M.O. 482

THE METEOROLOGICAL MAGAZINE

1947 Volume 76

INDEX

ILLUSTRATIONS

ERRATA

PAGE 8, line 10; *for* " 60° N. 40′ W." *read* " 60° N. 40° W."
PAGE 20, line 12; *for* " $l = 2w\sin\ \theta$ " *read* " $l = 2\omega\sin\ \phi$ "
PAGE 20, line 13; *for* " a = angle . . . " *read* " α = angle . . . "
PAGE 109, title of Fig. 1; *for* " Number of degs. of thunder " *read* " Number of days of thunder "
PAGE 117, line 27; *for* " intricate " *read* " intimate "
PAGE 163, line 9; *for* " rapid rise of 2°F " *read* " rapid rise of 2½°F."
PAGE 163, line 11; *for* " fell from 46° F. to 3 ° F." *read* " fell from 46° F. to 30° F."
PAGE 212, line 22; for "that of Fulvirch" read "that of Fuhrich."

See also pages 59, 111, 276

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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M.O. 482 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 76. NO. 895. JANUARY, 1947

FOREWORD

BY THE DIRECTOR OF THE METEOROLOGICAL OFFICE

The publication of the Meteorological Magazine ceased with the issue for June, 1940. The deciding factor was not so much the need for saving paper as the urgent necessity at that time of conserving manpower. The nation could not afford the time of the type-setters and other operatives involved in producing a journal of this kind.

It was not until publication had actually stopped that the value of the *Meteorological Magazine* was fully realised. We had not appreciated the important part it played as a means of keeping us informed of technical developments, as a link between Headquarters and outstations, and as a forum for the discussion of interesting technical points.

The zeal of the Editor, Dr. Brooks, did not allow the *Meteorological Magazine* to suffer complete eclipse, and a typescript edition, complete with diagrams and photographs, maintained a limited circulation. Some of the most interesting features which appeared in the " emergency " edition will be reproduced in the early numbers of this 1947 volume.

With the resumption of normal publication it is hoped not only to regain the original advantages which the magazine provided, but to make it of even greater value and interest than before the war. Articles will be included from time to time dealing with international meteorological matters, which will enable the meteorologist to appreciate how his own work fits into the general world pattern. There will be authoritative articles in simple non-technical language on the work of different sections of the Meteorological Office, and on interesting phenomena which occur from time to time. Regular accounts will also be given of the activities of the Meteorological Research Committee with an outline of the more important papers discussed at its meetings. It is further proposed to include a certain number of original papers on investigations carried out in the Meteorological Office, although the longer papers of this type will continue to be published as *Geophysical*

Memoirs and *Professional Notes* as in the past. Articles will be given describing important developments, such as the recent decision to establish a network of weather reporting ships in the North Atlantic, and explaining the part which the Meteorological Office will play in the scheme.

Although the *Meteorological Magazine* has hitherto been intended primarily for the staff of the Meteorological Office and its collaborators, it is hoped that it will find many regular readers amongst those who worked with us for the first time during the war, and also amongst those members of the community at large who, while having no official connexion with the office, are yet interested in the weather and the State weather service.

N. K. JOHNSON

PRESTWICK ATLANTIC TERMINAL

BY C. V. OCKENDEN, B.SC.

" . . . Well, that's about all, Skipper. Apart from the cold front in Zone 4 it should be a pretty good trip tonight. Oh ! while I think of it, would you mind asking Montreal if they could let us have three or four purple pencils ? " Trivial if you like, but typical of Prestwick airport during the war. Complete understanding existed between the meteorologist, the captain of the B.O.A.C. Liberator and the terminal on the other side of the Atlantic. And one knew that within 36 hours there would be a little parcel in the " debriefing " office, containing purple pencils which it would have taken months to obtain from stationery stores in Great Britain.

So great was the volume of air traffic at Prestwick that there were in fact three meteorological offices within the boundary of the airport. One was located in the Terminal building to give reports and forecasts to the local flying control, to " debrief " arrivals and do the normal observational, pilot-balloon, and climatological work associated with an outstation ; another was with the Air Transport Auxiliary Headquarters and had to provide route forecasts at a moment's notice for almost any route to almost any airfield in the British Isles (for every "delivery" aircraft arriving from Canada had to be flown away to the place where it was most required at the earliest moment); whilst the third office was housed with Signals and Transatlantic Control in a small country mansion called " Redbrae " a few hundred yards from the main Terminal building. The three offices were of course linked by 'phone and teleprinter so that their activities could be easily controlled by the senior forecaster on duty. In the following account it is to the work of the " Redbrae " Type I office that reference will usually be made.

In 1940 the need for more and yet more aircraft in order to win the war became very obvious. The Battle of Britain was on, production of aircraft in this country was far from sufficient and there was a serious shortage of shipping for transporting crated aircraft and spares across the Atlantic whilst losses by enemy submarine activity were mounting. Thus, despite the fact that up to that time the crossing of the North Atlantic had been considered an exceptional feat of airmanship, it was decided to start a regular

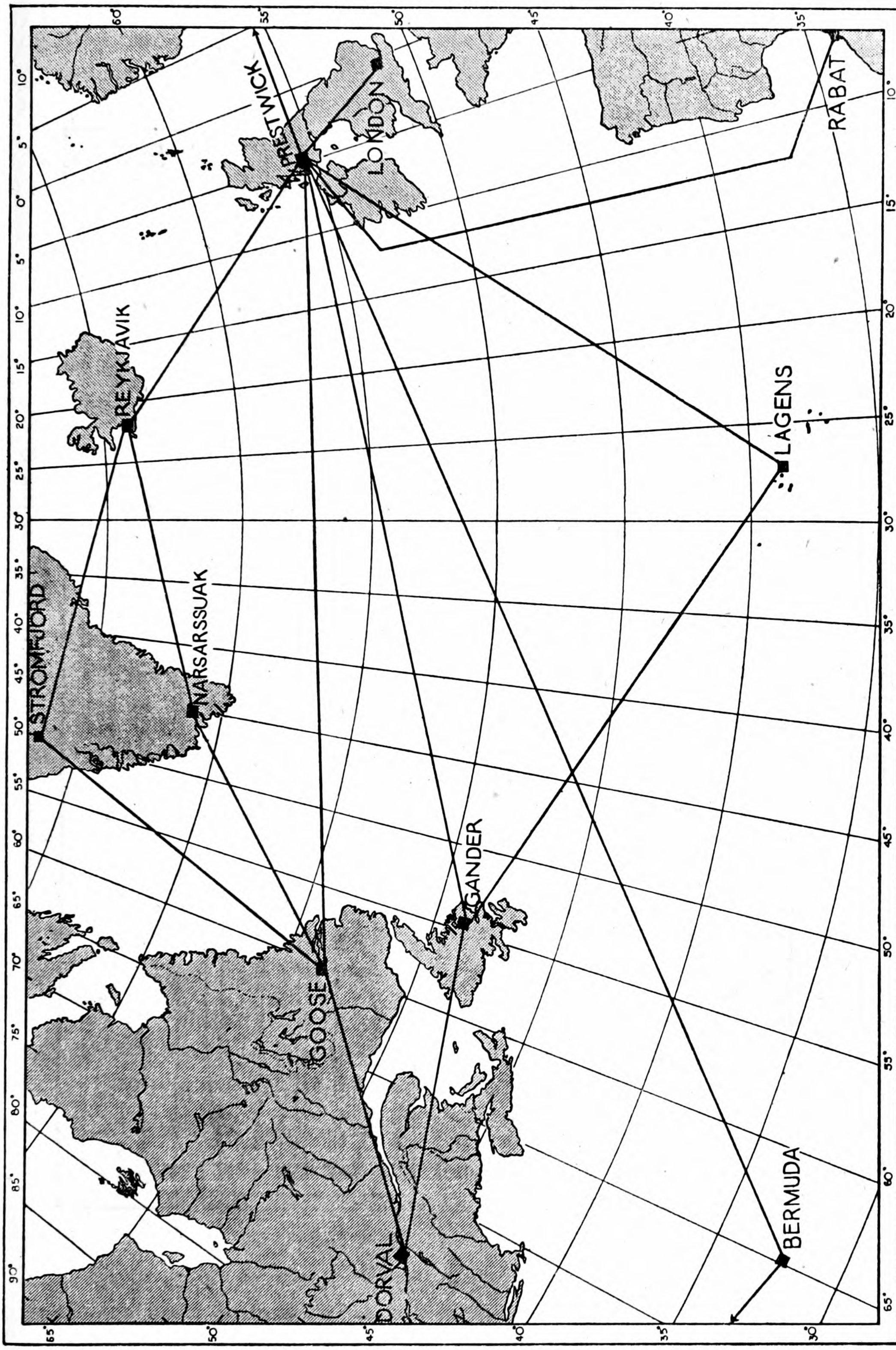

FIG. I—CHART SHOWING ATLANTIC AIR ROUTES (1944)

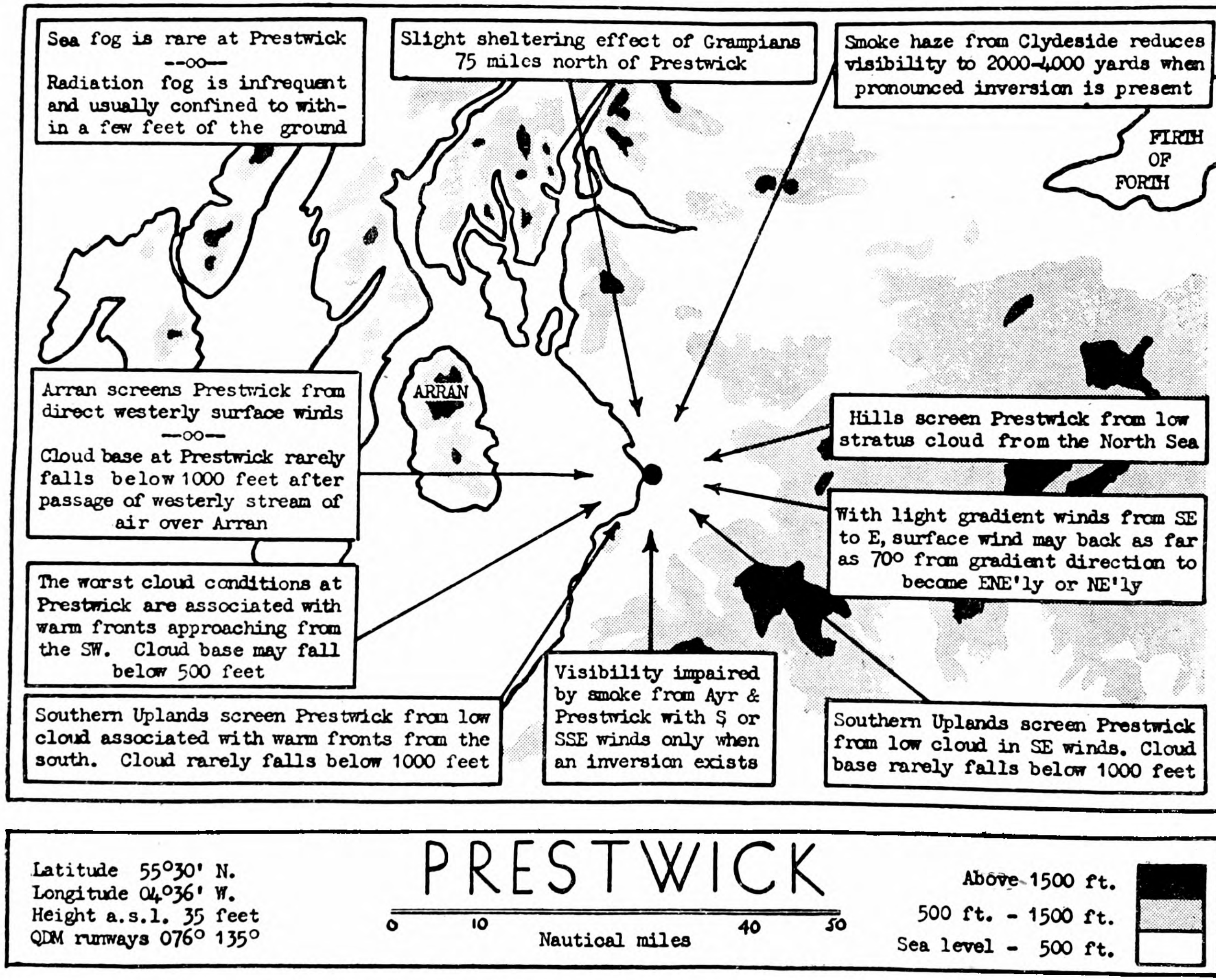

FIG. 2—CHIEF METEOROLOGICAL FEATURES OF PRESTWICK

air ferry service and to deliver by air to this country the much needed aircraft which were being built in the United States, in particular, Lockheed Hudsons required for Coastal Command. The organization built up was known as ATFERO and the first delivery flight of seven Hudson aircraft was made on November 10, 1940. Flying the Atlantic soon became a daily occurrence; in November 1943, 100 Fortresses were flown over in one day, and in one week in the summer of 1944, 525 aircraft from overseas (either direct from Canada or Bermuda or via Iceland or north-west Africa) were controlled from Prestwick. The main terminals for the direct crossing were Gander in Newfoundland and Prestwick on the Ayrshire coast. The advantages of Prestwick as the eastern terminal were threefold. It was out of the way of bomber and fighter bases, it involved no crossing of high ground and the number of occasions when it becomes unfit for flying because of bad weather is lower than at almost any airfield in the British Isles. In particular, fog is very rare. Fig. 1 shows the positions of Prestwick and Gander as terminals of the Atlantic Air Routes and Fig. 2 shows diagrammatically the chief meteorological features of Prestwick. It need hardly be said that the location of the terminals was a military secret during the early phases of the war, but the ban was lifted in October 1943.

It was in December 1940 that it was decided to deliver Catalina aircraft to this country by flying them from the States to Bermuda and thence to Greenock (later Largs was used, because visibility was better, there was no balloon barrage and it involved a much shorter journey to Prestwick for passengers and freight). The Battle of the Atlantic had made it necessary for us to have a large number of these long-range seaplanes for convoy duty and to hunt out enemy submarines. These flights, involving a non-stop ocean crossing of about 3,400 miles, were controlled by Prestwick T.A.C. (Transatlantic Air Control), and as the actual time of flight was not less than 20 hours and sometimes amounted to 24–26 hours it will be appreciated that the advisory route forecast sent to Bermuda from Prestwick called for a lot of hard thinking. A forecaster was usually sent to Greenock to interview incoming crews and pass the information by telephone to " Redbrae ".

Until the summer of 1941 crews which brought over delivery aircraft returned to Canada by boat, taking anything from 10 to 14 days, with the result that aircraft were being held up because of shortage of pilots, navigators and radio men. It was, therefore, decided to institute the Return Ferry Service (R.F.S.) and seven Liberators (three of which had already been flown over as deliveries) were put into operation by British Overseas Airways; thus was started the first regular two-way all-the-year-round cross-Atlantic air service for passengers and freight. In the autumn of 1941 a new airport at Dorval near Montreal was completed, and in a relatively short time Prestwick and Dorval came to be the main terminals for the B.O.A.C. service, short stops at Gander being made when necessitated by adverse weather or by strong head winds on the Atlantic. By 1942 the idea of flying short- and medium-range bomber and fighter aircraft to this country was developed using Greenland and Iceland as stepping-stones and the great new airfield near the mouth of Goose River in Labrador was completed. This base was soon to become one of the busiest airports in the world, and on account of its clearer skies it became a most useful alternative terminal for B.O.A.C. east–west flights from Prestwick. An enormous amount of traffic grew up on the northern route, and Prestwick was at times hard put to it to supply forecasts for, and to receive, all the aircraft which arrived from Iceland as well as from Gander, Goose and Montreal. It may be of interest to recall that on March 1, 1943 a glider towed by a Dakota made the flight from Montreal to Prestwick over this route, and thus set up a world record for distance for a glider carrying freight. Special forecasts had to be supplied for the flight because of the importance of vertical currents and temperature changes, and the accuracy of the forecast of upper winds for the last leg was such that the glider touched down at Prestwick from Iceland almost exactly on schedule. In addition to the weather hazards which in winter were often very great, especially on the Labrador to Greenland and Greenland to Iceland legs, communication difficulties were fairly frequent owing to radio " black outs " associated with aurora : in fact at times it was impossible to obtain vital weather information reliably for periods of two or three days at a time. The Americans set up radio-teletype links between Goose, Narsarssuak (Greenland), Meeks Field (Iceland) and Prestwick and the close co-operation which existed between both services ensured that all data was exchanged regardless of the route by which it was received.

Prestwick was by now (1942) despatching aircraft to north-west Africa—to Rabat/Sale, Marrakesh or Ras-el-ma ; delivery Liberators and Fortresses were being flown on to the Middle East and India and a regular mail service was established between Prestwick and Rabat and later extended to Lagens. This involved forecasters at " Redbrae " studying conditions in the Mediterranean as well as the Atlantic, and a daily exchange of forecasts with Rabat had to be instituted. For security reasons the route to north-west Africa lay along 12° W. ; forecasting for a southbound aircraft was a much easier proposition than for a westbound, because in general the trip could be made without having to ascend to any great height to avoid icing. However it meant that attention had to be paid every evening both to snow blizzards in Newfoundland and the possibility of sandstorms in Africa—for in the event of the African terminal being affected, there existed no nearby alternative airfield.

When Transatlantic Air Control was set up it was little thought that its activities would include looking after a route to Moscow, but on October 21, 1942, a B.O.A.C. Liberator took off on the first flight eastbound. A large amount of organizational work had been performed in the way of explaining our codes and procedure to our Russian allies, and, since it was too dangerous to fly direct, the route chosen took the aircraft as far north as the Arctic Circle. A point-to-point W/T channel was opened up with Moscow, daily forecasts were exchanged for a considerable time and many flights in both directions were carried out before it became strategically possible to open up the longer but meteorologically more favourable route through the Mediterranean. The reception hall of the airport was indeed one of the most cosmopolitan places in the world about this time, and in December 1942 their Majesties the King and Queen made a visit of inspection. The King was particularly interested in the meteorological briefing of a crew setting off for Montreal, and the photograph reproduced in Fig. 5 is probably unique, in it Her Majesty is being shown the pilot-balloon method of obtaining upper winds.

Late in 1943 aircraft began to arrive at Prestwick from Lagens in the Azores as a result of operation " Alacrity " in which a temporary runway consisting of about 1,000 tons of metal Summerfelt tracking was laid down in the incredibly short time of 48 hours. Within a few months B.O.A.C. westbound aircraft were being despatched from Prestwick via Lagens on occasions when strong head winds over the Atlantic and bad weather in Iceland made both the direct crossing to Gander and the northern route inadvisable.

Thus, by 1944 aircraft of almost every type—Hudsons, Fortresses, Mitchells, Marauders, Bostons, Venturas, Skymasters, Dakotas, Lightnings, were pouring into Prestwick airport from Dorval, Gander, Goose, Reykjavik or Meek's Field, Bermuda, Lagens, and north-west Africa, and Controllers and Met. forecasters were saddled with the tremendous task of ensuring the safety, as far as it lay within their powers to do so, of all aircraft flying these diverse routes. In one sense the meteorologist benefited by the numbers because each machine in flight represented a potential " reporting station ", and, with the dearth of surface weather reports, the logs handed in by captains and the few reports they were allowed to send by W/T whilst in flight were invaluable. By their aid it was possible for the terminals to correct the estimated positions of fronts in mid Atlantic and to follow pretty closely any changes in speed and characteristic from one synoptic chart to the next. Needless to say, the " first-timer " pilot on an eastbound flight was often not over scrupulous about turning-in a good description of the weather experienced during his flight, but the logs received from the regular Liberators on the B.O.A.C. Ferry service were most complete and included observations made every hour with notes of any unusual phenomena. The close co-operation given by some of the veterans of the R.F.S. will always be a pleasant memory; although they can be numbered on both hands, they had made altogether 1,000 Atlantic crossings by September 1944, and several Captains had individually completed, or were coming up to, 100 crossings by Christmas 1944. In 1942 one crew flew the Atlantic five times in nine days in the same Liberator aircraft.

Whatever the route, the procedure for supplying meteorological information was the same and was known as MOOF—Meteorological Organization for Overseas Flights. The Atlantic was divided into zones of 5 degrees of longitude; Prestwick terminal supplied an advisory forecast for the five zones from 5°W. to 30°W. whilst Gander did the same for the five zones between 30°W. and 55°W. In general, flights were made by night so that stellar navigation could be used, and every morning coded forecasts giving anticipated conditions for the following night were exchanged by direct W/T point-to-point channel; this channel, incidentally, also carried the fundamental synoptic data forming the basis of complete synoptic charts prepared four times daily. The forecast, which was of an " advisory " nature, was in a 5-figure code and gave anticipated weather, cloud base and tops, icing information and winds for 5,000, 10,000, 15,000 and 20,000 ft. for each " zone " in the sender's control, together with expected conditions at the terminal airfield and four or five alternative airfields. By about noon the forecaster at Prestwick was able to have ready a complete rough draft of expected conditions for the whole flight together with a pictorial diagram, and the Captain, Second Pilot, Navigator and W/T Officer of the westbound

Liberator attended the office with the B.O.A.C. representative for a " preliminary briefing ". The heights at which it seemed best to fly in various zones were discussed and a rough estimate of the time of flight worked out. An average head wind of 30 knots meant very careful consideration being given to the weather expected at Gander and Goose; if these could not be forecast as being " fit " with a fairly high degree of confidence, the Captain would usually decide against a direct flight and go via Iceland or the Azores (Lagens). On many occasions, however, it was possible to recommend a rhumb line course from Prestwick to Halifax or a " composite " course via a point about 60°N. 40° W. to Goose, depending on the position of an Atlantic depression. A great deal of attention was paid to the construction of upper-air charts and, with the increase of data derived from radio-sonde ascents in Great Britain, Iceland, Greenland and three or four U.S. cutters at more or less fixed positions in the Atlantic, it was possible at a fairly early stage to produce a chart for 10,000 ft., which proved extremely useful. Later, contour charts for 750 mb. and 500 mb. were substituted, and by 1944 the confidence of R.F.S. pilots in the upper winds given for the crossing was increased to such an extent that an additional 2,000 lb. pay-load was being carried whilst delays on schedule were reduced to a very small percentage. The actual route and time of take-off having been decided at the midday conference, a signal would be sent to Dorval requesting any amendments to their forecast to reach Prestwick by a stipulated time, and on receipt of any amendment which might cause a radical change of plan, the B.O.A.C. representative was informed and arrangements made for another briefing. Any minor amendments were incorporated in the typed documents handed to the Captain at the final briefing which took place one hour before take-off. These consisted of 15 or so sheets (giving forecasts for zones and terminals), a tracing of the " actual " synoptic chart for 1200 G.M.T. and a " composite " chart, all stapled together in a stout cover. The " composite " chart was very popular amongst transatlantic pilots for it portrayed the positions of lows and highs and fronts in each zone as they were expected to be positioned by the time the aircraft reached that zone. It was realised that there are obvious theoretical objections to this method of presentation, but there is no doubt that it helped the pilot to get a better appreciation of the development of the situation between time of take-off and touch-down than an ordinary " prebaratic " chart drawn for a fixed hour.

Immediately the Liberator aircraft was airborne, a signal was flashed to the Canadian terminal giving the E.T.A. (expected time of arrival) and " point of no-return " (the furthest point from which the aircraft could if necessary return to its base of departure having regard to the quantity of fuel carried, the load and the winds it would encounter) and the forecaster compiled a coded message to the meteorologist at the destination giving details of the forecast carried by the aircraft. The purpose of this was to enable the Canadian service to send any important amendments to the aircraft on the last half of the 10-hour (approx.) crossing; for instance, if the wind at 5,000 ft. was given as 270° 35 knots and it became evident that in the last two zones a more probable value was 300° 28 knots, a simple code introducing " add 30 subtract 7 " indicated to the pilot that he should add 30° to the direction and subtract 7 knots from the speed, whilst it gave no information which could be of much use to the enemy. It must be remembered

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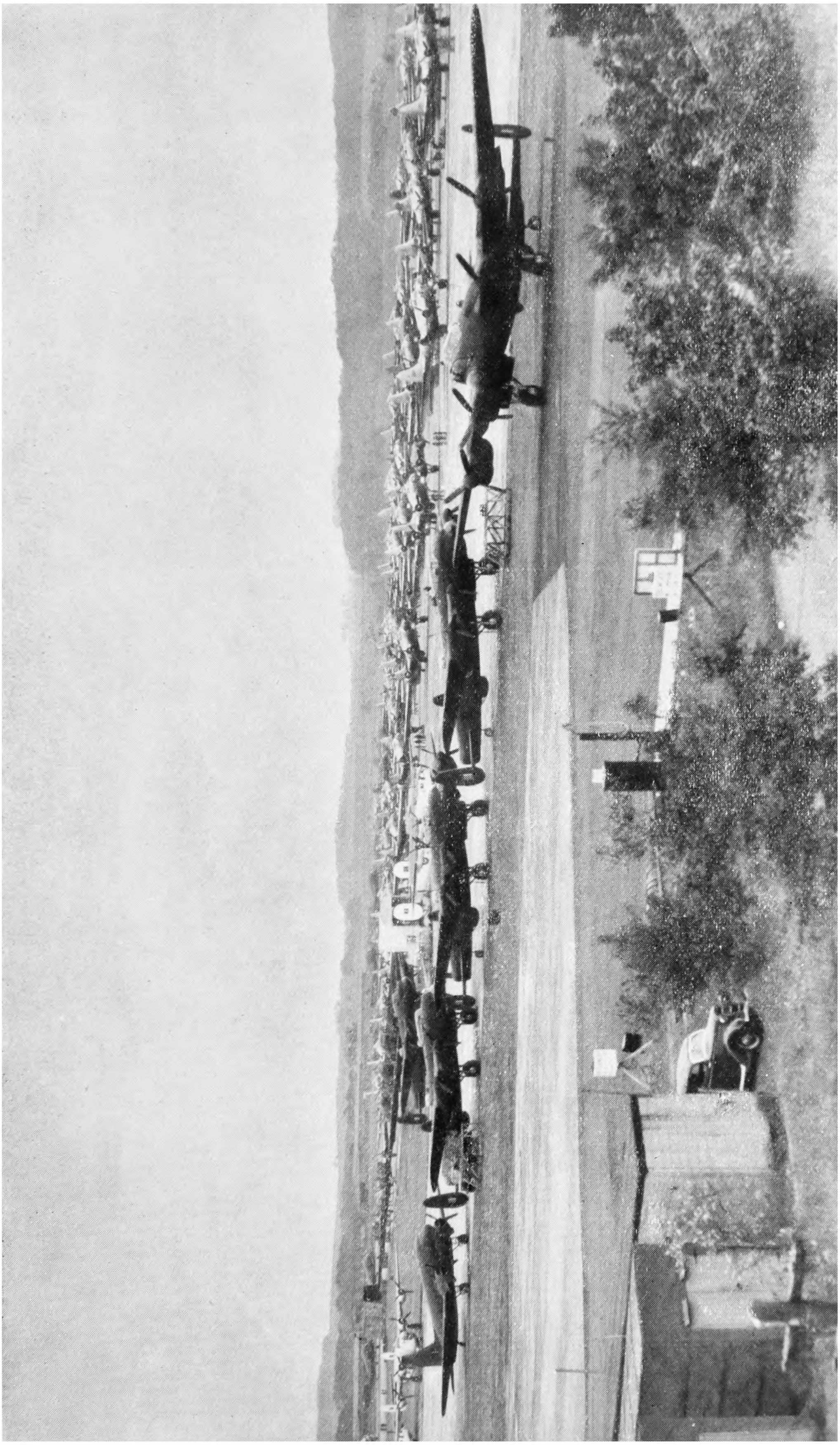

FIG. 3—PRESTWICK LANDING FIELD ON A BUSY DAY

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To face page 9]

Reproduced by the courtesy of Scottish Aviation Ltd.

FIG. 4—GENERAL VIEW OF PRESTWICK AND THE AIRPORT

that every single figure of all meteorological coded messages exchanged by wireless had to be encyphered or decyphered, and this added enormously to the work of assistant staff on both sides of the Atlantic, also, radio fade-outs being fairly frequent at some periods, a good deal of skill was often called for in patching up corrupt messages especially if there happened to be an inexperienced W/T operator on duty at the sending or receiving signals office. When conditions became really bad, messages were cabled. Soon after the nightly departure of the westbound return Ferry aircraft (frequently three or more took off at intervals of half an hour), the forecaster would begin to receive advices from Dorval, Gander or Goose of the departure of batches of eastbound delivery aircraft and so throughout the night he was kept busy drawing up and analysing current charts, sending routine messages to other North Atlantic bases, advising Controllers of probable developments in regard to conditions at United Kingdom bases, sending amendment messages to aircraft in flight, answering their requests for specific information and keeping an eye on the half-hourly broadcasts of " actual " conditions transmitted from Prestwick for several alternative airfields in Great Britain. Meanwhile, the westbound aircraft, with its load of passengers who had had supper in Scotland and would have breakfast in Newfoundland, was not forgotten, and when, some time after dawn, the signal was received giving its time of arrival the forecaster went off to his breakfast, tired but with a feeling of professional pride that another westbound flight had been accomplished within 20 minutes or so of the estimated flight time.

The full story of the activities of Prestwick airport in wartime would be a long one. " Atlantic Bridge " (H.M. Stationery Office, London, 1945) ends with these words : " The Atlantic air is now mastered : its history is only beginning ". During the coming year the establishment by international agreement of several ocean weather stations will be effected and many a wartime pilot will sometimes give a thought to the days when Gander and Prestwick formed the sole supports of the one-span bridge which carried so much vital traffic between two hemispheres.

THE NUMERICAL BASIS OF CLIMATE

BY C. E. P. BROOKS, D.SC.

Part I. The Significance of Averages

The number of meteorological observations even for a single station which has been in operation for many years is so great that it is not humanly possible to comprehend the whole. Hence the practice has grown up of representing them by a few figures, mainly the arithmetical means for the months and year, and, for some elements, the extremes also. In view of the importance which climatologists attach to an " average ", it may be of interest to inquire briefly into its meaning.

If we look at a collection of averages of temperature for the British Isles, we find for example that St. Mary's in the Scilly Isles and Birmingham in the heart of England have nearly the same average temperature at 1300 G.M.T., but this does not necessarily mean that the conditions of temperature at that time are the same at these two places—far from it. To bring out the differences which may be masked by similarity of average, Table I shows the frequency of temperatures at each place in two-degree steps during April in the ten years 1928–37. A glance at the table shows that while temperatures in the Scilly Isles tend to be uniform, clustering closely round the average, those at Birmingham are much more variable—a fact which is of course directly explained by the difference between the thermal properties of sea and land.

TABLE I—TEMPERATURE (° F.) FREQUENCY PER 10 YEARS AT 1300 IN APRIL

Note : " 37° " means the step from 36·0° to 37·9° F.

	37°	39°	41°	43°	45°	47°	49°	51°	53°
Scilly	0	0	2 ~~0~~	1	10	25	52	76	75
Birmingham ..	5	14	10	26	36	36	39	33	29
	55°	**57°**	**59°**	**61°**	**63°**	**65°**	**67°**	**69°**	**71°**
Scilly	45	12	1	1	0	0	0	0	0
Birmingham ..	32	21	6	4	4	4	0	0	1

The range at Scilly is from about 41° to 61° F. or 20°; that at Birmingham from about 37° to 71°F. or 34°, but the latter is obviously greatly extended by the isolated reading of 71°F. As a better, but still rough, measure of variability we may take the range of values within which half the observations lie. These are known as the lower and upper quartiles. We find that at the Scilly Isles there is an even chance that the temperature on any one occasion will lie between 49·4° and 53·5°F., while at Birmingham the corresponding limits are 45·1° and 53·7°F. Similarly, we can calculate the deciles or ten-percentiles, so called because ten per cent. of the values lie below the lower decile and ten per cent. above the upper decile. These are particularly useful when we wish to compare the extremes in series of very different numbers of observations. For example, in marine data we may have a thousand ships' observations in one " square " (of five degrees of latitude by five degrees of longitude) and only a hundred in a neighbouring square. Other things being equal, the extremes of, say, sea temperature in the former are likely to be greater than in the latter simply because there are ten chances to one of picking up an unusually high or low figure. On the other hand the deciles are directly comparable, and they have the additional advantage of ruling out " mistakes ". In an element with a comparatively small range of variation the observed extremes may quite likely be due to errors of observation, and the omission of ten per cent. at each end rules out such errors.

In future, in accordance with the usual statistical procedure, we shall refer to the average as the mean. Other statistical terms in frequent use are the median and mode. The median is simply the middle observation, so that any single reading is as likely to be above as below the median. The mode is the most frequent value. When the observations are symmetrically distributed about the mean, the median and mode coincide with the mean, but if the range extends much further above than below the mean so that the distribution is asymmetric or skew with a long tail to the right, then both median and mode will be below the mean.

The median is readily found by counting,* but it is difficult to find the mode by inspection. Most series of meteorological observations are, by statistical standards, rather short, and the distribution is irregular. In such cases we can plot the frequencies as a graph and draw a smooth curve through them noting the point at which the curve reaches its highest level, but another way in suitable cases is given by the simple expression

$$\text{Mode} = \text{Mean} - 3\,(\text{Mean} - \text{Median}).$$

In some distributions there is more than one mode; for example, individual cloud amounts in western Europe have two, at 0 and 10 tenths, and the mean cloud amount is almost the least frequent value.

The various statistical measures in our series for Scilly and Birmingham are as follows:— Table II

	Mean	Quartiles		Deciles		Median	Mode
				degrees Fahrenheit			
Scilly	49·42	45·1	53·7	42·0	56·9	49·1	48·5
Birmingham ..	51·38	49·4	53·5	47·3	55·2	51·5	51·7

The observations are shown graphically in Figs. 1 and 2. In Fig. 1 the

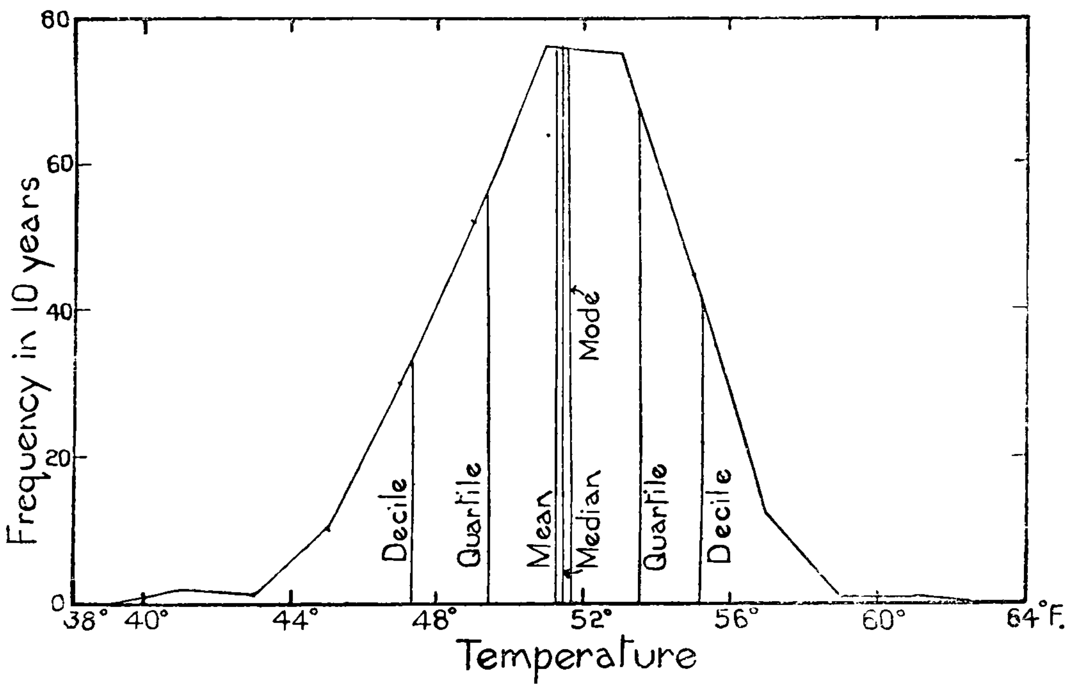


FIG. 1—FREQUENCY DISTRIBUTION 1300 TEMPERATURE, SCILLY, APRIL

* In computing the median, quartiles, etc., from a frequency table such as Table I, the assumption is made that in any one cell the values are uniformly distributed. For example, in 300 observations the median lies midway between the 150th and 151st from the left-hand margin. At Scilly there are 90 observations less than 49·95°F. and 76 from 49·95 to 51·95°F. The figure of 49·95 lies between the 90th and 91st observation and the mean of the 150th and 151st is taken as $49{\cdot}95 + 2 \times 60/76 = 51{\cdot}5$°F.

frequencies for Scilly are plotted as points, the abscissa being the mid temperature of the step and the ordinate the frequency. This type of diagram gives a good representation of the frequency distribution where three or more consecutive plotted points lie near a straight line, but it is liable to give the impression that near the centre of the diagram the frequency is lower than it actually is. For example, if figures had been available for the step 51°–53°F., they would probably have shown a peak frequency above 80 in 300.

In Fig. 2 the frequency of values in each step at Birmingham is represented by a horizontal line drawn across the width of the step ; this is known as a frequency polygon or " histogram ". It is a more accurate representation of the statistics than is the type shown in Fig. 1, but since it takes no account of the probable distribution inside each step, it is less suggestive of the true form of the frequency curve.

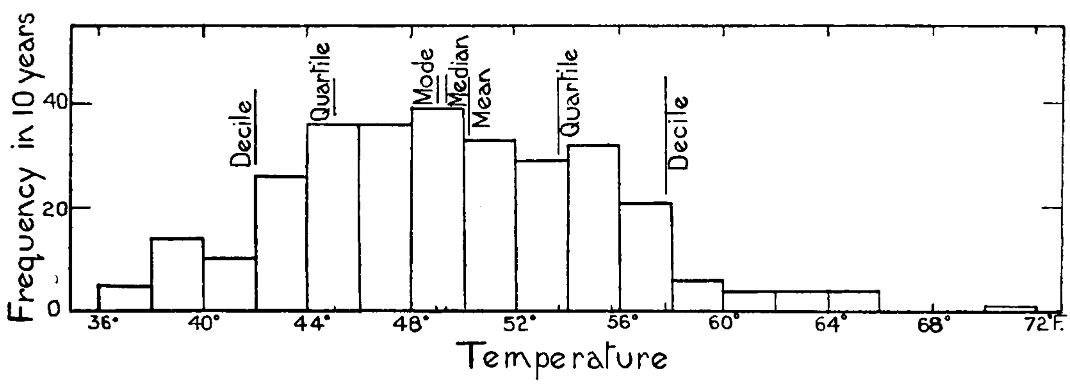


FIG. 2—FREQUENCY HISTOGRAM 1300 TEMPERATURE, BIRMINGHAM, APRIL

The direct comparison of frequency tables is a cumbersome method of measuring the relative variability of two series of data. Even the quartiles depend finally on the exact values of two individual readings, and neglect both the extremes and near-average readings. It is much more desirable to be able to express the variability by a single figure which takes account of the scatter of all the readings. Two such measures are available : the mean deviation and the standard deviation.

The mean deviation is simply the average difference, taken irrespective of sign, between the individual observations and their mean. This is the simplest possible measure of variability and is frequently used. For various reasons, both theoretical and practical, however, a more convenient measure is the square root of the mean of the squares of the differences between the individual observations and their mean. This is known as the " standard deviation ", and is commonly denoted by the Greek letter σ

In our two examples of temperature, the values of mean deviation and of the ratio of the latter to the former, are as follows :—

	Mean deviation	Standard deviation	Ratio
	°F.	°F.	
Scilly	2·40	3·03	1·26
Birmingham	4·86	6·19	1·27

In series of observations which are fairly symmetrically distributed about a central peak, the standard deviation is about 1·25 times the mean deviation.

In such series also, half the observations will lie inside limits approximately two-thirds of the standard deviation (more accurately, $0 \cdot 6745\sigma$) on either side of the mean. This value, $0 \cdot 6745\sigma$, is known as the "probable error" For temperatures at Scilly and Birmingham in Table I, we have the following values :

	Interquartile range	Mean $\pm \cdot 6745\,\sigma$
	°F.	°F.
Scilly	49·4–53·5	49·4–53·4
Birmingham ..	45·1–53·7	45·3–53·6

The standard deviation is a very important quantity in considering the significance of a mean value. For statistical purposes an "observation" is one of any series of comparable values. For example, we may have the mean temperature of each of a very large number of Januaries, and we can compute the standard deviation of the mean January temperature from the mean of the whole long series. If now we divide our very long record into a number of shorter series of, say, ten years each, we shall find that the mean of any one ten-year series will not, as a rule, be the same as the long-period mean, and the sum of the squares of the differences between the individual values and the 10-year mean will be less than the sum of the squares of the differences between the individual values and the long-period mean. In other words, the value of σ calculated from only 10 years will generally be too small. If we have only one 10-year series, we do not know the long-period mean, so that we cannot calculate the true value of σ, but we can obtain an approximate measure of the most probable value of σ by dividing by one less than the number of observations. Thus the standard deviation of monthly mean temperatures calculated from 10 observations is obtained by dividing the sum of squares of differences by 9 instead of by 10, and taking the square root. In mathematical language,

$$\sigma = \sqrt{\{\Sigma\,(T - T_m)^2/(n - 1)\}}$$

where T is the temperature of individual months, T_m is the mean and n is the number of months ; Σ means the sum of all values.

So far we have been considering the standard deviation of individual "observations", either daily readings or monthly means, which we have denoted by σ. Suppose now we group our observations into successive pairs and take the average of each pair. We can form a new frequency distribution of these means of pairs and calculate their standard deviation, which we may call σ_2. It can be shown quite simply that if successive observations are independent, i.e. if there is no relation between the mean temperature of January in two successive years, which appears to be sufficiently true for practical purposes, σ_2 will be $1/\sqrt{2}$ times σ, the standard deviation of individual values. Similarly, if we take groups of n observations, the standard deviation of their means will be $1/\sqrt{n}$ times the standard deviation of the individual values.

This enables us to assess the accuracy of a mean or "normal" of a climatological element very simply. Consider the temperature of London in January. Observations for 50 years give a mean value of 38·51°F., and the standard deviation of the individual values is 3·48°F. Now we can imagine that this 50 years is only one of a large number of possible 50-year periods which would give a whole series of 50-year means. From the one example which we have, we can assess the standard deviation of these 50-year averages as $\sigma/\sqrt{n}$, i.e. $3{\cdot}48/\sqrt{50}$ or 0·49°F. Half of them would differ from the average of the whole set by at least $0{\cdot}67 \times 0{\cdot}49$ or 0·33°F., the "probable error". Hence there is an even chance that the particular 50 years which we have differs from the true mean by as much as 0·33°F., and the most we can say is that there is an even chance that the true January mean temperature lies between $38{\cdot}51 + 0{\cdot}33$ and $38{\cdot}51 - 0{\cdot}33$, i.e. between 38·84° and 38·18°F. To obtain a mean which is probably accurate to the nearest 0·1°F., which is the way mean temperatures are usually quoted, we should need no less than $(0{\cdot}67/0{\cdot}05)^2$ or 4,356 years of observation !

(*To be continued*)

THE VELOCITY PROFILE IN THE LOWEST 400 FT.

BY R. FROST, B.A.

Many meteorologists, attracted by the analogy between the flow of liquids in pipes and the flow of air over the ground, have assumed that near the surface the velocity profile could be represented by a power law of the height above the surface. Hellmann,* who set up recording anemometers at heights of 5, 25, 50, 100 and 200 cm. and took continuous readings for nearly three months, found that the mean wind at these heights fitted a power law $V = Az^m$ where $m = 0{\cdot}27$, and found that the index increased to 0·33 when night observations only were used.

Heywood, who fitted a power law to mean wind velocities at heights of 13 and 19 metres above the ground, the means being taken over a period of two years, found a value of $m = 0{\cdot}26$.

Giblett fitted a power law to mean wind velocities measured by anemometers at heights of 50 ft. and 150 ft. at Cardington, the winds being grouped according to the temperature difference between 143 ft. and 4 ft., and found that m increased with increasing stability from a value of about ·01 when the temperature difference was -5°F. to 0·62 when the temperature difference was $+7$°F. and had a value of 0·143 when the temperature difference was zero.

During the period from October 1943 to November 1944, a series of observations of wind speed, temperature and humidity were carried out at the Royal Air Force station at Cardington in the course of an investigation into the formation of mist and fog by Mr. W. G. Swinbank of the Meteorological Office. The observations were made with instruments suspended from a balloon of the type used in the defence of Great Britain, which was raised to a height of 400 ft., measurements of wind speed, temperature and humidity being taken at heights of 5, 25, 50, 100, 200 and 400 ft.

These observations from Cardington afford the first direct opportunity of investigating the velocity profile of the wind in the lowest 400 ft. of the atmosphere with different temperature gradients. The wind observations

* The list of references is on p. 17.

on each ascent were grouped according to the temperature difference ΔT between 400 ft. and 4 ft., all observations in which the wind failed to reach a speed of 10 m.p.h. at 400 ft. being omitted. Means of wind speeds at each height in each ΔT category were then taken and the results are exhibited in Table I.

TABLE I

No. of Observations	Temperature difference 400 ft.–5 ft.	Mean wind speed (m.p.h.) 5	25	50	100	200	400
81	−2 to 0	6·48	8·98	10·35	12·49	14·50	17·98
130	−1 to 1	4·45	6·60	7·93	9·42	11·60	15·09
104	0 to 2	5·71	8·02	9·76	11·61	14·68	19·39
53	2 to 4	3·08	4·96	6·60	8·47	11·57	16·66
35	4 to 6	1·87	3·06	4·83	7·20	10·51	15·80
28	6 to 8	1·30	2·54	4·64	7·32	10·66	14·69
15	8 to 10	0·93	2·26	3·80	5·93	8·09	13·33
14	10 to 12	0·79	1·50	3·00	4·79	7·86	13·64

The observations on which the above table is based were made during the evening or night when the lapse rate of temperature with height was in general negative. In order to supplement these observations and to investigate the velocity profile under conditions of positive lapse ràte, observations made at Cardington during the day-time, at slightly different heights, were also utilized. Table II, based on these observations, is computed in the same way as Table I.

TABLE II

No. of Observations	Temperature difference 350 ft.–4 ft.	Mean wind speed (m.p.h.) 4	30	80	150	350
80	−4 to −2	8·60	11·68	13·81	14·96	16·60
57	−2·5 to −1·5	7·98	11·26	13·51	14·79	17·23

In Fig. 1 logarithms of the mean wind speeds are plotted against logarithms of the heights, and it can be seen that for each value of ΔT the points lie on a straight line. It follows therefore that the velocity profile in the lowest 400 ft. at Cardington can be represented by a power law of the height above the surface, in which the index of the power is a function of ΔT.

With high stabilities there is a tendency for the mean wind speed at 5 ft. to lie somewhat above the line through the remaining points. This can probably be accounted for by the fact that with high stabilities the majority of the winds at 5 ft. used in this analysis were of the order of 1 m.p.h., at which speeds a cup anemometer is not very reliable.

Values of the index m for each value of ΔT have been calculated by the method of least squares and are given in Table III. Two values of m for each value of ΔT have been derived, the first by using observations at all heights, the second by omitting the readings at 5 ft. The second set of values of m is probably the more reliable, but for most purposes the differences are unimportant.

TABLE III

Temperature difference	−4 to −2	−2·5 to −1·5	−2 to 0	−1 to 1	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12
m, all observations	·145	·17	·23	·27	·28	·39	·50	·60	·61	·67
m, excluding observations at 5 ft.	·145	·17	·25	·29	·32	·44	·59	·63	·62	·77

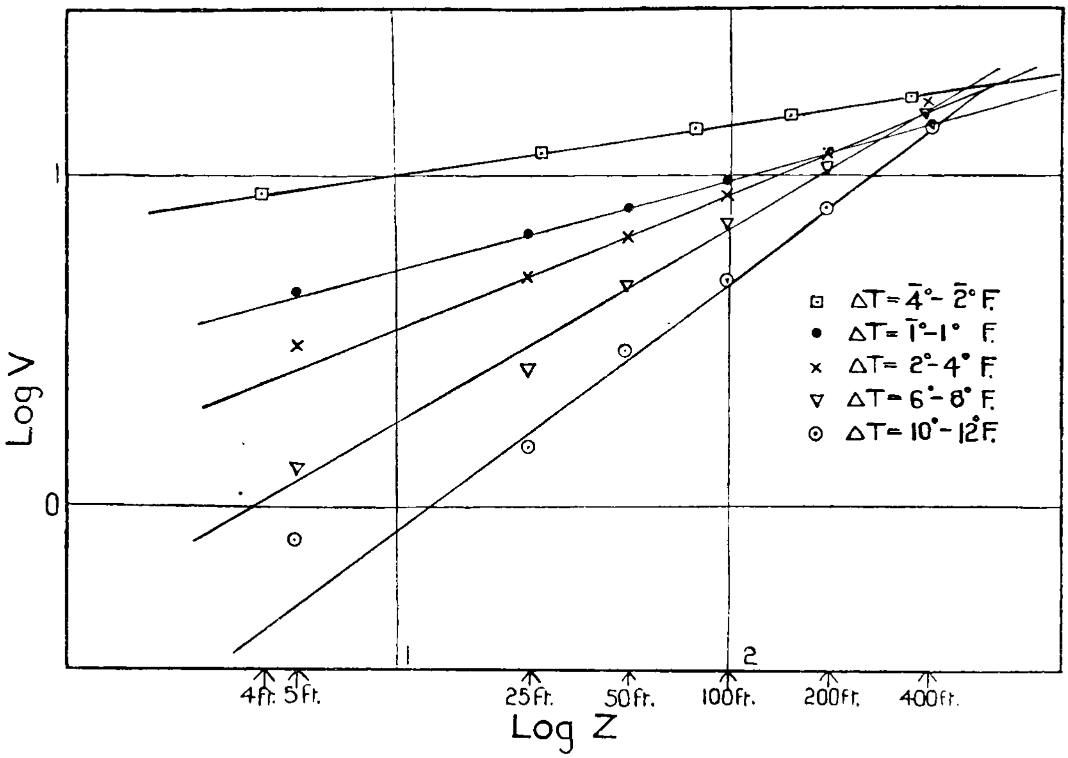


FIG. 1—VARIATION OF WIND WITH HEIGHT FOR VARIOUS TEMPERATURE DIFFERENCES BETWEEN 400 FT. AND 5 FT.

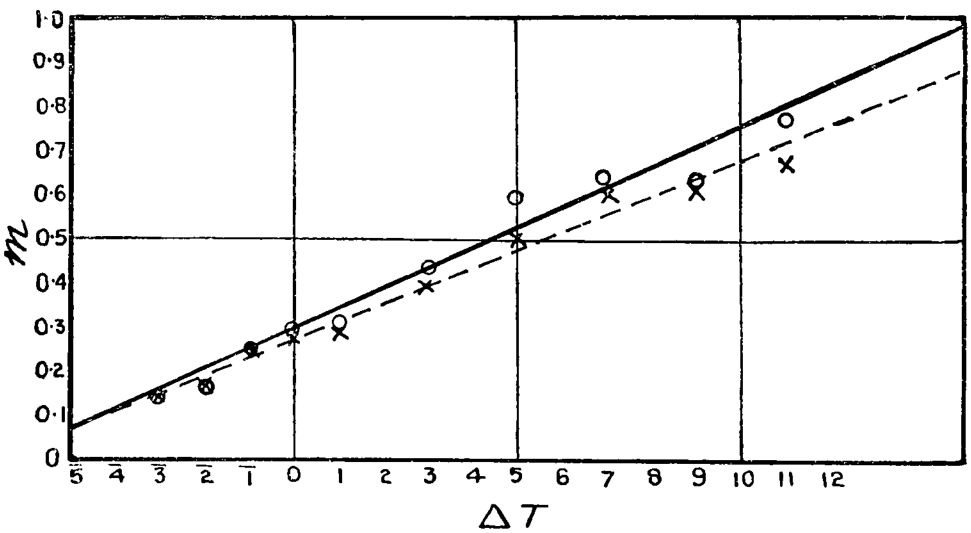


FIG. 2—OBSERVATIONS SHOWING THE RELATIONSHIP BETWEEN THE INDEX OF THE POWER AND ΔT

Values of the index calculated from observations at all heights are marked X.
Values calculated with the observations at 5 ft. omitted are marked O.

Reproduced by the courtesy of Graphic Photo Union

FIG. 5—HER MAJESTY THE QUEEN BEING SHOWN THE PILOT-BALLOON METHOD OF OBTAINING UPPER WINDS

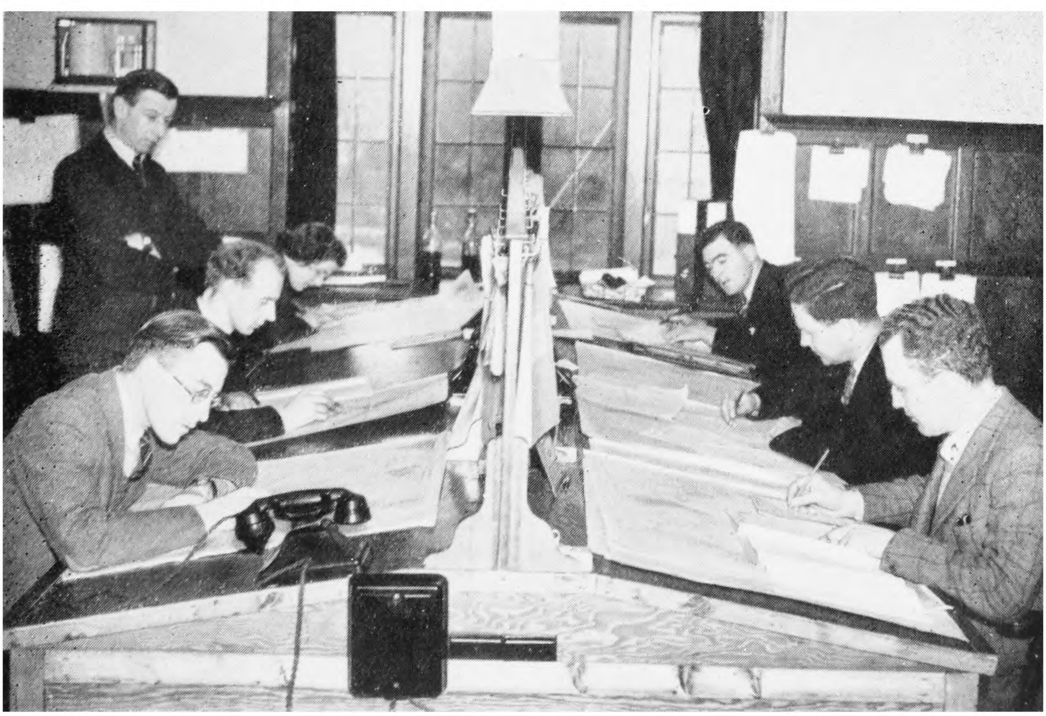
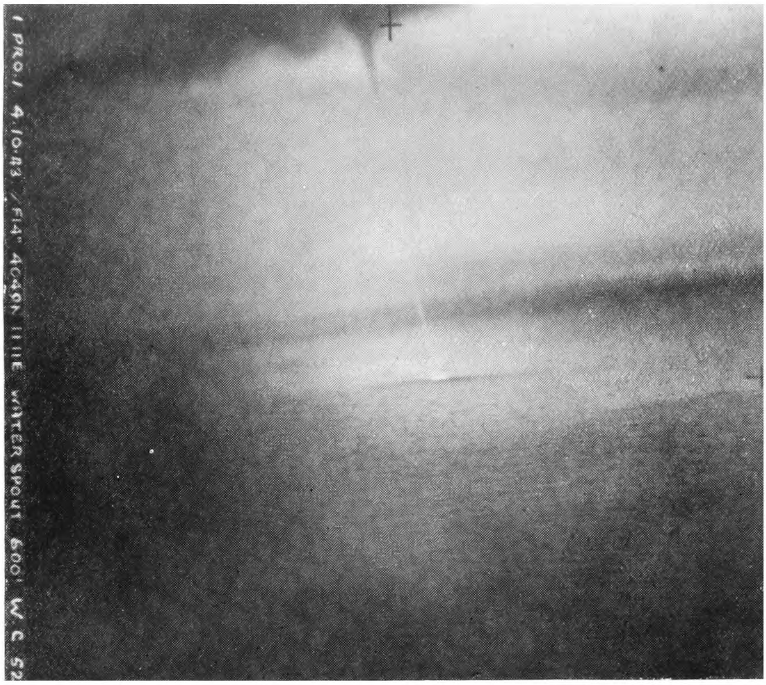


FIG. 6—INTERIOR OF METEOROLOGICAL OFFICE AT TRANSATLANTIC AIR CONTROL, PRESTWICK (see pp. 1–9)



WATERSPOUTS IN THE TYRRHENIAN SEA
(see p. 22)

The values of m for each value of ΔT are shown graphically in Fig. 2, and it can be seen that over the range of ΔT discussed which varies from superadiabatic lapse rates to very heavy inversions, the relationship between m and ΔT is very nearly linear.

An important consequence of this is that means of wind observations made under any conditions of temperature lapse rates can also be represented by a simple power law in which the index of the power is the same linear function of the mean temperature differences between 400 ft. and 4 ft. Thus, according to Johnson and Heywood the mean lapse rate in the lowest 100 m. (330 ft.) for all hours of the year is zero. Hence the index of the power law calculated from annual means should, from Fig. 2, be 0·27 to 0·29 in good agreement with Heywood's own value and also Hellmann's.

The discrepancy between the values given by Giblett and those of Table III could be accounted for by the difference in exposures of the two anemometers at Cardington, and will be discussed elsewhere.

I am indebted to the Director of the Meteorological Office for permission to use the unpublished data from Cardington.

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OVERHEAD SMOKE PALLS FROM THE CONTINENT

During the war there were two outstanding examples of smoke palls at a considerable height which drifted to England from the continent. The most remarkable of these was on June 10, 1940, when the pall extended from Essex at least as far west as Stroud and persisted for several hours, drifting into the Midlands. A pilot reported a smell of petrol when flying in the smoke. It evidently originated in burning petrol dumps in north France, especially in the Havre-Rouen area. Its base was at about 6,000 ft. and it must have been of considerable depth. It was carried across in a SSE. upper current of about 15 to 20 knots, and had evidently accumulated over the area of origin on the previous afternoon and evening, when the upper wind was very light and when conditions favoured vigorous convection to a considerable height. At low levels it did not drift to the same area, at least during its most intense phase in the morning, as there was a shallow SW. current during the night and early morning.

Mr. E. V. Newnham wrote the following description of the phenomenon at Stonehouse, near Stroud :—

" The light reminded me very much of that which accompanied the eclipse of the sun (not quite total in London where I observed it) a few years ago, and from this it seems a fair deduction that the obscuring layer of nearly uniform high-level smoke or haze reduced the sunlight unselectively, i.e. it acted like a shutter. There was certainly no reddening of the light. The intensity was so reduced that the sun even towards noon could be looked at in comfort with the naked eye, yet was sharply defined. A bit more reduction of the light would have given a fair imitation of moonlight (full moon). At the time I thought the smoke or haze might be the result of big fires in the battle zone, the wind at the time being easterly."

The same unselective effect was noticed at Dunstable. The reduction in the sun's heat seemed large relative to the reduction of illumination, as compared with the effect of a normal smoke pall. At Kew the maximum temperature was only 63°F., whereas the Mildenhall temperature at 1,000 ft. was 67½°F. at 0600 and 70°F. at 1600. The visibility at Kew was below 1,000 yds. at both 1300 and 1800. This is most abnormal in June, and must be unprecedented on a day without appreciable rain. Even at Croydon, which was much less affected by local smoke, the temperature was 63°F. at 1300, and the maximum was 66°F. Cold surface air spreading northward caused a sharp fall of temperature at Mildenhall in the afternoon.

Mr. H. V. Sims observed the phenomenon at Earls Colne (Essex), and at 1330 there was a shower of four or five minutes' duration which spotted everything with black. The shower was from high stratocumulus castellatus clouds which existed in patches over the eastern part of the area of the smoke pall.

The second occasion was on the evening of September 12, 1944. Mr. L. W. Hubbert sent a description of it from Winslow (Bucks). A pilot reported that it extended from 4,500 to 7,000 ft. and was thickest at 5,000 ft., and that the ground was frequently invisible from 6,000 ft. Viewed from the ground, the smoke had a greyish-brown appearance, although in the zenith the sky could usually just be discerned. Ground visibility in the area was 6 to 12 miles. The pall seems to have been about 30 miles wide and 40 miles long, though it was not of uniform thickness and had some clear gaps in it. Some observers confused it with high cloud. The edge of the smoke was in wisps, with some resemblance to cirrus. The composition of the smoke was normal, as the sun's disc appeared red.

Mr. Hubbert traced back the trajectory of the air at the level of the smoke and found that it was over the middle Rhineland at about 2300 to 2400 on the previous night, when there was a concentrated incendiary raid on Darmstadt. There can be little doubt that this was the origin of the smoke.

C. K. M. DOUGLAS

OFFICIAL NOTICES

It is not yet possible to resume the "Climatological Table for the British Empire" which appeared in the *Meteorological Magazine* up to its suspension. Arrangements have been made to collect the information, and it is hoped to publish the values for January 1947 in the course of a few months.

OFFICIAL PUBLICATIONS

The *Meteorological Magazine* is the first of the publications of the Meteorological Office, suspended during the war years, to be resumed. The *Monthly Weather Report* and *Daily Weather Report* were maintained throughout for official use, though for reasons of security they were not available for general issue at the time. Other peace-time publications will be resumed as soon as possible, and it is intended to make a special effort to publish the war-time arrears. In particular, *British Rainfall* will appear in two volumes of three years each, covering the years 1940 to 1942 and 1943 to 1945 respectively.

The text will necessarily be contracted, but all the essential tables and maps will be included. The series of annual volumes will be resumed with that for 1946.

The results of some of the important researches carried out during the war years will appear in the revived series of *Geophysical Memoirs* and *Professional Notes*. The *Annual Report of the Director* will also be revived, but it is not yet possible to take up again the issue of the *Weekly Weather Report*, the *Observatories Yearbook* and the *Réseau Mondial*.

The appearance of new publications of the Meteorological Office will be announced regularly in this column, with brief summaries of their contents.

ROYAL METEOROLOGICAL SOCIETY

At the usual monthly meeting of the Society held at 49, Cromwell Road, on December 18th, Mr. Gordon Manley, President, in the chair, the following papers were read :

F. V. Appleby—A note on the classification of rainstorms.

Approaching the problem from the point of view of the water engineer, the author set out to find a simple measure of the " magnitude " or " significance " of a rainstorm.

Using the total rain R which falls in a storm and the intensity i in inches per hour as variables, a method is described of plotting the data for any storm as a vector of length R making an angle θ with the x-axis such that $\tan \theta = i$. This gives a short line of steep slope for storms of short duration and a longer line of lesser slope for storms of greater duration.

It was found that if falls such as those tabulated by Bilham, the Ministry of Health and others, were grouped in series according to the frequency with which they were likely to occur, e.g. " noteworthy " falls once in 10 years, " remarkable " falls once in 40 years and so on, the ends of the vectors representing any series lay roughly on a semicircle the diameter of which gave a measure of the significance of the storm. If we call this measure of significance μ, μ is given by the equation $R = \mu \cos \theta$, or $\mu^2 = R^2 (i^2 + 1)$. For rates of fall likely to occur once a year in this country, μ is approximately $0{\cdot}56$, and for storms once in 160 years, $\mu = 5{\cdot}40$.

A relationship $i^2 = (0{\cdot}25 + \mu^2/t^2)^{\frac{1}{2}} - {\cdot}50$ was obtained for the intensity, and curves were plotted for $\mu = {\cdot}56$ for comparison with the Ministry of Health's standard figures for urban drainage (frequency once per year) and for $\mu = 2{\cdot}61$ for comparison with Bilham's series of " remarkable " falls (frequency once in 10 years).

A discussion followed in which mention was made of the omission of any reference to the area covered by the storm, a factor of some importance in many engineering problems.

W. Schaffer—Inclined streamline flow.

Professor Sheppard gave at very short notice a clear account of the salient features of Capt. W. Schaffer's paper.

This paper which is mathematical and difficult to summarise (it will occupy 14 pages in the *Quarterly Journal*) gives equations of motion for air currents flowing at an angle to the horizontal ; from these an equation is developed relating the veering or backing of the wind with height to the rate of ascent of the air and the local rate of rise of temperature. The paper is illustrated by simple numerical examples.

Beginning with thermal winds roughly at right angles to the surface isobars and causing winds veering with height, it follows that warmer air is being advected. Next we consider air with a lapse rate less than the dry adiabatic ; if this rises, it cools. Finally, the following equation is produced :

$$\frac{d\alpha}{dz} = -\frac{g}{lV^2T}\left\{w\,(\Gamma - \Gamma_1) + \frac{\partial T}{\partial t}\right\}$$

where g, t, w, z have their usual significance,

Γ = adiabatic lapse rate, taken as positive

Γ_1 = actual lapse rate

l = $2\,\omega \sin \phi$

α = angle between the horizontal component, V, of the wind vector and the W.–E. line.

For ascent $d\alpha/dz$ is negative in the northern hemisphere and positive in the southern hemisphere, i.e. for an ascending current the wind veers with height within the rising air stream in the northern hemisphere and backs with height in the southern (unless $\partial T/\partial t$ is negative and numerically large). This agrees with evidence of pilot-balloon results.

For an actual example, take values such as $V = 10^3$ cm./sec., $w = z$ cm./sec., $l = 7\cdot3 \times 10^{-5}$, then the change in direction is about 17° per Km. (when $\partial T/\partial t$ is small). It may be noted that a rising temperature at a fixed point produces the same effect as an upward component in the wind.

One can go on to consider a normal surface trough with warm air, so that isobars aloft form a ridge, and from the foregoing considerations quickly pick out the areas of ascent or descent or alternatively, convergence and divergence.

