecture.) *Proc. Instn elect. Engrs, London*, **115**, 1968, pp. 1319–1331.
- MASON, B. J., D.Sc., F.R.S.; The thunderstorm. *Physics Educ., London*, **3**, 1968, pp. 122–130.
- MASON, B. J., see JONAS, P. R. and MASON, B. J.
- MASON, B. J., D.Sc., F.R.S. with KUHNS, I. E.; The supercooling and freezing of small water droplets falling in air and other gases. *Proc. R. Soc., London, A*, **302**, 1968, pp. 437–452.
- MENMUIR, P., see TINNEY, E. B. and MENMUIR, P.
- MURRAY, R., M.A.; On certain large-scale synoptic features of the summer over the British Isles and autumn mean temperature in central England and autumn rainfall over England and Wales. *Met. Mag., London*, **97**, 1968, pp. 321–327.
- MURRAY, R., M.A.; Sequences in monthly rainfall over Scotland. *Met. Mag., London*, **97**, 1968, pp. 181–183.
- MURRAY, R., M.A.; Some associations between monthly rainfall over England and Wales and central England temperatures. *Met. Mag., London*, **97**, 1968, pp. 141–145.
- MURRAY, R., M.A.; Some predictive relationships concerning seasonal rainfall over England and Wales and seasonal temperature in central England. *Met. Mag., London*, **97**, 1968, pp. 303–310.
- NEAVE, C. F.; Tropical storm ‘Lily’ 19th April–3rd May, 1966. An account of its history and behaviour. *Mem. E. Afr. met. Dep., Nairobi*, **4**, No. 4, 1967, pp. 1–15.
- NEWTON, W. G., see CORFIELD, G. A. and NEWTON, W. G.
- NICHOLLS, J. M., see HARROLD, T. W., BROWNING, K. A. and NICHOLLS, J. M.
- NICHOLLS, J. M., see HARROLD, T. W. and NICHOLLS, J. M.
- PARKER, A. E., B.Sc.; Some notes on baroclinic instability. *Met. Mag., London*, **97**, 1968, pp. 340–349.
- PARKER, A. E., see RATCLIFFE, R. A. S. and PARKER, A. E.

