

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 76. NO. 904. OCTOBER, 1947

DIRECTION-FINDING AND THE MEASUREMENT OF WIND BY RADIO

BY D. N. HARRISON, D. PHIL.

It was in 1937 that the first practical steps were taken by the British Meteorological Office towards the development of radio-sonde. At that time "radio-sonde" meant an instrument for signalling temperature and humidity, but today the word is applied to the whole process of exploring the upper atmosphere with balloon-borne radio apparatus; by this means measurements of temperature, relative humidity and wind are regularly obtained, and if in the future our instruments can be made to tell us the dew point, density of ionization or of ozone or other gases, intensity of solar or cosmic radiation, magnetic field, or any other quantity in which geophysicists may become interested, no doubt these observations will legitimately be included in the term "radio-sonde" and will become part of the routine duties of Meteorological Office observers. In this article we are concerned primarily with wind measurements, and the measurement of temperature and humidity will only be touched upon in so far as it is necessary for an understanding of the development of present technique.

The Director's decision was that a method should be developed for the measurement of temperature, humidity and wind with one balloon-borne transmitter. There were already in existence (a) the radio-sondes referred to above and (b) a well established technique of direction-finding by radio between stations on land or sea, or aircraft; we will consider these in turn.

There are three basic methods by which temperature (for instance) can be signalled by radio apparatus:

- (1) A variable frequency, which may be either the radio frequency or a modulation frequency.

- (2) The chronometric method, or Ol'ond cycle, in which the temperature is measured by the variable time interval between two contacts which are repeated cyclically.

(3) A series of arbitrary signals, such as morse signs, occurring at pre-determined temperatures.

Instruments working on all these principles had been made in various countries, but none up to that time in Great Britain.

Direction-finding is basically the operation of observing the direction of arrival of a signal, using either the phase difference of the E.M.F.s induced in a pair of receiving aerials, or the E.M.F. round a closed loop induced by the oscillating magnetic flux through it. Either the aerial system is fixed and consists of two pairs of aerials or two coils in perpendicular planes, the direction being measured by comparing the E.M.F.s with a radio-goniometer ; or it consists of a single pair or coil which can be rotated about a vertical axis and, by noting the changes of signal strength, set in the plane of the wave front, which is the position of minimum pick-up.

Direction-finding can be applied to the measurement of wind if simultaneous observations of the bearing of a balloon-borne transmitter are made from two stations at regular intervals of time. The points of intersection of the rays are the plan positions of the balloon, and the displacement between successive points is a measure of the vector mean wind in the interval, that is, over the layer of finite depth through which the balloon has ascended.

Neither temperature nor wind measurements are of any use unless it is known where they are made, and this means, in addition to the plan position, the height above the earth. Since it was not practicable to design the direction-finders to measure angles of elevation, the transmitter is made to signal the pressure in a similar way to the temperature. The temperature and wind measurements are then related directly to pressure, or if desired the height can be calculated from the pressure and temperature.

For direction-finding the following conditions are desirable :

(1) A constant radio frequency, since the signal has to pass through a receiver, and the operator cannot be continually tuning in. Thus any radio-sonde transmitter with a variable radio frequency was ruled out, even if it had not been objectionable in other ways.

(2) A continuous signal, since observations are made either aurally or with a current meter or cathode-ray oscillograph. This rendered unsuitable radio-sonde methods using discontinuous signals, that is, methods (2) and (3) above.

The remaining method, a variable modulation frequency, was employed in a transmitter already in course of development, and it was found that this gave a signal suitable for direction-finding. In addition, a vertically polarised signal is required, that is to say, one in which the electric vector is in a vertical plane and the magnetic vector horizontal. Such a signal is provided by a vertical transmitting aerial, and therefore the transmitter is suspended from the balloon by its aerial.

In Meteorological Office direction-finders rotating aerials are used. The signal picked up is passed to a receiver and presented to the observer as an audible signal in a pair of headphones. The observer hears, in fact, the music

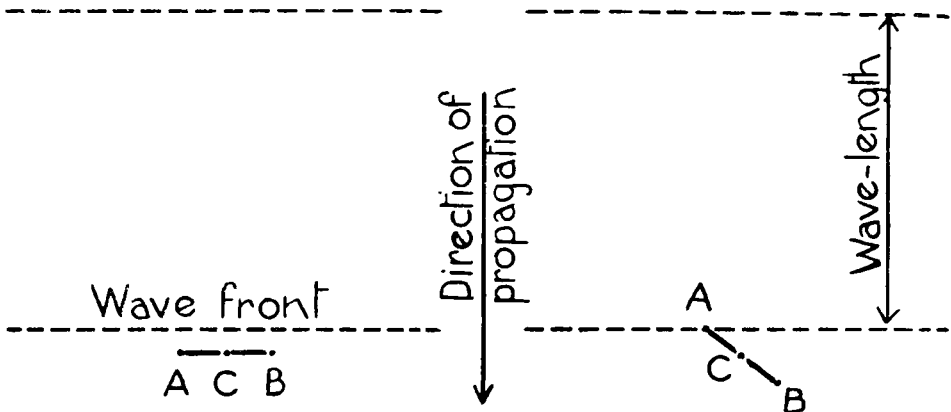
which is being broadcast by the transmitter, music consisting of a single note whose pitch varies with the pressure, temperature and relative humidity of the atmosphere at the point where the transmitter is. He is not concerned with these variations of pitch, but with the signal strength or loudness, and the observation consists in turning the aerials until this is a minimum ; the direction of the transmitter is then at right angles to the plane of the aerials. Under ideal conditions the minimum signal strength is zero, and a very small rotation of the aerials to either side produces an audible signal, so that the direction, or apparent direction, can be determined with a high degree of accuracy ; but conditions are not always ideal, as we shall see, and the apparent direction is not always the true one.

One of the first questions to be settled, since it affects the design of the apparatus, was the wave-length to be used. The shorter the wave-length, the smaller and lighter the apparatus, an important consideration, especially for the transmitter, which has to be lifted by a balloon. Other considerations were the range from which signals would be audible and the accuracy of the D.F. bearings ; moreover, by international agreement only certain wave-lengths were available. After trials it was decided to use wave-lengths between 10.7 and 10.9 m. (frequencies : 28.0 to 27.5 Mc./sec.) All these matters were dealt with by the National Physical Laboratory for the Meteorological Office.

The next question was the choice of sites for the D.F. stations. This was of crucial importance, since the accuracy of the bearings depends greatly on the properties of the site. And it was not enough to find one good site ; two are required to form a base line, and in order to ensure continuity under all conditions three sites in the form of a triangle were ultimately found necessary. The length of base-line originally aimed at was about 10 Km., but this was increased later. There are not many parts of the country where there would be any hope of finding first-class sites for a D.F. lay-out. Search was first made in the flat country of Essex, but although this appeared promising it was found that severe interference would have been caused by one of the early radiolocation stations which had been set up in that neighbourhood ; the area finally chosen was Salisbury Plain, and the work of development was placed under the control of the Meteorological Officer at Larkhill.

In order to understand what is involved in the choice of a D.F. site, let us consider what is happening when an observation is made. Ideally we have a vertically polarised signal with a wave front in the vertical plane, travelling in a horizontal direction past the receiver. When the aerial system is set in the plane of the wave front and normal to the direction of propagation, the potential difference at the receiver input terminals is zero, since the E.M.F.s induced in the two vertical aerials, or in the vertical members of the rectangular loop, are in phase and their difference is always zero (Fig. 1). When the aerial system is rotated from the plane of the wave front (Fig. 2) the E.M.F.s are no longer in phase and an oscillating potential difference is applied to the receiver ; this may be enough to give an audible signal when the angle of rotation is only 0.1° from the zero position, and so our bearing is read with an accuracy better than the nearest tenth of a degree ; this is known as a "sharp minimum." If the signal is not arriving horizontally but from a transmitter in the air, then, provided that the plane of polarization remains vertical, the only difference is a reduction of signal strength, and no error is introduced.

Now suppose that there is another signal of the same frequency as the first, coming from a different direction ; this might be due to something on the ground picking up and reflecting or re-radiating some of the energy. Our aerials, which are parallel to the wave front of the primary signal, are not parallel to that of this secondary signal, and therefore in general an E.M.F. will be induced and there will be an audible sound in the telephones. The effect of this will depend on the phase difference between the primary and secondary signals. With the aerial system used, the effect of the secondary wave train is as though it were resolved into two components, one in the same direction as the primary and the other at right angles to it, and each of these can be resolved with respect to time into a component in phase with the primary (or in phase opposition, that is, having a phase difference of half a cycle) and



AB-aerial system, C - axis of rotation

FIG. 1—AERIAL SYSTEM IN PLANE
OF WAVE FRONT
(Plan)

FIG. 2—AERIAL SYSTEM ROTATED
FROM PLANE OF WAVE FRONT
(Plan)

a component in quadrature, that is, having a phase difference of one quarter of a cycle. The components parallel to the primary make no difference to the observation, except a small change of signal strength. Of the components at right angles to the primary, that in phase quadrature causes the minimum to be “not silent” and “flat”, that is to say, there is a sound in the telephones even in the minimum position, and although this position is not altered it is more difficult to determine accurately. The component at right angles and in phase or in opposition causes a sharp minimum to be found in a different position, and so gives rise to an error of bearing ; the apparent bearing is deflected towards the secondary ray if the phases are the same and away from it if they are opposed, and the amount of error depends on the amplitude of the secondary in relation to the primary.

It can be seen therefore that the effect of a reflected ray making a given angle with the direct ray depends on the phase difference, and this in turn depends on the "path difference" of the two rays. In Fig. 3 the path difference between the direct ray from the transmitter T to the receiver D and that which goes *via* the reflecting object A is $TA + AD - TD$. If this is a whole number of wave-lengths the two signals are in phase and the bearing obtained is Dt. If A is moved to A' and the path difference increased by half a wave-length (5.4 m. in our case), the observation gives a bearing Dt'. At an intermediate position the correct bearing DT will be found, but the minimum will be flat. If A is near to D and the transmitter far away, a movement of the transmitter from T to T' may not appreciably alter the path difference, and the angle TDt, which is the error, may only change slowly with azimuth; but if A is far from D, as in Fig. 4, it is possible for a small movement TT' of the transmitter to alter the path difference by half a wave-length, and in this case the D.F. error will change rapidly with azimuth.