Among other things, the paper also shows that the fall in pressure along a line in an upper-level surface, this line being the projection on this surface of the sloping trajectory ending at this surface, is

$$\rho g H^2 \left\{(\Gamma - \Gamma_0) + \frac{1}{w}\frac{\partial T}{\partial t}\right\}/2T.$$

For an application of this, assume that an upper-level chart is drawn for 3,000 gdm.. (about 10,000 ft.) and an intermediate chart is drawn for 1,500 gdm., the difference between the two levels being roughly $1\cdot53 \times 10^5$ cm. Let the lapse rate be 7×10^{-5} °C./cm. Then to rise a height $H = 1\cdot53\times10^5$ cm. the change of pressure at the upper level comes out to 2·4 mb. Now if D is the distance along the 1,500 gdm. stream line direction for the upper-level pressure to fall 2·4 mb., then the air flow will incline upwards at approximately $1\cdot5\times10^5/\mathrm{D}$ radians. For example, if D = 600 Km., the angle with the horizontal will be

$$\frac{1\cdot5 \times 10^5}{6 \times 10^7} = \frac{1}{400} \text{ radians or } 0\cdot15°.$$

METEOROLOGICAL RESEARCH COMMITTEE

The 45th Meeting of the Meteorological Research Committee was held on December 12, 1946.

Some further consideration was given to the possibility of exploring the constitution of the upper atmosphere by means of searchlight beams.

Two panels were formed ; one to supervise work relating to the meteorological aspects of icing on aircraft and the other to consider how various problems in tropical meteorology can best be tackled.

A proposal to investigate the correlation between temperature and velocity fluctuations due to turbulence in the atmosphere was examined and approved.

The Committee also considered papers on the size distribution of cloud particles, on a comparison between the Mk. V and the M.O. electrical aircraft psychrometer, and on the use of Elsasser's radiation chart.

LETTERS TO THE EDITOR

The Green Flash observed over the Atlantic

I have recently received a letter from Professor Sir Geoffrey Taylor in which he refers to an observation of " green flash " which he made while crossing the Atlantic by air. The following passage is taken from his letter:—

" I saw a very fine green flash as the sun went down behind a huge sheet of cloud extending apparently from 300 miles east of Newfoundland to near Ireland. I had hardly expected a cloud sheet to have a sufficiently definite top to show the green flash, but it was a really fine display."

June 29, 1944. N. K. JOHNSON

The Blue (?) Flash*

The following description of a curious sunset phenomenon refers to observations made at sunset on August 20th, 1943, from the beach about two miles west of Rhyl. I had gone there on purpose as everything previously had appeared favourable for observation of the green flash. The air was very transparent, and the Isle of Man was visible, which is a rare occurrence. All round was a gorgeous display of colour : it was one of those rare occasions when an artist would be justified in painting the Carnarvonshire mountains in lavish purple. The cirrus near the sun was golden, and in the east it was red. Just as the upper limb of the sun was disappearing, its colour appeared a beautiful blue, a trifle bluer than the deepest sky-blue seen with maritime polar air in spring.

I was viewing it through powerful binoculars, which, at the moment, excluded from the field of view all the coloured mountains and clouds, so I do not think that the unusual colour of the flash was connected in any way with the coloured surroundings. Perhaps it was due to the use of the binoculars themselves.

11, *Percy Road, Wrexham, August* 22, 1943. S. E. ASHMORE

* A flash of a vivid blue colour was described by Mr. S. T. A. Mirrlees in the *Meteorological Magazine* for August, 1935.

NOTES AND NEWS

Waterspouts in the Tyrrhenian Sea

The photographs facing p. 22 have been forwarded by Fl/Lt. R. Kennedy. They were taken on October 3, 1943, at 1427 G.M.T. from an aircraft at a height of 600 ft., at a distance of a mile. The sky was overcast to the east, 5-tenths stratocumulus to the west. The weather was calm but the wind freshened to 15 knots from 335° at this point. Two spouts appeared to be stationary and two more were forming ; a large area of water was disturbed.

Another waterspout, the photograph of which is not reproduced, was observed two days later at 0720 G.M.T. The wind was 8 knots from 320° increasing in squalls. No movement of the spout was observed. It formed in five minutes from an area of extremely turbulent water, and developed a pronounced kink after 10 minutes. Its total life is not known.

REVIEWS

Geomagnetism, by Sydney Chapman and Julius Bartels. The International Series of Monographs on Physics. 8vo., 9 × 6, Vol. I, pp. xxv + 542, Vol. II, pp. x+507. Oxford, The Clarendon Press, 1940. Price 63*s*. net.

For some ten years Professor Chapman and Professor Bartels have had in hand the preparation of an important treatise on Geomagnetism. It appears in print when the countries they represent are at war,* though it is noted that they initial the preface as from London and Washington respectively. In a note acknowledging many facilities received from institutions in Britain, Germany, America and other countries, the authors specially record their indebtedness to Dr. J. A. Fleming, of the Carnegie Institution of Washington. It is fitting that a work of this sort should have a somewhat international flavour because there is perhaps no branch of science in which the world-wide aspect is more patent and the need for world-wide co-operation more clearly recognised.

The book is in two volumes : Vol. I contains Part 1, an account of the observed facts of geomagnetism and the methods by which they are recorded ; Vol. II contains Parts 2 and 3—Part 2 indicating how the data are analysed and synthesised and Part 3 being a discussion of the physical causes. This is broadly the plan, but the writers, in the interests of a logical exposition of facts and principles, have not attempted to confine each part strictly to the limits just described.

Brief accounts are given of related phenomena, the leading facts concerning the lunar and solar motions, the disturbances and other properties of the sun's atmosphere, earth currents, aurora and the ionosphere, magnetic prospecting and the relation of magnetism to geology. An indication is given of the many ways in which geomagnetism is now at last actually contributing powerfully to the problems to which its exponents of a generation ago rather vaguely hoped that it might one day contribute, providing avenues of research into the earth's interior, the earth's high atmosphere and the sun's atmosphere. For these reasons, and because of the links of geomagnetism with problems of radio and telegraphic communication and cosmic ray

[continued on p. 24

* This review was written in 1942.

RAINFALL OF NOVEMBER, 1946

Great Britain and Northern Ireland

Co.	Station	In.	Per cent of Av.	Co.	Station	In.	Per cent of Av.
London	Camden Square ..	3·49	148	*Glam.*	Cardiff, Penylan ..	6·83	169
Kent	Folkestone, Cherry Gdns.	4·49	138	*Pemb.*	St. Ann's Head ..	5·43	136
,,	Edenb'dg, Falconhurst	5·99	169	*Card.*	Aberystwyth	4·50	122
Sussex	Compton, Compton Ho.	7·02	184	*Radnor*	Bir. W.W., Tyrmynydd	12·38	186
,,	Worthing, Beach Ho. Pk.	4·22	132	*Mont.*	Lake Vyrnwy	11·10	191
Hants	Ventnor, Roy. Nat. Hos.	4·42	138	*Mer.*	Blaenau Festiniog ..	13·63	128
,,	Fordingb'dg, Oaklands	5·17	151	*Carn.*	Llandudno	2·75	95
,,	Sherborne St. John ..	6·28	220	*Angl.*	Llanerchmedd ..	6·92	164
Herts	Royston, Therfield Rec.	4·50	193	*I. Man*	Douglas, Boro' Cem.	8·13	173
Bucks	Slough, Upton ..	4·58	206	*Wigtown*	Pt. William, Monreith	7·19	167
Oxford	Oxford, Radcliffe ..	4·51	196	*Dumf.*	Dumfries, Crichton R.I.	7·38	201
N'hant	Wellingboro', Swanspool	4·39	204	,,	Eskdalemuir Obsy. ..	10·81	186
Essex	Shoeburyness	2·96	139	*Roxb.*	Kelso, Floors	4·37	189
Suffolk	Campsea Ashe, High Ho.	3·46	156	*Peebs.*	Stobo Castle	6·33	191
,,	Lowestoft Sec. School	3·66	156	*Berwick*	Marchmont House ..	5·38	179
,,	Bury St. Ed., Westley H.	3·77	164	*E. Loth.*	North Berwick Res. ..	4·41	197
Norfolk	Sandringham Ho. Gdns.	5·02	203	*Midl'n.*	Edinburgh, Blackfd. H.	3·29	147
Wilts	Bishops Cannings ..	4·63	162	*Lanark*	Hamilton W.W., T'nhill	4·46	125
Dorset	Creech Grange ..	5·95	144	*Ayr*	Colmonell, Knockdolian	6·51	130
,,	Beaminster, East St...	8·30	209	,,	Glen Afton, Ayr San.	8·35	152
Devon	Teignmouth, Den Gdns.	6·30	197	*Bute*	Rothesay, Ardencraig	6·71	132
,,	Cullompton	6·39	186	*Argyll*	Loch Sunart, G'dale ..	5·64	75
,,	Barnstaple, N. Dev. Ath.	5·07	129	,,	Poltalloch	5·62	100
,,	Okehampton, Uplands	11·21	211	,,	Inveraray Castle ..	7·54	89
Cornwall	Bude, School House ..	4·59	129	,,	Islay, Eallabus ..	4·89	91
,,	Penzance, Morrab Gdns.	6·85	150	,,	Tiree	3·88	80
,,	St. Austell, Trevarna..	6·89	140	*Kinross*	Loch Leven Sluice ..	6·40	178
,,	Scilly, Tresco Abbey..	4·63	134	*Fife*	Leuchars Airfield ..	5·69	248
Glos.	Cirencester	5·73	192	*Perth*	Loch Dhu	11·94	137
Salop	Church Stretton ..	6·22	212	,,	Crieff, Strathearn Hyd.	6·46	149
,,	Cheswardine Hall ..	4·91	190	,,	Blair Castle Gardens..	5·04	144
Staffs	Leek, Wall Grange P.S.	5·77	185	*Angus*	Montrose, Sunnyside..	6·46	244
Worcs.	Malvern, Free Library	4·38	174	*Aberd.*	Balmoral Castle Gdns.	5·79	157
Warwick	Birmingham, Edgbaston	6·57	276	,,	Aberdeen Observatory	5·98	203
Leics.	Thornton Reservoir ..	5·28	234	,,	Fyvie Castle	6·82	197
Lincs.	Boston, Skirbeck	4·49	225	*Moray*	Gordon Castle.. ..	3·70	128
,,	Skegness, Marine Gdns.	3·99	185	*Nairn*	Nairn, Achareidh ..	2·89	128
Notts.	Mansfield, Carr Bank..	5·58	230	*Inv's*	Loch Ness, Foyers ..	2·72	70
Ches.	Bidston Observatory..	3·83	153	,,	Glenquoich	10·31	85
Lancs.	Manchester, Whit. Park	4·99	189	,,	Ft. William, Teviot ..	5·78	70
,,	Stonyhurst College ..	6·82	151	,,	Skye, Duntuilm ..	8·67	145
,,	Blackpool	4·97	143	*R. & C.*	Ullapool	4·06	79
Yorks.	Wakefield, Clarence Pk.	4·20	198	,,	Applecross Gardens ..	6·12	94
,,	Hull, Pearson Park ..	5·07	231	,,	Achnashellach ..	5·53	64
,,	Felixkirk, Mt. St. John	4·38	179	,,	Stornoway Airfield ..	5·41	98
,,	York Museum.. ..	5·39	258	*Suth.*	Lairg	6·28	157
,,	Scarborough	3·95	160	,,	Loch More, Achfary ..	7·81	91
,,	Middlesbrough ..	3·49	165	*Caith.*	Wick Airfield ..	4·21	134
Norl'd	Newcastle, Leazes Pk.	4·18	178	*Shet.*	Lerwick Observatory..	5·82	137
,,	Bellingham, High Green	5·56	162	*Ferm.*	Crom Castle	4·15	119
,,	Lilburn, Tower Gdns.	5·05	151	*Armagh*	Armagh Observatory..	4·20	148
Cumb.	Geltsdale	5·00	152	*Down*	Seaforde	5·73	151
,,	Keswick, HighHill ..	11·30	200	*Antrim*	Aldergrove Airfield ..	3·53	109
,,	Ravenglass, The Grove	7·12	159	,,	Ballymena, Harryville	3·94	97
West.	Appleby, Castle Bank	6·12	184	*Lon.*	Garvagh, Moneydig ..	3·73	95
Mon.	Abergavenny, Larchfield	9·14	239	,,	Londonderry, Creggan	3·93	96
Glam.	Ystalyfera, Wern Ho.	14·35	218	*Tyrone*	Omagh, Edenfel ..	4·19	110

phenomena, there has in recent years been a growth of interest in the subject, so that a comprehensive treatise is particularly to be welcomed.

Some of the primary problems of the earth's magnetism, such as the origin of the main field and the cause of the secular change, have still to be solved ; and though progress has been made in many directions, the writers remark that Part 3 (the physical interpretation) is the part with which they feel least satisfied and the part which, they hope, will be the first to need revision.

A. H. R. G.

THE WEATHER OF NOVEMBER, 1946

Apart from the extreme north-west, the last three weeks of November in Britain were characterised mainly by an excess of rain. For the first few days these islands lay between a depression over the Atlantic and an anticyclone over eastern Europe. The latter gradually spread westwards and extended over Britain on the 5th and 6th. On the 7th it split into two parts, one situated over Iceland and the other over eastern Europe, and this distribution was maintained with little change throughout the remainder of November, with a series of deep depressions moving eastwards or north-eastwards across western Europe. The average pressure distribution for the month shows a minimum (below 1004 mb.) over north-west Scotland and an anticyclone (exceeding 1020 mb.) over southern Russia. The abnormal character of the month is more clearly brought out by the differences of pressure from average, which range from —7 mb. over southern Ireland and southern England to +5 mb. over Iceland and the greater part of Russia. The latter country was reported in *The Times* to be suffering from drought.

Rainfall in Britain was especially persistent in the latter part of the month. The heaviest daily fall of which information is so far available was 6·83 in. at Princetown on the 23rd ; at this station the nine days from the 19th to 27th inclusive gave the remarkable total of 16·78 in.

Temperature was generally two to four degrees above the normal, but in England this was brought about mainly by the high night temperatures. There was, however, a very warm spell during the approach of the anticyclone on the 3rd to 6th, when record day temperatures for November up to 71°F. were reported. After this the effect of the warm oceanic winds was to some extent reduced by the lack of sunshine, and day temperatures were not remarkable.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days' difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England & Wales	71	27	+3·5	178	+5	63	15
Scotland ..	69	16	+2·1	136	+3	78	16
Northern Ireland	65	26	+2·3	116	+1	86	21

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OCEAN WEATHER SHIPS

BY COMMANDER C. FRANKCOM, R.N.R.

History.—Prior to the year 1936, synoptic observations from the sea were provided almost entirely by voluntary observers in merchant ships, apart from those obtained from the relatively small number of naval vessels. These observations, although extremely valuable to the forecaster, were necessarily restricted in nature, and more or less haphazard as regards position.

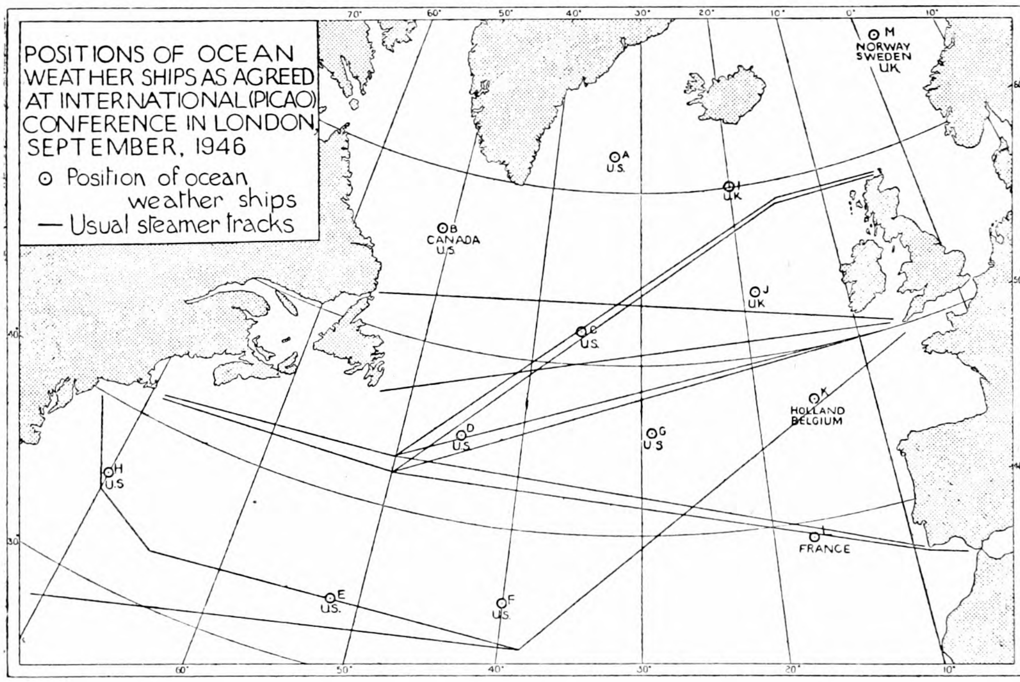
As transoceanic aircraft became a possibility, it became obvious that more detailed information was necessary than could be obtained from voluntary observers in moving ships in order to provide meteorologists and aircraft with accurate information about weather conditions at sea, both on the surface and in the upper atmosphere.

In 1936–7, the British Meteorological Office placed a meteorologist aboard a cargo steamer on the North Atlantic trade route during several voyages and obtained a regular series of special synoptic observations as an experiment. Visual observations of cloud heights and of upper winds were obtained in this ship by the use of pilot balloons.

In 1938–9, the French Government fitted up the merchant vessel *Carimaré* as a stationary meteorological ship in the North Atlantic. Observations of conditions in the upper atmosphere by radio-sonde were successfully obtained in this ship as well as those of surface conditions, and the results transmitted by radio. At about the same time, the Germans had two special vessels performing similar functions in connexion with their transoceanic airways—one operating in the North Atlantic and the other in the South Atlantic. The British Meteorological Office was exploring the possibility of fitting up a vessel specially for this type of work in the summer of 1939.

The war of 1939–45 put an end to all the above activities, and in the early part of that war observations from the oceans were only obtainable from naval vessels and from aircraft. As the war progressed, both sides used various ingenious methods to obtain weather observations from the oceans for their own use. In the latter part of the war, owing to the large number of Allied aircraft regularly crossing the Atlantic, the United Kingdom and United States authorities employed a number of small naval vessels as stationary meteorological ships in that ocean.

When the war finished, the naval stationary vessels were gradually withdrawn, and observations were once more obtainable from merchant vessels. It was realised however, that such observations were not sufficient, and early in 1946 the Conference of Directors of the International Meteorological Organization at a meeting in London passed a resolution urging the establishment of stationary meteorological ships in certain ocean areas. Shortly afterwards, the Provisional International Civil Air Organization (PICAO) passed a similar resolution in Dublin. In the summer of 1946, at a meeting of the member states of PICAO in London, it was agreed that a total of 13 stationary meteorological ships would be established in the North Atlantic by July, 1947.



The PICAO Agreement.—The United States, Canada, France, Holland, Belgium, Norway, Sweden, Great Britain, Eire, Denmark, Iceland, Portugal and Spain were all signatories to the "Ocean Weather Ship" agreement. It was agreed that the allocation of stations would be as follows:—

United States	7
Canada and United States, jointly	1
France	1
United Kingdom	2
Norway, Sweden and U.K. jointly	1
Holland and Belgium, jointly ..	1

Eire agreed to provide an annual monetary contribution towards the scheme. It was decided that Portugal, Denmark and Iceland already contributed sufficiently to the safety of transoceanic aircraft by the establishment of meteorological stations in the Azores, Greenland and Iceland respectively.

It was decided that on an average it would need at least two ships to maintain one ocean weather station. The minimum size vessel which could satisfactorily perform the necessary duties was considered to be one of about 1,300 tons displacement, having a length of about 200 ft. and being of a suitable type for North Atlantic work.

The duties of the ship would include :

(*a*) *Meteorological observations.*—Surface observations every three hours.

Special observations, when necessary, of meteorological phenomena and of important changes in the weather.

Upper air wind observations by radar methods not less than four times daily.

Upper air temperature, pressure and humidity by radio-sonde not less than twice daily.

All the above observations would be reported by radio at the appropriate international hours. In addition, observations from certain merchant ships and other ocean weather ships would be collected and re-transmitted by radio.

(*b*) *Search and Rescue Services*—for aircraft and shipping in distress, as necessary, for which the requisite equipment will be provided aboard the ships. This implies the provision of special boats and other life-saving equipment, radar and special radio equipment, including beacons on which aircraft can " home ". The general scheme is that aircraft in distress can " home " on the ocean weather station and alight near enough for a rescue to be effected.

(*c*) *Navigational aids to aircraft in flight*, for which special radio beacons will be fitted aboard the ships.

(*d*) *Oceanographical and other scientific observations* as far as it is practicable.

The attached map shows the agreed distribution of the ocean weather stations, together with an approximation of the usual transatlantic steamer tracks. It should be emphasised that the establishment of these ocean weather stations will not in any way lessen the importance of observations from merchant ships. The network of observations from the oceans can never approach the density obtainable from stations ashore, but the closer the density the more able is the meteorologist to forecast coming weather changes. The ocean weather ships will merely approximate to islands from which regular observations, both on the surface and in the upper air, are obtainable—the immense gaps being filled in by observations from merchant vessels. It is hoped that the establishment of these stations will not only further the safety of transoceanic aircraft and shipping, but that they will also be the means of greatly improving the accuracy in forecasts for the benefit of the whole community.

The British plan for the operation of their two stations is to employ four ex-naval corvettes of the " Flower " class. These vessels are about 200 ft. in length, are built on whaler lines and have a loaded displacement of about 1,400 tons. They are oil-fired steam vessels, having reciprocating engines and a single screw, and a maximum speed of about 16 knots, economical

(79108) A 2

speed 9 knots. They have established a reputation for being excellent sea boats, having been employed on convoy escort and other duties in the Atlantic, in all weathers, during the recent war.

The British ocean weather ships will carry civilian crews, and they will be administered by the Meteorological Office. Special accommodation will need to be fitted to house the crew of 12 officers, 20 petty officers and 22 ratings, to the modern standards laid down by the Ministry of Transport. A steel shelter will be erected on deck for the filling of radio-sonde balloons; special radio equipment, radar and motor lifeboats will need to be fitted. The work of conversion of these vessels will be carried out in Admiralty dockyards. It is probable that the ships will be based in the River Clyde area.

The photograph facing p. 32 shows H.M. corvette *Snowflake*, one of the vessels which has been allocated to the Meteorological Office. It will be appreciated that with the removal of her guns and the structural alterations necessary to convert her to an ocean weather ship her appearance will be considerably altered.

In addition to a normal complement of Deck and Engine Room officers and ratings, stewards and cooks, the ships will carry meteorologists and radio technicians. It is anticipated that each vessel will spend about 27 days at sea, followed by a spell of 15 days in port—which latter period is necessary for leave to be given to the ships' companies and for necessary repairs, storage and refuelling to be carried out. It is anticipated that the accommodation and food aboard the ships will be good and that generous leave will be given to the ships' companies.

When on station, in the Atlantic, the ships will, as far as possible, remain "hove to", more or less head on to the wind and sea. Navigation will need to be accurate to ensure remaining in the vicinity of their station, as far as possible, within reasonable limits in all weathers, but the ships will, of course, make way through the water and vary their position from time to time. Life aboard these small ships at sea will be relatively exacting, at times monotonous, at times exciting—but for the man who likes ships and the sea and the study of the weather, it will, in general, always be interesting. The work will undoubtedly be unusual, and apart from its importance for scientific and practical meteorological purposes, its potential value for the safety of human life is without question. Those who go down to the sea in ships . . .

SNOW COVER IN THE BRITISH ISLES

BY GORDON MANLEY, M.A., M.SC.

The experience of the three severe winters 1940–2 coupled with the war-time diffusion of much of our city population over the countryside directed attention to the frequency with which snow may be expected to cover the ground in various parts of Great Britain. Those of us who in pre-war years had to pursue their avocations in upland northern districts were well aware that this was a feature of the British climate which tended to be overlooked, a fact the more understandable when it is recalled how large a proportion of our population dwells in lowland towns of considerable size. In a paper by the present writer*, this aspect of British climatology was

* *Quart. J.R. met. Soc., London,* 65, 1939, p. 2.

considered, using as a basis the figures published by the Meteorological Office since 1912. With the aid of some of the conclusions in this paper and making a more extensive survey of the data especially from lowland stations, it has become possible to illustrate the frequency of snow cover by means of a map. Few countries have as yet published maps of the distribution and frequency of snow cover; in western Europe indeed, the difficulties are considerable, as will be evident when the construction of the map under review is described. One of the most useful discussions of the duration of snow cover is that of Hebner for Germany.*

Snow cover has been observed and recorded in the British Isles at official stations since 1912; at first, rather few stations appear to have completed their records, and an examination of the figures also suggests that for a year or two some observers were not quite clear as to the criterion to be adopted. A day with "snow lying" is recorded, if at the 0900 observation the countryside surrounding the station, at the same level and typical of the station itself, is more than half covered with snow. Observations based on this criterion are now as a rule fairly consistent between adjacent stations, but in earlier years this was not always so. For example, one station in a Scottish mountain valley, although at a low level, recorded some remarkably high figures about the time of the last war quite out of keeping with any other station in the vicinity; after investigation the writer concluded that a temporary observer, probably carrying on under difficulties, had recorded "snow lying around the station" whenever snow covered the adjacent mountains 1,500 ft. or more above. After the war, however, the establishment of a number of permanent airfields (such as Cranwell, Lympne) and the renewal of more detailed observations at many climatological stations provided, from 1921 onward, a very consistent series of records, especially from country districts; and a further valuable series was forthcoming from many county agricultural stations after 1925. Country districts for obvious reasons are preferable to towns, as far as records of snow cover are concerned; more will be said about the effect of London in this respect.

It must not be forgotten that observations of snow cover, even when the criterion is carefully laid down from headquarters and applies to a single fixed hour, are not always easy. In Cambridgeshire for example, the winters of 1940 and 1942 provided a considerable number of days when a thin powdering of snow covered considerably more than half of a large grass playing field adjacent to the writer's house. But ploughland in the neighbourhood at the same time did not give an impression of prevailing snow cover at all, except at times when one approached a field in which the furrows ran east and west. As nearly three-quarters of Cambridgeshire is ploughland, observers locally are often liable to differ in their opinion whether the countryside is or is not thinly covered. In more hilly districts the observer's opinion may well be swayed in favour of snow cover in places where most of the slopes in view have a northerly aspect and remain largely covered with snow when southerly slopes, or even ground at the level of the observer would be virtually free from snow. There are also a few exposed stations at which snow, on the majority of occasions on which it falls, is liable to drift considerably; around such stations there may be considerable drifts in the

* Die Dauer der Schneedecke in Deutschland. Stuttgart, 1928.

roads and in the lee of walls, yet the ground is often sufficiently clear at the observing hour for the observer to record " no snow cover ". But when a large number of stations are compared, discrepancies arising from the various causes are to some extent smoothed out ; for the map under review, upwards of 150 stations were used. It was, however, throughout necessary to bear in mind the characteristics of the station and the probable reactions of the observers. For example, in considering the frequency of snow cover on the southern Pennines more weight was attached to the record from Oakes, near Huddersfield, than to that from Buxton, inasmuch as the Buxton station is well in the middle of the town and the earlier figures from it did not always appear to be consistent with other upland records ; they tended to be on the low side, and there is no reason to suppose that Buxton lies in an exceptional " snow shadow ".

Some notable difficulties arose from a familiar cause ; the thoroughly irregular distribution of stations. Decisions with regard to the frequency of snow cover in north Wales for example rest largely on the observations from Rhayader and Welshpool, with a very brief and imperfect record from Pen-y-Gwryd in Snowdonia. To this may be added the assumption based originally on the writer's observation of the frequent diminution westward in the amount of snow cover, with a corresponding rise in the snow line in a month such as March ; this is a well known feature of most of our British hill ranges. That diminution in amount is accompanied by diminution in the number of days of snow cover is borne out by observations from such Pennine stations as Oakes and Darwen in northern England, or West Linton and Eskdalemuir in southern Scotland, and Craibstone, Logie Coldstone, Glencarron and Achnasheen farther north. Even in the English Midlands, one of the largest gaps covers almost the whole of the uplands (Mendips, Cotswolds, Northamptonshire, Leicestershire) ; throughout this area, eight years' record from Cirencester (443 ft.) and eight from Leafield (612 ft.) with a patchy record from Rugby (390 ft.) afforded very scanty material from which to deduce how frequently a snow cover may be expected on the large area above 700 ft. Since these data were compiled stations at Little Rissington, Whipsnade, and also Vyrnwy in north Wales have begun recording ; so far, their results agree well with the estimates.

The frequency of snow cover is a climatological element subject not only to great variations from place to place, but also from year to year. The necessary compilation of available data was made in the early part of the war, and covered the years 1912–38. It was soon observed that over most of the country there were two exceptional years, 1917 and 1919, with a third (1937) rather less conspicuous in the statistics. By way of illustration, West Linton, with an average of 39·2 days yearly, recorded 88, 74 and 69 mornings with snow cover in these three outstanding years (also 70 in 1942), Eskdalemuir (average 24·7 days) recorded 90, 41 and 43 (68 in 1942), Cambridge (average of 7·7 days) 32, 28, 15 (29 in 1942) and Darwen in Lancashire (average of 12 days) 40, 34 and 27 respectively (1942, no record). In many places 1916 was also rather snowy ; hence it will readily be seen that the average for any given station would be likely to be considerably affected by the inclusion or omission of the years previous to 1920.

It may now be asked, what would the effect be if the data for the three severe winters of 1940–2 and the cold January of 1945 were incorporated in these averages. So far as snow cover is concerned the winters of 1941 and 1942 were comparable in many places with 1917 and 1919, and again, if these two outstanding years are included the effect will in general be to raise the averages for the whole period by a figure commonly of the order of 10 per cent. But it is not to be forgotten that the snow-free winter of 1943–4 goes some way towards redressing the balance. For the present it would seem reasonable to retain these averages for snow cover, 1912–38, which compare very closely with those for 1920–46. We can associate these averages with the published 30-year averages of temperature for 1906–35 or the unpublished series for 1911–40, and make further adjustments at the end of the present decade. By 1950 there will not only be a better network of stations, for example on the high Cotswolds and in north Wales, but more evidence will be forthcoming with regard to a possible incipient trend in the direction of severer winters corresponding with those prevailing between 1870–97. It is also worthy of recall that the late winter and spring months have tended in recent years to be relatively mild, and that in 1940–1, and again in 1941–2, there was little snow before January. Comparative figures are appended, in Table I, for six stations with longer records, which will serve to show the effect of the four cold Januaries since 1939. It will be seen that the annual totals at the lowland stations are affected ; Braemar shows little difference.

TABLE I—SNOW COVER : AVERAGE MONTHLY FREQUENCY

		Jan.	Feb.	Mar.	Apr.	May	Sept.	Oct.	Nov.	Dec.	Year	Range of Variation
Braemar,	1913–38	16·3	13·0	11·8	4·8	0·7	0·1	2·0	5·5	13·0	67·2	32 to
1,120 ft.	1913–45	17·2	13·9	11·7	4·3	0·7	0·1	1·7	5·3	11·9	66·8	142
West Linton,	1912–38	9·5	8·7	7·6	1·8	0·1	—	0·8	3·6	7·2	39·3	13 to
770 ft.	1912–45	11·0	9·0	6·9	1·5	0·1	—	0·6	3·0	6·5	38·6	88
Ushaw,	1912–38	4·9	4·6	4·7	0·8	0·1	—	0·1	1·4	4·0	20·6	3 to
594 ft.	1912–45	6·6	5·2	4·2	0·7	0·2	—	0·2	1·3	3·6	21·8	69
Cambridge,	1912–38	2·3	2·1	1·1	0·2	0	—	0	0·3	1·7	7·7	0 to
41 ft.	1912–45	3·6	2·6	1·1	0·2	0	—	0	0·2	1·5	9·2	32
Southport,	1912–38	1·6	1·0	0·8	0·1	0	—	0·1	0·7	0·6	4·9	0 to
30 ft.	1912–45	2·5	1·4	0·8	0·1	0	—	0·1	0·5	0·6	6·0	28
Kew, 18 ft.	1913–38	1·0	0·9	0·5	0·1	0	—	0	0·2	0·8	3·5	0 to
	1913–45	2·1	1·0	0·4	0·1	0	—	0	0·2	0·7	4·4	20

Features of the map.—Considering the coastal lowlands first : practically everywhere in a narrow strip round the coast from Norfolk to the Solway and north to the west of Scotland as far as Wester Ross, less than five mornings yearly with snow cover are to be expected. The strip broadens to include the whole of the lowlands of Devon and Cornwall below about 500 ft. (cf. Tavistock, 4·4 at 457 ft. and Redruth, 3·1 at 397 ft.). The neighbourhood of the Severn estuary (Cardiff, about 4) and a considerable patch of Hampshire are also included (South Farnborough, about 5) ; this appears to result from the fact that both areas lie in a slight " snow shadow " with regard to winds from between N. and E. Immediately adjacent to the sea the south and west coasts of England give about four days in Kent, two along the Sussex coast and round Southampton Water, between one and two in south Devon, less than one in Cornwall and west Pembrokeshire, nearly two at Holyhead, less than four at Douglas and five at Southport. Various places on the western Scottish islands and coasts give from two to five days, rising to six further inland at Greenock and Rothesay.

All the evidence goes to show that the inner London area records less than five days; the suburban stations generally give just under five, South Kensington about three, but Hampstead (450 ft.) records an average of 12·9 days.

The strip with less than five days yearly becomes very narrow along the east coast of Norfolk (Yarmouth nearly 5, Bungay above 7, Copdock above 8). Northward, Cromer has nearly 6 days, Skegness 6·8, Hull 7·1, but Spurn Head only 2·5, Scarborough 5·4, Tynemouth over 7. The average is generally from 6 to 8 on the eastern Scottish coast south of Angus, rising to 10 in Edinburgh and 12·6 at Aberdeen; it is generally about 10 very close to the Moray Firth, at Wick and in the lower Orkneys and Shetlands. In all this region however the rise in frequency with altitude is very rapid; near Aberdeen, Craibstone (325 ft.) records upwards of 25 days, and further inland Logie Coldstone (608 ft.) about 39 days. This very rapid rise in frequency of snow cover with altitude on our north-eastern coasts has already been discussed at some length in the paper cited above. It also applies very markedly near the coast of east Kent,* and probably the " 5 " and " 10 " isopleths as drawn on this map should be carried nearer the Kentish coast in spite of the low records from Margate and Dover on the coast itself.

The greater part of the southern English lowlands, e.g. in the Thames and Severn valleys, the Fenland, and also a large area in Shropshire, Cheshire and south Lancashire and smaller patches near the Humber and Carlisle experience from seven to ten mornings yearly with snow cover (Oxford 7·7, Cambridge 7·7, York about 11, Shrewsbury about 8, Welshpool 9·2, Leyland near Preston 8·5). To the south-west Marlborough even at 424 ft. averages only about 8; Cullompton (Devon) 3·8 illustrates the decrease towards Exeter.

With altitude and distance inland the increase is marked, especially towards the east coast. The higher North Downs generally exceed 10, with parts of the South Downs (Tunbridge Wells, 355 ft., nearly 8). In East Anglia, Norwich has over 12 days, Halstead (inland Essex) nearly 12; further inland, small areas on the highest of the Chilterns probably record upwards of 20 days. The whole of the higher ground of the Midlands and the Trent valley may expect from 10 to 15 at least (Birmingham, 535 ft., about 10; Mayfield near Ashbourne, 374 ft., about 16; Cranwell, 230 ft., over 14). Part of the lowland of Northumberland, Durham and north Yorkshire, with the Midland valley of Scotland falls into the 10–15 region (Catterick 13·5; Glasgow district, 10 at lower levels).

Northward and eastward, the rise on the flanks of the Pennines is marked, and if space and other circumstances had allowed the map could undoubtedly

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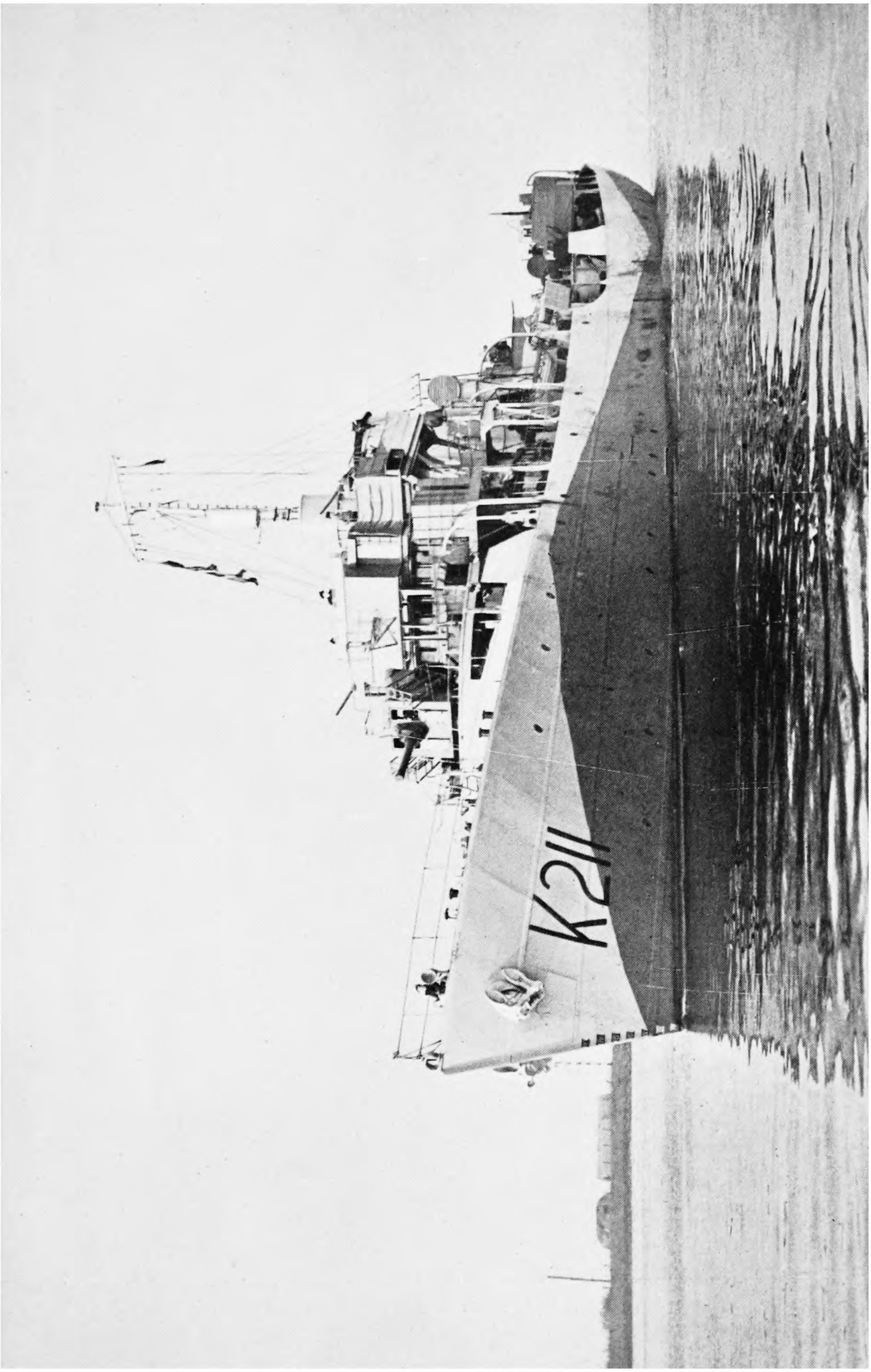
* *See* J. H. Dyson; *Quart. J.R. met. Soc., London,* **68,** 1942, p. 261.



H.M. CORVETTE *Snowflake*
(see p. 28)

FIG. 1—RIME AT ALLERTON PARK (YORKSHIRE) AT 1520, JANUARY 25, 1945
(see p. 46)

FIG. I—NUMBER OF MORNINGS WITH SNOW LYING, ANNUAL AVERAGE, 1912–38

have been improved by the inclusion of the "15" isopleth. There is probably a considerable area in high Leicestershire as well as most of Nottinghamshire with 15–20 days; Mansfield nearly 19 at 357 ft. and small areas may just exceed 20. Much of industrial Yorkshire and Durham also falls into this category (Huddersfield 17, Meltham 16, Durham 17), but on the lee side of the Pennines the average frequencies at similar levels are lower

(Giggleswick about 16, Stonyhurst about 9, Darwen 12). All the evidence indicates that the shores of Morecambe Bay are relatively free from snow cover, no doubt on account of the fact that the region frequently lies in a " snow shadow " so that the quantity in any given fall is commonly a good deal smaller than further east; further there are fewer snowfalls (cf. the article by the present writer in the *Meteorological Magazine, London,* **75,** 1940, p. 41).

Snow cover at higher levels.—One of the chief defects of British climatology arises from the shortage of high-level records; there are very few stations at levels above 1,000 ft. Deductions with regard to the frequency of snow cover on high ground must largely be based on the observed rate of increase in places where stations at different altitudes lie close together (cf. York 11 days, Harrogate (478 ft.) 21, Cally 5, Dumfries 11, Eskdalemuir 25). It has been already shown in the paper cited above that these increases can in large measure be related to the mean temperature in such a way as to make it possible to calculate the probable frequency of snow cover at higher levels.

On this basis, the greater part of the central and eastern Pennines above 1,000 ft. may expect over 30 days with snow lying; this becomes 50 or more in several upland areas, above about 1,600 ft., notably round the Peak and in several larger upland areas further north; the largest lies on the Durham-Cumberland-Westmorland border. The Upper Teesdale record, kept by the writer at 1,840 ft. indicates an average frequency of snow cover of about 80 days. The east Yorkshire uplands, although generally lower, have also a high expectation of snow cover; from 20–30 days on the higher Wolds, and upwards of 30 on all the higher moors towards Cleveland (Castleton, 450 ft., about 25). Elsewhere on a small-scale map it is impossible to show the detail on all summits; but it will be observed that a strip " between 30–50 days " almost connects the Pennines and the Lake District across Shap Fell. Not far away in Northumberland, Bellingham (849 ft.) averages about 31 days.

Considerable areas in the Southern Uplands of Scotland (Leadhills, 1,310 ft., 61 days on a short record) and a very large area in the central Highlands have over 50 days (Balmoral 60·2, Braemar 67·2, Dalwhinnie probably over 60). In this district a sizeable region, notably in the eastern Highlands, is shown as " more than 100 days ". Small areas further north and south, generally too small to show on a map of this scale, may also exceed 100 days, for example on the highest summits of the Southern Uplands, the Lake District, Crossfell and north Wales. On the summit of Ben Nevis (4,406 ft.) the number of days with snow cover is of the order of 230 days.

At high levels however, it is not safe to say that the frequency of snow cover increases with a close relationship to the fall of mean temperature. Drifting removes much of the snow cover from the summits, and in the winter of 1940 for example it was observed that the upper slopes of Helvellyn above 2,000 ft. were largely bare while the valleys were still heavily and continuously covered. Attempts have been made to estimate the duration of large snow drifts at high levels, i.e. above 2,000 ft., and it would appear that in any given year " large drifts " are likely to survive for between one third and one half as long again as " snow cover ". This is important especially with regard to upland roads; so many of these are badly sited and may remain blocked by drifts even when the surrounding countryside is almost entirely clear.

Little has been said hitherto with regard to snow cover in Wales. As elsewhere, upland stations are few and deductions rest to a considerable degree on the data from Rhayader (757 ft., about 16 days), Cantref (1,080 ft., probably 16 days) and the Herefordshire station of Bromyard (393 ft., 9 days) with occasional brief records from elsewhere, e.g. an older record from Wistanstow in Shropshire. The evidence goes to show that much of the Welsh upland, although relatively high is considerably freer from snow than the Pennines, especially towards the south-west. The Brecon Beacons too appear to afford an interesting example of "snow shadow" with regard to the valleys lying to the south and west. Towards Pembroke the diminution is reminiscent of Cornwall (Haverfordwest 5·0, Swansea 2·4, Aberystwyth 1·0, St. Ann's Head 0·5 days).

Dartmoor presents an interesting problem; in occasional years a Channel snowstorm, as one may call it, resulting from a winter secondary passing up-channel, gives, for orographic reasons, a very heavy and lasting accumulation on this upland. But many years pass without any exceptional fall of this kind, and the reputation of Dartmoor for snowfalls seems to be somewhat exaggerated if the average experience of the period 1912–38 is any guide. Although Princetown is the highest of the official stations in Great Britain (1,359 ft.) the average yearly number of mornings with snow cover is only about 17. It is probable that there is a small area towards the northern end of the moor with about 30 days. This average of 17 mornings yearly still holds for Princetown when the years 1939–45 are included.

In recent years the Association for the Study of Snow and Ice (now the British Glaciological Society) has begun to collect more precise data with regard to the frequency and duration of snow cover at high altitudes, but this work had to be discontinued during the war. A note on some of the results will be found in the *Quarterly Journal of the Royal Meteorological Society* for January 1941. This work has now been revived and contributions from upland observers will be very welcome.

Ireland.—Here again there are only too few stations; it is however evident that a very large part of the lowlands can expect less than five days yearly with snow cover (Birr Castle about 4 days, Armagh 7·3, Newtonforbes about 7, Markree upwards of 4, Dublin (Phœnix Park) less than 4). One station only records from above 500 ft. (Seskin, 535 ft., in south-east Ireland, with 5·2 days). The southern and south-western coasts resemble those of Cornwall in having everywhere less than 1 day; and it would appear that only small areas on the highest of the mountain ranges are likely to carry snow for upwards of 30 days. Even the areas with more than 10 days are restricted to small patches above 400 ft. in the north-east, and perhaps 1,000 ft. further to the south.

Conclusion.—It must be remembered that the accompanying map represents the distribution of a climatic element for which the data are as yet imperfect. It would scarcely be wise at this stage to endeavour to make a detailed map; and the mapping of the monthly frequencies of snow cover is also difficult as yet, indeed perhaps inadvisable until a longer term of years is available. One of the most noteworthy features, however, at the more northern high-level stations is the frequency of snow cover in March and April by comparison with the south; it will be noted that in the north the chance of snow cover in March is nearly as great as in January (1912–38) although the inclusion of 1939–45 somewhat restores the balance.

It is also not impossible that as our knowledge grows more light may be thrown upon the relationship between snow cover and soil temperature. For example, the rather low frequency of snow cover in the Fens compared with the same level in the inner parts of Essex and Suffolk (Cambridge 7·7, Halstead 11·6), may possibly owe something to the soil temperature as well as to a decreased supply of snow. There is much room for further work in regard to this hitherto neglected element of the British climate.

Some readers may also question the relationship between " mornings with snow lying at 0900 " and " days of snow cover ". There is reason to believe that the number of mornings with snow lying and the number of whole days with snow cover are approximately equal whenever the mean temperature of the month in question is below 38° F.; but this is not yet conclusive. Nevertheless, for the majority of our uplands the accompanying map can be regarded as a reasonably close representation of the duration of snow cover in an average year, apart from occasional scattered drifts.

The range of variation between extreme years is large; some typical examples are given for six stations in the table above. Taking the stations with long records into account it would appear that, at inland places averaging 10 days yearly, the probable range of variation is from 0 to between 30 and 40 days. Stations at which the average is 20 may record up to 70 days with snow cover in an extreme year; as a whole we may say that in an occasional year snow cover will be experienced up to between three and four times the average expectations. At the higher-level eastern Scottish stations the range of variation appears to be less, from rather under half to just over double the normal; at western Scottish stations the variability is greater. Elsewhere, mild coastal stations with an average between three and five days may occasionally record from 15 to 20. In the other direction it may be said of the majority of stations with averages of less than 12 days that an occasional year will occur without snow cover being recorded.

THE NUMERICAL BASIS OF CLIMATE

BY C. E. P. BROOKS, D.SC.

Part II.—*Frequency Curves*

In Part I two examples were given of the frequency distribution of temperatures, and Fig. 1 showed how the numbers of observations in each two-degree step form a symmetrical curve with a peak in the centre. The progression is not quite regular, but we can reasonably suppose that this is due to the limited number of observations, and that if instead of only 300 days we had many thousands, the small irregularities would almost completely disappear. The disadvantage of a short series can be largely overcome in many cases by constructing a theoretical " frequency curve " to represent the distribution which would probably be given by such a large number of observations.

The theory of frequency curves was first developed in the study of errors of observation. For example, consider the barometric pressure in a room at some particular instant of time, and suppose that in the room there is a large number of barometers with a different observer for each instrument, reading it to a thousandth of an inch. All the readings, corrected for temperature, ought to be the same, but in practice they would be found to show small discrepancies. These might be due to small differences in the barometers or attached thermometers, different errors of parallax, small differences of time in reading (if pressure is changing) and many other causes—the list is endless. Over the whole series of observations positive and negative errors will tend to cancel out, and the most probable value of pressure in the room is the mean of all the readings. But with one observer negative errors may predominate and the actual reading will be lower than the mean, with a second, positive errors may predominate, while with a third, positive and negative errors will be equal and the reading will be correct. In most readings positive and negative errors will nearly, but not quite, cancel out, and readings near the mean will be more numerous than those departing widely from it.

In the case of the barometer readings the errors are of human origin, but that is not a necessary feature. Thus we can regard the 1300 temperature on any one April day as a shot by nature at getting the normal 1300 temperature in April, disturbed by a whole series of small "accidents"—wind, rain, sun, etc.—each of which is as likely to contribute to a high as to a low temperature. Thus the theory of errors can be applied equally well to climatological observations. Let us see how this theory can be used to calculate a frequency curve.

Suppose that we toss up two pennies. There are four possible results, all equally likely—two heads; head, tail; tail, head; two tails. In 400 trials we should expect to come near the following result (though it is unlikely that it would be realised exactly):—

Number of heads ..	2	1	0
Frequency	100	200	100

It is more convenient to describe the distribution in terms of the "probability" of any single event as a fraction of unity, an event which is certain to occur (for example that the two pennies will come down head or tail and not on edge) having a probability of 1·0. The probabilities of 2, 1 and 0 heads are therefore respectively $\frac{1}{4}$, $\frac{1}{2}$, $\frac{1}{4}$. If we tossed three pennies we might have 3, 2, 1 or 0 heads and a little calculation will show that the probabilities of these results are respectively (in eighths), 1, 3, 3, 1. Anyone familiar with elementary algebra will recognise at once that the numbers 1, 3, 3, 1 are the coefficients of the terms in the expansion of the binominal $(a + b)^3$. To reduce them to fractional probabilities, we consider that since the probability of a head or of a tail is the same, $a = b = \frac{1}{2}$, and the probabilities for any one throw are given by the actual terms of the series $(\frac{1}{2} + \frac{1}{2})^3$, namely

$$(\tfrac{1}{2})^3,\ 3\,(\tfrac{1}{2})^2\,(\tfrac{1}{2}),\ 3\,(\tfrac{1}{2})\,(\tfrac{1}{2})^2,\ (\tfrac{1}{2})^3.$$

If we tossed n pennies at once, the probabilities of n, $(n - 1)$, . . . 0 heads would be given by the expansion of $(\frac{1}{2} + \frac{1}{2})^n$.

In nature the sources of error are by hypothesis unlimited, and in an element such as temperature which is as likely to be above as below the mean, n becomes infinite. The number of points in the expansion of $(a + b)^n$ also becomes infinite; in other words, they trace out a continuous curve, which is symmetrical about the mean value. This is known as the "normal frequency curve", and its shape depends solely on the value of σ, the standard deviation of the observations. As explained in Part I, the standard deviation is the square root of the mean of the squares of the differences of the individual observations from their average. Hence, if we know the mean and standard deviation of a limited series of observations, we can determine the distribution which would most probably be given by a very much larger number.

TABLE III—NORMAL FREQUENCY DISTRIBUTION

Probability (P) that a positive or negative value of x/σ will be equalled or exceeded (values = $P \times 1{,}000$).

x/σ	·00	·01	·02	·03	·04	·05	·06	·07	·08	·09
0·0	500	496	492	488	484	480	476	472	468	464
0·1	460	456	452	448	444	440	436	433	429	425
0·2	421	417	413	409	405	401	397	394	390	386
0·3	382	378	375	371	367	363	359	356	352	348
0·4	345	341	337	334	330	326	323	319	316	312
0·5	309	305	301	298	295	291	288	284	281	278
0·6	274	271	268	264	261	258	255	251	248	245
0·7	242	239	236	233	230	227	224	221	218	215
0·8	212	209	206	203	201	198	195	192	189	187
0·9	184	181	179	176	174	171	169	166	163	161
1·0	159	156	154	151	149	147	145	142	140	138
1·1	136	133	131	129	127	125	123	121	119	117
1·2	115	113	111	109	107	106	104	102	100	99
1·3	97	95	93	92	90	89	87	85	84	82
1·4	81	79	78	76	75	73	72	71	69	68
1·5	67	65	64	63	62	61	59	58	57	56
1·6	55	54	53	52	51	50	49	48	47	46
1·7	45	44	43	42	41	40	39	38	37	37
1·8	36	35	34	34	33	32	31	31	30	29
1·9	29	28	27	27	26	26	25	24	24	23

	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
2	23	18	14	11	8	6	4·7	3·5	2·6	1·9
3	1·3	1·0	0·69	0·48	0·34	0·23	0·16	0·11	0·07	0·05
4	0·032	0·021	0·013	0·009	0·0054	0·0034	0·0021	0·0013	0·0008	0·0005

A, the proportion of the total area to the left of the ordinate corresponding to x/σ, is given by $A = 1 - P$ for positive values of x/σ and by $A = P$ for negative values of x/σ.

In practice the distribution is usually given in the form of the fraction of the area (marked out by the curve and the base line of zero frequency) which lies to the left or right of the vertical representing any given fraction of the standard deviation. In case any readers would like to try the rather fascinating game of fitting a normal frequency curve, a table is given here (Table III). As an example, we will apply it to the data for Scilly given in Part I. We have:

Mean temperature = 51·38° F., σ = 3·03° F.

The process is quite simple. The steps of temperature in Table I are each 2° F., so that the steps of $x/\sigma = 2/3{\cdot}03 = 0{\cdot}66$. The values 49·95 and 51·95 on either side of the mean of 51·38 differ from the latter by − 1·43 and + 0·57 respectively, giving values of $x/\sigma = -\,{\cdot}47$ and $+\,{\cdot}17$. From these we proceed upwards and downwards by adding 0·66 successively. The calculation for a few steps is shown in Table IV.

TABLE IV—CALCULATION OF A NORMAL FREQUENCY CURVE

Temperature limits	x/σ	Probability per mille (Table III)	Difference	Difference × 0·3
° F.				
45·95	−1·79	37		
			92	28
47·95	−1·13	129		
			190	57
49·95	− ·47	319		
			181 }	
Mean (51·38)		(500)	} 248	74
			67 }	
51·95	+ ·17	433		
			230	69
53·95	+ ·83	203		

The third column, probability per mille, is read off against the value of x/σ in Table III, and gives us the total frequency of values below 51·38, 49·95, 47·95, etc. or above 51·38, 51·95, 53·95, etc. The differences between these probabilities give the probability per mille of a reading in the corresponding temperature step. Thus since we expect 319 observations per mille below 49·95° F. and 129 per mille below 47·95° F., the difference, 190, is the expectation for the range 47·95 to 49·95. To reduce this to a total of 300 observations, we multiply by 300/1000 or 0·3. For the central step, 49·95 — 51·95, we add together the expectations for the ranges 49·95 — 51·38 and 51·38 — 51·95. The calculated values are shown by the smooth curve in Fig. 3, in which the observed values are indicated by crosses. It will be seen that the smooth curve threads its way evenly among the crosses, indicating that the normal frequency curve is a good " fit " for the observations.

The normal curve is only one of a great number of possible frequency curves, but it is the most typical of those met with in climatology. Many distributions are generally similar, but are not quite symmetrical, falling off from the peak more steeply on one side than the other ; these are known as " skew " curves. Annual, and to a still greater extent, monthly rainfall totals for example are generally steeper on the left, so that the highest values are further above the mean than the lowest values are below the mean. This is to be expected, for rainfall has a lower limit at zero, but no upper limit ; it may (and monthly totals often do) exceed the mean by more than the mean value. Other curves are quite different ; the frequency of daily rainfall gives a " J " curve, high on the left and decreasing continuously to the right, and the frequency of individual cloud amounts in western Europe gives a " U " curve, high at both ends.

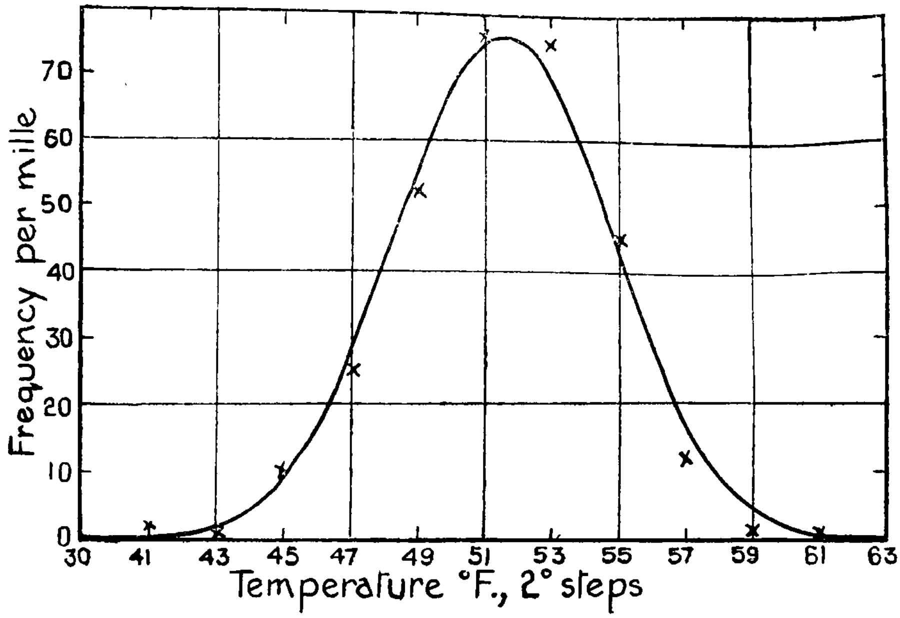


FIG. 3—OBSERVED AND COMPUTED FREQUENCIES OF TEMPERATURE AT SCILLY, APRIL, 1300, 1928–37

Fig. 4 is a histogram of the annual rainfall at Glenquoich, Scotland, 1869–1943. The horizontal lines show the observed frequencies. The broken line shows the result of fitting a normal frequency curve, and it can be seen that while this represents the general run of the histogram it shows appreciable discrepancies, especially in the extreme values, while the "mode" occurs at 111 in. (which is of course the mean annual rainfall) instead of at 104 in. In such a case, where the departures from the normal curve are not too great, the latter can be "adjusted" by taking account of the

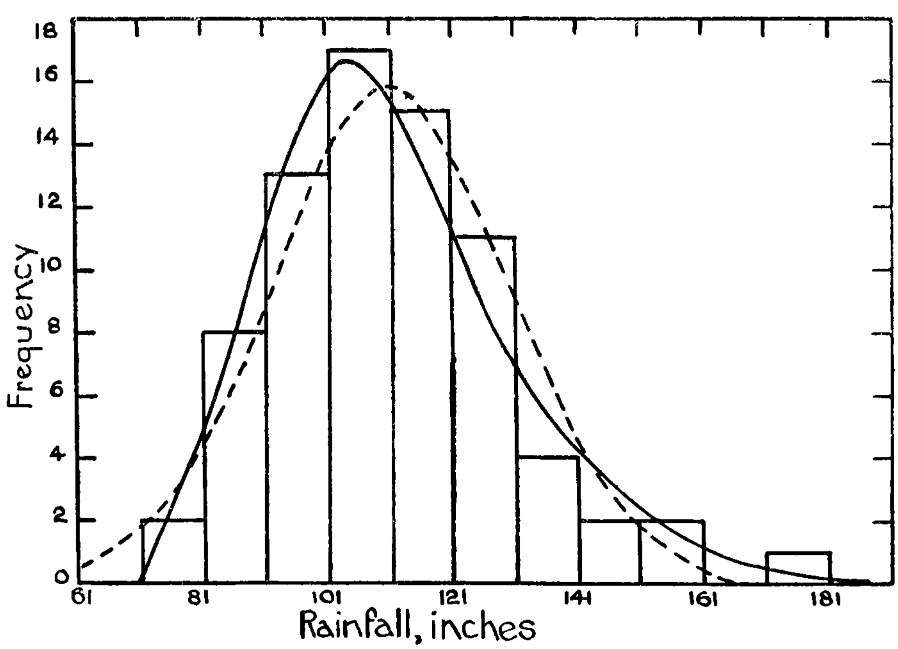


FIG. 4—FREQUENCY DISTRIBUTION, ANNUAL RAINFALL, GLENQUOICH

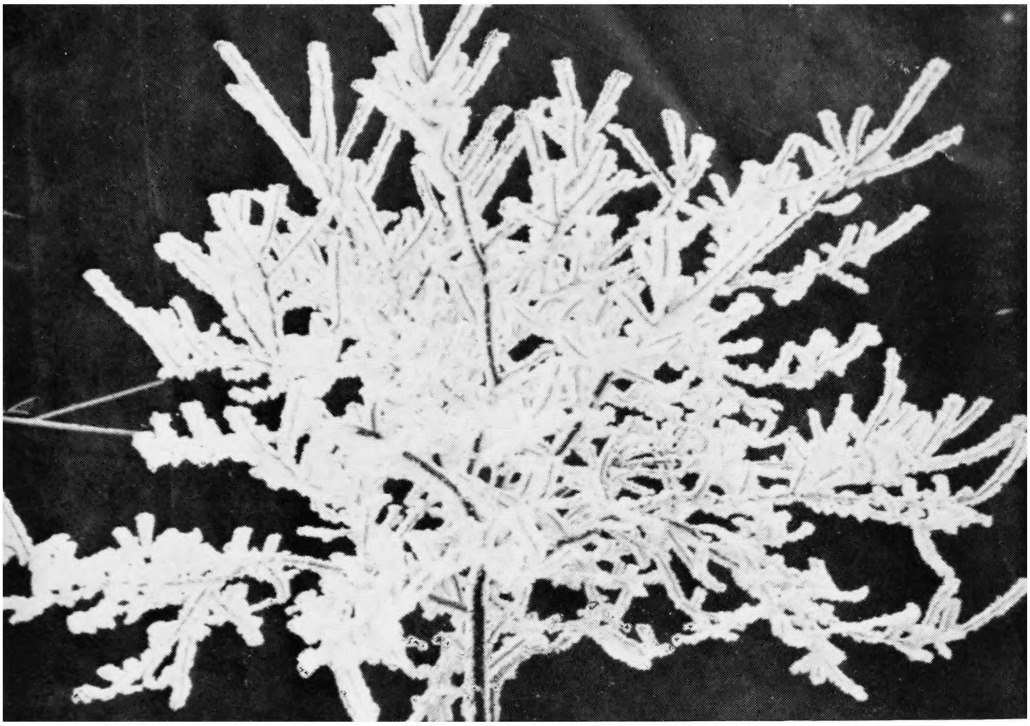


FIG. 2—RIME AT LINTON-ON-OUSE (YORKSHIRE), JANUARY 24, 1945
(see p. 46)

FIG. 3—RIME AT DOWNHAM MARKET (NORFOLK), DECEMBER 27, 1944
(see p. 46)

FIG. 4—RIME AT KILLADEAS (NORTHERN IRELAND), FEBRUARY 1, 1945
(see p. 46)

FIG. 5—RIME AT KILLADEAS (NORTHERN IRELAND), FEBRUARY 1, 1945
(see p. 46)

cubes as well as the squares of the departures from average. Since the squares are always positive, they must give a symmetrical curve, but the cubes have the same sign as the original departures. Hence the sum of the cubes is a measure of the skewness, and its sign, plus or minus, indicates whether the frequency is extended upwards or downwards. A description of the process of fitting an adjusted frequency curve would be beyond the scope of this article, but the result is shown by the full line of Fig. 4. This is a very good fit.

Fig. 5 shows the mean annual frequency of days exceeding various amounts of rain at Kilmarnock. Thus in an average year there are 211 days of 0·01 in. or more, 167 days of 0·04 in. or more, and so on, up to 2 days of 1 in. or more. The values are marked by crosses and a smooth curve has been drawn through them by eye. With curves of this shape it is often worth while to plot them in a different way, and the small circles show the logarithm of the frequency plotted against the amounts of rainfall. The points now lie very clearly

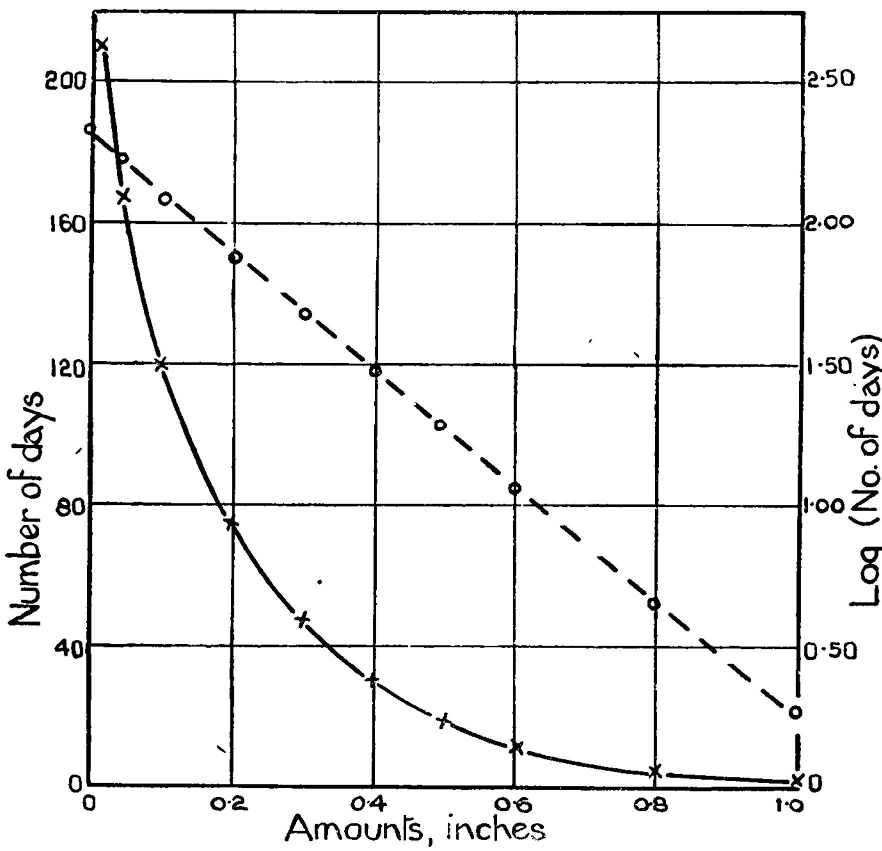


FIG. 5—NUMBER OF DAYS EXCEEDING VARIOUS AMOUNTS OF RAIN AT KILMARNOCK

along a straight line. If we put r for the amount of rainfall and f for the frequency with which it is exceeded, the equation of the straight line is very nearly

$$\log f = -2r + 2 \cdot 3.$$

This enables the probable number of days exceeding any other limit to be calculated. For example, if $r = 1 \cdot 5$ in., $\log f \doteq -0 \cdot 7 = \bar{1} \cdot 3$, and the expected frequency is 0·2 or once in five years. Actually there were 7 such falls in 29 years.