- PARKINSON, I. N., B.A., see CROSSLEY, A. F. and PARKINSON, I. N.
- PASQUILL, F., D.Sc.; Empirical equation for plume rise. *Atmos. Envir., London*, **2**, 1968, p. 228 (discussion contribution).
- PASQUILL, F., D.Sc.; The vertical component of atmospheric turbulence. *Atmos. Envir., London*, **1**, 1967, pp. 693-694.
- PERRY, J. D., B.Sc.; Sea temperatures at ocean weather station 'I'. *Met. Mag., London*, **97**, 1968, pp. 33-43.
- PILSBURY, R. K.; Photography and the weather. *Kodak prof. News, London*, No. 32, 1968, pp. 16-20.
- RACKLIFF, P. G.; The Pacific satellite meteorology seminar, 1967. *Met. Mag., London*, **97**, 1968, pp. 72-75.
- RATCLIFFE, R. A. S., M.A.; Forecasting monthly rainfall for England and Wales. *Met. Mag., London*, **97**, 1968, pp. 258-270.
- RATCLIFFE, R. A. S., M.A. and PARKER, A. E., B.Sc.; Forecasting wet spells in south-east England. *Met. Mag., London*, **97**, 1968, pp. 1-12.
- REUBEN, B.; An unusual and expensive sunshine recorder. *Weather, London*, **23**, 1968, pp. 125-126.
- RIDER, N. E., D.Sc.; Meteorological instrumentation I: basic considerations and some recent developments in surface instrumentation. *Jnl scient. Instrum., London*, Ser. 2, **1**, 1968, pp. 265-271.
- RIDER, N. E., D.Sc., see BIRD, L. G. and RIDER, N. E.
- ROACH, W. T., Ph.D., D.I.C.; The Barnacle tornado. *Weather, London*, **23**, 1968, pp. 418-423.
- ROBINSON, G. D., Ph.D., F.Inst.P.; Fifty years of changes in some meteorological instruments. *Jnl scient. Instrum., London*, Ser. 2, **1**, 1968, pp. 973-976.
- ROBINSON, G. D., Ph.D., F.Inst.P.; Transmission of solar radiation in the spectral region 0.55 to 0.64 μm and the Ångström turbidity coefficient. *Meddn Sver. met. hydrol. Inst., Stockholm*, Ser. B., **28**, 1968, pp. 58-60.
- ROBSON, M. E.; Radiosonde ascents aboard a merchant ship. *Bull. Wld met. Org., Geneva*, **17**, 1968, pp. 132-134.
- SALTER, P. R. S., B.Sc.; An exceptionally heavy rainfall in July 1968. *Met. Mag., London*, **97**, 1968, pp. 372-380.
- SAWYER, J. S., M.A., F.R.S.; Weather forecasting. HUGHES, L. E. C. and HOLLAND, F. W. (editors); Electronic engineer's reference book, 3rd edn. London, Heywood Books, 1967, pp. 1303-1306.
- SCRAGG, A.; A hundred years of meteorology at Shoeburyness. *Met. Mag., London*, **97**, 1968, pp. 115-120.
- SHACKLETON, W.; How to make your own humidity slide rule. *Weather, London*, **23**, 1968, pp. 318-324.
- SHELLARD, H. C., B.Sc.; Results of some recent special measurements in the United Kingdom relevant to wind loading problems. *Int. res. Sem., Ottawa, Sept. 1967*. Wind effects on buildings and structures. Toronto, University of Toronto Press, 1968, Vol. 1, pp. 515-533.
- SHELLARD, H. C., B.Sc.; The winter of 1962-63 in the United Kingdom—a climatological survey. *Met. Mag., London*, **97**, 1968, pp. 129-141.
- SINGLETON, F., B.Sc., D.I.C.; The International Symposium on Floods and their Computation, 15-22 August 1967, Leningrad. *Met. Mag., London*, **97**, 1968, pp. 60-62.

- SMITH, C. V., M.A., B.Sc.; World Meteorological Organization Commission for Agricultural Meteorology, Fourth Session, Manila, 1967. *Met. Mag., London*, **97**, 1968, pp. 187–190.
- SMITH, D. P.; Runway visual range at United Kingdom airports. *Met. Mag., London*, **97**, 1968, pp. 51–55.
- SMITH, F. B., Ph.D.; Conditioned particle motion in a homogeneous turbulent field. *Atmos. Envir., London*, **2**, 1968, pp. 491–508.
- SMITH, F. B., Ph.D.; The Eulerian-Lagrangian time-scale relationship in one-dimensional turbulence. *Proc. U.S. Atom. Energy Comm. met. Inf. Meeting, Chalk River, Sept. 1967*, Chalk River, Atomic Energy of Canada Limited, 1967, pp. 476–484.
- SMITH, F. B., Ph.D.; Modification of the wind profile due to changes in surface roughness. *Proc. U.S. Atom. Energy Comm., met. Inf. Meeting, Chalk River, Sept. 1967*, Chalk River, Atomic Energy of Canada Limited, 1967, pp. 463–475.
- SMITH, L. P., B.A.; Effective transpiration: a meteorological parameter for grassland. ECKARDT, F. E. (editor); Functioning of terrestrial ecosystems at the primary level. *Nat. Resour. Res. V. Paris*, UNESCO, 1968, pp. 429–433.
- SMITH, L. P., B.A.; Forecasting annual milk yields. *Agric. Met., Amsterdam*, **5**, 1968, pp. 209–214.
- STEVENSON, Catherine M., B.A.; An improved Millipore filter technique for measuring the concentrations of freezing nuclei in the atmosphere. *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 35–43.
- STEVENSON, Catherine M., B.A.; An analysis of the chemical composition of rain-water and air over the British Isles and Eire for the years 1958–1964. *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 56–70.
- STEVENSON, Catherine M., B.A.; The snowfalls of early December, 1967. *Weather, London*, **23**, 1968, pp. 156–161.
- STEWART, K. H., Ph.D. and WILDMAN, P. J. L., Ph.D.; Preliminary results from the Meteorological Office on Ariel 3. *Nature, London*, **219**, 1968, pp. 714–715.
- STUART, W. F.; Micropulsation activity at Lerwick. *Jnl atmos. terr. Phys. London*, **30**, 1968, pp. 337–344.
- THOMPSON, N., B.Sc.; Interaction between the oceans and the atmosphere. *Met. Mag., London*, **97**, 1968, pp. 90–92.
- THOMPSON, N., B.Sc.; The diurnal range of temperature in Scottish glens. *Met. Mag., London*, **97**, 1968, pp. 124–125.
- TIMPSON, Margaret S., see BENWELL, G. R. R. and TIMPSON, Margaret S.
- TINNEY, E. B., B.Sc. and MENMUIR, P., B.Sc.; Results of an investigation into forecasting night-minimum screen temperatures. *Met. Mag., London*, **97**, 1968, pp. 165–172.
- TUNNELL, G. A., B.Sc.; Synoptic ice maps of the Meteorological Office. *Jnl Inst. Navig., London*, **21**, 1968, pp. 439–447.
- TYLDESLEY, J. B., B.A.; Weather in Constable's paintings. *Weather, London*, **23**, 1968, pp. 344–348.
- VIRGO, S. E., O.B.E., see GORDON, J. and VIRGO, S. E.
- WATT, G. A.; A comparison of effective temperatures at Bahrain and Sharjah. *Met. Mag., London*, **97**, 1968, pp. 310–314.
- WHYMAN, A. J., see BROWNING, K. A., HARROLD, T. W., WHYMAN, A. J. and BEIMERS, J. G. D.