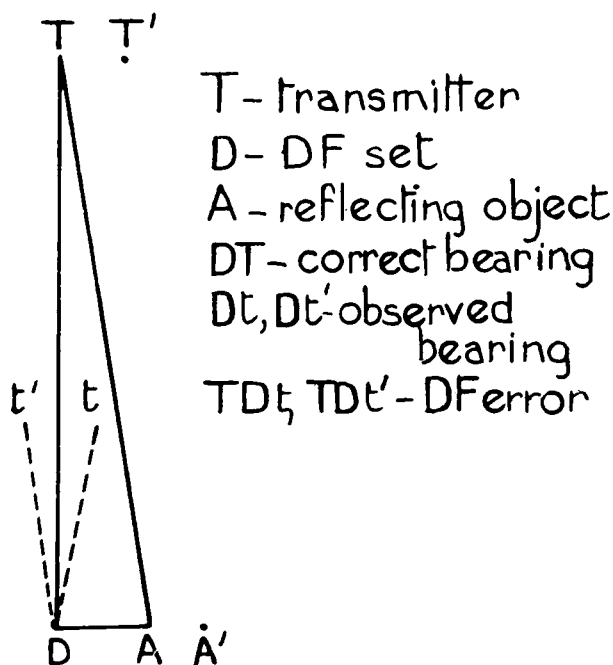


FIG. 3

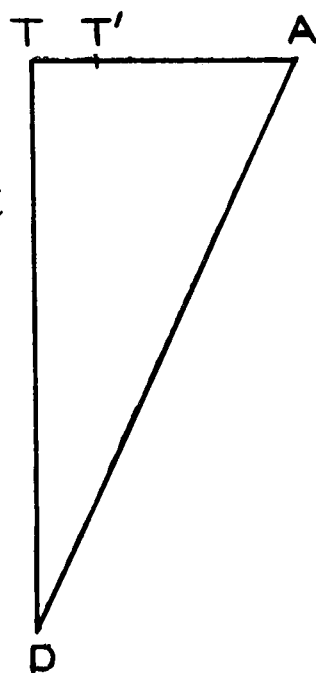


FIG. 4

In practice energy from the transmitter is picked up and scattered by innumerable objects, such as trees, buildings, hills or animals, so that the error characteristics of a site are very complicated, and great care is needed in the selection of the site and in the construction of the hut to house the D.F. set. In addition, the acquisition of a chosen site may present difficulties, owing to the conflicting claims of agriculture and meteorology.

During 1938 two sites 9 Km. apart were established near to Larkhill, and after a period of trials ascents were begun on a routine basis on July 18, 1939. In the first transmitters the modulation frequency was fixed, so that the height had to be estimated from the rate of ascent of the balloon, but at a very early stage pressure-measuring elements which varied the modulation frequency were introduced. Temperature elements came later. During 1939

and 1940 other D.F. sites were established, the lay-out was changed for various reasons and the length of base line was increased to 30 Km. (19 miles).

At first, loop aerals were used on the D.F. sets. These, however, suffer from the disadvantage that the unwanted horizontally polarised component of the signal, introduced by the swinging of the transmitter on its suspension, causes variations in reading, which increase with the angle of elevation. The loops were soon replaced by aerals of the Adcock type (see photograph facing p. 224), which are much less sensitive to changes in the plane of polarization. Incidentally, however, it is interesting to note that this objectionable phenomenon has been turned to good account in the measurement of atmospheric turbulence by observations with a loop aerial.

In those early days communication between the D.F. sites and the control-office at Larkhill was by means of portable wireless sets, which had to be removed from the huts during the observations, and brought back after the ascent for the operator to pass in his readings to the plotter (in code, in case the enemy should hear) ; if the sets failed, the nearest public telephone was used, and if this failed nothing could be done until the operator had returned to Control by car. By the end of 1940, however, a telephone system was in operation, by means of which all D.F. sites were in continuous communication with Control and the flight of the balloon could be followed from minute to minute. The starting point of the ascent was chosen according to the expected wind, with a view to getting favourable angles of intersection of the bearings and preventing the balloon from going near the base-line where it could not be located with accuracy. This meant that a party of men had to be sent by road, with cylinders of hydrogen and other gear, sometimes as much as 30 miles, to prepare the balloon and have it ready at the appointed place and time.

Ascents were made once, twice or three times a day, day and night, according to a fixed programme, and in all weathers. Many were the hardships endured by the radio-wind operators. After allaying the suspicions of the local police, to fill and manage a balloon 6 ft. in diameter in a strong wind, in the lee of some building or haystack, with or without an admiring crowd, is itself no small feat, even in daylight. Add to this darkness, a temperature below freezing, perhaps rain or snow, and the blocking of the valve with ice through the expansion of the hydrogen as it issues from the cylinder. Eventually all is ready, and balloon and transmitter are launched without suffering shipwreck and without the suspension wrapping itself round a tree. The operators ring up Control from the near-by telephone box (they took care that there was one) to make sure all is well. "No signal," says Control : the transmitter has failed, and they must begin again. It would not be surprising if the boys got to know those villages where a friendly cup of tea was likely to be offered.

The D.F. men also had their adventures. D.F. sites are in lonely places, and strange figures frequenting lonely huts by night, A.D. 1940, were apt to arouse the curiosity of military patrols, especially if they happened to be wearing flying-suits for warmth which made them look like enemy parachutists. Or after the night's work you might fail to make rendezvous with the van which was to take you back to quarters ; it was then a very exhausted man who finally arrived. Or again, a few years later, you might be stationed at a remote site in Shetland, living on the job and doing your own house-

keeping, your sole *raison d'être* to make D.F. observations ; after you had been cut off by snow-drifts for a spell, supplies dropped by aeroplane would not have come amiss, and you would not have objected to returning to base in dinghy and pinnacle when the land approaches were impassable.

Nor must we forget the drivers, who had their full share of these hardships, and without whose services the work could not have been done.

The year 1942 saw the establishment of a third D.F. site near Larkhill, forming, with the two already in existence, a triangle with sides of 30 Km. or more. This made possible the abandonment of the "mobile release" technique, and the use of the control station as the starting point for all ascents, a great economy of effort. The Ford van used for these expeditions was also abandoned. We calculated that it had travelled 100,000 miles in three years, and it was only one of several vehicles in use.

Fig. 5 shows a portion of a typical graph, obtained by plotting the simultaneous readings made at 1 minute intervals at the three D.F. sites (these are outside the figure). If the observations were perfectly accurate they would meet at a point, but by reason of the errors they form triangles. The balloon is assumed to be at the "inscribed centre" of the triangle. Since the wind is measured by the displacement between successive points, it will be seen that constant or slowly varying D.F. errors, even though large, may have a less adverse effect on accuracy than smaller errors which vary erratically from minute to minute. Hence the characteristics of the D.F. sites are all-important.

During 1941 another radio-sonde station was established at Fazakerley, near Liverpool, and this was followed by stations at Downham Market (Norfolk) and Lerwick (Shetland). These locations were dictated largely by meteorological considerations, and owing to the nature of the country the best D.F. sites available were in some cases very inferior. Nevertheless, at each station three D.F. sites were set up, with base lines varying in length from 30 Km. to 75 Km. (47 miles). Eventually all four stations were working to a programme of four ascents per day. In this way measurements of wind direction and speed were obtained with great regularity up to a height of some 20 Km. (12 miles) above the earth, the limiting factor being the size and quality of the balloons obtainable. It is to the credit of the British manufacturers that such good results were obtained during the period of rubber shortage.

With the advent of radar it became apparent that a new tool was to hand, which sooner or later would supersede direction-finding in the measurement of winds. The D.F. method presents a considerable administrative problem in the transport of staff to and from the sites. It was found by trials that radar sets, designed to plot the tracks of aircraft, could follow a balloon carrying a reflector instead of a radio-sonde transmitter, and, operating from one fixed point, could locate it in plan and in height with much greater accuracy than the radio-sonde method was capable of, even under the best conditions. After the war the Meteorological Office acquired a number of surplus Army radar sets, and these have replaced the D.F. sets at all stations except Larkhill, and will be used at radio-sonde stations in many parts of the world. These radar sets have the disadvantage that their range is limited, and when winds are strong observations are not obtained up to the bursting point of the balloon. In view of the importance of wind measurements in the stratosphere it was