Fitting frequency curves to the less simple types of distributions, especially those which are cut off sharply at one or both ends, such as individual cloud amounts or Beaufort wind forces, is difficult and laborious, and is probably rarely worth while for meteorological data. A classification of frequency curves and descriptions of how to fit them are given by W. P. Elderton in "Frequency Curves and Correlation" (3rd edition, Cambridge, 1938).

(To be continued)

METEOROLOGICAL OFFICE DISCUSSIONS

Monday Evening Discussions of foreign papers of special interest were started as a feature of Meteorological Office activities by Sir Napier Shaw as long ago as 1905 and always proved popular. The opportunity of refreshing old acquaintances in an informal atmosphere must account for much, but it is also pleasant, as well as useful, for the staff, many of whom are much pre-occupied with the business of providing and administering meteorological services, to meet on the plane of scientific progress.

These meetings, which occurred on alternate Monday evenings between October and March, were held with little interruption until March, 1939. The outbreak of war prevented them from being resumed in October, 1939. It was with considerable pleasure therefore that it was learnt some time ago that the Director, Sir Nelson Johnson, could now see his way to re-opening the series. His selection for the inaugural meeting on February 10 was the paper by V. J. Oliver and M. B. Oliver "Forecasting the weather with the aid of upper air data"*, with an invitation to Dr. R. C. Sutcliffe to open the discussion.

The meeting was attended by some 120 of the staff, many of whom had come up from their stations in the country for the occasion. After the informal atmosphere had been created over a welcome cup of tea the Director introduced the session with remarks on the purpose of the meetings including a tribute to the late Sir Napier Shaw, the founder of the Discussions.

With the aid of illustrations from the paper, projected by the epidiascope, Dr. Sutcliffe then gave a fairly complete account of the paper, which in his opinion was ideal for the basis of a discussion containing as it did so many practical propositions for the consideration of the forecaster, propositions which were related mainly with the dynamical behaviour of the atmosphere. The paper covered so much ground that the authors had been compelled to reduce the theoretical arguments to almost skeleton form, and Dr. Sutcliffe suggested that this was scientifically regrettable, as incomplete theorising, of the facile descriptive variety, was unconvincing to the critical reader. Nevertheless he was persuaded that many of the rules given were a fair statement of what was actually observed to occur, and that the arguments based on Rossby's vorticity considerations and on shear of wind with height could not lightly be dismissed even if they were open to criticism. Amongst the many comments made in the course of his account mention might be made of his warning that although frontal characteristics were modified by the overrunning or the lagging behind of the upper wind, one could not infer upsliding or downsliding—essentially dynamical processes—with a simple

* Published by the Institute of Meteorology, Chicago University, 1944.

kinematical picture of air descending or ascending above a wedge of cold air regarded as acting like a solid wedge; and, another point, that the notion of pressure changes by advection of warm or cold air was something which could be used to account for almost anything, that the authors had used warm air advection to account for rising pressure at 10,000 ft. and for falling pressure at the surface according to convenience; they could not have it both ways, at least not to carry conviction. But Dr. Sutcliffe was a convinced disbeliever in the implications of advection except as defining the difference in pressure between one level and another; only dynamical consideration would determine at what level the changes took place.

The Deputy Director, Mr. E. Gold, then made a few pertinent remarks and threw the meeting open to discussion and it was stimulating to see how many of the younger members of the scientific staff were ready to make considered contributions. Mr. Kirk interested everyone with a reference to his meeting Mr. Oliver and Dr. J. Bjerknes in Italy and to a discussion there of these same problems. Mr. Miles, now on Prof. Brunt's staff at the Imperial College, brought up the question of Rossby's trajectories with north-easterly winds in connexion with cyclonic development which he said seemed to work well on some occasions but not on others. Mr. Matthewman, from the upper-air section at Dunstable, provided some very rapid and neat quantitative inferences from the fundamental equation relating vorticity changes with divergence, and showed that appreciable cyclonic curvature might be present in a wind of southerly origin without any convergence having occurred. He was also sceptical about the ignoring of lateral shear as compared with streamline curvature in the vorticity determination. He noted that in solid rotation the shear and curvature terms are of equal magnitude; and that a small shear of 2·5 m.p.h. in 100 miles, difficult to observe in practice, might be equivalent, in a practical example, to the change in apparent vorticity due to movement across five degrees in middle latitudes.

Mr. C. K. M. Douglas, head of the Central Forecasting Branch of the Office, was very alive to the importance of the dynamical approach but stressed the absence of any agreed principles or accepted technique which could at present be applied to a routine service as distinct from a research organization.

After other contributions Dr. Sutcliffe replied with the statement that in his opinion one weakness was that vorticity considerations alone ignored the necessity for ensuring that the field of pressure was suitably modified to fit the changing field of motion. Other writers, by contrast, studied the changes in the pressure pattern and tended to ignore the processes required to bring the circulation into quasi-geostrophic agreement. It was his opinion that this requirement of mutual adjustment was fundamental and he went on to indicate a possible line of attack.

The whole discussion was a lively and stimulating experience, and we look forward to further such meetings. The Director in his closing remarks announced the next occasion as Monday, March 3, when Mr. L. G. Cameron would open a discussion on a paper entitled "Insolation in relation to cloudiness and cloud density" by B. Haurwitz.*

Subsequent discussions this session will be held on March 31 and April 21.

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* *J. Met., Milton, Mass.*, **2**, 1945, p. 154.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of this Society was held on Wednesday, January 22, 1947, at 49 Cromwell Road, Mr Gordon Manley, President, in the Chair. The Council for 1947 was elected and the Symons Medal presented to Prof. D. Brunt, F.R.S., in recognition of "his outstanding original work in many fields of meteorology and his eminent services to our science in general as well as to this Society in particular", and of "his professional success both as teacher of students of many nationalities and as writer of an outstanding text-book embodying the first critical account, in logical and readable form, of the physics and dynamics of the atmosphere".

In his presidential address Mr. Manley drew the attention of the audience in view of the prevailing interest, to some recent Antarctic discoveries notably the unexpected height of the ice cap south-east of the Weddell Sea. Speaking as a geographer he then turned to the extent and character of the contributions to meteorology that the geographer could make. No would-be meteorologist should lack a sound mathematical and physical training at the undergraduate stage; but he suggested that the geographical attitude of mind was also worth cultivating. Hence if more contacts were to be made between physicists and geographers in some of our universities the production of graduates able to make useful contributions to meteorology would be encouraged. Through such contacts indeed many geographers with a knowledge of physics might also make useful contributions, especially with regard to many aspects of climatology in which there was still much room for development, and at a time when more independent university work was required.

LETTERS TO THE EDITOR

Extremes of Low Temperature

From time to time it happens that the thermometer reading of − 23° F. at Blackadder (Berwickshire) on December 4, 1879, is resurrected as the lowest trustworthy reading ever recorded for the British Isles. It seems high time that the complete story was told.

The most authoritative comment on the reading is that of Alexander Buchan at the Half-Yearly General Meeting of the Scottish Meteorological Society on February 25, 1881.* In drawing attention to the fact that January 1881 had been colder than any of which they had previous record in Scotland, Buchan remarked that the greatest cold occurred at Springwood Park, Kelso, where the thermometer fell to − 16° F. He went on to explain that the thermometer at Blackadder by which a temperature of − 23° F. had been recorded in December 1879 was an exposed one and could not be taken into account in making comparisons with other places. It may be added that Buchan had inspected the Society's stations at Springwood Park and Blackadder between March and July 1880.

The reading of 1879 at Blackadder is mentioned in *Symon's Meteorological Magazine* of 1880, but the only other authority beside Buchan who need be quoted in detail is Marriott, Assistant Secretary of the Royal Meteorological Society.† Marriott was not content to accept the Blackadder report without

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* *J. Scot. met. Soc., Edinburgh*, **6**, new series, 1901, p. 77.

† *Quart. J.R. met. Soc., London*, **6**, 1880, pp. 102–12.

further check and subsequently he asked for additional information from Dr. C. Stuart (former President of the Berwickshire Naturalists' Club). The resulting replies to specific questions were :—

The thermometer was an " upright registering thermometer ".

It had been compared with another in the possession of Sir G. H. Boswell, having the scale engraved on the tube. The latter had been tested at Kew.

The " *maker* " was Lennie of Edinburgh.

It had a northern exposure, 2 *ft. from the ground, with a sloping board about* 2 *in. across overhead, to keep off the wet.* It was mounted on a metal frame, painted white, a well-finished instrument (the italics are ours).

The observer was Mr. John Reid, gardener to Sir G. H. Boswell. He kept a regular register and sent returns to the Scottish Meteorological Society.

There was no mistake whatever made in the reading.

The site was open, with wood outside garden wall, and river Blackadder distant about 100 yds. The height above sea level was between 100 and 200 ft.

The thermometer was graduated to 30° F. below zero, with divisions on the frame.

The conclusions to be drawn from these notes are :—first, that the Blackadder readings should be rejected once for all, they were not obtained under reasonably standard conditions ; and secondly, that so far as the statistics go there is nothing to choose between the extremes of low temperature in the Braemar district of the Cairngorms (— 17° F.) and the relatively flat Kelso district of Berwickshire (— 16° F.).

It seems desirable to ensure now also against the further publication of another low reading (— 26° F.) which has proved to be erroneous. This reading was said by local inhabitants to have been recorded by Baird and Barry in the Lairig Ghru (Cairngorms) during a blizzard which they did not survive. The reading has been published with reservations in the *Rothmill Quarterly Magazine*, *The Scotsman*, and the *Journal of the Royal Horticultural Society*, but so far as is known, nowhere else.

By the courtesy of Mr. Baird, senior, it has been possible to consult the actual diary of the journey. This establishes that the reading was + 6° F. (26 degrees of frost) on the night of December 28–29, 1927. The diary does not mention how the thermometer was exposed.

W. A. HARWOOD

Meteorological Office, Edinburgh.

NOTES AND NEWS

Rime in December, 1944 and January, 1945

Soft rime consists of ice crystals which are deposited on surfaces, especially on points and edges of all objects, in supercooled fog or mist and it is comparatively rare in our climate. Christmas Day 1944 was very cold with considerable fog at inland stations in England, and a quite unusual deposit of rime made the countryside exceptionally beautiful. These conditions persisted for some days.

At Stonehouse, Gloucestershire, on the 27th rime was observed to the tops of tall elms as well as on shrubs, palings, grass verges, roofs etc.; on the 29th sunshine caused a partial thaw on the higher branches of trees and surfaces facing south, but severe frost occurred again on the morning of the 30th and the rime persisted for a while on small trees, shrubs and grass. The table gives the maximum, minimum and grass minimum temperatures at Stonehouse.

	December					
	25th	26th	27th	28th	29th	30th
	degrees Fahrenheit					
Maximum	29	28	32	35	35	39
Minimum	28	20	16	20	19	20
Grass minimum	17	13	9	14	11	15

It will be seen that the temperature did not rise above 32° F. for the three consecutive days 25th, 26th and 27th, while temperature fell to 16° F. in the air and to 9° F. on the grass on the morning of the 27th. Fig. 1 (facing p. 33) shows the deposit of rime at Downham Market (Norfolk) on December 27, 1944.

Photographs published in *The Times* of December 28, 1944, show similar conditions at Abinger, Surrey and at Cassiobury Park, Watford, while another published in *The Times* of January 3, 1945 indicates that the same conditions existed also near Dinant on the Meuse, Belgium. A photograph showing a similar deposit of rime at Sealand, near Chester, on December 15, 1928 is published in the *Meteorological Magazine* for February, 1929.

Another widespread period of rime occurred at the end of January, 1945, during an intensely cold spell which embraced the whole of the British Isles. The photographs, facing pp. 40 and 41, taken at places as far apart as Northern Ireland and East Anglia, indicate the exceptional nature of the phenomena.

From January 19 to 25 severe northerly gales brought arctic air over northern Europe, with periods of snow. As the wind moderated, the snow-covered surface cooled even further, with the development of mist and fog over a wide area. In eastern England, after a period of stagnation during which temperatures fell to between + 5° F. and − 5° F., a light easterly drift was established bringing in air off the sea with a surface dew point of about 25° F. The temperature rose gradually, with widespread fog and consequent deposit of rime. Fig. 2 shows the deposit at Linton-on-Ouse (Yorkshire) on January 24 and Fig. 3 the deposit at Allerton Park (Yorkshire) on the afternoon of January 25.

The photographs in Figs. 4 and 5 show conditions at Killadeas in Northern Ireland on February 1, 1945. No details are available, but it appears that following the cold weather which accompanied an anticyclone over the British Isles on January 29, light moist winds set in from the Atlantic with a gradually rising temperature. A number of photographs were obtained at Stonehouse (Gloucestershire) showing the rime deposit on trees, shrubs, etc. on January 26, following a period of intense cold and fog.

Acknowledgments are due to the officials (mainly at Meteorological Office stations) who kindly forwarded the large number of photographs from which these examples have been selected. All the photographs have been placed in the collection in the Library of the Meteorological Office at Harrow.

RAINFALL OF DECEMBER, 1946

Great Britain and Northern Ireland

County.	Station	In.	Per cent of Av.	County.	Station	In.	Per cent of Av.
London	Camden Square ..	1·95	82	*Glam.*	Cardiff, Penylan ..	4·66	93
Kent	Folkestone Cherry Gdns.	3·07	96	*Pemb.*	St. Ann's Head ..	4·31	91
,,	Edenb'dg, Falconhurst	3·22	98	*Card.*	Aberystwyth	3·33	84
Sussex	Compton, Compton Ho.	4·61	110	*Radnor*	Bir. W.W., Tyrmynydd	8·31	101
,,	Worthing, Beach Ho.Pk.	3·20	106	*Mont.*	Lake Vyrnwy.. ..	7·95	114
Hants.	Ventnor, Roy. Nat. Hos.	3·84	116	*Mer.*	Blaenua Festiniog ..	14·20	112
,,	Fordingb'dg, Oaklands	3·48	88	*Carn.*	Llandudno	3·63	125
,,	Sherborne St. John ..	2·81	85	*Angl.*	Llanerchmedd ..	6·15	140
Herts.	Royston, Therfield Rec.	2·04	88	*I. Man*	Douglas, Boro' Cem...	5·48	111
Bucks.	Slough, Upton ..	2·33	92	*Wigtown*	Pt. William, Monreith	4·83	106
Oxford	Oxford, Radcliffe ..	2·12	86	*Dumf.*	Dumfries, Crichton R.I.	4·86	114
N'hant	Wellingboro', Swanspool	2·21	94	,,	Eskdalemuir Obsy. ..	6·53	93
Essex	·Shoeburyness	2·05	111	*Roxb.*	Kelso, Floors	1·60	69
Suffolk	Campsea Ashe, High Ho.	2·81	122	*Peebles.*	Stobo Castle	3·56	94
,,	Lowestoft Sec. School	3·05	131	*Berwick*	Marchmont House ..	1·92	68
,,	Bury St. Ed., WestleyH.	2·47	102	*E. Loth.*	North Berwick Res. ..	1·83	85
Norfolk	Sandringham Ho. Gdns.	2·78	109	*Midl'n.*	Edinburgh, Blackfd. H.	1·87	80
Wilts.	Bishops Cannings ..	2·46	75	*Lanark*	Hamilton W.W., T'nhill	3·90	90
Dorset	Creech Grange ..	4·35	99	*Ayr*	Colmonell, Knockdolian	5·48	98
,,	Beaminster, East St...	5·75	120	,,	Glen Afton, Ayr San.	5·80	91
Devon	Teignmouth, Den Gdns.	4·36	103	*Bute*	Rothesay, Ardencraig	6·15	113
,,	Cullompton	4·43	101	*Argyll*	Loch Sunart, G'dale..	7·74	89
,,	Barnstaple, N. Dev. Ath.	4·28	97	,,	Poltalloch	6·02	94
,,	Okehampton, Uplands	6·87	97	,,	Inveraray Castle ..	9·78	98
Cornwall	Bude School House ..	3·66	84	,,	Islay, Eallabus ..	6·89	116
,,	Penzance, Morrab Gdns.	6·06	107	,,	Tiree	5·18	99
,,	St. Austell, Trevarna..	6·57	108	*Kinross*	Loch Leven Sluice ..	3·71	94
,,	Scilly, Tresco Abbey..	5·33	114	*Fife*	Leuchars Airfield ..	2·24	91
Glos.	Cirencester	2·27	68	*Perth*	Loch Dhu	9·91	98
Salop	Church Stretton ..	3·69	110	,,	Crieff, Strathean Hyd.	5·09	114
,,	Cheswardine Hall ..	2·67	95	,,	Blair Castle Gardens..	3·97	104
Staffs	Leek, Wall Grange P.S.	4·43	118	*Angus*	Montrose, Sunnyside	3·63	131
Worcs.	Malvern, Free Library	2·14	77	*Aberd.*	Balmoral Castle Gdns.	2·88	85
Warwick	Birmingham, Edgbaston	2·87	107	,,	Aberdeen Observatory	2·86	89
Leics.	Thornton Reservoir ..	2·55	95	,,	Fyvie Castle	3·19	93
Lincs.	Boston, Skirbeck ..	2·49	116	*Moray*	Gordon Castle ..	1·72	64
,,	Skegness, Marine Gdns.	1·74	79	*Nairn*	Nairn, Achareidh ..	·72	37
Notts.	Mansfield, Carr Bank	3·18	110	*Inv's*	Loch Ness, Foyers ..	2·77	63
Ches.	Bidston Observatory	2·66	100	,,	Glenquoich	10·57	72
Lancs.	Manchester,Whit.Park	3·03	94	,,	Ft. William, Teviot ..	7·90	77
,,	Stonyhurst College ..	4·67	96	,,	Skye, Duntuilm ..	5·29	85
,,	Blackpool	3·96	121	*R. & C.*	Ullapool	3·50	57
Yorks.	Wakefield, Clarence Pk.	2·32	96	,,	Applecross Gardens ..	5·45	85
,,	Hull, Pearson Park ..	2·39	99	,,	Achnashellach ..	7·87	83
,,	Felixkirk, Mt. St. John	2·69	112	,,	Stornoway Airfield ..	4·19	71
,,	York Museum ..	2·18	97	*Suth.*	Lairg	3·66	91
,,	Scarborough	2·83	119	,,	Loch More, Achfary ..	6·56	71
,,	Middlesbrough ..	2·04	105	*Caith.*	Wick Airfield ..	1·90	62
Norl'd	Newcastle, Leazes Pk.	2·24	95	*Shet.*	Lerwick Observatory	5·91	123
,,	Bellingham, High Green	2·79	77	*Ferm.*	Crom Castle	4·35	105
,,	Lilburn Tower Gdns.	2·22	84	*Armagh*	Armagh Observatory	3·82	122
Cumb.	Geltsdale	3·17	83	*Down*	Seaforde	4·62	112
,,	Keswick, High Hill ..	7·74	116	*Antrim*	Aldergrove Airfield ..	3·71	108
,,	Ravenglass, The Grove	7·08	155	,,	Ballymena, Harryville	4·54	102
West.	Appleby, Castle Bank	3·90	98	*Lon.*	Garvagh, Moneydig ..	4·25	106
Mon.	Abergavenny,Larchfield	4·49	101	,,	Londonderry, Creggan	5·85	134
Glam.	Ystalyfera, Wern Ho.	7·39	88	*Tyrone*	Omagh, Edenfel ..	5·55	131

During the first week of December the pressure distribution was of the usual winter type, with depressions near Iceland and an anticyclone over the Atlantic in latitude 30° to 40° N.; there was also an anticyclone north and north-east of the Caspian Sea. A depression occupied the North Sea on the 3rd and 4th and another crossed the British Isles on the 7th to 10th, pressure falling to 963 mb. at Plymouth on the 8th. On the 11th areas of very high pressure began to move westwards across Russia; 1060 mb. was exceeded north-east or north of Moscow on the 12th, 13th and 14th and in Norway on the 16th. These anticyclones extended their influence to France and the British Isles mainly from the 14th to 20th, while the main area of cyclonic activity lay far to the west and north. On the 23rd the eastern high pressure area retreated again to the Urals, and from then until the end of the month the Azores anticyclone re-appeared and depressions again passed from the neighbourhood of Newfoundland north-eastward across or to the south-east of Iceland. On the 26th pressure fell below 960 mb. north of the Faroes. In the Mediterranean depressions were unusually frequent, especially in the latter half of the month.

The chart of mean pressure for December shows a deep depression (below 992 mb.) in southern Greenland, where pressure was 8 mb. below normal. An anticyclonic belt of 1020–1025 mb. extended from south-eastern United States to Spain, and an intense anticyclone (1032 mb., 15 mb. above normal) lay over eastern Russia. In the Mediterranean mean pressure was below 1010 mb., a deficit of more than 5 mb.

The rainy weather which had characterised conditions in western Europe since the beginning of November gave way about December 14 to a period of dry cold conditions. A severe cold spell set in in Germany on the 15th, and according to *The Times* canals in western Germany were ice-bound by the 20th. These conditions spread to the British Isles, where severe frost was experienced at times from the 16th to 21st inclusive, particularly in England. The mean temperature for the week ending the 21st was 9° or 10° F. below the average in south and east England. On the morning of the 21st air temperature fell to 10° F. or below locally in northern districts of England. A shallow depression over Denmark moving west was associated with appreciable snowfall in south-east England on the 19th.

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days diff. from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England & Wales	55	8	−2·5	101	+1	149	25
Scotland ..	54	15	−1·5	89	−2	129	18
Northern Ireland	50	18	−2·2	113	0	123	23

M.O. 482 AIR MINISTRY

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THE INTERNATIONAL METEOROLOGICAL ORGANIZATION

National meteorological services grew up in many countries during the nineteenth century, and began to exchange their observations. The need for standardising the methods was soon felt, and for observations at sea international co-operation was sought by a Conference on Maritime Meteorology at Brussels in 1853, but no discussion of land stations was held until 1872. In that year Dr. C. Bruhns, Director of the Leipzig Observatory, invited a number of well-known meteorologists to a conference at Leipzig, of whom 52 attended, including one representative of America. This Congress was recognized as filling an urgent need, and was quickly followed by another, at Vienna in September 1873, at which a permanent " International Meteorological Committee " was formed ; this Committee met in London in 1876 and Utrecht in 1878. The latter meeting laid down a constitution for the " Second International Meteorological Congress " at Rome in 1879, and may be considered as the birth-place of the International Meteorological Organization, which, apart from interruptions caused by wars, has functioned continuously ever since. The Members of the Organization are Directors of Meterological Services. The " I.M.O." aims at perfecting and co-ordinating the various meteorological activities of the world, including the standardization of meteorological procedures, the publication and exchange of meteorological observations and statistics and the application of meteorology to aviation, marine navigation, agriculture, etc. Upon its activities depends the ability of each country to obtain promptly and accurately from other countries the reports which are plotted on synoptic charts, and on which weather forecasts are based. The I.M.O. comprises the Conference of Directors, the International Meteorological Committee, various Regional Commissions, a number of Technical Commissions and a permanent Secretariat.

The Conference of Directors is composed of the Directors of State Meteorological Services of practically all nations and Directors of certain other independent meteorological organizations and institutes. At present it has about 100 members representing 84 countries and colonies. It is presided over by the President of the International Meteorological Committee, who is at present Sir Nelson K. Johnson, K.C.B., D.Sc., Director of the Meteorological Office of Great Britain. Before 1939 it met every six years or less to approve standard methods of observation and analysis and to decide generally upon measures of international co-operation between meteorological services. A Conference was held in London in 1946 to pick up the threads of international co-operation broken by the war; the next will be in Washington this year.

The International Meteorological Committee consists of 25 members elected by the Conference of Directors, together with the Presidents of the Technical Commissions. It acts for the full Conference during the interval between meetings of the latter; it is empowered to receive recommendations from the Technical Commissions and to approve them for universal adoption and to initiate any necessary measures for the development or improvement of international meteorology. The President of the Committee (Sir Nelson Johnson) is the chief executive officer of the Organization. The Committee normally meets every three years; the last meeting was in Paris in 1946.

International meteorology is truly world-wide, and from 1935 onwards local interests have been in the hands of a series of "Regional Commissions", which co-ordinate the activities of all the meteorological services within their regions, and link up with neighbouring regions. There are six Regional Commissions, representing respectively Africa, Asia, South America, North and Central America, south-west Pacific and Europe.

The Technical Commissions are formed to consider and make recommendations upon any technical questions referred to them by the Conference of Directors or the International Meteorological Committee. They exist to prepare the ground in matters concerning international co-operation in the various branches of applied meteorology. There are at present ten Technical Commissions, dealing with: aerology, aeronautical meteorology, bibliography and publications, agricultural meteorology, climatology, projection of meteorological charts, instruments and methods of observation, maritime meteorology, hydrology and synoptic weather information; meetings take place at intervals not exceeding three years.

The Secretariat is located in the permanent headquarters of the Organization at Lausanne, Switzerland. It is responsible for organizing meetings of the Conference, Committee and Commissions, and arranges for the publication of their approved resolutions, minutes and reports. It also serves as a centre for information on world meteorological services, and, in consultation with the Presidents of the Committee and Commissions, conducts the day-to-day work of the Organization. The Secretariat is maintained by annual contributions from the various national services, the contribution of a major service being 5,400 Swiss francs, that for a medium service 2,700 Swiss francs, with correspondingly lower contributions from smaller services. The financial affairs of the Organization are managed and the Secretariat is administered by an Executive Council of six members, which meets every year under the President of the International Meteorological Committee.

The I.M.O. collaborates with other international organizations whose work is related to meteorology, such as the Provisional International Civil Aviation Organization (P.I.C.A.O.), the International Union of

Telecommunications and the International Ice Patrol Service. The character of the collaboration usually consists in inviting the other bodies to send delegates to meetings of the Commissions with which they are primarily concerned.

The relationship between the I.M.O. and the United Nations is under discussion with a view to exploring the possibilities of the Organization becoming linked to U.N.O. without losing its world-wide character and independence. The present status of the I.M.O. is little more than that of a voluntary association. Steps are being taken to place the Organization upon a more official footing, and the draft of an International Convention has been prepared and is expected to be finally agreed and signed at the Conference of Directors in Washington next September. The adoption of the Convention will not affect materially the aims, functions or the internal structure of the Organization.

During the 1939–45 war, the activities of the I.M.O. were necessarily much curtailed. With the return of peace it became necessary to resume its activities and to restore the international procedures which had been in operation prior to 1939. The task confronting the Organization was rendered more complicated by two factors. The first was the development of long-range flying and the consequent demand for a corresponding development in the meteorological arrangements for aviation. The second new factor was the introduction of improvements in the field of scientific and technical meteorology. These advances in meteorology had been made by a few countries to meet the demands of war. It was now necessary to spread the new knowledge universally, and to apply it to meet the requirements of peace.

An extraordinary meeting of the Conference of Directors was held in London between February 25 and March 2, 1946 (see photograph facing p. 60), to set the machinery of the Organization into immediate operation again, at the same time adapting its internal organization to meet the changed world conditions. Meetings of the Commission for Aeronautical Meteorology, of the Commission for Synoptic Weather Information and of the European Regional Commission were held in Paris during June and July, 1946, and were immediately followed by a meeting of the International Meteorological Committee.

A further meeting of the European Regional Commission was held in Paris in January, 1947, whilst the remaining Regional Commissions will hold meetings during the first half of the year. Meetings of all the Technical Commissions are to be held at Toronto during August and the first half of September, 1947, and will be followed by a Conference of Directors in Washington D.C. during the latter half of September.

THE SEVERE WINTER OF 1946 TO 1947

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

Though the really notable cold spell only developed late in the winter, there were two earlier severe spells of relatively short duration, both due to the westward movement of Russian anticyclones. The first was from December 15 to 21, while the second only lasted from January 5 to 7, but gave considerable snowfall in the east and Midlands, and continuous frost for 48 hours over a substantial area. Both spells were naturally longer and much more severe on the continent, and even the second one lasted for ten days in north Germany. There followed a spell of unusual mildness (rare in the middle of a severe winter) and temperatures reached 57°F. locally on January 16. On January 18 there was a pronounced anticyclone over Brittany and deep depressions over Finland and south Greenland. Temperature was relatively high over Europe generally, including all European Russia except the north-east, and there was nothing to suggest that a severe spell was approaching, but nevertheless it was the last mild day over a large part of Great Britain until nearly the middle of March, and even later in the north. The anticyclone over Brittany declined, and an initially weak wedge of high pressure to northward built up, until on the 21st the highest pressure was off north-west Norway. From the 19th to 22nd temperature remained below 40°F. at many places and there was some night frost. Really wintry weather commenced in the south-east on the 23rd, with the onset of a very cold NE. wind, supplied by a NNE. current over Finland, which had come round the north side of the depression mentioned previously. Snowfalls with severe drifting began in Kent and Sussex and part of East Anglia on the 23rd and continued for some days, and slighter snowfalls occurred over a larger area.

The developments between the 24th and 26th, which finally established the wintry spell and extended it over the whole country, were of great interest from the synoptic standpoint. By 0600 on January 24, the anticyclone which had formed off north-west Norway had moved south-west to Scotland with central pressure 1040 mb. and the col over Finland between this high and the Siberian high had a pressure of only 1031 mb. Mild air from the north-west formed a warm sector over the north Baltic, and a small depression formed there and moved rapidly south-west to England as a trough of low pressure, under the influence of a strong NE. " thermal " wind aloft over the whole area. The combination of the fall of pressure in the British Isles with a renewed rise in Finland resulted in a very cold easterly current over England and Wales on the 26th, giving continuous frost which extended over most of Scotland and Ireland two or three days later. The upper air charts were very useful to forecasters during this period.

From the above account it is clear that the development which started the long cold spell was wholly different from those associated with the short earlier spells, and there is no definite evidence of any connexion between them.

On January 28 a trough of low pressure over Russia separated the Siberian high from the more westerly high, but this high extended far enough east to give a protracted cold spell.

Throughout most of February pressure remained high over Scandinavia and was even higher round north and central Greenland. At times there was a belt of high pressure from Greenland to Siberia. The Greenland anticyclone undoubtedly played an essential part in the maintenance of the easterly type throughout most of February, and was entirely responsible for the prolongation of the severe weather for a fortnight after the Scandinavian anticyclone had given way, and for three weeks in the north. The Greenland system extended to a higher level than the more easterly one. The radio soundings from the American ship off the south-east coast of

Greenland (about 61°N., 32°W.) showed that the average height of the 500 mb. surface in February was about 300 ft. higher than over Scandinavia at the same latitude, and NE. winds at 500 mb. were frequently observed by the ship. There was also high pressure in the Greenland area in February 1895 and in January 1940.

The winds from some easterly point which began on January 22 lasted in most districts without a break until February 22, giving one of the longest (if not actually the longest) spells of E. wind ever recorded in this country. It was an exceptionally dull period except in west Scotland, and at Kew there was no sunshine from February 2 until the 22nd, the longest sunless period since records began. February was the dullest on record and duller than any month since December 1890. Under these circumstances it was naturally the day temperatures rather than the night temperatures which were the outstanding feature. At Greenwich the mean maximum for February was the lowest of any month since before 1841. Frost was continuous from February 11 to 23 over a large area. There were ice floes in the North Sea, and the exceptionally low sea temperature intensified the later phase of the cold period, especially in March.

There were only brief periods when conditions favoured severe night frost. Late in January exceptionally cold air came over from the south-east behind a west-moving trough, and there were two extremely cold nights in the south, even in areas where the night was partly cloudy and where the wind was appreciable. Further north there was only one very cold night. A weak wedge of high pressure gave the lowest temperatures of the winter over most of the country on the 23rd to 25th, in places the lowest since 1895, and a similar ridge on March 1 to 3 gave further severe frost especially in the north. Over most of Scotland severe night frost continued until March 9, and intermittently until the 15th, and there was another severe frost over the greater part of England and Wales on the night of March 5 to 6.

There can be little doubt that the winter was the snowiest of which we have any precise knowledge. Snow fell every day down to a low level in some parts of Great Britain from January 22 till at least March 17, and over the major part of Great Britain and Northern Ireland the ground was continuously snow covered from January 27 until March 13, and for a few days longer in some northern regions. Level depths exceeded 2 ft. in some areas, and heavy drifting occurred at times at all exposed places throughout the British Isles, with dislocation of rail and road traffic on an unprecedented scale. Even Cornwall suffered severely and Scilly had two considerable falls. North-west Scotland was the least affected part of Great Britain. In the north-east there was perhaps no single snowstorm as bad as that of February 18 to 20, 1941, but the six weeks' aggregate must have been greater at most places.

The conditions associated with individual snowstorms can only be dealt with briefly. A trough of low pressure which moved west from the continent covered virtually the whole of Great Britain with a coating of dry snow on January 27 to 28, and a depression which formed out of this trough became centred over the western English Channel and prolonged the snowstorm in south-west England, resulting in the isolation of many villages and the blocking of railways.

The four other main storms in southern and central districts were associated with complex depressions from the Atlantic, which were deep off our south-west coasts but partly filled as they moved away, the first two south-east and the other two east-north-east. In all four cases the belts of snow were associated with occlusions, but moved to northward of the sea-level position of the occlusion, from which they were separated by belts of light or occasional precipitation. In the March case a second belt of precipitation came up from south-west. The area chiefly affected only extended as far north as south Lancashire and Yorkshire. In the first case (February 2 to 4) the snow was followed by a three days' thaw in the south-west and a two days' thaw over a considerable area in the south, which much reduced the depth of snow. There was prolonged snow without thaw from Lincolnshire to north Wales, heaviest in the east and on high ground. The second storm on February 8 to 9 was somewhat similar, but the subsequent thaw only lasted for 48 hours in the south-west and 24 hours in the south-east. The third storm on February 21 gave very dry powdery snow even in the extreme south. The fourth major storm in the southern and central areas, that of March 4 and 5, was the worst of the winter, though in the south-west and extreme south the precipitation was mainly rain, with glazed frost in places. The level depth of this fall exceeded a foot over a large area, and drifting was exceptionally severe (see photographs between pp. 60 and 61). The failure of the thaw to spread so far as it did after the earlier February storms was interesting from the synoptic standpoint and illustrates the difficulties with which forecasters have to contend. The motion of the occlusion on February 8 to 9 was approximately that of the component of geostrophic wind at right angles to it, while on March 4 to 5 there was a large difference, as much as 40 m.p.h. for one 6-hour period. The large ageostrophic motion of the cold air low down both held up the front and added substantially to the intensity of the snowfall.

It is well known that depressions in the English Channel area give the worst snowstorms in the south, and notable examples occurred in January 1881, March 1891, April 1908, December 1927 and January 1939. These all had different features, especially as regards the preceding conditions, and none resembled that of March 4 to 5, 1947, sufficiently to be of any use to the forecaster.

In the north the most notable February snowstorm occurred on the 26th, when a polar-air depression moved north-east from south-west Ireland across south-east Scotland. That day was brilliantly fine in south-east England, and the mildest of the month. During the severe period as a whole, much of the snow in the north-east district was of the showery type, and the totals showed marked local variations, but were very large in some areas. There was another severe general snowstorm in north England, south Scotland and north Ireland (the worst of the winter in some areas) on March 12 to 13, with bad drifting. A warm front became stationary near the Scottish border and then retreated.

The final thaw commenced in the south on March 10, but in Scotland only on March 16. For nearly a week conditions were very changeable in the south, with more frost and very cold days and occasional snow, alternating with thaw and considerable rain. In spite of the interruptions in the thaw there was very serious flooding, the worst in the Thames Valley since 1894. The end of the wintry spell over the country as a whole can be taken as March 16, 7½ weeks after its onset. There was an exceptionally severe gale in the south on the evening of that day, affecting much of England and Wales. The synoptic developments for March 3 to 14 showed certain features which were unique in our area, not so much in their general nature as in their speed. Deep occluded depressions to westward filled up at an astonishing rate as new systems formed further east, and the cold air swept quickly southward again.

Though large accumulations of snow in March are frequent on high ground, there is no precedent to recent conditions over the country as a whole for a long time past. In the last week of February and in early March 1895 the mean maximum temperature was up to or slightly above 40°F. over practically the whole country.

Some other points of contrast with other severe periods are worth noting. There is no record of such a long spell of bleak E. wind and dull weather as occurred this year, but short spells are fairly common. Dullness is rather characteristic of E. winds in winter, partly owing to the North Sea and partly to clouds already existing on the continent. If the geostrophic wind is E. rather than NE., continental clouds are the commonest cause of dullness in south-east England, though stratocumulus sometimes forms when the air crosses a short stretch of sea.

Though dullness is the typical feature of easterlies, there are also bright spells, and the two coldest previous Februaries, 1895 and 1929, both had long bright periods and both were associated with much lower continental temperatures, drawn from the heart of Siberia. In the earlier part of the 1929 spell there was a considerable depth of cold air, and later the continental anticyclone was further south and there was marked subsidence in the SE. current, an ideal situation for clear skies. In the recent severe spell there was never enough subsidence to clear the clouds except in the brief periods which gave severe frost. The very cold air was always shallow, generally with a marked temperature inversion somewhere between 3,000 and 5,000 ft., favouring persistent clouds. The air supply did not come from so far east as in the earlier periods, and the trajectories were often complex. Even when the lower air had come from north Russia only a shallow layer reached our area. Sometimes the supply was from the Black Sea area, and was affected during transit by precipitation falling into it from warmer Mediterranean air aloft.

On the average over many years the largest number of severe night frosts occur in arctic air, originally from north or north-north-east. This seldom gives a long cold spell unless easterlies follow, but there was a 10-days severe spell in January, 1945, and a 16-days spell in January, 1881, this being the longest spell of this type of which we have any knowledge. During the blizzard of January 18 to 19, 1881, there was a ridge of high pressure from Denmark to Austria, and the air over southern England came back from east France and west Germany, its original source being northerly arctic.

The conditions at the onset of the recent severe period have been described in detail, and it is worth mentioning that the long cold spells of 1890, 1895 and 1917 also originated with the advance of a ridge of high pressure from west or north-west towards Scandinavia. Westward movements of Siberian anticyclones resulted in eight days of severe cold and twelve consecutive night frosts in February 1929, and in eight days of severe cold in the south-eastern area in December 1938, but no really long spell of continuous severe cold

(79600) A * 2

originated in this way. The problem presented by long cold spells is on a hemispherical, possible even a global scale, and the Siberian anticyclone alone does not provide an adequate explanation of them. It does not appear to be the primary factor in most cases, though from some aspects a Scandinavian anticyclone can be regarded as a kind of western extension or outpost of the Siberian system.

THE NUMERICAL BASIS OF CLIMATE

BY C. E. P. BROOKS, D.SC.

Part III. Significance Tests and the Analysis of Variance

It often happens that in the course of an investigation we have to decide whether or not a certain hypothesis is consistent with the data. A suitable test for this purpose was designed by K. Pearson in 1900 and is known as the " chi-square " test; it consists simply in forming the sum :—

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where O is the observed frequency and E the expected frequency in each cell, the only proviso being that E must be at least 5. We also need to know the number of " degrees of freedom " in the table, i.e. the number of cells which can be filled up arbitrarily before the remainder are fixed by the total number of observations, and by the other features of the distribution which are used in computing the expected values. Suppose for example that we have 100 observations classified into six frequency cells. We can fill up five cells arbitrarily, but then the number in the sixth cell is fixed by the total. If we now fit a normal frequency curve to this distribution, we are using two other properties of the distribution, namely the mean and the standard deviation. Consequently the degrees of freedom are $6-1-2=3$.

In this imperfect world there is rarely if ever complete agreement between expectation and observation, and we must frame our judgment of the soundness of a hypothesis on a comparison of the actual measure of disagreement with that to be expected by the operation of chance errors. Two main levels may be distinguished :—

(i) if χ^2 is so large as to give a probability of less than 5 per cent., i.e., so large that it would only arise by chance once in more than 20 trials, we regard the hypothesis as not consistent with the facts.

(ii) if χ^2 is so small as to be above the 95 per cent. level of probability, the inference is that we have accumulated sufficient observations almost to eliminate the results of chance errors. The hypothesis fits the facts very well, but this does not mean that the hypothesis is necessarily true; that is a matter for physical reasoning or further experiment.

Most good textbooks of statistics contain in some form or other a table of values of χ^2 corresponding to different levels of probability for various numbers of degrees of freedom. A convenient table is included in " Industrial Experimentation " (Ministry of Supply, 1946) published by H.M. Stationery Office at the modest price of two shillings.

As a simple example, we will test the popular belief that a solar or lunar halo is a prognostic of rain. Table 5 has been reconstructed from some data given by H. Neuberger for central Pennsylvania. The figures not in brackets show the actual observations classified into four groups—halo followed by precipitation ; halo not followed by precipitation ; day without halo followed by precipitation ; day without halo not followed by precipitation. The figures in brackets give the distribution which would be expected if there were no tendency for a halo to be followed either by precipitation or fine weather, the 2,284 days being divided in accordance with the frequency of haloes, no haloes, rain and no rain. Thus the number of days with haloes, 646, is divided in the ratios 1,316/2,284 and 968/2,284 ; similarly for the number of days without haloes.

TABLE V. HALOES AND SUBSEQUENT PRECIPITATION

	Precipitation within 48 hours		
	Yes	No.	Total
Halo	497(372)	149(274)	646
No halo ..	819(944)	819(694)	1,638
Total ..	1,316	968	2,284

In this example we have

$$\chi^2 = \frac{(125)^2}{372} + \frac{(125)^2}{274} + \frac{(125)^2}{944} + \frac{(125)^2}{694} = 138$$

There is only one degree of freedom, because the total numbers of days of rain and haloes are fixed, so that after one cell is filled, the remainder can be filled in only one way. The value of χ^2 is very large, and from a table of χ^2 for one degree of freedom we find that the probability of such a distribution occurring by chance is much less than 0·01 per cent. In other words the odds are more than 9,999 to 1 that there is a real tendency for haloes to be followed by precipitation within 48 hours. Note that this is not the same as the probability that any individual hàlo will be followed by precipitation, which can be seen from the table to be less than 4 to 1.

In this example the figures were actually given as percentages, and it took some trouble to estimate the number of observations. The latter is vitally important however, for if we had taken the original table at its face value, and assumed that there were only 100 observations, we should have calculated χ^2 as 6·1, and the odds against this value occurring by chance are only 69 to 1 ; still significant but not so overwhelming as with 2,284 observations.

This significance test can also be applied to a frequency distribution, in order to see whether it is consistent with some particular assumption as to the type of distribution. For example, we have the following frequencies of numbers of days with screen frost at Greenwich in January, 1841–1905 :—

Number of frosts	0–4	5–9	10–14	15–19	20–24	25–30
Number of months	10	16	15	12	10	2

From these figures we calculate the mean frequency as 12·2 per month, $\sigma = 6 \cdot 8$.

If there were no connexion between the weather of one day and the next, the frequency distribution would follow a well known law due to Bernouilli.

Suppose we had a drum containing millions of discs, some white (representing frosts), and the remainder black (no frost), and took out 65 sets of 31 each. We do not know the proportion of white to black in the drum, but we find that the average number of white discs in a set of 31 is 12·2. The best assumption we can make as to the proportion is that there are 122 white to 188 black discs, i.e., the probability p of drawing a white disc on any one trial is 12·2/31 or 0·4, and the probability q of drawing a black disc is 0·6. The numbers of white and black discs actually drawn will vary from one set of 31 to another, and a little consideration will show that this is another case of the binomial series described in Part II. The expected frequency distribution of the numbers of white discs will be given by the expansion of $65(0{\cdot}4+0{\cdot}6)^{31}$, 65 being the number of sets and 31 the number in each set. The theoretical frequency distribution given by this series is as follows :—

Number of frosts ..	0–4	5–9	10–14	15–19	20–24
Number of months ..	0	6	40	18	1

Comparison with the observed figures shows a wide discrepancy, and this is confirmed by the significance test. Grouping the figures to obtain at least five in each cell we have :—

Frequency	0–9	10–14	15–31
Observed	26	15	24
Expected	6	40	19

$$\chi^2 = 67{\cdot}2$$

There is only one degree of freedom, because the mean value as well as the total of 65 has been used in computing the " expected " distribution. The probability that the observed distribution is consistent with the expected distribution is less than ·001, or in other words the odds that it is not consistent are more than 999 to 1.

The reason for this discrepancy must be that our hypothesis is at fault, in other words that the numbers of frost days are not distributed according to chance. To investigate the question we can adopt another useful technique known as the " analysis of variance ".

The assumption with which we began was that all the 65 sets of 31 discs were drawn from the same drum. Bernouilli showed that in such a case the standard deviation of numbers of either white or black discs would be given by $\sigma_B = \sqrt{(npq)}$. In our example n is 31, $p=0{\cdot}4$ and $q=0{\cdot}6$, so that $\sigma_B=2{\cdot}7$. But suppose that each set of 31 was drawn from a different drum, in which the proportions of white and black discs varied from drum to drum. In this case the standard deviation σ of the observed series is compounded of the Bernouilli standard deviation σ_B and the standard deviation of the proportions in the different drums, multiplied by 31, which we will call σ_D.

We cannot combine standard deviations directly, but we can combine their squares, or variances. Thus

$$\sigma^2 = \sigma_B{}^2 + \sigma_D{}^2.$$

We do not know σ_D directly, but we know σ and have an approximation to σ_B based on the observed mean frequency $[\sigma_B = \sqrt{(31 \times {\cdot}4 \times {\cdot}6)}]$, and so we can calculate σ_D. This gives

$$\sigma_D{}^2 = 6{\cdot}8^2 - 2{\cdot}7^2 = 46{\cdot}2 - 7{\cdot}3 = 38{\cdot}9.$$

From this we infer that the character of the month accounts for more than four-fifths of the variability in the number of frosts from one January to another, and the variability due to chance to less than one-fifth.

This gives us a useful method of estimating the frequency distribution of phenomena when we know only the mean frequency. It happens that for any one phenomenon the ratio of the observed standard deviation σ to the Bernouilli standard deviation σ_B is almost independent of the frequency of the phenomenon, the average values being about 1·5 for thunder, 2 for fog, gale and rain and 3 for frost and snow.

If we know the average frequency, we can calculate σ_B from $\sqrt{(npq)}$, and multiplying by the appropriate ratio (in this case taken as 3), find an approximate value of σ. If p lies between about 0·25 and 0·75, the distribution is sufficiently normal to use the normal frequency table given in Part II. In this way the following frequency distribution of frosts at Greenwich was computed :—

Number of frosts ..	0–4	5–9	10–14	15–19	20–24	25–30
Observed ..	10	16	15	12	10	2
Expected ..	10	13	16	14	8	4

Grouping the last two cells together, we find that $\chi^2 = 1\cdot 0$, with 3 degrees of freedom. This corresponds with a level of probability of about 70 per cent., so that the differences between the observed and expected figures can reasonably be attributed to chance.

When p is less than 0·25 or more than 0·75, the distribution is not sufficiently normal for this method to be used. A discussion of this case would be beyond the scope of these articles, but it can be said here that there is no simple solution.

The latter part of this article is based on some work by Miss N. Carruthers and myself in 1944, but we subsequently found that F. Baur had covered much the same ground in 1930 (see *Met. Z., Braunschweig*, **47**, 1930, p.381).

In these three articles I have dealt with only a few of the many possible applications of statistical methods to climatic data, but sufficient I hope to illustrate the general principles and to show how interesting and fruitful the subject can be.

Errata, Part I.

PAGE 10, Table I, Scilly, column headed 41° ; *for* " 0 " *read* " 2 ".

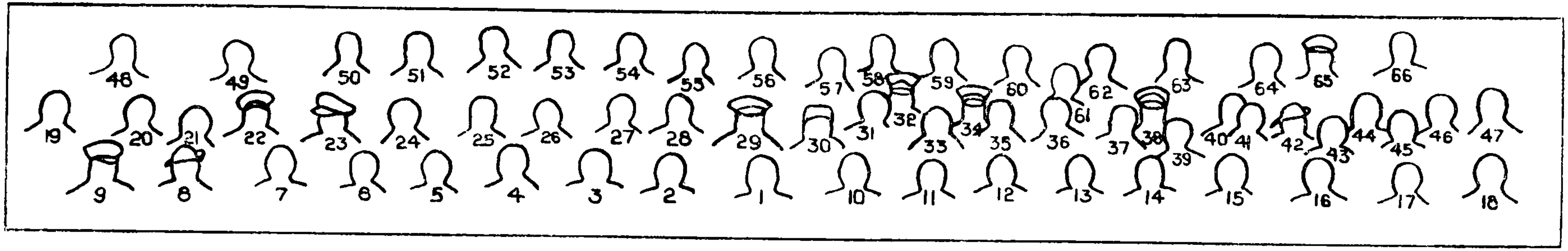
PAGE 11 ; *for* table following line 12, *substitute* the following :—

TABLE II

	Mean	Quartiles		Deciles		Median	Mode
	degrees Fahrenheit						
Scilly	51·38	49·4	53·5	47·3	55·2	51·5	51·7
Birmingham ..	49·42	45·1	53·7	42·0	56·9	49·1	48·5

PAGE 13, line 6 ; *for* " Mean $\pm$ ·6745 " *read* " Mean $\pm$ ·6745 σ ".

PAGE 14, line 11 ; *for* " $(0\cdot 67/0\cdot 05)^2$ or 4,356 years " *read* " $(0\cdot 67\,\sigma/0\cdot 05)^2$ or more than 2,000 years ".



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EXTRAORDINARY CONFERENCE OF DIRECTORS OF THE INTERNATIONAL METEOROLOGICAL ORGANIZATION, LONDON, 1946
(see p. 51)

THE ALFRETON—MATLOCK ROAD ABOUT ½ MILE EAST OF WESSINGTON, MARCH 15, 1947, ABOUT 1300 G.M.T.

The drifts are approximately 12 to 14 ft. high. This part of the road is about 400 ft. above M.S.L.

THE ALFRETON—MATLOCK ROAD ABOUT ½ MILE EAST OF WESSINGTON, MARCH 15, 1947, ABOUT 1300 G.M.T.

The drifts are just forming during the blizzard. The drift against the telegraph pole is about 12 ft. high.

THE ALFRETON—MATLOCK ROAD ABOUT 1,000 YARDS EAST OF WESSINGTON, MARCH 16, 1947, AT 0900 G.M.T.

The 5-ft. drifts along the road ahead completely blocking it.

These photos are reproduced by the courtesy of Mr. F. Tomlinson

RIME AND SNOW, PRINCETOWN, FEBRUARY 14, 1947

Glazed frost occurred on February 11, and rime commenced forming on the 12th and was cumulative up to the 16th.

GLAZED FROST, PRINCETOWN, MARCH 6, 1947

Weather clear (no mist) but no sunshine.

GLAZED FROST, PRINCETOWN, MARCH 6, 1947

Single telephone wire showing thickness of ice. The wire can be seen as a thin black line down the centre and the mark half way up is where the ice has cracked when the wire fell down.

RIME, PRINCETOWN, FEBRUARY 16, 1947

Rime formation on $\frac{1}{4}$ in. diameter twigs feathered out to 4 in. This was no doubt due to the continuous easterly winds from the 11th to 16th. The rime formation was cumulative from the 12th to 16th.

These photos are reproduced by the courtesy of Mr. J. Hyde

To face p. 61]

Official U.S. Navy photograph

WATERSPOUT IN THE GULF OF TONKIN, AUGUST 8, 1945
(see p. 63)

METEOROLOGICAL OFFICE DISCUSSIONS

The Monday evening discussion held at Victory House on March 3 was devoted to the consideration of a paper in the *Journal of Meteorology* on " Insolation in Relation to Cloudiness and Cloud Density " by Bernhard Haurwitz of Harvard University, U.S.A.*

Introducing the paper for discussion, the Director emphasised the importance of work of this nature to agricultural meteorology, a section devoted to the study of which has recently been incorporated in the Climatological Branch of the Meteorological Office, and also outlined certain developments in direct measurements of insolation planned by the Meteorological Office in this country.

The discussion was opened by Mr. L. G. Cameron who first of all made it clear that the author was only seeking a general climatological relationship between the elements mentioned, and that he was thinking in terms of total radiation from the sun and the sky on a horizontal surface. In view of the scarcity of data on insolation, the author declares his intention of attempting to establish a relationship between insolation, cloudiness and cloud density since observations of cloudiness are far more numerous throughout the world than are records of the duration of sunshine, which however, if available, are better indicators of insolation, especially with broken skies, than is total cloudiness.

Using observations of cloudiness, cloud density and air mass (secant of the zenith distance of the sun) related to the insolation, all recorded at the Blue Hill Meteorological Observatory, Boston, Mass., the equation

$$T = \frac{a}{m} e^{-bm}$$

was chosen to express the insolation (T) as a function of the optical air mass (m); a and b being constants for each cloudiness and cloud density. Least square curves for the insolation at the various air masses with different degrees of cloudiness and cloud density were obtained which clearly showed the increasing importance of density in limiting insolation, at a given air mass, with the higher degrees of cloudiness. A comparison of the insolation for a number of air masses at given cloudiness and cloud density with that from a cloudless sky established the fact that the ratio of insolation decreases as a rule with increasing air mass. Finally annual and monthly mean values of insolation have been computed, and the results used to construct a series of annual curves which illustrated the fact that with increasing cloudiness the differences between the insolation at different densities become more pronounced and the annual amplitudes become smaller.

In the course of the general discussion which followed the summary of the paper Dr. Stagg, announcing that the work at Kew was now approaching the stage when a study on similar lines could be attempted with some confidence, went on to describe how the various types of radiation were measured. Mr. Sumner considered that the chief defect in the paper was that atmospheric turbidity is not taken into account. Using the results given in the paper, he had found that the amount of insolation getting through to the ground on

* *J. Met., Milton Mass.* **2**, 1945, p.154.

a cloudless day at Kew corresponded to that with a cloud cover of 8–9 tenths of density $2\frac{1}{2}$ according to the Haurwitz method. Dr. Brooks expressed the opinion that the paper was of considerable value especially if the expressions found within it were used to construct a much needed map of the radiation received over this country. He also called attention to an interesting application of the work to geological problems by citing the case of the permo-carboniferous glacial deposits in South Africa and India. According to Wegener the glacial conditions necessary for the deposition of this conglomerate were brought to South Africa as a result of a re-orientation of the earth's axis which put the south pole into the region of South Africa. Without any such alteration however the necessary glacial conditions might have been produced by permanent monsoon conditions with a continuous cover of 10-tenths cloud of density 4, during permo-carboniferous times.

Some criticism was levelled at the coarse grouping of the total cloudiness especially in the 4–7-tenths group which in itself embraces quite a wide range of solar radiation, whilst Mr. Swinbank and other speakers, in criticising the crude definitions of cloud density (0–4 according to the " International Cloud Atlas "), thought that the data available deserved a more accurate classification. Mr. L. H. G. Dines was inclined to think that the effect of atmospheric turbidity was at times over-estimated since his work on clear days with very good visibility at Kew had revealed that even under those conditions only 2 thirds of the possible insolation was received. Dr. Scrase asked, but was answered in the negative, whether the paper made any reference to the effects of cloud height since Dr. Atkins had found that the amount of illumination for the same thickness of cloud was directly proportional to the cloud height. Mr. B. C. V. Oddie raised the interesting point that, when considering insolation in relation to plant growth, it was not the total insolation which mattered so much as the amount received at the various wave-lengths.

METEOROLOGICAL RESEARCH COMMITTEE

The 46th meeting of the Meteorological Research Committee was held on January 30, 1947.

At this meeting a revised research programme was considered and adopted. The new programme contains more problems than the old programme but fewer of the problems have been allotted priority PX.

Further consideration was given to the question of exploration of the constitution of the upper atmosphere by the use of projectors using pulsed light. Certain preliminary steps to test the feasability of this were decided upon. Other matters considered by the Committee included meteorological research by the School of Agriculture, Cambridge, and a paper dealing with the height of the tropopause over monsoonal regions.

LETTERS TO THE EDITOR

Unusual Wet-bulb Reading

On Sunday morning, March 9, the dry-bulb thermometer in the screen in my garden read 30°F. and the wet-bulb 32°F. These were the readings when I opened the door of the screen. Neither thermometer had been touched in any way. I was very surprised and I naturally verified the readings. It was a fine morning and the temperature must have been lower during the night. The wet bulb was covered with ice. If this had been newly formed, the temperature would have been 32°F., but if the water round the wet bulb had frozen earlier in the night one would have expected the wet bulb even when covered with ice to have read at least as low as the dry bulb. There was no fog or mist.

E. GOLD

March 10, 1947.

Supercooled water on pond ice

At 1530 on January 24, 1945, I visited the large pond at Pantyrochain, which is two miles north-north-east of the weather station at Wrexham, and there partook of what might have passed as skating had the ice not been so rough and bumpy. The pond is roughly circular, and several hundred yards across. Near the middle I found a patch, about a quarter of an acre in extent, which from a distance appeared brownish, and covered in places with a little snow. I travelled at speed to investigate, and on reaching the edge of the patch, the skates sank their full depth into soft material and I was precipitated headlong into about two inches of very liquid slush. Its appearance was that of the slush produced on roads after municipal authorities have applied salt to the snow, and it was of a brownish tint, and contained much liquid water. The dry bulb at Wrexham twenty minutes before was 22°F., and the temperature on the snow surface about 16°F., moreover the temperature at ground level had been below freezing point (and at times below zero) for about 116 hours previously. It was therefore a matter of no little surprise to me to find liquid water on the surface of the ice, which was at least 5 inches thick.

S. E. ASHMORE

11, *Percy Road, Wrexham*

[It would be interesting to have a chemical analysis—there was possibly some soluble substance which lowered the freezing point.—Ed. M.M.]

NOTES AND NEWS

A waterspout in the China Seas

The photograph facing p. 61 was obtained by a U.S. Navy Typhoon reconnaissance plane on August 8, 1945, in the Gulf of Tonkin between Hainan and the south China coast. The storm in which it occurred developed on the "equatorial front" on August 4, intensified and moved north-westward across northern Luzon and developed into an intense typhoon in the South China Sea, finally dissipating along the China–Indochina border on August 11. It was followed throughout its history by search planes, some of which flew directly into the "eye".

The storm lacked the usual symmetry and towards the close of its life gave indications of developing a frontal structure. By the 9th the storm had moderated, but a violent squall line or front had developed, extending north-north-east to south-south-west east of Hainan for over 100 miles. The clouds in the photograph are probably part of this developing squall line.

Although the waterspout itself is not very well shown in the photograph, other interesting features stand out clearly. Note the wind shear shown by the band of rougher water parallel to the line of cloud drawn into a spiral eddy system around the base of the waterspout. Other eddies or atmospheric wave motion also appear along the line of shear which may possibly develop into other waterspouts.

This photograph appeared with a number of others in a U.S. Navy publication "Typhoon Reconnaissance June through September 1945". We are indebted to Mr. R. A. Buchanan for calling our attention to it and obtaining a copy for reproduction, and to the U.S. Navy for permission to reproduce.

Small tornadoes or whirlwinds in the British Isles

We are indebted to the Rev. T. L. Jackson of Ampleforth College, Yorkshire, for the following description of a small whirlwind observed at Ampleforth on May 31, 1946.

"About 7 p.m. on Thursday, May 31, one of our workmen and his family were in their cottage; it had been raining heavily—very heavily—and was beginning to slacken off, when the attention of the family was attracted by the sound of a violent wind. Running to the window at the back of the cottage which looks out on the hillside, they were just in time to see a small black cloud, about the size of a cottage, with its base at the ground level, approach from the south-east at about 'cycling speed'. Two horses grazing in the field saw the cloud coming and bolted. The cloud approached the remains of an overgrown hedge, which mainly consisted of a few medium size oak trees (about a foot and a half in diameter), and as it passed snapped one of them off at ground level, though it left the trees about ten yards farther up the hill intact. The cloud then passed off in a north-westerly direction and, crossing over the public road, passed over the hedge on the other side of it. Here it uprooted two good-sized elm trees, though here again trees quite close (about five yards) were left intact. The cloud then passed on up over the hill and disappeared." The wife and child in the cottage both said they thought there was a twisting motion inside the cloud.

Mr. Jackson goes on to say that the disturbance was evidently a very small one, as there is no trace of any effect on the barogram at the College. Also he can find no evidence of any damage other than the three trees.

The synoptic charts show that at approximately 1800 G.M.T., that is 7 p.m. B.S.T., on May 31, the time at which the phenomenon was observed, a cold occlusion passed over Ampleforth. Conditions were suitable, therefore, for such developments. Small tornadoes or whirlwinds are not so unusual in Great Britain as might be expected from the normal temperate, equable climate usually experienced in this country. As recently as September 20 during a widespread gale in England, a gust of 100 m.p.h. was registered at Scilly, and Mr. L. G. Howes, of Rhode House, Colyford, Devon, writes that "the north-north-west hurricane line of progression appeared to pass close by as I could see trees being blown down in a line as it progressed. One tree was picked up bodily and turned round." The last sentence suggests the whirling movement of the small tornado. These exceptionally heavy gusts occurred in the turbulent NW. wind which occurred after the passage of an occlusion associated with a vigorous complex depression moving east from St. George's Channel. Then there were the destructive tornadoes at Whipsnade Zoological Gardens and Sheepcot Farm, Berkshire, on Jan. 18, 1945. These developed with the passage of a line squall associated with a vigorous depression and a trough moving in a south-easterly direction over the country; a gust of 113 m.p.h. was registered at St. Ann's Head. Again on October 24 of the same year, a whirlwind occurred at Wivelsfield and Newtimber in mid Sussex causing considerable damage. A very disturbed spell of weather occurred from October 24 to 26 and on the 24th a depression moved north-east from the west of Ireland to east Scotland. The whirlwind is often preceded or accompanied by heavy rain or thunderstorms demonstrating the high degree of turbulence associated with the phenomenon.

L. F. LEWIS

An account of the damage caused by the storm of January 18, 1945, in Berkshire was received from Mr. A. R. Maxwell Hyslop, who writes as follows:—

" I have just returned from Berkshire where I was told of and saw the traces of a very extraordinary storm which took place some weeks ago. You may have full particulars of it already, but in case you have not (and this seems possible because of its curiously limited range) I think it worth writing. It seems to have been a kind of tornado in miniature. I have seen traces of the damage, from Sheepcot Farm, lying south of the main Reading–Wantage road in the civil parish, Abelicoz, of Aston Upthorpe, in a straight line across the back of Lokingdon Hill to near Cholsey Station, G.W.R. I don't know whether it did damage on either side of that stretch; but within it it lifted a large wood and corrugated iron barn off its birch foundations (at Sheepcot Farm), blew down two other solidly built barns, blew down a solid garden wall, and, which seems most surprising of all, not only uprooted a large number of trees of all sizes near Lokingdon but actually snapped off the trunks and branches—some as thick as a man's body—at heights of from 10 to 30 ft. above the ground. No lives, I believe, were lost. Apparently it happened on a stormy, but not noticeably wild day and lasted only about 2–3 minutes, and the width of the destructive passage was not more than 200–300 yards at most; some people say less ".

The date of the storm was verified by Mr. F. J. K. Cross, of Aston Tirrold Manor, who adds: " It took my farm buildings by the Reading–Wantage Road, then it devastated Lokingdon farm buildings and swept by Westfield and took the garden wall. The shearing off of the trunks and branches at roughly one height was most noticeable."

Boston Flood, 1810

The *Lincolnshire Standard* of January 1, 1944, gave some details of the great flood on November 10, 1810, at Boston, Lincs. Knowledge of the rainfall of such early years is limited, but at South Kyme, some 10 miles west-north-west of Boston the total for November 1810 was 5·94 in., which is not a very arresting figure. The graphic account describes how an extraordinarily strong ENE. gale, accompanied by continuous rain, gathered up strength in the course of the day. It was the day before full moon and a high tide was expected in the evening, but by five in the afternoon the storm was at its height and it raged for two hours. " Vessels lying in the river Witham between the bridge and Skirbeck Quarter rolled gunwhale under ",—a circumstance never before witnessed there and all the more significant when one remembers that this part of the river is about four miles from the sea. Several vessels off the coast were lost with all hands, and the flood-tide brought havoc on land. For nearly an hour the flood-tide appeared to be stationary as the waters surged relentlessly forward up the river and over the sea walls. Nothing like it within living memory had been seen before on that coast. About 8 p.m. it began to ebb. The force of the water broke down not only the ancient sea banks, but also newly constructed sea banks, inundating farm lands and buildings and dwelling houses. Many people sought refuge in the rafters of their houses until rescuers came by boat.

Mr. H. W. Wheeler, in " History of the Fens ", published in 1868, quotes a fuller account of this disaster, together with notes on earlier and subsequent floods. The description adds that the whole extent of coastal country from Wainfleet to Spalding (some 10 miles to the north and to the south of Boston) suffered considerable damage, and attributes much of the blame to " an impetuous ESE. wind that rose to a hurricane ".

M. SHIRLEY

St. Elmo's Fire in Shetland

The following report of an unusual electrical phenomenon experienced on January 5, 1943 has been received from the Keeper of the remote Whalsey Skerries Lighthouse in Shetland.

" From 5.30 to 6.30 a.m. from the tower balcony, the top of the flagpole and gutter around the dome were seen to be illuminated. An effect was also felt at finger tips, which glowed and hissed, especially if one's arm was extended over the balcony rail."

The description suggests the brush-like discharges of electricity sometimes seen on masts and yards of ships at sea known as St. Elmo's Fire.

REVIEWS

Forecasting Weather. By Sir Napier Shaw; 3rd edition, with a supplementary note on sixteen years' progress in forecasting weather, by R. G. K. Lempfert. 8vo, $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. xliii + 644. London, Constable and Co. 1940. *Illus.* Price 42*s.* net.

In January, 1940, there appeared in this Magazine a review of a new treatise on terrestrial magnetism and electricity. The reviewer said " It is an imposing work (794 pages), but what makes the greatest impression on me is that practically everything described in this volume has been done since I became interested in terrestrial magnetism and atmospheric electricity in 1903 ". Yet terrestrial magnetism as a science is old, at least as old as meteorology. What was known about terrestrial magnetism and atmospheric electricity before 1903 was substantial, though it now seems small in relation to the advance made since that time.

