M.O. 626 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 86, No. 1,021, JULY 1957

ERNEST GEORGE BILHAM, B.Sc., D.I.C.

The news of the sudden death of Mr. Bilham from coronary thrombosis on Sunday, May 5, 1957, came as a great shock and sorrow to his many friends, past and present members of the Office. It is less than four years since he retired, to enjoy, as we hoped for many years, "the small house and large garden" of Cowley's desire, where, with Marvell, he could reckon the "sweet wholesome hours with herbs and flowers". His death seems to us a premature ending of a happy time.

E. G. Bilham entered the Meteorological Office in April 1915; he served for a year as resident observer at Kew Observatory; a year with Mr. W. H. Dines at Benson; seven years as a forecaster at headquarters; six years as Superintendent of Instruments and eight years as Superintendent of Climatology both at South Kensington; fourteen years as Head of the Forecast Division. An account of the main features of his career in the Office was published in the *Meteorological Magazine* for July 1953 but there are, naturally, aspects not mentioned there. One of the earliest indications of his ability for clear exposition was his examination of the isallobars of moving depressions which disposed of the idea that isallobaric charts would solve the forecaster's problem; but at the same time indicated the conditions under which such charts could be of real assistance to the forecaster. The paper was published in the Swedish *Geografiska Annaler* 1921.

In the 1920's the French Meteorological Service pressed for the use of the "face of the sky", the *systèmes nuageux*, and the sequence of its changes as fundamental elements in the basic information of synoptic reports. They were also using series of charts of barometric change over different time intervals. Bilham was sent to Paris to gain experience in the practical application of these methods in the French Meteorological Office. This stood him in good stead many years later when it fell to him to take a leading part in preparing the "scales and specifications" for synoptic reports at the first post-war meetings of the International Meteorological Organization at Paris in 1946 and Toronto in 1947.

A small thing but worthy of mention was Bilham's introduction of the Meteorological Office tie; it certainly appealed to those who had at heart, as Bilham had, the solidarity of the Office.

Bilham was happy and fortunate in his love of music and the playing of music by Bach was an ending of hope and consolation to the simple funeral service at Headington on Thursday, May 9. How naturally right it was too, that the rain, forecast by Dunstable, was refreshing the lawns and flowers and trees of that garden of rest, and, as we were returning, cascaded from the windows of heaven in confirmation of the announced instability of the earthly atmosphere.

"Mr. Bilham was a good man." These six words, spoken simply and spontaneously by the messenger who stepped forward courteously to open the door for me as I left Dunstable to go to the funeral, live in my mind. Spoken by servant of master they rank with the prayer of the Elder Servant, number one in C. L. Hind's *100 Best Prayers*.

E. G. Bilham was born on December 1, 1891. He married in 1918, Miss R. Corrin, who survives him as do also their son and daughter, to whom goes the natural sympathy of those of the Office who knew him.

E. GOLD

ATMOSPHERIC CHEMISTRY

By B. C. V. ODDIE, B.Sc.

The atmosphere contains a wide variety of simple inorganic acids and salts in the gaseous form, as minute solid particles and as very small droplets of solution. These substances are washed into the soil by rain and, since some of them are of kinds which are essential to plant-growth, they have considerable importance in agriculture. It is for this reason that atmospheric chemistry, as it is coming to be called, is a new branch of meteorology but by no means a new branch of science: for it has been systematically studied by agricultural research workers for more than a century.

The subject entered the meteorological world as a result of collaboration between Dr. H. Egnér of the Royal Agricultural College of Sweden and Prof. C.-G. Rossby of the Institute of Meteorology (University of Stockholm). Under their energetic leadership a network of stations was inaugurated in 1954 to serve the needs of both agriculturalists and meteorologists. This network, originally Scandinavian, has since extended to Holland, Belgium, West Germany, northern France and Great Britain. The principal sampling technique consists simply of collecting the rainfall in a glass funnel for a period of one month, at the end of which a measured proportion is sent for analysis. At most stations, a sample is also taken by drawing air continuously through a very dilute solution of nitric acid and hydrogen peroxide, in which most of the common ions are absorbed: and this solution is likewise sent for analysis at the end of each month. Both rain-water and solution are analysed for sulphur (SO_3 and SO_4), chlorine, ammonia, sodium, potassium, magnesium and calcium, and in addition the rain-water is analysed for nitrate, carbonate, acidity (pH) and electrical conductivity.

It will be seen that the greater importance attaches to the rain-water analyses—the traditional technique of the agriculturalist and indeed the natural one, since he is directly interested in the rain-water as a sort of dilute chemical fertiliser. To the meteorologist, whose object is a general study of chemical processes in the atmosphere, the technique is less satisfactory, as we shall see presently. Nevertheless, it has so far proved the more rewarding, even from the meteorological standpoint, and has thrown a great deal of light on a remarkable phenomenon. Nearly all of the sodium and chlorine in the air is derived from sea-salt, which finds its way into the atmosphere as spray. One naturally expects this salt to be brought down by rain and, therefore, that the ratio of the mass of chlorine to that of sodium in rain-water will be the same as in the sea—i.e. 1·8. In fact, the ratio is nearly always less than this—at least, it is so in Scandinavia, the only region for which there is yet a substantial body of information. It is only about 1·3 even near the windward coasts, and farther to the east it often falls to about 0·6.

An obvious explanation comes at once to mind—as the salt is washed out by rain, some new sodium compound is added to the air, being derived from inland sources. Thus the Cl : Na ratio present in the air would decrease with increasing distance from the sea, and would be shown in the rain-water analyses. But there is no obvious source of the new sodium compound in the necessary quantities. The only other explanation possible seems to be that the sea-salt is somehow gradually dissociated into two parts, one containing the sodium and the other the chlorine; and that the former is more readily brought down by rain than the latter. Cauer[1] suggested that the sea-salt is oxidized by ozone to form sodium hydroxide and free chlorine, and that the latter then combines with water vapour to give hydrochloric acid. This, Cauer supposed, is not brought down by rain because it is present either as a gas or as droplets of solution too small to serve as condensation-nuclei. None of this seems very plausible at first sight, and yet some such mechanism seems necessary to explain the apparent fact that, with winds from the sea, most of the sodium is deposited within a hundred miles or so of the coast, while the chlorine is not.

What then happens to the chlorine? It is certainly not accumulating in the atmosphere, and must therefore be returning to the earth, probably in rain. Rossby and Egnér[2] followed up this idea, and sought for occasions on which the rain brought down a high proportion of chlorine: and they found that, when the winds reaching Scandinavia were southerly and had therefore been over land for several hundred miles, the Cl : Na ratio in the rain-water was in fact very high, sometimes reaching 3·5. Further studies on the same lines enabled Rossby to distinguish four zones of chemical climate, which are successively farther from the windward coast. These zones are,

(i) A coastal zone where unaltered sea-salt predominates and the Cl : Na ratio in rain-water approaches 1·8.

(ii) A zone where the salt is largely dissociated and little chloride brought down by rain: the Cl : Na ratio is low.

(iii) A zone where little sodium remains and the principal condensation-nuclei are chlorides other than sodium chloride: the Cl : Na ratio is high.

(iv) A zone where most of the ions originating in the sea have already been lost. The chlorine and sodium present are derived from the ground, where sodium is the commoner. The Cl : Na ratio is therefore low, but the amounts of both are very small.

The explanation embodied in this classification is, of course, largely hypothetical, and much more information will be needed before it can be confirmed. One may doubt, however, whether this additional information can ever be obtained with the present type of equipment for, striking as its successes have been, a little consideration shows that it has very serious limitations. The samples come to the analyst as solutions so that all the physical properties of the dissolved matter have been lost before the study begins. One cannot hope to tell whether a given ion was present in the air as a gas, a solid, or a solution-droplet, nor which ions were combined together, nor anything about the masses of the particles. Very little can be judged about the distribution of materials in the vertical, for the air samples are taken at the surface, and it is impossible to judge how far they represent conditions at the cloud level; while the rain-water samples can tell one little about the composition of the atmosphere at any level, since it is the whole point of Rossby and Egnér's results that the two are not related in any predictable manner.

One can get a hint of how much is lost by the use of these methods from the work of Junge[3]. He endeavoured to estimate the ions present in the gaseous form by sampling air after it had been drawn through a millipore filter. At the same time he collected the aerosols by means of a "cascade impactor" which separated them into two classes according to size—the "giant nuclei" of diameters between 0·8 and 8 microns, and the "large nuclei" with diameters between 0·08 and 0·8 microns. Smaller nuclei, present as a rule in greater numbers but of relatively small total mass, were not collected. Junge found that in maritime air the Cl : Na ratio in the "giant" particles was always substantially the same as in sea-water, whereas in the "large" particles it was low—about 0·5. He believes that the two classes are of quite different origin, the "giant nuclei" coming from the sea whereas "almost all the large ions are of continental origin, even over the ocean". Evidently quite considerable differences of constitution, particularly differences in the Cl : Na ratio, could be accounted for by the mere mixing of nuclei of these two different types, without any necessity to assume the dissociation of salt. Junge also found that a surprisingly large proportion of some ions was present in the gaseous form—about half the chloride and nine-tenths or more of the ammonium, sulphate and sulphite.

It is not, in general, impossible to reconcile these results with the findings of Rossby and Egnér, but they do suggest that there may be far more complex interactions than have yet been imagined, and one can hardly disagree with Junge's view that "a real step forward in the understanding of the basic processes of air chemistry can be gained only if aerosols and gases are measured simultaneously but separately and if aerosols, in turn, are separated according to size". It is not easy to judge, however, whether even Junge's technique really achieves this kind of separation. Most of the particles in the air are, in fact, minute droplets. Junge endeavours to remove these from the air by a filter; but one would imagine that they would evaporate on the filter, and that all the volatile part would then pass through, and be treated in the analysis as a gaseous constituent of the air. Again, the "cascade impactor", which Junge uses to separate his particles, has generally been found unsatisfactory for droplets smaller than about two microns in diameter, as they are apt to evaporate on their way through the instrument.

Junge might fairly have added, to the passage quoted above, that a short sampling period is also essential to a satisfactory technique. One can only hope to establish clear-cut relationships between synoptic weather and chemical climate if each sample represents a distinct synoptic type. That Junge is able to sample for a few hours only, whereas in the Scandinavian network the sampling period is a month, is in theory a great advantage of his methods. In practice, the application of his methods to an extensive network would raise very serious administrative problems: the chemical analysis of such small quantities of material is difficult, and can only be carried out in a few specialized institutions. These have already had some difficulty in absorbing the analytical work of the present network. Any considerable increase in the analysis would necessitate the building of special laboratories for the purpose, at considerable expense.

We have, then, neither a completely satisfactory sampling technique, nor even a very clear idea of what sort of technique we want. Thus, for the believers in atmospheric chemistry the only course open at present is to make the best possible use of the existing methods and network. Attention is being concentrated on the International Geophysical Year, because during that period an exceptional amount of observational material, which may be related to the chemical constitution of the atmosphere, will be collected—data on winds, precipitation, ozone-concentration, numbers of condensation nuclei and intensity of solar radiation. It is hoped that the study of atmospheric chemistry against this background will either yield valuable new information or, at least, enable the usefulness of the present sampling technique to be assessed more reliably than is now possible.

The immediate aim is to fill the more serious gaps in the network before the start of the International Geophysical Year. The largest gap is in Great Britain where there are at present only five stations—Aberdeen, Edinburgh, Leeds, Harpenden, and Newton Abbot—whereas for a satisfactory network, by Scandinavian standards, there should be about twenty-five. Last summer, therefore, Prof. Sheppard and Dr. Goody (who had already been responsible for the setting up of the five existing stations) suggested to the Meteorological Research Committee that the Meteorological Office should co-operate in the programme, at least during the International Geophysical Year[4]. The proposal was accepted, though with some reservations: to set up the twenty additional stations which were desirable was hardly practicable, because there was not time to arrange for the manufacture of the equipment by a contractor, and the Meteorological Office's own constructional resources, already engaged in other preparations for the International Geophysical Year, could not undertake so large a task. It was decided, therefore, that the Office would endeavour to set up five or six stations, at Lerwick, Stornoway, Eskdalemuir, Irvinestown, Camborne and probably one other. All the places named are so placed that they will sample the air almost straight from the Atlantic, and before it has undergone much pollution from industrial sources. They will thus be complementary to the chain organized by Prof. Sheppard and Dr. Goody, which lies mostly in the east. The sampling equipment is being constructed by the Instruments Division of the Meteorological Office at Harrow, and it is hoped to install it not later than the beginning of June.

As already indicated, the present plan of the Meteorological Office is to maintain these stations during the International Geophysical Year. It is still uncertain whether all or any of them will be retained after that. However, the whole subject of atmospheric chemistry is to be debated by the World Meteorological Organization's Commission for Aerology at a meeting to be held in Paris in June 1957, and this body will probably make recommendations as to the future of the observing network. Although one cannot anticipate these recommendations, it is almost inconceivable that the Commission will propose the abandonment of the network, for its observations are not only most intriguing in themselves but also provide an essential background for a large number of other studies. There are, for example, various special chemical studies which have hitherto been pursued only occasionally and in isolation, such as the variation in chemical constitution of the air with height above the ground, the relationship between the ozone-concentration in the lower atmosphere and the synoptic situation, the variations of the chemical constitution of rain-water with the size of the raindrop and with its location in the pattern of precipitation. In addition, there is an important group of studies concerning the physical properties of aerosols—their size-distribution, electric charges and mobilities, and especially their activity as freezing- and condensation-nuclei. All these form with atmospheric chemistry a single natural group. They all have considerable importance both in meteorological theory and in their practical applications, and they can only be studied satisfactorily if they are treated as a whole, by a unified organization based on a well designed sampling network. It is to be hoped that the Commission for Aerology will be able to make proposals which will, at least, lead towards a sampling procedure which will be sufficiently comprehensive to meet all these varying demands, without being impossibly expensive.