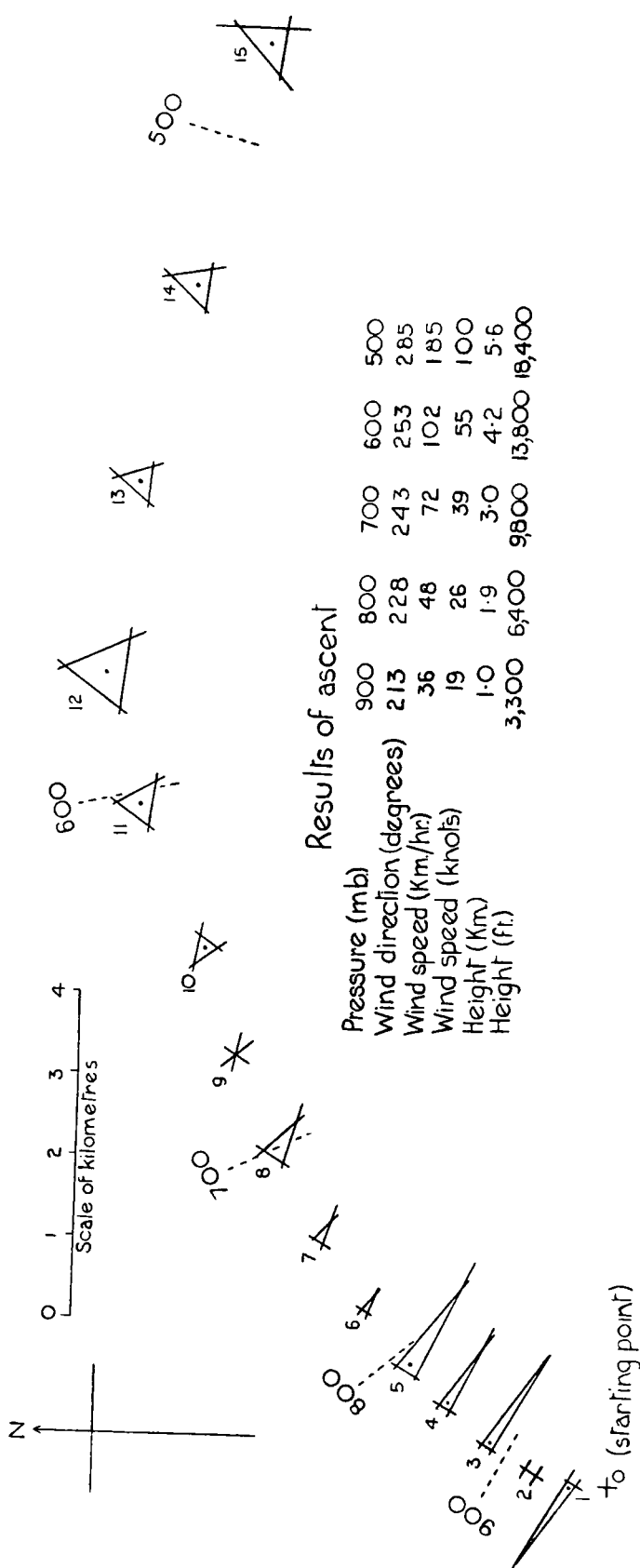
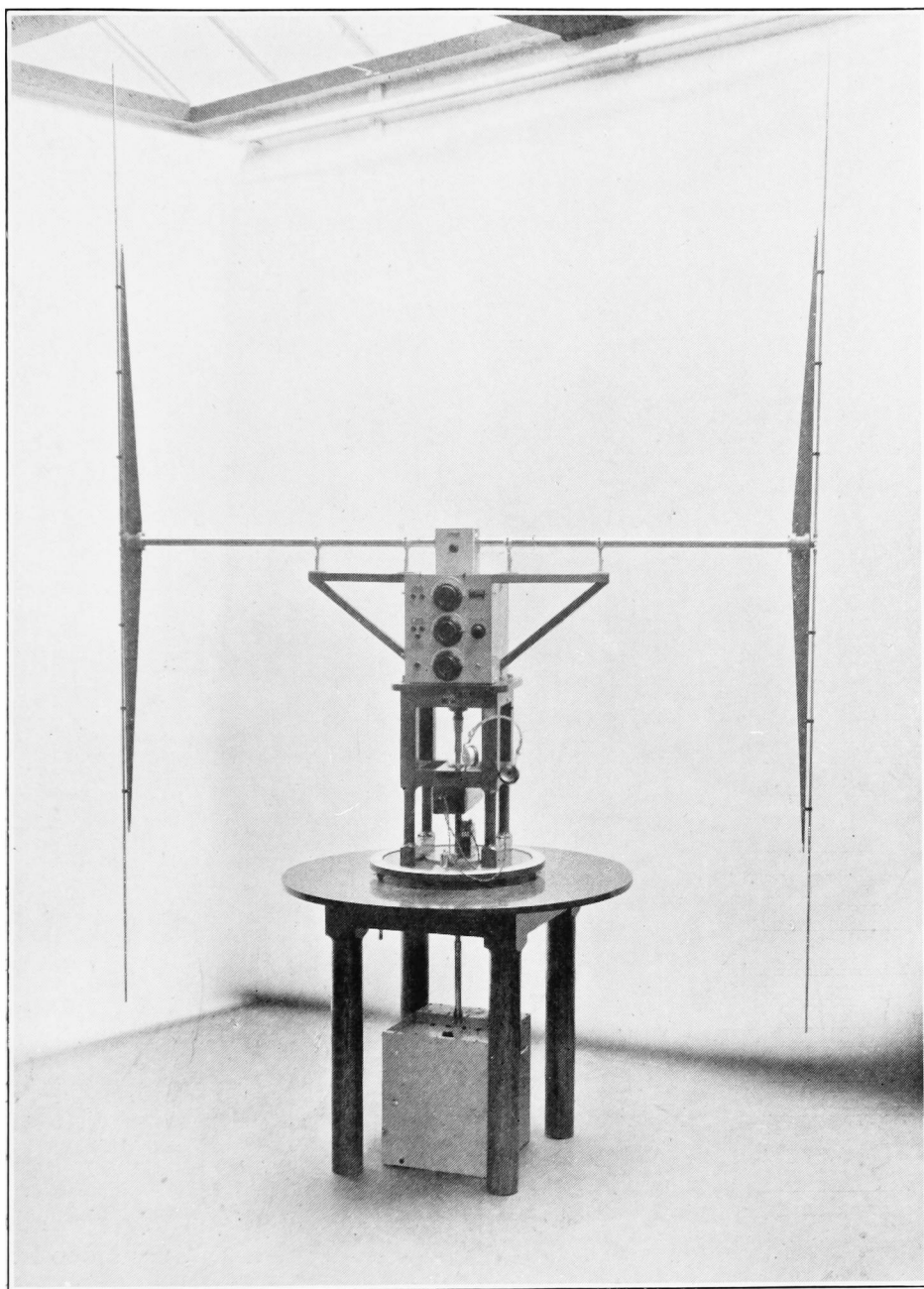


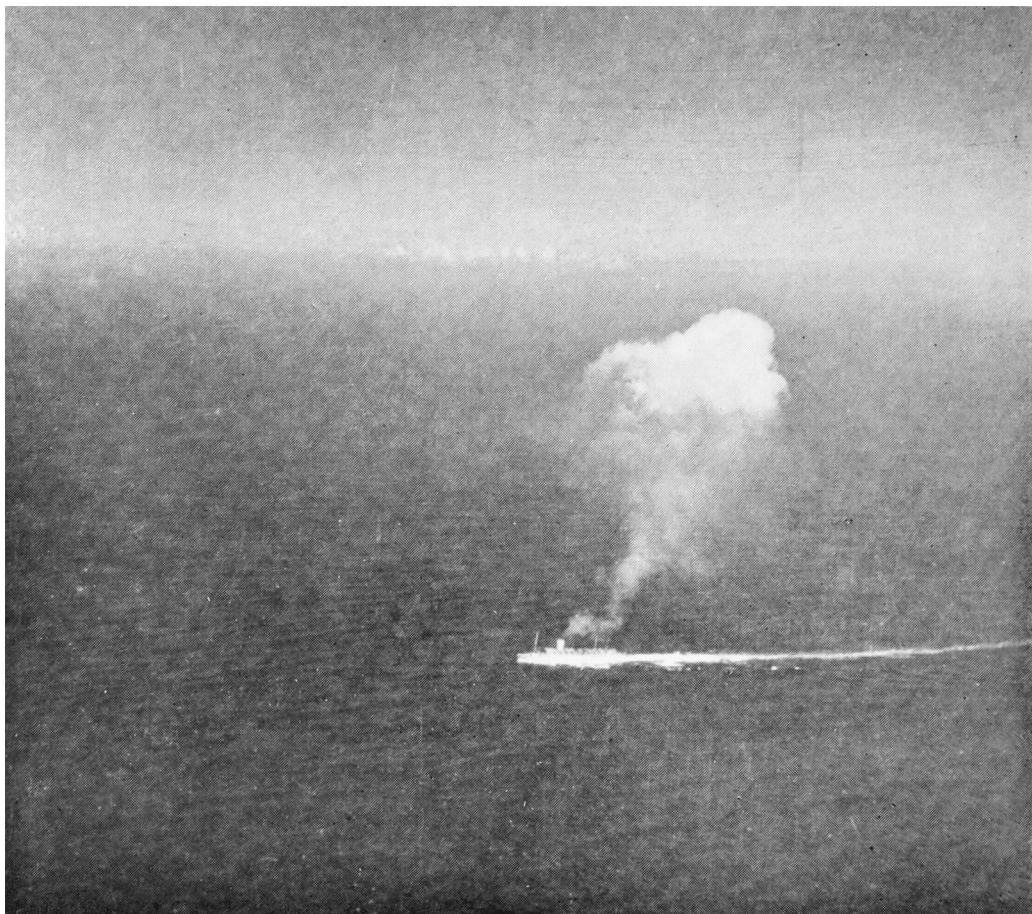
FIG. 5—GRAPH OF D.F. BEARINGS
($\frac{1}{2}$ size of original graph)

The smaller figures indicate the time from start in minutes, the larger figures with dotted lines intersecting the balloon track indicate the pressure in millibars.



COMPLETE DIRECTION FINDER

For telephone intercommunication a breast microphone is plugged into a jack mounted on the rotor.



Photograph by R.A.F.

CLOUD FORMED OVER THE SMOKE TRAIL OF A MOVING VESSEL

This photograph was taken at 1750 G.M.T., June 2, 1944, at 41°07'N. 30°20'W. The captain of the aircraft escorting the ship reported that the cloud fragment formed repeatedly over the smoke trail, lasted for five to ten minutes and then dispersed. This happened about three times per hour.

Aircraft operating in the area throughout the day gave average conditions as 1 to 3 tenths cloud, base 1,200–1,300 ft., tops mainly under 2,000 ft. but occasionally 2,500 ft. ; the temperature at 1,800 ft. was given as 68°F. Examination of the synoptic chart at 1800 G.M.T., June 2, 1944, gives a reasonable estimation of surface conditions as dry-bulb temperature 67° or 68°F., dew point 64°F., giving a condensation level of about 1,000 ft., there being a marked inversion above, as was indicated by the measured temperature of 68°F.

decided that at one station the D.F. method should be retained. Thus the Larkhill direction-finders, which were the first to be installed, will be the last to disappear. It is a proof of the skill of the radio experts of the National Physical Laboratory that, in spite of a continual urge for improvement of the results, the sets and method of observation have remained practically unchanged for more than eight years. Radar sets of another type, with longer range but lower accuracy, are in use for wind measurements on the Atlantic weather ships.

What of the future ?

Experiments are being made in the manufacture of larger balloons, with which it is hoped that heights above 30 Km. will be reached and information gained about hitherto unexplored regions of the atmosphere. In instrumental techniques, the tendency is toward greater accuracy, and more automatic operation, making less demand on the skill of the observers and more on that of the maintenance technicians. Thus increasingly do we cut ourselves off from Mother Nature, as we pursue our researches into her secrets. The science of the air becomes the technique of the wireless valve and the differential equation, for breath and sunshine we substitute the automatic recorder and the calibration graph, for the "wind on the heath, brother," the monthly tabulation; and, instead of life-giving contact with the elements we study, we watch in a darkened room Nature's face metamorphosed into green or blue geometry on the screen of a cathode-ray tube. More of thought and less of feeling. Yet if these things speak less to our instincts and starve some part of our nature, at least we can say that they minister to the mathematician in us, and every technical advance, while restricting the scope for art and skill of hand and eye in one direction, widens that of mind in another and opens fresh opportunities for adventure on the sea, in the air or in distant parts of the earth.

COLD POOLS

BY C. K. M. DOUGLAS, B.A.

Definition.—In the course of the last five years the term "cold pool" has developed among upper air analysts and has become increasingly widespread among forecasters generally. It is an outcome of modern upper air technique, and by way of introduction it is necessary to describe this briefly. Upper air charts are based on the heights of isobaric surfaces. The contours of heights above sea level can be regarded as the same as isobars for most practical purposes. The contours of the height interval between two isobaric surfaces are called "thickness lines", and it can easily be shown that the thickness depends only on the temperature of the layer of air between the isobaric surfaces. The standard surfaces in this country are 1000, 700, 500 and 300 mb. The 1000 mb. contours represent the sea-level isobaric chart in terms of heights which are positive or negative according as the sea-level pressure is above or below 1000 mb. The thickness of the whole layer from 1000 mb. to an upper isobaric surface is called the total thickness, and the thickness between two other isobaric surfaces (e.g. 700 to 500 mb.) is called the partial thickness. The geostrophic wind derived from the total thickness lines is the "thermal" wind, a term which was in use in the 1914-18 war if not

earlier. Its theoretical basis was developed by Napier Shaw about 1912. Recently the term "partial thermal wind" has been introduced, corresponding with partial thicknesses.