And if we must be candid how different is the position in meteorology. The appearance of a third edition of Sir Napier Shaw's " Forecasting Weather " provides an excellent means of measuring the corresponding rate of progress. In this edition of 644 pages some 60 pages cover the " sixteen years' progress in forecasting weather " since 1923. The 1923 edition had grown by 200 pages over the 1911 edition, but in this case the change was accounted for in large measure by revision and the inclusion of additional subjects rather than by entirely new knowledge. Van Everdingen in reviewing the 1923 edition commented on the slow rate of progress of the science despite " an enormous increase in the number of reporting stations, of observed data and of wireless messages " and thought it had gained little by these crowded data for the lower strata.

The new matter in the third edition is from the pen of Mr. R. G. K. Lempfert and brings the work up to date with a clear and compact account of synoptic developments, structure of depressions, air masses and fronts. Upper air observations in forecasting, practical applications of forecasting and forecasting for long periods. Approximately half of this can be regarded as connected with the collection and distribution of information, terminology and the charting of data, and the remaining half as representing proportionately the advance in fundamental knowledge of the science. To quote Sir Napier it becomes more and more " obvious that we must not only have the pile of observations . . . but we must also find the skill to compile and co-ordinate the facts in some general description which gives the effective results and disregards the unimportant details ".

A.H.R.G.

Light and Colour in the Open Air, by M. Minnaert. Translated by H. M. Kremer-Priest and revised by K. E. Brian Jay. 8vo, $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. viii + 362. London, G. Bell and Sons, Ltd. 1940. Price 15*s*. net.

This is a most delightful book which will equip the attentive reader to derive greatly enhanced enjoyment from his walks abroad, whether by noonday, evening or night, on the hill-top, the sea-shore or by pond and stream. Many of the phenomena described are of everyday occurrence, so that we scarcely give them a thought, and yet when they are pointed out they are a never-failing source of pleasure ; examples are the curious tricks of shadow cast by the sun, described in the chapter on " Sunlight and Shadows ", and of reflection, especially from slightly moving water, in " Reflection of Light ". Sunlight shining through shallow water also produces some strange effects by refraction. The reviewer has already tried many of the experiments or observations suggested, sometimes with success, sometimes without, the failures no doubt being due to lack of experience.

The finest effects arise in the atmosphere : mirages caused by the curvature of light, distortion of the setting sun, the green ray, scintillation, rainbows, haloes and coronae, the light and colour of the sky, and the illumination of clouds. These will be of especial interest to meteorologists, both for the descriptions and the theory ; in particular, the detailed account of twilight phenomena is very welcome. Some of these atmospheric phenomena are rare, but others are much more common than is generally supposed, as is shown by the records published by the Dutch Meteorological Institute.

The observer must carefully distinguish between optical phenomena which have a real existence in the outer world, and those which originate in the eye of the beholder—hence the chapter " The Eye ", which sets out some of the weaknesses and irregularities of human vision. Other subjective phenomena are dealt with in " After-images and contrast phenomena ", such, for example, as the apparent blue colour of shadows in moonlight, beats in railings and the curious effects of rotating wheels.

It is often thought that observations of optical phenomena require expensive apparatus, but the author shows that this is not so. For most purposes the eye alone is enough, though it must be trained in observation, and especially in the discrimination of fine shades of light and colour, and in the estimation of angles. For most other purposes the simplest aids are sufficient, gadgets that are available in every home or that can be made in a few minutes. Even the polarization of light, for example in a rainbow, can be seen with an ordinary piece of blackened glass, though of course a Nicol prism is better.

The book covers such a multitude of subjects that it is impossible to mention a tithe of them. Though the treatment is simple, it is quite scientific, and where necessary the author does not hesitate to use elementary trigonometry or algebra. The value of the book is greatly increased by the numerous photographs, many of them of considerable meteorological interest. Plate Vb, " Mirage along a Sunlit Wall ", showing the triple image of a boy, is one of the oddest (it reminds one of Browning's " Setebos and Setebos and Setebos "), but perhaps most remarkable is the frontispiece photograph of the Spectre of the Brocken.

C.E.P.B.

An Investigation into the variation of the lapse rate of temperature in the atmosphere near the ground at Drigh Road, Karachi, by S. Mal, B. N. Desai and S. P. Sircar. Memoirs of the India Meteorological Department. Vol. XXIX, Part 1, 4to., 12-in. × 9¼-in., pp. i+53. *Illus.* Delhi, 1942. *Rs.* 2-2 or 3*s.* 6*d.*

During October 1929, observations were commenced at Drigh Road, Karachi, to obtain records of the behaviour of temperature in the lowest layers, up to 260 ft., of the atmosphere. These observations were continued until April 1933, but unfortunately, owing to certain gaps in the work, only the period between August 1930 and July 1931 was sufficiently continuous to be of value. The data obtained during this period form the basis of this memoir, which sets out to discuss the diurnal, seasonal and annual variations of temperature and lapse rates and their fluctuations on clear and cloudy days and nights. In addition, careful attention has been given to the growth and decay of nocturnal inversions and the characteristics of the lapse rates associated with the formation of fog.

A wireless mast, offering excellent exposure, at the airship base, Drigh Road, was chosen for the investigation and louvred screens containing the thermographs erected at 4 ft., 56 ft. and 156 ft. It is most unfortunate that the additional thermographs erected at 16 ft. and 256 ft. failed to produce a sufficient continuity of records to be of any value. Especially is this so in the case of the lower instrument since it is in the very lowest layers of the atmosphere that the most rapid temperature changes are recorded.

After a clear and very concise description of the instruments used, their installation and the observation technique adopted, the memoir proceeds to present a large amount of data either as observed or reduced to a form more suitable for the purposes of the work. Detailed records are thereby made available, but in some cases, as in the presentation of graphical data the months of January, April, July and October only are chosen since they are considered representative of the winter, pre-monsoon, monsoon and post-monsoon seasons.

Commencing with the hourly values of temperature at different heights, the work proceeds to careful and instructive analyses of the mean hourly lapse rates, the extreme values of the lapse rates and the frequency of the occurrence of lapse rates of various magnitudes. Some very definite and almost startling illustrations of the well known fact that lapse rates near the ground bear little or no relation to the lapse rates in the free atmosphere are given.

Whilst the various elements analysed have in most cases been related to conditions on cloudy and cloudless days, it is felt that much more of the data could have been correlated with more of the atmospheric elements.

The discussions regarding the development of stratus cloud over Karachi during the monsoon months and the lapse rates associated with the development of fog are illuminating and should prove of immediate practical value.

The memoir contains much useful data which will no doubt prove of interest to any investigator conducting research in the same field.

L.G.C.

Methods in climatology, by Victor A. Conrad. 8vo., 9 in. × 6 in., pp. xx + 228. *Illus.* Cambridge, Mass. Harvard University Press and London, Oxford University Press. 1944. 4 dollars.

Because climatological observations are so easy to make and—superficially—so easy to discuss, climatologists have in the past been for the most part content with a superficial study of them by means and extremes. Frequency tables, even of individual elements, are relatively rare in climatological literature; this may be due to the space they occupy, but even that simple index of variability, the standard deviation (see *Met. Mag., London,* **76,** 1947, p. 12) has been very slow to make its way. In the last few years however climatologists have become more statistically minded, and an evident need has grown up for a textbook on the application of statistical methods in climatology.

Dr. V. Conrad has now covered the whole field in a rapid and vigorous survey. He begins with the nature and organization of meteorological observations; then follow two chapters on the simpler statistical devices—means, quartiles, standard deviation, coefficient of variation and relative variability. The last mentioned, defined as 100 × mean deviation/mean, has been widely used in British work on variability of rainfall. The account of random sampling is of interest, though the method when applied to duration of rainfall in temperate latitudes does not give such good results as in the example quoted for Batavia. The chapter on curve fitting includes the straight line, logarithmic and exponential curves and the second order polynomial. The author regards the calculation of constants by the method of least squares as unnecessarily laborious and gives instead a method of approximation, but the reviewer thinks that if common sense is applied to the arithmetic, the least-square method is little if any more laborious, while it is definitely preferable on technical grounds. This section ends with a chapter on harmonic analysis especially as applied to monthly and hourly data.

The second part of the book describes methods of representing some of the characteristics of different elements, either for practical applications, as accumulated temperatures or "degree-days", or for purposes of study. The proposed method of computing resultant winds from directions only, by assuming that the mean velocities from different directions are proportional to the frequencies, is interesting but unsound. The reviewer found that if the distribution of winds is normal, the theoretical relationship between frequency and velocity is approximately that mean velocity from any one direction is proportional to the frequency raised to the power of 0·3. The frequencies and mean velocities of surface winds at Sealand in January showed the same relationship. This does not differ very much from the assumption that the mean velocity is the same from all directions. Rather curiously, in his example for Batavia (p. 104), the author, while implying that he uses the frequency-velocity relation, actually calculates the resultant on the basis that the mean velocities from all directions are the same, which is probably why the result comes out so well. On p. 105 it is stated that the number of calms should be excluded in deriving the resultant wind; surely this is incorrect even though in an extreme case, such as an Alpine valley, it may appear to have some purpose. It should be made clear that the velocity equivalents quoted for the Beaufort scale refer to anemometers at a height of 6 metres.

Part III deals with the comparison of neighbouring stations and reduction to standard periods. Of interest here are the criteria of "relative homogeneity" for testing whether either of two synchronous series which it is proposed to compare is affected by some non-natural factor such as a change of site. This leads on to a chapter on total and partial correlation, various graphical methods of representation such as streamlines of wind, and numerical methods of characterising different climates. Finally the author sets out briefly his views on how a monograph on the climate of a region or a place should be written.

The book will be of great value as a simple non-technical introduction to the statistical treatment of climatological data, and it is supplemented by extensive footnote references (in which, however, British authors are rather conspicuously few; E. G. Bilham, for example, has made some quite important contributions to the subject, but his name does not appear). Each specialist will think that the treatment of his particular subject is too brief but on the whole the balance is fairly maintained. There is, however, one important detail, namely, the sequence of weather, which is almost entirely neglected, and this at least should be remedied in a future edition.

C.E.P.B.

RAINFALL OF JANUARY, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·48	80	*Glam.*	Cardiff, Penylan ..	3·32	90
Kent	Folkestone Cherry Gdns.	2·44	108	*Pemb.*	St. Ann's Head ..	5·96	171
,,	Edenb'dg, Falconhurst	3·44	140	*Card.*	Aberystwyth	2·87	89
Sussex	Compton, Compton Ho.	4·01	126	*Radnor*	Bir. W.W., Tyrmynydd	6·16	98
,,	Worthing, Beach Ho.Pk.	2·51	108	*Mont.*	Lake Vyrnwy.. ..	6·68	121
Hants.	Ventnor, Roy. Nat. Hos.	3·10	121	*Mer.*	Blaenau Festiniog ..	10·16	124
,,	Fordingb'dg, Oaklands	3·32	120	*Carn.*	Llandudno	5·42	225
,,	Sherborne St. John ..	2·48	106	*Angl.*	Llanerchmedd ..	5·46	173
Herts.	Royston, Therfield Rec.	1·49	86	*I. Man*	Douglas, Boro' Cem...	4·91	147
Bucks.	Slough, Upton ..	1·74	94	*Wigtown*	Pt. William, Monreith	5·20	159
Oxford	Oxford, Radcliffe ..	1·37	76	*Dumf.*	Dumfries, Crichton R.I.	6·00	186
N'hant	Wellingboro', Swanspool	1·79	97	,,	Eskdalemuir Obsy. ..	6·53	121
Essex	Shoeburyness	2·30	170	*Roxb.*	Kelso, Floors	1·87	107
Suffolk	Campsea Ashe, High Ho.	1·90	104	*Peebles*	Stobo Castle	5·54	185
,,	Lowestoft Sec. School	1·95	117	*Berwick*	Marchmont House ..	2·42	108
,,	Bury St. Ed., WestleyH.	1·69	94	*E. Loth.*	North Berwick Res. ..	2·04	119
Norfolk	Sandringham Ho. Gdns.	1·95	100	*Midl'n.*	Edinburgh, Blackfd. H.	2·22	126
Wilts.	Bishops Cannings ..	1·94	84	*Lanark*	Hamilton W.W., T'nhill	3·25	98
Dorset	Creech Grange ..	3·77	116	*Ayr*	Colmonell, Knockdolian	4·84	112
,,	Beaminster, East St...	4·07	117	,,	Glen Afton, Ayr San.	6·70	131
Devon	Teignmouth, Den Gdns.	4·17	143	*Bute*	Rothesay, Ardencraig	5·78	128
,,	Cullompton	5·05	156	*Argyll*	Loch Sunart, G'dale..	7·78	110
,,	Barnstaple, N. Dev. Ath.	3·24	99	,,	Poltalloch	5·39	107
,,	Okehampton, Uplands	5·96	117	,,	Inveraray Castle ..	7·36	90
Cornwall	Bude School House ..	2·92	96	,,	Islay, Eallabus ..	4·17	89
,,	Penzance, Morrab Gdns.	5·24	138	,,	Tiree	3·80	89
,,	St. Austell, Trevarna..	4·69	110	*Kinross*	Loch Leven Sluice ..	4·15	132
,,	Scilly, Tresco Abbey..	4·57	146	*Fife*	Leuchars Airfield ..	3·43	188
Glos.	Cirencester	2·26	90	*Perth*	Loch Dhu	12·09	133
Salop	Church Stretton ..	..	..	,,	Crieff, Strathearn Hyd.	5·83	145
,,	Cheswardine Hall ..	1·85	84	,,	Blair Castle Gardens..	5·48	164
Staffs.	Leek, Wall Grange P.S.	2·02	70	*Angus*	Montrose, Sunnyside	3·83	192
Worcs.	Malvern, Free Library	2·15	97	*Aberd.*	Balmoral Castle Gdns.	3·38	122
Warwick	Birmingham, Edgbaston	2·11	104	,,	Aberdeen Observatory	4·56	209
Leics.	Thornton Reservoir ..	1·77	89	,,	Fyvie Castle	3·97	168
Lincs.	Boston, Skirbeck ..	1·95	120	*Moray*	Gordon Castle ..	1·69	84
,,	Skegness, Marine Gdns.	1·56	90	*Nairn*	Nairn, Achareidh ..	..	..
Notts.	Mansfield, Carr Bank	2·49	116	*Inv's*	Loch Ness, Foyers ..	3·07	73
Ches.	Bidston Observatory	1·93	91	,,	Glenquoich	9·25	67
Lancs.	Manchester, Whit. Park	2·31	92	,,	Ft. William, Teviot ..	8·55	88
,,	Stonyhurst College ..	3·65	85	,,	Skye, Duntuilm ..	3·56	67
,,	Blackpool	3·26	119	*R. & C.*	Ullapool	2·43	54
Yorks.	Wakefield, Clarence Pk.	2·67	139	,,	Applecross Gardens ..	4·95	90
,,	Hull, Pearson Park ..	2·06	114	,,	Achnashellach ..	5·89	65
,,	Felixkirk, Mt. St. John	2·67	133	,,	Stornoway Airfield ..	2·75	56
,,	York Museum ..	2·47	140	*Suth.*	Lairg	2·49	76
,,	Scarborough	1·99	100	,,	Loch More, Achfary ..	4·79	66
,,	Middlesbrough ..	·99	62	*Caith.*	Wick Airfield ..	2·96	120
Norl'd	Newcastle, Leazes Pk.	1·48	75	*Shet.*	Lerwick Observatory	3·77	88
,,	Bellingham, High Green	4·17	146	*Ferm.*	Crom Castle	1·91	57
,,	Lilburn Tower Gdns.	2·79	135	*Armagh*	Armagh Observatory	1·51	60
Cumb.	Geltsdale	2·34	84	*Down*	Seaforde	5·10	162
,,	Keswick, High Hill ..	7·05	140	*Antrim*	Aldergrove Airfield ..	2·95	109
,,	Ravenglass, The Grove	4·41	132	,,	Ballymena, Harryville	3·70	100
West.	Appleby, Castle Bank	4·28	134	*Lon.*	Garvagh, Moneydig ..	5·01	146
Mon.	Abergavenny, Larchfield	4·09	121	,,	Londonderry, Creggan	3·14	87
Glam.	Ystalyfera, Wern Ho.	5·46	86	*Tyrone*	Omagh, Edenfel ..	3·78	107

WEATHER OF JANUARY, 1947

January was an unusually stormy month in the Atlantic, especially during the first half, when deep depressions followed irregular tracks south of Greenland and Iceland. Pressure fell below 948 mb. south-west of Reykjavik on the 3rd and in the Atlantic west of the British Isles on the 5th and 8th, and below 940 mb. south-west of Greenland on the 10th, in the centre of an enormous depression which filled almost the whole North Atlantic. Later in the month the depressions became smaller and less deep, and at the same time an intense anticyclone moved from northern France to Scandinavia where it remained until the end, extending its influence over Great Britain most of the time. On the 24th and 25th it was actually centred over northern Scotland, where pressure exceeded 1040 mb. on the 24th. By the 27th a definite easterly current had developed over England and very cold weather set in. Taking the month as a whole, mean pressure exceeded 1025 mb. over Finland and northern Russia, and was below 990 mb. over southern Greenland and the ocean to the south-east. Pressure was more than 15 mb. above normal over northern Norway and more than 10 mb. below normal over much of the North Atlantic.

The weather was characterised by frequent gales from the 1st to 17th, a very mild spell around the middle of the month and severe conditions during the last week. On the 15th temperature rose to 56°F. at Prestwick airport on the west coast of Scotland and on the 16th to 57°F. at numerous inland stations in England, while minimum temperatures did not fall below 50°F. at a number of places on the 15th and 16th. On the 20th pressure became high over Scandinavia and high pressure persisted there until the end of the month. From the 25th onwards depressions passed east to the south of the British Isles and cold easterly winds set in over the United Kingdom, with snow at first in east and south-east England, later extending over much of the country. At the Scilly Isles level snow lay to a depth of 7 in. on the morning of the 30th, a most unusual occurrence in these islands. The cold was intense over England and Wales during the last week; the deviation from the average for the week beginning on the 26th was −11·6°F. On the morning of the 30th temperature in the screen fell to −5°F. at Writtle in Essex.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days, difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England & Wales	57	−6	−3·7	113	−1	103	20
Scotland ..	56	8	−1·7	116	−2	108	17
Northern Ireland	54	18	−2·5	103	−1	82	16

M.O. 482 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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THE CENTRAL FORECASTING OFFICE, DUNSTABLE

BY E. G. BILHAM, B.SC., D.I.C.

On February 4, 1940, the Forecast Branch of the Meteorological Office took possession of its war-time headquarters on the outskirts of Dunstable. The decision, that in the event of war the communications centre for the forecasting service should be established in a provincial location, had been made nearly two years earlier. The principal requirement from the communications aspect was that the site should be conveniently placed in relation to the main Post Office land lines. This requirement, in conjunction with other desiderata such as reasonably easy access from London, proximity to a town to facilitate the housing of personnel, and good wireless reception conditions, led to the selection in 1938, of a site on high land (about 500 ft. above sea level) just outside Dunstable.

At a later stage it was decided that, as a war-time provision, the main forecasting centre should be at the same place as the communications centre. Dunstable was therefore planned as a combined forecasting and communications headquarters of the meteorological service. Plans were prepared and were being considered when in the summer of 1939 the threat of war became so imminent that immediate action was necessary. New plans based on the use of standard hutting were quickly prepared and building was begun.

A modern forecasting centre such as Dunstable was planned to be involves, however, a great deal more than the mere provision of roofs and walls, and much still remained to be done when war was declared at the end of August 1939. As a temporary measure, pending the completion of Dunstable, the Forecast Division was evacuated to offices already prepared at Birmingham. This emergency centre was occupied at three days' notice, without disturbing the flow of current synoptic information to outstations.

The move to Dunstable was made under appalling weather conditions and was a complicated operation. A 24-hour service had to be maintained without interruption, so it was necessary to move the staff by stages, the last contingent travelling by car over roads deep in thawing snow. The change over of teleprinter lines was made between 1500 and 1600 on February 4, 1940. The 1500 reports were dealt with at Birmingham and the 1600 reports were dealt with at Dunstable. It was an outstanding feat in the history of the Post Office Engineering Department and was accomplished without a hitch.

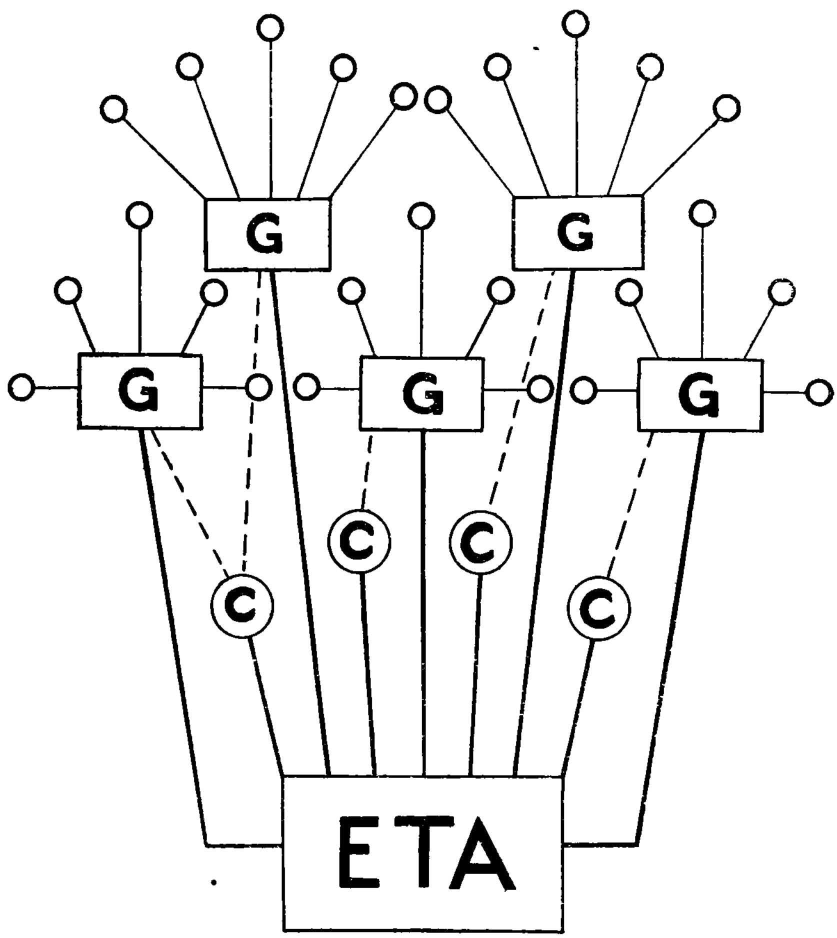


FIG. 1—SCHEMATIC DIAGRAM TO ILLUSTRATE THE ORGANIZATION OF METEOROLOGICAL SERVICES FOR THE ROYAL AIR FORCE

C = Command headquarters

G = Group headquarters

Airfield forecasting units are indicated by small circles

The location of the evacuation centre (at Birmingham) had been kept secret, and it was known by the code name of ETA (the Greek letter η). By the time Dunstable was ready for occupation, everyone had become used to speaking of the provincial headquarters of the Forecast Service as " ETA " and the name was retained for the new station.

To explain the role of ETA in the forecasting organization it is necessary to describe briefly the arrangements which are in operation for supplying the Royal Air Force with weather reports and forecasts. The general principle is that every important airfield has its own Meteorological Office, which is responsible for the meteorological services needed by aircraft using that airfield. This means that there are a very large number of separate forcasting offices in all parts of the country, in each of which charts are drawn and forecasts are prepared. In general, the forecasting offices also act as weather reporting stations. The normal procedure is to furnish a coded report every hour and to plot a chart every 3 hours, based on observations at the " synoptic hours " 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 G.M.T.

The first obvious necessity for such a service is that there must be a highly efficient network of communications to collect the hourly reports and re-distribute them to the forecasting centres, so that all of them may be continuously supplied with up-to-date information for the whole area. The second necessity is a system of co-ordination to ensure that the views as to the main developments of weather expressed by the forecaster at one station will not differ materially from those expressed by the forecaster at another station close by.

Fig. 1 is an attempt to set out the organization diagrammatically. At each operational Group Headquarters there is a Type I Meteorological office which exercises a sort of parental control over a number of subsidiary offices of lower categories. The fundamental analyses and forecasts are originated at the Central Forecasting Office (C.F.O.) which thus furnishes guidance to all the forecasting offices in the system. There are also Type I offices at Command Headquarters, and these are responsible for the general co-ordination of the meteorological services within the Command. Fig. 1 is of course purely diagrammatic and highly simplified. The number of local forecasting offices represented by the small circles actually amounts to some hundreds.

The requirement of a rapid and efficient network of communications is met by the meteorological teleprinter system. The general lay-out of the system is represented by the full lines in Fig. 1. Main lines radiate from C.F.O. to Group offices where they terminate on switchboards. The Group switchboards have connexions to all the stations controlled by the Group, which can thus be put into direct communication with C.F.O. whenever desired. In addition to the main lines to Groups and Commands, C.F.O. also has direct teleprinter lines to the British Air Forces Overseas Headquarters in Germany, the Headquarters of the American Forces in Europe, the Forecast Centres of the French, Belgian and Dutch Meteorological Services, Broadcasting House, the Central Telegraph Office, the Admiralty, etc. (see Fig. 2).

The system for collecting reports works in the following way. Each reporting station in a Group teleprints its coded message to the Group Headquarters where two teleprinters are available to receive them. The Group then compiles a collective message in standard form and teleprints it to C.F.O. At C.F.O. there is a separate teleprinter for each Group in the system, and there is, therefore, no delay in transmission. Connected to each of these teleprinters at C.F.O. there is a " reperforator " which produces a punched tape record of the message at the same time that it is received in typed form. By about 8 minutes past the hour practically all the hourly reports have been received in this way.

Punctually at 10 minutes past the hour, the operator throws the switches on the main panel to the "send" position, and then passes the punched tapes through an automatic transmitter which broadcasts the messages at high speed to all stations. This main broadcast of British and near continental data is completed by the half hour. The remainder of the hour, until H 55 minutes, is occupied with broadcasts of foreign data, upper air data, thunderstorm locations (SFERICS), ships' reports, analyses and forecasts, and special reports of suden changes. This main broadcast to all stations is supplemented by a second broadcast to Groups only.

The teleprinter room, though one of the most interesting features of C.F.O., represents only one side of the communications system (see Fig. 3 facing p. 84). Parallel with the teleprinter room and almost equalling it in size is the wireless reception room, manned by a civilian unit of the R.A.F. (No. 90 Group) (see Fig. 4 facing p. 84). Here are received practically all the meteorological transmissions of foreign data available for the northern hemisphere, as well as direct interceptions of reports from ships at sea and meteorological reconnaissance aircraft. Both rooms of course function continuously day and night. In the adjacent "auto room" transmissions are made continuously by radio channels to overseas and foreign services too distant to be connected to the teleprinter broadcast.

Mention must also be made of the AIRMET radio-telephony broadcasting system which is operated under the joint auspices of the Air Ministry and the Ministry of Civil Aviation. This service, which is the post-war successor to the "Borough Hill" broadcasts of pre-war days functions from 7 a.m. to 10 p.m. in summer, 6 p.m. in winter, and is intended primarily to serve the needs of flying clubs and private fliers using the smaller airfields. The hourly schedule includes navigational warnings, statements of the general weather situation and expected developments, reports of actual weather conditions from selected stations, and talks by the forecaster twice in every hour, in which the weather factors of importance for flying are dealt with in detail.

Dunstable also acts as the control station of the SFERIC service for the location of sources of atmospherics, within a range of 1,500 miles, using a radio direction-finding method. The results which are of great importance in relation to flying operations, and also as an aid to forecasting, are broadcast at frequent intervals on both the teleprinter and radio-broadcasting systems.

In the forecast room (see Fig. 5 backing Fig. 4) surface charts covering most of Europe and the northern Atlantic are plotted every 3 hours, and smaller scale charts are plotted every 6 hours (at main synoptic hours) for an area extending westward as far as the Pacific coast of North America, eastward to the Urals, northward to Spitzbergen and southward to north Africa. For the AIRMET service these are supplemented by large scale charts for the British Isles prepared hourly. Upper air contour charts are drawn every 6 hours for the 700, 500 and 300 mb. pressure levels. Full analyses for the main synoptic hours are made both for the surface and upper air distributions, and prognostic charts are prepared for periods of 24 hours ahead in the case of the surface charts, and 12 hours ahead in the case of the upper air charts. These analyses and

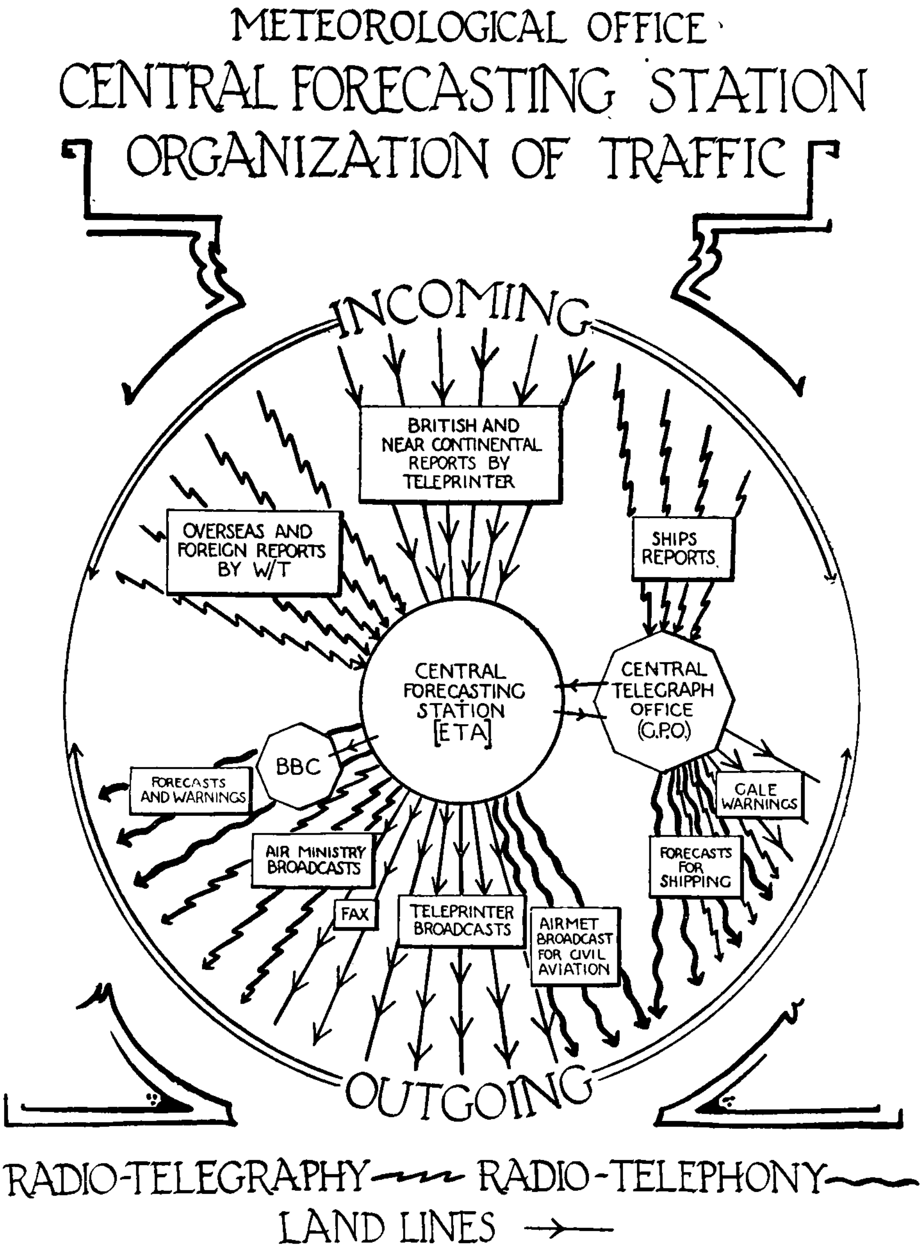


FIG. 2—TRAFFIC CHANNELS FOR THE COLLECTION AND DISTRIBUTION OF INFORMATION AT C.F.O.

Teleprinter, wireless telegraphy and wireless telephony channels are indicated by straight lines, zig-zag lines and wavy lines respectively. FAX is an installation for the direct transmission of weather charts in facsimile by land-line (not at present in operation)

prognoses, together with detailed forecasts for aviation and technical appreciations of the situation are broadcast for the general guidance of outstations in preparing forecasts for local use.

The forecasts and warnings prepared at C.F.O. also include those broadcast by the B.B.C., forecasts for the Press, and a large number of special forecasts, warnings and notifications of specified conditions required by shipping, public services, industrial organizations, and members of the general public.

The installations at C.F.O. include a printing plant operated by H.M. Stationery Office. Four large lithographic presses produce the *Daily Weather Report* which is now issued in three sections, the *British Section* (4 pages), the *Upper Air Section* (4 pages) and the *International Section* (2 pages of charts issued daily and 4 pages of data issued every four days). The lithographic transfers for these reports are prepared by draughtswomen in the forecast room. The C.F.O. printing plant also produces many of the blank plotting charts used in the synoptic service, instrumental charts and marine charts.

In this short account of C.F.O. it has not been possible to describe all its activities in full detail, but it is hoped to publish further articles in which special features such as the AIRMET broadcasting installation will be more adequately dealt with. The first of these, on SFERICS, follows immediately.

SFERICS

BY C. V. OCKENDEN, B.SC.

" Sferic " is the code word which has been used for some years now to designate reports of positions of areas in which thunderstorms are taking place. " Sferic " is derived from atmospheric (the French use " atmos " as the code word), which gives the clue to the basis of the method employed in obtaining the information.

In 1906 in a paper to the Royal Society, Marconi wrote " It would be exceedingly interesting to investigate whether there exists any relation between the direction of origin of these waves and the bearing or direction of distant terrestrial or celestial storms from whence these stray electric waves probably originate ". Twenty years later in the *Meteorological Magazine* for July, 1926, Mr. Bilham reviewed a paper by Watson Watt on " The directional recording of atmospherics " in which it was mentioned that the movement of a trough associated with thunderstorms over Tunis was determined from the directions of arrival of atmospherics at Lerwick, Ditton Park and Aboukir.

To-day in 1946, in the British Meteorological Service, we have regular observations being made 12 times daily by 4 specially selected stations equipped with modern cathode ray direction-finding sets to " fix " the location of thunderstorms with a high degree of accuracy up to a range of 1,000 to 1,500 miles. Several other countries, notably France, America, Germany and Switzerland have for a long time been conducting researches into the various methods for " pin-pointing " atmospherics, and at the recent Conference of the International Meteorological Organization in Paris it was recommended that efforts be directed towards international exchange of " Sferic " reports for the benefit of meteorological services in all countries. It need hardly be said that in war-time the " Sferics " organization was of the greatest importance ; not only did it provide a means of warning those who had to plan 1,000-bomber raids of the existence of thundery activity over the areas in which they were particularly interested, but it kept forecasters primed with extremely reliable information concerning the positions and movements of fronts over enemy-held territory and over sea areas from which weather reports were unobtainable. The modern " Sferic " sets are costly but maintenance is a relatively small item, and only a few personnel are required to carry out the observations. In view therefore, of the enormous increase in civil flying over long air routes, and the high frequency of accidents attributable to aircraft being involved in cumulonimbus clouds, a Sferic organization is likely to be a very paying proposition in peace-time. Radar methods for storm detection are being developed, but the range of operation is at present less than a tenth of that covered by " Sferics ".

The four stations to which reference has already been made are situated at Dunstable (lat. 51° 53′ N., long. 00° 33′ W.), St. Eval (lat. 50° 28′ N., long. 04° 59′ W.), Leuchars (lat. 56° 23′ N., long. 02° 53′ W.) and Irvinestown (north Ireland) (lat. 54° 29′ N., long. 07° 38′ W.), the " control " station being Dunstable which is also the central forecasting station and communications centre of the Meteorological Office. The fourth station, Irvinestown was only established in 1944, and has been found very useful in checking " fixes " obtained from the other 3 stations, and in enabling good results to be obtained in the event of one of the others being temporarily out of action through technical trouble or a breakdown in communications. At each station there are two huts—one containing the cathode ray direction-finding (C.R.D.F.) equipment, amplifiers, display tube, power packs and so on, whilst the other houses the four fixed vertical frame aerials, or " loops ", two oriented in a true north-south plane and the other two in a true west-east plane. The co-planar frames are connected in series, and with this symmetrical arrangement the mutual induction between the two pairs of loops can be reduced to less than 1 part in 1,000. Precautions are taken to avoid errors through local electrical interference. A photograph of a Sferic set showing the amplifiers, cathode-ray tube and plotting table is shown in Fig. 1 (in centre of this issue) whilst Fig. 2 gives an exterior view of the huts as erected at Dunstable. The receivers are arranged to work on a frequency of about 10 Kc./sec. (30,000 m.) because, although atmospherics can be recorded on practically any frequency, the maximum energy is found between about 8 and 12 Kc./sec. Two other advantages in using this frequency are (1) bearing errors due to polarization are reduced, and (2) this frequency is not much used by commercial W/T transmitting stations. It is possible to tune the sets to stations such as Rugby (16 Kc./sec.), Annapolis (17·8 Kc./sec.), Varberg (17·2 Kc./sec.), etc., and hence obtain a check on bearings found for these fixed transmitters.

The output from the amplifier connected to the N-S frames is fed to the X plates of the cathode-ray tube and that from the amplifier connected to the E-W frames goes to the Y plates. Thus, impulses picked up only on the N-S frames cause the spot of light on the tube to be drawn out into a N-S line whilst a signal received on the E-W frames gives an E-W line. Signals from any other direction will give a line on the tube in an intermediate position dependent upon the resultant of the two deflecting forces, and the direction can be determined to the nearest degree from a graduated circle which is engraved on the glass face. The tubes as used at present have a " persistent " fluorescent coating so that, although the duration of a lightning flash may be only between 1/500 and 1/1,000 second, the afterglow persists long enough for an observer to make an accurate reading of the bearing. It is hoped soon to make tests with auxiliary tubes, adapted to photograph the flashes on a continuously moving film which can be examined at leisure afterwards and the results compared with the visual observations. No provision is made for determining the " sense " of bearings—there is an ambiguity of 180°, but this is resolved in the plotting operation. The most modern sets are being fitted with a " brilliance modulation " device which secures that the tube is only illuminated for a very short period corresponding to the receipt of the ground wave; polarization errors due to the arrival of waves reflected back from the ionosphere will thus be considerably reduced.

Observations are normally made twelve times daily, each " run " having a duration of 15 minutes commencing at the following (clock) times :—0700, 0900, 1015, 1130, 1220, 1400, 1515, 1630, 1830, 1945, 2100 and 2200.

The four stations are interconnected by telephone tie lines with a switchboard at Dunstable, and the observer at this control station, keeping a constant watch on the tube during a " run ", calls out " now " immediately a flash occurs on the tube which is of sufficient length to enable its bearing to be determined. During periods of great activity flashes may be so frequent that it is not altogether easy to be certain that all stations have identified the same flash, but doubtful cases are weeded out during the plotting process. When a flash is " called " bearings from each station are telephoned in turn to a " Recorder " in the control office who logs them, and at the end of the " run " they are all plotted on a sheet of perspex fixed over an outline map covering an area from the western Atlantic to the Ural mountains and from north Norway to north-west Africa. The map actually employed at Dunstable is an Admiralty chart on a gnomonic projection with point of tangency near the centre of the quadrilateral formed by the 4 observing stations. In general, the bearings do not all intersect at an exact point, but form a small quadrilateral, and the " fix " is taken to be at the centre of this unless there are reasons for believing that more weight should be given to the reading from any particular station or stations. The plotting operation occupies about 5 to 10 min. and on completion, the information is put into a simple coded message for broadcast by teleprinter and W/T. The symbolic form of the Code used for W/T issues is

SFERIC $GGGa_1A_1$ LLllk LLllk - - - SFERIC $GGGa_1A_1$ LLllk LLllk etc.

where GGG denotes the time in hours and tenths, a_1 gives an indication of the nature of the distribution of the sources from which activity has been recorded, A_1 gives the probable error of the fix and the degree of activity, whilst the groups LLllk, give latitude and longitude of fixes to the nearest ½ degree. This code has been adopted by America so that no difficulties arise in exchanging reports obtained from their network which comprises C.R.D.F. stations in Bermuda, Florida and New Jersey.

Fig. 3 is a reproduction of the synoptic chart for 1300 G.M.T. on April 11, 1944, on which have been plotted the positions of thunderstorms found by " Sferics " fixes on that day. It will be noted that there were sporadic storms over Britain in the late afternoon in the rear of the occlusion which had reached the North Sea by 1300 G.M.T. and that isolated centres of activity were located just south of the Alps. The most interesting feature

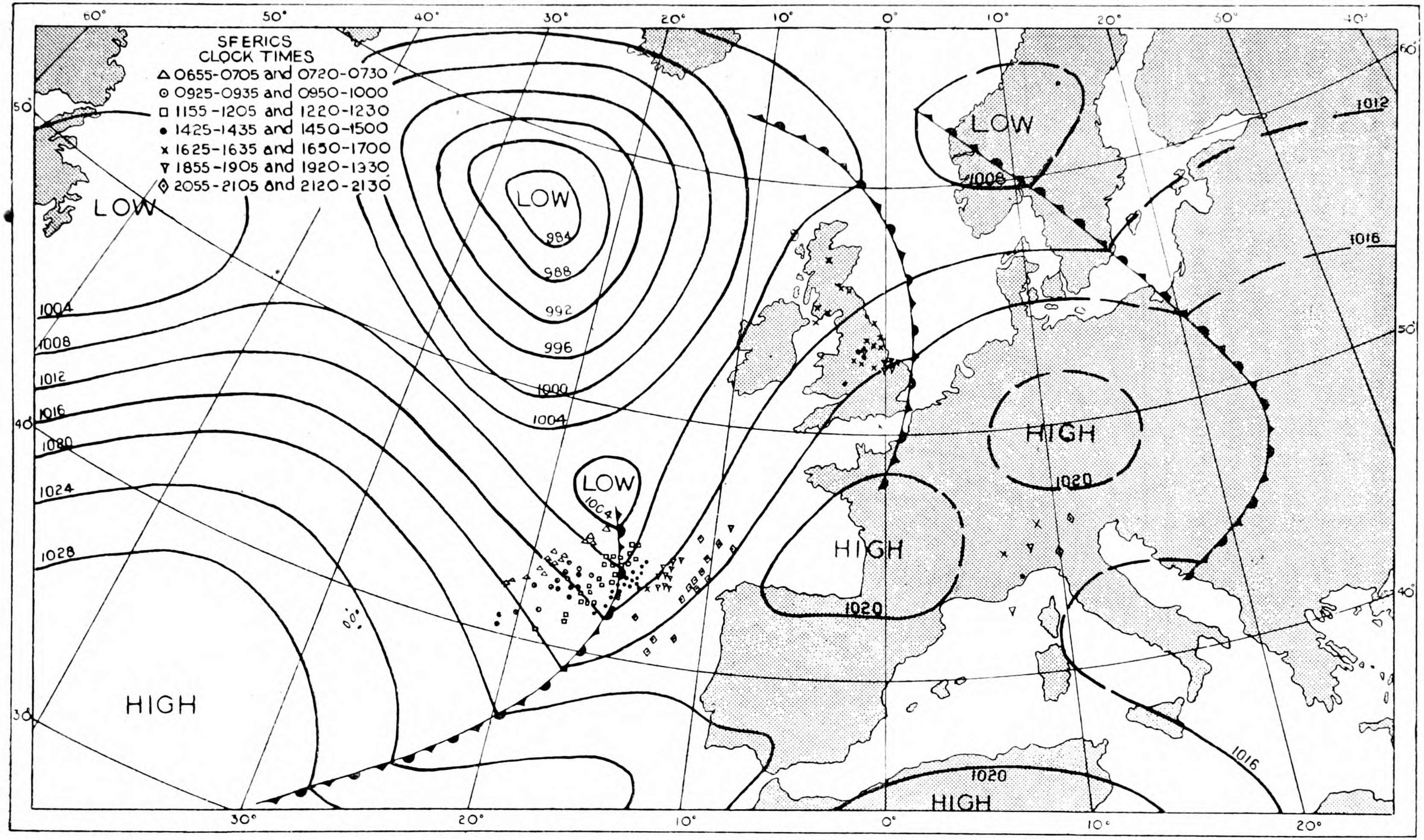


FIG. 3—SYNOPSIS CHART FOR 1300, APRIL 11, 1944
showing positions of storms found by "Sferics" fixes during the day

of the chart, however, is the regular progression of storms associated with the cold occlusion which was moving quickly eastwards along with the secondary depression centred about 500 miles off north-west Spain. The chart forms a good example of the way in which " Sferic " reports can be used by forecasters to determine the probable position and movement of a " front " when no other evidence is available.

Figs. 4 and 5 show charts for November 22 and 23, 1946. Numerous " Sferics " were asociated with the very deep depression in the Atlantic and it is remarkable that whilst cumulonimbus cloud was reported, none

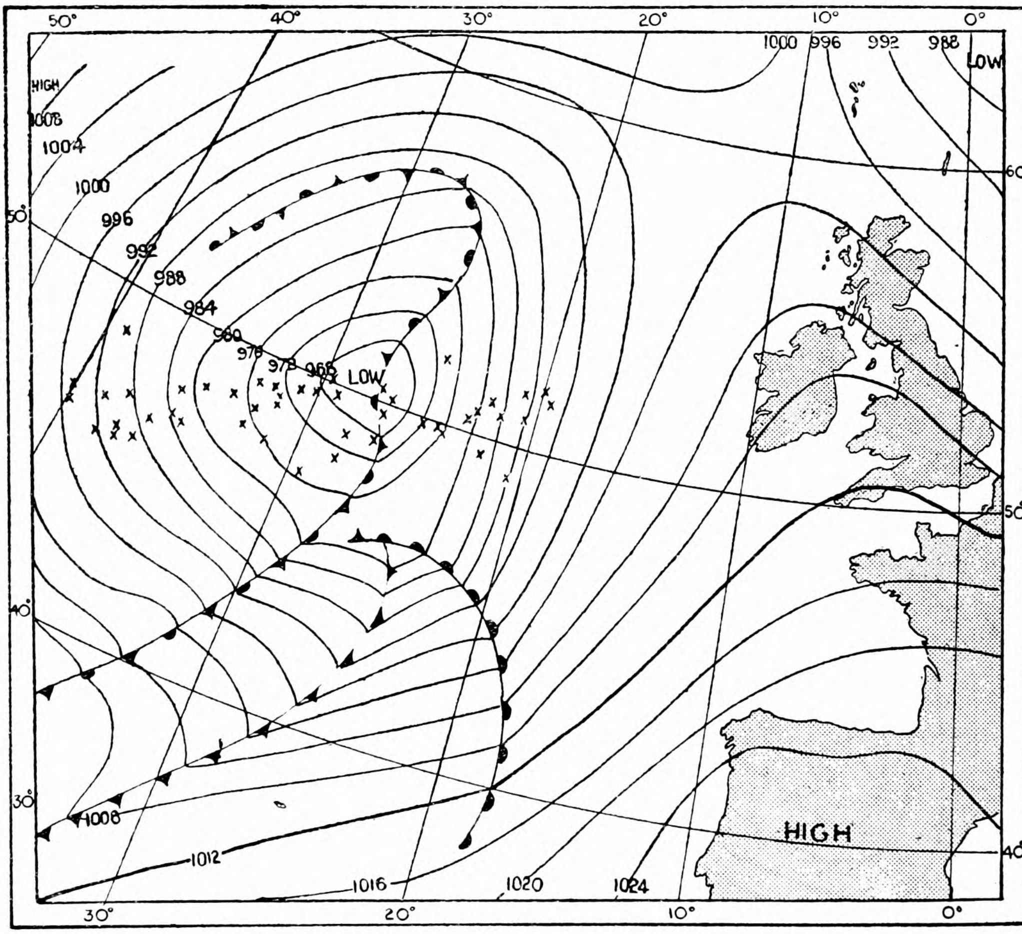


FIG. 4—SYNOPTIC CHART FOR 1800, NOVEMBER 22, 1946, showing positions of thunderstorms found during the day

of the ships' observations gave any indication of actual thunderstorms which were of vital concern to aircraft on the North Atlantic air route. Douglas has pointed out that thunderstorms have a far closer relation with cyclonic vorticity than with any particular kind of air mass, but it is rather unusual to find so much activity not associated with a front as far north on the Atlantic. On the following day, Sunday, November 24, the activity occurred chiefly along a cold front associated with a wave disturbance which moved north-eastwards across the British Isles. The storms were mostly confined to the portion of the front between latitudes 40° and 50° N. as is usually the case, but the north-easterly movement of the main area of activity towards the Brest peninsula and extreme south-west England is clearly shown on the chart (Fig. 6). Broadly speaking, atmospherics that occur with cyclonic waves appear as rather distinct concentrated and elongated groups travelling with the speed of the wave. The maximum is found at or near the apex of the warm sector, and since very often much Sferic activity is reported even before the wave has developed closed isobars, this is of great assistance in identifying young waves on fronts. In the case of well established cold fronts it is found that there is a maximum of Sferic activity at or immediately in the rear of the front, a minimum between 200 and 300 miles behind the front and a

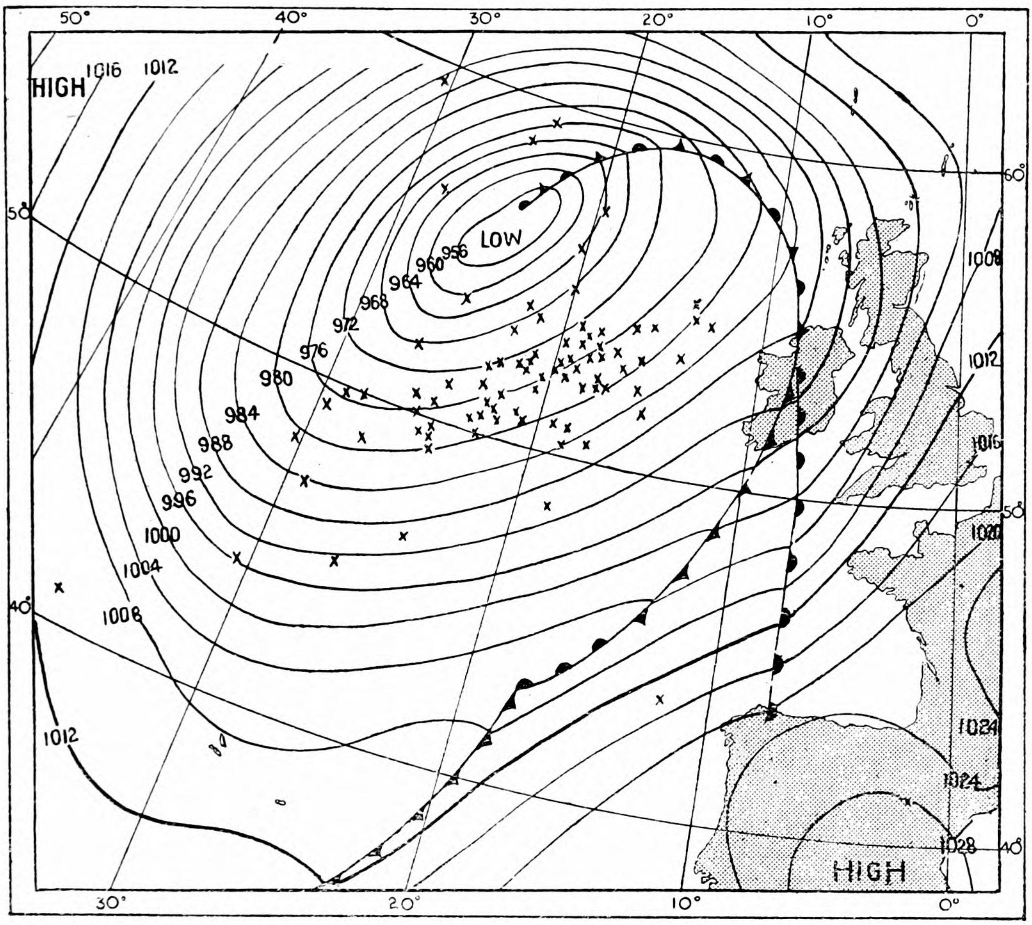


FIG. 5—SYNOPTIC CHART FOR 1200, NOVEMBER 23, 1946, showing positions of thunderstorms found during the day

secondary maximum between 300 and 500 miles within the cold air.

It will be realised that the Sferics organization, whilst it is of the greatest value in giving information regarding the existence and movement of storms which have already broken out, cannot be of assistance in forecasting whether storms will or will not develop and it cannot distinguish between high-level and low-level storms. However, for comparatively short air routes to the continent, Sferic observations are of the greatest use to briefing officers at terminal airports in advising pilots the best route to fly to avoid encountering large banks of cumulonimbus clouds with their associated severe turbulence, icing and " static ". In view of the danger attaching to flying in such conditions and in order to avoid discomfort to passengers, pilots will be prepared to make considerable detours if by so doing storm areas can be avoided. Successful tests have been made in transmitting " Sferic " charts (as well as " prebaratic " and other charts) by facsimile apparatus direct from the control station to selected receivers, including a despatching airfield, and there is a great future for direct picture transmission which eliminates laborious coding, decoding and plotting ; a pilot can be shown the exact " fixes " of any large number of storms just as they have been plotted at the Sferic control station.

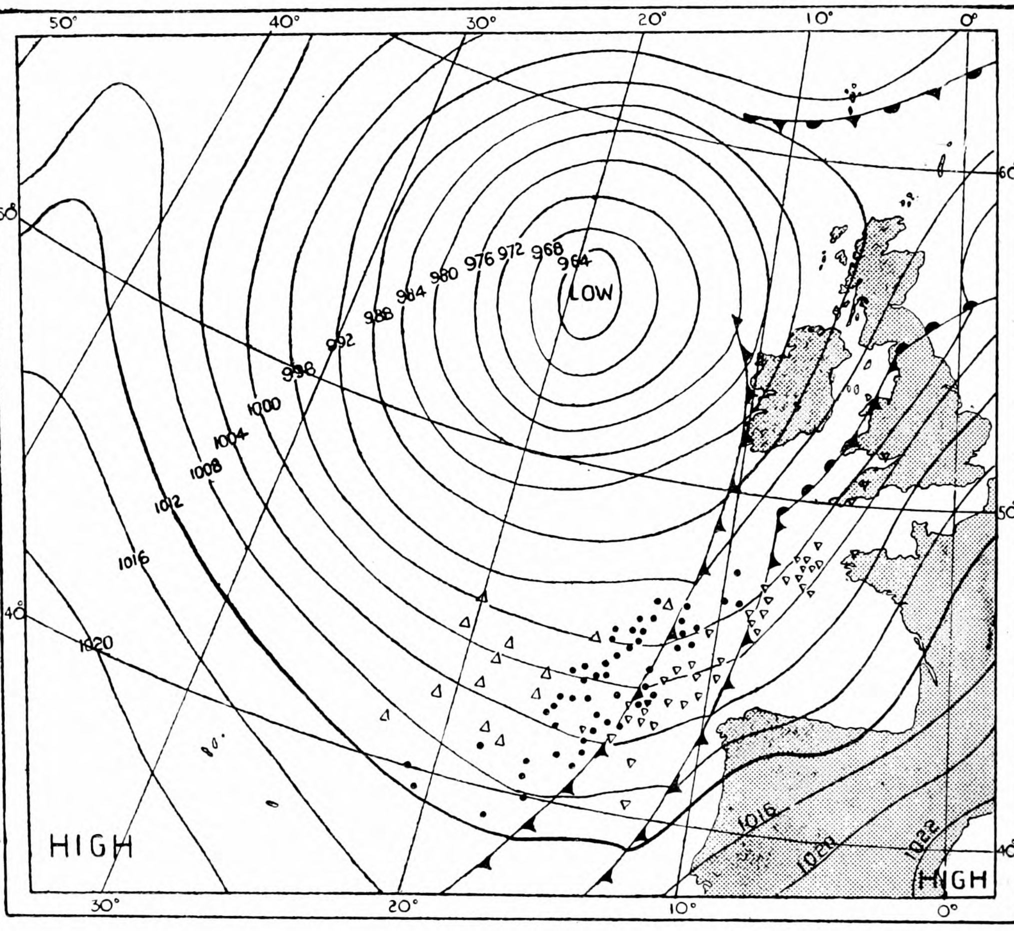


FIG. 6—SYNOPTIC CHART FOR 0600, NOVEMBER 24, 1946
△ indicates fixes obtained between 0700 and 1030
• indicates fixes obtained between 1130 and 1645
▽ indicates fixes obtained between 1830 and 2215

In concluding this account of the Sferics organization as it exists at present, it may be mentioned that plans for the future, besides including photographic recording already mentioned, envisage the use of a spaced-loop aerial system which would reduce polarization errors and enable a 24-hour thunderstorm-location service to be provided. The possibility of measuring the intervals between the time of arrival of successive " echoes " from the ionosphere (as many as 20 have been recorded) is also being considered as a means of calculating the distance of the source ; if successful, this would mean that fixing the position of a storm could be done from a single station.

FIG. 3—TELEPRINTER ROOM AT C.F.O.

On these machines hourly coded weather reports from about 400 stations in the United Kingdom and adjacent continental areas are received within 8 minutes of the hour of observation

(see p. 76)

FIG. 4—WIRELESS RECEPTION ROOM AT C.F.O.

(see p. 76)

FIG. 5—IN THE FORECAST ROOM AT C.F.O.

Right, Mr. C. K. M. Douglas, C.B.E., left, Mr. J. Harding

(see p. 76)

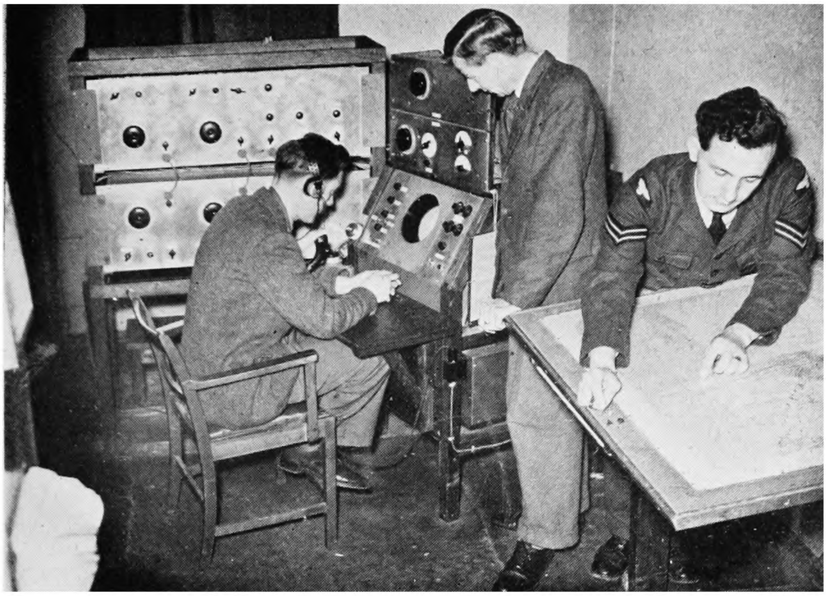
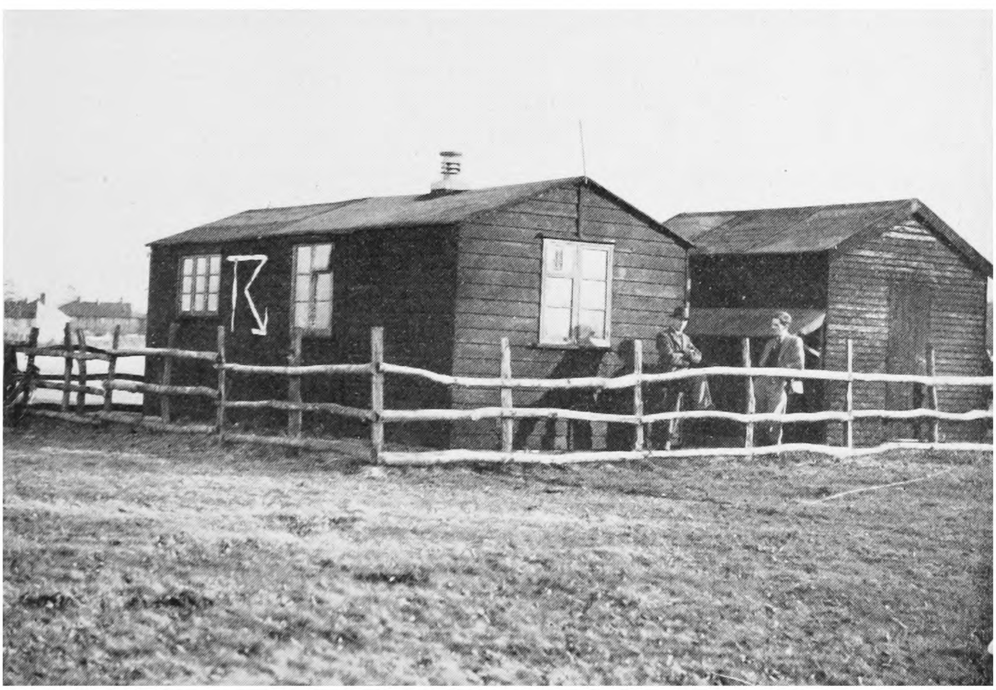


FIG. 1—SFERIC SET SHOWING AMPLIFIERS, CATHODE-RAY TUBE AND PLOTTING TABLE

(see p. 79)



Reproduced by courtesy of " News Chronicle."

FIG. 2—CATHODE-RAY DIRECTION-FINDING HUT AND FRAME AERIAL HUT AT DUNSTABLE

(see p. 79)

A " GLORY " PHOTOGRAPHED FROM A LIBERATOR, JANUARY 25, 1945
(see p. 88)

" CONTESSA DEL VENTO " CLOUD, MILLOM, CUMBERLAND, JUNE 20, 1947
(see p. 88)

METEOROLOGICAL OFFICE DISCUSSIONS

March 31, 1947. Heat transfer by infra red radiation in the atmosphere. By W. M. Elsasser (*Harvard Met. Stud. Milton Mass.*, No. 6, 1942). *Opener*—Dr. J. M. Stagg.

Meteorologists have long awaited a ready means of estimating the contribution made by radiation processes to heat exchanges in the atmosphere and between the ground and the atmosphere. The formation and intensification of temperature inversions, incidence of ground frosts and formation and persistence of fog, and the changes in thermal structure of moving air masses represent some of the practical problems affected to greater or less extent by long-wave radiation transfer. But development of knowledge of the processes involved has been badly hampered by uncertainties about the absorption coefficients of water vapour as the primary radiator, and, to a less degree, by difficulties in handling the equations.

Using the latest information provided by his American colleagues on the absorption characteristics of water vapour in the three main regions of its infra-red spectrum (3 to 8μ, 8·5 to 17μ and above 17μ) Elsasser ingeniously developed a generalised absorption coefficient, which, with a transmission function, allowed him to devise a diagram from which the up and down fluxes of radiation at any level in the atmosphere can be estimated when the vertical distribution of temperature and humidity are known. Absorption by carbon dioxide, the only other important radiator in the lower atmosphere, is concentrated in a narrow band at 15μ and is intense there. A layer in which temperature gradients may be ignored can therefore be regarded as giving a nearly full black body flux at the temperature of the carbon dioxide.

Dr. Stagg explained the procedure which Elsasser had followed in building up the generalised absorption coefficients from detailed laboratory measurements and computations based on molecular structure in the rotational band above 17μ, from older and less detailed measurements in the region around 6μ and from estimates based on spectro-heliographic data in the more transparent region between 8μ and 13μ.

Apart from uncertainties in the grafting of each of those regions on to its neighbour, a doubtful factor is introduced in the pressure correction to the absorption coefficients. Spectroscopic theory says that the intensity of line absorption by water vapour should depend on the air pressure but the evidence of laboratory experiments led Elsasser to adopt a correction proportionate to the square root of the pressure.

With the absorption coefficients settled, Elsasser developed an expression for the total radiation flux reaching the ground from the atmosphere in terms of the transmission function, and so it became possible to integrate numerically the equations of radiative transfer. Dr. Stagg showed how the radiation chart is used in typical problems.

In the course of the discussion Prof. Brunt expressed some doubt about Elsasser's method of generalising from line to band absorption and of marrying the laboratory data with those inferred from theory ; he emphasised the need for more measurements of long-wave atmospheric radiation. Dr. Robinson said measurements had recently been made at

Kew Observatory and had been compared with estimates made from Elsasser's chart. The chart values could be up to 15 per cent. too high. Using values of long path emissivity of water vapour derived from the Kew measurements, Dr. Robinson had devised a graphical means (based on F. A. Brooks' procedure) of estimating the radiation flux in the atmosphere, which gives values consistently nearer the measured values than those from Elsasser's chart. Mr. Swinbank said that during the course of measurements of changes of temperature and humidity up to 1,500 ft. at Cardington he also had found Elsasser's chart values of radiation too high. Mr. Gold referred to the law of variation of absorption with thickness of the medium and Mr. Sheppard explained F. A. Brooks' technique of deducing radiation values from emissivities : Mr. Belasco described how he had used the Elsasser chart to estimate atmospheric cooling by radiation in two different types of air mass. Dr. Sutcliffe said synoptic meteorologists looked forward to having a ready means of assessing quickly and accurately the magnitude of the effects of radiative transfer in synoptic processes.

In winding up the discussion Dr. Stagg said Elsasser clearly appreciated the weak links in his development and would be the first to agree with those speakers who had stressed the need for more accurate measurements of atmospheric radiation.

LETTER TO THE EDITOR

Rime

In the article on " Rime " in the *Meteorological Magazine* of February, 1947 (p. 45), it is described as " a crystal deposit ", without qualification, and I think most meteorologists think of rime as a crystal deposit.

Seligman in his excellent book on " Snow Structure and Ice Forms " states of rime : " Seen under the microscope it has entirely different external characteristics from those of the hoar deposits. It consists of agglomerations of frozen water droplets which do not exhibit the marked external crystalline structure of hoar crystals, being in the form of minute accretions of ice." Seligman goes on to explain that the deposit is not amorphous strictly speaking and that the ice is not colloidal but crystalline.