- WILDMAN, P. J. L., Ph.D., CARRUTHERS, G. P. and ELSE, C. V.; The Meteorological Office experiment in Ariel III. *Radio electron. Engr. London*, **35**, 1968, pp. 97–101.
- WILDMAN, P. J. L., see STEWART, K. H. and WILDMAN, P. J. L.
- WOODLEY, K. E. with ROSS, J. G.; Parasitic disease forecasts: experiences in Northern Ireland. *Rec. agric. Res., Belfast*, **17**, Pt 1, 1968, pp. 23–29.
- WOODS, J. D., Ph.D., D.I.C.; CAT under water. *Weather, London*, **23**, 1968, pp. 224–235.
- WOODS, J. D., Ph.D., D.I.C.; An investigation of some physical processes associated with the vertical flow of heat through the upper ocean. *Met. Mag., London*, **97**, 1968, pp. 65–72.
- WOODS, J. D., Ph.D., D.I.C.; On the formation of certain billow clouds. *Q. Jnl R. met. Soc., London*, **94**, 1968, pp. 209–210.
- WOODS, J. D., Ph.D., D.I.C.; Wave-induced shear instability in the summer thermocline. *Jnl Fluid Mech., London*, **32**, 1968, pp. 791–800.
- WOODS, J. D., Ph.D., D.I.C. with FOSBERRY, G. G.; The structure of the thermocline. Underwater Association Report, 1966–67, London 1967, pp. 5–18.
- WRIGHT, P. B., B.Sc.; A widespread biennial oscillation in the troposphere. *Weather, London*, **23**, 1968, pp. 50–54.
- WRIGHT, P. B., B.Sc.; Wine harvests in Luxembourg and the biennial oscillation in European summers. *Weather, London*, **23**, 1968, pp. 300–304.
- WRIGHT, P. B., B.Sc. and EBDON, R. A.; Upper air observations at the Seychelles, 1963–64. *Geophys. Mem., London*, **15**, No. 111, 1968.

APPENDIX II

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

ANDREWS, J. B., Ph.D.

Rainfall intensity statistics. *Road Research Laboratory, Crowthorne*. 6 March.

BARTLETT, J. T., Ph.D.

Understanding the weather. *A course of 8 lectures for schoolmasters, Twickenham College of Technology*. February and March.