A cold pool is defined by at least one closed thickness line. In marginal cases, especially where the network of observations is wide, the drawing may be to some extent arbitrary, and the existence of a closed contour may depend on the unit employed. A small and weak cold pool may be limited to one set of partial thicknesses, but the more pronounced pools, with which this note is chiefly concerned, extend through the troposphere. Some of the weak ones are an incidental product of a heterogeneous atmosphere. Cold pools are most frequent where the latitudinal temperature gradient is weak; in the neighbourhood of the British Isles this gradient is low for the latitude and the incidence of cold pools is relatively high.

In general, deep cold air is much more limited in area than shallow cold air, and the tendency is for the cold air to subside and spread out laterally. The cold air is in most cases bounded partly by fronts, but is practically never entirely so bounded. There are also wide zones of transition, and to describe a cold pool as dome-shaped is a very rough statement which should be interpreted with caution.

Cold pools and upper depression.—We have seen that absolute contours give the pressure distribution aloft, while thickness lines show the temperature distribution. These are closely related variables, and both are necessary for a description of atmospheric structure. Their relative importance varies according to the problem in hand. The pressure aloft depends partly on sea-level pressure and partly on the temperature of the underlying column of air; the importance of the temperature increases upwards and is dominant in the upper half of the troposphere. Thus a well marked cold pool is also an upper depression, though they do not coincide exactly unless the sea-level depression also coincides. The converse proposition that an upper depression is a cold pool does not hold so regularly. If there is no horizontal temperature gradient the geostrophic wind decreases slightly with height, varying inversely as the absolute temperature, the decrease from sea level to 500 mb. being of the order of 10 per cent. Some upper depressions have weaker E. winds than their sea-level counterparts and the thickness charts show pronounced troughs rather than closed lines, and "cold tongue" appears to be the best descriptive term.

The term "warm pool" has been little used, perhaps because the displacements between an upper anticyclone and a warm pool is generally smaller than between a cold pool and an upper depression. This is due to weaker surface gradients and the dominant influence of warming by subsidence. For over thirty years "warm anticyclone" has been the recognised term to describe the whole three-dimensional system and it should remain so, but logically "warm pool" should be used to describe closed (highs on thickness charts. The central areas of cold pools and anticyclones are often large and flat. The "cold depression" is the analogous term to the warm anticyclone, and it should be preferred to cold pool whenever pressure and wind systems rather than temperature distribution are under discussion. The brevity of the word "pool" is undoubtedly an attraction.

The formation of cold pools.—The great majority of cold pools in our area, including all the pronounced cases, are due to outbreaks of polar air.

There is first a tongue of cold air with a trough on the thickness lines, and then the cold air is cut off to northward and a pool of cold air is left. It was pointed out by R. C. Sutcliffe, in 1942, in a memorandum circulated officially, that since the thermal wind is parallel to the thickness lines the sea-level isobars give the geostrophic advection of total thickness. Thus the important thing for the initial development of the cold trough is a pronounced north component in the sea-level geostrophic wind. The next stage is the cutting off of the cold supply and the warming by advection, subsidence, or both combined, of the northern part of the cold trough and the preservation of its southern end, so that it becomes a cold pool. This is bound up with the problem of the life history of depressions.

The existence of cold depressions extending through the troposphere was discovered by W. H. Dines about 40 years ago, and when the Norwegian ideas were introduced about 1920 the cold depression was identified with the "dying" depression. More precisely, this is a depression which has reached or passed its most intense phase, and this is the most frequent type of depression in our area. The degree of coldness is very variable, only a proportion of cold depressions have a definite cold pool over them and the centre of the cold pool does not always coincide with the sea-level or upper depression at any stage. Though that part of the 500-mb. absolute height which depends on the temperature of the column of air below is found on the average to be dominant, this does not hold when the temperature gradient is weak and the sea-level pressure gradient is strong. Weak temperature gradients are frequent near cyclonic centres, and when the circulation is intense low down the position of the 500-mb. centre may be closer to the sea-level centre than to the centre of the cold pool.

Our illustration shows a cold pool over north-west France and another in the Gulf of Lyons. The sea-level centre was over England, and a trough over west France was moving slowly east and filling up. The wedge of relatively warm air protruding westward over England was associated with the occlusions. There was continuous rain over most of Great Britain, but only showers in France. The fact that cold pools are normally behind the continuous rain is one reason for attributing them to advection rather than to the ascent of air. The absolute 500-mb. contours show a large flat area over England and France. In spite of the complications mentioned above there are many old depressions, especially when the occlusion has been spiralled and destroyed, for which a rotating cylinder may serve as a rough working model. Even in the simplest cases the term vertical axis is almost never strictly justified. Since the height of a depression is so much less than its diameter a vertical axis is not to be expected. Most of the best examples of roughly cylindrical depressions with definite cold pools move south-east or south and there were more cases in 1944 than there have been since then.

In recent years there has been a large increase in our knowledge of three-dimensional structures and some increase in our understanding of the dynamical processes, but there are still great difficulties in the way of a complete understanding. In certain conditions mass ascent of air reduces the temperature on a definite isobaric surface, but in the conditions normally observed in a warm sector the amount of possible cooling due to this process is limited and the fall of temperature over the centre can be attributed mainly to advection.

The development of cyclonic circulation in the upper troposphere probably implies horizontal convergence at those levels and some subsidence of the column of air below. This must warm the column of air ; but this may not overcome the effect of the advection of colder air, and the southern extension of the upper trough may continue. If a cold pool is to form and persist subsidence must cease in that region, and this happens when the cold air spreads over the centre of the depression. The dynamical problem is a very difficult one.

The development of an actual pool involves a rise of temperature north of it. The circulation of the depression favours this, especially if there is a large warm air mass to east, as there often is in summer, but extraneous factors are generally involved, especially subsidence in a ridge of high pressure, and advection of warm air from west to north of the ridge.

The persistence and dissolution of cold pools.—When a very cold current crosses a warm sea it is heated from below very rapidly. An investigation of this problem by J. M. Craddock is a step towards a quantitative treatment. When the rate of warming is slow, a stage of equilibrium is sometimes attained between the warming by convection and the cooling by outward radiation aloft, and the cold pool may persist for many days. If a deep depression has a cold pool over it, the central pressure may rise by 30 or even 40 mb. (largely owing to surface friction) while the cold pool remains unaltered. It may outlive the depression, though rarely for long, since subsidence quickly destroys a cold pool. Absence of subsidence is sufficient in itself to produce a deficiency of upper air temperature, relative to the average for the time of year and locality. Subsidence is a common process, and its effect on the temperature may last for some time after it has ceased. In general subsidence has far more effect on temperature than has ascent of air since the ascending current is normally saturated. The whole process is essentially föhn-like. A cold pool extending to 500 mb. is very rare if the sea-level isobars below it have anti-cyclonic curvature, and it could not last long. With straight northerly isobars a cold upper trough is normal, but the mechanism for cutting off a well marked cold pool rarely exists. There is a high correlation between cold pools and cyclonic curvature at sea level, and absence of subsidence is the most important single factor. Large-scale external developments may produce subsidence of a cold pool, especially a small one, and rapidly destroy it. In addition to the adiabatic warming, there is no cold air available to replace the subsiding air, and warmer air flows in above.

New cyclonic development is apt to take place at the edge of a cold pool, and the upper and lower system may again roughly coincide later. Occasionally surface heating leads to cyclonic development close to the centre of a cold pool, as over the western English Channel on January 29–30, 1947.

Movement of cold pools.—If there is a definite sea-level pressure gradient in the area of the cold pool, there is quasi-geostrophic advection, but simple cases are rare. There is generally a slow movement related to that of dying depressions, the ideal case being a moving rotating cylinder. Sometimes a depression which has been stationary starts to move when it becomes weaker and smaller and is brought under the influence of external systems. The general empirical rule is that the depression moves in the direction of its strongest winds, though sometimes the stronger winds only show up 200 miles

or more from the centre. They usually show up at all levels, but occasionally only on the upper air charts. Close to the centre there is sometimes an approximation to a "cartwheel" vortex, and as Sir Napier Shaw pointed out there are concentric isobars in a cartwheel transported in a general current; chapter IX of Shaw's "Manual of Meteorology," Part IV, is worth reading in this connexion, as it is not self-evident that a moving system with concentric isobars can carry its air mass with it. The treatment is only approximate, since a wind system giving zero divergence of momentum does not provide for the pressure changes. A paper by C. H. B. Priestley * gives a dynamical treatment including divergence, and the conclusion is reached that a cold depression should move with its strongest winds. Though this is broadly true, there are significant departures from the rule. For example on August 4-5, 1947, a cold depression moved further south than the rule would have indicated. Recently E. Knighting has called attention to a theorem of Sir Geoffrey Taylor which makes possible a set of accelerations leading to such deviations from the simple rule.

The movement of a cold pool is probably affected by the influence of vertical movement on temperature, but most of the movement appears to be advective.

Though most cold pools move from a direction between west and north, they occasionally reach England from any direction, even from south-east, as on January 17-9 and November 1-2, 1946. On these occasions the cold air had previously come from the north; but, in winter, cold pools occasionally come west from Siberia. One of these penetrated as far west as France on December 21, 1938, with warm Mediterranean air coming up east of it and then round it.

Occasionally a cold pool moving south or south-east appears to control the motion of a sea-level depression further east, which moves almost in the opposite direction to what one would expect from its frontal structure and the associated thermal wind over it. Examples occurred near our own north-west and west coasts on October 4-5, 1945, and some 500 miles beyond our south-west seaboard on January 21-3, 1947.

Relation to forecasting.—The main forecasting applications of cold pools can be only briefly summarised. For a long time past it has been known that upper depressions and anticyclones exert a "steering" influence on smaller fast-moving cyclones. There is not yet agreement as to whether absolute contours or thickness lines are the most important for this. The problem is complex and the relative importance of the contours and thickness lines may vary according to the conditions. Owing to the persistence of the upper systems they are especially important for forecasting beyond 24 hours.

A warm front cannot penetrate a cold pool, though occasionally the surface pressure distribution suggests that it should advance. It is either delayed, as on May 10, 1947 or (more rarely) it dissipates, as on September 18-9, 1943. Frequently it is overtaken by a cold front.

The importance of cold pools for instability problems is obvious. The tephigram is the main basis for forecasting instability phenomena, but cold pools on the upper charts are very valuable for co-ordinating purposes, especially for forecasting for more than 12 hours ahead. Sometimes a small fast-

* PRIESTLEY, C. H. B.; Dynamical control of atmospheric pressure. *Quart. J. R. met. Soc.*, London, 73, 1947, p. 65.

moving cold pool confined to the upper air and undetectable on the sea-level chart is associated with sporadic thundery outbreaks along its track, chiefly in the afternoon and evening. The unexpected storm over London on the evening of August 23, 1947, provided an example of this. This small but remarkable cold pool moved quickly south-east after having previously moved west.