Clearly crystals may be formed by sublimation on the frozen drops of rime deposited by the supercooled fog. These drops would soon be at air temperature (or " iced "-bulb temperature), even if their temperature rose to 32° F. when they solidified ; and the vapour pressure in the supercooled fog would be higher than that over ice at the same temperature.

International Meteorological Publication No. 50 which contains a section on the description of hydrometeors by Dr. Bergeron defines " soft rime " as " white layers of ice crystals deposited chiefly on vertical surfaces —especially on points and edges of objects—generally in supercooled fog or mist. On the windward side soft rime may grow to very thick layers of a structure similar to that of hoar frost. This process is probably analogous to that of the formation of soft hail." : and " hard rime "— " opaque, granular masses of ice deposited in the same way as soft rime but in ' wet air ' or wet fog at temperatures below 0°C., thus developing a more compact and amorphous structure than soft rime, analogous to that of small hail."

The " Meteorological Glossary " substitutes " supercooled drizzle " for wet fog in the definition of hard rime.

The definitions in International Meteorological Publication No. 50 clearly require elucidation or amendment because there is no difference between supercooled fog or mist and wet fog at temperatures below 0° C.

E. GOLD

May 15, 1947.

NOTES AND NEWS

Award to Mr. E. Gold

On August 9, 1946, Mr. E. Gold was awarded, by the United States, the Medal of Freedom with Silver Palm.

The presentation was made on March 7, 1947, by Major General Clayton Bissel, Military Attache, American Embassy, at the Chancery of the American Embassy, 14, Princes Gate, S.W.7.

We publish below, a copy of the citation.

" Ernest Gold, British Civilian, for exceptionally meritorious achievement which aided the United States in the prosecution of the war against the enemy in continental Europe, as Deputy Director, Meteorological Office, Air Ministry, from November, 1942, to May, 1945. He was instrumental in setting up a system between his Office and the United States Army Air Forces Weather Service, making possible the successful exchange of information necessary in carrying out the vast air operations from bases stretching from North America to Europe and from Greenland and Iceland to Africa. His aggressive work, tireless efforts and close co-operation contributed in no small degree to the great success of the combined air operations in the European and Atlantic regions."

The Meteorological Association

During the recent war some six thousand volunteers came to lend their help to the British meteorological services. A goodly proportion were women, and whilst many wore Service uniform, others remained civilians. Many friendships inevitably grew up, not only among the war-time volunteers, but also between the volunteers and the regular staff of the meteorological services.

With the end of the war, many felt a desire to maintain their war-time friendships, and a suggestion was made by Mr. Alan Swinstead that something akin to an " old meteorologists' association " might be formed for this purpose. Enquiry revealed that there was likely to be a considerable measure of support for such a scheme, and it was also found that the airwomen meteorologists had indeed already formed an " Ex-Met.-W.A.A.F. Association ", with Mrs. Ward as its President.

After much effective spadework had been done by a trio consisting of Prof. Sheppard, Mr. D. C. Lloyd and Mr. W. P. Osmund, a meeting was held at King's College, London, on the evening of April 22, at which well over a hundred people were present. Under the able chairmanship of Prof. Sheppard, the meeting agreed to establish an organization, to be known as the " Meteorological Association", with the twofold object of :—

(*a*) fostering good fellowship among members and maintaining war-time friendships.

(*b*) assisting members to keep in touch with meteorology.

So far as the second of these objects is concerned, it is desired to make it quite clear that the Association is anxious not to compete in any way with the Royal Meteorological Society. On the contrary, the two bodies are regarded as complementary, and their activities as mutually supporting.

Membership of the Association is open to any person who is, or has been, a full-time practising meteorologist, whether as a member of the Meteorological Office staff or of H.M. Forces.

The meeting at King's College approved a set of Rules, fixed the Annual Subscription at 2s. 6d. and elected officers of the Association and a Committee.

The Ex-Met.-W.A.A.F. Association generously expressed their willingness to be incorporated in the new organization, of which the full title is "The Meteorological Association (incorporating the Ex-Met.-W.A.A.F. Association)".

The Committee was given a mandate to arrange the first Annual Reunion in the form of a supper-dance to be held in London in the autumn. Plans to this end are now going ahead, and it is hoped to announce particulars shortly.

All who are interested in the Association are invited to communicate with one of the Secretaries, Mr. N. B. Marshall in the case of men, and Miss Olive Cooper in the case of women. Their respective addresses are—17, Oxford Street, Teddington, and 7, Woodlands Avenue, Finchley, N.3. The formation of a strong and representative Association will also be assisted if readers mention it when next writing to their war-time colleagues.

N.K.J.

A "Glory" photographed from a Liberator

The photograph facing p. 85 was forwarded by S/Ldr. R. A. Buchanan. The photograph was taken at 1400 G.M.T. on January 25, 1945, from a Liberator aircraft based at the Azores. The aircraft was at 5,000 ft. and the height of the top of the stratocumulus was 3,000 ft.

The crew of the aircraft were questioned as to the colouring of the "glory" surrounding the shadow of the aircraft but could only say that the rings were reddish orange. There was no surrounding fog bow.

An unusual cloud formation

The photograph facing p. 85 was contributed by the Meteorological Officer, Millom, Cumberland.

The cloud is the eddy type known as "Contessa del vento" frequently formed to the lee side of isolated mountains. It is often observed over Mt. Etna with a westerly wind. This cloud type was observed at Millom, on the evenings of June 19 and 20, 1944; the photograph was taken on June 20. The synoptic situation on the day was as follows :—

Anticyclone centred west and later north-west of the British Isles. Feeble frontal system moving south-east across north Scotland and the

North Sea. Gradient at Millom, ENE. with air of relatively low humidity and potentially unstable above 700 mb.

By 1900, the easterly gradient having increased, the sea breeze dropped and a land wind resumed with a marked drop in humidity from 72 to 55 per cent. Cumulus dispersed within an hour leaving altocumulus and later the formation illustrated.

The severity of the winter of 1946-7

The following is an extract from a letter received from Prof. Dr. W. Bleeker and Dr. Van den Harn of the Koninklyk Nederlandsch Meteorologisch Instituut, De Bilt, Holland.

"As a result of last severe winter there exists an increased interest in the classification of cold winters among some scientific assistants at our Meteorological Office. To classify severe winters we used a method, called after the German meteorologist, Hellmann, who first applied it to a series of winters in Berlin. It works as follows :—

For each day of the winter the mean temperature is computed from hourly temperature observations. By adding all daily mean temperatures below freezing point one gets the 'characteristic number'. This number gives the degree of severity of a winter. In this country we have a continuous series of temperature observations since 1706, so that we could classify all winters from 1706 up to 1946. The following list shows the results (winters classified according to severity).

	Year	Duration in days	Characteristic number °C.
1.	1789*	87	-359
2.	1942	69	-331
3.	1830	61	-325
4.	1838	48	-320
5.	1795	56	-317
6.	1823	48	-315
7.	1740	75	-313
8.	1845	83	-312
9.	1799	52	-302
10.	1940	73	-300
15.	1891	60	-265
22.	1929	71	-218

* 1789 means winter 1788-1789.

We added two very famous winters of the last 100 years, to show that they did not rank among the ten coldest winters we had in this country.

Last winter reached the second place on the list with characteristic number -343 and a duration of 70 days.

Following details about last winter may interest you. There were three well separated frost periods. The first lasted from December 14 to 25. During 9 days in this period temperature did not rise above freezing point at all. The minimum temperature at De Bilt was 4° F. on December 21. On Christmas Eve there was a general thaw and milder conditions prevailed until January 4, when the second freeze-up began. This time the frost lasted only 5 days with temperature reaching its minimum (10° F.) on January 7.

It is remarkable that there did not fall any snow during the two first frost periods of this winter. In the middle of January weather became very mild with temperatures rising to 50° F. but then on January 21 the third and longest frost period began. It lasted until March 16. The first important snowfall occurred on February 2. The total snowfall up to the end of the winter is estimated to have been about 15 in. In this winter there were altogether 31 days with temperature below 20° F.

There were 48 ' ice ' days, as we call days on which temperature does not rise above freezing point (maximum below 0° C.). Since 1706 only the winter of 1789 had more ice days, viz. 49. The absolute minimum temperature in this country was observed at Groningen on February 24 ; it was —1° F.

The month of February was particularly cold, with a mean temperature of -5·5° C. (22·1° F.). As the normal mean temperature for the country is + 2·5° C. (36·5° F.), this month was 14·5° F. too cold.

Recently a new method for classifying cold winters has been developed by Dr. H. ten Kate. He compares the actual temperatures with daily normal temperatures. For every day of the " winter period " the difference between the real mean temperature and the normal mean is computed. As the ' winter period ' does not coincide with the meteorological winter (December 1-March 1) it is necessary to decide which dates are to be considered as the beginning and the end of the period. In every cold winter there is a central part, the main body of the winter, e.g. in 1947 from January 21 until the middle of March but other frost periods may occur, separated from the main body by a thaw. Now it appears reasonable to take these periods into account if two conditions are satisfied :—

(1) the number of frost days must be at least half the number of thaw days, by which it is separated from the main body.

(2) taking the thaw period and the separated frost period together, the mean temperature of the two periods must be at least 2° C. (3·8° F.) below the normal mean.

In 1947 e.g. the main body of the winter may be extended by adding the frost period from December 14-25, as the two conditions are satisfied. So for 1947 the ' winter period ' lasts from December 14 until the middle of March. By adding all differences : normal mean temperature minus real mean temperature, we get a negative sum, which again is called ' characteristic number '.

The winter is classified according to its characteristic number. The classification we get in this way is as follows :—

	Winter period	Characteristic number °C.	Mean difference from normal °C.	Duration in days
1.	1829-1830	-534	-5·5	97
2.	1844-1845	-533	-4·8	112
3.	1813-1814	-504	-4·4	114
4.	1946-1947	-489	-5·3	92
5.	1941-1942	-465	-6·9	67 "

[Estimates of the relative severity of winters in this country have generally been made on the basis of the mean temperature of the three winter months December to February. Values of mean temperature at sea level over the British Isles are available since January, 1881, and from these the following winter means have been calculated :—

	° F.		° F.
1895	35·2	1917	36·9
1891	36·1	1940	37·3
1947	36·5	1929	37·9

1895 means December, 1894, to February, 1895.

This method is rather crude, and an alternative was devised based on that used by C. Easton in "Les hivers dans l'Europe occidentale". This gives equal weight to the mean temperature, the number of frost days (minimum temperature below 32° F.), and the number of ice days (maximum temperature below 32° F.). Writing S for the severity of the winter, T for the mean temperature in degrees Fahrenheit of the months November to March, F for the number of frost days and I for the number of ice days in the same period, T_O, F_O, I_O for the long-period averages of these elements and σ for their standard deviations, we have

$$S = (T_O - T)/\sigma_T + (F - F_O)/\sigma_F + (I - I)/\sigma_I$$

The constants were calculated for Greenwich ; multiplying the terms on the right hand side by 15 to give convenient numbers,

$$S = 9(41 - T) + (F - 45) + 3(I - 4)$$

From 1841 onwards, the indices of the ten most severe winters in London calculated by this method are :—

1891	134	1940	85
1947	133	1895	72
1879	109	1847	70
1855	103	1880	70
1845	89	1942	60

The winter of 1895, though intense, was short, and its index calculated by this method does not take a high place. 1947 is practically equal to 1891 as the most severe winter of the past century in London, mainly by virtue of the long period of maxima below 32° F.

In discussing the winter of 1947 however it has to be remembered that temperature and frost are not the only factors to be considered. The depth and duration of snowfall, and the persistence of easterly winds are also of importance. These factors were examined for England as a whole. In the matter of snowfall, the two most severe winters were 1881 and 1947, followed by 1940 and then 1917 and 1895. 1929 and 1891 were even less notable. In respect of frequency of easterly winds 1947 was far more severe than any other year since 1881. It was followed by 1940, 1917 and 1895, and finally 1929 and 1891.

It is not possible to assign exact numerical values to the factors of snowfall and easterly winds but taking these into account as well as mean temperature and duration of frost, it appears that from at least 1881 onwards 1947 was by far the most severe winter in this country. It was followed by 1895 and 1940 about equal, 1891 only slightly less severe then 1917 and 1881 a long way behind and finally 1929.

We cannot readily go back to 1789, but otherwise the conclusion seems to be that in this country, as in Holland, the winter of 1946–7 was the most severe for at least a century. Ed. *M.M.*]

Temperatures of winter months at Kew Observatory

The two accompanying diagrams show graphically the mean temperatures of different combinations of winter months at Kew Observatory.

In Fig. 1 the horizontal lines show the average mean temperature (mean of maximum and minimum) of each group of months for the years 1906–35. The ends of the columns show the temperature in individual winters ; the deficits in cold winters are indicated by the shaded columns below the line and the excesses of mild winters by the black columns above the line. Fig. 1 (a) represents the three coldest months December to February which meteorologists generally regard as " winter ", (b) refers to January to March, (c) to the four coldest months December to March, and (d) to the five months November to March which with short transitional periods make up the winter half-year.

The winter of 1946–7 shows up as the second coldest since 1871 in diagrams (a) (b) and (c), falling short of 1890–1 as regards December to February and December to March, while in January to March it was just exceeded by 1894-5. Over the whole five-month period however, owing to a mild November, 1946–7 does not show up as exceptionally severe.

Another point brought out in all four diagrams is the group of severe winters from 1884–5 to 1894–5, which far exceed any period of similar length since 1871.

Fig. 2 shows the mean temperatures during the most prolonged and severe cold spells of the past century, and brings out the persistence of winter in 1946–7 (almost exactly paralleled 100 years before) compared with the relatively short intense frost of 1895.

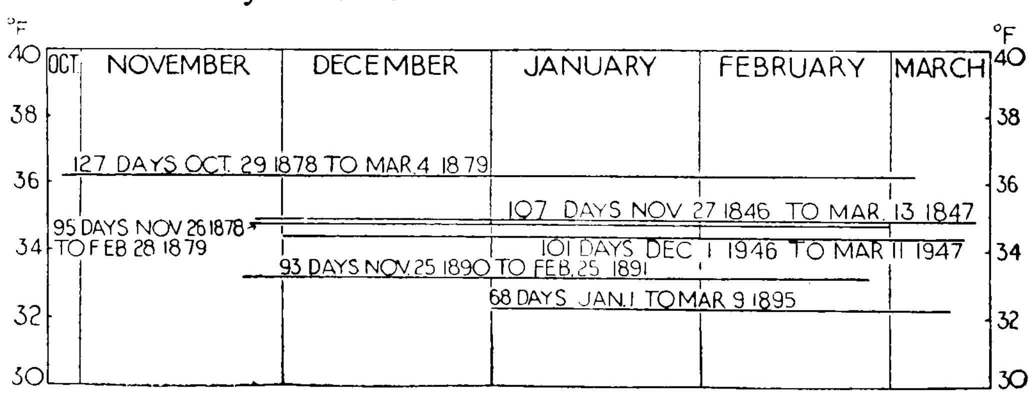


FIG. 2—MEAN TEMPERATURE DURING COLD SPELLS OVERLAPPING CALENDAR MONTHS

All values relate to Kew Observatory except 1846-7 which refer to Greenwich Observatory

Fantastic icicles at Dunstable

We are indebted to Mr. W. Hayes for the sketch on page 94 which shows some of the fantastic icicles up to 5 ft. long that were seen hanging

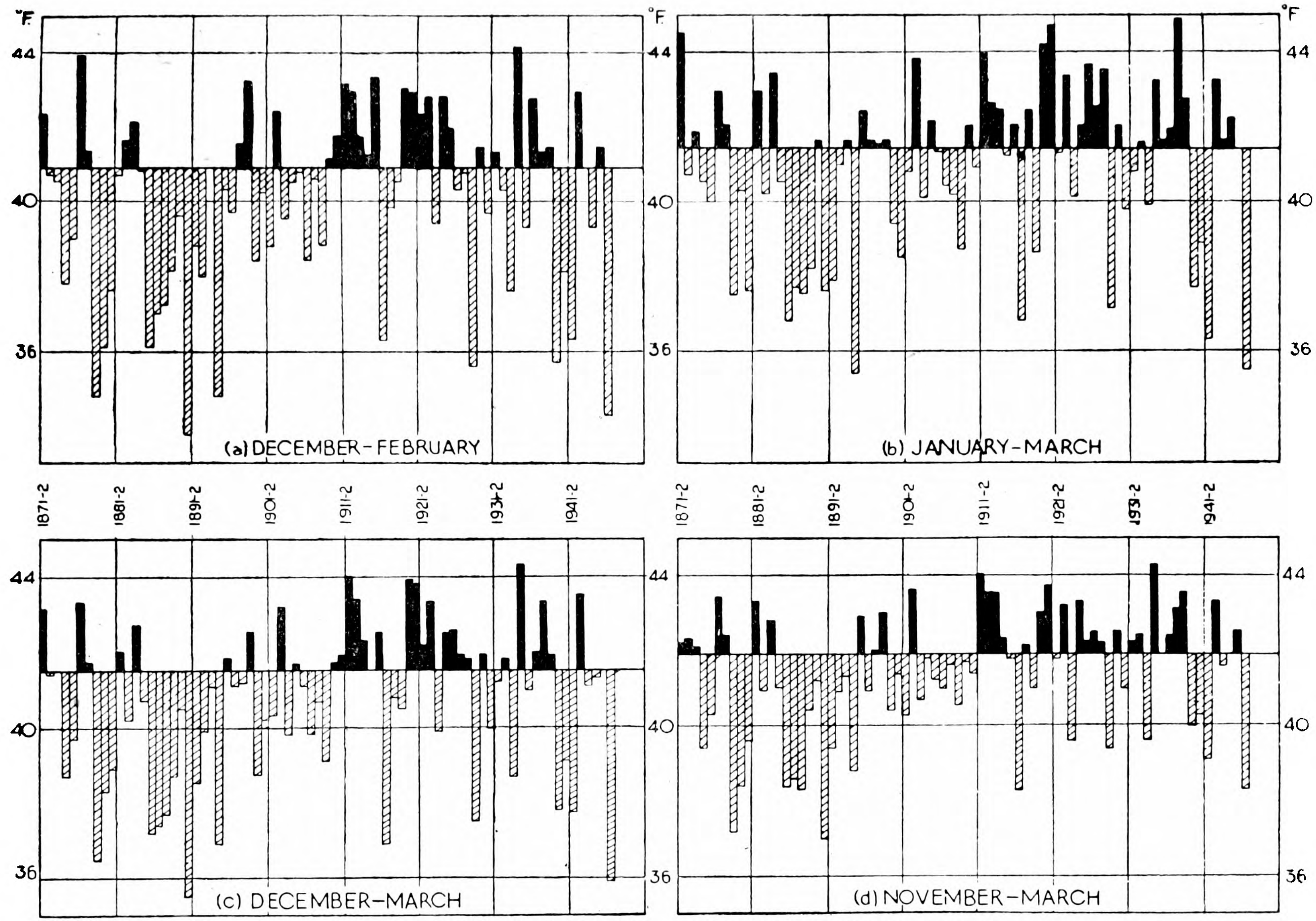
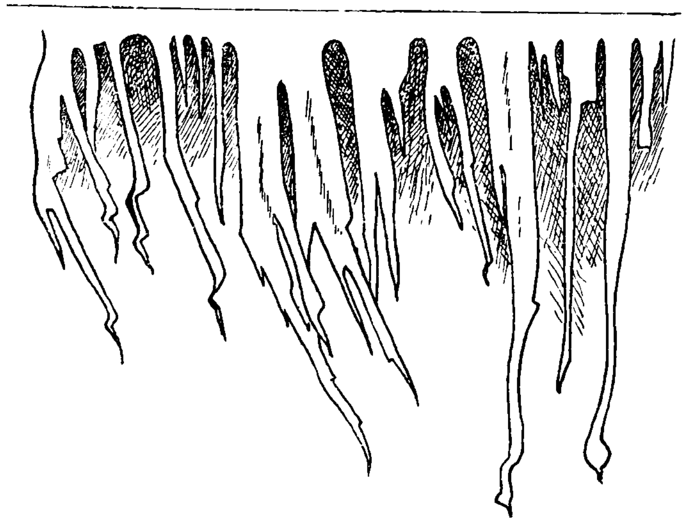


FIG. 1—KEW OBSERVATORY. MEAN TEMPERATURE WINTER MONTHS
Average temperature (1906-35) given by black line ; mild periods full black areas ; cold periods hatched areas

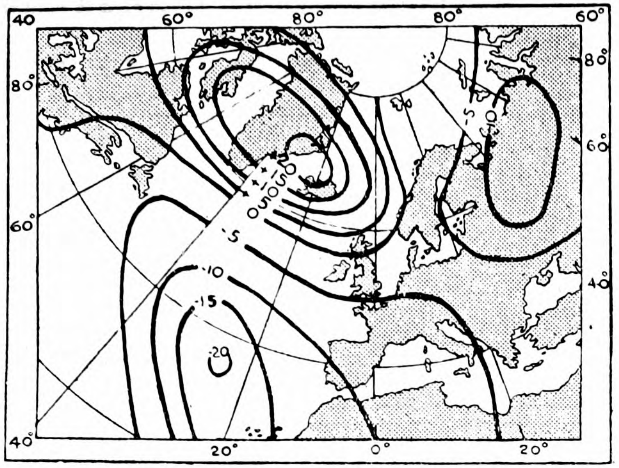
from the eaves of a building at the Meteorological Office, Dunstable, in March, 1947. A strong wind blowing along the building caused the bend in the icicles exposed to its full effect.



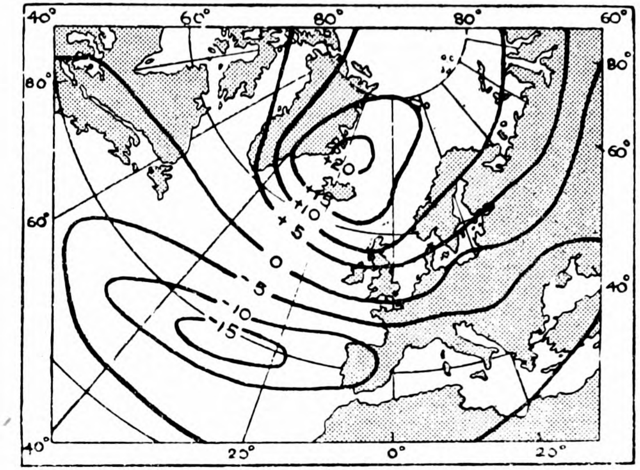
Distribution of pressure in February, 1947, compared with other severe winters

In the great majority of winter months pressure is highest in the latitude of the Azores and decreases steadily northwards to Iceland and southern Greenland. In February, for example, the long period average is 1021 mb. at Horta in the Azores and only 999 mb. at Reykjavik in Iceland. In February, 1947, this distribution was completely reversed, the mean for the month being only 1009 mb. at Horta compared with 1023 mb. at Reykjavik, while further north at Myggbukta in East Greenland it was as high as 1035 mb. This means that the westerly winds which normally prevail over Britain were replaced by easterly winds.

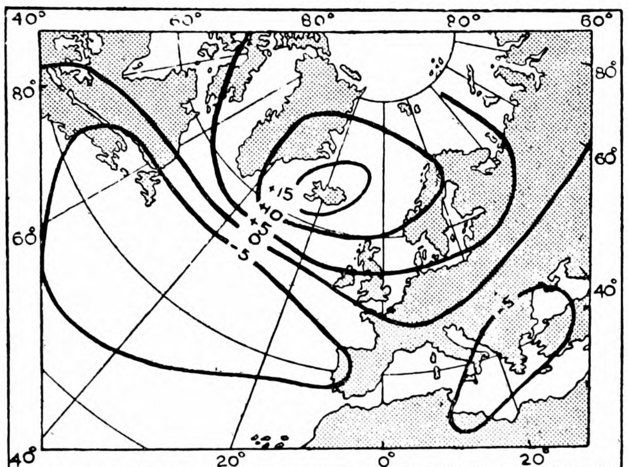
Maps of the deviation of mean pressure from normal are often good indicators of the general character of the month. Fig. 1 shows the deviations for the four very severe months of January 1881, February 1895, January 1940 and February 1947. In all cases the greatest excess of pressure lay over Iceland or East Greenland but there were some significant differences. In January 1881 pressure was below normal over almost the whole of Europe, including Ireland and England, but the gradient was not steep and the isanomals ran largely north and south. This month was very snowy but not intensely cold. In February 1895, on the other hand, pressure was above normal over all northern Europe, including the British Isles, and the isanomals ran west-east. This month was intensely cold but not very snowy. January 1940 was rather similar. Finally, February 1947 showed the steepest pressure gradient of the whole series over Britain, agreeing with the great strength and persistence of the easterly winds ; the isanomals run east and west, pointing to severe and prolonged cold, but pressure was below normal over Ireland and England, in accord with the heavy snowfall. The relatively low pressure over England also favoured cloudy weather, cold days but not such intense night frosts as in 1895.



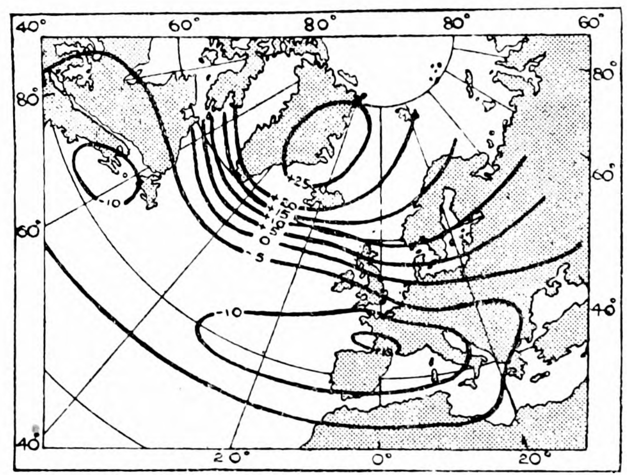
(*a*) January, 1881



(*b*) February, 1895



(*c*) January, 1940



(*d*) February, 1947

FIG. 1—DEVIATIONS OF MEAN PRESSURE

RAINFALL OF FEBRUARY, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	1·55	93	*Glam.*	Cardiff, Penylan ..	1·75	60
Kent	Folkestone, Cherry Gdns.	1·55	75	*Pemb.*	St. Ann's Head	3·49	125
,,	Edenb'dg, Falconhurst ..	2·52	114	*Card.*	Aberystwyth	·15	6
Sussex	Compton, Compton Ho.	2·27	86	*Radnor*	Bir. W. W., Tyrmynydd..	2·78	53
,,	Worthing, Beach Ho. Pk.	2·04	103	*Mont.*	Lake Vyrnwy	(2·50)	(56)*
Hants	Ventnor, Roy. Nat. Hos.	1·85	88	*Mer.*	Blaenau Festiniog ..	(1·80)	(22)*
,,	Fordingb'dg, Oaklands	1·15	46	*Carn.*	Llandudno	·92	47
,,	Sherborne St. John ..	1·46	67	*Angl.*	Llanerchymedd	1·12	44
Herts.	Royston, Therfield Rec.	1·39	90	*I. Man*	Douglas, Boro' Cem. ..	1·05	33
Bucks.	Slough, Upton	1·12	66	*Wigtown*	Pt. William, Monreith ..	·78	25
Oxford	Oxford, Radcliffe ..	1·66	101	*Dumf.*	Dumfries, Crichton R.I.	·99	30
N'hant.	Wellingboro', Swanspool	1·74	108	,,	Eskdalemuir Obsy ..	1·21	24
Essex	Shoeburyness	·89	72	*Roxb.*	Kelso, Floors	2·20	129
Suffolk	Campsea Ashe, High Ho.	1·69	122	*Peebles*	Stobo Castle	1·61	58
,,	Lowestoft Sec. School ..	2·30	164	*Berwick*	Marchmont House ..	2·71	130
,,	Bury St. Ed., Westley H.	1·44	96	*E. Loth.*	North Berwick Res. ..	1·25	80
Norfolk	Sandringham Ho. Gdns.	1·43	87	*Midl'n.*	Edinburgh, Blackfd. H.	1·44	87
Wilts.	Bishops Cannings ..	1·24	58	*Lanark*	Hamilton W. W., T'nhill	·80	28
Dorset	Creech Grange	2·73	95	*Ayr*	Colmonell, Knockdolian	·43	11
,,	Beaminster, East St. ..	1·73	57	,,	Glen Afton, Ayr San. ..	·94	21
Devon	Teignmouth, Den Gdns.	2·18	82	*Bute*	Rothesay, Ardencraig ..	·82	21
,,	Cullompton	1·44	52	*Argyll*	Loch Sunart, G'dale ..	·04	1
,,	•Barnstaple, N. Dev. Ath.	·49	18	,,	Poltalloch	·17	4
,,	Okehampton, Uplands ..	1·62	37	,,	Inveraray Castle.. ..	·23	3
Cornwall	Bude School House ..	1·09	44	,,	Islay, Eallabus	·65	15
,,	Penzance, Morrab Gdns.	2·37	71	,,	Tiree	·18	5
,,	St. Austell, Trevarna ..	2·17	57	*Kinross*	Loch Leven Sluice ..	2·92	103
,,	Scilly, Tresco Abbey ..	5·28	189	*Fife*	Leuchars Airfield ..	2·17	124
Glos.	Cirencester	1·21	53	*Perth*	Loch Dhu	1·25	17
Salop.	Church Stretton ..	..	..	,,	Crieff, Strathearn Hyd..	2·89	82
,,	Cheswardine Hall ..	1·19	67	,,	Blair Castle Gardens ..	·88	32
Staffs.	Leek, Wall Grange P.S.	·71	33	*Angus*	Montrose, Sunnyside ..	2·40	130
Worcs.	Malvern, Free Library ..	1·54	86	*Aberd.*	Balmoral Castle Gdns. ..	2·42	93
Warwick	Birmingham, Edgbaston	2·01	119	,,	Aberdeen Observatory ..	1·47	72
Leics.	Thornton Reservoir ..	1·74	104	,,	Fyvie Castle	2·78	124
Lincs.	Boston, Skirbeck ..	1·55	106	*Moray*	Gordon Castle	·96	50
,,	Skegness, Marine Gdns.	·89	58	*Nairn*	Nairn, Achareidh ..	·64	40
Notts.	Mansfield, Carr Bank ..	2·46	127	*Inv's*	Loch Ness, Foyers ..	·26	8
Ches.	Bidston Observatory ..	·81	48	,,	Glenquoich	· 0	0
Lancs.	Manchester, Whit. Park	·41	21	,,	Ft. William, Teviot ..	·08	1
,,	Stonyhurst College ..	1·09	33	,,	Skye, Duntuilm	·24	5
,,	Blackpool	· 76	34	*R. & C.*	Ullapool	·50	12
Yorks.	Wakefield, Clarence Pk.	3·27	191	,,	Applecross Gardens ..	·14	3
,,	Hull, Pearson Park ..	2·07	185	,,	Achnashellach	·54	8
,,	Felixkirk, Mt. St. John..	2·81	166	,,	Stornoway Airfield ..	·44	10
,,	York Museum	1·91	127	*Suth.*	Lairg	1·65	53
,,	Scarborough	2·05	122	,,	Loch More, Achfary ..	1·74	26
,,	Middlesbrough	2·37	182	*Caith.*	Wick Airfield	1·43	63
Norl'd.	Newcastle, Leazes Pk. ..	2·64	173	*Shet.*	Lerwick Observatory ..	2·67	84
,,	Bellingham, High Green	1·36	54	*Ferm.*	Crom Castle	1·14	39
,,	Lilburn Tower Gdns. ..	3·83	192	*Armagh*	Armagh Observatory ..	·65	29
Cumb.	Geltsdale	1·50	49	*Down*	Seaforde	1·46	48
,,	Keswick, High Hill ..	1·26	26	*Antrim*	Aldergrove Airfield ..	3·14	46
,,	Ravenglass, The Grove..	·87	28	,,	Ballymena, Harryville ..	1·63	50
West.	Appleby, Castle Bank ..	1·17	40	*Lon.*	Garvagh, Moneydig ..	·70	22
Mon.	Abergavenny, Larchfield	2·46	77	,,	Londonderry, Creggan ..	1·11	35
Glam.	Ystalyfera, Wern Ho. ..	1·81	35	*Tyrone*	Omagh, Edenfel ..	1·16	39

* Brackets indicated that the figures are partly estimated

M.O. 482 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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P.I.C.A.O.

BY J. DURWARD, M.A.

What is P.I.C.A.O. ? Many meteorologists must have asked themselves this question from time to time. The word is actually the abbreviated title of the Provisional International Civil Aviation Organization and the object of this note is to set out the genesis of the organization, its structure, its method of working and its activities, particularly in the field of meteorology.

Historical.—In order to get a clear picture, it will be necessary to go into international civil aviation matters between world wars 1 and 2 in some detail.

At the beginning of world war 1, aviation was in its infancy. During that war there was a rapid development of military aviation and it was clear that there would be rapid developments in international civil aviation after the war. Accordingly, representatives of the Governments who met in Paris in 1919 to make the treaties of peace and the Covenant of the League of Nations prepared also a " Convention relating to the regulation of aerial navigation."

The Convention stated the principles which should govern international flying, in particular, that each state would accord freedom of innocent passage above its territory to the aircraft of other states. It laid down the rules with regard to certificates of airworthiness, and the procedure to be observed on flights from one country to another. It also instituted a permanent Commission, the " International Commission of Air Navigation " to carry out the duties specified in the Convention and to see that the technical annexes to the Convention were amended or extended as necessary.

These annexes specified the details of registration of aircraft, certificates of airworthiness, form of logbook, rules as to lights and signals, rules as to licences, including medical tests for the operating crews and meteorological tests for pilots and navigators, specification of international aeronautical maps and the information to be entered on them, arrangements for the collection and dissemination of meteorological information and finally Customs provisions. The Meteorological Annexe of 1919 was completely revised in 1925 and further revisions were made year by year as aviation developed. These latter were generally technical in character, such as the modification of codes to ensure co-ordination with the International Meteorological Organization (I.M.O.).

The International Commission instituted by the Convention of 1919 was a permanent Commission under the direction of the League of Nations. The representatives of the United States had participated in the preparation of the Convention and its annexes. In particular in the preparation of the Meteorological Annexe, Major Blair, formerly of the Mount Weather upper air station of the United States, took an active part. The inclusion of the " League of Nations " condition had the consequence that the United States did not become a party to the Convention nor participate in the work of the Commission. The Union of Soviet Socialist Republics was also not a party to the Convention. The headquarters of the permanent Commission were in Paris.

As the United States did not adhere to the Convention and was rapidly developing civil aviation in the western hemisphere they called a Convention of the American States at Havana in 1928, and drew up there the " Pan-American Convention " which was broadly confined to a statement of the principles which the states adhering to it would observe in dealing with one another on questions of civil aviation. This Pan-American Convention made no arrangements for specifying uniform standards or for periodical discussion of common problems through the agency of a permanent organization.

The International Commission for Air Navigation was very largely a legislative body and, during the period between the wars, regional conferences were held in Europe to deal with the practical procedures required internationally in the day-to-day operation of the civil aviation services between the countries concerned. The first of such Conferences was the A.F.B.—Anglo-Franco-Belge Conference—which began in 1921, and was gradually extended until it included representatives of practically all the countries of Europe.

In order to ensure proper co-ordination of the meteorological arrangements agreed upon at meetings of this and similar conferences, the International Meteorological Organization instituted at Warsaw in 1935 a special Commission for Aeronautical Meteorology. This commission was constituted of two representatives nominated by the Aviation Authority in each State to represent the Meteorological Service responsible in that State for meeting aviation requirements.

This Commission held meetings at Paris in 1937, at Berlin in 1939, and drew up a system of regulations to form the basis of a complete revision of the Meteorological Annexe of the Air Convention.

When it became apparent that world war 2 would be decided in favour of the Allies within measureable time and United States civil aviation, which had previously been largely confined to the western hemisphere, would be extended to and would indeed become prominent in other continents, it was necessary to consider what should be the regulations governing this and other international flying.

The seat of the International Commission for Air Navigation was in Paris and was inaccessible. As the League of Nations was to be replaced by another organization it was a natural corollary that the International Commission for Air Navigation should also be replaced by another organization. Accordingly a Conference was called at Chicago in November 1944 to consider the preparation of an agreement which could form the basis of a world-wide convention. As Spain was invited to the Conference, the U.S.S.R. refused to participate and is not a signatory to the agreement nor a partner in the organization which grew out of the Chicago Conference and will be described below.

The deliberations of the delegates of the 52 nations represented at Chicago resulted in the adoption of a number of resolutions and recommendations constituting the Final Act of the Conference. The Final Act also contained the texts of the Convention on International Civil Aviation, the International Air Transport Agreement, the International Air Services Transit Agreement and the Interim Agreement on International Civil Aviation.

Twelve draft sets of regulations dealing with technical subjects were adopted as draft Technical Annexes to be incorporated later in the Final Act. Annexe I entitled " Meteorological Protection of International Aeronautics " was based largely on the regulations drawn up by the Commission for Aeronautical Meteorology of the International Meteorological Organization and on the Meteorological Annexe to the 1919 Convention.

The Chicago Conference, recognizing that some time must necessarily elapse before the formalities of ratification of the Convention could be completed, provided through the Interim Agreement for the establishment of a provisional organization of a technical and advisory nature to function until a convention came into force. This is known as P.I.C.A.O. Its seat is in Montreal, and Dr. Alfred Roper, the Permanent Secretary of the International Commission for Air Navigation set up under the 1919 Convention, became the secretary of this new organization.

Organization of P.I.C.A.O.—The governing bodies of P.I.C.A.O. are the Interim Assembly and the Interim Council.

The Interim Assembly is composed of delegates from member states (the number of which in April 1946 was 43). The Assembly meets annually and is responsible *inter alia* for the financial agreements of the Organization, the examination of matters referred to it by the Council and the election of member states to be represented on the Council.

The Interim Council is the executive instrument of the Organization—it constitutes in fact an international parliament on civil aviation matters.

It is composed of not more than 21 member states elected by the Assembly for a period of two years. The Council provides for the establishment of such subsidiary working groups as may be considered desirable, among which there are a Committee on Air Transport, a Committee on Air Navigation and a Committee on the International Convention for Civil Aviation. The Council supervises and co-ordinates the work of these three technical committees, receives and considers their reports, transmits to each member State these reports together with the findings of the Council and makes recommendations to the member States individually or collectively.

The President of the Interim Council is Dr. Edward Warner and the Secretary General, Dr. Albert Roper. The latter is the chief executive officer of the Organization. It is his responsibility to select and appoint the staff and to direct the activities of the bureaux of the secretariat. There are at present three bureaux corresponding broadly to the three committees mentioned above. Each bureau is divided into sections, e.g. the Air-Navigation Bureau includes among others a meteorology section—the chief of which is Mr. F. Entwistle, formerly Assistant Director, Meteorological Office.

How P.I.C.A.O. works.—As stated above, one of the duties assigned to the Council was the establishment of the committees on Air Navigation, Air Transport and the International Convention on Civil Aviation. The first of these "studies, interprets and advises on standards and procedures with respect to communications systems and air-navigation aids and recommends the adoption of minimum requirements and standards". Due to the amount of detailed work that is involved in the drafting of these standards and recommended practices the work of the Air-Navigation and Air-Transport Committees has been assigned to various technical sub-committees (now called Divisions) including working groups on airfields, air routes and ground aids, rules of the air and air traffic control, meteorology, communications, search and rescue, maps and charts, etc. These Divisions or working groups of the main technical committees consist of representatives of member states and are not to be confused with the corresponding sections of the Secretariat, the staff of which are the administrative staff of P.I.C.A.O. The first meeting of the Meteorological Division was held in Montreal in November 1945; the second in October 1946.

To implement the standards and recommendations of the Technical Divisions P.I.C.A.O. launched a programme of regional meetings. These meetings consider the standards and their application to the requirements of particular regions. They also consider the value for civil use of the facilities developed during the war by the Allied Governments. Several such meetings have already been held at :—

Dublin, to consider the North Atlantic region	March, 1946
Paris, to consider the Europe-Mediterranean region ..	May, 1946
Washington, to consider the Caribbean region	August, 1946
Cairo, to consider the Middle-East region.. ..	September, 1946

The findings of these regional conferences are incorporated in a report to the Air-Navigation Committee which forwards its recommendations to the Interim Council, which in turn recommends to member States the implementation of the agreed procedures for a particular region.

Meteorology and P.I.C.A.O.—The function of the Meteorological Division of P.I.C.A.O. is to study, interpret and advise on standards and procedures with respect to the meteorological protection of international aeronautics. To date progress has been as follows :—

Annexe I of the Final Act of Chicago was based on Annexe G of the International Commission for Air Navigation (I.C.A.N.) and the "Règlement" developed by the International Commission for Aeronautical Meteorology (C.I.M.Aé.) at Berlin in 1939. There are 6 sections as follows :—

I. Classification of meteorological information.

II. General organization for meteorological protection of international aeronautics.

III. Networks of meteorological stations.

IV. Telecommunications requirements for the meteorological protection of international aeronautics.

V. Procedures for meteorological protection of flights on international air routes.

VI. Climatological information.

Consideration was given to the contents of Annexe I at the meeting of the Meteorological Division at Montreal in 1945 and the P.I.C.A.O. publication

" Recommendations for Standards, Practices and Procedures", February, 1946, sets the material out under 8 headings :—

1. Definitions.
2. General.
3. Meteorological service for international aeronautics.
4. Classification of meteorological information.
5. Meteorological observing stations and observations.
6. Aeronautical climatology.
7. Telecommunications for meteorology.
8. Procedures for meteorological service on international air routes.

As a result of the Dublin and Paris regional meetings a new publication entitled " Procedures for Air Navigation Services—Meteorology " has been produced. This is intended to apply meantime to the North Atlantic and Europe-Mediterranean regions only. It contains several ideas, however, which may be incorporated later in the Recommendations for Standards, Practices and Procedures after discussion by the Meteorological Division.

Procedures applicable to any one region are published in separate publications—" Supplementary Regional Procedures ". These contain details of meteorological offices, exchange of data, type of meteorological services on various air routes etc. The details of these publications are produced at the regional conferences.

Relationship between P.I.C.A.O. and the I.M.O.—It will be obvious from the scope of the " Recommendations for Standards, Practice and Procedures " that the meteorological activities of P.I.C.A.O. require careful co-ordination with those of the I.M.O. if duplication and consequent waste of effort are to be avoided.

The relationship between P.I.C.A.O. and I.M.O. was discussed at some length at the meeting of the C.I.M.Aé. in Paris in June, 1946. It was agreed by all that the joint efforts of the two organizations should have as their object :—

(*a*) Ensuring the best possible meteorological service for international aviation.

(*b*) Ensuring co-ordination between the meteorological arrangements for aviation and other international aviation arrangements and between the meteorological arrangements for aviation and other sections of the meteorological service.

(*c*) Avoiding confusion in meteorological instructions.

(*d*) Minimising duplication of work.

The efforts of the two organizations should in fact be directed towards the production of general regulations specifying the meteorological arrangements for international aviation which will be the same for all states whether members of the P.I.C.A.O. or not. The following procedure was finally recommended :—

(*a*) P.I.C.A.O. will invite the I.M.O. to send representatives to meetings of the P.I.C.A.O. Meteorological Division.

(*b*) The standards and practices developed at these meetings will be dealt with according to P.I.C.A.O. procedures with a view to their adoption as international standards and recommended practices for the member States of P.I.C.A.O.

(*c*) These standards and practices will also be dealt with according to I.M.O. procedures with a view to recommending them for application by all meteorological services represented in the I.M.O.

(*d*) The P.I.C.A.O. standards and recommended practices will contain a statement to the effect that they have been prepared in collaboration with the I.M.O.

(*e*) With regard to questions of general meteorology, P.I.C.A.O. will continue to accept the recommendations of the I.M.O.

As already mentioned the next meeting of the P.I.C.A.O. Meteorological Division was held in October 1946 and one of its chief duties was the consideration of the " Recommended Standards, Practices and Procedures ", which it is hoped will then be given a large measure of finality. It is too early yet to say how the procedure recommended for adoption in Paris will work in practice but with a good deal of give and take on both sides there is no reason why the two organizations should not work together for the common good.

AN AZIMUTHAL METHOD OF MEASURING CLOUD HEIGHT WITH A SEARCHLIGHT

BY E. G. BILHAM, B.SC., D.I.C.

The normal method of determining the height of the cloud base at night is to direct a vertical searchlight beam on to the cloud and measure the angle of elevation E of the spot of light from a point at a known horizontal distance L from the searchlight. The height h of the cloud base is then given by $h = L \tan E$. The length L of the base line is normally about 1,000 ft.

The precision of the method clearly depends upon the accuracy with which the angle of elevation E can be measured. In practice a limit to the observational accuracy is set by the fact that the spot of light is never sharply defined, because of the diffuse nature of the cloud surface. A reading to the nearest whole degree is therefore the best that can be expected.

Curve I in Fig. 1 shows the relationship between E and h for the case $L = 1{,}000$ ft. It will be seen that for heights exceeding 4,000 ft. the rate of increase of E with h is very small. The increase of elevation between $h = 5{,}000$ ft. and $h = 10{,}000$ ft. is in fact only 5·6 degrees. As E can only be measured to the nearest degree, cloud heights in this range can therefore only be measured to about the nearest 1,000 ft. The new code for height of cloud adopted by the International Meteorological Committee at Paris in 1946 provides for reporting observations to the nearest 300 ft. in this range. Provision is also made for reporting the height of medium cloud as well as low cloud. It is necessary therefore to consider means of improving upon the accuracy obtainable by the present method.

Some improvement in the dispersion of the angles of elevation can be obtained by increasing the length of the base line. Curve II in Fig. 1 shows the result of increasing L to 4,000 ft. Comparing curve II with curve I it will be seen that the slope is increased for heights above about 3,000 ft. and reduced for heights below that value. In other words we secure a gain in the precision of measurement for the greater heights at the cost of a loss in precision for the lower heights. There are, moreover, very serious objections to increasing the base line much beyond 1,000 ft. One objection is the deterioration in the visibility of the spot of light ; another is the increased cost of laying the electric cable between the searchlight and the point of observation.

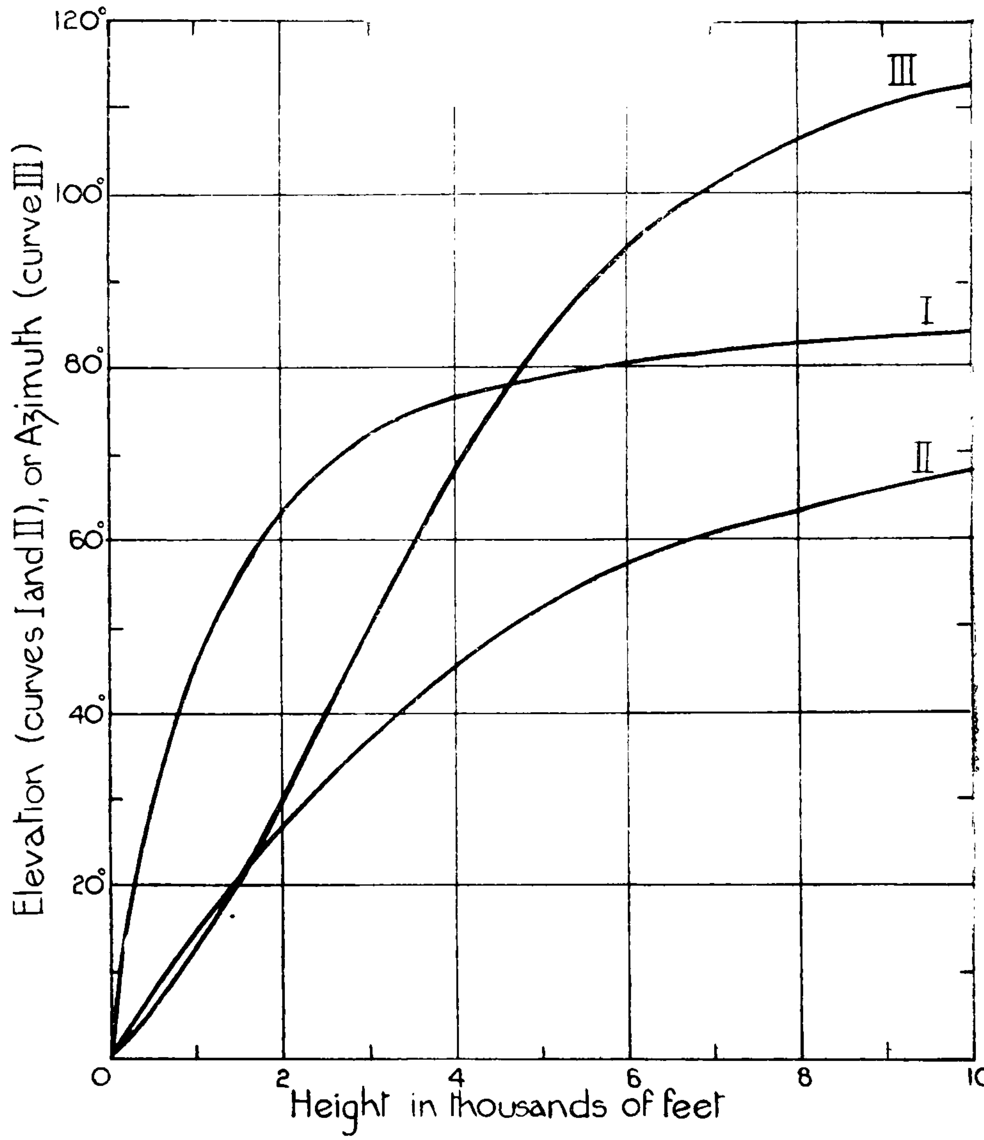


FIG. 1—RELATIONSHIP BETWEEN HEIGHT OF CLOUD BASE AND ELEVATION OR AZIMUTH

Curve I—for vertical beam with base line $L = 1{,}000$ ft.
Curve II—for vertical beam with base line $L = 4{,}000$ ft.
Curve III—for inclined beam with base line $L = 1{,}000$ ft.
$\alpha = 76°$, $\beta = 45°$

We are therefore led to consider whether any advantage can be obtained by using an inclined searchlight beam instead of a vertical beam.

If the searchlight beam is tilted out of the vertical in a direction transverse to the line of sight, both the azimuth and elevation of the spot of light will vary with the height of the cloud. It is possible therefore to make use of the variation of azimuth to determine the height of the cloud. If, in Fig. 2, α is the angle of inclination of the beam to the horizontal plane, β is the angle of orientation of the beam and θ is the azimuth of the spot of light (δ and θ both being measured from the direction of the base line as zero), it is readily shown that

$$h = L \tan \alpha . \sin \theta . \operatorname{cosec} (\beta + \theta) \qquad ..(1)$$

The simplest case is that in which β is 90°, that is to say, when the beam is tilted in a direction at right angles to the base line. Equation (1) then reduces to

$$h = L \tan \alpha . \ \tan \theta \qquad ..(2)$$

Comparing equation (2) with the equation $h = L \tan E$ we see that the result is the same as that which would be obtained by the elevation method with a base line of length $L \tan \alpha$. If, for example, we used a 1,000 ft. base line and inclined the beam at an angle $\tan^{-1} 4$, or 76°, to the horizontal, equation (2) would become $h = 4{,}000 \tan \theta$, and the curve of relationship between h and θ would be identical with curve II of Fig. 1. In other words we should secure such advantages as are possessed by curve II, with a base line only 1,000 ft. long.

Investigation shows however that we can do very much better if we make the angle of orientation β less than 90°. Curve III shows the relation between height and azimuth for the case $\alpha = 76°$, $\beta = 45°$, $L = 1{,}000$ ft. It will be seen that for heights exceeding 2,000 ft. curve III is substantially steeper than either curve I or curve II. In particular the change of θ between $h = 5{,}000$ ft. and $h = 10{,}000$ ft. is 31 as compared with a change of 5·6° in E (curve I) for the same difference of height, using the same length of base line.

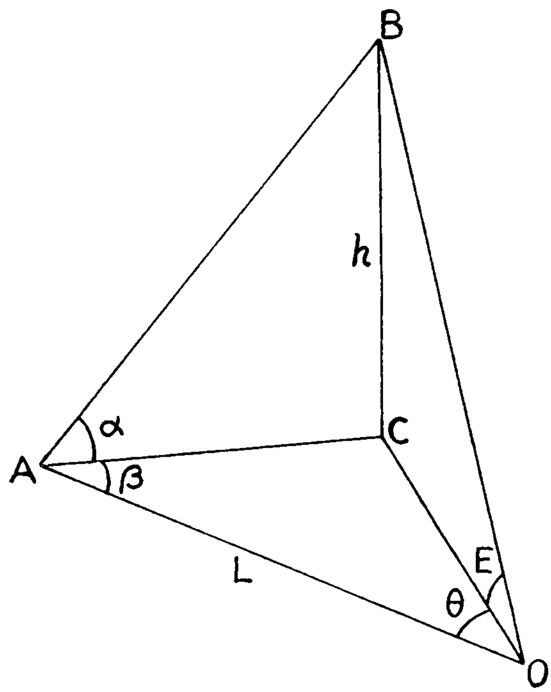


FIG. 2

A—Searchlight
B—Spot of light on cloud
C—Point on ground vertically below B
O—Point of observation
AB—Searchlight beam
AO—Base line of length L

It will be seen from Fig. 2 that

$$BO = (h^2 + CO^2)^{\frac{1}{2}}$$

$$CO = CA \frac{\sin \beta}{\sin \theta} = h . \ \cot \alpha . \ \sin \beta . \ \operatorname{cosec} \theta .$$

Thus $BO = h\,(1 + \cot^2 \alpha.\ \sin^2 \beta.\ \operatorname{cosec}^2 \theta)^{\frac{1}{2}}$.

For the case $\alpha = 76°$, $\beta = 45°$ this becomes

$$BO = h\,(1 + \tfrac{1}{32}.\ \operatorname{cosec}^2 \theta)^{\frac{1}{2}}.$$

For all values of h above about 1,000 ft. the square root of the quantity in brackets differs little from unity. Consequently the "slant range" of the spot of light is never very different from the height of the cloud.

For heights below about 2,000 ft. the rate of change of elevation with height is very rapid, and is in fact rather more rapid with a tilted beam orientated at 45° to the direction of the base line than with a vertical beam. It is concluded therefore that the best method of applying the searchlight method is to use the inclined beam system here described, making measurements of elevation for heights up to 2,000 ft., and of azimuth for greater heights.

For use when elevation is measured, we have from Fig. 2

$$h = L \sin \beta.\ \operatorname{cosec}(\beta + \theta).\ \tan E \qquad \cdot\cdot(3)$$

where E is the angle of elevation. From this expression, combined with equation (2) values of height in terms of angle of elevation can be calculated.

The value 76° for α was chosen for purposes of illustration, and it is not necessarily the best value to adopt for routine use. We have referred to the steepness of the curves in Fig. 1 in judging the advantages of different systems, but a better method of assessment is to study the variation of the quantity $100\,\triangle h/h$, where $\triangle h$ is the change of height represented by a change of one degree in the measured angle. The quantity $100\,\triangle h/h$ is thus the percentage error of height due to an error of one degree in the angle, and we should select the system for which this quantity is less than some agreed limit over the widest possible range of heights.

By differentiating equation (1) with respect to h and θ we obtain

$$\frac{\delta h}{h} = [\cot \theta - \cot(\beta + \theta)].\ \delta\theta \qquad \cdot\cdot(4)$$

The corresponding expression for a vertical beam is obtained by differentiating $h = L \tan E$, giving

$$\frac{\delta h}{h} = 2 \operatorname{cosec} 2E.\ \delta E \qquad \cdot(5)$$

In Fig. 3 curves have been plotted for values of α equal to 70°, 75° and 80° (L = 1,000 ft., β = 45°) and the curve for a vertical beam (L = 1,000 ft.) has also been drawn. If we adopt 5 per cent. as the limit of error to be tolerated we see that the required precision is only obtained with the vertical beam between 400 ft. and 2,500 ft. Using the azimuthal method the corresponding range is 900 ft. to 8,500 ft. for $\alpha = 70°$, 1,200 ft. to 11,500 ft. for $\alpha = 75°$, 1,900 ft. to 17,500 ft. for $\alpha = 80°$. As we propose to use the azimuthal method only for heights exceeding 2,000 ft., 80° is about the best value of α to select. There is no advantage in making α greater than 80° because we should get increasingly large errors at the lower end of the scale without any compensating advantages.

As regards β, the angle of orientation, we note that the whole range of azimuths for heights zero to infinity is comprised within the range $\theta = 0$ to $\theta = 180° - \beta$. This consideration indicates that β should be made small. We saw that there was a substantial gain in changing from $\beta = 90°$ to $\beta = 45°$, but a trial calculation for $\beta = 30°$ gave a less favourable curve than that for $\beta = 45°$, the value of $\Delta h/h$ tending to become large at the lower and upper ends of the scale. On the whole it would appear that 45° is about the optimum value.

It is recommended therefore that for the routine application of the method the values $\alpha = 80°$, $\beta = 45°$ should be standardised. The length of the base line should be as near as possible to 1,000 ft. It would be necessary of course to supply the observer with a simple form of theodolite, in which the telescope was replaced by a simple sighting rod or tube, instead of the present alidade. It would also be necessary to supply him with a table for converting readings of elevation and azimuth into heights and the corresponding code figures. A skeleton of such a table, calculated from the standard values, is given in Table I. At no point in the scale would it be necessary for the observer to measure both the elevation and the azimuth though it might be desirable for him to do so, as a check, for heights in the neighbourhood of 2,000 ft.

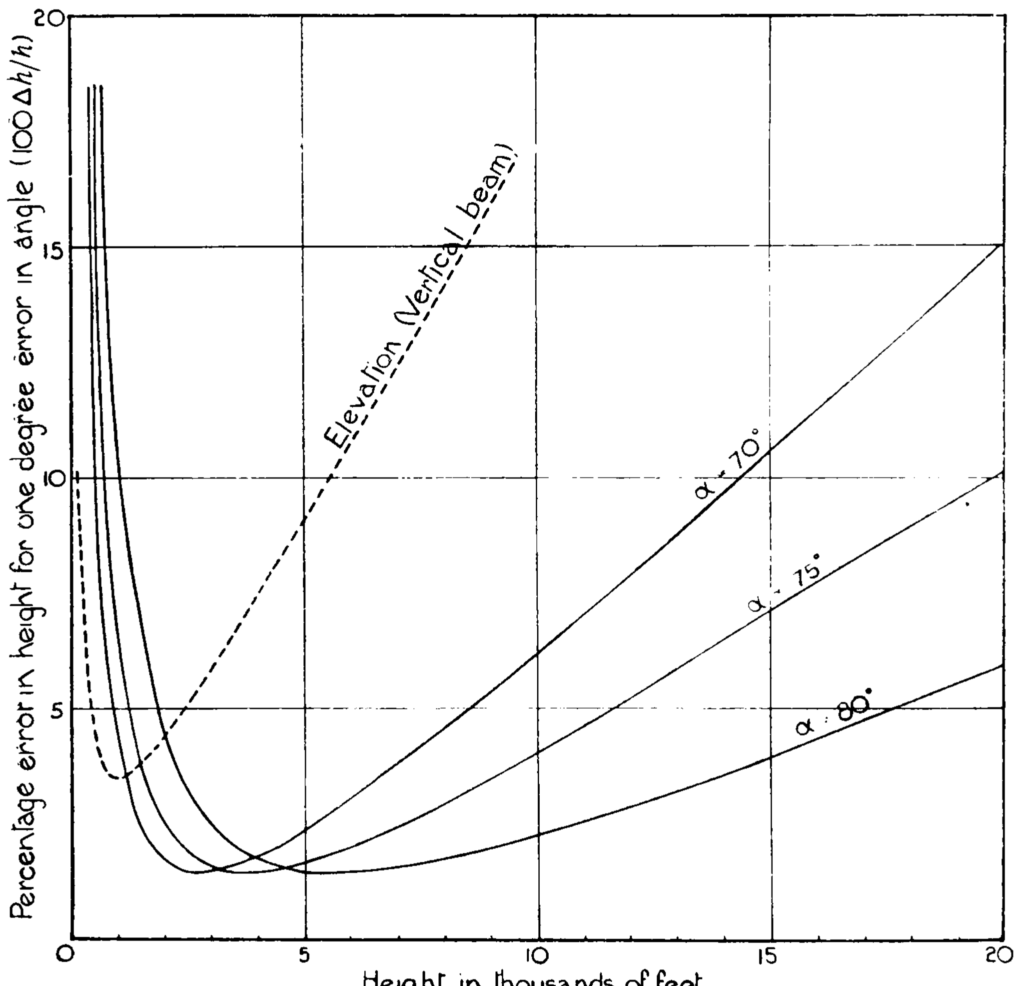


FIG. 3—PERCENTAGE CHANGE OF HEIGHT CORRESPONDING TO ONE DEGREE CHANGE OF AZIMUTH (FULL-LINE CURVES) OR ELEVATION (BROKEN-LINE CURVE)

In conclusion, it is perhaps necessary to point out that only the geometrical aspect has been considered in this note. It is not necessarily true to say that satisfactory measurements up to great heights could be obtained by taking an existing cloud searchlight and tilting it in the manner here recommended. It seems probable that a more powerful searchlight will be necessary to cover the extended range of heights now envisaged. Information on this and other points arising in the practical application of the method will be gained from trials which are planned to be carried out at Dunstable.

TABLE I

$L = 1{,}000$ ft. $\alpha = 80°$, $\beta = 45°$

Elevation	Height	Code figure †	Azimuth	Height	Code figure †
°	ft.		°	ft.	
5	85	01	20	2,140	21
10	170	02	25	2,550	25
15	260	03	30	2,935	29
20	350	03	35	3,300	33
25	425	04	40	3,660	37
30	540	05	45	4,015	40
35	650	07	50	4,360	44
40	760	08	55	4,715	47
45	890	09	60	5,085	51
50	1,040	10	65	5,470	55
55	1,220	12	70	5,880	56
60	1,460	15	75	6,330	56
65	1,750	17	80	6,820	57
70	2,150	21	85	7,380	57
			90	8,020	58
			95	8,780	59
			100	9,740	60
			105	10,960	61
			110	12,610	63
			115	15,030	65
			120	18,980	69

† Code 46* (h_1h_1)

Short base lines.—It will be seen from equation (1) that for given values of α, β and θ the height of the cloud base is directly proportional to L the length of the base line. Consequently, the operational table for any length of base line L can be obtained from the table calculated for $L = 1{,}000$ ft. by multiplying the heights by $L/1{,}000$.

At stations which are not on airfields there is often substantial difficulty in obtaining a base line as long as 1,000 ft., and it is therefore of interest to examine the effect of a large reduction in the value of L. The question is especially important in relation to the use of the method in a ship. We will therefore consider the extreme case of a base line of only 200 ft., which is rather less than the length possible in the corvettes to be used as British ocean weather stations. Table II has been calculated for this length of base line, and $\alpha = 80°$, $\beta = 45°$ as in Table I.

One result is immediately obvious, namely that for the lower heights the precision is very satisfactory. The new Paris code provides for a precision of 10 m. (33 ft.) for heights up to 300 m. (1,000 ft. approximately), and this standard is attained (assuming measurements of azimuth to the nearest whole degree) up to nearly 2,000 ft. The next step in the Paris scales, a precision of

100 m. (330 ft.), is attained up to nearly 5,000 ft., but beyond that point the precision falls off rather rapidly, though it is no worse than that obtained with a 1,000 ft. base line using the ordinary vertical beam method. The conclusion reached is therefore that the azimuthal method should give satisfactory readings of height of low cloud with a base line as short as 200 ft. Medium cloud height (above 8,000 ft.) could only be roughly determined. Difficulties associated with the rolling and pitching of the ship are of course not considered here.

TABLE II

$L = 200$ ft., $\alpha = 80°$, $\beta = 45°$

Azimnth	Height	Azimuth	Height
°	ft.	°	ft.
5	130	90	1,600
10	240	95	1,760
15	340	100	1,950
20	430	105	2,190
25	510	110	2,520
30	590	115	3,010
35	660	120	3,800
40	730	121	4,020
45	800	122	4,280
50	870	123	4,580
55	940	124	4,930
60	1,020	124	5,350
65	1,090	126	5,870
70	1,180	127	6,510
75	1,270	128	7,330
80	1,360	129	8,430
85	1,480	130	9,970

Heights are given to the nearest 10 ft.

THE FREQUENCY OF THUNDERSTORMS AT KEW OBSERVATORY

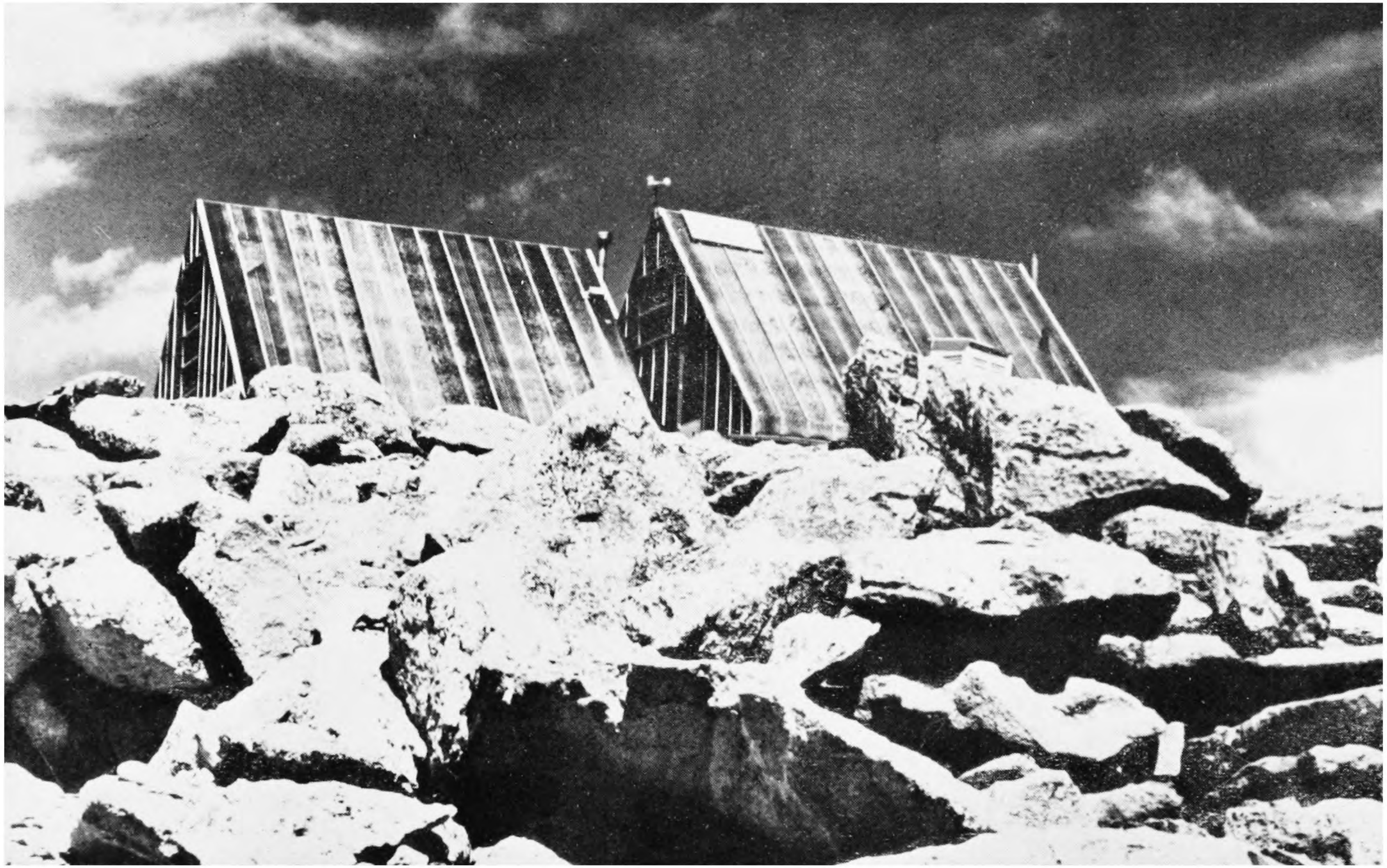
BY B. V. BISHOP

The periods reviewed in this paper are 1887–1945 for secular variation and 1910–35 for dirunal and annual variation. Throughout the period there has been little change in the routine of observations. No specific watch was kept for thunderstorms, but with thunder being an important meteorological phenomenon anyone who heard thunder would inform the observer, and an entry would be made in the register. Under such a system some occasions of thunder would be missed, but the number would be very small in working hours. After the observatory was closed in the evening the resident caretaker took observations at 10 p.m., and he also noted all occasions when he heard thunder through the night. From January, 1914, onwards there was a resident observer as well as a caretaker at the observatory. In this way the record is probably complete between 7 a.m. and 10 p.m. but outside these hours there

Photograph by S.A.A.F.