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AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE NORTH POLAR REGIONS IN JULY

By H. HEASTIE, M.Sc.

Introduction.—In a previous article[1] the decision to start the revision of *Geophysical Memoirs No. 85—Upper winds over the world*, by constructing circumpolar charts of the standard isobaric surfaces was explained and some of the charts for January were shown. This article presents, with a brief description, some of the corresponding charts for July. The complete set of charts is given elsewhere[2].

Data.—Data for the same fixed period, 1949–53, were used: sources are listed elsewhere[3]. The labour of extraction was eased by the receipt of further micro-film data for Norwegian stations from Det Norske Meteorologiske Institut, Oslo and of manuscript data for Alaska and the Aleutians from the United States Weather Bureau.

Method of constructing the charts.—The method used was similar to that described briefly in reference 1, although there was one slight complication. For Siberia no data at all for July 1949 were available. For this month the monthly mean 500-mb. contour chart published in the monthly supplement to the *German daily weather report*[4] was accepted over Siberia and the 700–500-mb.

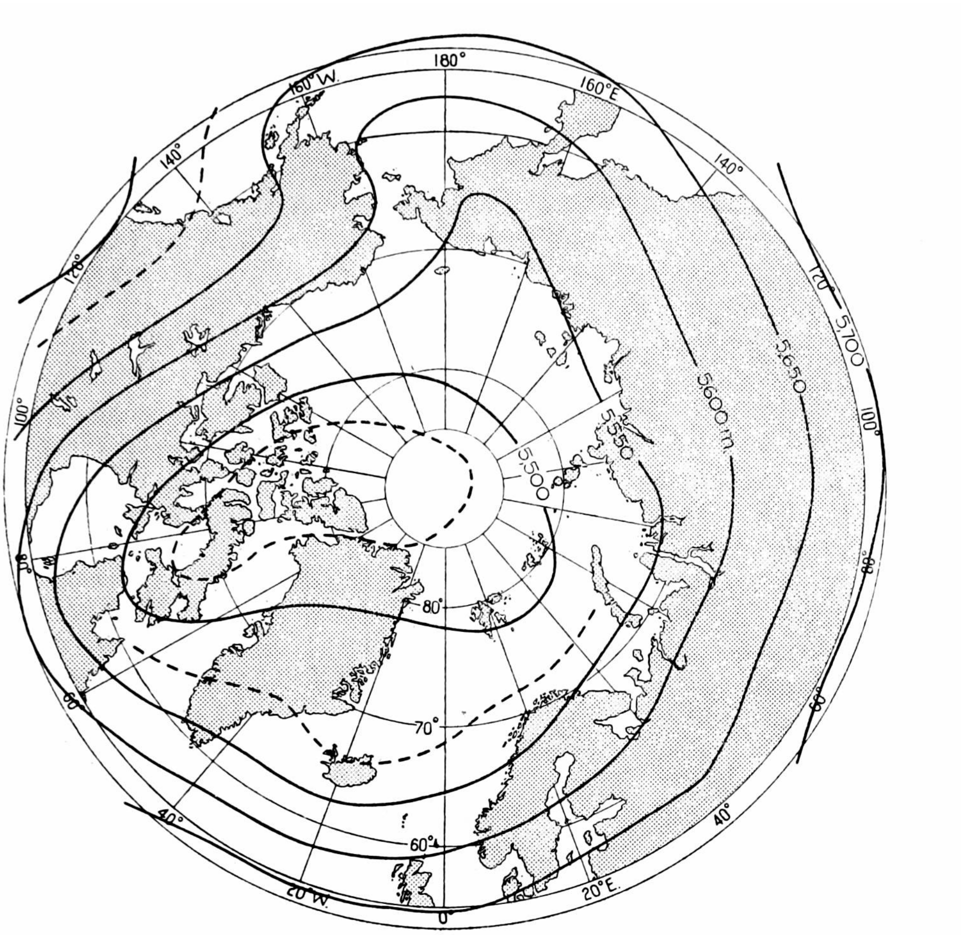

FIG. I—AVERAGE 500-MB. CONTOURS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

thickness chart constructed over this area by correlating the 700–500-mb. thickness with the 500-mb. contour height along the meridians 20°E., 40°E. . . . 180°E. for the four years 1950–53. As the grid values obtained fitted in reasonably well with the rest of the chart drawn from data and as the nine values obtained for the pole lay within a ten-metre range, the method was regarded as satisfactory. The 500–300-mb. thickness and the 300-mb. temperature charts were computed in a similar manner.

For a large part of the area covered by the charts no night time ascents were available and the effect of solar radiation on the various types of radiosondes used by the different countries had to be considered. In most cases, with the exception of the Union of Soviet Socialist Republics, the problem was solved more or less satisfactorily. Unfortunately the Russian ascents were made in daylight and very little is known about the characteristics of the Russian instrument.

The charts.—The July contour charts show some marked differences from those for January. In January there is mainly westerly flow in the troposphere with considerable asymmetry about the pole. The very cold arctic winter stratosphere leads to a thermal pattern which reinforces this flow so that the January charts present a picture of mainly westerly flow increasing with height

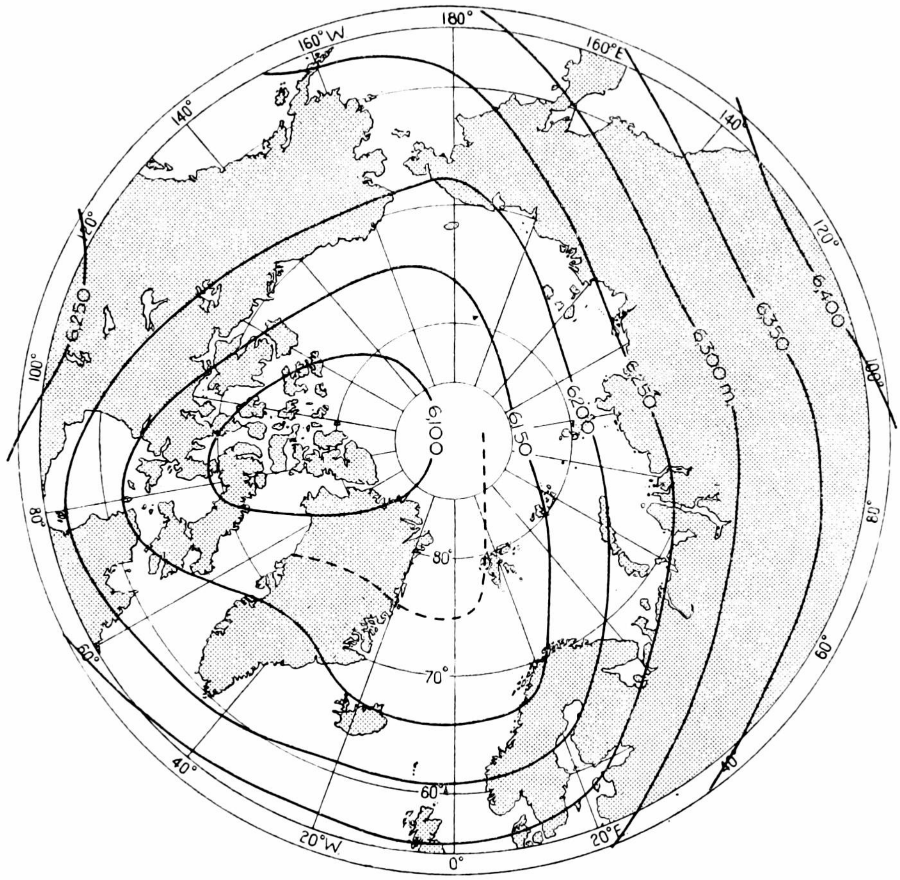

FIG. 2—AVERAGE 700–300 MB. THICKNESS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

and becoming almost symmetric about the pole at the 100-mb. level. In July there is again mainly westerly, though much weaker, flow in the troposphere (Fig. 1). The 700—300-mb. thickness chart (Fig. 2), representing the thermal pattern in the troposphere, shows a centre of low thickness over northern Canada and, as the main low centre on the 700-mb. chart lies near the pole, this causes the main axis of the tropospheric flow to tilt southwards with height along the 90°W. meridian. In the region considered the tropopause is everywhere below the 200-mb. surface and the very warm arctic summer stratosphere is reflected in the 200–100-mb. thickness chart (Fig. 3) which shows an easterly thermal centred on the pole. The resulting contour charts show a mainly westerly flow over Eurasia at all levels with a maximum at the 200-mb. level. Over the Canadian sector of the chart the centre of low contour height is transferred southward from about 87°N. at 700 mb. to about 68°N. at 100 mb. (Fig. 4) and lies between the 70°W. and 90°W. meridians. The flow round this low centre increases generally up to 300 mb. and, above 200 mb., decreases to less than 15 kt. everywhere at 100 mb. Hence, up to 100 mb., where the January charts show increasing symmetry with height, the July charts become more asymmetric with height. Temperature lapses 100–25 mb. shown on the Air Weather Service charts[5] suggest that from about 25 mb. upwards the circulation is again tending towards symmetry about the pole with a contour

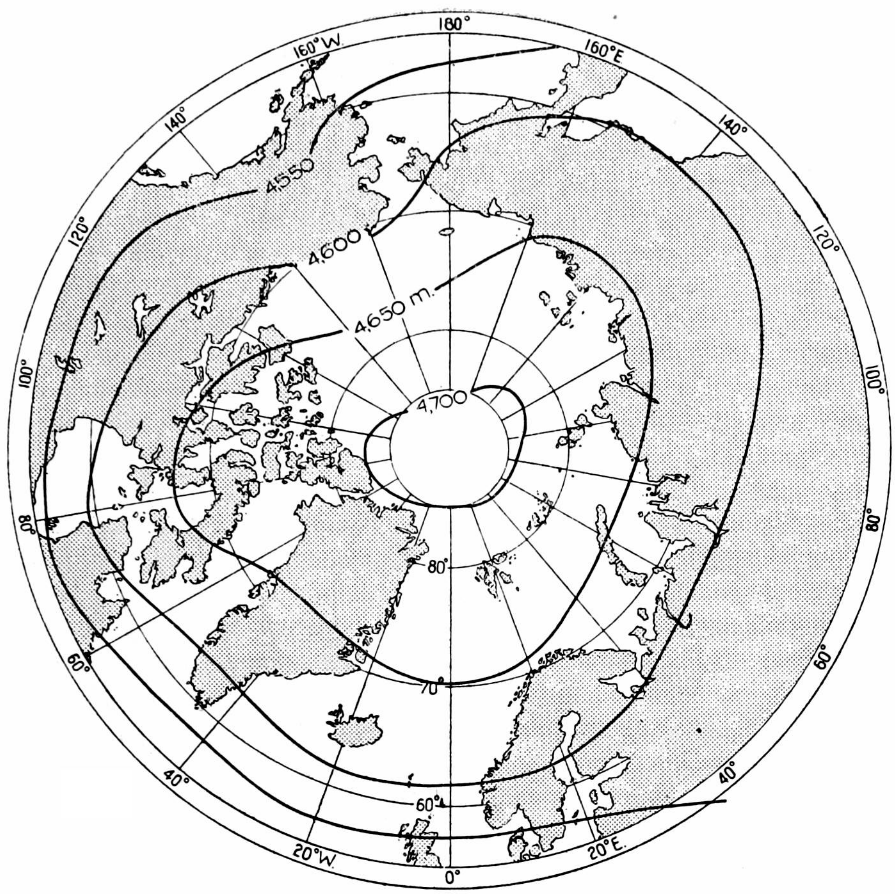

FIG. 3—AVERAGE 200–100 MB. THICKNESS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

high moving northwards over central Siberia towards the pole and the Canadian low centre moving southwards and being absorbed.

One interesting feature arising out of the symmetry of the thickness pattern and the asymmetry of the contour pattern in the stratosphere may be mentioned here. Over a large area of the chart north of the Arctic Circle the flow in the stratosphere (Fig. 4) is directly across the thickness pattern (Fig. 3). Neither the flow in the troposphere (Fig. 1) nor the tropopause pressure chart[6] suggests any appreciable vertical motion of the atmosphere in this area and the implied temperature changes are presumably due to radiative effect. For the layer 200–100 mb. the heating of the air moving poleward from 70°–75°N. appears to be of the order of 0·5°C. per day over 2–4 days. The stratosphere over this area is in continuous sunlight during the whole of July, but no attempt has been made to estimate whether variation in solar altitude or in ozone concentration could account for this heating.