Most cold pools are cold at low levels also, but if they extend well above the 700-mb. level thunderstorms are normally developed by surface heating in the central area. In the absence of surface heating the weather is often fine. If a cold depression is moving, there is a slight tendency for worse weather ahead of it than behind it, but this does not hold invariably. Some moving vortices giving severe gales are accompanied by practically no rain.

The southerly thundery type in summer is associated with a cold pool or a cold trough to westward.

The formation of cold pools and their relation to depressions, briefly outlined on page 226 is part of the general forecast problem. In certain complex situations the development of a cold pool in a position west or south-west of the British Isles may prevent an expected cold outbreak from reaching England, as on October 4-5, 1945 and April 24-6, 1946, or may terminate it unexpectedly quickly as on May 3, 1947. Such developments are at present difficult to predict, but as our knowledge of cold pools increases an improvement can be hoped for. The formation of a cold pool in a suitable position, and its related isobaric features, is one of the few developments likely to produce unexpectedly high temperatures at any season. The element of surprise is more likely to work the other way, owing to a sudden advance of cold air or (in winter) its failure to move away when the pressure distribution seems to indicate that it should do so.

A METEOROLOGIST IN THE ANTARCTIC

BY H. H. LAMB, M.A.

Part I

When the new whaling factory ship *Balaena*, owned by United Whalers Ltd. of London, sailed for the Antarctic in the autumn of 1946, she carried, in addition to her whaling crew and various scientific workers whose activities were closely related to the whaling and the production of whale oil, aircraft for reconnaissance purposes and an Air Ministry meteorologist.

The company's chief object in carrying a meteorologist was to guard the safety of the aircraft and their crews against weather hazards, since the only previous attempt to use aircraft for whale-spotting in Antarctic waters (by a Norwegian company in 1929) had ended in disaster, with the loss without trace of aircraft and crew in thick weather after very little flying. The *Balaena* venture was not only completed in safety and almost without incident, but also provided an interesting example of an industrial application of meteorology in a new field, which might be further developed. It was the opinion of the leading whale-gunners in the expedition that the forecasts provided were of economic value in assisting the taking of whales, and that the organisation in another season of a direct radio-telephone liaison enabling short-period weather inquiries to be made from the small whaleboats to the meteorologist on the floating factory would further increase this economic usefulness of the forecasting service. The gunner has to decide whether to leave the body of a newly

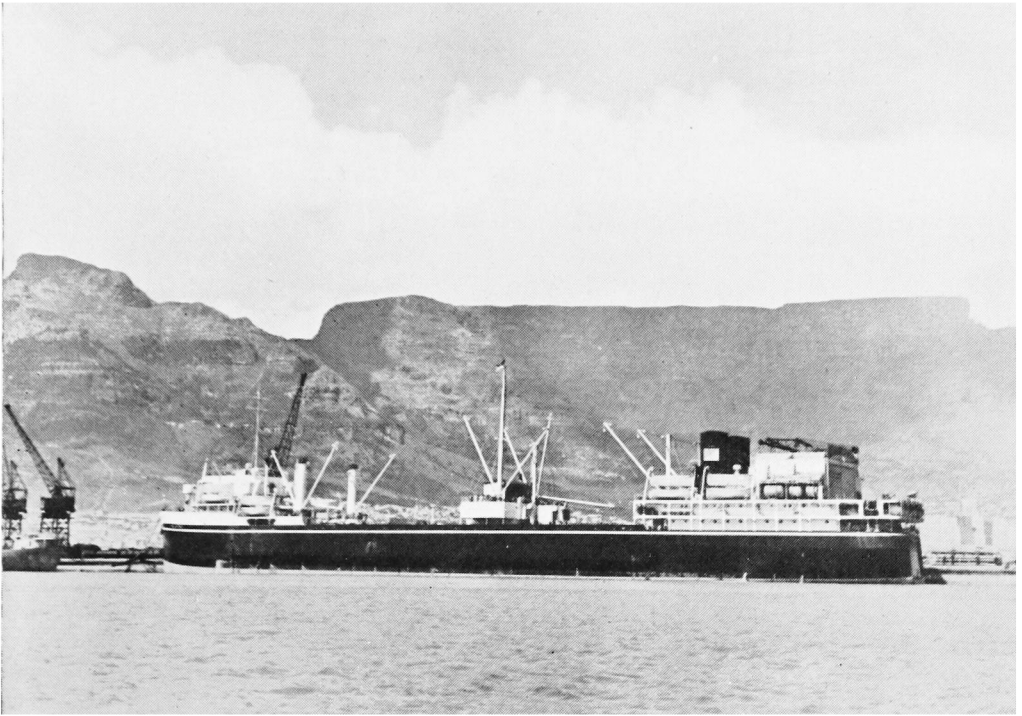
killed whale afloat, inflated with compressed air and flagged to mark its ownership, whilst he goes off after further quarry ; if thick weather is imminent he will deliver the whale to the factory without delay.

The experience was also an interesting one for the meteorologist himself. A voyage to the southern whaling grounds offered glimpses of many new places and climes, and on the professional side it presented stimulating and previously untried problems, with corresponding opportunities to show the success of applying familiar and sound meteorological techniques in an entirely new setting.

This was the first regularly maintained weather-forecasting service in the Antarctic, based upon routine daily weather maps and the same fundamental methods as are used at home, and we may be pleased that this should coincide with the first flying venture of its kind to return home with a clean safety record. That it proved possible to maintain a consistent series of weather maps over regions where the observation network was so sparse was something of a surprise, and reflects the extremely regular manner in which the theoretical weather processes work themselves out over the world's widest ocean. Indeed the rush of the departure, involving hasty preparations at short notice, and the fact that my hands were more than full throughout the expedition in tackling 6 hours of weather mapping and forecasting work each day on top of the observation programme which alone had fully occupied the meteorologist and voluntary helpers on other Antarctic expeditions, meant that until the season was well advanced I was simply applying experience of North Atlantic and Iceland meteorology to the problems of the Southern Ocean and Antarctica. It was only as the season went on that I became fully aware myself, in the light of the various tests and checks which had been possible from time to time, just how well this technique worked. At the same time I gradually managed to familiarise myself with the classical writings of Simpson and Meinardus on the meteorology of the Antarctic.

We sailed out of Belfast, where the ship had been built since the war in Harland and Wolff's yards, on September 27, 1946. The rush to have the vessel ready for the 1946-7 whaling season meant that at the date of sailing the factory existed mainly as heaps of parts on deck ; these were assembled during the voyage south and got into working order just before the whaling began. The ship was designed as a floating factory and base for twelve steam-driven whaling trawlers, known as whaleboats or catchers. These smaller vessels each of 200 to 300 tons have a gun-platform and cannon at the bows, from which the whales are shot with a harpoon that incorporates a small bomb which explodes inside the beast. *Balaena's* 32,000 tons displacement made her a big ship and a steady ship, either for those inclined to seasickness or for the meteorologist with his theodolite following pilot balloons from the flight deck astern ; but there was little enough room for all the multifarious activities on board, and the scenes of carnage on deck and the smells and atmospheric pollution from the boilers in which the whale oil—so valuable for our margarine and soap rations—was produced, imposed a severer test on the squeamish than any rough sea.

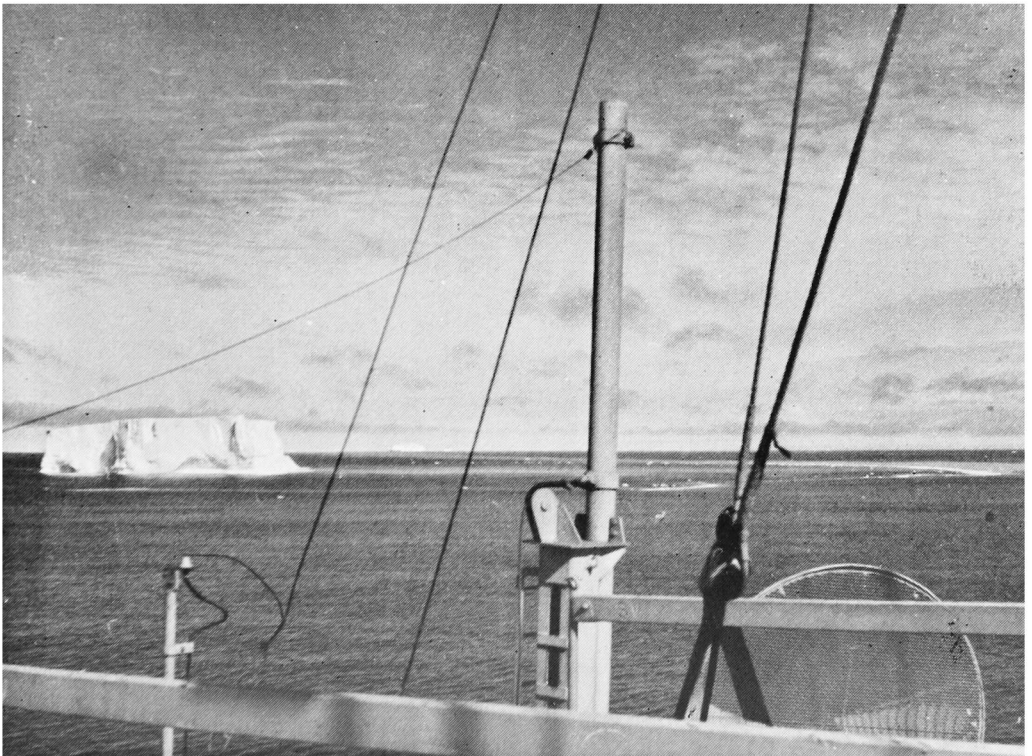
The voyage took us north through the Hebrides and across to Norway to pick up the skilled whaling crew, and from there south with calls at Southampton, the Canary Islands and Cape Town. This enabled us to stock up with fuel oil and the most enviable stores of food and drink for the five-month