Rain in February. *BBC sound broadcast 'Woman's Hour'*. 2 February.

Electrification of thunderstorms. *University of Warwick*. 2 May.

Cloud physics. *Physics Departments, Washington and Lee University and Virginia Military Institute, joint meeting at Lexington, Virginia*. 19 August.

Some recent developments in cloud physics. *University of Virginia, Charlottesville, Virginia*. 21 August.

On the deformation of single crystals of ice. *Solid State Physics Group, University of Virginia, Charlottesville, Virginia*. 22 August.

Cloud physics. *A course of 5 lectures, Royal Military College of Science, Shrivenham*. 21–22 September.

Cloud physics. *A course of 20 lectures, Department of Meteorology, University of Reading*. Throughout academic year.

BENWELL, G. R. R., M.A.

Further work on the 10-level model and A pressure oscillation in a 10-level model. *Royal Meteorological Society, London*. 19 June.

BRAZELL, J. H., M.Sc.

Climatological information for the building industry. *WMO Symposium on Urban Climates and Building Climatology, Brussels*. 14–25 October.

BROWNING, K. A., Ph.D., D.I.C.

The impact of radar in meteorology.

Ground Radar Seminar, Royal Radar Establishment, Malvern. 1 April.

Physics Seminar, Royal Radar Establishment, Malvern. 4 April.

Royal Meteorological Society, Welsh Centre, Cardiff. 23 October.

Cloud dynamics. *International Cloud Physics Conference, Toronto*. 29 August.

Radar observes the weather. *Royal Meteorological Society Sixth Form Lecture, London*. 29–30 October.

BUCHANAN, R. A., M.A.

Meteorological services for industry. *Ministry of Technology Regions—Wales*. 19 March; *South-west England*. 19 March; *Scotland*. 9 April; *North of England, and Yorkshire and Humberside*. 10 April; *East Midlands*. 2 July.

Meteorology and the food industry. *Food Industry Study Group of the Operational Research Society, London School of Economics*. 6 March.

BUSHBY, F. H., B.Sc.

Forecasting research in the Meteorological Office, Bracknell. *Deutsche Meteorologische Gesellschaft, Offenbach*. 14 March.

Use of computers in weather forecasting. *British Computer Society, Manchester*. 30 October.

Further developments of a model for forecasting rain and weather. *WMO/IUGG Symposium on Numerical Weather Prediction, Tokyo*. 28 November.

CORBY, G. A., B.Sc.

Numerical simulation of the atmospheric general circulation. *Colloquium of the Theory Division, Culham Laboratory, U.K. Atomic Energy Authority, Abingdon*. 26 June.

CRABTREE, J., B.A.

Local forecasting techniques. *Royal Meteorological Society, Scottish Centre, Edinburgh.* 29 November.

DRAKE, J. C., Ph.D.

Cloud physics. *Sir John Cass College, University of London.* 12 February.

FRITH, R., O.B.E., Ph.D.

The earth's high atmosphere. *Bradford University.* 9 January.

Discussion on peaceful uses of outer space. *BBC Overseas Service sound broadcast.* 4 September.

GILCHRIST, A., M.A.

Application of finite difference methods in meteorology. *Symposium on Mathematical Models in Oceanography and Meteorology. Liverpool University.* 28 March.

GLOYNE, R. W., Ph.D.

Environment and hill potential. *European Grassland Federation, Aberdeen.* 1-4 July.

GOODISON, C. E., C.Eng., M.I.E.R.E.

Satellites in the service of meteorology. *Space Communications Symposium, Northern Polytechnic, London.* 5-6 June.

GORDON, J., B.Sc.

Meteorological services for industry and the general public. *Institution of Highway Engineers, East Midlands Branch, Cambridge.* 8 October.

GRANT, D. R., B.Sc.

The measurement of evaporation from a field of barley. *Plant Breeding Institute, Trumpington, Cambridge.* 17 December.

HIDE, R., Ph.D.

Source-sink flows in a rotating fluid.

University College, London. 15 January.

Physics Department, Newcastle University. 26 January.

Mathematics Department, Manchester University. 13 March.