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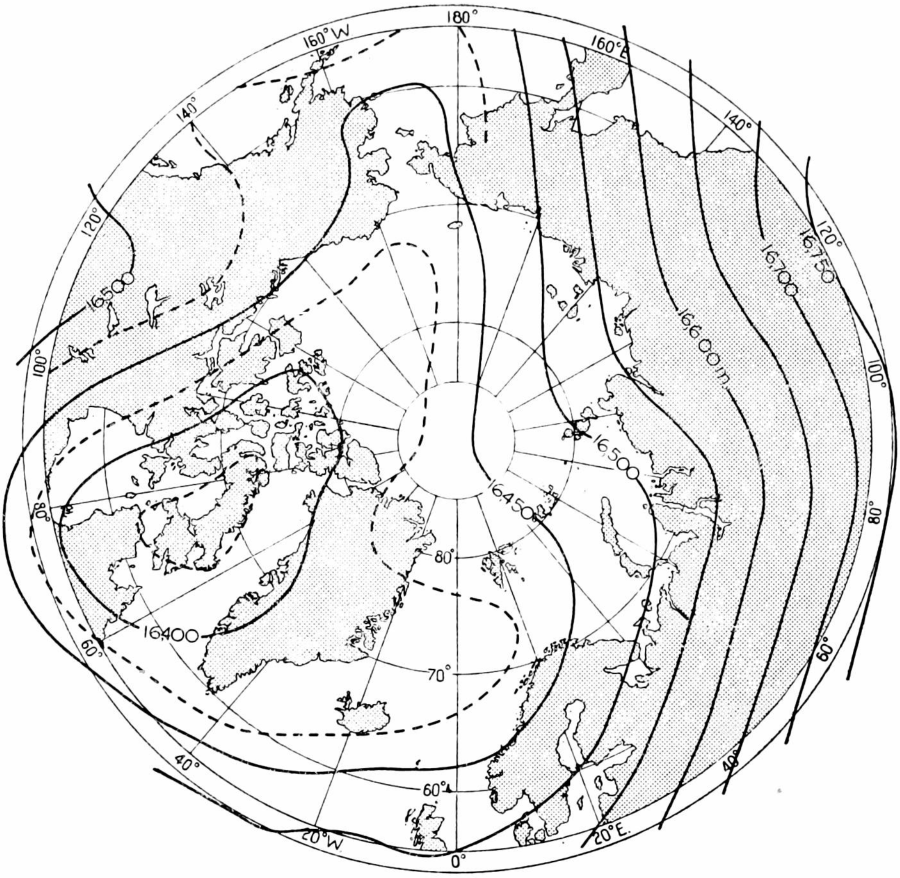

FIG. 4—AVERAGE 100-MB. CONTOURS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

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THE APPLICATION OF CLIMATOLOGICAL DATA

By R. G. VERYARD, B.Sc.

In the Meteorological Office centenary issue of the *Meteorological Magazine* in June 1955 a series of articles was published under the general heading of "The Meteorological Office Faces the Future". The articles dealt with scientific research and development, services for aviation and defence, and forecasting and public services, but no reference was made to the future of climatological services. The intention of this article is to repair that omission. It is also hoped that the article will enable observers called upon to render climatological returns to appreciate the need for introducing new forms and to feel that their labour in completing these forms is worth while.

When the Meteorological Office was founded, in 1855, its primary function was to obtain climatological information for the benefit of shipping. Thus the climatological work of the Office is as old as the Office itself. As in other countries, the original aim of this work was to build up a statistical picture of general weather conditions as a contribution to meteorological knowledge. It was soon realised that climatological data could have a wider practical value. For example, over 50 years ago Sir Napier Shaw presented a paper to the Royal Society on "An apparent periodicity in the yield of wheat for eastern England 1885–1905". An apparent relation was derived between the yield of wheat and the aggregate rainfall for the three autumnal months of the preceding year. Ever since then climatological data have been applied to the problems of the grower and today there is a separate branch of the Office which makes a special study of the application of meteorological information and knowledge to farming, horticulture and forestry. Other fields in which, for many many years, important use has been made of long series of observations are those of water supply and hydro-electric power supply. Indeed, the organization of rainfall observations in this country, originally in the hands of the British Rainfall Organization and now of the Meteorological Office, is one of the finest in the world—not that it is perfect by any means. Many other examples could be given of the application of climatological data and meteorological knowledge to various fields of human endeavour—to air and sea navigation, to building and architecture, to engineering, to insurance, medical research, and so on. For a detailed account reference should be made to the report in the *Meteorological Magazine* for January 1956 of an Office discussion on the subject. From a reading of this account it will be realised that the profitable expenditure of large sums of money on capital investment may well depend on a reliable assessment of climatic risks. A forecast may be of little use if the recipient is not prepared for the type of weather that is to occur.

What are the basic requirements for the provision of an efficient climatological consultant service? Obviously, the first requirement is for an adequate supply of reliable data, i.e. observations of temperature, rainfall, wind, etc. suitably distributed in space and time. In regard to reliability, it is essential that a high standard of accuracy be maintained. Actually, the acceptable standard of accuracy will depend on the user's requirements, but it could be said that the accuracy needed for synoptic purposes is not always sufficient for climatological purposes. A comparatively small margin in the assessment of areal rainfall, e.g. in connection with the construction of dams, or the maximum wet bulb "design" temperature, e.g. in connection with the construction of cooling towers or air conditioning plant, might involve very large sums of money. To ensure that basic data are accurate involves the selection of suitable sites, regular inspection of instrumental equipment, checking of observational procedures and practices, and the scrutiny of climatological returns. Scrutiny by eye is a tedious task and calls for the sustained effort of experienced staff. The value of reliable data cannot be over-emphasized but accuracy alone is not enough. It is imperative that long period *homogeneous* data are available. This means that there must be as little change of exposure as possible at the site of observation and also no effective change in observing procedure or practice. When one considers the effect of urbanization or the growth of trees, the frequent changes in the layout of buildings at, and the siting of, airfields (whence much of our basic data are derived), the changes in methods of reporting (e.g. from tenths to eighths in respect of cloud amount), it is not surprising to learn that in the British Isles there are hardly any long period homogeneous data. Hence the reason for the recent decision, promulgated in Meteorological Office Standing Orders, to endeavour to maintain a number of "key" stations at which, it is hoped, the exposure will remain unchanged. Another reason for trying to maintain in perpetuity at least a small number of stations, is the need for a body of "representative" data. Hitherto, the Office has not suffered from a surfeit of data except perhaps in respect of the more common items of observation, e.g. temperature and rainfall, in southern England, where there are a goodly number of the non-official climatological stations which co-operate with the Meteorological Office. There are many areas for which the available data are quite inadequate, especially in respect of wind and rainfall. Moreover, most of the stations which provide climatological returns are the "co-operating" stations, at which observations are made only once a day. However, the time is coming when it will be necessary to limit the ever increasing mass of data by applying some kind of statistical sampling technique in order to determine, in the light of known and potential requirements, for how many stations observations of temperature, rainfall, wind, sunshine etc. should be made, for how many hours per day over a period of how many years. Already, the collection of basic data is being limited by restricting the returns of hourly, 3-hourly, 6-hourly or daily observations to a selection of stations only, by restricting the period for which hourly tabulations of sunshine are required, and so on. Unfortunately, before it will be possible to apply sampling techniqes it will be necessary to have adequate data—homogeneous data.

Another fundamental requirement is that data should be readily made available in the form required by the user. The processing of meteorological data, i.e. the determination of averages, frequencies, extremes, standard deviations, by manual procedures is a laborious business and even when the results have been worked out they are not always in the form required for answering an inquiry. For example, it is not possible to find from the *Climatological Atlas of the British Isles*, or other Meteorological Office data publications, the frequency distribution for a given place of the rainfall amounts, in 1, 2, 3 . . . . *n* consecutive days—yet this type of information is often wanted. It was realised a long while ago that to prepare, by hand, climatic atlases for the oceans from the data provided by ships, e.g. moving observing stations, would be a gigantic task, and a far-sighted decision was made to put the marine data on to punch cards for processing by machine methods. As a result the Marine Division of the Meteorological Office, having several million cards to work with, is now in the happy position of being able to deal effectively with many inquiries and problems relating to meteorological conditions at sea—except perhaps for those parts of the oceans which are not regularly crossed by ships and for which the available data are therefore scanty—which it would have been quite impracticable to tackle in any other way. An account of the extraction and compilation of marine meteorological data by mechanical methods was given by H. T. Smith in *The Marine Observer*, Vol. XIV, 1937. Several years ago a similar wise decision was made in respect of upper air observations and we have already seen the fruits thereof, namely, the publication in the M.O. 555 series of the machine-analysed data for our upper air stations. The application of the punch card system to upper air data was described by D. Dewar in the *Meteorological Magazine*, Vol. 78, 1949.

Now it has been decided to put surface land data also on to punch cards. Hence the introduction, with effect from January 1 this year, of new forms for climatological returns, initially from official observing stations. The fundamental reason for these new forms is that, having little or no meteorological knowledge, a machine assistant (who does the punching) cannot be expected to sort out exactly from a complicated array of data, as in the *Daily Register* or on the old climatological forms, the actual figures which have to be punched on the cards in a prescribed order. That is why the new design of climatological forms corresponds to the design of the punch cards. If it were possible, as in the United States, for the cards to be punched at the observing stations by the meteorological assistants, then the forms could be dispensed with—although they would still be required from the co-operating stations, who could hardly be expected to punch the data themselves. Maybe, the day will come when the data required from official stations can be punched (or put on to a magnetic tape) directly from the teleprinter tapes at the Central Forecasting Office. But this would raise the question of accuracy. Teleprinter messages are by no means free from mistakes. However, even this difficulty might be overcome. In fact, the National Weather Records Centre at Asheville in the United States has already dispensed with the personal scrutiny which, in this country, is regarded as such an important feature of the work. Special machine procedures have been evolved to exercise "quality control" and internal consistency checks on the observations. Data are tested for "reasonableness" and only those which are rejected as out of line (for example the machine will pick out observations of cloudiness and cloud height which are contradictory) are scrutinized by a meteorologist. Nevertheless, to ensure accuracy, all the necessary computations for upper air data are repeated at Asheville before such data are punched.

It should not be imagined, however, that the introduction of machine facilities is a simple straightforward business. There are many possible snags. In the first instance it is necessary to consider very carefully, in the light of past and foreseeable uses of climatological data, precisely how and what information is to be punched. Obviously the selection of units is important. Frequent changes in the past militate against the use of synoptic codes. The instructions for entering data on the climatological forms must be quite unambiguous. Then there is the need for tidiness and clarity in entering figures on these forms. A badly written 6 or 9 can easily be mistaken for a 0. Like all other meteorological services which have introduced punch card methods (see for example the article on introduction of punch card methods into the Australian Meteorological Service in *Weather* of February 1952) we have had our "teething troubles"—so we are proceeding very warily. When these troubles have been overcome it is hoped to introduce new forms, to go with punch cards, for use by the co-operating observers.

What are in fact the advantages of punch card methods? Perhaps the simplest answer is that sorting into categories (e.g. for the determination of frequencies), the computation of totals (e.g. for the determination of averages), the calculation of squares and products (e.g. for the determination of correlation or standard deviation), can generally be performed more accurately and more quickly by machine than by hand. Of enormous advantage is the facility for determining the frequency of simultaneous occurrence of given values of two or more elements, e.g. cloud and visibility (in connection with landing conditions at airfields), wind and rain (in connection with the problem of "driving" rain), dry bulb and wet bulb temperature (in connection with problems of air conditioning), temperature, humidity and wind (in connection with the cooling power of the air). Compound analyses of the type mentioned would be impracticable without machine methods. An important feature is the capability of the machine, known as the tabulator, for listing data in a form suitable for printing and publication. Many of the data publications of the United States Weather Bureau are produced in this way at Asheville. It is hoped that a day will come when we shall use the tabulator for the publication of the *Monthly Weather Report.* Perhaps also one of these days the machine processing of climatological data will facilitate the prediction of trends and the issue of probability forecasts based on analogues or objective procedures.

However, as far as the machine processing of surface land observations is concerned, it must be expected that future progress will not be rapid. It will be some time before sufficient data have been punched to eliminate the need for dealing with inquiries and investigations by manual methods, although it is hoped to get a "backlog" punched back to January 1, 1949 (when the last big change in synoptic code took place) for a small selection of stations. Nevertheless, we are looking hopefully ahead, and steps have already been taken to centralize machine facilities in a Machine Pool to serve the Meteorological Office as a whole. As yet, the available machines have certain limitations and some analysis must still be done by hand but, maybe in the not far distant future, when the Meteorological Office headquarters has settled down at its future home at Bracknell, we shall see the rather humble machine set-up which we have at present, developed with the support of the outstations into a really important unit of our organization, a unit capable of rendering an increasingly valuable contribution to the economic life of the country.

METEOROLOGICAL OFFICE DISCUSSION

Hydrology and British Rainfall

The fifth discussion of the 1956–57 series, held at the Royal Society of Arts on February 18, 1957, was opened by Mr. A. Bleasdale, who also repeated the opening statement in the lecture theatre of the Royal Botanic Gardens, Edinburgh, on March 28, 1957. This report includes an account of the discussions at both meetings.

Mr. Bleasdale explained that from the very wide field which the title could be taken to cover, he had chosen to restrict attention to deficiencies of knowledge on the rainfall side of hydrology. Though it was not suggested that others who wished to contribute to the discussion should feel themselves similarly restricted, he thought that it would be useful to give special attention to deficiencies of hydrological data and to methods which might be applied to overcome them.

The most accurate possible knowledge of precipitation was fundamental in nearly all hydrological investigations, and for water supply inquiries especially the need for full and precise information was of growing importance. The rate of increase in the demand for water was beginning to cause concern and even alarm, as evidenced by quotations from *The Economist* of January 26, 1957[1], and from a statement by the Minister of Housing and Local Government in November 1956[2]. In each case it was emphasized that the water supply problem is becoming a dominant factor in the development of industry, and that the future standard of living and well-being of the people are bound up with its adequate solution. In this context it was a serious responsibility to keep under review the outstanding problems of rainfall measurement, as a basic contribution to the general effort of hydrological research.