CLOUD DISPERSAL

This photograph was contributed by Dr. R. Frith, who was the Meteorological Officer at George, South Africa. It illustrates the dispersal of cloud over the lee side of a range of mountains. The cloud covers the sea and the 10-mile wide belt between sea and mountains. The height of the mountains shown varies from about 1,800 ft. in the foreground to 5,200 ft. (the highest peak).



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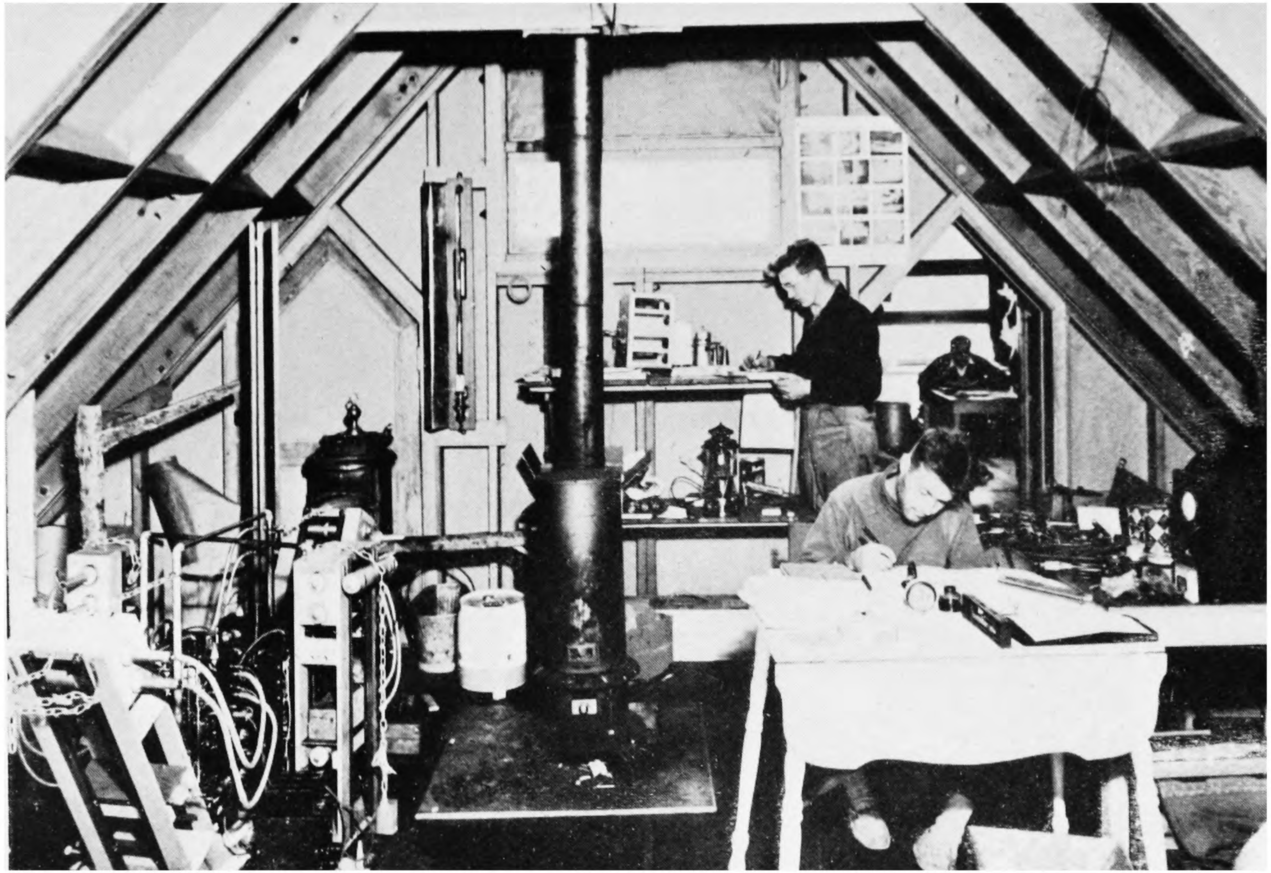
STORM LABORATORY ON THE PEAK OF MT. EVANS, COLORADO, U.S.A.

Living quarters are on the left, research laboratory on the right.

(see p. 115)



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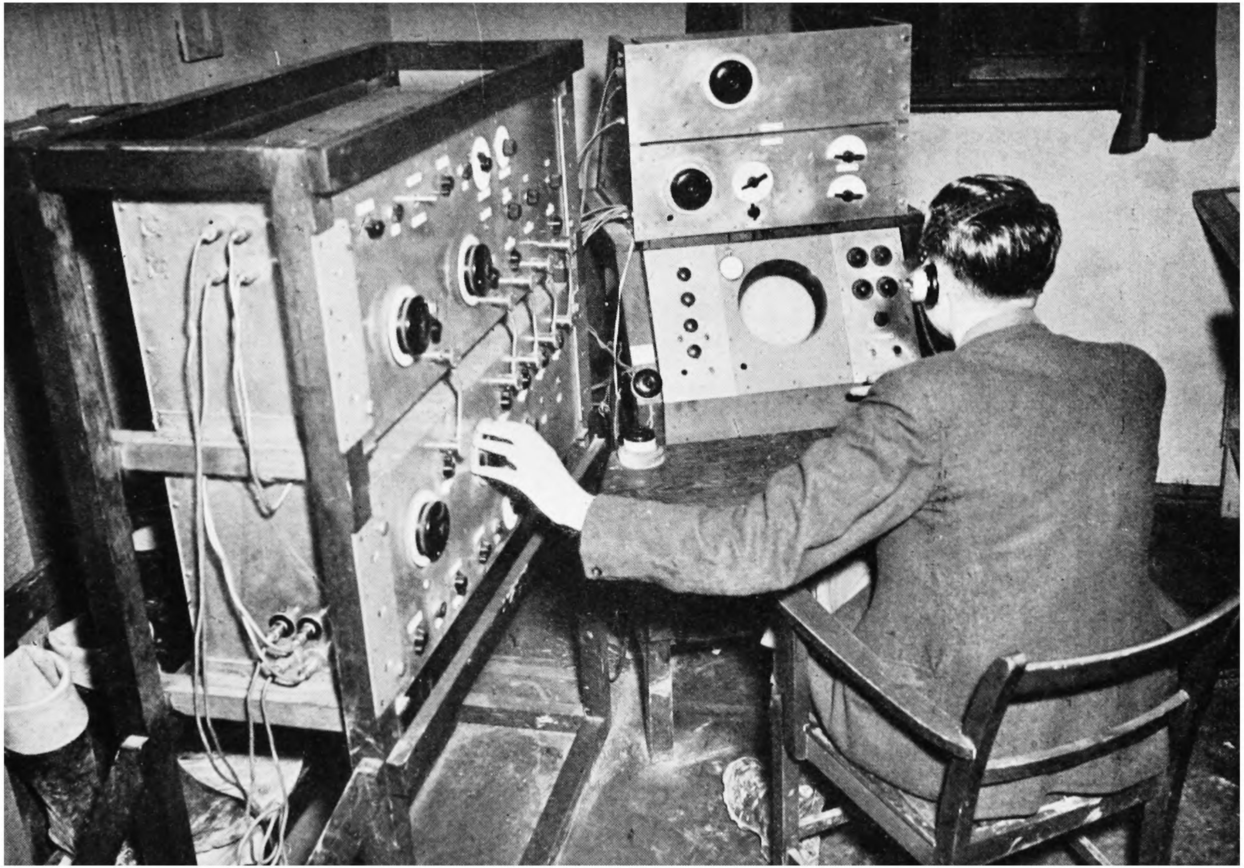
INTERIOR OF THE RESEARCH LABORATORY ON MT. EVANS

(see p. 115)



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" SFERIC " DIRECTION-FINDING APPARATUS AT DUNSTABLE

The bearings of distant-lightning flashes are read on the scale of degrees on the cathode-ray tube. (See article " Sferics " in *Meteorological Magazine*, April, 1947, p. 88) must have been cases of distant thunder which were not reported. In spite of this defect in the method of observing it is considered that the available data give a good representation of the frequency. The years prior to 1910 were not used in computing the diurnal variation owing to the rather large number of occasions when insufficient indication of time was given to enable allocation to definite 2-hour periods.

Secular Variation.—The total number of days on which thunder was heard in each year from 1877 to 1945 is given in Fig. 1. The variations are considerable, the extremes being 27 days in 1924 and 4 days in 1877. The mean is 14·9 days per annum.

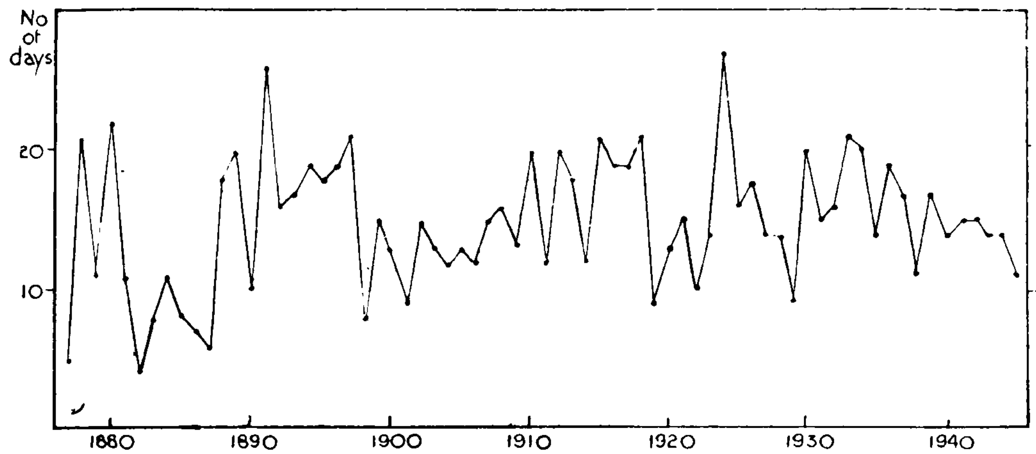

FIG. 1—NUMBER OF DEGS. OF THUNDER IN EACH YEAR AT KEW OBSERVATORY

Annual Variation.—Fig. 2 shows the annual variation at Kew. The figures show that on the average thunder occurred on one day in 11 in summer (May–August), one day in 43 in the equinoctial months (March, April, September and October) and one in 178 in winter (November–February). A comparison of the monthly totals of days with thunder (D) with the totals of two-hourly

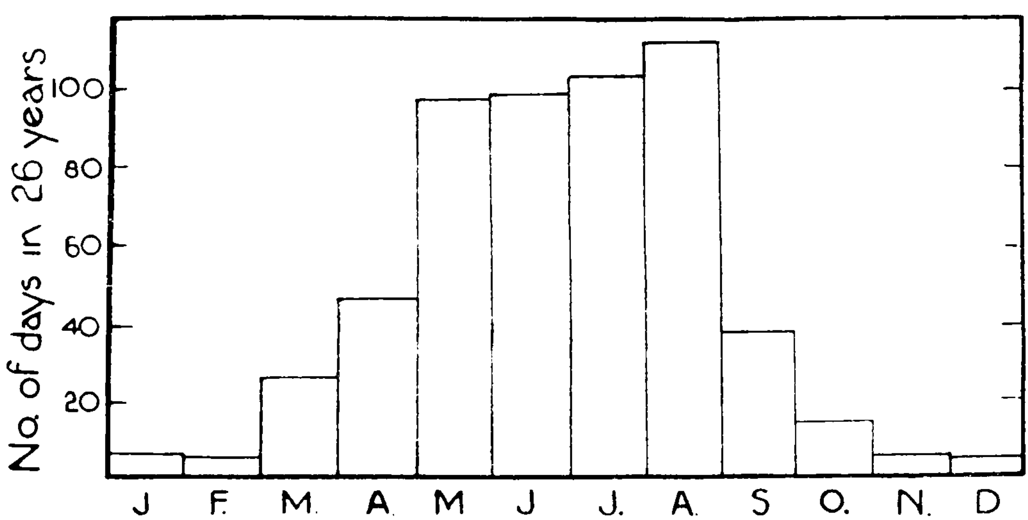

FIG. 2—ANNUAL VARIATION IN THE FREQUENCY OF THUNDER, KEW OBSERVATORY, 1910-35

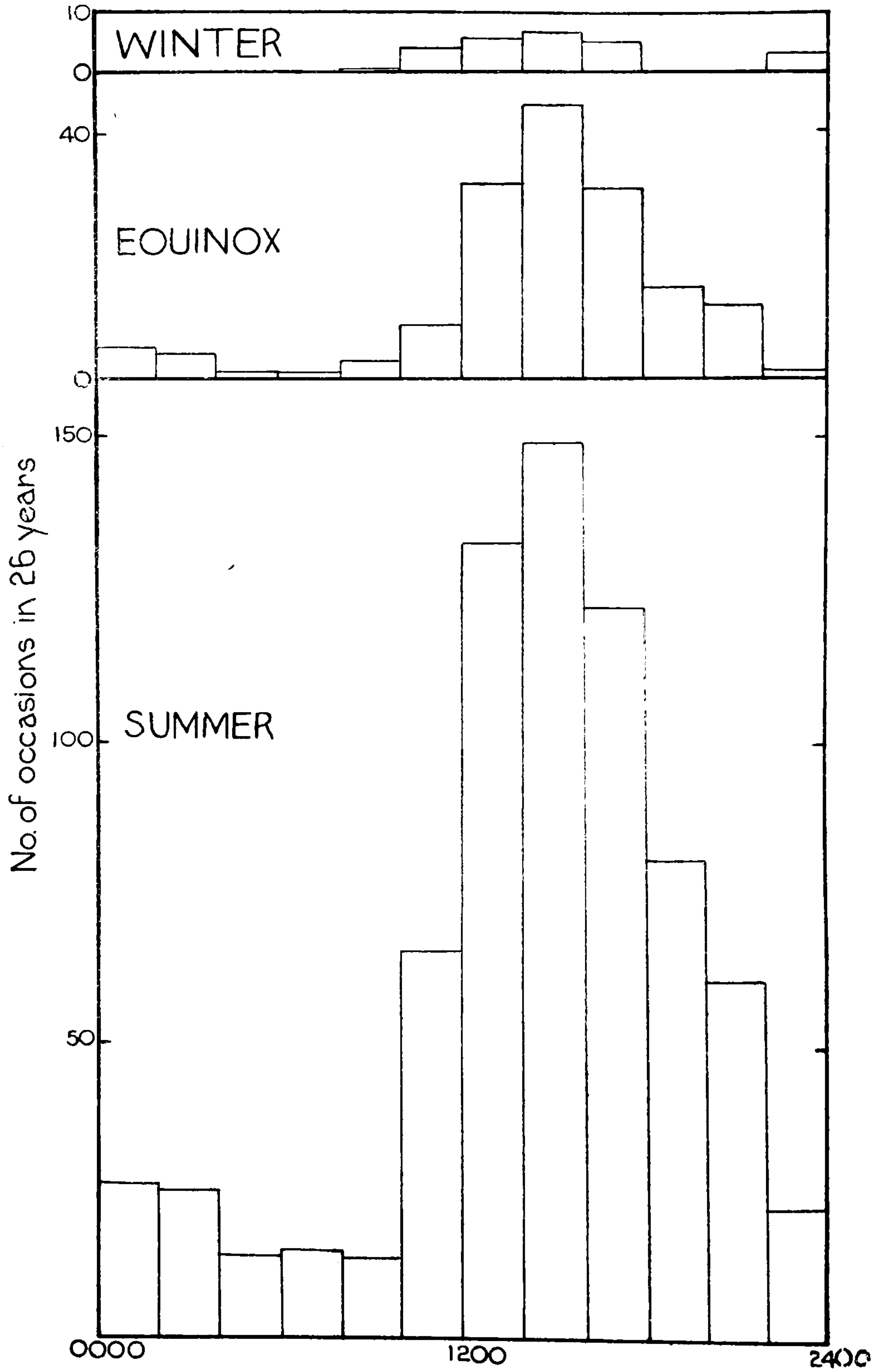

FIG. 3—DIURNAL VARIATION IN THE FREQUENCY OF THUNDER, KEW OBSERVATORY, 1910-35

periods with thunder (H) shows the ratio H/D to be 1·8 in summer, 1·3 in the equinox and 1·2 in winter. During the flat maximum in the summer which is the most notable feature of the annual variation, this ratio remains fairly constant with a maximum of 1·9 in June.

Diurnal Variation.—The number of occasions on which thunder was heard in each two-hourly interval is shown in Fig. 3 for the three seasons. The chief hours of thunderstorm activity are from noon to 6 p.m. in which 58 per cent. of the occasions occur, the rise to the maximum being more rapid than the fall. A comparison of the night hours with those of the early morning when people would normally be awake would seem to bear out the assumption that the effect of the incomplete observational routine mentioned earlier is small.

Comparable data for other parts of England do not seem to be available but valuable information regarding Scotland will be found in " The meteorology of Edinburgh " by R. C. Mossman (*Trans. roy. Soc. Edinburgh*, **38,** 1896, p. 681.), and " The diurnal periods of thunderstorms in Scotland " by A. Buchan (*J. Scot. met. Soc. Edinburgh*, **5,** 1880, p. 324).

METEOROLOGICAL OFFICE DISCUSSIONS

A discussion was held at the Meteorological Office on April 21, 1947, on " The present-day accuracy of meteorological instruments " which had formed the subject of the presidential address given by Mr. W. E. Knowles Middleton to the Canadian Branch of the Royal Meteorological Society in January 1946*. The discussion was opened by Dr. F. J. Scrase who gave a brief outline of the paper, the purpose of which was to consider the effect of the fine structure of the atmosphere on the possible and desirable precision to which meteorological instruments should be read and to enquire whether existing instruments provide such accuracy. This was followed by a short account of the random and systematic errors of mercury barometers and Dr. Scrase concluded by summarising the information now available about the accuracy of the Meteorological Office radio-sonde.

Among the points raised in the discussion which followed was a suggestion that an optimum lag coefficient might be worked out for a thermometer which would be large enough to smooth out the rapid fluctuations but not so large as to mask the longer-period changes of temperature. Another point was the need for a more definite statement of acuracy requirements for synoptic work and a suggestion that these requirements should depend on the frequency of the observations, both in space and time, and on the rate of change of a meteorological element with space and time. The errors of evaporation and rainfall measurements were discussed at some length and the forecaster's need for observations of rate of rainfall rather than amount was stressed. Other points discussed were the accuracy required and obtainable in sea-temperature observations and the value of gust measurements in comparing wind speed in different places.

It is hoped to publish a longer article on this subject shortly.

ERRATUM

January, 1947, page 14, line 24 ; *for* " wind velocities at 13 and 19 metres " *read* " wind velocities at 13 and 95 metres ".

* *Quart. J.R. met. Soc., London*, **72,** 1946, *p.* 32.

METEOROLOGICAL RESEARCH COMMITTEE

The 47th meeting of the Meteorological Research Committee was held on April 11, 1947. Consideration was given to the report of the Tropical-Meteorology Panel and the recommendations of that Panel regarding problems of tropical meteorology for inclusion in the research programme were adopted.

A paper on the diurnal variations of fog at sea was discussed.

ROYAL METEOROLOGICAL SOCIETY

The Symons Memorial Lecture at the Royal Meteorological Society on " Weather Forecasts ", by Mr. E. Gold was given in the rooms of the Society, 49, Cromwell Road, on April 16, 1947.

The lecturer began by referring to the criticism that weather forecasts were wrong nine times out of ten. He said that if there were any person present of that opinion he made him the following offer. On any occasion when the forecast for south-east England issued through the B.B.C. at 5.55 p.m. forecast precipitation in London and there was none before 6 p.m. next day, or made no mention of precipitation and there was precipitation in London before 6 p.m. next day, he (the lecturer) would give him a guinea, on condition that for any occasion when precipitation was forecast and precipitation fell in London before 6 p.m. the next day, or when precipitation was not forecast and no precipitation fell, the person would give him, the lecturer, half a guinea.

The lecturer said that the last previous occasion on which a Symons lecture had been specifically on the subject of weather forecasts was in 1919—a lecture given by Mr. R. G. K. Lempfert. He then mentioned two points made by W. H. Dines 45 years ago, as justifying the lecture and the weather forecaster's effort. The two points were that the man who refused to act because he could not be quite certain of the result of his action would rightly be held to be a lunatic, and that there was the same actual certainty yesterday about the weather of to-day as about the sun rising this morning.

In the preparation of a weather forecast there are broadly five stages—observation, collection, manipulation, analysis and prognosis.

In connexion with manipulation and analysis, a number of new " isopleths " have been introduced for which new specific names were proposed. They are:—

isobaths	=	lines of equal thickness of the layer of air between two isobaric surfaces.
hydrotherms	=	lines of equal temperature of the surface water of the sea.
brechotherms	=	lines of equal wet-bulb temperature (usually on an isobaric surface).

The lecturer also proposed to use " anemolapse " for the vertical change of wind by analogy with " hydrolapse " recently introduced to denote the vertical change of water vapour in the air.

With regard to observations, the instruments had been improved and new instruments added and more detail given in the eye observations. Weather was reported by 100 different specifications. The forms of high, medium and low cloud and the height of the base of cloud were reported separately. It was easier to get the height of the base of cloud by night than it was by day (by means of the cloud searchlight). The same applies to observation of visibility where constant light sources at two or three suitable distances are provided and an optical wedge meter used. But the most notable advance was in respect of upper air observations which were now provided for all levels in the troposphere and well into the stratosphere by the methods known as radio-sonde and radar-wind observations, irrespective of the weather conditions. He mentioned appreciatively the long series of observations—THUM reports—made in vertical ascents by aircraft of the Royal Air Force and the more recent meteorological reconnaissance flights of aircraft flying 500–600 miles out into the Atlantic in all weathers. The results of one such flight made in the middle of the night in mid winter into the centre of one of the deepest Atlantic depressions with a central pressure of 944 mb. were shown plotted on an isobaric chart.

The collection of reports, which are necessarily put into figure code, is made in the United Kingdom on a teleprinter network radiating from the Central Forecasting Office at Dunstable, and in the European exchange partly by teleprinter and partly by collective wireless transmissions from main centres—London, Paris, Rome, Moscow—while the general issue for world use of reports covering the whole European area is made from Rugby. Manipulation is partly by charts and partly by diagrams, notably the tephigram. On charts the information is plotted round the position of the station according to a model agreed upon internationally. The upper air information is used, individually on the tephigram and collectively for the construction of isobaths, contour lines, isotherms and brechotherms on isobaric surfaces, generally the 700, 500 and 300 mb. isobaric surfaces. More detailed information for the lower layers of the atmosphere to give the anemolapse and the hydrolapse is utilised especially in connexion with forecasting fog and the time of its formation.

The drawing of the charts and their analysis calls for a very high degree of technical and professional skill. It has not been found practicable to formulate a rigid rule for the determination of a front. One cannot say that if the discontinuity of temperature exceeds X° there is a front, and if it is less than X° there is no front. It is necessary for the forecaster to assess the combined significance of the temperature, the dew point, the wind, the weather and the sequence of events, as displayed on successive charts, in placing fronts, occlusions or frontal zones on the charts.

The application of the upper air information by tephigrams to forecasting thunderstorms was illustrated by examples and mention made of their use in forecasting maximum temperature. The use of isobaths and contour lines in forecasting the motion of depressions and other isobaric systems was illustrated by the sequence of charts for February 22 to 23, 1946. The very marked divergence in 24 hours of air at different levels, originally in the same vertical, near the middle of a fast moving wedge was also shown, the lower air moving north-east to between Shetland and Norway, while the upper air moved south-east to the Mediterranean.

The sequence of synoptic charts for March 14 to 16, 1947, illustrated a forecast of snow after a fine night, due to the return, as a warm front, of a cold front which had previously moved southwards into France, and the subsequent development of the small intense depression which caused the severe gales on Sunday, March 16.

A second series of charts—March 3 to 6—showed how a warm front which advanced from the south-west across France and the English Channel was retarded so much by ageostrophic winds due to the acceleration parallel to the front of the cold air in advance of it that the warm front instead of moving north into England was stopped at the south coast and reversed its motion to become a cold front moving south into France. The retardation of the front reached the exceptionally large value of 30 knots. It was practically equal to the geostrophic wind in the warm air at right angles to the front.

A third series of charts illustrated the conditions preceding D Day, June 6, 1944. On June 3, 1944, owing to the likelihood of strong winds and low cloud on June 5 the date of the operation was postponed until June 6, when the sting and the cloud in the north-westerly winds were taken out by their passage across the British Isles.

The lecture concluded with a reference to the possibility of devising rules which could be utilised in the construction of an electronic brain for the manipulation of the vast amount of material now at the disposal of the forecaster, and the further possibility that the forecaster's assistance might be required in determining the disposition of places of release of atomic energy designed to modify the weather to fit the prebaratic.

LETTERS TO THE EDITOR

Extremes of low temperature

Since February 9, 1945, when I sent in my letter on unauthenticated extremes of low temperature (published in the *Meteorological Magazine* for February, 1947), the erroneous value −23° F. has been published again in *The Scottish Geographical Magazine*, December, 1945, p. 76, and in *Weather*, January, 1947, p. 2.

Will you please, in your next issue, clear me of responsibility for omitting these from the letter as published, mentioning that the letter dates to February, 1945, and that it was not referred back to me before publishing it now.

W. A. HARWOOD

April 25, 1947.

(NOTE : The two omissions are regretted.—*Ed. M.M.*)

Value of local observations

On Friday, April 4, 1947, the value of a local observation in determining the synoptic situation over a much greater area was demonstrated to me with unusual force.

The 0600 G.M.T. chart on that day showed Scotland in ridge conditions, with an anticyclone centred well to the north and the depression G, 981 mb., at 53° N. 35° W. The depression was well occluded and not expected to develop.

During the forenoon the proverbial local farmer drew my attention, in conversation, to the exceptionally long and heavy cross swell which was running then, with the addition that he expected severe gales over the week-end.

The 1200 G.M.T. chart gave the first indication of the secondary H which deepened considerably, and did in fact produce severe gales in western Scotland. A pilot reported an accurate wind of 62 m.p.h. at 500 ft. over a good part of the Isles that day.

Undoubtedly, the observation of swell enabled the forecast of gales to be made earlier and with greater confidence than would have been the case had the synoptic chart been my only source of information. The observation was the first indication of the vigorous developments which were taking place many hundreds of miles away.

JOHN PATRICK

Stornoway Airport, April 21, 1947.

NOTES AND NEWS

The highest laboratory

The world's highest fixed laboratory, especially constructed and suited to the study of great storms and cosmic rays is on the top of Mt. Evans, Colorado, U.S.A., where scientific research workers are equipped with highly specialized instruments.

Research work started as early as 1931 when A. H. Compton did his first field work on cosmic rays at Summit Lake, which is 1,000 ft. below the peak of Mt. Evans. The wind velocity on the peak is excessively high and at night was often sufficient to scatter the equipment and level the tents which the early workers and their associates used for laboratories and living quarters. There are frequent sleet and heavy snowstorms, and fire hazard prevented the safe heating of tents, consequently the indoor temperatures often fell to 30° F. or lower. Both apparatus and workers were without protection from electric storms.

Yet the scientists have carried on their investigations in meteorology and astrophysics as well as in cosmic rays, and highly valuable data have been secured by the United States Weather Bureau. Later it became evident that if any prolonged or accurate observations were to be made, adequate shelter must be provided for workers and scientific apparatus, and the Massachusetts Institute of Technology collaborated with the University of Denver in erecting the present building.

Mt. Evans, 65 miles from the city of Denver, with an altitude of 14,260 ft., is the highest easily accessible mountain peak in the United States, and there is living accommodation on the highway leading to the laboratory, at altitudes of 6,000, 8,000 and 10,600 ft. above sea level.

The laboratory (see photographs in the centre of this issue) consists of two rooms, one room being used as the actual place for research work and the other one for living quarters. To withstand the high wind velocity, a roof truss construction is employed, which made the omission of side walls possible. Cables fastened to the floor joists run through the pillars of the foundation to heavy metal plates cemented into the rock. The building is thermally insulated and is provided with " no draft " ventilation.

For protection against lightning, the end walls and roof are covered with thin copper shingles and the lower side of the floor is covered with metal hardware cloth. The copper and hardware cloth are joined and earthed, thus converting the whole building into a Faraday cage. The copper of the roof is not thick enough to interfere materially with cosmic ray measurements.

M. LORANT

Retirement of Mr. Corless

Mr. Richard Corless, Assistant Director, retired on April 11, 1947, after service in the Meteorological Office since October 1, 1907. At Sidney Sussex College, Cambridge, he had been 16th Wrangler in 1906 and had taken a First Class in Natural Sciences Tripos Part I in 1907. He was amongst the first of the new category of highly trained scientific officers introduced by the late Sir Napier (then Dr.) Shaw and he joined in the capacity of " Assistant to the Director ", becoming " Clerk of Publications " in 1910 and " Secretary to the Director " in 1913.

This was the era of a new movement in British meteorology. In this period Lempfert, Gold, Whipple and Dobson had also joined the Office : Cave, W. H. Dines and his sons and Harwood were at work on new means of exploring the upper air, Simpson was in the Antarctic, G. I. Taylor on the *Scotia* ; Schuster, Rayleigh, Aitken, C. T. R. Wilson and others were interested and keen in meteorological controversy. New methods of analysis of weather charts were being tried. The scientific interests of Corless, in common with Shaw and Lempfert, lay, in those days, in the tracing of air trajectories, the structure of line squalls and associated phenomena and the structure of depressions. Shaw's thoughts were running on the ideal of a new establishment for investigation and research on the upper air and the physical processes of weather.

The outbreak of war in 1914 brought most of the scientific work, then in hand or planned, to an end and probably changed the whole course of British meteorology. Mr. Corless and others had new responsibilities thrust upon them and his appointment in October, 1916, as Superintendent of Instruments came at a time when the meteorological sections of the British military forces were clamouring for more equipment, particularly for the balloons, theodolites and slide rules required to measure the upper winds needed by airmen and gunners in the various theatres of war. Mr. Corless then as on other occasions " delivered the goods ".

From 1923, Mr. Corless was successively head of the Climatology, British Rainfall and Forecast Branches of the Meteorological Office. In January 1939, he was promoted Assistant Director, having under his charge the Branches concerned with Marine Meteorology, Climatology, Instruments and Personnel.

At the outbreak of war in 1939, it was foreseen that questions of administration and personnel were going to increase enormously in number and complexity and Mr. Corless's directorate responsibilities were thereafter concentrated upon these. Under his charge the numbers of meteorological staff, civilian and military, rose from some 900 in 1939 to about 6,800 at the peak of the war and again, with demobilization and releases, had fallen to about 2,600 at the time of his retirement in April, 1947.

At a meeting held at Victory House on March 31, Sir Nelson Johnson, in making a presentation on behalf of the staff to Mr. Corless, referred to the esteem in which he was held by his colleagues, on account of his high ability and intellectual probity. Mr. Corless in a witty reply gave some interesting information on the inner history of the old Office in Victoria Street and some of the developments of later years.

Mr. Corless was awarded the C.B.E. in 1946.

Retirement of Mr. A. T. Bench

Mr. A. T. Bench retired from the Meteorological Office on March 12, having reached the age of 65, after more than 49 years' service. He entered the Office, which was then housed at 63, Victoria St., on January 24, 1898, as a Boy Clerk in the "Autographic Records" Branch, and became a Probationer in the Forecast Division in September, 1902. He remained in forecasting for 18 years, and his memories of this period include the final telegraphic message from Victoria Street on the removal to South Kensington in 1910, and the receipt of the first wireless message from the Eiffel Tower in 1913. In October, 1920, he was transferred as Principal Assistant to the British Rainfall Organization on its incorporation in the Meteorological Office, passing to the new General Climatology Branch on its formation in 1925. He remained in that Branch until his retirement. His interest in the Meteorological Office was not purely "work" however; he took an interest in staff activities as Treasurer of the M.O. Staff Council and in other ways. On the outbreak of the war in 1939 he moved with the Climatology Branch to Stonehouse, Glos., and was very helpful to the new assistants who came from all parts of the country, while Mrs. Bench was of the greatest possible help in the Canteen arrangements.

REVIEWS

"*Here is the weather forecast,*" by E. G. Bilham. Size 7½ in. × 5 in. pp. 220. *Illus.* London, Golden Galley Press Ltd. 1947. Price 10*s.* 6*d.* net.

Mr. Bilham's new book lifts the veil, for the layman, on the varieties of activities and processes which converge to the result introduced to millions of listeners by the familiar words of the title. Few readers nowadays will be surprised that there is no mystery to reveal; the story is one of specialised organization and the application of scientific principles. The answer to the question "How is it done?" is given here in and around an intricate, well-knit and most interesting survey of the workings of a modern national weather-forecasting service—that of the Meteorological Office, Air Ministry. The interest of this survey, with backward glances at the state of meteorological knowledge and facilities in the early days of the Meteorological Office less than 100 years ago, is enhanced by the increased demands made upon and met by the service, and the additions to the technical resources at disposal during recent years.

Full prominence is given to the numerous aspects of accurate and adequate meteorological observations—whether made from land stations, ships at sea or aircraft—from the more simple instrumental and non-instrumental variety to the use of modern electrical techniques for measuring with almost laboratory precision (comparatively speaking) the wind, pressure, temperature and humidity to great heights. The chapters, describing how radio and radar procedures, still in the relative infancy of their meteorological association, have been adapted to precise meteorological upper air measurements, to the location of thunderstorms and to the detection of thick cloud and rain, will be of wide appeal. These observational matters, the highly efficient telecommunications organization which exists for the rapid collection of the coded reports by the Central Forecasting Office and their distribution to the forecasting centres which meet the requirements of the Services and Civil Aviation, and the arrangements for the international exchange of weather reports form the prelude and support to the sections dealing with, the synoptic charts—surface and upper air—on which the vast amount of observational data is plotted for assimilation and consideration by the forecaster, the behaviour of weather systems, the types of weather and the fundamental notions of forecasting. These latter sections necessarily involve sufficient simple exposition of atmospheric processes. This is skilfully achieved. The final chapter discusses the accuracy attained in forecasts, the prospects for the future and some of the methods which have been tried, with unreliable results, with the object of forecasting for periods of several days or weeks.

The authoritative, attractively written treatment of the whole subject, generously illustrated and provided with a glossary of meteorological terms, is just what is required by the general reader. It gives him an excellent insight into the ways of the weather, will promote a better understanding of the daily weather situation and lead to a better appreciation and extended use of the forecasts available to all by radio and the press and of special forecasts obtainable on application ; also, not improbably, to a demand for the use in forecasts of more technical expressions if thereby the meaning can be better conveyed, or for the publication of adequate weather charts in the press as soon as the paper situation permits. The book merits a wide circulation. It would be a first-rate choice for reading by the upper forms of senior schools. The very few errors of fact noticed are due mainly to changes which have occurred since the author's part was completed (the preface is dated May, 1946) and are unimportant.

H. W. L. ABSALOM

Discussion of upper air data obtained from aeroplane meteorological flights over Peshawar and Quetta during the years 1927–36, by R. Ananthakrishnan. Memoirs of the India Meteorological Department. Vol. XXIX, Part 2, 4to., 12 in. × 9¼ in., pp. 55–88 *Illus.* Delhi, Manager of Publications. 1942. Price Rs. 2–12 or 4*s.* 6*d.*

In this paper, data derived from observations made by the above flights are presented in commendable detail, together with a comparison with soundings over Agra and Poona, and should provide anyone investigating upper air conditions over that part of India with any data required. Values of the various elements at 0·5 Km. or 1 Km. intervals up to 5 Km. above sea level were obtained from the original observations by graphical interpolation ; it would have been helpful if the height column in each table had been headed " Height above M.S.L.", surface readings being given in brackets. Unfortunately it is not stated (either here or in the earlier scientific note to which reference is made) whether readings have been corrected for aircraft speed or not, so there is a possibility that readings as given are about 1·3° F. too high (assuming the same correction, −1·2° F., as was subsequently applied to the Duxford Meteorological Flight readings taken over the same period).

Interesting features shown by the tables are discussed in the accompanying text but there is little that calls for special comment ; the wet-bulb potential temperature tables are particularly interesting, revealing, as they do, the change in stability of the lower layers of the atmosphere throughout the year. The relation between this instability and the incidence of thunderstorms is commented upon. This relation would only be expected to hold however if conditions at higher levels follow the same trend.

A brief note on ice accretion together with a table of freezing levels concludes the paper. As these levels are generally above 3 Km., icing is not likely to interfere with normal flying in these regions.

D. DEWAR

RAINFALL OF MARCH, 1947

Great Britain and Northern Ireland

Co.	Station	In.	Per cent of Av.	Co.	Station	In.	Per cent of Av.
London	Camden Square ..	5·75	314	*Glam.*	Cardiff, Penylan ..	7·57	240
Kent	Folkestone, Cherry Gdns.	5·94	273	*Pemb.*	St. Ann's Head ..	8·94	329
,,	Edenb'dg, Falconhurst	6·06	244	*Card.*	Aberystwyth	5·53	202
Sussex	Compton, Compton Ho.	8·20	296	*Radnor*	Bir. W. W., Tyrmynydd	13·39	249
,,	Worthing, Beach Ho. Pk.	6·63	345	*Mont.*	Lake Vyrnwy	11·30	248
Hants.	Ventnor, Roy. Nat. Hos.	6·90	337	*Mer.*	Blaenau Festiniog ..	14·15	164
,,	Fordingb'dg, Oaklands	7·68	330	*Carn.*	Llandudno	5·38	265
,,	Sherborne St. John ..	6·49	290	*Angl.*	Llanerchymedd ..	6·03	203
Herts.	Royston, Therfield Rec.	5·19	284	*I. Man.*	Douglas, Boro' Cem. ..	7·84	265
Bucks.	Slough, Upton ..	5·41	308	*Wigtown*	Pt. William, Monreith	6·72	236
Oxford	Oxford, Radcliffe ..	5·23	317	*Dumf.*	Dumfries, Crichton R.I.	6·64	222
N'hant	Wellingboro', Swanspool	4·74	265	,,	Eskdalemuir Obsy ..	5·70	116
Essex	Shoeburyness	3·62	268	*Roxb.*	Kelso, Floors	4·06	208
Suffolk	Campsea Ashe, High Ho.	3·51	209	*Peebs.*	Stobo Castle	3·35	116
,,	Lowestoft Sec. School	4·00	248	*Berwick*	Marchmont House ..	5·74	217
,,	Bury St. Ed., Westley H.	4·05	214	*E. Loth.*	North Berwick Res. ..	4·53	241
Norfolk	Sandringham Ho. Gdns.	4·71	248	*Midl'n.*	Edinburgh, Blackfd. H.	3·75	190
Wilts.	Bishops Cannings ..	5·29	235	*Lanark*	Hamilton W. W., T'nhill	3·25	116
Dorset	Creech Grange.. ..	8.43	299	*Ayr*	Colmonell, Knockdolian	5·02	149
,,	Beaminster, East St. ..	8·75	299	,,	Glen Afton, Ayr San.	4·53	108
Devon	Teignmouth, Den Gdns.	8·69	334	*Bute*	Rothesay, Ardencraig ..	3·99	111
,,	Cullompton	6·51	238	*Argyll*	Loch Sunart, G'dale ..	3.00	54
,,	Barnstaple, N. Dev. Ath.	5·78	221	,,	Poltalloch	2·72	71
,,	Okehampton, Uplands	9·42	227	,,	Inveraray Castle ..	2·78	44
Cornwall	Bude, School House ..	6·12	251	,,	Islay, Eallabus ..	4·18	109
,,	Penzance, Morrab Gdns.	9·43	295	,,	Tiree	1·98	59
,,	St. Austell, Trevarna ..	11·65	339	*Kinross*	Loch Leven Sluice ..	4·76	159
,,	Scilly, Tresco Abbey ..	7·71	294	*Fife*	Leuchars Airfield ..	3·48	178
Glos.	Cirencester	7·19	311	*Perth*	Loch Dhu	6·50	99
Salop	Church Stretton ..	6·87	285	,,	Crieff, Strathearn Hyd.	6·54	204
,,	Cheswardine Hall ..	5·05	238	,,	Blair Castle Gardens ..	2·12	81
Staffs.	Leek, Wall Grange P.S.	5·12	188	*Angus*	Montrose, Sunnyside ..	3·07	148
Worcs.	Malvern, Free Library	6·40	330	*Aberd.*	Balmoral Castle Gdns.	3·32	116
Warwick	Birmingham, Edgbaston	6·79	355	,,	Aberdeen Observatory	4·00	166
Leics.	Thornton Reservoir ..	4·71	256	,,	Fyvie Castle	3·54	130
Lincs.	Boston, Skirbeck ..	4·30	276	*Moray*	Gordon Castle	2·60	112
,,	Skegness, Marine Gdns.	4·49	270	*Nairn*	Nairn, Achareidh ..	1·17	64
Notts.	Mansfield, Carr Bank ..	4·94	236	*Inv's*	Loch Ness, Foyers ..	1·73	54
Ches.	Bidston Observatory ..	4·33	228	,,	Glenquoich	2·40	25
Lancs,	Manchester, Whit. Park	4·99	221	,,	Fort William, Teviot ..	1·92	29
,,	Stonyhurst College ..	6·31	171	,,	Skye, Duntuilm ..	2·25	51
,,	Blackpool	5·13	216	*R. & C.*	Ullapool	1·00	27
Yorks.	Wakefield, Clarence Pk.	5·15	286	,,	Applecross Gardens ..	2·05	44
,,	Hull, Pearson Park ..	4·28	235	,,	Achnashellach	1·61	24
,,	Felixkirk, Mt. St. John	4·37	222	,,	Stornoway Airfield ..	1·35	35
,,	York Museum	4·43	264	*Suth.*	Lairg	2·65	85
,,	Scarborough	3·15	175	,,	Loch More, Achfary ..	2·44	50
,,	Middlesbrough.. ..	2·73	174	*Caith.*	Wick Airfield	1·73	76
,,	Baldersdale, Hury Res.	4·47	144	*Shet.*	Lerwick Observatory ..	1·94	61
Norl'd	Newcastle, Leazes Pk.	3·49	169	*Ferm.*	Crom Castle	4·34	140
,,	Bellingham, High Green	4·26	145	*Armagh*	Armagh Observatory ..	..	..
,,	Lilburn, Tower Gdns. ..	6·85	259	*Down*	Seaforde	7·34	251
Cumb.	Geltsdale	4·41	158	*Antrim*	Aldergrove Airfield ..	4·01	160
,,	Keswick, High Hill ..	5·48	122	,,	Ballymena, Harryville..	4·38	139
,,	Ravenglass, The Grove	5·99	194	*Lon.*	Garvagh, Moneydig ..	4·01	129
Mon.	Abergavenny, Larchfield	9·60	316	,,	Londonderry, Creggan	3·96	125
Glam.	Ystalyfera, Wern Ho. ..	12·99	242	*Tyrone*	Omagh, Edenfel ..	4·71	150

WEATHER OF MARCH, 1947

Conditions remained very unsettled throughout the month over the whole of the Atlantic between 40° and 60° N., the British Isles, Baltic Sea, Norwegian waters and Barents Sea, with the continual passage of complex depressions unrelieved by a single interval of more settled weather. Pressure fell below 968 mb. on the 3rd north-east of the Azores and on the 19th in mid Atlantic, below 964 mb. in mid Atlantic on the 21st and in two centres west of the British Isles on the 22nd, and below 968 mb. in mid Atlantic on the 25th and in the St. Lawrence on the 26th. By contrast pressure was high throughout the month over Greenland and Iceland, except for a deep depression over Iceland on the 24th to 25th. Pressure was also generally high south-east of Bermuda and south-west of Spain, but no really stable persistent anticyclone developed.

The average pressure distribution for the month shows an intense high (exceeding 1022 mb.) over Greenland and a rather indefinite high area (above 1016 mb.) from the Great Lakes to the West Indies, while the whole Atlantic from Newfoundland to the British Isles was occupied by a trough of low pressure (below 1000 mb. in the eastern half) which turned north-east over Scandinavia. Pressure was more than 10 mb. above normal between Iceland and Greenland and 13 mb. below normal from Ireland to the Azores.

The severely cold weather of February with considerable snow at times, persisted until the 16th, when milder conditions with rain spread north-east with a gradual thaw. There was heavy snow over much of England and Wales with severe drifting on the 4th and 5th, while in east, central and south Scotland heavy snowstorms occurred during the second week. On both occasions road and rail traffic were seriously interrupted. On the 16th a small depression developed off our south-west coasts and moved north-east across England deepening as it moved. A widespread and severe gale occurred with gusts of 98 m.p.h. at Mildenhall and 93 m.p.h. at Cardington. The second half of the month was fairly mild in the south but it continued unsettled with frequent rain. The melting of the deep snow combined with frequent rainfall produced floods on an unprecedented scale large areas in England being inundated. It was the wettest March in England and Wales since records began to be available in 1868.

As far as can be estimated at present it was the coldest March over Scotland as a whole since before 1901. The lowest temperature recorded in the screen was −6° F. at Peebles, Braemar and Houghall on the 4th and at Braemar on the 8th.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days diff. from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
February, 1947							
England and Wales	52	−5	−10·2	82	−3	47	11
Scotland	43	−2	− 8·4	43	−5	114	25
Northern Ireland ..	42	12	− 8·5	39	−7	75	17
March, 1947							
England and Wales	60	−6	− 3·5	255	+7	61	19
Scotland	59	−6	− 5·7	105	−1	95	28
Northern Ireland ..	59	(5)	− 4·5	156	+1	73	22

M.O. 482 AIR MINISTRY

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INSTRUMENTS BRANCH OF THE METEOROLOGICAL OFFICE IN WAR AND PEACE

BY F. J. SCRASE, M.A., SC.D., F.INST.P.,
SUPERINTENDENT OF INSTRUMENTS

Historical.—A separate branch " to deal with questions arising out of the supply of meteorological instruments for the Navy, observers on ships of the mercantile marine, Colonial Governments, and the stations of various kinds " was first constituted in the Meteorological Office, at 63 Victoria Street, at the beginning of October, 1905. Before then such questions had been dealt with by the Marine Branch. Mr. R. G. K. Lempfert took charge of the new Branch temporarily until Mr. E. Gold was specially appointed as the Superintendent of Instruments in 1906. In those days the work of the Branch appears to have been almost entirely concerned with questions of supply and the *First Report of the Meteorological Committee*, for 1905–6, when the staff of the whole Meteorological Office only numbered 52, records that the total expenditure on instruments in that financial year was £2,229 and that 1,018 instruments were supplied to the Navy, 747 to merchant ships and 58 to land stations. Ocean weather observations were considered of primary importance in those days.

On October 1, 1910, the Instruments Branch moved with the rest of the Headquarters of the Office to the new building at Exhibition Road, South Kensington. The staff of the Branch then numbered seven, the total staff of the Office being 74. In the 1914–8 war the annual expenditure on instruments rose steeply to a peak of £28,199, and more attention began to be paid to the development of new instruments, notably an aircraft psychrometer. Soon after 1919, when the Meteorological Office became attached to the Air Ministry, the Instruments Branch was designated by the short title M.O.4. After a relatively uneventful period of 15 years the Branch expanded very slowly to meet the increased demands arising in the rearmament period before the last war. In August, 1939, the staff of the Branch numbered 25 but facilities for research and development were still very limited.

The Branch remained at South Kensington until November, 1939, when it was evacuated to Wycliffe College, Stonehouse, Gloucestershire. Here, during the war years, a large expansion took place to meet the needs of the Services and in 1941 it was found necessary to re-organise the Branch into two sections, the functions of which will be described later. At the end of August, 1945, M.O.4 moved to its present location at Headstone Drive, Harrow, where it occupies a floor space of 27,500 sq. ft. in the main building and in outbuildings. The main building is shared with the Marine and Climatological Branches.

General organization.—The work of the Instruments Branch at the present time divides into two main parts. One covers the scientific and technical aspects and the other the supply aspects of meteorological equipment. Each of these divisions is subdivided into smaller sections, the organization of which is shown in outline in the diagram on p. 123.

At the present time the staff of the Branch consists of 6 scientific and (temporary) technical officers, 19 experimental officers, 57 assistants and clerical staff and 46 of industrial grade. Many changes of staff have taken place in the past year and the peace-time establishment and organization is under review. The work of the Branch has changed appreciably since the end of the war, mainly because of the transfer of radio-sonde work from Kew, but it has not diminished appreciably, for the heavy war-time demands of the Services have given place to almost equally heavy peace-time demands for civil aviation and agriculture, for new projects such as the ocean weather ships and radar-wind stations, and from Dominions, Colonial and Foreign services.

Technical Section.—The work of this section includes research, design and development of instruments, test and inspection and the calibration of instruments for upper air measurements, including radio-sondes.

Research and development is, in the main, concentrated on the instrumental problems included in the research programme of the Meteorological Research Committee. These problems, which at present number about 50 and are of varying degrees of priority, fall into five main categories :—

(*a*) meteorological instruments for surface observations on land,

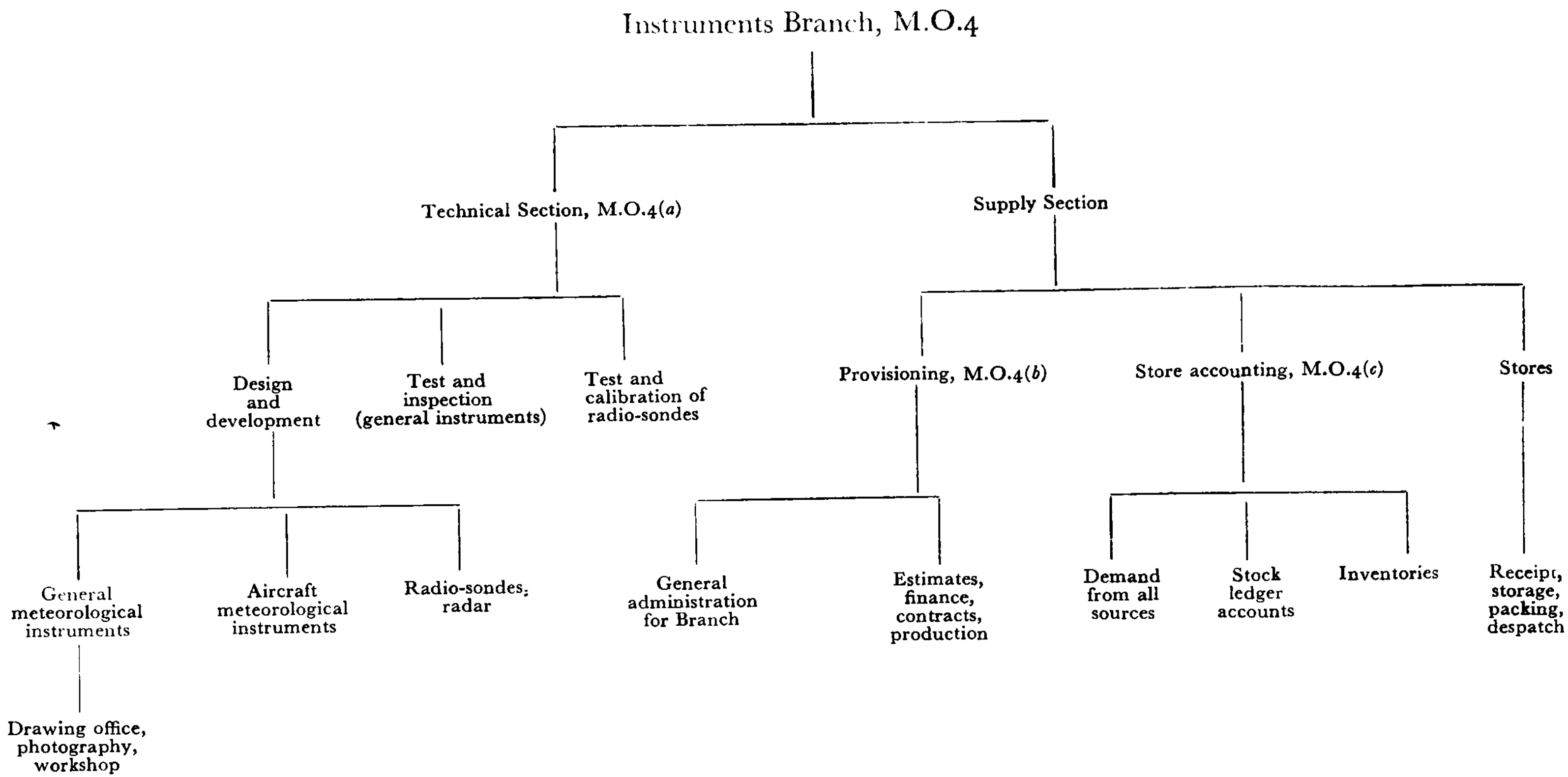
(*b*) marine meteorological instruments,

(*c*) meteorological instruments for use on aircraft,

(*d*) radio-sondes and associated ground equipment,

(*e*) the application of radar and electronic techniques.

In the problems involving radio applications the Branch is guided by a technical advisory panel of representatives from the Directorate of Communications Development, Ministry of Supply, the National Physical Laboratory and the Meteorological Office. The resources of Government scientific establishments such as the Telecommunications Research Establishment, the Royal Aircraft Establishment, the Research and Development Establishment at Cardington and the National Physical Laboratory are drawn upon to an appreciable extent, and in the development of meteorological instruments for aircraft there is close collaboration with the Meteorological Research Flight and with Professor G. M. B. Dobson of Oxford University. In many cases the development of an instrument is carried right through the research and experimental stages to the making of the prototype production model in the Branch ; in fact, when certain new instruments were required urgently during the war the Branch undertook small-scale production as well. In other cases,



GENERAL ORGANIZATION OF THE INSTRUMENTS BRANCH.

after the experimental stages have been passed, a contract is placed with a suitable firm of instrument makers for the development of the prototype production model. Close contact is kept with the manufacturers and much assistance is received from and given to them.

The experimental laboratories of the Branch are on the first floor of the main building at Harrow. Specimens of current designs of instruments are displayed in one of the larger rooms and another room is used for exhibiting instruments of historic interest. Instruments recently developed, or at present in process of development, include the radio-sonde Mk.II, the chronometric radio-sonde, the photo-electric frost-point hygrometer, the aircraft electrical-resistance psychrometer, the photo-electric visibility meter, the day-time cloud searchlight and the Bibby chronograph for recording wind velocity or rainfall. It is hoped that articles describing the development of some of these instruments will appear later. The equipment of the section includes two small wind tunnels (one of the open jet type) both of which were made in the Branch to the design of one of the officers. A lattice tower on the roof of the main building is used for service trials of anemometers. In a well equipped workshop in one of the outbuildings, the construction of prototype instruments and experimental apparatus is supervised by the senior instrument maker. There is also a drawing office and a photographic studio and darkroom. The preparation of detailed specifications and of instructions for installing, operating and maintaining equipment is an important part of the work. A disadvantage of the Harrow premises is the lack of outside space for field trials of equipment ; this has been overcome temporarily by the use of some ground at Northolt airport.

Testing and inspection is undertaken in several large rooms specially fitted up for this purpose on the ground floor at Harrow. All new instruments received from the makers and all instruments returned from outstations are examined and tested and, where necessary, calibrated. The equipment in the main test room, a view of which is reproduced in the photograph facing p. 128, includes decompression and low-temperature chambers, a humidity control cabinet and standard barometers. A smaller room contains apparatus for calibration of resistance thermometers and indicators of electrical psychrometers and frost-point hygrometers. Another room houses the balloon inflation and inspection apparatus. The assessment of damage of instruments returned from operational use is undertaken and arrangements made for their repair either in the Branch workshop or at the makers. The total number of instruments tested in 1946, excluding radio-sondes and balloons, was just under 50,000. This may be compared with the average number of 5,000 for the years about 1930 and with the peak figure of 61,360 in 1944. The total number of pilot and sounding balloons which passed through the test section during the war reached 2¼ millions.

Calibration of radio-sondes, which during the war was undertaken at Kew Observatory and Larkhill, was recently transferred to the Instruments Branch. The section dealing with this work is housed in a number of rooms on the ground floor. To deal with the rapidly increasing requirements of radio-sonde stations some new plant, including two Kelvinator "stratosphere" low-temperature and low-pressure cabinets, each capable of taking 64 temperature or pressure elements at a time, has been installed. In addition, several Kew-pattern calibration vessels and humidity chambers are in operation. A photograph of the plant is reproduced in the photograph facing p. 129. At present all new radio-sondes are individually tested and calibrated in the Branch (over a pressure range of 1050 to 50 mb. and a temperature range of +80° to —90° F.) but it is hoped that the bulk of this work will eventually be undertaken by the makers. In April, 1947, the total number of radio-sondes calibrated was 1,150 and the output is increasing every month. In addition to the work on new instruments, recovered radio-sondes are examined and, if not too badly damaged, are reconditioned and re-calibrated.

Supply Section.—The work of maintaining supplies of equipment for Meteorological Office stations and for other services is divided into three sections covering the provision, issue and accounting, and storage of the equipment. The first two sections are mostly concerned with work of an administrative or clerical nature and are accommodated in offices on the second floor at Harrow. The stores section is housed in outbuildings, and in the basement of the main building.

Provisioning.—Estimates of Meteorological Office requirements of equipment and similar requirements for other services, including Dominions and Foreign Governments, are co-ordinated and arrangements are made to obtain the stocks to meet them. These arrangements include the placing of contracts and local purchase orders with manufacturers and the raising of requisitions on Government stores. In this work close liaison has to be maintained with the Finance, Contracts and Equipment Branches of the Air Ministry. It is also the responsibility of the section to see that the production of new equipment progresses satisfactorily. In 1946 the total expenditure on new instruments amounted to £170,600 ; the peak figure was reached in 1944 when the total was £225,134. In peace time some of the expenditure is offset by the sale of equipment to other services. The provisioning section also prepares the " Priced vocabulary of meteorological stores " and assists in the preparation of the authorised establishments of equipment for the various types of Meteorological Office stations.

Before leaving the subject of provisioning it is appropriate to acknowledge here the special efforts made during the war, often in the face of extreme difficulties, by the many firms of instrument makers in the supply of the large number of instruments ordered by the Office. It would need a very long list to name them all but it may be of interest to mention that eight firms have supplied the Office during both the world wars. Moreover, two very old established firms have, in fact, been supplying the Meteorological Office throughout the 92 years of its existence.

Store accounting.—This subsection deals with all incoming demands for equipment and arranges for its issue and accounting. As already indicated, demands are received not only from the stations of the Meteorological Office but also from other Government Departments, from Dominions and Foreign Services and from voluntary observers. A large proportion of issues, therefore, have to be arranged on repayment terms. The number of individual demands dealt with in 1946 was 8,968 which may be compared with the peak figure of 12,470 reached in 1944. The store accounting system consists essentially of the keeping of stock ledgers under various headings and, in the case of equipment issued to Meteorological Office stations and to observing ships of the Merchant Navy, in the maintenance and annual checking of inventories.

Stores.—The whole of the basement at Harrow is used for storage and there are also storerooms in the outbuildings and the sub-basement. The total storage space at present available amounts to about 13,500 sq. ft. but additional outbuildings are planned to accommodate stores which at present have to be left out in the open. Store-keeping is facilitated by a tally-card system in which current stocks are recorded. A stores reference number is allocated to each different item ; the total number of stores now handled is about 3,000, about one half of which is radio-sonde and radar equipment and the other half general meteorological stores. A very large proportion of the stores despatched is for destinations outside the British Isles. Recent large consignments, for example, have included shipments to Australia, New Zealand, Argentina, the Netherlands, Belgium, and east Africa, as well as to the widely scattered overseas stations of the Meteorological Office.

From what has been said it will be seen that the work of the Instruments Branch covers a wide field. New work which is now being undertaken includes arranging for the provision of much of the equipment of the ocean weather ships not only meteorological equipment but a dozen or more other categories of stores ranging from engine-room stores to food and water. In fact, of the many odd things which the Branch is now called upon to supply, " shoes and ships and sealing-wax " are almost literally typical examples. In concluding this account the writer wishes to acknowledge the devoted service of the members of the staff of the Instruments Branch, both temporary and permanent, during and since the war. At times, especially in the period leading up to D-day, very heavy demands at short notice strained the organization to the utmost, but the extra efforts which were required from all grades of the staff on such occasions were made without demur.

UNSOLVED PROBLEM OF CLIMATIC CHANGE

BY C. E. P. BROOKS, D.SC.

Part I. Facts

Twenty years ago I discussed* about fifty different theories of the causes of geological changes of climate, not one of which was completely satisfactory. Since then many more have been added to the list, including the notable contribution of Sir George Simpson, and it seems desirable to review the position.

Table I gives a brief summary of the geological eras, their approximate dates and their prevailing climate in middle and high latitudes. This table shows that conditions similar to or more severe than the present, with large ice sheets and frozen poles, are highly exceptional ; for at least nine tenths of geological time the earth seems to have enjoyed a mild equable climate up to high latitudes. The climate during these genial periods was not uniform ; as Sir George Simpson has emphasised, on a globe warmed by the sun thermal zones must always have existed, but the contrast between equator and poles does seem to have been much less than now, and for much of the time ice was probably unknown anywhere on the earth's surface. This halcyon existence has been rudely interrupted at least four times by the spreading out of great ice sheets. One of the first occurred in the Algonkian, near the beginning of the record, and effectually disposes of all theories of a cooling earth. The second

* BROOKS, C. E. P. ; Climate through the ages. London, 1926.

occurred about 500 million years ago, more or less simultaneously in North America, India, South Africa and Australia. The third, the famous Permo-Carboniferous ice age, was very remarkable ; ice spread out over enormous areas in South America, South Africa, India and Australia, reaching the sea in all these countries. Ice sheets extended on either side of the equator, while further north a rich vegetation flourished, reaching high latitudes in Spitsbergen. This ice age has been one of the great problems of geology since its discovery. The latest ice age, the Quaternary or Pleistocene, began less than a million years ago, and as late as 20,000 B.C. ice still covered great areas of Europe and North America ; this ice age may not yet be over.

TABLE I.—GEOLOGICAL SUCCESSION AND CLIMATE

Age of base	Formation	Climate of middle latitudes
million years		
1	Quaternary (Pleistocene)	Glacial
70	Tertiary	Mainly subtropical or temperate, becoming cold at close
110	Cretaceous	Cooler
140	Jurassic	Tropical to subtropical
190	Triassic	
225	Permian	Cool, glacial at first
270	Carboniferous	Temperate at first, becoming glacial at close in southern hemisphere
310	Devonian	Tropical to subtropical
340	Silurian	Cooler
390	Ordovician	Tropical to subtropical
500	Cambrian	Glacial at first, becoming subtropical
—	Pre-Cambrian	At least one period of glaciation

The last two ice ages at least were not single events ; the ice advanced and retreated several times. It is convenient to distinguish these main advances as " glaciations ", while the whole period is known as an " ice age ". In the Quaternary era there were four main glaciations in Europe and probably also in North America ; these have been given local names in different areas but the Alpine classification designed by Penck and Bruckner—Gunz, Mindel, Riss, Wurm—has become a sort of world-wide standard. The interglacials between Gunz and Mindel and between Riss and Wurm were relatively short, but the Mindel-Riss interglacial was much longer, of the order of 250,000 years. Outside Europe and North America, the number of known glaciations varies, but in many regions only two have been found. This may be because remains of earlier extensions of the ice have been destroyed or buried, but there is some evidence that in parts of the world, especially in the tropics, glaciation did not begin until relatively late, possibly the Riss. This lag may be due to the time required for the general cooling of the oceans by mel -water from the earlier ice sheets. It is becoming evident that the latest glaciation, the Wurm of the

Alps and the Wisconsin of North America, was practically contemporaneous over the whole world.

Each of these glaciations was again divided into two or three maxima separated by interstadial periods, and the concluding stages of the Wurm have been marked by a series of rapid retreats, separated by stand-stills or re-advances. The Wurm was formerly considered to have ended in Europe about 6,900 B.C., when the ice sheet, having retreated to Scandinavia, split into two small remnants, but a more natural view, climatically, is that favoured by Dr. H. Godwin and now generally accepted, which places the end of the late glacial period at about 8,500 B.C., when the tundra of north-western Europe was extensively replaced by forest. During the retreat of the ice in Europe, temperatures rose rapidly, and by about 7,000 B.C. were several degrees above the present. This was the " climatic optimum ", when Europe was rapidly occupied by a mixed forest of oak, alder, lime and other warmth-loving trees, which extended their limits far to the north and far up the mountains. This warm period continued until nearly 2,000 B.C., after which the climate deteriorated.