Mathematics Department, Liverpool University. 14 March.

Mathematics Department, Bristol University. 3 May.

Department of Applied Mathematics and Theoretical Physics, Cambridge University. 17 May.

Theory of the geomagnetic secular variation. *Meteorology Department, Imperial College, London.* 25 January.

Geomagnetism. *Mathematics Department, University College, London.* 7 February.

Planetary magnetic fields.

Clarendon Laboratory, Oxford University. 9 February.

Astronomy Society, Keele University. 9 May.

Astronomy Centre, University of Sussex. 4 October.

Mathematics Department, Queen Mary College, London. 9 October.

Jupiter. *Department of Astronomy, Leicester University.* 21 February.

Magnetohydrodynamic planetary waves.

Mathematics Department, King's College, London. 1 March.

Culham Laboratory, U.K. Atomic Energy Authority, Abingdon. 6 March.

Department of Applied Mathematics and Theoretical Physics, Cambridge University. 16 May.

Thermal convection in a rotating fluid. *Mathematics Department, University College, London.* 20 March.

Topics in geophysical fluid dynamics. Inaugural Lecture, *University College, London.* 20 May.

Lectures on rotating fluids. *Mathematics Department, University of East Anglia.* 31 May, 3 June and 4 June.

HOPKINS, J. S., B.Sc.

Probable maximum precipitation and a statistical approach to the estimation of extreme rainfalls. *Water Resources Board, Reading.* 30 October.

JOHNSON, D. A., Ph.D.

The production of ice splinters in clouds. *Royal Meteorological Society Summer Meeting, Oxford*. 10 July.

An experimental investigation of charging due to the fracture of freezing water drops. *Symposium on Physics of Ice, Munich*. 13 September.

KEERS, J. F., B.Sc.

An empirical investigation of interaction between storm surge and astronomical tide on the east coast of Great Britain. *Joint Scientific Meeting, Hamburg*. 1–5 April.

KNIGHTING, E., B.Sc.

Course of lectures on dynamical meteorology. *Department of Meteorology, Reading University*. January to March.

Numerical weather prediction. *Scientific Society, ICI Ltd, Northwich, Cheshire*. 20 March.

The role of dynamical meteorology in weather forecasting. *Royal Meteorological Society, Scottish Centre, Edinburgh*. 25 October.

LAMB, H. H., M.A.

The history and development of our climate. *Geographical Society, University College of Swansea*. 5 March.

Britain's climate, its variability and some of its extremes. *Institute of Mechanical Engineers, Manchester*. 21 March.

The climatic background to the birth of civilization. *British Association, Dundee*. 26 August.

Investigation of climatic sequence—a meteorological empirical approach. *Scientific Committee on Antarctic Research (SCAR) Quaternary Studies in the Antarctic, Cambridge*. 25 July.

Investigating the history and behaviour of our climate. *Geographical Association, Tyneside*. 17 October.

LAWRENCE, E. N., B.Sc.

The earth's climate and sunspot cycles. *London Chapter of the American Meteorological Society, High Wycombe*. 24 January.

LIMBERT, D. W. S.

The thermal balance of sea ice at Halley Bay and Visibility, temperature and humidity régimes in blowing snow. *SCAR symposium on Antarctic glaciological exploration, Hanover, U.S.A.* 2–7 September.

MCCAFFERY, W. D. S., B.Sc.

Meteorological services for the construction industry.

Ministry of Public Building and Works lecture series:

Southend Technical College. 15 January.

St Albans Technical College. 21 February.

MASON, B. J., D.Sc., F.R.S.

Programme Adviser for 'Working with weather'. *ATV Network Production*. (An Adult Educational Series of thirteen programmes with scripts prepared and presented by Meteorological Office staff, see also page 95.)

Recent developments in meteorology and weather forecasting by computer. *Physics Society, Cambridge University*. 25 January.

A new era of weather forecasting and the World Weather Watch. *Nottingham University*. 22 February.

Weather forecasting by computer. *Physical Society, Durham University*. 12 March.