Mr. Bleasdale then dealt in turn with the problem of the areal assessment of precipitation, and with problems of measurement at a point under the five headings: exposure and shielding of rain-gauges, rainfall measurement in rugged terrain, snow, dew, and fog precipitation.

Areal assessment of precipitation.—In hydrology the accurate measurement of precipitation at a point is only a beginning. It is necessary to assess the amount of water, in any form, which reaches the ground from the atmosphere over an area. In Britain we have the advantage of one of the densest rain-gauge networks in the world (the average density being about fifteen times that in the U.S.A.[3], for example), but the distribution of rainfall stations is very irregular. Amongst the gathering grounds of overground water-supply undertakings there are probably a dozen or so throughout Britain with rain-gauge networks conforming with standards recommended in 1937[4], a notable example being the Birmingham Waterworks area in central Wales with 32 gauges covering about 71 square miles[5]. In the majority of areas there are deficiencies, and in some the networks are very sparse. The assessment of areal precipitation, as carried out in the Meteorological Office, involves at some stage the drawing of isohyetal lines, often based on a rather limited number of reliable observations. Though it is possible to develop a high degree of skill, allowing for effects of altitude, slope and aspect, the subjective factor remains—in varying degree in different areas—and in Britain objective tests of the accuracy of such methods have not been developed.

Attempts to develop tests have been made in the U.S.A.[6, 7, 8], and the superficial indications are that the standard error of estimates in the most favourable areas in Britain may be about 3 or 4 per cent. But the standard error is a function of rain-gauge density, the size of the area, the time interval covered by the rainfall data, and the type of rainfall. Bearing in mind that it is higher for thundery rainfall in summer than for widespread frontal rain, conditions in Britain may in general be more favourable than in areas studied in the U.S.A., and routine monthly estimates of general rainfall for the most favourable areas may have a standard error as low as 2 per cent. For the most difficult areas, it may be hoped that the standard error does not exceed 10 per cent. There is a need for attention to this problem to determine the margins of uncertainty inherent in the estimates.

Completely objective methods for assessing areal precipitation have been suggested, the earliest being the Thiessen polygon method[9]. By drawing the perpendicular bisectors of the lines joining adjacent gauges on the map, the area is divided into polygons, each enclosing a gauge, and such that any point within a given polygon is nearer to the gauge included than to any other gauge. Each gauge reading is then weighted in proportion to the area of the associated polygon to obtain the areal estimate. The result is better than a straightforward arithmetic mean, but includes no allowance for topographic effects, which could be introduced only at the expense of much laborious arithmetic, or the introduction of subjective factors. The method might perhaps be adapted as part of a test of the adequacy of rain-gauge networks by the comparison, over a series of occasions, of the arithmetic means and the Thiessen polygon estimates.

Spreen developed an objective method based on a sound statistical technique for an area in western Colorado[10]. This was a multiple regression analysis, carried out graphically, relating the winter precipitation of 32 stations to altitude, slope, degree of exposure, and aspect. He obtained a multiple correlation coefficient of 0·94, "indicating that about 88 per cent of the original variance was attributable to the four topographic parameters". On such a basis it would be possible to draw a very detailed isohyetal map and make a completely objective estimate of areal rainfall with a known standard error. Mr. Grindley had attempted to adapt this method for British conditions, using areas in Cornwall and south Wales, but the results were not so satisfactory.

Radar has also been used for the determination of precipitation pattern and areal amount. Intensive studies have been made by the State Water Survey Division of Illinois, some of the earlier reports being very optimistic, and later conclusions rather more cautious[11, 12]. Difficulties include: the uncertainty of the relationship between radar echo intensity (proportional to the sum of the sixth powers of the rain-drop diameters) and rainfall intensity (proportional to the sum of the cubes); and a possible change of the rainfall pattern as observed by radar, perhaps a few thousand feet above the ground, before the rain reaches the surface. Radar, as we know it at present, cannot replace rain-gauge networks entirely, but can give additional information about rainfall distribution which is the more valuable the sparser the network of conventional gauges. If the expense and labour are considered to be justified, radar methods would be useful in areas where networks are necessarily sparse, and also in special investigations. Marshall, Hitschfield and Gunn reach a similar conclusion in a recent evaluation of the technique[13].

As the assessment of areal rainfall is of fundamental importance in hydrology, there is a need for the development of rigorous statistical tests to be applied to areal estimates, so that any such estimate can be associated with an accurately determined standard error, a task which probably requires the collaboration of first-class statisticians.

Measurement at a point.—Consideration of the errors which may arise in point measurements must also be incorporated in the statistical evaluation of areal estimates, and these in themselves pose formidable problems. A useful guide to the literature on rainfall measurement is given by Kurtyka, with over 1,000 references, mostly annotated, up to year of publication 1952[14].

Exposure and shielding of rain-gauges.—The standard exposure of rain-gauges in Britain represents a compromise to avoid the worst effects of excessive catch through in-splashing, and loss of catch due to wind eddies caused by the gauge. The wind effect, discussed as early as 1811 by Luke Howard[15], is known to be serious in exposed situations. In some other countries, where the standard height of the rim of the gauge above the ground is greater than in Britain, the problem is aggravated, so that more attention has been given to the design of rain-gauge shields (see references in Kurtyka indexed under "shields" and "exposure").

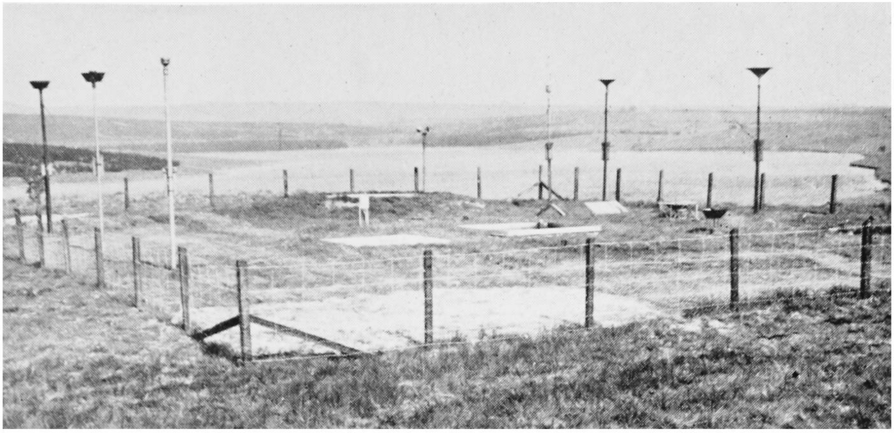
As a result of experiments in 1926–32[16], the standard shield in Britain became the turf wall (photograph between p. 208 and 209), though other devices have been used experimentally. Dutch experiments in 1935–45 were based on a pit gauge as the standard of comparison[17]. The rim of the gauge was surrounded by a brush with vertical 2 in. bristles on a wooden base, the brush being surrounded over a wider area by a grid, with the rain-gauge rim, brush and grid all flush with the ground. (The brush device was suggested in 1842 by Thomas Stevenson who introduced the standard thermometer screen[18].) In these experiments the British turf wall proved almost as good as the pit and brush standard, and gauges with Nipher-type shields (see Kurtyka) were intermediate between the turf-wall gauges and those with the standard British exposure without protection. Experiments now in progress at Stocks Reservoir (photographs between pp. 208 and 209) near Slaidburn, Yorkshire, under Mr. Law, Engineer of the Fylde Water Board, appear to be confirming the Dutch results (but using grid gauges without the brush).

There have been doubts about whether the brush and grid gauges, designed to avoid errors from either in-splashing or wind eddies, are in fact free from in-splashing. This could be tested by having a closely-packed group of nine square gauges surrounded by brush and grid. On occasions of negligible wind the separate catches of the nine gauges should show a symmetrical pattern with amounts a in the centre, $(a + b)$ in each side gauge (in-splashing possible along one side), and $(a + 2b - c)$ in each corner gauge (in-splashing possible along two sides, with perhaps a small reduction, c, arising from a corner effect). If the amount for in-splashing, b, is not completely negligible, the installation could be used to test improved devices of the brush and grid type.

Experience has shown that it is necessary and quite practicable to improve the performance of exposed gauges by some form of shield. This increases the expense and trouble of recording rainfall, and in particular the correct maintenance of a turf wall on rough moorland is not easy. There is a need for increased interest in the exposure and shielding of rain-gauges, and meanwhile an adequate programme of inspections is important, so that at least the existing defects may be known, even if they cannot be fully corrected.

Rainfall sampling in rugged terrain.—Apart from problems of loss of catch in exposed situations, there is the hydrological problem of the distribution of rainfall on the ground in hilly country, which is distinct from the purely meteorological problem requiring the correct measurement of rainfall by means of gauges with horizontal rims. A windward slope intercepts more rainfall per unit projected area, and a leeward slope less, than a horizontal surface. The problem has been neglected in Britain, the neglect having been encouraged by insistence that, wherever possible, the gauges must be set up on level sites. Whilst there is much to be said for the rule for the majority of rainfall observers, it definitely introduces a bias in the sampling of rainfall in hilly country. An approach which has been investigated in several countries in Europe[19, 20, 21, 22, 23] and in the United States of America[24] makes use of gauges with the rims parallel to the slope of the ground on which they stand. Two versions have been employed: the "tailored" or "stereo"-gauge, with the upper part of the funnel formed from a vertical cylinder, cut off obliquely to match the slope at the chosen site; and the ordinary gauge set normal to the slope, instead of vertically (photographs between pp. 208 and 209), which provides readings requiring a correction factor $1/\cos \alpha$ (where α is the angle of the slope) before being plotted on the rainfall map. The ideal would probably be a stereo-gauge flush with the slope, surrounded by a brush and grid which had previously been tested for the prevention of in-splashing. Hamilton has indicated a simpler solution in his conclusion that the shielding of sloping gauges is unnecessary, even with the rim as much as 40 in. from the ground[24], but this is a conclusion which may legitimately arouse slight suspicion about an otherwise excellent report.

An adequate network of sloping rain-gauges would need to be much denser than a conventional network of standard gauges, possibly by a factor of two or three, to provide sufficient sample data for the great variety of slopes in a catchment area. A practicable compromise might be to supplement a conventional network with a small number of paired gauges, sloping and standard, to obtain some information about correction factors for various slopes in different conditions. The actual distribution of rainfall on the ground in hilly country is a problem beyond the scope of the radar technique.



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EXPERIMENTAL RAIN-GAUGE INSTALLATION AT STOCKS RESERVOIR

(see p. 208)

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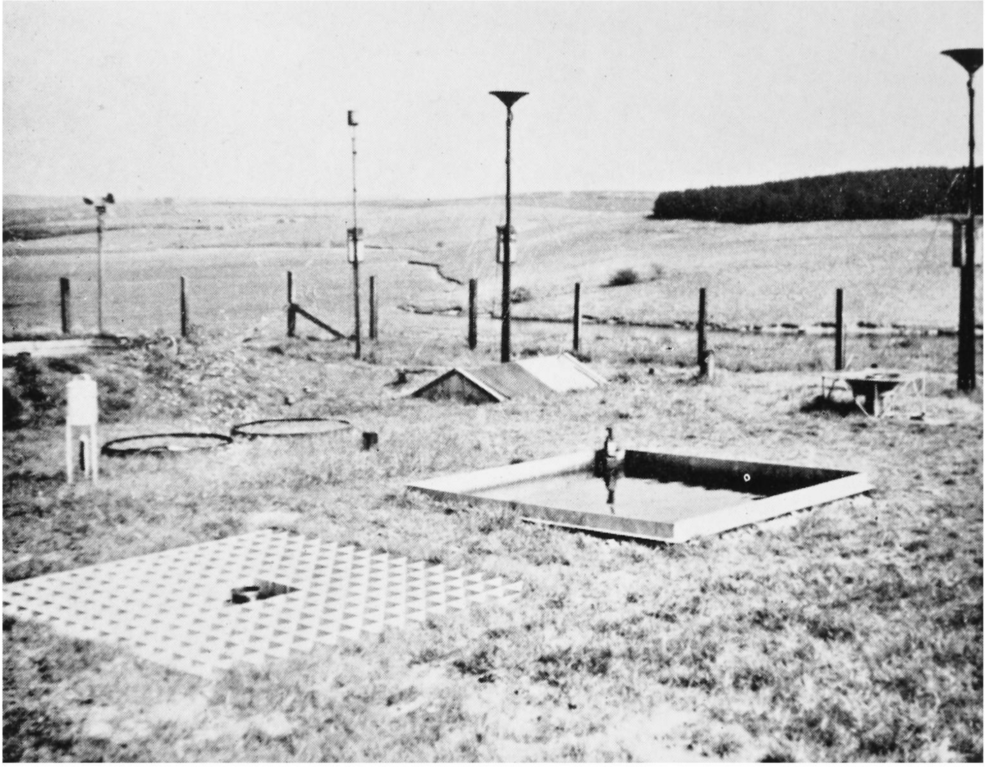
EVAPORATION PAN AT STOCKS RESERVOIR

United States Weather Bureau class A type.