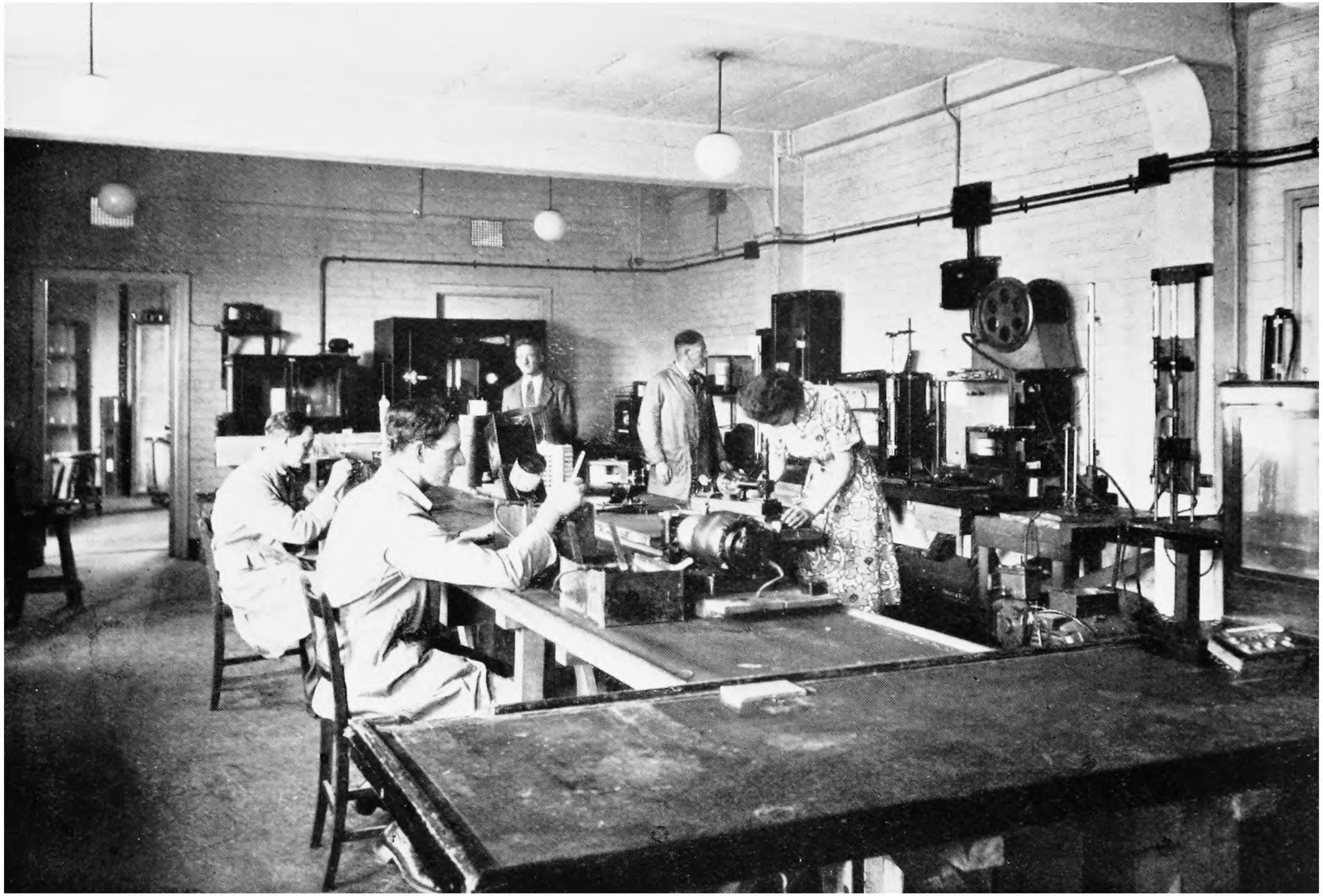
There is no evidence that the Quaternary ice age is over ; in fact the occurrence and ending of the climatic optimum rather point in the opposite direction. It is possible that we are already in the second half of an inter-glacial, and that some thousands of years hence ice will again spread out from Norway and the Alps.

More remarkable than the temperature oscillations of the post-glacial period are the variations of rainfall. The late-glacial and early post-glacial were dry in Europe, in spite of the increasing warmth ; these are known as the pre-Boreal and Boreal periods. The next stage, the Atlantic period, was warm and rainy, and many of the peat-bogs began to form at this time. Peat mosses even grew in Spitsbergen, which is now too cold. Then followed an interval, the sub-Boreal, which has been the subject of much discussion. Peat-bogs dried up, lakes dwindled and there is every appearance of severe drought, but it is not clear whether this was a prolonged dry period lasting more than a thousand years, a short intense drought of a few centuries followed by conditions resembling the present, or merely an alternation of groups of dry and wet years. In fact, its existence has been denied altogether, but this extreme view is rare and hardly tenable. During the last part of the sub-Boreal conditions cannot have differed much from the present. This stage ended somewhere about 500 B.C. with the rather sudden onset of a cold wet period, the sub-Atlantic, which was severe at first but gradually passed into present-day conditions.

In other parts of the world the post-glacial sequence is not so well known as in Europe, though the climatic optimum appears to have been widespread if not world-wide, and there is evidence of a dry period in North America which may by roughly contemporaneous with the sub-Boreal. We must however spare a few words for climatic variations in the equatorial regions, which play a large part in several modern theories of climatic change.

The combined efforts of a number of investigators, especially L. S. B. Leakey, E. J. Wayland and E. Nilsson, have shown that in east Africa there have been a series of fluctuations of lake levels on a gigantic scale. The general succession is shown in Table II. Nilsson has further shown that the expansions of the lakes ran parallel with the expansions of the mountain glaciers, and it is probable

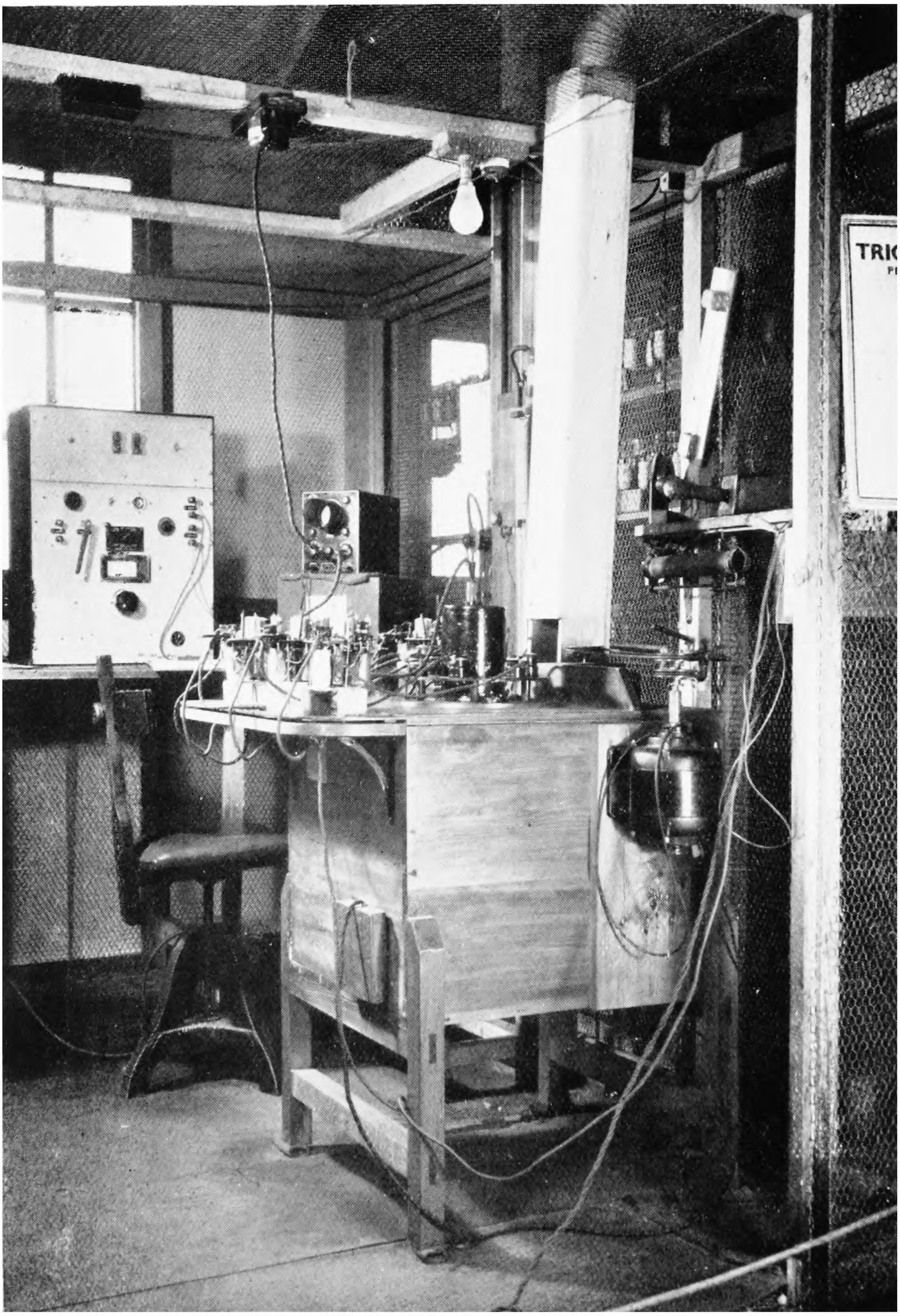
[To face page 128



MAIN TEST ROOM AT HARROW

(see p. 124)

To face page 129]



KEW-PATTERN RADIO-SONDE CALIBRATING PLANT

(see p. 125)

though not yet certain that the " pluvial " periods correspond roughly with the glaciations of higher latitudes.

TABLE II—SUCCESSION OF PLUVIAL AND INTERPLUVIAL PERIODS IN EQUATORIAL AFRICA

Post-pluvial	Alternating wet and dry phases Lakes dried up Wet phase Lakes dried up
Last pluvial (Gamblian)	Three extensions of lakes, separated by two periods of shrinkage
Interpluvial	Kamasia lake dried completely
Kamasian	Extremely wet and cold
Interpluvial ?	
Possibly an earlier pluvial	

A roughly similar succession has been found over most of the eastern half of Africa from the Nile Valley to Rhodesia.

When we turn to the historical period, in spite of a large amount of research, it is hard to come to definite conclusions about the reality and extent of climatic changes. Without going into details however, the results seem to be :—

(1) A generally dry period about A.D. 500 to 700 in Europe and much of Asia.

(2) A period of increased rainfall over most of Europe and Asia from about A.D. 1100 to 1250. This period was also very stormy in the North Sea, and there are indications that it was cold and stormy as far east as China.

(3) A marked advance of the glaciers in all parts of Europe beginning about A.D. 1600, followed by a series of oscillations until about 1850–1870, when a retreat set in which is still in progress. During this " little ice age " many glaciers are believed to have reached their greatest extent for over a thousand years. About 1600 also there began a rapid increase in the amount of pack-ice off Iceland.

Finally, instrumental observations during the past two centuries have shown that, even apart from isolated droughts, wet periods or severe winters, the general level of rainfall and temperature varies from one group of decades to another. The most notable example is the period of mild winters from about 1901 to 1930 which seems to have covered most of Europe and the Arctic, associated with a rapid retreat of the edge of the floating ice-cap. Such minor oscillations are however no monopoly of the present ; we find evidence of them wherever we can identify annual layers of sediment in the rocks. The sunspot cycle of 10–11 years for example seems to have persisted throughout geological time. The whole picture is one of an intricate series of superposed climatic variations, from gigantic swings over millions of years between ice ages and genial climates, all down the scale to changes of a few degrees between one decade and another and finally from year to year. In the second part we will discuss some of the theories which have been advanced to explain these changes.

(*To be continued.*)

GOLD VISIBILITY METER MK. II

BY J. R. BIBBY, B.A.

Introduction.—This instrument is based on a visibility meter designed by Mr. E. Gold, C.B., D.S.O., F.R.S.* and is used to measure the visibility at night. It is, in effect, a simple photometer used to measure the apparent brightness of a fixed lamp several hundred yards from the observer. This is done by observing the lamp through a graduated neutral filter which is varied until the lamp is only just visible. The meter reading then gives a measure of the transparency of the atmosphere, and by means of tables this can be related to the visibility which would be observed during daylight in an equally transparent atmosphere.

Description of the visibility meter.—The meter is illustrated in the photograph facing p. 136. The variable light filter A is cemented between glass plates approximately 20 cm. × 4 cm. which can slide in the main frame. The filter has the following properties :—

(*a*) It is neutral, i.e. it transmits light of all wave-lengths equally.

(*b*) It is almost completely transparent at one end, while at the other end it transmits only about 1/4,000 of the incident light.

(*c*) The variation of density along the filter is uniform in the sense that if the fraction of light transmitted is measured at a number of equidistant points along the filter, the figures for adjacent points will always be in the same ratio.

Two small neutral filters B (about 2 cm. square) are fixed to the frame of the instrument. These have the same uniform gradation of density as the main filter, but in the opposite direction. The superposition of a small filter on any part of the main filter therefore results in a uniform resultant density over the area of the small filter. One of these filters is nearly transparent, the other transmits only about 1/1,000 of the incident light. A moveable eyeshield C enables either of these filters to be used. The fraction of light transmitted varies (according to the position of the main filter) between about 1/2·5 and 1/4,000 if the clearer of the small filters is used, or between 1/2,500 and 1/4,000,000 if the denser filter is used.

The resultant opacity of the filters is indicated by two scales D fixed to the sliding filter, which move past two fixed marks E on the frame. The two scales, only one of which is visible in the photograph, correspond to the two alternative small filters, i.e. to the two positions of the eyeshield. The scales are graduated in terms of a special unit called a " nebule ", which is defined by the statement that a filter with an opacity of 100 nebules transmits 1/1,000 of the incident light. It follows that one nebule transmits 0·933 of the light falling on it.

The advantage of this unit lies in the fact that it represents approximately the smallest change in intensity which the eye can appreciate, and thus when using the meter the probable error of an observation by a careful observer will be of the order of one nebule. The range of the instrument expressed in nebules is from 15 to 120 for the clearer of the fixed filters, and from 115 to 220 for the

* See GOLD, E. ; A practical method of determining the visibility number V at night. *Quart. J. R. met. Soc., London*, **65**, 1939, p. 139.

denser filter. It follows from (*c*) that the nebule scales are linear (unit nebule divisions being about 1·7 mm. apart).

Method of using the meter.—First of all suitable lights must be selected. These may be specially installed, or existing lights may be used. The candle powers and distances may vary within fairly wide limits, but it has been found most convenient to have three 15 watt electric lamps, mounted on posts 2 m. high, at distances of 100, 500 and 1,500 m. from the observer. These lights should be white and, as far as possible, of constant intensity.

Having selected suitable lights, it is necessary to determine the visibility-meter reading when the lights are observed through the meter on a night of good visibility. This should be done immediately after dark on an evening when the visibility has been observed (during daylight) to be not less than about 20 Km., and when it is not expected to change much, e.g. when there is a fresh wind and a cloudy sky. These readings should be made on each light in turn, and by each observer separately, to allow for the differing sensitivity of different eyes. Full details of the procedure for making observations with the meter are given in Mr. Gold's paper, and are available in the Meteorological Office. Briefly, the observer should remain in darkness for five or ten minutes to allow his eye to accommodate itself to the darkness, and should then adjust the meter so that the light, as observed through it, is only just visible.

Having made these observations on a night of good visibility, tables or graphs (one for each observer and each ligh) can be prepared in the manner described in the next section. Then on subsequent nights the visibility may be measured by repeating the observation, but using only the most distant of the visibility lights which can be seen. If the visibility is less than on the previous occasion the meter reading will be lower, and the difference between the two (in conjunction with the tables or graphs described below) enables the visibility on the second occasion to be determined.

Relation between meter readings and equivalent daylight visibility.— Meter readings may readily be used to calculate the extinction coefficient of the air between lamp and observer as follows :—

The extinction coefficient μ is defined by the equation

$$I = I_0 e^{-\mu d}$$

where I is the apparent brightness of a lamp at distance d from the observer on the night in question, and I_0 its apparent brightness in perfectly clear air. If the visibility meter readings are n nebules for clear air and m nebules on the night in question, the apparent brightnesses as observed through the visibility meter are $I_0(0{\cdot}933)^n$ and $I_0 e^{-\mu d}(0{\cdot}933)^m$ respectively. But these must be equal, as they represent the faintest light visible to the eye, which is assumed constant. Thus we have

$$(0{\cdot}933)^n = e^{-\mu d}(0{\cdot}933)^m$$

or

$$e^{-\mu d} = (0{\cdot}933)^{n-m}$$

Taking logarithms to base 10,

$$0{\cdot}4343\mu d = 0{\cdot}03(n-m),$$

whence

$$\mu = 0{\cdot}0691(n-m)/d$$

The relation between the extinction coefficient μ and the equivalent daylight visibility V cannot be directly calculated without making rather far-reaching assumptions, and any formula resulting from such calculations must be verified experimentally before acceptance. The formula hitherto used with the Gold visibility meter (based on measurements by Bennett) is

$$\frac{n-m}{d} = \frac{134}{V^{1\cdot 1}}$$

$$\text{i.e.} \qquad V = \left(\frac{134d}{n-m}\right)^{0\cdot 91} \qquad ..(1)$$

This is equivalent to the relation

$$V = (9\cdot 26/\mu)^{0\cdot 91}$$

In all cases V and d must be in yards, and μ in yards $^{-1}$

Another relation between μ and V, due to Koschmieder, is now considered rather more accurate than Bennett's. Koschmieder's formula is usually expressed as $V = 3\cdot 91/\mu$, but this refers to the (daylight) visibility of an object which is perfectly black and seen against the sky. As real objects are rarely perfectly black, and are sometimes seen against terrestrial backgrounds, the formula, $V = 3\cdot 75/\mu$ probably gives the best relation between μ and the visibility as normally estimated in daylight. For use with the visibility meter this formula may be written alternatively as :—

$$V = \frac{54\cdot 3d}{n-m} \qquad ..(2)$$

In this case any unit of length may be used, provided that it is the same for V, d, and μ.

The differences between the formulae are negligible for visibilities above about 3,000 m. For lower visibilities the differences progressively increase, being about 20 per cent. at 1,000 m. and 50 per cent. at 100 m. Bennett's formula gives the higher values.

Whichever formula is used, the method of preparing conversion tables or graphs is similar. The reading n on a perfectly clear night must first be determined for each observer and each light. This is done by making observations on a night of known good visibility (as explained earlier), and by using formula (1), say, correcting for the non-infinite visibility by adding to the readings the quantity $54d/V$; i.e. if n_1 is the reading on a night of known visibility V then $n = n_1 + 54d/V$ where, as above, V is the visibility and d the distance of the lamp, in the same units. A series of graphs or tables (one for each observer and each light) can then be prepared, using equation (1) or (2), showing the relation between the meter readings and the visibility.

Accuracy obtainable.—It was stated above that the probable error of a single observation was about ± 1 nebule. The overall accuracy obtainable also depends, however, on errors arising from the following causes, which are quite independent of the small instrumental error ; errors from these causes would arise if the visibility were determined by direct observation on a series of lights extending to the limit of visibility :

(*a*) Variations in the sensitivity of the eye on different occasions.

(*b*) Random fluctuations in the brightness of the lamps (slow and regular changes in the lamps may be allowed for by repeating the measurements of n on every suitable night).

The probable errors due to these causes may be estimated as ± 5 nebules and ± 3 nebules respectively, and combining these with errors of ± 1 nebule in measuring both n and m, the overall probable error is about ± 6 nebules. It is seen from equation (2) that this corresponds to an error of about 11 per cent. when the visibility is the same as the distance of the light used, 22 per cent. when it is twice the distance, and 55 per cent. at five times the distance. It is clear, therefore, that only three well spaced lights are necessary to cover a range of visibilities from 100 m. to 5 Km. with reasonable accuracy, whereas without the visibility meter a more elaborate series of lights would be essential if the same accuracy were to be achieved. It must be remembered in this connexion that estimates of visibility made in daylight are subject to an uncertainty of roughly 20 per cent.

Two other possible sources of error may arise :—

(*a*) Uncertainty in the formula connecting μ and V.

(*b*) Lack of care in taking observations. It must be emphasised that carelessness in using the meter, especially neglect to allow time for the eye to accommodate itself to the darkness, may easily increase the errors by a factor of two or even three.

An improved visibility meter is being developed in the Meteorological Office with a view to eliminating some of the above sources of error. A more powerful light is used, and its apparent brightness is measured by means of a photo-electric cell.

HIGH-ALTITUDE SOUNDING BALLOONS

BY O. M. ASHFORD, B.SC. AND D. N. HARRISON, D.PHIL.

With the increasing activity in meteorological research in the stratosphere, the need for sounding balloons capable of carrying a useful load of 1 Kg. or more to a height of 100,000 ft. has become of considerable importance. The object of this note is to describe the development work on high-altitude balloons which is being carried out in this country under the supervision of the Instruments Branch of the Meteorological Office.

Sounding balloons are normally made in three sizes, 350 gm., 500 gm. and 700 gm. The average bursting height with a load of 1,500 gm. is in the region of 60,000 ft., but occasional ascents have been made to 75,000 ft. The main factors limiting the bursting height are the decrease in extensibility as the temperature falls, chemical action of oxygen and ozone and mechanical defects. Improvements might therefore be made (*a*) by using larger balloons or more than one balloon so that the elastic limit for a given load would not be reached until a greater height, (*b*) by using better antioxidants and/or dyes in the rubber mix, (*c*) by using materials other than natural rubber or (*d*) by using a valving technique to allow some hydrogen to escape when the internal pressure becomes too great.

It was estimated by the Research and Development Establishment, Cardington, that a balloon weighing 10 Kg., capable of expanding to 40 ft. diameter, would be necessary to carry a load of 1 Kg. to 100,000 ft. with reliability. As a step in this direction, the Guide Bridge Rubber Co. produced six balloons weighing 4,500 gm., four of which were flown at Larkhill with the results shown in Table I. The bursting heights, which were measured by radar, were variable, but the average of 71,000 ft. is appreciably greater than for smaller balloons. The last of these four gave a particularly interesting ascent. It passed out of range of the radar set at a height of 83,900 ft., while still rising. The remnants of the balloon and the radar target which it carried, were found an hour or so later at Brookham, near the Dorking-Reigate road. From the distance travelled it was deduced that the balloon must have reached a height of more than 100,000 ft. Further experiments are being made.

TABLE I—ASCENTS WITH 4,500 GM. BALLOONS

Weight carried	Free lift	Height burst	Rate of ascent to 40,000 ft.	Remarks
Kg.	Kg.	ft.	ft./min	
1·9	5·5	80,100	1,420	Radio-sonde carried in addition to radar reflector
1·2	5·0	45,000	1,400	—
1·2	3·5	58,500	1,310	—
1·2	2·5	(100,000)	800	Maximum height measured : 83,900 ft., when range too great for radar. Balloon found at Brookham, Surrey, and height of 100,000 ft. deduced from data.

To obviate the difficulty in tying two ordinary balloons together without the risk of the string chafing the rubber, the Guide Bridge Rubber Co. produced some special 700 gm. balloons with two diametrically opposite necks. Twenty-four of these balloons were flown at Larkhill, with the results shown in Table II.

TABLE II—ASCENTS WITH BALLOONS IN TANDEM

Ascent No.	Bursting height	Remarks
	ft.	
1	49,000	Lower balloon burst first (ascents 1–5)
2	51,000	
3	64,000	
4	>66,000	
5	74,000	
6	53,000	Radio-sonde switch stuck on temperature or humidity element with little subsequent change. Probable that upper balloon burst first and lower balloon remained floating (ascents 6–10)
7	56,000	
8	69,000	
9	76,000	
10	83,000	
11	>66,000	Switch stuck ; windmill started turning again after burst (ascents 11–12); Reading of 78,000 ft. on descent
12	>73,000	Reading of 93,000 ft. on descent
13	>67,000	Burst not observed ; radio-sonde failure
14	64,000	Two double-necked balloons used
15	71,000	Balloons joined by tube to equalise pressure

The ascents are grouped according to the nature of the termination, not chronologically. Except in ascent No. 14, the upper balloon was the normal 500 gm. type ; free lift of upper balloon normally 2,200 gm. and of lower balloon 2,000 gm.

Unfortunately, radar observations could not be made, and the bursting heights had to be estimated from radio-sonde readings. It was found that at extreme heights the windmill operated switch of the Meteorological Office radio-sonde does not function satisfactorily. The results were somewhat erratic but appreciably greater heights than usual were obtained on 11 of the 15 useful ascents. With the tandem balloons there are several possible variations in technique, e.g. upper balloon with greater free lift than lower, pressures equalised between balloons by connecting tube, etc., and it is considered that further experiments will lead to profitable results.

In tests made during the war, the Research and Development Establishment had found that balloons coloured with a special orange dye withstood exposure to daylight much longer than other balloons. A batch of seventy orange balloons was tested at Downham Market, but the bursting heights were if anything slightly lower than those obtained with white balloons, both by day and by night.

The obvious alternatives to natural rubber are artificial rubber and non-extensible materials such as that used by Dr. Regener*. Of the artificial rubbers, neoprene is best for meteorological balloons, and the Americans claim to have made some capable of reaching 100,000 ft.† Neoprene latex is not made in this country and there are practical technical difficulties in transporting it from America. No immediate experiments can therefore be made over here, other than with American balloons.

The non-extensible materials used by Regener are being examined and it is possible that some may be made in this country. The non-extensible balloons suffer from the disadvantage that they have to be very much larger at the start than ordinary balloons.

VARIATIONS OF TEMPERATURE IN LONDON, 1764–1939

BY L. F. LEWIS, M.SC.

This article, which was completed early in 1940, was written at the suggestion of the late Mr. Joseph Baxendell.

Much interest has been shown by meteorologists in recent years in the apparent upward trend of temperature in the northern hemisphere. In an examination of the long and reliable record of the Radcliffe Observatory, Oxford[1]‡, the writer[2] found that the curve of 20-year moving averages of mean annual temperature was a periodic one, and although the maximum now being experienced has extended over a long period of years it is less pronounced than the one indicated in the early part of the nineteenth century ; this suggested that the mildness of the first part of the twentieth century did not necessarily denote a change of climate but only a rather prolonged mild phase.

Dr. C. E. P. Brooks has collected and tabulated a series of mean temperatures for London from 1764 ; these are published in a paper by Professor D. Brunt[3], and at the request of the late Mr. J. Baxendell of Southport, curves (see Fig. 1) similar to those for Oxford, showing the variations of 20-year moving averages of mean temperature for summer (June to August), winter (December to February), and for summer minus winter (see Fig. 2) were prepared for a period back to 1764 by Mr. G. A. Tunnell, of the Meteorological Office. Later, a curve showing variations of annual mean temperature was also prepared (see Fig. 1). Each point on these curves represents the average temperature for the

* REGENER, E. ; Ballone mit grosser Steiggeschwindigkeit und Thermograph von geringer thermischer Trägheit. Schriften der Deutschen. Akademie der Luftfahrtforschung, Berlin. Heft 37, 1943.

† SPILHAUS, A. F. ; Recent developments in meteorological equipment. *Bull. Amer. met. Soc., Milton Mass.*, **27**, 1946, p. 399.

‡ The list of references is on p. 138.

20 years ending on the year shown by the abscissa of the point. The London observations of temperature are not a homogeneous series throughout ; from 1841 they represent observations at Greenwich Observatory and are reliable

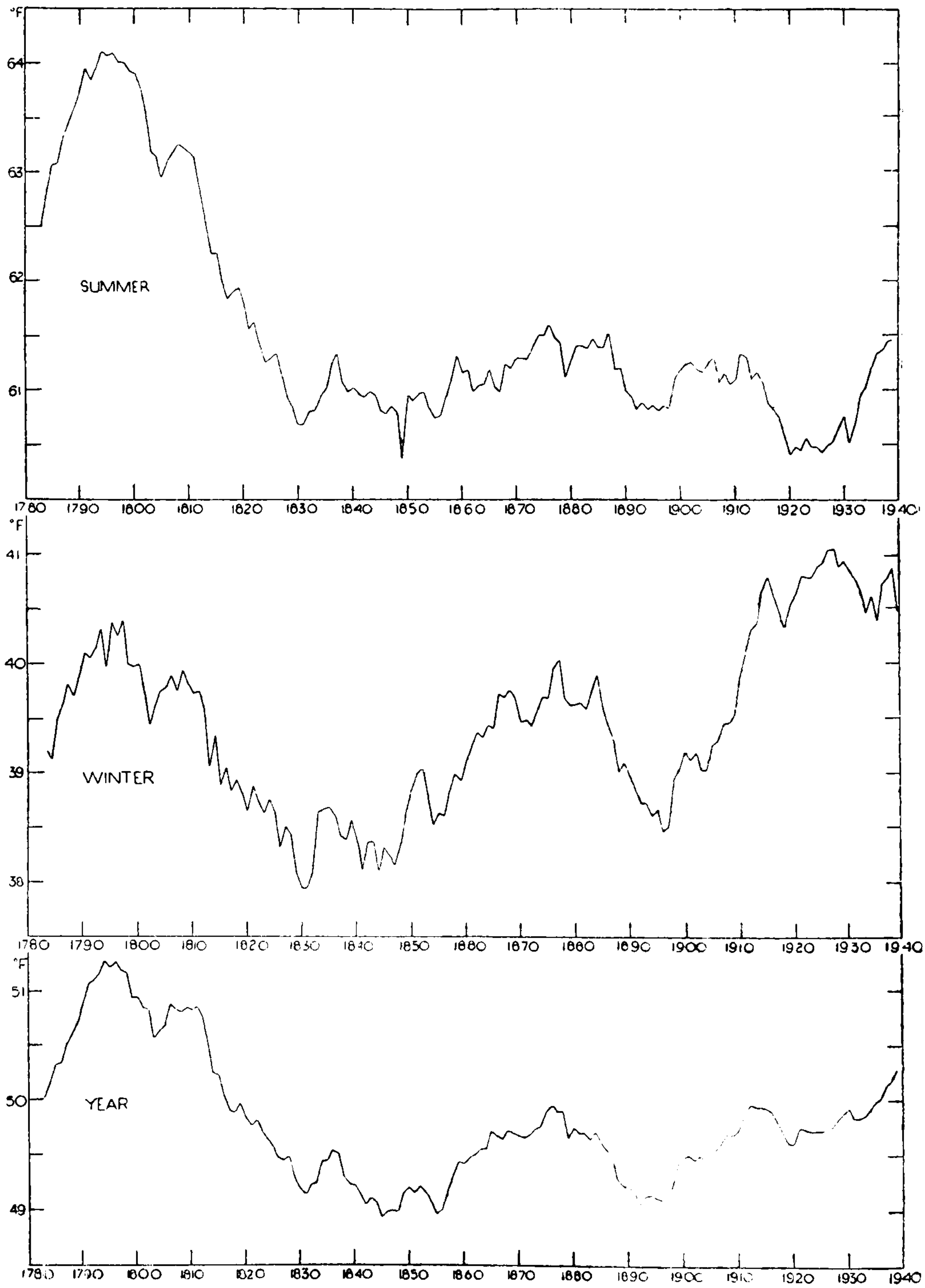
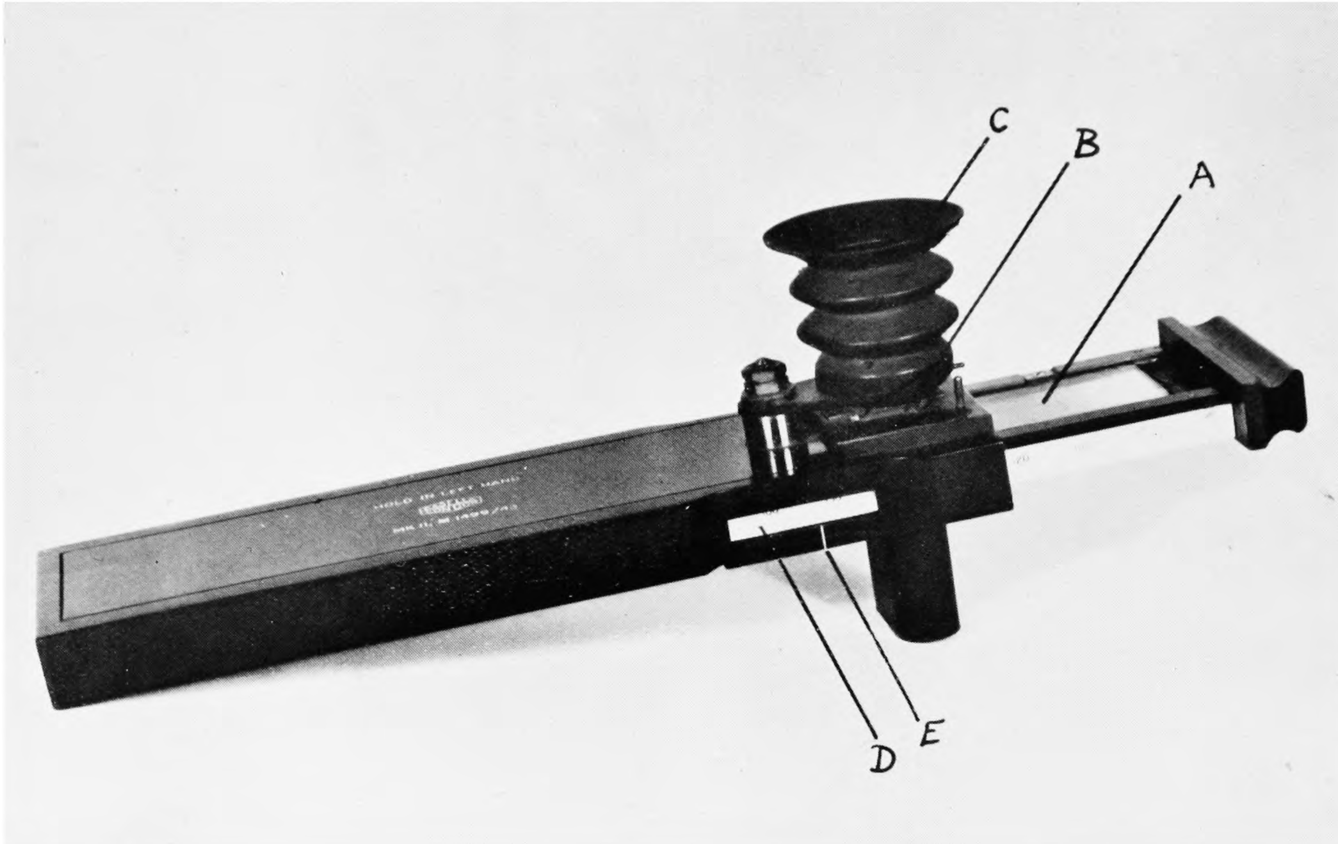
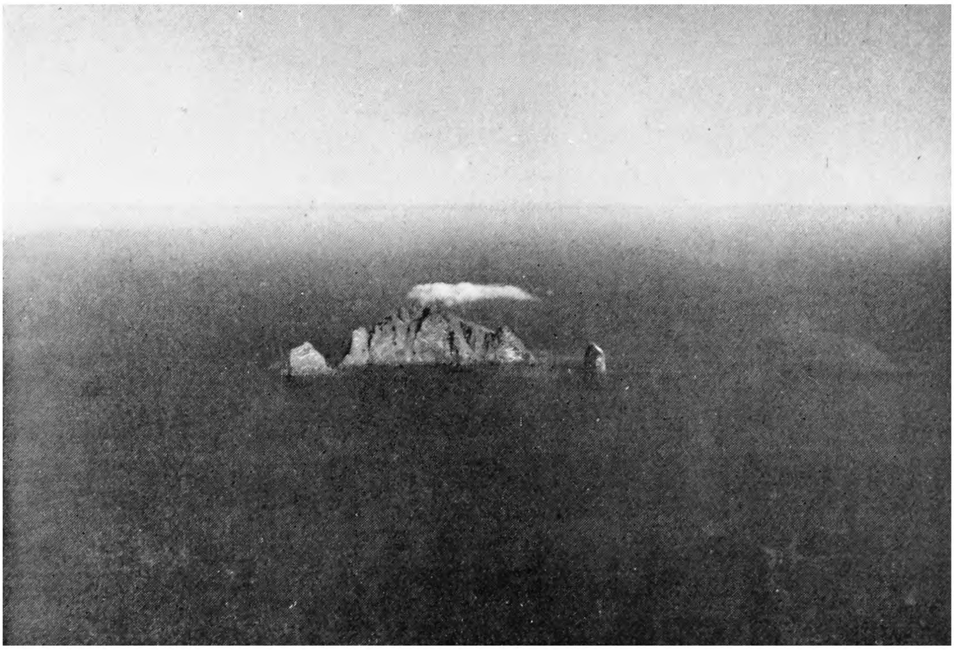


FIG. 1—TWENTY-YEAR MOVING AVERAGES OF MEAN TEMPERATURE AT GREENWICH



GOLD VISIBILITY METER, MK. II

(see p. 130)



R.A.F. Photograph

OROGRAPHIC CLOUD OVER ST KILDA, MAY 5, 1942 and homogeneous but, in the earlier years, the site and exposure of the instruments varied from time to time and the observations are therefore less reliable for purposes of comparison. The curve of 20-year moving averages of mean annual temperature shows two minima and three maxima during the whole period ; the periods between the two minima and possibly the two later maxima is roughly 50 years, but the first maximum occurs approximately 75 years before the second. This first maximum, which occurred during the end of the eighteenth and beginning of the nineteenth centuries is more pronounced than the other two. Turning to the seasonal curves, the curve representing the variation for the three winter months is broadly similar to that for the year.

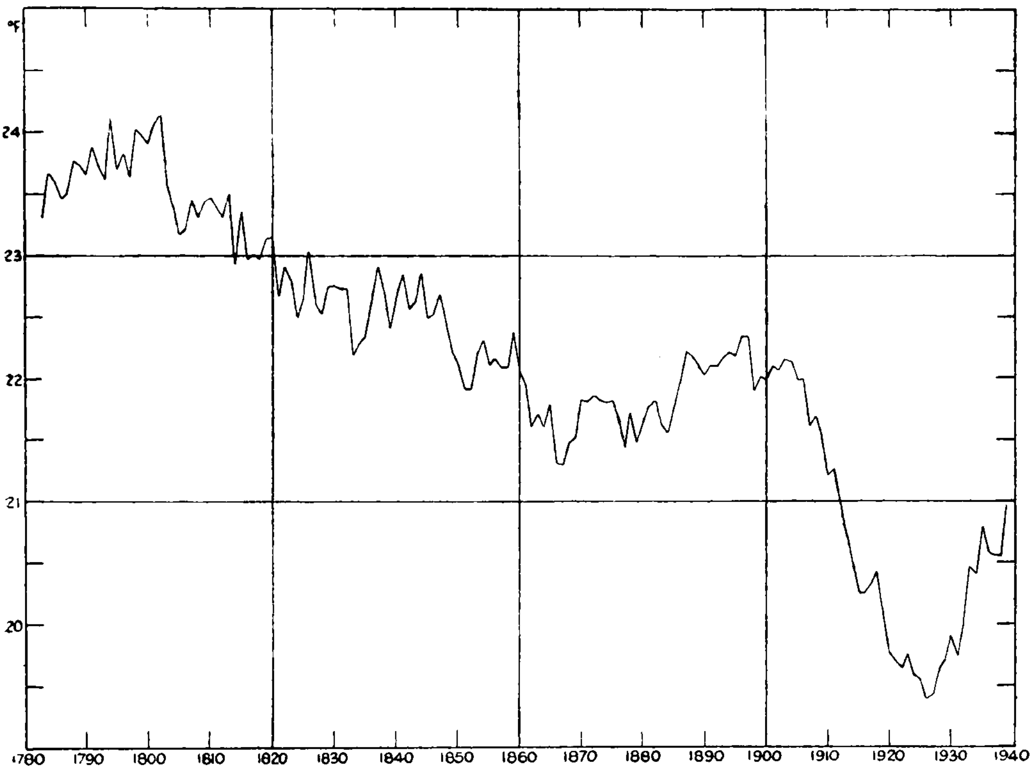


FIG. 2—TWENTY-YEAR MOVING AVERAGES OF MEAN SUMMER TEMPERATURE MINUS MEAN WINTER TEMPERATURE AT GREENWICH

The curve is not so smooth but the maxima and minima occur around the same periods ; in the winter curve, however, the maximum occurring in the first part of the twentieth century is the most pronounced, while in the annual curve that occurring at the end of the eighteenth and beginning of the nineteenth centuries is the most important. The summer curve shows no relation to the other two during the latter part of the period ; in fact, there is a minimum during the first thirty years of the present century instead of the considerable maximum shown at this time during the winter season. The exceptional maximum which occurs during the early years of the period under consideration in the summer months may, in part, be due to changes in exposure and site of the instruments referred to above, but with regard to the unusual warmth of these years the data given in a paper by Dr. C. E. P. Brooks and Miss T. M. Hunt[4] on variations of wind direction since 1341 is of interest. The authors show that in London the period 1792–1810 was one of remarkably steady southerly winds ; after this period the direction became progressively more we terly. It is well known that in summer southerly winds bring high temperatures in south-east England. From 1901–30 the resultant winds in summer were from WSW., the most westerly of all the periods analysed since 1651 ; this is in good agreement with the cool summers experienced during this time.

The curve in Fig. 2 represents 20-year moving averages of mean summer temperature minus mean winter temperature and shows the unusually equable conditions experienced in south-east England during the first quarter of the twentieth century. This curve indicates perhaps the most marked change in temperature conditions during the period under consideration ; there are minor fluctuations but on the whole it shows a fairly steady decrease in " annual range " of temperature, with a rapid decrease in the early decades of the twentieth century. The last part of the curve, however, shows a partial recovery.

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3. BRUNT, D. ; Periodicities in European weather. *Philos. Trans., London,* **225**, Series A, 1925, p. 247.
4. BROOKS, C. E. P. and HUNT, T. M. ; Variations of wind direction in the British Isles since 1341. *Quart. J. R. met. Soc., London,* **59**, 1933, p. 375.

METEOROLOGICAL RESEARCH COMMITTEE

The 48th meeting of the Meteorological Research Committee was held at the Meteorological Office, Harrow, on Thursday, May 8, 1947.

The papers considered included a review of progress in the development of meteorological instruments, two papers on the accuracy of radar methods of wind measurement, a note on balloon soundings up to a height of 30 Km., and a paper on the prediction of evaporation from saturated surfaces.

ROYAL METEOROLOGICAL SOCIETY

On May 14, Professor C. Störmer gave a lecture on " mother-of-pearl clouds " to the Royal Meteorological Society. These interesting clouds, which are occasionally seen in Norway before sunrise or after sunset, were shown to be associated in some cases with a depression north of Norway. They can be observed under f. hn conditions, when other cloud is absent. By using cameras designed for work on aurora the height of mother-of-pearl clouds has been measured. Usually they are at 25–30 Km., but they have been observed as low as 12–14 Km., and as high as 33 Km. On the two occasions when it was possible to determine the temperature at about the level of the clouds, it was found to fall to −75°C. and −83°C. On another occasion, photographs revealed that the air was in violent turbulence at the cloud level of 26–28 Km. The clouds are formed of very small water drops about 2μ in diameter.

Professor Störmer showed some very effective coloured slides and the occasional applause from Fellows showed that many of them were appreciating for the first time the beauty of these clouds.

An interesting discussion followed the lecture, in which most of the speakers had to put their remarks in the form of questions. Among the speakers were Dr. Stagg who asked whether the clouds moved, and how the water was able to reach such heights. Professor Sheppard asked whether it was possible that the closed isobar pattern extended up to those great heights on occasion, so that a sufficiently steep pressure gradient might lead to inflowing motion and ascent. Dr. Goldie pointed out that in the winter the air at 24–25 Km. north of about 60°N. has an upward motion on the average, particularly when a depression is north of 60° N. ; horizontally, the air has a poleward component and it is probably more or less saturated. Mr. Brewer mentioned the very low humidity of the stratosphere and pointed out that Professor Störmer's results showed that sometimes the temperature in the stratosphere must fall at great heights. Sir Charles Normand asked whether there were in fact more mother-of-pearl clouds over Norway than over the British Isles ; he pointed out that in the present state of our knowledge we could postulate movement of the air in almost any direction as necessary to the formation of these clouds, and suggested that the mountains of Norway might produce atmospheric waves. Mr. Ashford emphasised this last point by mentioning reports from German glider ascents, which showed that there are waves in the stratosphere, especially under föhn conditions ; he added that we have so far only a few observations of humidity in the stratosphere, and these chiefly on occasions of low tropopause ; humidity may not be low in all circumstances.

Professor Störmer replied briefly to some of the points which had arisen in the discussion. In conclusion, the President, Dr. Dobson, asked why the clouds are found at limited levels if they are due to rising currents, and how turbulence can occur at such heights. He pointed out that ozone observations showed that some fronts extend into the stratosphere, and wondered whether this fact was related to the mother-of-pearl clouds. The photographs suggested that the clouds were of two kinds since some showed definite lenticular formation and others indicated turbulent motion.

LETTER TO THE EDITOR

An account of the development of cumulus over a tar fire at Changi on March 1, 1947

This account is based on a log made at the time and a detailed description, including the evidence of five witnesses, written the same day by F/Lt. Craddock. Times are thought to be correct within one minute.

On the morning of March 1, 1947, F/Lt. Craddock went to the top of the water tower near Station Sick Quarters, Changi, to study cloud formation. At 1035, looking almost due south, he noticed black smoke rising from near the Changi runway (which is out of sight behind an eminence). The smoke rose in a dense, narrow column, which showed no inclination across the line of sight. Its form suggested a very elongated tree, and there was no sign of spin about a vertical axis. At about 1040 he noticed that the top of the column had a peculiar greyish appearance, and almost at once saw that condensation was taking place. At 1041 it was clear that the top of the smoke column had turned into a compact cumulus, which he tried unsuccessfully to photograph. He did however observe and log that the smoke column exactly filled the reflex view finder of the camera, which has a field of 33½°.

By 1044 the cumulus was quite well developed, and by 1050 the smoke column had dispersed, leaving a roughly spherical cumulus cloud, which drifted away to the north. F/Lt. Craddock had been examining that part of the sky since 1030 and it was perfectly clear to him that the cumulus had formed from the top of the smoke column. The sun was shining in an almost clear sky, and felt very hot, and the surface wind was imperceptible.

At the same time F/Lt. Smith was by the Changi runway making nephoscope observations, and saw the fire about a quarter of a mile to the west. He observed that the smoke column rose vertically and saw the cumulus form on top. The fire was in and around a tar boiler which had just been refilled with two barrels of tar, and it appeared that about one barrel of tar had actually been burnt. Estimates of the width of the smoke column near the base ranged from 10 to 24 ft. with 18 ft. probably about right. All witnesses described it as " very narrow ".

The water tower is 1,800 $\pm$ 20 yds. from the site of the fire, so that the height of the column at 1041 was approximately 3,580 ft. The rate of ascent was therefore almost 600 ft./min.

This incident shows :—

(1) that in favourable conditions the amount of heat energy which must be released to start cumulus formation may be very small.

(2) that a rising thermal current originating within a few feet of the ground may continue its ascent although perhaps in a diluted state until the condensation level is reached, even though the current starts with a linear diameter as small as 18 ft., and has no apparent spin.

W. H. SMITH
J. M. CRADDOCK

Changi, Singapore, April 22, 1947.

NOTES AND NEWS

Meteorological Association

The first annual reunion of the Association will take the form of a Supper Dance to be held on November 1, 1947, at the Royal Empire Society in Craven Street, near Northumberland Avenue. A section of the Royal Air Force Dance Band has been engaged to provide the music. Tickets will cost 10s. each, and may be obtained after September 1 from the Treasurer, 238 Sheen Lane, London, S.W.14. Dress is optional.

Functional English

Professor R. O. Kapp has recently given a series of four lectures on " The presentation of technical information " in which he introduced the idea of functional English and pointed out the reasons for some of the common faults in technical literature. The following general account of the lectures has been prepared, as the subject is of unusual importance to meteorologists who, because of the public interest in the results of their work, have to pay particular attention to the presentation of technical information. This report however, is not intended to be a complete summary of the lectures.

Functional English can be defined as the language which should be used to convey new information from mind to mind. This information may be presented in many different ways, e.g. as a report to a senior officer, as a written or spoken instruction to a junior, or as a paper to a learned society. The language used will vary with the type of information and with the identity of the persons addressed, but unless it induces receptivity in these persons it is not functional. Language used for all other purposes can be described as imaginative English, and a good functional style cannot be acquired merely by a study of good classic styles, for so much of the effectiveness of the best imaginative literature depends upon allusion, which should be absent from functional writing. The contrast between the styles can be summarised by describing functional English as the language of inspection and imaginative English as the language of introspection ; for full understanding, the one makes demands upon the recipient's reason and the other upon his insight. Functional English should always be simple and clear, and generally concise, but imaginative English may be vague and repetitive.

The problems to be overcome in presenting technical information are :—

(i) Linguistic,
(ii) Logical,
(iii) Psychological, including (*a*) association, (*b*) understanding, (*c*) memorising.

The linguistic problem involves the elimination of everything which interferes with the smooth flow of thought and includes the avoidance of vague or unfamiliar phrases, tortuous syntax, and ugly sounds or rhythms.

To be satisfactory logically the exposition should not contain unfamiliar ideas unless these are clearly and logically connected with ideas familiar to the recipient ; significant facts or figures should have their significance explained, and there should be no emphasis on matters of secondary importance.

Language can only be psychologically effective when the expositor is acutely aware of the person addressed, so that he can realise the extent of his knowledge and his capabilities of understanding. A good expositor will make it easy for the recipient to bring the new knowledge into association with his previous knowledge, to understand the new knowledge and to memorise it. In order to achieve the maximum effectiveness of association, understanding and memorising, the presentation of the information must be carefully timed, so that the recipient may be stimulated to put forward his greatest effort. Professor Kapp suggested that his classes should study the technique of a first-class music-hall comedian, who is necessarily a master in the art of timing so as to stimulate and maintain the interest of his audience.

It should not be inferred from what has been written that these lectures were concerned only with general principles. Professor Kapp passed on a number of practical hints, of which a few are given below.

A report on a given subject is usually meant to influence the actions of a reader ; a book or a paper is meant to influence his thought. In a report, details of experimental methods may thus often be omitted, but in a paper they should generally be included.

Tables (e.g. of data or results) may be regarded as basic knowledge, and text as assimilated knowledge. Text is therefore often necessary in addition to tables.

It is possible to be too concise. Enough words should be used to convey the information from mind to mind, though these are often far more than suffice merely to put the information on record. It is important to avoid meaningless phrases. They bore the recipient and make him less receptive.

It may be necessary to state the obvious, especially when the information is numerical, e.g. the quoted value is " high " or " low ". Words of comment such as " even ", " surprisingly ", etc., are useful to understanding.

The writer of functional English must explain and not imply, the reasoning must be done for the reader and not by the reader. Graphical presentation should be freely used, but care should be taken to avoid including on the graphs more material than is absolutely necessary.

Circumlocutions such as " in the case of ", " with reference to " are occasionally justifiable, but they are usually thought-dodging devices.

It is useful to read a manuscript some little while after it has been written.

Qualifications of statement should be avoided where possible and a qualification should never be put within a qualification. In illustrating these points, Professor Kapp provided examples of non-functional English from technical literature (including one from his own writing).

Probably the main value of these lectures lay in the logical basis on which Professor Kapp has built his conception of functional English. Using this basis it is possible to ask whether a particular piece of writing is functional or not, and to discover in what way it fails to achieve its object. Professor Kapp would not claim that his basis will necessarily be the best, but it is a great advance to have any standards by which to judge the adequacy of the presentation of technacil information.

W. H. HOGG

REVIEW

A comparison of Cherat surface observations of temperature and humidity at 0800 *hrs. L.T. with aeroplane observations over Peshawar plain at the same level*, by K. L. Bhatia. Scientific Notes of the India Meteorological Department. Vol. X, No. 116. 4to., 10¼ in. × 7 in., pp. 11–17, Delhi, 1942. Annas 6 or 7*d*.

This paper concerns a subject which is of considerable interest to people studying conditions near the surface of the earth. In this case it is the influence of the mountain surface on the free air.

Observations at Cherat Observatory (33° 50'N., 72° 01' E. height : 3 Km.) at 0800 local time have been compared with aeroplane ascents carried out near the observatory (about 20 miles away). In a total of 449 observations of free air temperature minus mountain air temperature, approximately evenly distributed throughout the year, it is found that the majority of observations are clustered round the mean value. This value is in general positive which is in agreement with other writers. Relative humidity and for most of the year vapour pressure are both higher over the mountain than in the free air. This indicates that during most of the year there is a flow of moisture from the mountain to the free air. The greatest differences come during the wetter months when one would expect the greatest amounts of evaporation. This paper would be of greater interest if the data were of more general application and could be used for mountains in general.

G. A. TUNNELL

RAINFALL OF APRIL, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·87	121	*Glam.*	Cardiff, Penylan ..	3·13	125
Kent	Folkestone, Cherry Gdns.	1·73	104	*Pemb.*	St. Ann's Head ..	3·38	165
,,	Edenb'dg, Falconhurst	2·15	115	*Card.*	Aberystwyth	1·76	86
Sussex	Compton, Compton Ho.	2·95	147	*Radnor*	Bir. W. W., Tyrmynydd	4·86	132
,,	Worthing, Beach Ho.Pk.	1·32	85	*Mont.*	Lake Vyrnwy	7·00	217
Hants	Ventnor, Roy. Nat. Hos.	2·01	120	*Mer.*	Blaenau Festiniog ..	7·81	126
,,	Fordingb'dg, Oaklands	2·88	157	*Carn.*	Llandudno	2·94	174
,,	Sherborne St. John ..	2·33	132	*Angl.*	Llanerchymedd ..	4·28	194
Herts.	Royston, Therfield Rec.	2·01	128	*I. Man.*	Douglas, Boro' Cem. ..	4·47	183
Bucks.	Slough, Upton	1·66	116	*Wigtown*	Pt. William, Monreith	4·32	196
Oxford	Oxford, Radcliffe ..	1·84	115	*Dumf.*	Dumfries, Crichton R.I.	5·72	242
N'hant.	Wellingboro', Swanspool	2·10	141	,,	Eskdalemuir Obsy ..	10·02	295
Essex	Shoeburyness	1·08	89	*Roxb.*	Kelso, Floors	3·94	251
Suffolk	Campsea Ashe, High Ho.	1·26	89	*Peebles*	Stobo Castle	6·73	322
,,	Lowestoft Sec. School ..	1·38	93	*Berwick*	Marchmont House ..	3·43	170
,,	Bury St. Ed., Westley H.	2·00	131	*E. Loth.*	North Berwick Res. ..	2·22	158
Norfolk	Sandringham Ho. Gdns.	2·06	136	*Midl'n.*	Edinburgh, Blackfd. H.	2·92	199
Wilts.	Bishops Cannings ..	2·32	150	*Lanark*	Hamilton W. W., T'nhill	5·53	296
Dorset	Creech Grange.. ..	2·45	113	*Ayr*	Colmonell, Knockdolian	4·23	167
,,	Beaminster, East St. ..	3·07	130	,,	Glen Afton, Ayr San ..	9·17	306
Devon	Teignmouth, Den Gdns.	2·80	139	*Bute*	Rothesay, Ardencraig	5·65	190
,,	Cullompton	1·95	86	*Argyll*	Loch Sunart, G'dale ..	7·90	189
,,	Barnstaple, N. Dev. Ath.	2·87	135	,,	Poltalloch	4·61	153
,,	Okehampton, Uplands	5·52	173	,,	Inverary Castle	10·38	226
Cornwall	Bude School House ..	1·90	101	,,	Islay, Eallabus ..	4·50	157
,,	Penzance, Morrab Gdns.	2·87	118	,,	Tiree	5·83	237
,,	St. Austell, Trevarna ..	3·09	110	*Kinross*	Loch Leven Sluice ..	4·51	235
,,	Scilly, Tresco Abbey ..	2·29	117	*Fife*	Leuchars Airfield ..	2·28	144
Glos.	Cirencester	2·62	140	*Perth*	Loch Dhu	14·87	314
Salop.	Church Stretton ..	2·86	131	,,	Crieff, Strathearn Hyd.	7·55	345
,,	Cheswardine Hall ..	2·24	128	,,	Blair Castle Gardens ..	4·92	233
Staffs.	Leek, Wall Grange P.S.	2·74	133	*Angus*	Montrose, Sunnyside ..	2·94	161
Worcs.	Malvern, Free Library	2·57	143	*Aberd.*	Balmoral Castle Gdns.. .	3·91	182
Warwick	Birmingham, Edgbaston	2·64	152	,,	Aberdeen Observatory	1·96	105
Leics.	Thornton Reservoir ..	2·22	131	,,	Fyvie Castle	1·82	85
Lincs.	Boston, Skirbeck ..	1·82	135	*Moray*	Gordon Castle	1·29	74
,,	Skegness, Marine Gdns.	1·78	133	*Nairn*	Nairn, Achareidh ..	1·44	103
Notts.	Mansfield, Carr Bank ..	2·30	138	*Inv's*	Loch Ness, Foyers ..	8·80	406
Ches.	Bidston Observatory ..	2·42	149	,,	Glenquoich	21·08	325
Lancs.	Manchester, Whit. Park	2·37	123	,,	Ft. William, Teviot ..	12·44	276
,,	Stonyhurst College ..	3·41	126	,,	Skye, Duntuilm ..	8·38	258
,,	Blackpool	3·39	180	*R. & C.*	Ullapool	4·54	150
Yorks.	Wakefield, Clarence Pk.	1·98	118	,,	Applecross Gardens ..	7·11	208
,,	Hull, Pearson Park ..	1·46	94	,,	Achnashellach	12·05	225
,,	Felixkirk, Mt. St. John	2·92	175	,,	Stornoway Airfield ..	5·66	197
,,	York Museum	1·73	108	*Suth.*	Lairg	3·22	139
,,	Scarborough	1·97	126	,,	Loch More, Achfary ..	10·11	208
,,	Middlesbrough.. ..	2·85	208	*Caith.*	Wick Airfield	1·81	91
,,	Baldersdale, Hury Res.	6·52	269	*Shet.*	Lerwick Observatory ..	4·24	185
Norl'd.	Newcastle, Leazes Pk. ..	3·16	199	*Ferm.*	Crom Castle	3·19	125
,,	Bellingham, High Green	5·44	252	*Armagh*	Armagh Observatory ..	3·60	171
,,	Lilburn Tower Gdns. ..	4·53	229	*Down*	Seaforde	3·55	135
Cumb.	Geltsdale	4·26	200	*Antrim*	Aldergrove Airfield ..	2·99	142
,,	Keswick, High Hill ..	11·86	386	,,	Ballymena, Harryville..	3·98	151
,,	Ravenglass, The Grove	4·39	177	*Lon.*	Garvagh, Moneydig ..	4·45	182
Mon.	Abergavenny Larchfield	4·83	191	,,	Londonderry, Creggan	4·53	176
Glam.	Ystalyfera, Wern Ho. ..	6·30	166	*Tyrone*	Omagh, Edenfel ..	4·43	168

WEATHER OF APRIL, 1947

The greater part of April was characterised by depressions travelling eastwards or north-eastwards across the British Isles or between Iceland and Scotland. Some of these reached considerable intensity, pressure in the centres falling below 964 mb. on the 6th, 960 mb. on the 14th and 956 mb. on the 21st. Pressure was generally high over France, and south-westerly winds prevailed over the British Isles, with mostly mild, sunny and pleasant weather in south-west England but excessive rainfall in Scotland. The best period was from the 9th to the 17th when conditions over England were mainly anticyclonic. Over the month as a whole the mean pressure ranged from 998 mb. at Reykjavik in Iceland to 1024 mb. at Nantes on the west coast of France, and there was a steep gradient for SW. winds over Great Britain.

Differences from average showed a large area of 10 mb. or more below normal, extending from Spitsbergen to south-east Greenland and the Gulf of Finland, and an anticyclonic belt from Bermuda to the Black Sea, over most of which pressure was 5–10 mb. above normal.

The deviation from the average mean pressure over the British Isles ranged from −5.0 mb. at Lerwick to +5.1 mb. at Lympne. The gradient was greatly increased above the average, the pressure chart being comparable with the normal chart for January. Winds from between S. and W. predominated and in all areas the total run of the wind exceeded the average ; at Lerwick, the average wind velocity was as high as 20 m.p.h. Gales occurred very frequently for the time of year, the stormiest periods being the 5th–8th and 20th–25th. The gale on the 23rd was unusually severe in England and Wales, the wind gusting to 88 m.p.h. at Aberporth, 87 m.p.h. at Bidston and 86 m.p.h. at Manchester (Ringway) on that day. The month was very wet on the whole ; in Scotland it was the wettest April in a record going back to 1869. More than three times the average occurred over much of central and south Scotland and over a small part of Cumberland. Less than the average was received in part of a coastal strip from Aberdeen to Wick, in the Thames Estuary, on the Suffolk coast and at a few scattered places chiefly in the south of England. Temperature somewhat exceeded the average especially in eastern districts ; the first four or five days and the closing days were rather cold and the remainder of the month mild on the whole, particularly the period 12th to 17th. Broadly speaking sunshine exceeded the average in eastern districts of England and was below the average at most places elsewhere.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days' difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	73	22	+1·5	143	0	102	37
Scotland	66	20	+0·7	215	+5	83	27
Northern Ireland ..	61	24	+1·2	156	+3	85	31

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ORGANIZATION OF METEOROLOGICAL SERVICES

The meteorological services of the different countries have been developed to meet their own national needs, and their organizations vary in accordance with the major economic features of the country concerned. In maritime countries like our own it was the desire for forecasts to meet the needs of shipping which first led to the formation of a state service, and the British Meteorological Office originated as a Department of the Board of Trade. Similarly, in the United States, the Weather Bureau was founded for the benefit of navigation both on the sea coast and on the Great Lakes ; in many other countries it was chiefly to meet the needs of agriculture that a knowledge of weather was first required, and in not a few the State Meteorological Service is still administered by the Department of Agriculture.

The first world war brought the importance of weather still more into the forefront particularly for flying operations, and after the war many countries found themselves with two or more services, which had grown up to meet the needs of the Army, the Navy, or the Air Force, in addition to the Civilian Service already providing for the peace-time needs of the people. The vital importance of weather in the development of civil aviation led in many countries to unification of the meteorological services under the Department of Aeronautics or of Transport. During the second world war history was to some extent repeated and there has been a further tendency towards the formation of a single state service which in some countries includes the colonial services also.

In Europe, in both France and Portugal the meteorological services at home and overseas have been unified. In France the new service, known as the Direction de la Météorologie Nationale, forms part of the Ministère des Travaux Publiques et de Transport. The meteorological services of the French colonies remain autonomous under the Colonial Governors but their work is co-ordinated under the Direction de la Météorologie Nationale by the Service Central de la Météorologie Coloniale. In Portgual the various meteorological services of Portugal, the Azores and the Colonies were combined in August 1946 into a National Meteorological Service under the President of the Council. There is also a Naval Service which is independent of the National Service.

Unification is not confined to Europe. In Egypt, in April of this year, the Meteorological Services of the Physical Department and of the Civil Aviation Department have been amalgamated into a single Meteorological Department under the Minister of Defence. A Meteorological Service has been formed in Anglo-Egyptian Sudan under the Sudan Posts and Telegraphs Department. Reorganization has taken place also in several of the South American Services, in Brazil in 1944, in the Argentine in 1945 and more recently in Peru ; in all cases it is intended that the reorganization should lead to increased activity. A state weather service known as the Chinese Weather Bureau has been established in China where it forms part of the Ministry of Education. The National Research Institute which was formerly responsible for the meteorological service of China devotes itself now purely to research and is entirely independent of the Weather Bureau though it is located only 100 yards from it and uses the same address.

The Meteorological Service of the U.S.S.R. has also developed very rapidly. The nucleus of the Service was formed as long ago as 1844 when the Central Geophysical Observatory was established in what was then St. Petersburg. After the revolution in 1917, there was at first a tendency for the separate departments to develop their own networks of observing stations and a stage was reached when the Ministries of Agriculture, Medicine, Forestry, Railways, etc., each had its own meteorological organization in addition to the independent institutes dealing with meteorology, hydrography, terrestrial magnetism, etc. In 1932 the various civilian meteorological organizations and institutes were united under the control of a State Hydrometeorological Service. Originally this was under the Department of Agriculture but later it became an interdepartmental service and finally it came directly under the Council of Peoples' Commissars. The Army and Navy continued to develop specialist services of their own. When war began in the U.S.S.R. the Hydrometeorological Service was largely militarised and combined with the other two services to form a single Hydrometeorological Service for the whole country.

The United States is exceptional in having three Government Meteorological Services, the Weather Bureau, the Weather Service of the U.S. Army Air Force and the Aerology Section of the U.S. Navy. The first provides meteorological information for the general public and the other two cater for the needs of the armed forces to which they are attached. Co-ordination between the three services is in the hands of a Committee of their chiefs. The Weather Bureau, by far the oldest of the three, was founded in 1870 as part of the Signal Service of the U.S. Army (later known as the Signal Corps), in 1891 it was transferred to the Department of Agriculture where it remained until 1940, when it was transferred to the Department of Commerce. In addition to the three State Services several of the private airlines in the United States have meteorological services to meet their own requirements both within and outside the United States.

In Europe in ex-enemy countries and in countries where the meteorological services were disorganised during the war new services are gradually being built up again. In Czechoslovakia the Service is under the Ministry of Transport ; there are two Meteorological Offices, the State Meteorological Office in Prague and the State Hydrological and Meteorological Office for Slovakia at Bratislava. In Greece the complete reorganization of the Meteorological Service and of the National Réseau of meteorological stations is under consideration by the Government.

In both Germany and Austria as a result of quadripartite agreement after the war ended meteorological organizations were set up in each of the four zones to meet the needs of the Allied Powers. The services were under the direct control of the Military Government of the occupying power, co-ordination being maintained through a Committee of Meteorology. In Austria the Allied Council approved the establishment of a united Austrian Meteorological Service from August 1, 1946. The Service is administered by the Ministry of Education of the Austrian Government through the Central Institute for Meteorology in Vienna but is still supervised by the Quadripartite Meteorological Sub-Committee of the Air Directorate, Allied Commission for Austria. In Germany the four zonal meteorological organizations came into being in 1946, their structure being based on a plan of British origin. At present the policy is determined by the Quadripartite Committee on Meteorology of the Allied Control Authority in Berlin. In the British Zone a Central Office, the "Meteorologische Amt für Nordwest Deutschland" (M.A.N.W.D.) has been established in Hamburg under the direction of the Chief Meteorological Officer of the zone. At some time in the future it is expected that the four German zonal organizations will be merged into one service, directed by Germans but controlled by an agency appointed by the Allied Control Authority.