Reproduced by courtesy of H. H. Lamb

WHALING FACTORY SHIP *Balaena*

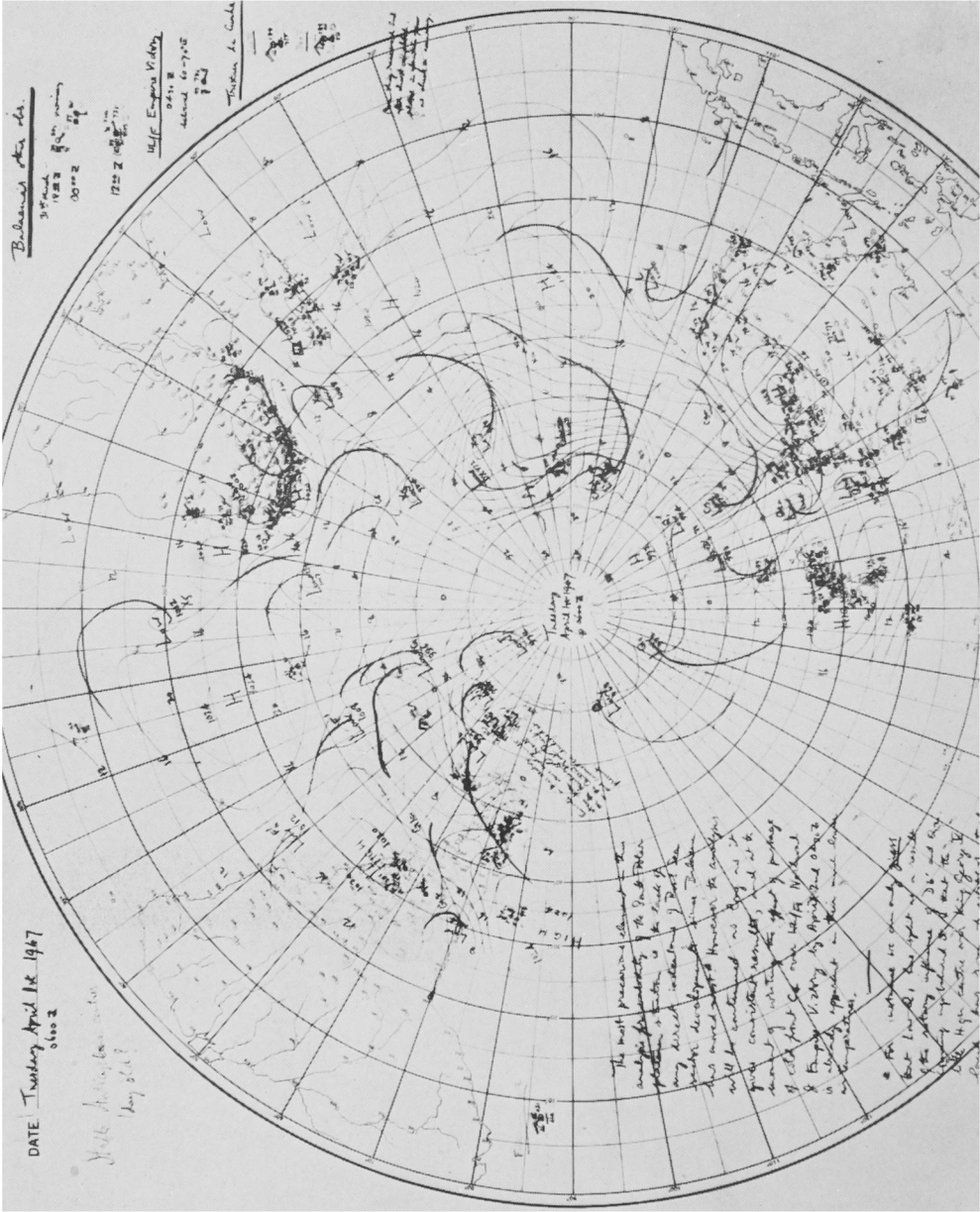
The *Balaena* in Cape Town docks at the foot of Table Mountain, November 1946.



Reproduced by courtesy of H. H. Lamb

BRILLIANT SUMMER MORNING IN ANTARCTIC WATERS, JANUARY 1947

This photograph shows a typical flat-topped tabular iceberg of the Far South with caverns at the water line. Note the brilliant white illumination of the altocumulus by iceblink or reflected light from extensive pack-ice; this cloud was estimated at 15,000-20,000 ft.



SAMPLE WORKING CHART, APRIL 1, 1947, 0600 G.M.T.
The synoptic weather pattern of the southern hemisphere derived for April 1, 1947, as completed April 2 with notes of points of uncertainty, etc., and used for forecasting for April 2-3.

sojourn amongst the ice. It also afforded a welcome dose of tropical sunshine nicely tempered by the waters of the Atlantic Ocean ; but it was a period of hard work in setting up instruments, care lest the cold-range thermometers for Antarctic use be subjected to too great heat in their stowage on board and more general preparations for work on the whaling grounds. All hands were too busy on the new ship for much help to be forthcoming ; and there was difficulty over the allocation of a meteorological working room, the need for which had not been understood. However, generous decisions were made at the eleventh hour by Mr. Trouton, Chairman of United Whalers, who was on board : a large store-room amidships was converted, furnished in Cape Town and equipped with a radio set ; and a full-time radio operator, an ex-R.A.F. pilot and operator, Mr. Robert Currie of Watford, was taken on for meteorological messages. The only drawbacks to the room provided were : first, difficulty of access, which was gained from the whaling deck by a ladder also used by the winch-drivers to reach the main winches and habitually coated in blood and fat ; and secondly the remoteness of the room from the navigating bridge, where the radiotelephone communicating with the whaling fleet was installed, and from the observation base forward on the top deck above the bridge. These snags were unavoidable at the late stage of proceedings when the allocation of the meteorological working room was decided, but they did involve the meteorologist in many journeys along the main deck, which meant wearing thigh boots as protection against the all-pervading slush produced by carnage and in which to climb over the mountainous piles of meat. These journeys were always tricky, and sometimes hazardous when the flensing knives and haulage cables were at work, but, these things apart, the enforced exercise probably helped to keep the meteorologist fit. The actual meteorological room was spacious and well adapted to its use, which also included flying control.

The aircraft were two Walrus biplanes, which were housed in a hangar aft. They normally flew at 80 knots about 1,000 ft. above the sea on reconnaissance work, but several times climbed to 10,000 ft. taking upper air temperatures. Although their whale-spotting was very successful, the whales were so unexpectedly plentiful that the most important work done in their 96 flying hours in the Antarctic was weather and ice-reconnaissance and the photographing of previously unknown stretches of the coast of Antarctica between 80° and 110° E. They could be launched by catapult or from the water with maximum free loads of 1,600 or 1,400 lbs. respectively ; of this 100-120 lbs. had to be given up to appropriate emergency gear such as dinghy, tents, sleeping bags and dehydrated rations for the three men on board.

The aircrews were mostly British ex-Fleet Air Arm personnel led by ex-R.A.F. W./Cdr. John Grierson, who made the first solo flight across Greenland in 1934. They were most co-operative and together we worked out a special flying-control technique to meet the problems of the Far South, which proved safe in our experience.

Experience taught that the general pattern of fronts and air streams over the Southern Ocean could be mapped better than had been expected ; but the area covered was wide, the charts necessarily on a small scale and the observation points far apart. This often meant one might know that a belt of fog or snow was in the offing but could not fix its position to within 30 to 50 miles, even though the observed progress and orientation of its associated cloud

system fitted the map and had been fully considered. This knitting together of the weather map and the cloud structure observable from the ship was of great importance, and gave an adequate basis for general weather forecasts covering the area of whaling operations for the next 24 hours or so (and sometimes longer), but it was still not possible to time the arrival of any given system of snow or fog with the degree of precision desirable for flight planning, in which an error of half an hour might mean disaster.

When snow or fog was believed to be in the offing at a time when a flight was planned, however, the aircraft itself could be used to supply the missing information. The technique used was for the aircraft to be sent out 30 or 50 miles from the factory directly towards the worst weather, to fix the position of this exactly or to establish a minimum range of clear weather; and this information would be signalled back to the flight control and meteorological room before the aircraft went off on another course to complete its mission. The weather map gave an idea of the pressure gradient favouring the advance of any frontal systems with which the bad weather might be associated; in general the belts of thick weather south of 60° S. were found to advance at no more than 10 to 20 knots in most situations in the Antarctic summer and they are sometimes reduced to a standstill and begin to move back in the opposite direction. These figures given for speeds of advance may be doubled in the Roaring Forties or anywhere between 40° and 60° S. The air reconnaissance and the weather map together established how long one could rely on clear weather.

On other days, when bad weather was still nearer, and on some occasions between successive snowbelts, flying was carried out in close liaison with the whaleboats up to a restricted distance. Meanwhile a weather watch was kept on the 10-mile distant horizon by a look-out posted on the "Monkey's Island" above the navigation bridge of the factory. This enabled the aircraft to be recalled safely by radiotelephone within half an hour, beating the weather in some cases by a few minutes.

Most of the fog which we experienced in eastern Antarctic waters was obviously frontal fog, occurring along isolated lines or belts, rarely more than 25 miles wide, which were thought to mark old occlusions. Frontolysis is supposed on theoretical grounds to occur only slowly and with great difficulty in high latitudes, and this seems to explain the most characteristic features of the weather of the Antarctic whaling grounds, referred to by the whalers as the "very local" (or strongly localised) weather, even over open sea far from the coast. Very long, trailing occlusions evidently survive long after the depression centres with which they were once associated have moved further east and died away. Thus the fog and snow which we experienced were nearly always arranged in distinct belts, usually continuous along their length but occasionally withered to mere patches along a line, and associated with recognisable frontal cloud sheets in all stages of activity or decay. Often these belts of thick weather were quite isolated and only 5 to 25 miles across, with fair or cloudy weather and clear visibility on either side. On other occasions, when a whole depression family had left a legacy of successive occlusions, successive and nearly parallel belts of fog or snow would be experienced with clear spaces 20 to 50 miles wide between them.

The longest flights (up to $4\frac{1}{2}$ hours duration) in the best weather were carried as far as a maximum distance of 125 miles from the ship.

(To be continued)

LETTER TO THE EDITOR

A series of waterspouts observed in the Straits of Singapore

At 1300 on August 10, 1947, from a point about 1 mile north-west of Changi airfield, I observed, to the east and distant 4-6 miles, a dark elongated cloud mass on the southern extremity of a large cumulonimbus (radar position: approximately 40 miles north-east of Changi). This projection was orientated north-east to south-west and similar in appearance to a line-squall. The remainder of the sky, apart from the huge cumulonimbus mass to the north-east, was covered with a layer of altostratus, estimated base 12,000 ft. thick, to the east and thinning off with breaks to the west. The wind was light southerly, and visibility over 20 miles.

On the under surface of this cloud projection, base approximately 2,000 ft., a funnel-shaped eruption formed while the sea surface immediately below appeared agitated. The eruption, in the shape of a thin semi-transparent column of cloud with dark edges, rapidly continued its descent, simultaneously with which the sea surface became more agitated, culminating in a column of water and spray rising to meet the descending cloud, the top appearing to merge at a height of approximately 80 ft. above the water.

After about three minutes the air column assumed a bent form with the curvature pointing southwards and the spout slowly subsided, leaving a slightly churned sea. The dark wispy outer edges of the cloud structure rotated rapidly in an anti-clockwise direction and, during its retreat to the cloud base, the less dark but apparently more solid core lagged behind the outer field by an estimated distance of 30 ft.