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INSTALLATION AT STOCKS RESERVOIR

Grid rain-gauge appears in left foreground.
(see p. 208)

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TURF WALL AT STOCKS RESERVOIR

(see p. 208)

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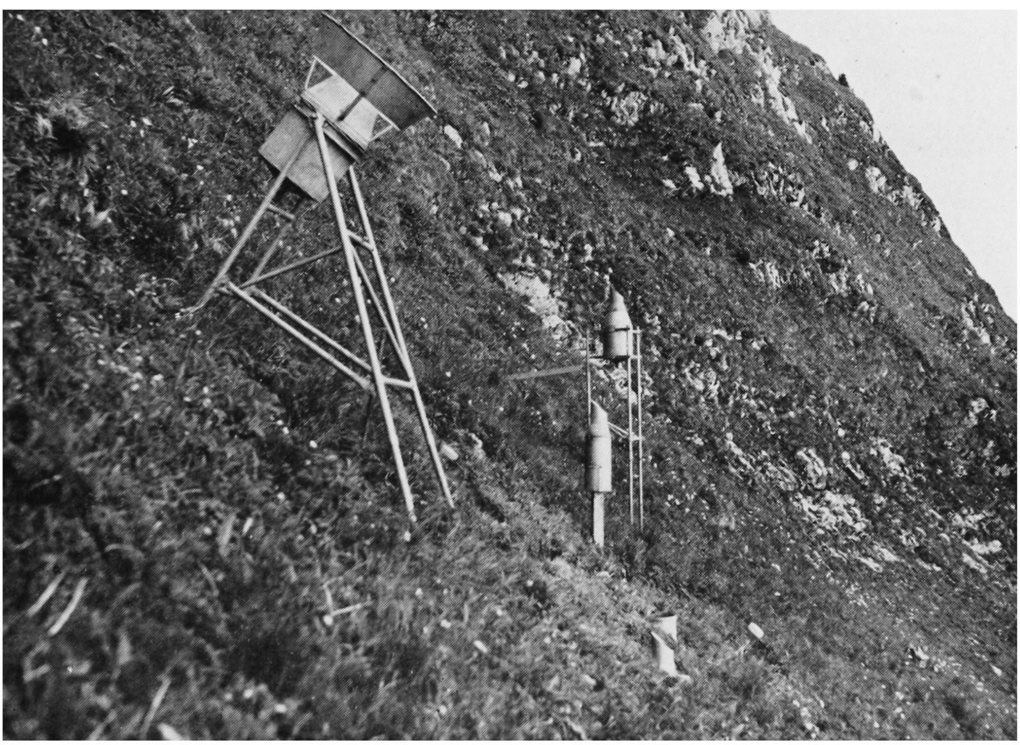

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TAILORED AND SLOPING RAIN-GAUGES ON A MOUNTAIN SLOPE IN SWITZERLAND

(see p. 208 and overleaf)

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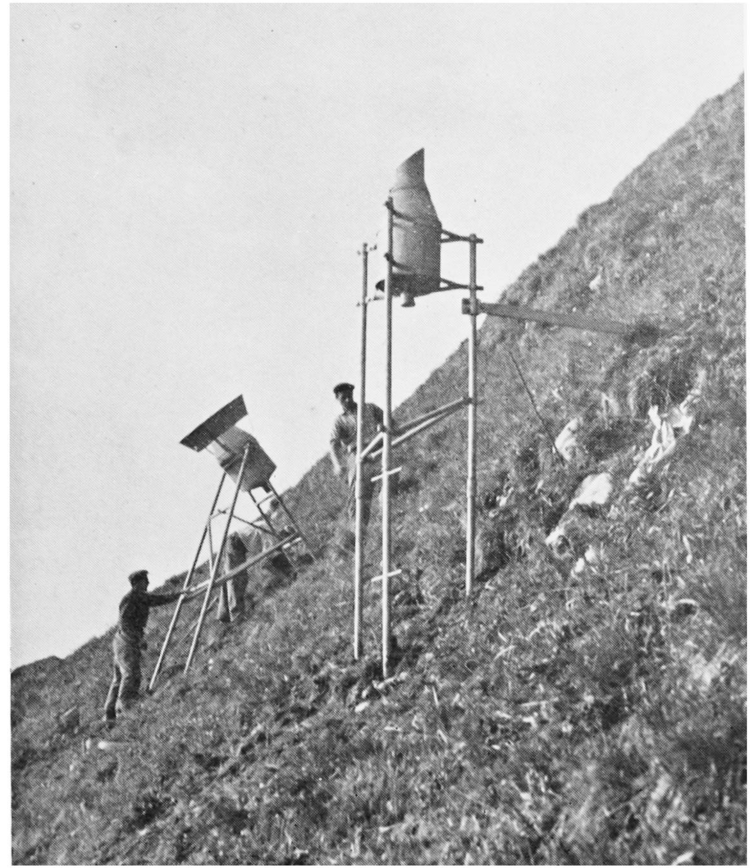

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TAILORED AND SLOPING RAIN-GAUGES ON A MOUNTAIN SLOPE IN SWITZERLAND
(continued)

Snow.—The ordinary rain-gauge is a very poor snow-gauge and supplementary observations of snowfall are necessary, either from samples cut from representative snow cover, or from special instruments. The well organized snow surveys of Canada, the United States[25, 26], and some European countries cannot be emulated in Britain because of the very irregular nature of the snowfall experienced, and we have so far relied largely on the initiative of individual observers. Quantitative data on snowfall could be obtained by methods which are basically quite simple, and it would probably be useful to imitate the organized snow survey methods at least to the extent of carrying out a pilot trial, perhaps on the gathering grounds of a water supply undertaking, or at Eskdalemuir, to obtain information about the required effort and to try out simple items of equipment.

Most snow-gauges (see references in Kurtyka) are modifications of the rain-gauge, a main part of the modification usually being some form of shield, since the errors due to wind effects are much more serious with snow than with rain. In the United States wind-tunnel work using sawdust for snow has led to a development of the type of shield originated by Alter, with improved catches both in the tunnel and in the field[27]. In Britain, two experimental snow-gauges have been produced and set up at Eskdalemuir, but there has been little snowfall since they were installed. Snow-gauges developed as modifications of the rain-gauge should, generally, measure rainfall as well as snowfall, but there is a gauge of a quite different type which measures the water equivalent of snow lying. This is the radio-active snow-gauge[28, 29] based on the principle that radiation from a slug of cobalt-60 (suggested as one of the most suitable radio-isotopes), buried in the ground, is reduced in intensity on passing through a layer of snow. The instrument is said to be accurate within 2 or 3 per cent and to have successfully measured up to 55 in. water equivalent. It is hardly likely that the device will be adopted to measure the very uncertain snowfall of Britain, but if it is there are some difficulties, and possibly dangers, to be considered.

Dew.—With a conventional rain-gauge there are some readings of "trace", and even of measurable small amounts, which result from dew. But it cannot be supposed that the rain-gauge collects a representative sample. Various attempts have been made to devise reliable dew-gauges, and the indications are usually that in Britain the total amount may be of the order of 1·0 to 1·5 in. a year. Work carried out in the United States during the 1940's gave a much higher value for "condensation-absorption", namely about 9 in., or 19 per cent of the total water supply available to plants and soil at the site of the investigation[30]. This rather startling result appears to have been accepted in a semi-popular account of the role of dew in the 1955 Yearbook of Agriculture of the United States Department of Agriculture[31], and to have been used as part of the basis of a paper by Buettner, of which only an abstract is at present available in Britain[32]. The paper includes "a brief survey of the laws on heat, mass and momentum transfer involved", and should be of outstanding interest to hydrologists, agricultural meteorologists and others, if it sufficiently supports the claim that the additional contribution of dew (and absorption from mist) "may result in a water supply usable to plants much in excess of precipitation measured with standard techniques". Meanwhile it seems permissible to be sceptical. If the energy released during the condensation of such substantial amounts of water does not become available to promote compensating processes of evaporation and transpiration, it is necessary to inquire how and when it is (in this context, harmlessly) dispersed. A possible explanation might be that some plants, because of structure or other individual properties, are able to capture this additional supply of water, but ultimately at the expense of others.

Fog precipitation.—Nagel has recently drawn attention to the possible deposition of substantial amounts of water from fog when the ordinary rain-gauge catches little or nothing[33]. He refers to similar work on Table Mountain going back to 1904, but his interest appears to be mainly meteorological. Other workers (Grunow[34, 35], Hori[36]) have attempted to relate the amount of precipitation caught by a fog-catcher to the amount caught by vegetation, particularly trees. Grunow concluded that fog-drip "is important for hydrological calculations in mountain forests and coastal mist belts".

The problem is a part of the more general problem of the effect of vegetation on the water balance of drainage areas, a subject about which little is known in an accurate quantitative sense. Results of investigations in different parts of the world are not altogether consistent. Mr. Law's experiments at Stocks Reservoir include some relevant work with respect to trees, and he has concluded that there is a water loss from afforested gathering grounds which is very serious for the water-supply engineer[37]. Mr. Bleasdale said that he had already expressed opinions contrary to Mr. Law's conclusions, based on arguments that the additional loss from trees would be compensated in various ways, part of the compensation coming from fog-drip[38]. This was not an appropriate time to pursue the substance of the argument, but to note that such disagreements exist, and to consider how to improve quantitative knowledge of the hydrological balance of vegetated areas, in order that the problems could eventually be solved. At this point too, it was suggested, the discussion of precipitation leads, through the introduction of the topic of fog-drip, to consideration of the whole field of hydrology, since this phenomenon above all others which had been mentioned, could not be adequately investigated in isolation.

Conclusion.—Mr. Bleasdale concluded with the suggestion that insufficient attention has so far been given to the determination of the limits of uncertainty associated with all types of hydrological measurements, and that this would be a profitable line of study, both to assess the value of attempted water balance investigations, and to stimulate efforts to improve methods of measurement.

Discussion in London

Mr. Veryard referred to the session of the Commission for Climatology of the World Meteorological Organization from which he had recently returned. It was evident that increased interest in water resources was world-wide, and was not confined to the special problem of the arid zones, but was closely linked with industrial development in moister regions. In this country there had been serious attention to the matter in the press, and the re-constitution of the Central Advisory Water Committee, with its Sub-Committee on Information on Water Resources, demonstrated official recognition of the problem. He re-emphasized the difficulties associated with the measurement of snowfall and of rainfall in rugged terrain, as discussed by the opener, and also referred to problems of evaporation measurement—the need to standardize instruments, partially recognized by the recommendation to install American type evaporation pans for the International Geophysical Year; and the need to build on the work of Penman and Ferguson to obtain estimates of evaporation for hydrological use. He compared the combined hydro-meteorological services of such countries as Sweden and the U.S.S.R. with the different situation in Britain, which called for the collaboration of several different organizations and depended on the maintenance of the good liaison which at present exists. He also drew attention to the need for developing the most useful forms of presentation of data, asking for guidance from users, and finally paid tribute to the thousands of voluntary observers on which the rainfall and hydrological work in this country depends so much.

Mr. Wolf spoke of the post-graduate course in hydrology at the Imperial College of Science and Technology, and of his special interests in the assessment of hydro-electric resources and in the investigation of floods. The amount and quality of data available for such work illustrated the problems of hydrological measurement, and of the patient effort required over periods of years to produce satisfactory results. For the assessment of areal precipitation he preferred to use both the Thiessen polygon method and the isohyetal method. He thought that there was a great need for further investigation in hilly country, and that the benefit to the national economy would amply repay the effort and expenditure. Owing to cautious underestimates of precipitation in some areas, hydro-electric projects had not always been developed to the fullest possible extent. He referred to the possibilities of using radar to forecast river floods, and concluded with the suggestion that there was a field for collaboration in hydrological research between the Meteorological Office and the universities.

Mr. Green discussed work he was doing in the Nature Conservancy with a network of percolation gauges, to obtain standardized measurements of potential evaporation. Estimates obtained by Penman's method appeared to be in closest agreement with observed values for the more maritime situations, whilst Thornthwaite's method appeared better where "continental" tendencies were more pronounced. There were sometimes very large negative values for observed potential evaporation in winter, and this might be an indication of the role of dew and hoar-frost, or might be connected with as yet unknown changes in soil structure at certain times of the year. Among other interesting items mentioned was that the large loss, much greater than potential evaporation, of an experimental drainage area in Upper Teesdale covered with undisturbed bog, gave a good measure of the contribution to ground water by percolation through the Carboniferous Limestone.

Mr. Law stated that there were a number of matters which he considered needed attention by the Meteorological Office. The first of these was the design of a rain-gauge which would give a correct answer wherever it was placed—whether on a moorland slope facing the prevailing wind, near ground level, or at the top of a forest canopy. He instanced transpiration gauges 33 inches in diameter with surfaces sloping at 1 in 5·5 into the prevailing wind, which in eleven weeks had caught 10 per cent more than had been caught on similar transpiration gauges with flat surfaces—yet similarly sloping rain-gauges had not caught anywhere near the 10 per cent extra. For measuring rainfall above a forest canopy he was experimenting with gauges with Nipher shields set up on 10-ft. poles, alongside other experimental rain-gauges. On level or gently sloping ground turf-wall gauges seemed approximately correct and should be used more often. (Photographs betwen pp. 208 and 209).

He thought the second item should be the investigation of the variation of the rainfall over an area. The recommended number of gauges for a water catchment area of 10,000 acres was 15, but he suggested one might as well try to draw a contour map with 15 spot levels as try to draw an isohyetal map based on that number of gauges. He suggested the Meteorological Office should arrange for 100 gauges to be spread over an exposed hilly area so that the variability from place to place could be assessed. He instanced Saddle Hill on his own catchment near Slaidburn in Yorkshire, where the annual rainfall varied between 70 inches and 80 inches or more over a distance of only 250 yards.

Regarding evaporation he thought it was a pity that evaporation tanks had gone out of favour during recent years and that this was partly due to the present inability to estimate with sufficient accuracy the rain falling into the tank. He hoped that in the near future the Meteorological Office would install evaporation tanks at stations with extremes of climate, and, by means of climatological observations, would reconcile the differences between measurements so obtained.