The physics of thunderstorms. *Physics Department, Manchester University (Schuster Colloquia)*. 13 March.

CERN, Geneva. 6 June.

Working with weather. *ATV, London*. 26 March, 9 July.

Recent developments in meteorology and the World Weather Watch. *Institution of Electrical Engineers, London (The 59th Kelvin Lecture)*. 25 April.

World Weather Watch. *BBC Overseas Service sound broadcast*. 29 April.

Weather forecasting in the satellite and computer age.

Royal Society of Edinburgh. 6 May.

U.K. Atomic Energy Authority, Abingdon. 3 July.

Worthing Science Society, Worthing. 1 October.

Royal Institute of Chemistry, Manchester (15th Dalton Lecture). 17 October.

Physical Society, University of Warwick. 31 October.

The physics of clouds, rain and snow. *Institute of Physics and the Physical Society 50th Anniversary, London*. 8 May.

The thunderstorm. *British Association, Junior Meeting, Norwich*. 16 July.

Floods in south-east England—interview. *BBC News, sound broadcast: BBC TV*. 16 September.

The role of satellites in observing and forecasting the global behaviour of the atmosphere. *Mathematical and Physical Society, Imperial College, London*. 8 October.

Weather forecasting—interview. *BBC TV, North Region News*. 17 October.

Forecasting by computer. *BBC sound broadcast 'New Worlds Programme'*. 18 October.

Weather forecasting in the computer age and the World Weather Watch. *Oxford University*. 29 November.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.

Models of mesosphere thermal structure and General circulation in the mesosphere.

Third Aeronomy Conference, Urbana, Illinois. 22–26 September.

Dispersion in the free atmosphere by large-scale wind systems. *Royal Society Discussion Meeting on the science of air pollution, London*. 14 November.

NICHOLLS, J. M., B.Sc.

Stratospheric leewaves. *U.K. Flight Safety Group, Shell Mex House, London*. 2 April.

U.K. sonic-boom research. *Lectures to various groups in the U.S.A.* 24 April–13 May.

OGDEN, R. J., B.Sc.

Weather for flying—today's and tomorrow's forecasting procedures. *Royal Aeronautical Society, Christchurch*. 2 October.

PARREY, G. E., B.Sc.

Meteorological services for the construction industry.

Institute of Building, Leicester Centre. 15 October.

Institution of Civil Engineers (East Midlands Association), Loughborough University. 7 November.

PASQUILL, F., D.Sc.

Opening address on meteorological aspects of air pollution. *Royal Society Discussion Meeting on the science of air pollution, London*. 14 November.

POTHECARY, I. J. W., B.Sc.

The use of satellites in meteorological analysis. *Royal Aeronautical Society, Southend*. 11 January.

RATCLIFFE, R. A. S., M.A.

The summer of 1968. *BBC sound broadcast*. 9 September.

READINGS, C. J., Ph.D., D.I.C.

Investigations into turbulence and the vertical transfer of energy in the planetary boundary layer. *Meteorological Physics Section of the Cavendish Laboratory and Meteorological Section of the Department of Applied Mathematics, Cambridge University*. 2 December.

ROACH, W. T., Ph.D., D.I.C.

Turbulence in thunderstorms and in mountain-wave conditions. *U.K. Flight Safety Group, Shell Mex House, London*. 2 April.

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

Some aspects of the co-ordination of forecasting in middle and low latitudes in relation to World Weather Watch. *CAeM Scientific and Technical Conference on Aeronautical Meteorology, London*. 21 March.

The global atmospheric research programme. *Department of Meteorological Physics, Cambridge University*. 6 May.

World Weather Watch, GARP and extended-range forecasting.

London Chapter of the American Meteorological Society, Ruislip. 12 November.

Department of Atmospheric Physics, Oxford University. 28 November.

SIMMONS, E. L., Ph.D.

An improved solid state amplifier for the Dobson ozone spectrophotometer and Some laboratory and field investigations of the accuracy of Brewer-Mast ozone sensors. *IUGG/WMO Ozone Symposium, Monaco*. 2–7 September.

SMITH, F. B., Ph.D.