A reasonably accurate estimation of the rate of retreat of the cloud was 2,000 ft./min.

During the period 1330-1400 (local time) eight such phenomena occurred and at one time there were three in progress simultaneously.

By 1410 the line-squall cloud had almost dispersed and in passing over the observer at 1420 gave rise to only a very sharp shower of five-minutes duration.

With its passage a very temporary strengthening of the wind to 15-20 knots was experienced, but this gave way to a steady light easterly.

W. H. SMITH

Changi, Singapore

NOTES AND NEWS

An expression for the Coriolis force

When air is moving over the surface of the rotating earth, it is necessarily following a curved path in space and so is subject to an acceleration depending on the earth's angular velocity. This gives rise to the Coriolis force, which is most familiar through the expression $2\Omega V \sin \phi$ where V is the horizontal wind velocity, ϕ is latitude, and Ω the angular velocity of the earth about its axis. This is a horizontal force directed to the right of the wind (in the northern hemisphere) but its magnitude is independent of the direction of the wind. In a recent article in *Nature** it is stated that the Coriolis force is given by

* THORPE, W. H.; Ising's theory of bird orientation. *Nature, London*, 58, 1946, p. 903.

$2\Omega v \sin \psi$, where ψ is the angle between the wind direction and the earth's axis; as this expression does depend on the wind direction, it appears to be at variance with the more familiar result. The discrepancy, which is apparent only, arises because $2\Omega v \sin \phi$ is only the horizontal component of the total force; there is also a vertical component $2\Omega u \cos \phi$, where u is the component of wind towards the east, and it is the combination of these two which gives the expression to which attention is now drawn.

The following is a direct proof of the formula. If the wind \mathbf{V} has components u, v, w towards east, north and vertically respectively, then the Coriolis force has the following components* in these directions:—

$$-2\Omega (w \cos \phi - v \sin \phi), \quad -2\Omega u \sin \phi, \quad 2\Omega u \cos \phi,$$

so that by combining these, the resultant force is found to be given by

$$2\Omega (u^2 + v^2 \sin^2 \phi - 2vw \sin \phi \cos \phi + w^2 \cos^2 \phi)^{\frac{1}{2}}$$

Further, the projection of the wind vector on the earth's axis is $v \cos \psi$, and this is equal to the sum of the projections on that axis of the three components of \mathbf{V} , viz. u, v, w . Since these are inclined to the axis of rotation at angles, $\pi/2, \phi, \pi/2 - \phi$ respectively, it is seen that

$$v \cos \psi = v \cos \phi + w \sin \phi,$$

and therefore

$$v \sin \psi = (u^2 + v^2 \sin^2 \phi - 2vw \sin \phi \cos \phi + w^2 \cos^2 \phi)^{\frac{1}{2}}$$

The magnitude of the resultant Coriolis force is consequently $2\Omega v \sin \psi$.

This property of the Coriolis force—the fact that its magnitude is simply related to the inclination of the direction of motion to the earth's axis—has been suggested as providing the means whereby birds are enabled to orient themselves on migratory and homing flights. The Coriolis force of course acts on a bird or other object in the same way as it acts on the air itself; the suggestion, which is discussed in the article already referred to, depends on the action of this force on the fluid in the semicircular canals of the birds' inner ears. While the explanation given appears to be a possible one from the purely physical point of view, there are many difficulties on the practical and biological sides which need to be cleared up before it can be finally accepted.

A. F. CROSSLEY

Summer aurora

It is exceptional for aurora to be seen during the summer months, so exceptional that the regular aurora watch at Observatories is suspended in summer. They are, however, sometimes seen in the absence of moonlight.

Sgt. G. L. T. Stewart of the R.A.F. Station, Framlingham, Suffolk, has recently contributed detailed notes on a remarkable series of summer aurora observed by him on the ten successive nights August 12–22, 1947, and also on the aurora of July 17–18. His original notes are being preserved in the Meteorological Office Library for future use, as such data are of great value in

* BRUNT, D.; Physical and dynamical meteorology. 2nd. edn., London, 1939. p. 170.

compiling auroral statistics. It is not possible to give full details here but a brief summary of Sgt. Stewart's notes will be of general interest.

The July aurora was observed from 2230 G.M.T. on the 17th to 0200 on the 18th, the watch being brought to an end by thick fog accompanying a sea wind from NNE. Among the details noted were a pale green draped arc extending from west-north-west to east-north-east, pale pink and yellow streamers, turning to pale green, followed by reddish rays extending across from north-west to north-east and changing to green. The rays reached up to 10° altitude in the north.

Some details of the August aurora are as follows :—

12th–13th—2230 to 2258. Whitish glow in the north and pale yellow rays.

13th–14th—2250 to 2400. Faint whitish glow and rays in the north ; 2315, bright rays for 10 minutes ; 2325, bluish bright rays steady for 2–3 min. and then pulsating for 5 min. ; this was the maximum phase. Fog terminated observations at 2400.

14th–15th.—Faint northern glow with luminous west to east strips.

15th–16th—2115 to 0200. 2115, active rayed arc in the north ; 2140, bundles of long rays inclined upwards towards east and moving from west to east ; brilliant green patch on lower edge of arc in the north-north-west and motionless crimson bundle of rays in the region of Bootes ; 2200, bundles broke into "searchlight" beams, motionless for 5 min., based on arc, colours : pale blue and green ; 2220–2345, white arc sometimes pulsating ; 2345–0005, faint very active rays in northern half of sky ; 0005, revival of brightness and rays in north-west ; 0006, distorted arc and motionless broad whitish rays from west to east across the sky, bright ; 0008, oval patch of vivid green in north-north-west ; 0010, rays turning red in west for 3 min. then whitish again, stationary ; 0015, seven beams, pale cream, in the north ; 0027 introduced another period of ray activity ; 0035–0200, aurora fading but with temporary revivals from time to time.

16th–17th—2100–0200. Glow in north, some rays.

17th–18th—2100–0225. Glow in north, with whitish rays ; 0110, brightest rays of the night, whitish ; 0120, very faint rays to south and south-east ; 0225, broad greenish beam. Observations terminated by dawn.

18th–19th—2100–0010. Glow in the north, greenish with some rays.

19th–20th—2130–0030. Pale whitish glow in the north ; 2240–2305 some intense ray activity in north—whitish or pale yellow, arc at 3° altitude ; 2305, glow becoming faint ; 0030, observations terminated by deterioration of visibility.

20th–21st—2200–0100. Glow in north changing from pale green to whitish, mostly faint ; about midnight, weak ray activity ; 0100, observations abandoned.

21st–22nd—2200–0100. Similar to 20th–21st.

[During the night of August 15–16, 1947, the entire aurora was also visible from darkness until 0230 at the Jodrell Bank Experimental Station of the University of Manchester.* Radio echoes were obtained on apparatus in use for the study of meteoric ionization on frequencies of 72 Mc./sec. and 46 Mc./sec. The estimated height of the auroral cloud was 480 Km.—Ed. M.M.]

* LOVELL, A. C. B., CLEGG, J. A. and ELLVETT, C. D. ; Radio echoes from the Aurora Borealis. *Nature, London*, 160, 1947, p. 372.

WEATHER OF AUGUST, 1947

The weather of August was prevailingly anticyclonic over a broad belt extending from southern Canada and the eastern United States across the Atlantic in about 40° N. to the Azores, then north-eastwards across the British Isles and Scandinavia. Pressure exceeded 1020 mb. between Bermuda and the Azores and over the Faroes, and most of the British Isles ; a large anticyclone covered most of the latter area almost continuously from the 25th to the 31st. Depressions were concentrated mainly in the area between Labrador and Iceland, especially southern Greenland, where the mean pressure for the month fell below 1005 mb. Departures from normal exceeded + 10 mb. between Stornoway and Oslo and - 5 mb. over southern Greenland.

Under these conditions very hot dry weather prevailed over large areas. In Toronto the meetings of the Technical Commissions of the International Meteorological Organization were held in intensely hot weather varied by a few violent thunderstorms. In the British Isles the month was exceptionally hot and dry, with abundant sunshine ; it was also unusually quiet, northerly and easterly winds predominating. It was probably the warmest August over the country as a whole since before 1881 and ranked with the Augusts of 1899 and 1911. At Oxford the mean temperature for the month was the highest for August since records were first taken in 1815. The maximum temperature at Bournemouth on the 16th, 93° F., was the highest ever recorded there. The deficiency of rainfall was as unusual as the warmth ; in Scotland it was not only the driest August on record but also the driest month ; in England and Wales it was the driest August on record, that is since 1869, but not the driest month. In small, scattered areas, chiefly in the west and north of Scotland but also locally elsewhere, no measurable rain fell throughout the month. Thunderstorms occurred at times and during a storm in the London area on the 23rd, 3.32 in. of rain fell in approximately 90 minutes at Sudbury, Middlesex, a "very rare" fall ; the heavy rain was, however, very local. The duration of bright sunshine was noteworthy ; August 1899 was probably somewhat sunnier on the whole but, at a number of widely distributed stations with long records, the total sunshine for August 1947 was higher even than in 1899, for example at Oxford, Sheffield, Douglas (Isle of Man), and Aberdeen. The mean cloud amount was also exceptionally low.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of average	No. of days differ- ence from average	Per- centage of average	Per- centage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	93	38	+ 5.1	16	— 12	156	58
Scotland	87	36	+ 5.1	4	— 17	179	51
Northern Ireland ..	83	45	+ 5.1	14	— 17	187	56