There seemed to be a general opinion that evaporation was fairly constant over an area such as a reservoir catchment, but he thought this was totally wrong, and that there could be as much relative variation in the evaporation as there was in the rainfall.

He said he would also like to see experiments carried out into the changes which could be made in evaporation and transpiration from catchment areas by the draining of bogs by moorland gripping. He was investigating the effects of planting conifers on water supply catchments but did not consider that the meeting was the proper place to discuss the detailed results.

Dr. Penman first discussed the difficulties of hydrological work on the extensive scale, dealing with areas of about the size of the Thames Valley. It was not yet possible to say whether land drainage operations seriously affected the flow of rivers, despite careful consideration of the problem by a committee of experts; their report was inconclusive. There was a need for intensive investigation on selected small catchments, and he thought that such research should be done by the Meteorological Office as it could not be successfully "farmed out". There were papers in the press reporting work done at Rothamsted on dew, showing that it amounted to about 1 inch a year. In opposition to a suggestion from Mr. Green he thought that to proceed from measurements of evaporation to estimates of rainfall was not possible; the degree of accuracy obtainable was not good enough. Neutron-scattering equipment was being obtained at Rothamsted for the measurement of soil moisture, and it could also be made available for experiments to determine the water equivalent of a layer of snow.

Mr. Reynolds illustrated by slides his investigations of the exposure of the rain-gauge at Bidston Observatory. The site was known to be poor, and comparisons with a nearby gauge, set up for a year on a better site, clearly showed the effects of some obstructions when the results were analyzed according to wind direction. There remained, however, a random variation of the relative catches on the two sites, and it was not possible to make completely satisfactory corrections to the data from a poor site.

Mr. Watkins introduced a new topic by referring to the purely man-made problem of storm-water drainage in built-up areas. This was under investigation by the Department of Scientific and Industrial Research Road Research Laboratory with the collaboration of the Meteorological Office on the rainfall side. There was a possibility of savings on expenditures of the order of £1,000,000 for the initial work in a new town, or over £600,000 a year in the London County Council area, by providing a sounder basis for the design of storm-water sewers. If such savings were only of the order of 3 to 5 per cent, as in one instance quoted, the amounts were still very considerable. He referred to arrangements now in hand for the collection of data on intense falls of rain in short periods, with the collaboration of engineers serving local authorities using open-scale rain recorders; and also to the intensive investigation of areal rainfall, using a close network of open-scale rain recorders, which is being carried out by the Meteorological Office at Cardington. These were of fundamental importance in the research with which he was concerned.

Dr. Leyton spoke of the interest of foresters in hydrology. There were some indications, from work in various parts of the world, that forests derived a substantial part of their moisture requirement from fog-drip and even by direct absorption from the air. On the other hand, Mr. Law's experiments on the water-losses caused by trees had come as a sharp stimulus to foresters in this country. They were considering how to start investigations to solve the problems, and resolve the inconsistent results reported by different workers, in a field in which foresters and water-supply engineers might find themselves in conflict.

Prof. Manley instanced work in Norway on the assessment of snowfall, in which maps of winter precipitation had been based on the data obtained from stream-gauging during the spring run-off. He thought that similar work could be carried out experimentally for a selected drainage area in Scotland.

Mr. Smith demonstrated, with approximate values of rainfall, run-off and evaporation appropriate to south-east England, that the useful assessment of the water balance of an area was more critical for the hydrologist than for the agricultural meteorologist. There was a reserve of about 3 inches of water which could be held by the soil, to become available to plants, which was of outstanding importance during the three-month summer period of high transpiration rates. This provided a "cushion" which enabled the calculated irrigation need to be successfully applied, without requiring a very high standard of accuracy. In the past the water-supply problem had also not required a very high standard, but in the future, even in the near future, the increasing demand for water would impose a greater need for accuracy of observation and for hydrological research. It was necessary to keep in mind three different levels in work of this kind, none of which we could afford to neglect. These were fundamental research, field experiments aiming directly at the general application of results, and the supply of information and advice. For this last, there was a constant and sometimes insistent demand which took no account of whether there were adequate basic data available. At all levels the urgency of work must be related to the certainty of a general water shortage in this country within the next two decades.

Mr. Gold was suspicious of the underlying idea, which is a tacit assumption in many rain-gauge investigations, that the gauge which catches the most rainfall is necessarily the best. He wondered whether the brush gauge which had been referred to was really free from in-splashing. The measurement of rainfall was not equivalent to a laboratory experiment with controls. He thought that it was unnecessary to attempt a high order of accuracy, which he considered to be unattainable because of time variations and space variations which could not be adequately sampled.

Discussion in Edinburgh

At this smaller meeting the discussion was more informal. The report is abbreviated with regard to some of the direct questions, with immediate replies, and to fuller information given about some of the references quoted by the opener.

In reply to *Mr. Gloyne* it was suggested that the standard errors mentioned for areal estimates of precipitation should be regarded in the usual way as positive or negative, though the additional sampling errors for individual gauges were likely to be more frequently negative than positive. In-splashing and some types of leak could cause positive errors. The standard errors suggested for areal estimates did not take full account of the special problems of rainfall measurement in rugged country.

Mr. Hamilton introduced discussion of the standard instrument and site to be adopted for experiments with rain-gauges, with *Mr. Cranna* pointing out that the Dutch brush and grid gauge was intended to serve this purpose by reducing both in-splashing and the effects of wind eddies.

Mr. Anderson pointed out that if the recommendations for rain-gauge densities for areas of a few square miles were extrapolated to a few hundred square miles a very large number of rain-gauges would be required. *Mr. Bleasdale* replied that for a large area, regarded as a single unit, a lower density of rain-gauges would be adequate, but, using the recommendations as a general guide, he would prefer to examine each area individually with the aid of a good contour map, rather than apply any rigid rule.

Mr. Cooper spoke of the difficulties of getting observers in remote areas of Scotland and thought that recording rain-gauges might provide a solution. He thought that the Meteorological Office did not favour the use of recording rain-gauges for this purpose. *Mr. Bleasdale* replied that the Meteorological Office was fully aware of the problem, but the unfortunate fact was that no recording rain-gauge had yet been devised which could be left unattended for long periods and give reliable results. The faults which could develop meant that in general a recording rain-gauge was more troublesome than an ordinary gauge, and should be visited at least once a day.

Mr. Cuthbertson thought that the future increase in the demand for water would be more on the industrial side than the domestic. Some industrial enterprises had not exercised sufficient control over water use when it was a small item in their economy, but it had been shown in the recent drought that much could be done to save water without limiting production. Moreover, there were still large areas undeveloped in Scotland. For the areal assessment of rainfall many water engineers developed their own systems of weighting the readings of individual gauges, on the basis of local knowledge of the catchment areas. The speaker emphasized the difficulties of maintaining turf walls on rough moorland, where they soon become overgrown, and drew attention to the great variety of protective fences in use, which surely called for some standardization. He regretted that there was not yet in existence for Scotland an organization completely equivalent to the River Boards system covering England and Wales, and thought that the time had come, under such a system, to pay more attention to the collection of run-off records. The excellent work of the British Rainfall Organization in the past had led many engineers to rely almost entirely on rainfall records, but he favoured a two-fold development from this position: first that there should be a drive towards more river-gauging, under a central authority, with particular attention to the undeveloped areas; and secondly that the Meteorological Office itself should give more attention to the undeveloped areas, and to features of the hydrological cycle other than rainfall, in particular to run-off measurements.

Mr. Colville thought that Mr. Cuthbertson, in his remarks on River Boards, had not done full justice to the River Purification Boards in Scotland, a number of which were already actively engaged in stream-flow measurement.

Mr. Wilson was impressed by Mr. Law's work on the effects of afforestation on water losses and discussed the serious implications by quoting in some detail from the paper which had been referred to. *Mr. Bleasdale* in his reply emphasized that whilst he did not entirely agree with Mr. Law's conclusions, he considered that experimental work of this kind was very valuable. There were practical limits to the extension of the work of the Meteorological Office, which other speakers had called for, and it was desirable that more engineers should take part in investigations of evaporation, and hydrological problems generally.

Mr. Dewar pursued the subject of evaporation measurement. So far as he knew there were only two evaporation tanks in Scotland, and much more information was required for moorland areas. He spoke of a hydro-electric scheme with which he was concerned, pointing out that a power output 10 to 15 per cent in excess of estimates had been obtained. This might be due to cautious underestimation of rainfall, over-estimation of evaporation, or neglect of a possible contribution from cloud and dew, which might stabilize the flow in a dry period. It was obvious that further research was required and he thought that the Meteorological Office should take a leading part in the work.

Mr. Aitken paid tribute to the Meteorological Office for the help given to the Hydro-Electric Board in planning their schemes, and for the interest shown on tours of inspection. The rainfall estimates supplied had been of paramount importance, though he confirmed that in general they had turned out to be about 10 per cent on the low side. He drew attention to the work of Mr. Green of the Nature Conservancy on potential evaporation, stating that the implications of some of the measurements in 1955 were rather disturbing. The need for more measurements of evaporation was again emphasized.

Mr. Cooper asked whether the Meteorological Office reviewed or revised their estimates of rainfall in the light of new data, and *Mr. Bleasdale* in reply explained that although maps and books of averages were published at relatively infrequent intervals, estimates were invariably reviewed for all areas of current interest and importance. The most up-to-date information could always be obtained by correspondence. He also mentioned present work on the new period for averages, 1916–50, for which information would be published in the near future, and referred briefly to some of the problems involved. Whilst it was true that there was an apparent trend towards increased rainfall (compared with the old standard period 1881–1915) in nearly all parts of the country, it was not possible to say whether this trend would be continued or reversed in future decades. A part of the apparent increase might also be due to additional information or to improved standards.

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LETTER TO THE EDITOR

Forecasting weather in the Mediterranean

For readers of the article on *Jet streams over north Africa and the central Mediterranean in January and February* 1954[1] who have a wider concern with the problems of forecasting weather in the Mediterranean the following additional notes contain some important points of common application.

Small waves and retarded cold fronts.—The cold fronts C_A and C_B (Fig. 2[1]) were retarded in the central Mediterranean and there was an improvement of weather ahead of them, contrary to forecast.

The cold front C_A passed Malta about 2100 G.M.T. on January 4 with thunder and considerable rainfall. C_B was expected to pass Malta about twelve hours later giving similar weather; nor was any great improvement expected between the two fronts. These expectations turned out to be false. Cold front C_B was retarded before reaching Malta and C_A was retarded between Malta and Benina. Waves or smaller ripples formed. C_B resumed its south-eastward march on the 7th.

The weather in Malta was surprisingly fine on January 5 and 6. Similar improvements of weather ahead of cold fronts which become retarded after reaching Tunisia and Sicily are common.

From 1500 G.M.T. on the 3rd to 1500 G.M.T. on the 4th considerable cooling took place over south-east France. The upper trough intensified and sharpened towards the south-west, backing the upper winds even over the western Sahara (e.g. Aoulef) until the 5th.

The sequence of high-level charts (illustrated by Fig. 3a–b[1]) shows this troughing of the flow over the western Sahara as a complementary development to the ridging and northward advance of J_S, the subtropical jet stream, over Libya and the central Mediterranean.

The first European cold front C_A had so far outrun (ahead of) the upper-level cold trough as to progress to a position south-east of Malta before being held up. The movement of the second cold front C_B was affected at an earlier point and a surface pressure trough developed westwards along the coast of French North Africa.

The backing of the main upper-wind stream had the further effect of bringing drier air from the African desert over Malta and the central Mediterranean with consequent clearing skies.

C_B resumed its progress eastwards when the upper cold trough over the western Mediterranean began to move—this in its turn being associated with the breakdown and replacement of the blocking anticyclones over the Atlantic, which allowed a fresh deep north-westerly air stream into the Mediterranean.

On the 6th there was an outbreak of medium-level thunderstorms over the desert at 28°N. south of Tripoli.

Several old cold fronts had earlier moved south of the Atlas mountains from the temperate zone and become hard to find over the central desert, where only occasional variations of the amounts of cirrus cloud could be traced in the scattered observing stations' reports. How far frontolysis had progressed over the Saharan sand is unknown. It is thought, however, that some cyclonic development took place on these old fronts in the region near 25°N., 0°–5°E., where several favourable factors may have been at work at the same time. Soon this general frontal system came clearly into the picture moving north in one section as the warm front (shown as "W" on Fig. 2b–c[1]) of a small frontal wave. There is some possibility of its having been associated with the jet stream J_S.

The region was south-east of a major cold trough and at the right-hand side of the (confluence) entrance to the most intense part of the jet J_S. Both these aspects betoken a cyclogenetic region in the sense used by Sutcliffe and other writers. Moreover, the release of thunderstorms would be helped (and probably ten is helped) by the mountains in this part of the desert, the Tuareg highlands (also known as Ahaggar), which have an extensive massif above 2,000 metres and one peak of 3,003 metres near Tamanrasset.

The sequence of surface charts (Figs. 2b–c[1]) shows how the small bulge on the front moved east-north-east with the main upper-wind stream and was carried into the eastern Mediterranean ahead of the various fresh cold fronts C_A, C_B etc. from the north. Similar thundery sequences are believed to pass fairly commonly across southern Tripolitania and over parts of Cyrenaica into the eastern Mediterranean in winter.

Thunderstorms and sferic associated with frontal waves and ripples over the Mediterranean and north Africa.—The main concentration of thunderstorms associated with cold fronts in and around the Mediterranean are commonly clustered in the neighbourhood of the tips of small waves and ripples on the front. This enables the passage of such ripples along the front to be followed with the aid of a network of sferic reports if and when these are available. It also explains the location of intense activity on fronts which are often quite inactive at other points along their length.