A review of some recent theories of the boundary layer of the atmosphere. *Department of Aeronautics, Imperial College, London*. 23 October.

STEWART, K. H., Ph.D.

Measurement of vertical distribution of molecular oxygen in the 100–200 km region. *Symposium on results of experiments on Ariel III, Greenbelt, Maryland, U.S.A.* 22–24 May.

SUMNER, E. J., B.A.

The collection of climatological data through the telecommunication network. *WMO Symposium on Data Processing for Climatological Purposes, Asheville, North Carolina, U.S.A.* 14 May.

WILDMAN, P. J. L., Ph.D.

Absolute calibrations of ultra-violet detectors in the wavelength range 1300Å to 3800Å carried out at the Meteorological Office. *European Space Research Organization Symposium, Munich*. 25–27 July.

WOODS, J. D., Ph.D., D.I.C.

Thermocline microstructure. *National Institute of Oceanography, Wormley, Surrey*. 23 January.

Thermocline research. *Scientific Society, City University, London*. 19 February.

Diurnal variation in thermocline structure. *Third Annual Symposium of the Underwater Association, London*. 23 February.

Microstructure of summer thermocline. *Miami Institute of Atmospheric Sciences and Marine Institute, U.S.A.* 3 June.

Direct observations of turbulence in the summer thermocline. *University of British Columbia, Canada*. 12 June.

Turbulence in the thermocline. *Woods Hole Oceanographic Institute, Massachusetts, U.S.A.* 17 June.

Transition from laminar to turbulence flow in the thermocline. *NATO Seminar, Imperial College, London*. 4 July.

Underwater mixing observed by skin-divers. *Royal Meteorological Society Popular Lecture, County Hall, London*. 25 and 26 November.

Micro-oceanography: the diver's contribution to physical oceanography. *Endeavour Society, University College of North Wales, Bangor*. 4 December.

WRIGHT, P. B., B.Sc.

Long-range weather forecasting. *Mathematical and Physical Society, Chelsea College, London*. 14 March.

The following Meteorological Office staff contributed to the ITV series 'Working with Weather'.

J. ARMSTRONG, N. BRADBURY, R. A. BUCHANAN, F. H. BUSHBY, R. H. CLEMENTS, V. R. COLES, G. J. EVANS, C. E. N. FRANKCOM, M. H. FREEMAN, D. M. HOUGHTON, H. H. LAMB, R. A. S. RATCLIFFE, J. S. SAWYER, L. P. SMITH, S. E. VIRGO and A. A. WORTHINGTON.

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 publications were issued during the period of this Report:

PERIODICAL

Annual Report on the Meteorological Office 1967.

Daily Aerological Record, containing information respecting meteorological conditions in the upper air over the British Isles (to 17 December 1968).

Daily Weather Report, containing weather maps for the northern hemisphere, British Isles, etc., and data (to 31 December 1968).

Daily Weather Report, Overseas Supplement, containing surface and upper air data (to 31 May 1968).

Monthly Summary of the Daily Weather Report (to November 1968).

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 1968).

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 1968).

Meteorological Magazine (to December 1968).

Monthly Weather Report (to May 1968).

Marine Observer (quarterly) (to October 1968).

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 September 1968).

The Observatories' Year Book, comprising the geophysical results obtained from autographic records and eye observations at Lerwick, Eskdalemuir and Kew Observatories. 1964 and 1965.

British Rainfall 1961.

SERIAL

Geophysical Memoirs: Volume XV.

111. Upper air observations at the Seychelles 1963–64, by P. B. Wright, B.Sc. and R. A. Ebdon.

Scientific Papers:

28. Numerical solution of atmospheric diffusion equations, by C. E. Wallington, M.Sc.
29. An investigation of air motion in frontal precipitation, by T. W. Harrold, B.Sc., D.I.C. and J. M. NICHOLLS, B.Sc.

OCCASIONAL

The measurement of upper winds by means of pilot balloons. 4th Edition.

London weather, by J. H. Brazell, M.Sc.

Tables of surface wind speed and direction over the United Kingdom.

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

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