RAINFALL OF AUGUST, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	·08	4	<i>Glam.</i>	Cardiff, Penylan ..	1·11	26
<i>Kent</i>	Folkestone, Cherry Gdns.	·03	1	<i>Pemb.</i>	St. Ann's Head ..	1·02	31
"	Edenbridge, Falconhurst	·12	5	<i>Card.</i>	Aberystwyth ..	·47	12
<i>Sussex</i>	Compton, Compton Ho.	·54	17	<i>Radnor</i>	Bir. W. W., Tyrmynydd	·57	11
"	Worthing, Beach Ho. Pk.	·70	31	<i>Mont.</i>	Lake Vyrnwy ..	·49	10
<i>Hants</i>	Ventnor, Roy. Nat. Hos.	·77	39	<i>Mer.</i>	Blaenau Festiniog ..	·37	3
"	Fordingbridge, Oaklands	·68	26	<i>Carn.</i>	Llandudno ..	·38	13
"	Sherborne St. John ..	·59	24	<i>Angl.</i>	Llanerchymedd ..	·58	16
<i>Herts.</i>	Royston, Therfield Rec.	·02	1	<i>I. Man.</i>	Douglas, Boro' Cem. ..	·31	8
<i>Bucks.</i>	Slough, Upton ..	·30	14	<i>Wigtown</i>	Pt. William, Monreith	·09	2
<i>Oxford</i>	Oxford, Radcliffe ..	·59	26	<i>Dumf.</i>	Dumfries, Crichton R.I.	·27	7
<i>N'hant</i>	Wellingboro', Swanspool	·00	0	"	Eskdalemuir Obsy. ..	·03	1
<i>Essex</i>	Shoeburyness ..	·53	30	<i>Roxb.</i>	Kelso, Floors ..	·22	7
<i>Suffolk</i>	Campsea Ashe, High Ho.	·69	35	<i>Peebles.</i>	Stobo Castle ..	·03	1
"	Lowestoft Sec. School ..	·15	7	<i>Berwick</i>	Marchmont House ..	·12	4
"	Bury St. Ed., Westley H.	·12	5	<i>E. Loth.</i>	North Berwick Res. ..	·20	6
<i>Norfolk</i>	Sandringham Ho. Gdns.	·03	1	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	·19	6
<i>Wilts.</i>	Bishops Cannings ..	·52	17	<i>Lanark</i>	Hamilton W. W., T'nhill	·03	1
<i>Dorset</i>	Creech Grange. . .	1·23	43	<i>Ayr</i>	Colmonell, Knockdolian	·06	1
"	Beaminster, East St.	1·02	33	"	Glen Afton, Ayr San. ..	·00	0
<i>Devon</i>	Teignmouth, Den Gdns.	1·20	53	<i>Bute</i>	Rothsay, Ardenraig ..	·03	1
"	Cullompton ..	·81	27	<i>Argyll</i>	Loch Sunart, C'dale ..	·24	4
"	Barnstaple, N. Dev. Ath.	·32	10	"	Poltalloch ..	·09	2
"	Okehampton, Uplands	·95	22	"	Inveraray Castle ..	·18	3
<i>Cornwall</i>	Bude School House ..	·32	11	"	Islay, Eallabus ..	·00	0
"	Penzance, Morrab Gdns.	·84	26	"	Tiree ..	·16	4
"	St. Austell, Trevarna ..	1·77	49	<i>Kinross</i>	Loch Leven Sluice ..	·15	4
"	Scilly, Tresco Abbey ..	1·23	45	<i>Fife</i>	Leuchars Airfield ..	·50	16
<i>Glos.</i>	Cirencester ..	·42	14	<i>Perth</i>	Loch Dhu ..	·02	0
<i>Salop</i>	Church Stretton ..	·67	20	"	Crieff, Strathearn Hyd.	·05	1
"	Cheswardine Hall ..	·74	22	"	Blair Castle Gardens	·04	1
<i>Staffs.</i>	Leek, Wall Grange, P.S.	·65	18	<i>Angus</i>	Montrose, Sunnyside ..	·07	3
<i>Worcs.</i>	Malvern, Free Library	1·18	41	<i>Aberd.</i>	Balmoral Castle Gdns...	·81	27
<i>Warwick</i>	Birmingham, Edgbaston	·63	23	"	Aberdeen Observatory	·00	0
<i>Leics.</i>	Thornton Reservoir ..	·21	7	"	Fyvie Castle ..	·14	4
<i>Lincs.</i>	Boston, Skirbeck ..	·00	0	<i>Moray</i>	Gordon Castle ..	·53	17
"	Skegness, Marine Gdns.	·06	2	<i>Nairn</i>	Nairn, Achareidh ..	·32	13
<i>Notts.</i>	Mansfield, Carr Bank ..	·16	6	<i>Inw's</i>	Loch Ness, Foyers ..	·51	17
<i>Ches.</i>	Bidston Observatory ..	·29	9	"	Glenquoich ..	·03	0
<i>Lancs.</i>	Manchester, Whit. Park	·37	11	"	F. William, Teviot ..	·01	0
"	Stonyhurst College ..	·21	4	"	Skye, Duntuiln ..	·20	4
"	Blackpool ..	·53	15	<i>R. & C.</i>	Ullapool ..	·09	3
<i>Yorks.</i>	Wakefield, Clarence Pk.	·33	13	"	Applecross Gardens ..	·06	1
"	Hull, Pearson Park ..	·69	24	"	Achnashellach ..	·07	1
"	Felixkirk, Mt. St. John	·23	8	"	Stornoway Airfield ..	·49	13
"	York Museum ..	·27	11	<i>Suth.</i>	Lairg ..	·24	8
"	Scarborough ..	·61	22	"	Loch More, Achfary ..	·28	5
"	Middlesbrough ..	·46	17	<i>Caith.</i>	Wick Airfield ..	·06	2
"	Baldersdale, Hury Res.	·19	5	<i>Shet.</i>	Lerwick Observatory ..	·03	1
<i>Norl'd</i>	Newcastle, Leazes Pk.	·04	1	<i>Ferm.</i>	Crom Castle ..	1·21	29
"	Bellingham, High Green	·36	10	<i>Armagh</i>	Armagh Observatory ..	·56	15
"	Lilburn, Tower Gdns.	·25	9	<i>Down</i>	Seaforde ..	·77	21
<i>Cumb.</i>	Geltsdale ..	·11	3	<i>Antrim</i>	Aldergrove Airfield ..	·34	9
"	Keswick, High Hill ..	·02	0	"	Ballymena, Harryville..	·26	6
"	Ravenglass, The Grove	·22	5	<i>Lon.</i>	Garvagh, Moneydig ..	·31	8
<i>Mon.</i>	Abergavenny, Larchfield	·87	29	"	Londonderry, Creggan	·49	11
<i>Glam.</i>	Ystalyfera, Wern Hos. .	·63	10	<i>Tyrone</i>	Omagh, Edenfel ..	·45	11

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, APRIL, 1947

STATIONS	PRESSURE		TEMPERATURES						RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE			
	Mean of day M.S.L.	Diff. from normal	Absolute		Mean Values						Total	Diff. from normal	Days	Mean	Per- cent. of poss.		
			Max.	Min.	°F.	°F.	°F.	°F.								Diff. from normal	Wet bulb
London, Kew Observatory	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.	hrs.	%			
Gibraltar...	1017.5	+ 4.1	65	32	56.3	41.7	49.0	44.9	72	6.5	1.68	+ 0.23	11	39			
Malta ..	1022.9	+ 6.5	76	47	68.6	58.0	63.3	59.1	78	4.5	0.07	—	2	69			
St. Helena ..	1020.8	+ 7.4	79	48	69.0	54.4	61.7	56.6	56	4.1	0.14	—	3	—			
Freetown, Sierra Leone..	1014.9	— 1.7	72	58	69.4	61.1	65.3	61.6	96	8.6	4.04	+ 0.82	24	—			
Lagos, Nigeria ..	1011.0	+ 1.8	89	71	85.1	77.4	81.3	77.3	83	5.6	3.12	— 0.94	6	55			
Kaduna, Nigeria ..	1010.8	+ 1.4	95	69	90.0	72.8	81.4	80.2	88	8.7	4.40	—	10	41			
Chileka, Nyasaland ..	1008.1	—	98	69	94.4	73.8	84.1	71.3	57	5.9	1.44	— 1.64	1	56			
Salisbury, Rhodesia ..																	
Cape Town ..	1018.0	+ 1.6	87	44	72.1	54.2	63.1	56.5	84	3.6	1.16	— 0.71	9	—			
Germiston, South Africa ..	1017.0	—	82	39	72.4	52.6	62.5	54.8	71	4.0	1.56	—	8	72			
Mauritius ..	1015.6	— 1.7	85	63	81.5	70.7	76.1	71.2	81	5.1	5.45	+ 0.33	24	65			
Calcutta, Alipore Obsy ..	1004.5	— 1.9	108	74	99.3	79.5	89.4	78.7	79	2.5	0.47	— 1.71	3	77			
Bombay ..	1007.3	— 1.5	99	72	89.0	77.1	83.1	75.3	78	8.2	2.52	+ 2.47	7	55			
Madras ..	1006.7	— 1.7	105	77	96.7	80.5	88.6	79.4	76	4.9	1.03	+ 0.40	2	84			
Colombo, Ceylon ..	1009.1	+ 0.4	89	73	87.7	77.3	82.5	76.5	83	6.8	4.83	+ 4.90	16	59			
Singapore ..	1008.3	— 0.6	93	71	87.5	74.2	80.9	77.3	85	—	8.83	+ 1.20	18	—			
Hongkong ..	1013.7	+ 1.1	83	60	73.8	64.9	69.3	65.2	82	—	2.38	— 3.27	14	25			
Sydney, N.S.W. ..	1017.9	— 0.5	78	51	70.9	57.3	64.1	63.6	97	6.7	7.37	+ 1.85	19	49			
Melbourne ..	1019.2	— 0.3	87	41	69.1	51.7	60.4	54.2	75	6.6	3.29	+ 1.12	17	44			
Adelaide ..	1019.8	— 0.0	88	46	72.5	54.7	63.6	56.0	55	5.4	1.71	— 0.01	11	57			
Perth, W. Australia ..	1015.0	— 3.4	85	48	75.6	57.5	66.5	59.8	63	5.2	3.96	+ 2.31	8	62			
Coolgardie ..	1017.4	— 0.9	88	48	74.8	54.2	64.5	55.1	70	4.7	1.33	+ 0.37	8	—			
Brisbane ..	1015.2	— 2.4	85	56	78.2	61.8	70.0	62.9	65	4.3	6.54	+ 2.77	12	69			
Hobart, Tasmania ..	1019.1	+ 4.3	75	42	64.0	48.3	56.1	51.1	76	6.4	0.88	— 0.97	12	50			
Wellington, N.Z. ..	1017.6	— 0.5	72	41	61.6	49.6	55.6	53.2	81	7.3	5.05	+ 1.17	12	42			
Suva, Fiji ..	1011.1	+ 0.5	89	68	85.5	74.6	80.1	76.1	84	6.1	11.25	— 0.96	16	61			
Apia, Samoa ..	1010.1	+ 0.2	91	72	88.9	74.3	81.6	78.2	79	4.8	4.78	— 5.37	17	66			
Kingston, Jamaica ..	1015.3	+ 1.2	90	68	87.1	70.2	80.3	72.2	72	2.7	0.55	— 0.69	3	75			
Grenada, W. Indies ..	1014.4	+ 1.9	86	72	84.8	75.9	80.3	75.4	78	7.0	1.10	+ 1.06	8	—			
Toronto ..	1017.5	+ 1.4	68	27	50.3	34.1	42.2	35.7	75	6.3	2.33	+ 0.04	12	33			
Winnipeg ..	1016.1	— 0.6	83	15	44.4	26.3	35.3	27.4	—	6.3	1.35	— 0.05	7	47			
St. John, N.B. ..	1018.1	+ 4.7	57	19	44.7	29.2	36.9	31.7	—	6.8	4.35	+ 0.84	13	45			
Victoria, B.C. ..	1019.4	+ 1.9	74	29	58.2	40.6	49.4	41.8	93	5.1	2.62	+ 1.10	14	54			