It frequently happens that a cold front gives thunder in the Sicilian–Tunisian Narrows and later passes over Malta giving no precipitation and innocuous cloud, yet later again aircraft reports indicate activity east of Malta. The alternative case also arises when intense thunderstorms affect Malta in association with a front which passed almost unnoticed through the Narrows and again faded out farther east. Such cases baffled the forecaster's efforts to handle them until it was realized that these patches of activity moved along the fronts in association with waves which are liable to deepen as they move north-east, especially when the airmass contrast or the thermal instability is great.

Origins and associations of the Mediterranean jet stream examined in January 1954.—The jet stream in the Mediterranean sector seems to have been continuous over Cyprus and Asia Minor with the winter jet stream across Asia. Data were insufficient to determine whether there was also a continuous wind maximum farther west over the Atlantic in latitudes probably about 25°N. There was nothing conclusive about this, but some of the following relationships may be found useful in other cases.

Before the development of the sequence of early January 1954, the mainstream of the upper westerlies in the higher latitudes split over the western North Atlantic, initiating a blocking pattern. This development seems to have been associated with an outstandingly intense phase of the cold pole over Hudson Bay and south-west of Baffin Land from December 25, 1953 onwards. The main branch of the flow could be traced north around over Iceland and turned south again (more and more sharply as time went on) over the British Isles as a north-westerly and later north-easterly air stream, having no doubt the usual structure of a middle latitudes jet stream. On either side of this main branch the upper flow split into several strands, none of which appeared to be of any great breadth or strength save, perhaps, a northward branch over west Greenland and the Davis Strait.

There were signs of another maximum in the high-level winds near the Atlantic coast of north Africa in 25°N. on December 29 and 30, which may have continued from farther west or may have only marked the intensification of the upper westerlies south of the sharpening cold trough east of the north Atlantic blocking anticyclone.

The following observations from Fort Trinquet (25°14'N., 11°35'W.) considerably exceeded the contemporary wind speeds in the Wheelus Field–Benina sector:

		300 *mb.*		200 *mb.*	
Dec. 29, 1953	0300 G.M.T.	260°	75kt.	260°	105kt.
Dec. 30, 1953	0300 G.M.T.	280°	97kt.	270°	158kt.

The wind velocities measured at Fort Trinquet through the 1953–54 winter showed no consistent relationship with periods of peak velocity farther east. This may indicate that maxima near the north-west coast of Africa are associated rather with a subtropical jet stream in the Atlantic sector. There were seven main maxima at Fort Trinquet between October and April; only two of these, on December 30 (the case studied) and March 4, appeared related to and preceded maxima farther east.

In general the maxima in longitudes 0°–15°W. during the 1953–54 winter appeared to be farther south (mean latitude 26°N.) than in longitudes 15°–30°E. (mean latitude 32°N.).

By contrast the maxima at Aoulef (27°04'N., 1°08'E.) were in most cases related to those farther east and occurred either on the same day or one day earlier or later than in 15°–20°E.

Maxima in 30°E. were related to maxima noted at the central Mediterranean and Libyan stations in four cases out of six, and came 0 to 4 days later in 30°E.

During the period January 1–10, 1954 the western Saharan upper-wind stations Fort Trinquet, Colomb Béchar (31°51'N., 2°13'W.) and Aoulef indicated a continual confluence in the flow at levels above 500 mb. over that area.

H. H. LAMB

Harrow, January 7, 1957. J. ROBINSON

REFERENCE

1. LAMB, H. H., FLEMING, J., HOYLE, H. D. and ROBINSON, J.; Jet streams over north Africa and the central Mediterranean in January and February, 1954. *Met. Mag., London,* **86,** 1957, p. 97.

METEOROLOGICAL OFFICE NEWS

R.A.F.V.R. (Meteorological Section).—*Awards.*—It was announced in Air Ministry Orders dated May 1, 1957, that the undermentioned officers in the Meteorological Section of the Royal Air Force Volunteer Reserve had been granted the Air Efficiency Award. We offer them our congratulations.

Flight Lieutenant H. T. Carter.
Flying Officer K. H. Humphreys.

NOTES AND NEWS

Science Museum

International Geophysical Year Exhibition

The Science Museum, South Kensington, London, S.W.7, announces that an exhibition to illustrate the scope and aims of the International Geophysical Year will be on view at the Museum from May 10 to October 31.

The exhibition includes a representative collection of scientific instruments of the types to be used during the Year. The exhibits will cover earth satellites, high altitude rockets, meteorology, terrestrial magnetism, aurorae, solar flares, cosmic rays, glaciology and oceanography.

An illustrated handbook is being published in conjunction with the exhibition, presenting a general account of the phenomena to be studied and the observations to be made during the Year.

The Museum is open, free of charge, from 10 a.m. to 6 p.m. on weekdays and 2.30 to 6 p.m. on Sundays.

A lamp protector for a tilting-siphon recorder and a grass-minimum thermometer support

We are indebted to Mr. G. M. Puckle, Observer at the Bodiam, Sussex, climatological station for information on two appliances which he has devised and found useful.

"A lamp protector is illustrated in Fig. 1. When no electric supply is available, a small paraffin lamp of the nursery night light type can be placed inside a tilting-siphon rain recorder to prevent freezing. A difficulty experienced when

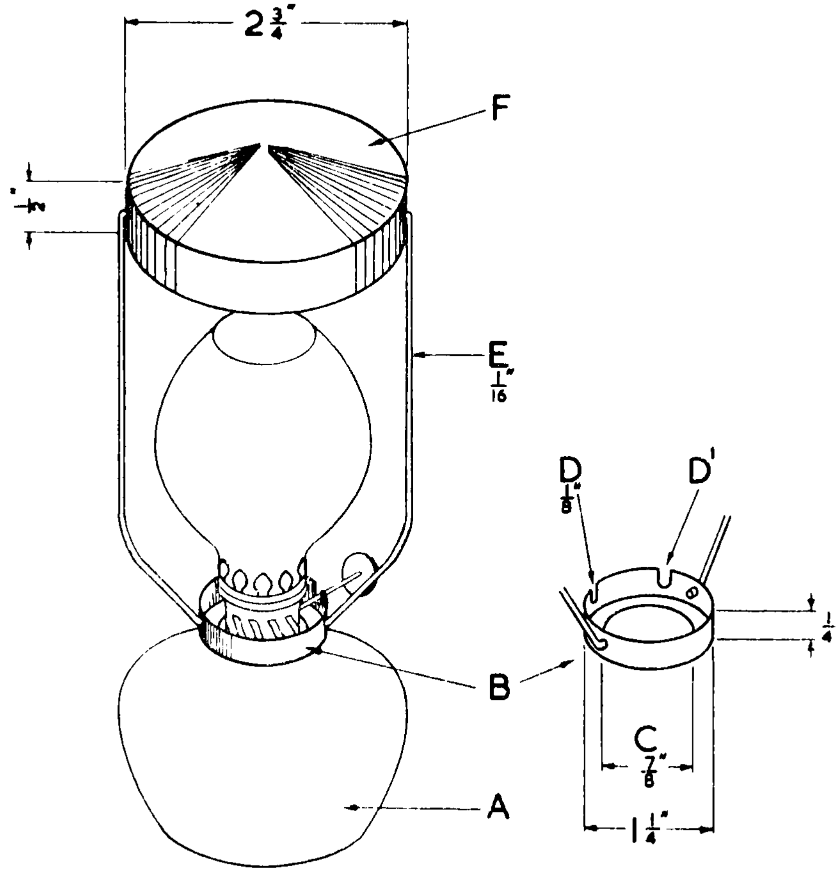

FIG. 1—LAMP PROTECTOR FOR A TILTING SIPHON RECORDER

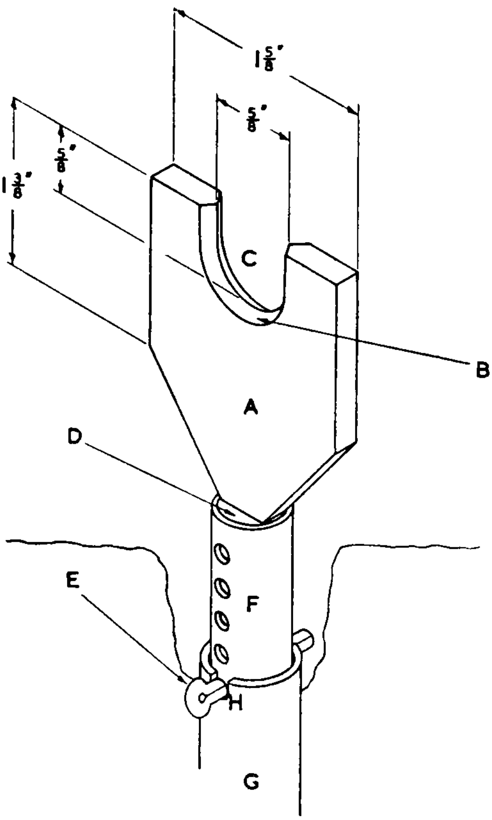

FIG. 2—GRASS MINIMUM THERMOMETER SUPPORT

such a lamp is used is dripping, on the wick, of water condensed on the cold collector of the recorder from the water vapour produced by combustion. To prevent this dripping from extinguishing the lamp the fitting of a roof to the lamp in the shape of a flat round tin lid, F, of about 2¾-in. diameter has been found effective. The lid is beaten out until dome-shaped. It is then supported by two wires, E, fitted into it and which are fixed in turn to a collar, B, round the lamp-glass holder, made by making a hole in a smaller lid and filing a notch, D and D_1, for the shaft of the wick winder.

The grass-minimum thermometer support illustrated in Fig. 2 is intended to permit of easy removal for grass cutting. The supports are fitted to two vertical tubes which slide down into slightly wider tubes fixed in the ground. The details are as follows:—

A is made of $\frac{3}{16}$-in. three-ply wood and painted white.

At C, the wood is shaved off to a knife-edge around the U cut out, B, to receive the thermometer. The stalk of this, D, is fixed inside a brass ½-in. tube, F, then holes, ⅛-in. between them, are drilled in, F, to allow a split-pin, E, to pass through. This pin rests in grooves, H, cut in the top of the outer tube, G, and allows the thermometer to be levelled.

The outer tube, G, is driven into the ground to about 1 in. below the surface. These supports are easily removed for weeding or cutting grass to the correct height, and save a lot of time".

REVIEWS

Report of Director of Meteorological Services, Federation of Rhodesia and Nyasaland, 1954–55

This is the first annual report on the Federal Department of Meteorological Services formed on July 1, 1954 by fusion of the three separate services of Northern and Southern Rhodesia and Nyasaland. The early part, as might be expected in a report addressed to a newly constituted Federal Assembly, is mainly explanatory of the functions of a meteorological service in general and the organization of the Rhodesia-Nyasaland service in particular together with an account of the changes at Federation.

The services provided are mainly for Civil Aviation and Agriculture; forecasts are also provided for the general public. As in many other developing countries, communications difficulties are a great handicap to synoptic meteorology and it is interesting to see how these are met without a specialized telecommunications system. There are 1,460 rainfall stations irregularly distributed over 476,000 square miles; it is estimated that the number of stations will have to be doubled in order to provide data for an accurate rainfall map.

On the research side, in a region where temperate-latitude forecasting techniques are not of much help, it is not surprising to find that a good deal of attention is given to radar storm-detection. Two well equipped meteorological observatories are maintained and in 1954–55 plans were well advanced for the establishment of a third observatory for the special purpose of studying the weather of the area of Lake Nyasa.

A. G. FORSDYKE

Les anomalies du réseau aérologique européen. J. Lugeon and P. Ackermann. 11 in. × 8½ in., pp. 31, *Illus.*, Station centrale suisse de Météorologie, Zurich, 1956.

Resolution 7 of the first session of CAe-I[1] asked for an investigation to be made for a trial period of one year of the homogeneity of the upper air network over Europe. *W.M.O. Technical Note* No. 14[2] presents the bare statistics of the resulting investigation which was carried out under the supervision of the Director of the Swiss Meteorological Service, the various European meteorological services contributing the basic data. The paper under review also gives the results of the investigation together with a useful and interesting discussion.

The results are presented in two sets of charts. The first shows the mean thickness of the layers 850 to 500 mb. and 500 to 300 mb. over Europe for the two periods October 1953 to March 1954 and April to September 1954 and for each of the hours of observation 0300 and 1500 G.M.T. (8 charts). The second shows the 12- and 24-hr. variances of the thickness of the same layers for the same periods (16 charts). The anomalies shown up by these charts are striking, especially on the first set, and should be studied by everyone who has occasion to draw upper air charts. The effects of lag and of direct radiation on the instrument are the two main sources of systematic error in radio-sonde observations. Anomalies caused by lag errors are clearly shown by the charts of mean thickness for 0300 G.M.T. Unfortunately it is not possible to deduce corrections from these charts though for some instruments they must be of the order of 1°C. in the troposphere. Mean radiation errors in the troposphere are deduced for seven different types of radio-sonde for the two periods and these values will be useful to the synoptic meteorologist as a rough guide. It was hoped that the charts of 12- and 24-hr. variances would show up those radio-sondes most liable to random day-to-day errors. Observations from French- and American-type instruments show most variation but the variance charts are difficult to interpret because of real geographical differences.

Since early 1956 radio-sonde observations made by the Meteorological Office have been corrected for errors of lag and radiation[3]; some other European observations are also corrected. Eventually it is hoped all radio-sonde observations will be so corrected but until this is done anomalies such as are demonstrated in this paper will remain.

REFERENCES

1. Geneva, World Meteorological Organization. Commission for Aerology. Abridged final report of the First Session. Toronto, 1953.
2. LUGEON, J. and ACKERMANN, P.; Homogeneity of the radio-sonde network in Europe. *W.M.O. Tech. Note, Geneva*, No. 14, 1955.
3. HAWSON, C. L.; Meteorological Office practice for the application of radiation and lag corrections to temperatures measured by radio-sonde Mk. IIB. *Met. Mag., London*, **85**, 1956, p. 75.

J. K. BANNON

LATE RAINFALL REPORTS 1957
Great Britain and Northern Ireland
JANUARY

County	Station	In.	Per cent. of Av.
Cornwall	Scilly, Tresco Abbey ...	2·35	75
Aberd.	Dyce, Craibstone ...	2·45	104

MARCH

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
Suffolk	Felixstowe	1·19	79	*Argyll*	Poltalloch	6·20	161
Devon	Ilfracombe	4·21	146	,,	Inveraray Castle ...	9·01	142
Notts.	Mansfield, Carr Bank...	1·91	91	*Fife*	Leuchars Airfield ...	1·52	78
Ches.	Manchester, Ringway...	2·79	128	*Perth*	Loch Dhu	9·21	140
Lancs.	Squires Gate	1·85	82	*Inverness*	Loch Ness, Garthbeg ...	3·87	116
Yorks.	Hull, Pearson Park ...	1·51	83	*R. & C.*	Inverbroom, Glackour	5·41	109
Cumb.	Geltsdale	2·72	97	,,	Achnashellach	7·54	111
Mon.	A'gavenny, Plâs Derwen	3·68	110	*Caith.*	Wick Airfield	3·48	153
Glam.	Cardiff, Penylan ...	5·10	162	*Shetland*	Lerwick Observatory ...	4·37	138
Carn.	Llandudno	1·85	91	*Antrim*	Aldergrove Airfield ...	2·28	91
Midl'n.	Edinburgh, Blackf'd. H.	1·52	77	*L'derry*	Garvagh, Moneydig ...	2·75	88
Bute	Rothesay, Ardencraig...	5·78	161				

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 17—Temperature-compensated equivalent headwinds for jet aircraft. By A. F. Crossley, M.A.

The effect of an increase of air temperature on the performance of certain types of jet aircraft is expressed in terms of that headwind which, if the temperature were standard, would have the same effect on the range in still air as is produced by the actual temperature. This headwind is then combined with the ordinary headwind to give the temperature-compensated equivalent headwind. The fundamental formula and expression are derived in §2 for the mean and standard deviation of the compensated equivalent headwind over a period for any one point of the track on the assumptions of normal frequency distribution of wind and temperature. Next, similar statistics are developed for the whole cruising stage of a route supposed flown at constant-pressure level. Finally in §3 the formulae are adapted for a flight in which a gradual increase of pressure altitude takes place as fuel is consumed. The application of the theory to air-route operation is described in §4, with a worked example for the route London to New York in both directions in July at a height in the neighbourhood of 40,000 ft. This report does not apply to recent types of jet aircraft such as the Comet IV which have sufficient power in reserve to make their performance practically independent of the temperature effect.

WEATHER OF MAY 1957

Lowest pressure on the North Atlantic was in the usual position for May, near 57°N. 45°W., the value (1006 mb.) being a little low but probably within the range of commonest values: an unusual feature was that lowest pressure had been concentrated in the same position already on the April mean map. May 1957 was a month without impressive anomalies anywhere in the region between Europe and the eastern Pacific, except perhaps over southern Mexico and over the central Mediterranean where pressures were 3 mb. below normal in regions of normally small variability. The high pressure system over the Polar Basin was rather more intense than usual and extended farther south in ridges of high pressure towards Hudson's Bay and Scotland. The Azores anticyclone also extended well to the north-east.

Average temperatures for the month were 3 to 4°C. above normal at 50°N. across the Canadian Prairies and 3 to 4°C. below normal over central Europe, where there was an unusual prevalence of winds from a northerly point. Elsewhere temperatures seem to have been mostly near normal.

Rainfall exceeded twice the normal over Lapland and was above normal from northern Scandinavia and Jan Mayen all down the North Sea to the middle German Highlands. There were rainfall excesses of a similar order in many parts of the Mediterranean. There was rather less than the normal rain, owing to lee effects, in a strip across central Europe and over most of the Baltic, also in parts of western Europe affected by the Atlantic anticyclones.

In the British Isles weather during the first six days of the month was dominated by a large anticyclone which remained almost stationary to the west of Ireland. In England and Wales it was generally dry with north-easterly winds, cloudy and rather cold in eastern districts but milder and sunnier in the west and north. In Scotland wind was generally north-westerly and weather cloudy with occasional rain. Arctic air reached Scotland on the 3rd but in the south it was sunny and warm with temperatures rising well into the sixties, except near the east coast, and reaching 70°F. at Poole, while Plymouth reported 13·5 hours of sunshine. With the spread of the arctic air southwards, the following day was about 10°F. colder, and on the 5th light sleet and snow showers reached as far south as East Anglia. Nearly the whole of the month's rain fell during a two-weeks period of rather thundery, cyclonic weather which commenced on the 7th. Winds backed to the south and there was widespread rain on the 7th and 8th, as pressure fell generally and fronts from the Atlantic moved into the western part of the country, and on the 9th rain was heavy and prolonged locally, some places recording nearly an inch during 24 hours. Extensive early morning fog persisted in many parts of central and southern England until midday on the 10th, but on the 11th one centre of a complex depression in the eastern Atlantic entered our south-west approaches, afterwards swinging north-east over the country, giving widespread thunderstorms, particularly on the 12th. The complex depression remained to the west of Ireland during the next three days and there were further outbreaks of thundery rain and scattered thunderstorms in many places, and on the 16th a small secondary moved north-eastwards from the Irish Sea to the northern North Sea accompanied by strong winds, heavy showers and local thunderstorms. A depression formed off south-west England on a trailing cold front on the 17th and continued to deepen as it moved over the Irish Sea and thence to north-east Scotland; rainfall was widespread and heavy in places near the centre of the depression, more than one inch being recorded at both Valley and Ronaldsway in 24 hours. The following day was fine and sunny as pressure rose generally over the British Isles, and after the passage of a further rain belt on the 20th, high pressure became established over the whole country. For most of the remainder of the month pressure was highest to the north and north-west of the country, with easterly winds in the south, which were strong at times in the English Channel. The 26th and 27th were particularly sunny days with more than 14 hours of sunshine in many places but on the 28th dull weather reached Scotland from the north-west and spread slowly south. During the last few days of the month there was a good deal of cloud in the east and Midlands but long sunny periods in the west.

The dry weather of April continued in parts of Wales and the western half of England during the first week of May. Many stations which commenced a dry period about April 20th had no measurable rain until May 6th, and on that day absolute droughts of 41 days were reported from stations in the Lower Wye Valley. Places along the east coast reported less than half their average amount of rainfall, while Anglesey had more than 150 per cent. In England and Wales the total rainfall during April and May was the lowest for these two months since 1896. The severe frosts of the 5th to 7th caused widespread but rather variable damage particularly in the Midlands, East Anglia and Kent; many growers fear that summer crops will be about 10 days late for this reason. The break in the drought was welcome but after the prolonged sunshine during the last week the land became very dry and seed germination poor.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	76	23	−1·1	83	−1	111
Scotland	74	18	−0.6	74	−2	107
Northern Ireland ...	69	27	−0·4	80	−4	108

RAINFALL OF MAY 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	1·22	69	*Glam.*	Cardiff, Penylan	1·73	71
Kent	Dover	1·50	90	*Pemb.*	Tenby	2·52	110
,,	Edenbridge, Falconhurst	1·65	89	*Radnor*	Tyrmynydd	3·35	98
Sussex	Compton, Compton Ho.	1·61	73	*Mont.*	Lake Vyrnwy	3·31	103
,,	Worthing, Beach Ho. Pk.	·86	52	*Mer.*	Blaenau Festiniog	4·54	80
Hants.	St. Catherine's L'thouse	·66	40	,,	Aberdovey	1·95	78
,,	Southampton (East Pk.)	1·57	79	*Carn.*	Llandudno	1·63	92
,,	South Farnborough	1·15	66	*Angl.*	Llanerchymedd	3·59	153
Herts.	Harpenden, Rothamsted	1·28	66	*I. Man*	Douglas, Borough Cem.	3·07	123
Bucks.	Slough, Upton	1·13	67	*Wigtown*	Newton Stewart	3·42	130
Oxford	Oxford, Radcliffe	1·66	89	*Dumf.*	Dumfries, Crichton R.I.	3·02	110
N'hants.	Wellingboro' Swanspool	1·70	88	,,	Eskdalemuir Obsy.	2·19	66
Essex	Southend, W. W.	1·19	82	*Roxb.*	Crailing	1·40	70
Suffolk	Felixstowe	1·55	117	*Peebles*	Stobo Castle	1·90	84
,,	Lowestoft Sec. School	1·39	86	*Berwick*	Marchmont House	1·41	57
,,	Bury St. Ed., Westley H.	1·26	69	*E. Loth.*	North Berwick Gas Wks.	1·44	73
Norfolk	Sandringham Ho. Gdns.	1·45	79	*Midl'n.*	Edinburgh, Blackf'd. H.	1·55	76
Wilts.	Aldbourne	1·93	93	*Lanark*	Hamilton W. W., T'nhill	2·08	87
Dorset	Creech Grange	2·01	99	*Ayr*	Prestwick	1·90	97
,,	Beaminster, East St.	2·40	116	,,	Glen Afton, Ayr San.	3·20	107
Devon	Teignmouth, Den Gdns.	1·78	97	*Renfrew*	Greenock, Prospect Hill	2·28	70
,,	Ilfracombe	1·79	87	*Bute*	Rothesay, Ardencraig	...	...
,,	Princetown	4·28	100	*Argyll*	Morven, Drimnin	1·46	45
Cornwall	Bude, School House	1·57	85	,,	Poltalloch	2·14	74
,,	Penzance	3·19	144	,,	Inveraray Castle	2·09	53
,,	St. Austell	3·28	136	,,	Islay, Eallabus	1·72	65
,,	Scilly, Tresco Abbey	1·28	76	,,	Tiree	2·76	110
Somerset	Taunton	1·57	92	*Kinross*	Loch Leven Sluice	1·91	78
Glos.	Cirencester	1·59	75	*Fife*	Leuchars Airfield	1·26	65
Salop	Church Stretton	1·77	70	*Perth*	Loch Dhu	3·98	89
,,	Shrewsbury, Monkmore	1·45	74	,,	Crieff, Strathearn Hyd.	2·69	108
Worcs.	Malvern, Free Library	1·82	84	,,	Pitlochry, Fincastle	1·92	91
Warwick	Birmingham, Edgbaston	1·26	53	*Angus*	Montrose Hospital	1·60	78
Leics.	Thornton Reservoir	1·31	65	*Aberd.*	Braemar	1·09	46
Lincs.	Boston, Skirbeck	1·90	108	,,	Dyce, Craibstone	1·52	60
,,	Skegness, Marine Gdns.	2·00	118	,,	New Deer School House	1·06	49
Notts.	Mansfield, Carr Bank	·84	40	*Moray*	Gordon Castle	1·35	64
Derby	Buxton, Terrace Slopes	2·49	80	*Nairn*	Nairn, Achareidh	·83	47
Ches.	Bidston Observatory	1·39	73	*Inverness*	Loch Ness, Garthbeg	1·31	53
,,	Manchester, Ringway	1·45	68	,,	Loch Hourn, Kinl'hourn	3·25	61
Lancs.	Stonyhurst College	2·16	76	,,	Fort William, Teviot	2·16	55
,,	Squires Gate	3·08	148	,,	Skye, Broadford	...	...
Yorks.	Wakefield, Clarence Pk.	1·35	69	,,	Skye, Duntulm	2·11	74
,,	Hull, Pearson Park	1·14	59	*R. & C.*	Tain, Mayfield	1·46	71
,,	Felixkirk, Mt. St. John	1·37	73	,,	Inverbroom, Glackour	1·49	50
,,	York Museum	·94	47	,,	Achnashellach	2·15	51
,,	Scarborough	·93	49	*Suth.*	Lochinver, Bank Ho.	2·23	88
,,	Middlesbrough	1·04	54	*Caith.*	Wick Airfield	1·33	64
,,	Baldersdale, Hury Res.	2·05	83	*Shetland*	Lerwick Observatory	2·42	116
Norl'd.	Newcastle, Leazes Pk.	1·53	77	*Ferm.*	Crom Castle	2·12	76
,,	Bellingham, High Green	1·52	63	*Armagh*	Armagh Observatory	2·43	102
,,	Lilburn Tower Gdns.	1·90	82	*Down*	Seaforde	2·89	110
Cumb.	Geltsdale	2·67	103	*Antrim*	Aldergrove Airfield	1·74	77
,,	Keswick, High Hill	2·87	90	,,	Ballymena, Harryville	1·55	54
,,	Ravenglass, The Grove	2·90	104	*L'derry*	Garvagh, Moneydig	1·94	76
Mon.	A'gavenny, Plâs Derwen	2·44	82	,,	Londonderry, Creggan	1·49	57
Glam.	Ystalyfera, Wern House	3·47	99	*Tyrone*	Omagh, Edenfel	2·20	85

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt·37 K16.