In conclusion a brief list of some of the Meteorological Services, classified according to the Departments by which they are administered, may be of some interest. The classification cannot of course be very rigid, owing to differences in the names and functions of the Departments in the different countries. The information is taken chiefly from Publications Nos. 2 and 52 of the International Meteorological Organization.

Agriculture.—Burma, Bolivia, Brazil, Bulgaria, Costa Rica, Finland, Guatemala, Haiti, Hungary, Mexico, Philippines.

Aeronautics or Air.—Algeria, Argentina, Australia, Cameroons, Great Britain, Greece, Italy, Palestine, Peru, Rhodesia, Spain, Syria, Tunis.

Communications, Transport, Works, Interior, Posts and Telegraphs.—Anglo-Egyptian Sudan, Canada, Czechoslovakia, France, India, Iraq, Lebanon, Netherlands and Netherlands East Indies, Poland, Switzerland, Sweden, and South Africa.

National Defence, Navy, Marine, War.—Chile, Cuba, Denmark, Egypt, Portuguese East Africa, Roumania, Thailand, Uruguay, Venezuela.

Commerce or National Economy.—Colombia, Ecuador, Eire, United States.

Education or Research.—Belgium, China, Salvador, Norway, New Zealand and Samoa, Yugoslavia.

UNSOLVED PROBLEM OF CLIMATIC CHANGE

BY C. E. P. BROOKS, D.SC.

Part II. Theories

At one time or another more than fifty different theories have been put forward to account for geological changes of climate. If we leave aside a few freaks, these fall into five broad classes : variations of solar radiation ; changes in the elements of the earth's orbit ; movements of the continents relative to the poles and to each other ; changes in the constitution of the earth's atmosphere ; and changes in the configuration of the earth's surface.

Quite early after the discovery of ice ages, theorists naturally turned to the sun, and evolved ingenious mechanisms for decreasing solar radiation, either the amount emitted by the sun, or the amount reaching the earth. In 1929 however Sir George Simpson [1,2*] pointed out that glaciation implies increased snowfall and therefore stronger solar radiation to give the necessary evaporation. His argument was that the sun is a variable star, at present near its mean phase. As radiation increases, so does evaporation, cloud and precipitation. The proportion of precipitation falling as snow decreases, but for a time the actual snowfall increases ; this causes glaciation. But as the sun grows still hotter, snow turns more and more to rain and finally vanishes ; this is an interglacial and also a pluvial period in the tropics (see page 129). Radiation reaches its maximum and begins to decrease, bringing a second glaciation, but as it falls to its minimum, although the ratio of snow to rain becomes very high, the total amount is insufficient to maintain the glaciers and there follows a long dry cold interglacial.

This theory accounts well enough for the series of individual glaciations (though there are difficulties about the cold interglacial), but it does not consider the cause of the ice age as a whole. If as is assumed, the sun is a periodically variable star, glaciations should have recurred at short intervals throughout geological time ; the theory cannot account for the long genial periods. This difficulty was to some extent overcome by F. Hoyle and R. A. Lyttleton[3], who supposed that at intervals of time of the order of 100 million years the sun passes through clouds of interstellar matter. The particles on and near the track fall into the sun, their kinetic energy being converted into heat and giving rise to increased solar radiation. Since the cloud would in general be densest near the centre, radiation would rise to a maximum and then decrease again, the time of passage being of the order of 100,000 years. Further, since many such clouds are irregular, the one causing the Quaternary ice age may have had two centres, so giving two maxima of radiation and four glaciations. The combined theory appears to be possible and does not conflict wildly with the data, though it fails to account for the long mild periods and there remain also a number of minor difficulties.

The second group of theories, which relate climatic changes to the elements of the earth's orbit, goes back to Croll's famous argument in 1875 that glaciation occurred in periods of great eccentricity of the earth's orbit in the hemisphere with winter in aphelion. This supposes that glaciations alternated in the two hemispheres, which we now know to be untrue. Further, it is unlikely that a very cold winter and a very hot summer would cause glaciation ; in fact as early as 1876 J. J. Murphy pointed out that glaciation was more probable in the hemisphere with summer in aphelion, and the view that low summer radiation is more important than low winter radiation for glaciation is now generally accepted. Eccentricity is not the only factor however ; the obliquity of the ecliptic, which governs the latitude of the Arctic and Antarctic circles, is equally important, and the variations of this factor coincide in both hemispheres. Detailed calculations of radiation in the summer half-year, taking all astronomical factors into account, were published by M. Milankovitch in 1921, and

* The list of references is on page 151.

have recently been made the basis of an elaborate reconstruction of the Quaternary ice age by F. E. Zeuner[4]. Zeuner shows that the variation of the present snow-line with latitude closely follows the variation of radiation in the summer half-year, and argues that with changing astronomical conditions a rise of the winter temperature increases the snowfall and the corresponding fall of summer temperature enables the snow to persist through the summer (the sun remaining unchanged, a decrease of summer radiation is accompanied by an approximately equal increase of winter radiation). Zeuner also follows up various secondary effects such as reflecting power of snow, change of tracks of depressions, lowering of sea level due to locking up of water in the form of ice, and the delayed isostatic effect of ice in depressing the land. The result is a detailed scheme of changes of climate and sea level which fits in very well with the most recent geological interpretations. The chief difficulties are that here again we have a theory of glaciations, but not of the succession of ice ages and genial periods, and that the changes of radiation associated with these astronomical factors seem very small in relation to the mighty consequences they are supposed to have brought about. In particular, the minute changes of radiation near the equator bear no relation at all to the great sequence of pluvial and interpluvial periods, and the latter are more adequately accounted for either on Sir George Simpson's theory or as secondary effects of the glaciation of higher latitudes on the atmospheric circulation.

Movements of the continents relative to the poles, or *vice versa*, account for the appearance of climatic change by denying its reality. The idea dates back to 1886 but is now generally associated with the name of A. Wegener, who constructed a detailed hypothesis of the drift of continents relative to each other and to the poles, which appeared to explain away all the evidence for long-term climatic changes, though he had to turn aside to astronomical causes for the details of the Quaternary Ice Age. Even at the time of publication the theory met with a very mixed reception, and since then difficulties have accumulated. The theory of continental drift now finds little support ; practically its only remaining claim to favour is that no other theory seems able to deal so easily with the low-latitude glaciation of the Permo-Carboniferous.

The suggestion that long-period variations of climate might be due to changes in the amount of carbon dioxide in the atmosphere was first made by S. Arrhenius in 1896, and has had a chequered career depending on the state of knowledge of the absorption of radiation in the atmosphere. Favourably received at first, it was almost abandoned in the 1920's, but was revived by G. S. Callendar[5], who attributed the Permo-Carboniferous and Quaternary ice ages to the exhaustion of carbon dioxide by the great forests of Carboniferous and Tertiary times and the resulting formations of coal and lignite respectively. Callendar clinched his argument by pointing to the great liberation of the gas in recent decades by human agencies, and the general rise of temperature since about 1885. The latter rise covered too short a period to form the basis of a satisfactory argument (as subsequent events have shown). The geological changes in the composition of the atmosphere may have had a long-term effect on climate and may have been a contributory factor in the occurrence of ice ages, but they cannot have caused the rapid changes from one glaciation to another within an ice age.

Finally we come to a large and diverse group of theories which depend only on the effect of the ordinary geological processes of elevation, erosion and depression of continents on the configuration of the earth, the height of mountain ranges and the course of ocean currents. The importance of land and sea distribution is obvious on any world map of temperature or precipitation, and its geological significance was pointed out by Charles Lyell ; elevation as a cause of climatic change was emphasised by W. Upham in 1890, while the possible effect of a deflection of the Gulf Stream has been toyed with since early days. At first sight the calculated effects are insufficient to explain the great geological changes of climate but this difficulty was overcome by the discovery of a critical dividing line between glacial and non-glacial climates . On the other hand the geographical theory fails to account for the sequence of glaciations within an ice age and is in some trouble over the peculiar climates of the Permo-Carboniferous. The latter difficulty has to some extent been removed by recent work, such as that of B. Haurwitz on the power of dense cloud to reflect solar radiation, and by the experiments of P. Lasareff on oceanic circulation. The climate of the Permo-Carboniferous was unique, but so also was the distribution of land and sea, and the geographical explanation may not be entirely ruled out.

Another difficulty is that the major ice ages were not synchronous with the major periods of mountain building, but lagged some millions of years behind them. This was met by A. Wagner by the suggestion that mountain building releases great quantities of earth heat which for some time keep the nascent glaciers mobile and easily destroyed, so that it is not until this earth heat is largely dissipated that great ice sheets can develop.

From this rapid survey we see that the possible factors of climatic change are manifold and diverse. Some, like variations of solar radiation and continental drift, are possible and could undoubtedly have effected some of the changes observed, but there is little or no evidence that they actually occurred ; in the case of shifting continents the evidence is on the whole adverse. The changes in the earth's orbit presumably occurred very much as calculated by Milankovitch, and must have produced some effect on climate. There are sequences of deposits in earlier geological ages which point to rhythmic changes of the annual variation of temperature over periods of 20,000 years or so, and these are reasonably attributed to the precession of the equinoxes. But these effects are small, and it seems unlikely that any such changes, which leave the total solar radiation unaltered, could possibly have resulted in climatic changes so vast as the alternation of glacial and interglacial periods. Moreover, none of these theories account for the genial periods which make up by far the greater part of geological time. Changes in the amount of carbon dioxide in the atmosphere have most probably occurred, and by their selective absorption of radiation may have modified temperature somewhat, but probably not to a sufficiently large extent ; moreover they are necessarily slow and could not explain the rapid fluctuations during an ice age. Finally changes in land and sea distribution are probably able to account for genial climates and ice ages, but not for the alternation of glacial and interglacial periods. The conclusion forced upon us is that no single cause can explain all the phenomena of geological changes of climate, and we must look to a combination of causes.

If we look at the problem from another angle, we reach the same conclusion. We cannot know for certain that solar radiation has varied widely from one geological period to another, but when we consider the known changes of the sunspot cycle, such variations appear inherently probable, and if they occurred, their consequences must have resembled those described by Sir George Simpson.

The known changes of the elements of the earth's orbit appear to fit the details of the Quaternary ice age very well. We know that the composition of the earth's atmosphere must have changed, and the changes fit the positions of the great ice ages in the geological sequence. Finally, we know that the configuration and elevation of the land masses have undergone great changes, and the changes of climate inferred from palaeogeography fit in well with the known facts of palaeoclimatology.

In physical experiments, the correct procedure is to keep all the factors constant save one, and to observe the effects of varying that one. It happens that during the past 3,000 years or so there have been no appreciable changes in the elements of the earth's orbit, the configuration of the land or (until man took a hand in the nineteenth century) the composition of the atmosphere. The only remaining factor, solar radiation, may or may not have been constant, but at least there is evidence that the aspect of solar activity represented by sunspots has varied greatly. The data are somewhat scanty but both sunspots and aurorae appear to have been unusually numerous between about 1070 and 1375. This was a period of increased rainfall generally and of great storminess in the North Sea, but not of an extension of glaciers, which so far as can be determined remained quiescent. There was a period of reduced solar activity from 1380 to 1510, during which the climate of Europe seems to have been on the whole rather mild and dry. On the other hand the " Little Ice Age " which began about 1600 does not appear to show any connexion with solar activity and is at present unexplained. The solar theory, like all other theories of climatic change, remains unproved.

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DIURNAL VARIATION OF EVAPORATION FROM NATURAL SURFACES

BY E. J. SUMNER, B.A.

Part I

In the past, evaporation studies have been determined by the needs of water engineers and agriculturalists, who are principally interested in the total evaporation over a long period of time rather than changes in the evaporation rate over short periods. The present article is concerned with the diurnal variation of evaporation and indicates a way of finding it based on energy considerations. A similar method has been applied to the diurnal variation of evaporation from oceans by Sverdrup[1]* but, to the author's knowledge, it has not been applied to the earth before.

By far the larger part of the evaporation from a surface covered with living vegetation is due, not to direct evaporation from the underlying soil, but to transpiration from the plants themselves, and the two words are used synonymously in this context.

Energy Method.—Briefly, it is proposed to find the amount of heat available at a given time for the evaporation of water from the earth.

Let I be the surplus radiant energy absorbed by unit area of the ground per unit time, that is, the radiation from sun and sky minus the effective back radiation from the surface. If H_E is the heat used in evaporation and H_C is the rate at which heat is dissipated to the atmosphere, then by the Conservation of Energy

$$H_E + H_C = I - \int_0^\infty \frac{\delta(cT)}{\delta t}\, dz \qquad .. \ (1)$$

where the integral is equivalent to the heat stored in the ground per unit time, T being the temperature, z the depth below the surface, t the time, and c the thermal capacity of the soil per unit volume.

The surface temperature, T_G say, may be analysed into its various harmonics and expressed mathematically by a Fourier series of the form

$$T_G = A_0 + \sum A \sin(\alpha t + \beta) \qquad .. \ (2)$$

In practice only two or, at the most, three harmonics are necessary.

Assuming that the earth is an isotropic substance and that the isothermal surfaces are planes parallel to the surface so that there is no inflow of heat from the sides, then T satisfies the following differential equation :—

$$\frac{\delta T}{\delta t} = \mu \frac{\delta^2 T}{\delta z^2}$$

where μ is the thermal diffusivity of soil, here assumed to be constant. The solution of this equation with the appropriate boundary condition (2) is

$$T = A_0 + Bz + \sum A e^{-\sqrt{(\alpha/2\mu)}.z} \sin\left(\alpha t - \sqrt{\frac{\alpha}{2\mu}} \cdot z + \beta\right)$$

from which we get

$$H = \int_0^\infty \frac{\delta(cT)}{\delta t}\, dz = \int_0^\infty c \left\{ \sum A\alpha e^{-\sqrt{(\alpha/2\mu)}.z} \cos\left(\alpha t - \sqrt{\frac{\alpha}{2\mu}} \cdot z + \beta\right) \right\} dz$$

$$= c \sum \sqrt{(\alpha\mu)} \cos\left(\alpha t + \beta - \frac{\pi}{4}\right) \qquad .. \ (3)$$

If we write the ratio H_C/H_E as R, the so-called Bowen's ratio, and put H_E equal to LE, where E is the rate of evaporation at the time considered and L is the latent heat of evaporation of water (585 cal./gm.), equation (1) becomes

$$EL\,(I + R) = I - c \sum A \sqrt{(\alpha\mu)} \cos\left(\alpha t + \beta - \frac{\pi}{4}\right) \qquad .. \ (4)$$

* The list of references is on page 157.

In order to evaluate E, the rate of evaporation, it merely remains to find R since all the factors on the right of equation (4) are calculable provided the necessary climatological observations exist.

Derivation of Bowen's ratio. The following analysis is fundamentally the same as that given by Bowen[2] himself with a few modern refinements.

In the earth's atmosphere the equations for the transfer of heat and moisture (or its heat equivalent) take the form

$$\left.\begin{aligned} H_C &= -\mu_1 \rho c_p \left(\frac{\delta T}{\delta z} + \gamma\right) \\ H_E &= -\mu_2 \rho \frac{0{\cdot}621\, L}{p} \cdot \frac{\delta e}{\delta z} \end{aligned}\right\} \quad \ldots (5)$$

where, in the steady state, H_C and H_E are constants independent of the height. In these equations μ_1 and μ_2 are the coefficients of eddy diffusivity of heat and moisture respectively, T is the air temperature, e the vapour pressure, c_p the specific heat of air at constant pressure (0.241), p the atmospheric pressure, ρ the density of air, and γ the dry adiabatic lapse rate (1.0°C./100m.)

Integrating equations (5) we get

$$H_C \int_0^h \frac{dz}{\mu_1} = \rho c_p \left(T_G - T_A - \gamma h\right)$$

$$H_E \int_0^h \frac{dz}{\mu_2} = \rho \frac{0{\cdot}621\, L}{p} (e_G - e_A)$$

where the suffixes G and A refer to the value of the appropriate element at the ground and at a low height h, respectively.

Now, since the agency involved in the vertical transport of moisture and of heat is the same, viz. eddy diffusion and convection, we can equate μ_1 and μ_2, making the two integrals the same, so that

$$R = \frac{H_C}{H_E} = \frac{p c_p}{0{\cdot}621\, L} \cdot \frac{T_G - T_A - \gamma h}{e_G - e_A}$$

Putting in numerical values for c_p and L, and ignoring the small quantity γh, which is only .03, when h is equal to 3m. (screen height at Kew), then

$$R = \frac{0{\cdot}66 p}{1{,}000} \cdot \frac{T_G - T_A}{e_G - e_A} \quad \ldots (6)$$

It should be noted that this ratio is exact under the conditions specified and is in no way affected by the variation of μ_1 and μ_2 with height. The validity of applying it to the present problem and the degree of inaccuracy entailed will be discussed later.

We are now in a position to determine E, the rate of evaporation.

Diurnal evaporation from a grass surface.—The results of the calculations for Kew for all seasons of the year 1927 (except winter) are shown in Fig. 1. The curve for winter was excluded because R was found to approach 1 on many occasions, so that a small percentage error in Bowen's ratio would produce a manifold error in the computed evaporation or deposition. Values for the thermal diffusivity of soil (ranging from 4 to 5 × 10^{-3} sq. cm./sec.) and the Fourier coefficients for the diurnal variation of ground and air temperatures were given

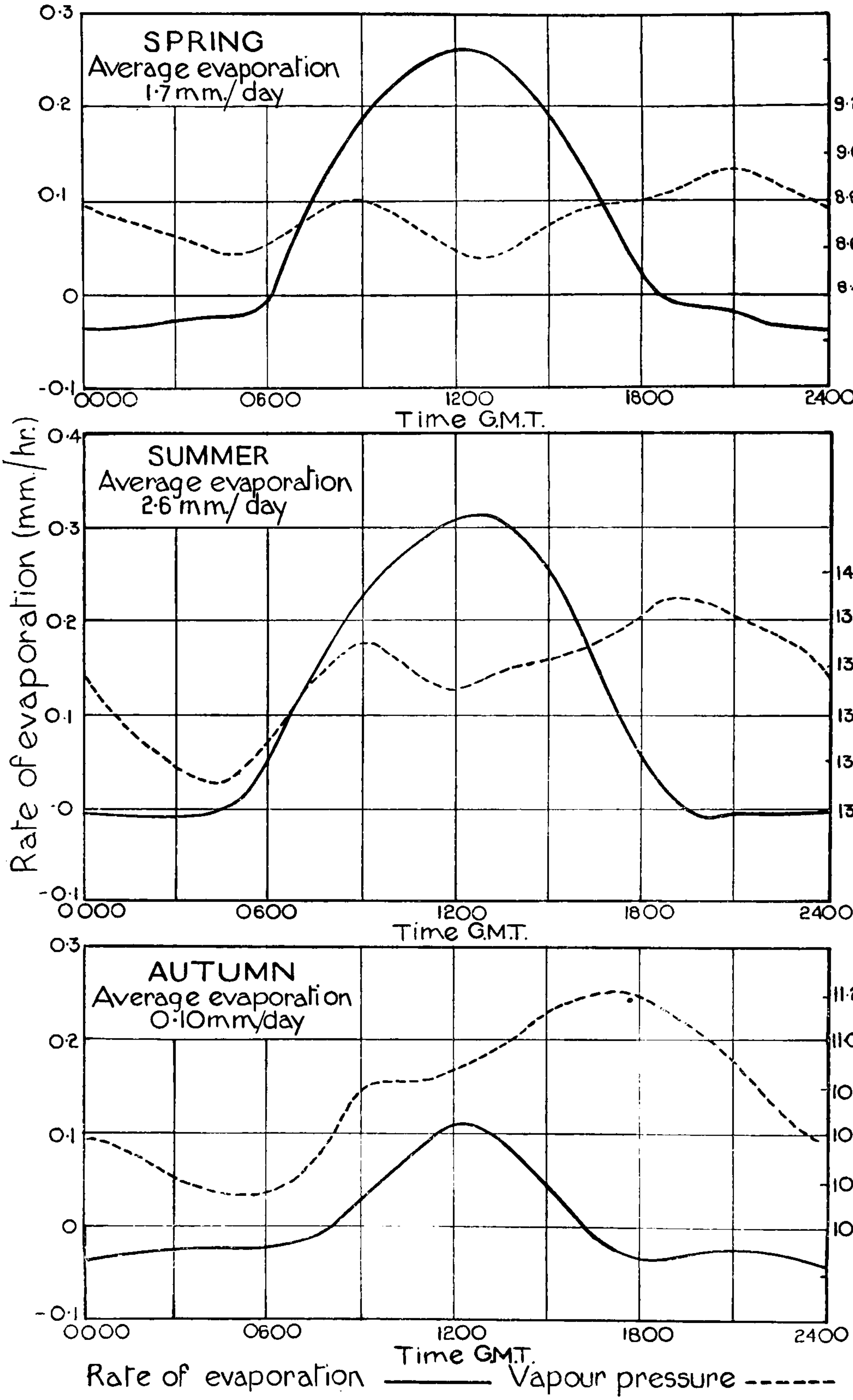

FIG. 1—DIURNAL EVAPORATION AT KEW, 1927

in a paper by H. L. Wright[3], while such information as the mean sunshine, the mean vapour-pressure, etc., was taken from the *Observatories' Year Book* for 1927.

The year in question was an abnormal one in some respects, having a warm sunny spring and a cloudy summer and autumn with plenty of rain. The relatively high sunshine in spring partly accounts for the high evaporation found for this season.

Since diurnal readings of evaporation are practically non-existent it is impossible to check the shape of these curves satisfactorily. However one can compare the average values of the total evaporation with existing values.

Dr. H. L. Penman[1] of the Rothamsted Experimental Station, found by actual measurement of the evaporation from experimental tanks with a covering of turf, the following average values for 1945 : about 2·5 mm./day during the summer months, and roughly 1·9 mm./day in spring. These figures are in good agreement with those for Kew.

The following readings, due to Wallén, and taken from a paper by Ångström[5] are tabulated with those obtained for Kew.

		Average total insolation reaching the ground	Mean air temperature	Evaporation
		cal./sq. cm./day	°C.	mm./day
Spring	Stockholm	277	4.0	1.0
	Kew	270	9·9	1·7
Summer	Stockholm	355	15·3	2.2
	Kew	310	15·5	2.6

Wallén's figures were found from the difference between rainfall and run-off over a long period of time. The summer values are in good agreement, whereas those in spring are very much smaller for Stockholm owing to the lower temperature.

Commentary.—For evaporation to proceed two things are necessary : a continuous supply of energy and a mechanism for transporting vapour away from the evaporating surface so as to maintain a moisture deficit in the air immediately in contact with it ; if either is absent evaporation soon ceases. Near to the earth's surface the flux of moisture is effected mainly by molecular diffusion, and the moisture gradient within the semi-boundary layer controls the rate of flow and hence the rate of evaporation. Conditions at the ground are generally very different from those at a few metres above it, and it is quite possible for evaporation to stop even when humidities at screen height are well below saturation. Another consideration is the fact that plants, unlike free water surfaces, can exercise a limited amount of control over transpiration losses by means of stomatal movements. The stomata (pores) of most plants are markedly sensitive to light intensity, closing up at night and opening promptly at sunrise.

With these ideas in mind it is easier to interpret the diurnal curves. They all show the controlling influence of solar radiation (see Fig. 2), so that the maximum rate of evaporation is reached around midday and not in the middle of the afternoon when the evaporativity of the air at screen height is greatest. Another feature they have in common is the absence of evaporation at night and its early start immediately after dawn when stomatal control is relaxed.

In spring and autumn there is a quite noticeable increase in the rate of dew deposition soon after 2100 as the initial rapid release of heat stored in the ground begins to diminish. Although this effect is not visible in the other mean curves it is probable that individual days at all seasons would show a similar tendency.

Of the available heat energy, on an average about 60 per cent. goes in evaporation, about 20 per cent. is stored in the ground during the day, and the rest is given off to the atmosphere. These proportions, of course, vary from place to place.

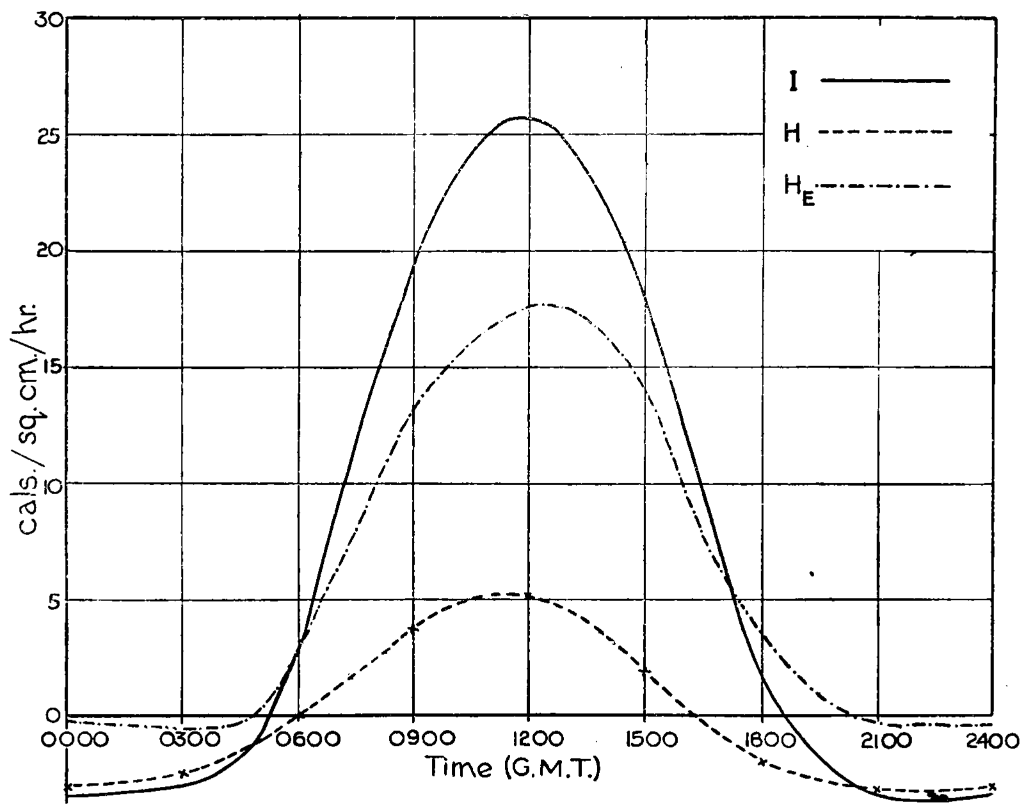

FIG. 2—DIURNAL VARIATION OF AVAILABLE SOLAR RADIATION, BODY HEAT AND HEAT OF EVAPORATION AT KEW DURING SUMMER, 1927

It is well known that grass-covered soil is subject to less extremes of temperature than bare earth. This is partly due to the insulating effect and the thermal capacity of the grass itself, but mainly to the heat absorbed in evaporation. The surface layers of bare soil soon dry up under evaporation and remain dry until rain falls again, whereas plants are enabled to collect much sub-soil moisture and maintain their transpiration rate for very much longer periods.

Variation of Vapour Pressure.—The variation of vapour pressure at any point above the earth depends both on the rate of evaporation from the surface below and the vertical transport of moisture away from it due to eddies together with advection effects resulting from lack of horizontal homogeneity. No attempt

[To face p. 156.

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ALTOCUMULUS CASTELLATUS AT BRISTOL, APRIL 16, 1947

(see p. 161)

LOW STRATUS CLOUD AT GIBRALTAR

September 18, 1946—Light easterly situation.

Photographs by E. L. Hawke

WRECKAGE OF OUSELEY KIOSK IN WHIPSNADE ZOOLOGICAL PARK, JANUARY 18, 1945

The right-hand photograph shows a 12-ft. strip of corrugated-iron roofing caught 30 ft. above ground by a neighbouring tree.

(see p. 162)

has been made to treat the subject quantitatively here, but the broader qualitative effects are very conspicuous in the curves which are included in Fig. 1, of the mean diurnal variation of vapour pressure at screen height (3 m.).

They all show the same characteristics : an initial fairly rapid increase in the vapour pressure, due to evaporation at a time when the atmosphere is stable so that the available moisture is confined to a thin layer of air, followed by a temporary drop, or a steadying up in autumn, when turbulence and convection make their presence felt. The moisture content of the air almost invariably decreases with height at this time of the day, so that increased turbulence transports drier air downwards. Ultimately evaporation gains control again and the rise is resumed. A considerable lag is evident in the upward diffusion of vapour in spring and autumn.

It is interesting to note that the biggest variation in vapour pressure is in autumn in spite of the small amount of evaporation. This reflects the stabler atmospheric conditions experienced at this time of the year, when evaporated moisture is spread over a shallow layer of air and, what is more important, deposited moisture is abstracted from a still shallower layer.

(To be continued)

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METEOROLOGICAL RESEARCH COMMITTEE

The 49th meeting of the Meteorological Research Committee was held on June 19 with Prof. G. M. B. Dobson as Chairman in succession to Prof. S. Chapman.

Some time was spent in considering the machinery for promoting international co-operation in meteorological research. The papers considered by the Committee included a note on the shape of falling raindrops, a paper dealing with the estimation of the pressure-pattern flight path for time of minimum flight and a report on some measurements of turbulence in clear air by means of smoke puffs.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held at 49, Cromwell Road, on May 21, Prof. G. M. B. Dobson, President, in the Chair, the following papers were read :—

Professor O. G. Sutton—The problem of diffusion in the lower atmosphere.

Prof. Sutton introduced the paper by remarking that, for the first time, it had been possible to publish some of the large amount of experimental data on the diffusion of gas which had been accumulated at the Chemical Defence Experimental Station Porton in the last 25 years. This experimental ground work, of good accuracy, was of fundamental value for the study of diffusion.

The paper gives an account of the theory of diffusion, developed by the author between 1932 and 1938, based on a concept which permits turbulent mixing to be treated as a continuous process. Using results from aerodynamic theory, the eddy diffusivity is related to the correlation coefficient R_ξ between an eddy velocity at any given instant and its value ξ seconds later. As the measurement of R_ξ directly is generally impracticable, it is necessary to find a suitable expression for it in terms of readily measurable quantities. The expression chosen is, in the case of vertical diffusion

$$R_\xi = \left(\frac{\lambda}{\lambda + \overline{w'^2}\,\xi}\right)^n \qquad , n \geqslant 0$$

in which λ is the kinematical viscosity of the fluid and n is obtained from wind-velocity measurements, it being shown that the index in the power-law representation of the wind velocity profile is $n/(2-n)$. The final expressions for diffusion from point and line sources at ground level give excellent agreement with observation when the value of $\overline{w'^2}$ (the mean-square vertical eddy velocity) is obtained from the records of a Taylor bi-directional vane by drawing an oval round the trace in the manner described by Best.*

Difficulties in the treatment are discussed, the chief being that when true values of mean square eddy velocity are employed instead of the " extreme " values given by the vane technique, then the theoretical rate of diffusion is considerably smaller than that found experimentally. This may be due to one of two causes :—

(i) The value of Kàrmàn's constant may be greater for the atmosphere than 0·4, the value found in laboratory work on fluid flow.

(ii) The surface of the earth may not be aerodynamically smooth.

These possibilities are discussed and it is finally suggested that both may be important.

Prof. D. Brunt welcomed the publication of this work and hoped that further papers in this field would follow. In the ensuing discussion several speakers paid tribute to the inspiration Prof. Sutton's work had afforded in the study of atmospheric diffusion. On the question of the source of the discrepancy referred to by Prof. Sutton, Prof. P. A. Sheppard considered there was little justification for an " atmospheric " value of Kàrmàn's constant. He felt the discrepancy resulted from the fact, now becoming well established, that flow over the earth's surface was, in general, aerodynamically rough, in which case the kinematical viscosity would not be expected to appear in the formulation.

W. G. V. Balchin and N. Pye—A microclimatological investigation of Bath and the surrounding district.

In this investigation the authors use the term " microclimatology " to mean the comparison of standard surface observations within a region of a few square miles ; they are not concerned with microclimatology in the sense in which it is sometimes used by agriculturists, viz., the comparison of observations made for special purposes in the lowest few feet of the atmosphere.

The authors showed a great deal of ingenuity in overcoming the difficulties of starting this investigation and they were finally able to obtain daily observa-

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* BEST, A. C. ; Transfer of heat and momentum in the lowest layers of the atmosphere. *Geophys. Mem., London*, 7, No. 65, 1935.

tions from 28 stations for 15 months. These records are not yet completely analysed, but the authors are already able to publish some interesting results. For example, maximum temperatures show that the valley stations are 3 to 4°F. warmer than the hill-top stations in winter, and 5 to 7°F. warmer in summer; on nights with " valley inversion " however, stations in the valley are 4°F. colder than those on the plateau ; these inversions occurred on more than one third of the nights and would have been still more frequent but for the " urban effect " of the city.

Many interesting slides were shown and those which dealt with the distribution of rainfall were particularly useful. It was clear that in 1945 the hill tops received 4 to 5 in. more rain than the valley bottoms, and that the windward slopes were wetter than leeward slopes.

There was a stimulating discussion at the end of the paper ; although not all the speakers agreed with some of the terms used by the authors, they were all convinced of the value of this type of work.

At the meeting of the Society held at 49, Cromwell Road, on June 18, Professor G. M. B. Dobson, President, in the chair, the following papers were read :—

Sir Gilbert Walker—Arctic conditions and world weather.

It is widely recognised that there have been large changes in recent years in northern regions, including a widespread temperature rise and an increase in the pace of the circulation. One of the most promising suggestions for the explanation of European weather changes is the disturbance of conditions by ice increases in the northern seas, and a considerable amount of work has been devoted to this relationship. During the past 30 or 40 years the mechanism of control seems to have changed fundamentally and the present paper represents a preliminary attempt to find out the relations of recent years. Conditions so closely associated 20 or 30 years ago that their connexion inevitably seemed to be a physical reality have in some cases changed materially, their relationships being diminished or even reversed.

The correlation derived between arctic pack-ice and Thorshavn temperatures suggests that the weather changes may be regarded as being made up of three component variations (*a*) relatively rapid, covering a few days (*b*) of medium length, three to nine months·(*c*) of slow change, covering four to twelve years or more. The effect of the slow changes are largely got rid of by taking departures from smoothed curves.

The annual values of the pack-ice of the Greenland and Barents Seas are correlated with meteorological conditions. It is found that the closest relationship occurs between the ice of one spring and summer season and pressure conditions of the previous winter. Wind thus appears to be the deciding factor, according with Speerschneider's dictum that the effect of wind on the amount of ice is so great that a severe ice year ought to be called a year of pronounced or abnormal wind conditions. Heavy ice years are found to be associated with high pressure in the previous winter in east Canada, Greenland, Iceland, Spitsbergen, Norway and the Faroes and with low pressure in the more southern regions such as the Azores, Austria and Siberia. At some stations there is evidence of a marked change of relationship between 1900 and 1910.

The correlation of the pack-ice with pressure and temperature at Stykkisholm and Thorshavn suggests the possibility of forecasting the general ice conditions at the beginning of March. The value of the joint coefficient, ·66, is however not large enough to justify an annual prediction.

For the ice off the Newfoundland Bank the data are more complete, but more baffling. The coefficients of –·76 and –·80 of this ice with pressures in Iceland and Greenland, based on over 20 years before 1906, have since become small. Many other striking changes are also shown for the period since 1905. The series of data must however be extended and the relationships corroborated before actual use of them for forecasting can be made.

The fundamental change in the relationships which occurred about 1905 must be physical in origin, but the nature of the change is still very obscure. It is suggested that there has been a large increase in the amount of ice carried into Baffin Bay by the easterly ocean current through the Canadian Archipelago. This would imply stronger westerly wind impelling the current, and consideration of pressure data from Barrow for 1922–40 appears to substantiate this. It seems however to have been overlooked that while the Newfoundland ice data used were derived from the numbers of bergs reaching the Bank, few or no bergs come through the Canadian Archipelago or Smith Sound. The places of origin of the great majority are all well known and are situated on the west coast of Greenland. The quantity of Newfoundland bergs must therefore primarily depend on previous conditions in west Greenland.

S. Duvdevani—An optical method of dew estimation.

All previous methods of observing dew depended on weighing, both before and after exposing to nocturnal radiation, a number of, usually hygroscopic, substances, ranging from gypsum plates to blotting paper and woollen cloth. These methods therefore suffer from the defect that, since they involved the careful use of the balance, they can only be used at research stations and not at many stations over a wide area.

Mr. Duvdevani's dew gauge depends on a simple eye observation of the appearance of the dew on a standard surface and comparing it with a number of photographs, each of which corresponds to a known amount of dew deposition as measured at a research station with Leick plates. The standard gauge finally adopted by Mr. Duvdevani in Palestine consists of a rectangular wooden block, 32 cm. × 5 cm. × 2·5 cm., coated with red oil paint.

A dew scale has been worked out, each number of the scale corresponding to a photograph in the dew atlas used with each observation, and it has been found that the personal effect in estimation leads to insignificant errors since discrepancies never amount to as much as a whole dew number.

As was pointed out in the meeting, the dew gauge suffers from similar defects to those of the evaporimeter in that it measures the amount of dew that would be deposited on standard substances and not the amount actually deposited on the ground or on plants.

As distinct from previous methods of measuring dew, the dew gauge measures the maximum dew deposited during the night not the net deposit of dew and it is not necessary to observe the gauge exactly at sunrise. Light rain has a different optical appearance on the gauge from dew and there is therefore no possible confusion between the two sources of moisture.

In Palestine, the gauge measures amounts of dew within the range 0·01 to 0·35 mm. but this range can be modified to suit other climates by applying a different coat of paint or by placing the gauge at a different height from the ground. Mr. Duvdevani emphasised that though the gauge gives valid data for monthly and annual totals, it does not yield accurately the amount of dew on any particular night.

LETTERS TO THE EDITOR

Instability in the uplifted warm air of occlusions

During a year's practical investigations on the North Atlantic Ocean which I conducted on board the S.S. *Manchester Port* in 1936–7, three examples of marked instability in the uplifted warm air of occlusions were experienced.*

In the first case there was lightning accompanied by rain and hail squalls. In the second case thunder and lightning were observed and there was a heavy shower (this was the only occasion on which thunder was heard at sea during the whole year's investigations). In the third case there was a period of heavy rain which corresponded to a rain belt of about 100 miles. In the last case one of the flying boats, *Caledonia*, then conducting a series of experimental transatlantic flights passed through the occlusion at about the same place and time and the pilot reported cumulonimbus cloud to 16,000 ft.

It was placed on record that it was " perhaps significant that in all three cases the warm air had only recently been occluded", that is, the marked instability was experienced near the apex of the warm sector of each of the respective depressions. It is of interest to note that the tentative suggestion implied in the above statement has since been confirmed by one of the more recent meteorological observational devices to which reference was made by Sir Nelson Johnson in his paper " Recent Advances in Meteorological Methods."† In that paper he points out that the development of the cathode-ray tube as a means of locating the position of electric atmospheric disturbances has enabled the distribution of such disturbances within cyclones to be investigated. It has been found that with occluded depressions " there is a maximum of atmospherics at the very apex of the warm sector suggesting that the velocity of ascent of the warm air is also greatest at this point."

This, theoretically interesting, result is of obvious practical importance to all forecasters, especially those engaged on aviation forecasting.

D. A. DAVIES

June 9, 1947.

Unusual cloud formation over Bristol

The following sequence of cloud formation occurred over Bristol during the afternoon of April 16, 1947 :—

From noon, excellent cirrocumulus developed to the south-west and was moving from 200° with a relative speed of 60 m.p.h. At 1300, small patches of altocumulus castellatus developed, at some 18,000–20,000 ft., and enlarged to a well-formed mushroom type of cloud. From about 1430, the medium cloud

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* London, Meteorological Office ; Report on a year's meteorological investigations on the North Atlantic Ocean. *Atlantic met. Rep., London,* No. 7, 1939.

† *Nature, London,* **157**, 1946, p. 24.

precipitated to a great length, retaining its mushroom-like top and producing the rare phenomena of a " parachute " appearance.

The photograph facing page 156 was taken between 1500 and 1700 G.M.T. looking north-east.

R. G. HOSKINS

April, 1947.

[The photograph shows an exceptionally good example of virga. The tops of the clouds probably consisted of supercooled water drops.

The Larkhill soundings do not show any outstanding feature, but at 1800 the lapse rate was slightly above the saturated adiabatic between 400 and 350 mb. (roughly 23,000 and 27,000 ft.). Relative humidity differed little from 70 per cent. between 550 and 350 mb., but there was very dry air lower down, the relative humidity being 7 per cent. at 850 mb. The upper winds over Larkhill showed no shear at any height which can explain the distortion of the precipitation trails towards the south-east, so that this effect must have been a local one. At 1800 over Larkhill, the wind at 500 mb. was 260° 25 kt. and above that it veered and increased slowly with height.

The general synoptic situation was one in which unstable medium and high clouds are frequent. There was a declining anticyclone over Germany and a new anticyclone coming in from the Atlantic. A slow-moving cold front over Ireland was still giving slight rain, but when it reached southern England next morning it gave no rain. A belt of falling pressure moved on ahead of the front and produced a flat pressure distribution over England, France and the Bay of Biscay by 1800. There was " sferic " activity over north Spain and the southern part of the Bay of Biscay during the afternoon and evening.

C. K. M. DOUGLAS]

NOTES AND NEWS

Small tornadoes or whirlwinds in the British Isles

In the March 1947 issue of the *Meteorological Magazine*, accounts were given of several small tornadoes or whirlwinds in the British Isles and mention was made of damage suffered at Whipsnade Zoological Gardens on January 18, 1945. Below we give a more detailed account of this and also of a small tornado which occurred in Birmingham on February 4, 1946.

Tornado-like characteristics appear to have developed during the passage over Dunstable Downs of the line-squall which crossed central and southern England on January 18, 1945, to the accompaniment of thunder, lightning and widespread heavy rain and hail. Within five minutes, between 1350 and 1355 G.M.T., very severe damage was done along a track not more than about 150 yds. wide in the northernmost area of Whipsnade Zoological Park, Bedfordshire, at a height of about 750 ft. above sea level. The Ouseley kiosk was demolished, the corrugated iron roof being smashed to pieces and large portions being whirled into adjacent trees, one section to a height of 30 ft. above ground (see photographs facing p. 157). Some 120 yds. to the north-west of the kiosk, the Bison shed had its upper part carried away ; this consisted of heavy-gauge corrugated iron with timber supports, including five lengths 13 ft. × 4 in. × 3 in., weighing approximately 15 cwt., and was blown *en masse* for a distance of about 300 yds. to north-eastward, where four lengths of 3 in. by 2 in. quartering were each driven end-on into the turf to a depth of 2 ft. After first striking the ground the corrugated iron roofing again became airborne and finally came to earth a further 100 yds. or so to the north-east, where it disintegrated. Numerous trees, among them sound and sturdy young oaks, were split and broken in the track of the storm.

During the tornado-like squall, which was accompanied by heavy rain, thunder and lightning, the thermograph in the Superintendant's garden—well away from the zone of destruction—showed an almost instantaneous fall of temperature of 5°F. followed by a rapid rise of 2 °F. It was reported at Dunstable that the barometer rose suddenly 2 mb. just before 1400 in the midst of a rapid fall, the temperature fell from 46°F. to 3 °F., the wind gusted to 62 m.p.h. with a veer from SW. to W. and there was heavy precipitation from 1325 to 1350.

The noise occasioned by the squall and by the demolition of the Ousely kiosk and the Bison shed were such that numbers of the staff were led to believe that a rocket-bomb had fallen in the park. Masses of chalk were blown for some hundreds of feet out of the flint pit to the south-east of the Ouseley kiosk.

E. L. HAWKE

The Birmingham City area experienced two brief but very intense thunder squalls within 24 hours in February 1946. The first occurred in the evening of the 3rd and the second about midday on the 4th.

I give my own private record of the weather of the 3rd, this was as follows :—

" A dull day with moderate to fresh, squally winds, varying in direction from SSW. to WSW. Slight intermittent to continuous rain fell between 0445 and 0940. Moderate intermittent to continuous slight rain fell most of the afternoon, but at 1900 there was an almost complete clearance of the sky. At 2040 cloud began to spread rapidly from the west and a faint rumble of thunder was heard ; at 2043 a much louder peal of thunder ; at 2045 a vivid flash of lightning and five seconds later a clap of thunder which shook doors and windows like a near by bomb explosion (reverberations prolonged over ten seconds) ; at 2050 commenced to rain moderate to heavy, no more lightning until 2055 ; thunder not quite so heavy as previous clap ; at 2058 the wind which had been fairly steady at 16 to 18 m.p.h. over the previous two hours shot up to a gust of 64 m.p.h. with a vivid flash of lightning and a rather terrifying clap of thunder and a torrential downpour of hail and rain which was driven almost horizontally by the squall. By 2105 the precipation had practically ceased and by 2115 the wind had died down to an average of 20 m.p.h. The sky cleared and continued so until midnight, the wind remaining fresh WSW. The whole storm or at least the major portion of it only lasted 20 minutes. Strangely enough there was no sudden change of wind direction during the squall, only a slow movement from SW. to W."

Now to carry on to the weather of the 4th ; I will quote again my record of the conditions as seen from the observatory.

" Fine from midnight to 0600 except for a very slight shower at 0200 ; sky becoming cloudy by 0900 with slight showers at 1050 and 1140 ; at 1240 a sudden squall, (gust 46 m.p.h. sudden wind change SW. to W.), accompanied by rather intense thunder and lightning (but not so bad as the previous evening), broke over the area ; a heavy shower of rain and hail occurred, (hailstones

$\frac{3}{8}$ in. diameter), ending with sleet at 1255. The weather cleared soon after and remained mainly fair for the rest of the day."

The main items of damage as reported in the newspapers were as follows :—

Houses were struck by lightning at Woodlands Farm Road, Pype Hayes, and also a factory in Cliveland Street which is nearer to the City centre. In the same area as the factory and about half a mile to the eastward a large hoarding was blown across what is normally a busy main road, (Aston Road in the vicinity of Love Lane) ; fortunately no one was injured. Further to the north in the Witton area some damage was done to house property by wind and in the same district it was reported that two men (one of them about 15 stones in weight) were blown violently to the ground and injured.

Further details of the storm on the 4th are given by the following letters.

The first is from H. M. Myers of the I.C.I. (Metals) Ltd., Witton, who writes :—

" I was holding a meeting in my office and at 12.45 p.m., approximately, the sky went as dark as night with violent thunder and lightning striking a few yards away. A terrific wind developed suddenly, to such an extent that we all feared that the building (very strongly constructed) was coming down. The noise of the wind, which only lasted a few seconds, rose to a shriek and the roof was lifted off a nearby building and carried about 20 yards away. At the same time the gable wall of another brick-built building was taken out completely without disturbing the roof. Slates were blown off roofs and glass was shattered in windows a considerable distance away, and telephone wires were down everywhere.

" I was in the track of the tornado, or whatever it was and judging from the damage it would appear to cover a width of only about 10 to 15 yards. Lightning was observed to strike during the short duration of the storm.

" I should add that I have had experience of 14 days' gales on the Atlantic, including one night of ' whole gale ' when shipping disappeared without trace, but I have never before experienced wind velocity such as occurred on Monday, but being indoors at the time I could not guess at the speed."

The second is from L. Hancox who writes :—

" We were in a building at Witton which was struck by the lightning, thunderbolt, or whirlwind, at exactly 1245 ; to me it seemed a combination of all three.

" It went very dark and then started to hail very hard. Then for a few seconds the hailstones were terrific and everything seemed to go to pieces. There was a sort of ripping tearing noise and everything seemed to vibrate, glass, slates and bricks started to fly about and then came an explosion, the roof fell in and the air was filled with a definite sulphurous taste ; everybody had it in their throats for some little while.

" In my opinion there was definitely a whirlwind or tornado with the storm, it could be heard coming and in those few seconds everybody sought cover. Luckily only one or two people were slightly hurt. An entire wall of one building appeared to be ' sucked out '."

The third letter is from H. T. Patchett, the Works Manager of Messrs. Higgs Motors Ltd., also of Witton and in the very near vicinity of the I.C.I.

"Whilst the thunderstorm was at its height, sudden gusts of wind, apparently, swept across our buildings and actually sucked out of a 'North-light' building, in various places, sheets of glass measuring 7 ft. by 2 ft. to the extent of 450 to 500 sq. ft. in area.

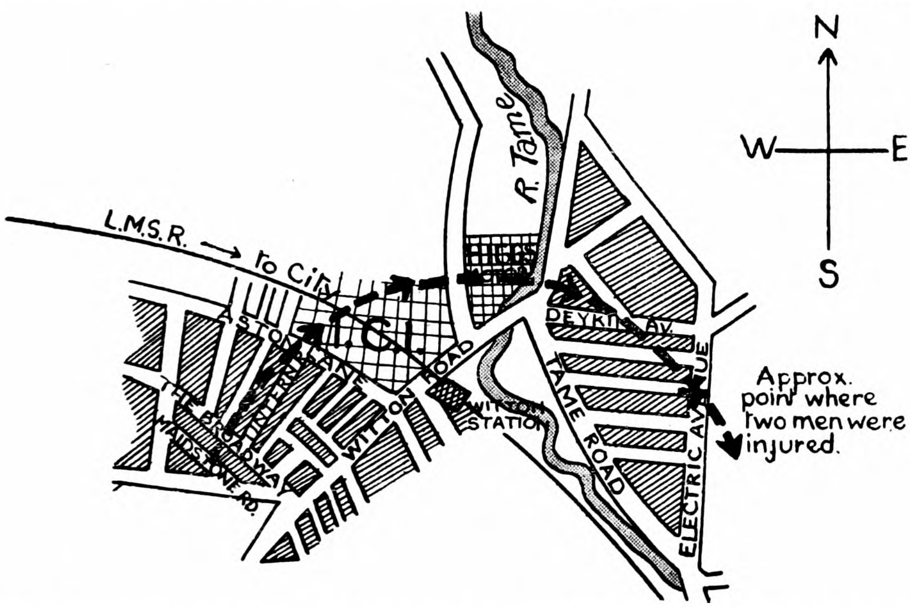
"In addition it ripped from the roofs some scores of feet of lead flashing. In front of the works, five trees that were planted between fifteen and twenty years ago, were torn out of the ground.

"The approximate time that this damage occurred was 12.45 p.m. and it was fortunate that the workers were not in the buildings and that the glass was sucked out instead of being blown in. This area seems to have been in the centre of a severe storm."

I do not think that there can be the slightest doubt from these three descriptions, that a small but rather intense tornado struck this particular portion of the Witton area during this storm.

The map below shows the route followed by the tornado.

A. L. KELLEY



[On February 3, 1946, a very deep depression was centred to the south of Iceland. A well marked cold front passed over the Birmingham area at 1900 G.M.T. The geostrophic wind across the front was about 60 m.p.h.

On the 4th the depression was still centred in the same position and a very unstable westerly air current giving heavy showers was blowing across the British Isles. No front could be traced in the Birmingham area near the times specified.—Ed. *M.M.*]

WEATHER OF MAY, 1947

The month opened with three days of cold NE. winds associated with high pressure to the north-west of the British Isles, but after about the 3rd, low pressure over the Atlantic west of Ireland caused light south-easterly winds with mild damp weather but little rainfall. A brief anticyclonic spell on the 12th–13th was followed by rather indefinite pressure distributions but moderately fine sunny weather until the 24th. On the 25th a deep depression developed over the Atlantic some distance west of Ireland while an anticyclone lay over Germany. This distribution persisted with little change until the end of the month. The resulting air stream from the continent gave a spell of fine very hot weather over much of England, but thundery conditions developed in parts of western England, Wales, Scotland and Northern Ireland.

The average pressure chart for the month shows anticyclones (above 1020 mb.) extending from north-east Greenland to include the Baltic, and from Bermuda eastwards across the Atlantic and a depression below 1009 mb. centred about 55° N. 35° W. The highest pressures of 1022 mb. in Sweden were 8 mb. above normal, and the lowest, about 1009 mb. south-west of Ireland, 5 mb. below normal. Elsewhere pressures differed little from the average for the month. Over the British Isles mean pressure exceeded the average in the northern half and was somewhat below the average in the south-west, the deviation at 0900 ranging from + 5·9 mb. at Lerwick to —1·9 mb. at the Scilly Isles. As a result winds from some easterly points were more frequent than usual and the total run of the wind was considerably below the average. The weather was warm and quiet, with frequent thunderstorms. Mean temperature exceeded the average ; over England and Wales as a whole it is estimated that it was the warmest May since before 1901. At Southport and Sheffield the mean temperature was the highest for May since records were started in 1871 and 1883 respectively. The period 28th–31st was exceptionally warm ; the temperature rose to 85°F. or somewhat above at numerous stations in England on the last three days. With regard to rainfall, broadly speaking, less than the average occurred in the north of Scotland and the eastern half of England and more than the average elsewhere. More than twice the average was received in parts of Angus and Fife, the extreme south-west of Scotland, locally on the west coast of Lancashire, in the neighbourhood of Bradford and Huddersfield and at Seaforde, County Down. On the other hand less than 25 per cent. was registered in an area extending south-south-east from the Humber across the Fens and the neighbouring part of Norfolk. In Shetland and Orkney, where it was the driest May since 1919, the rainfall amounted to little more than 25 per cent. of the average. Thunderstorms were reported on 9 days at Dumfries, Bellingham and Wakefield. Sunshine exceeded the average in east and north-east England and in Orkney and Shetland and was, on the whole, below the average elsewhere. In Orkney and Shetland it was the sunniest May for at least 25 years. The last week was very sunny over most of England, particularly in the eastern districts and the Midlands.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days diff. from average	Percentage of average	Percentage of possible duration
	°F.	°F.	F	%		%	%
England and Wales	90	28	+ 3.1	103	+ 1	94	39
Scotland	81	27	+ 2.3	124	+ 1	93	31
Northern Ireland ..	74	33	+ 2.2	156	+ 3	93	35

RAINFALL OF MAY, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	.97	55	*Glam.*	Cardiff, Penylan	2.48	101
Kent	Folkestone, Cherry Gdns.	1.12	67	*Pemb.*	St. Ann's Head	3.36	167
,,	Edenb'dg, Falconhurst	1.73	94	*Card.*	Aberystwyth	2.97	143
Sussex	Compton, Compton Ho.	1.51	68	*Radnor*	Bir. W. W., Tyrmynydd	3.93	115
,,	Worthing, Beach Ho. Pk.	1.35	82	*Mont.*	Lake Vyrnwy	3.70	109
Hants.	Ventnor, Roy. Nat. Hos.	1.59	94	*Mer.*	Blaenau Festiniog	3.78	67
,,	Fordingb'dg, Oaklands	1.80	87	*Carn.*	Llandudno	3.47	195
,,	Sherborne St. John	1.50	77	*Angl.*	Llanerchymedd	3.98	169
Herts.	Royston, Therfield Rec.	.90	46	*I. Man.*	Douglas, Boro' Cem.	4.02	161
Bucks.	Slough, Upton	1.89	113	*Wigtown*	Pt. William, Monreith	4.97	211
Oxford	Oxford, Radcliffe	1.88	100	*Dumf.*	Dumfries, Crichton R.I.	4.45	162
N'hant	Wellingboro', Swanspool	1.15	59	,,	Eskdalemuir Obsy.	3.49	106
Essex	Shoeburyness	1.15	88	*Roxb.*	Kelso, Floors	2.91	151
Suffolk	Campsea Ashe, High Ho.	.38	25	*Peebles.*	Stobo Castle	3.14	138
,,	Lowestoft Sec. School	.57	35	*Berwick*	Marchmont House	3.27	132
,,	Bury St. Ed., Westley H.	.54	30	*E. Loth.*	North Berwick Res.	3.87	194
Norfolk	Sandringham Ho. Gdns.	.31	17	*Midl'n.*	Edinburgh, Blackfd. H.	2.93	143
Wilts.	Bishops Cannings	2.05	105	*Lanark*	Hamilton W. W., T'nhill	3.29	138
Dorset	Creech Grange	2.35	115	*Ayr*	Colmonell, Knockdolian	3.53	138
,,	Beaminster, East St.	2.64	128	,,	Glen Afton, Ayr San.	5.58	186
Devon	Teignmouth, Den Gdns.	2.64	144	*Bute*	Rothesay, Ardencraig	5.09	168
,,	Cullompton	3.19	148	*Argyll*	Loch Sunart, G'dale	4.27	120
,,	Barnstaple, N. Dev. Ath.	1.73	84	,,	Poltalloch	4.02	139
,,	Okehampton, Uplands	3.62	135	,,	Inveraray Castle	4.45	113
Cornwall	Bude School House	3.45	187	,,	Islay, Eallabus	4.54	171
,,	Penzance, Morrab Gdns.	2.71	123	,,	Tiree	3.61	144
,,	St. Austell, Trevarna	4.27	176	*Kinross*	Loch Leven Sluice	3.88	159
,,	Scilly, Tresco Abbey	3.38	200	*Fife*	Leuchars Airfield	4.26	218
Glos.	Cirencester	1.55	75	*Perth*	Loch Dhu	6.10	136
Salop	Church Stretton	2.94	116	,,	Crieff, Strathearn Hyd.	4.11	165
,,	Cheswardine Hall	2.85	129	,,	Blair Castle Gardens	3.74	184
Staffs.	Leek, Wall Grange, P.S.	2.89	121	*Angus*	Montrose, Sunnyside	4.60	225
Worcs.	Malvern, Free Library	1.96	91	*Aberd.*	Balmoral Castle Gdns.	3.06	132
Warwick	Birmingham, Edgbaston	2.44	114	,,	Aberdeen Observatory	2.89	124
Leics.	Thornton Reservoir	1.26	63	,,	Fyvie Castle	2.61	101
Lincs.	Boston, Skirbeck	.43	24	*Moray*	Gordon Castle	1.67	79
,,	Skegness, Marine Gdns.	.13	8	*Nairn*	Nairn, Achareidh	1.52	85
Notts.	Mansfield, Carr Bank	2.04	96	*Inv's*	Loch Ness, Foyers	2.05	84
Ches.	Bidston Observatory	3.92	206	,,	Glenquoich	2.97	54
Lancs.	Manchester, Whit. Park	2.15	101	,,	F. William, Teviot	3.52	89
,,	Stonyhurst College	2.49	87	,,	Skye, Duntuilm	2.43	85
,,	Blackpool	4.40	202	*R. & C.*	Ullapool	1.04	42
Yorks.	Wakefield, Clarence Pk.	3.19	162	,,	Applecross Gardens	1.95	60
,,	Hull, Pearson Park	.55	28	,,	Achnashellach	1.94	46
,,	Felixkirk, Mt. St. John	2.22	118	,,	Stornoway Airfield	2.05	84
,,	York Museum	1.55	78	*Suth.*	Lairg	2.58	102
,,	Scarborough	.89	47	,,	Loch More, Achfary	1.52	35
,,	Middlesbrough	1.48	77	*Caith.*	Wick Airfield	1.24	60
,,	Baldersdale, Hury Res.	1.83	71	*Shet.*	Lerwick Observatory	.60	29
Norl'd	Newcastle, Leazes Pk.	1.80	91	*Ferm.*	Crom Castle	3.84	138
,,	Bellingham, High Green	3.17	132	*Armagh*	Armagh Observatory	3.54	149
,,	Lilburn, Tower Gdns.	2.45	106	*Down*	Seaforde	5.38	205
Cumb.	Geltsdale	2.27	88	*Antrim*	Aldergrove Airfield	3.17	140
,,	Keswick, High Hill	3.34	105	,,	Ballymena, Harryville	3.34	117
,,	Ravenglass, The Grove	4.97	178	*Lon.*	Garvagh, Moneydig	4.52	177
Mon.	Abergavenny, Larchfield	3.22	121	,,	Londonderry, Creggan	4.08	156
Glam.	Ystaeyfera, Wern Ho.	4.17	119	*Tyrone*	Omagh, Edenfel	4.36	168

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JANUARY, 1947

Stations	Pressure: Mean of Day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Temperatures: Mean values Min.	Temperatures: Mean values ½ Max. and Min.	Temperatures: Mean values Diff. from normal	Temperatures: Mean values Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hrs.	%
London, Kew Observatory	1016·3	−0·6	52	15	40·5	31·1	35·8	−4·7	33·6	86	6·5	1·35	−0·41	15	1·6	19
Gibraltar	1018·3	−3·2	69	40	59·6	50·0	54·8	-0·1 —	51·8	91	7·2	5·27	—	14	—	—
Malta	1014·1	−2·9	66	44	58·0	49·1	53·5	—	52·2	81	5·4	3·06	—	14	5·1	51
St. Helena	1014·2	−1·8	72	57	68·4	59·3	63·9	+0·5	59·8	97	9·7	3·37	+1·33	24	—	—
Freetown, Sierra Leone	1010·3	+1·0	90	69	84·3	75·1	79·7	+0·9	72·9	81	4·7	0·00	−0·41	0	8·2	70
Lagos, Nigeria ..	1010·2	+0·6	96	61	93·0	70·0	81·5	+0·6	74·6	83	6·5	0·00	—	0	6·8	58
Kaduna, Nigeria ..	1010·9	—	97	52	88·9	57·4	73·1	−0·5	52·2	14	1·6	0·00	0·00	0	9·7	84
Zomba, Nyasaland ..																
Salisbury, Rhodesia ..																
Cape Town ..	1014·4	+1·0	86	54	78·4	61·5	69·9	0·0	60·9	64	2·8	0·52	−0·16	6	—	—
Germiston, South Africa	1010·8	—	88	53	80·1	59·2	69·7	—	60·2	65	4·2	4·43	—	15	8·9	65
Mauritius	1008·9	−2·8	94	71	87·3	74·7	81·0	+1·7	75·6	80	6·4	6·11	−2·05	21	7·3	55
Calcutta, Alipore Obsy.	1014·8	−1·0	83	50	78·8	57·2	68·0	+1·4	57·3	84	2·0	0·24	−0·18	1	8·2	75
Bombay	1011·5	−2·1	90	62	84·8	67·1	75·9	+0·4	65·9	78	1·5	0·00	−0·10	0	9·9	89
Madras	1012·4	−1·7	87	68	83·0	71·9	77·5	+1·3	72·6	92	5·6	5·34	+4·20	8	8·2	72
Colombo, Ceylon ..	1010·5	−0·3	89	69	85·4	72·9	79·1	−0·4	73·6	95	6·3	3·13	−0·12	13	6·6	56
Singapore	1009·2	−1·2	91	71	87·0	73·5	80·3	+0·6	76·7	83	—	11·51	+1·62	19	—	—
Hong Kong	1018·3	−1·4	75	49	66·1	58·3	62·2	+2·0	59·3	87	—	2·60	+1·28	9	2·1	19
Sydney, N.S.W. ..	1013·4	+1·0	86	59	77·2	64·4	70·8	−0·8	64·9	66	5·3	1·67	−2·00	10	8·6	61
Melbourne	1012·6	−0·3	103	46	80·4	55·6	68·0	+0·6	57·9	48	5·5	0·65	−1·24	4	8·5	59
Adelaide	1013·9	+0·9	103	52	85·4	60·3	72·9	−0·8	60·8	40	5·5	0·21	−0·51	6	9·7	69
Perth, W. Australia ..	1013·0	+0·5	99	51	83·3	62·2	72·7	−1·1	62·8	50	3·8	0·01	−0·33	1	10·5	86
Coolgardie	1011·6	+0·2	105	55	93·4	64·6	79·0	+1·6	60·7	37	2·4	0·25	−0·21	2	—	—
Brisbane	1011·6	+0·3	92	66	84·8	70·8	77·8	+0·6	72·1	64	7·7	11·91	+5·46	14	7·6	56
Hobart, Tasmania ..	1011·2	+0·9	93	43	71·7	51·0	61·3	−0·7	54·0	56	6·3	0·79	−1·04	12	8·9	60
Wellington, N.Z. ..	1013·8	+0·5	74	43	66·8	52·2	59·5	−1·7	55·7	75	8·2	1·93	−1·40	7	6·8	46
Suva, Fiji	1008·0	+0·5	92	72	86·3	75·2	80·7	+0·8	76·8	83	6·7	11·73	+0·30	22	7·3	56
Apia, Samoa ..	1007·6	−0·3	89	72	87·4	75·2	81·3	+2·3	78·7	80	7·4	16·55	−0·50	23	6·8	53
Kingston, Jamaica ..	1015·2	+0·1	91	66	80·4	70·2	75·3	−1·5	71·2	70	2·3	0·41	−0·55	2	9·3	83
Grenada, W. Indies ..	—	—	85	69	83·2	74·0	78·6	+1·5	74·1	76	6·7	4·88	+0·50	20	—	—
Toronto	1016·1	−1·8	48	0	34·2	19·9	27·1	+4·9	23·4	—	8·2	1·57	−1·22	8	2·2	24
Winnipeg	1013·4	−7·5	38	−25	16·9	−3·2	6·9	+10·8	3·6	—	5·6	1·46	+0·55	11	2·2	26
St. John, N.B. ..	1014·8	−0·7	50	−10	31·8	11·5	21·7	+2·5	18·8	—	5·7	4·90	+0·10	15	3·9	42
Victoria, B.C. ..	1018·9	+2·9	53	5	41·1	26·8	33·9	−5·1	32·4	90	6·9	7·12	+2·58	19	2·3	26

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ARTIFICIAL STIMULATION OF RAIN FORMATION

BY J. K. BANNON, B.A.

Considerable newspaper publicity has been given to reports from the U.S.A. and Australia of rain-making experiments carried out in those countries; " dry ice " pellets or other very cold substances have been sprinkled on clouds which have by this means been induced to release rain or snow. The Moscow press has also reported that workers at the Institute of Physics of Odessa University have caused rain to fall from clouds by dusting them with calcium chloride powder.

The Australian experiments have been described briefly by Kraus and Squires[1]*, but the writer has been unable to find any detailed description of the American or Soviet work. It seems likely, however, that the general mechanism stimulated by the Americans and Australians is the same whereas the Russian method relies on the hygroscopic nature of the sprinkled particles and the growth of water drops on them.

Australian experiments.—In the Australian experiments granulated carbon dioxide was dropped, in quantities of a few hundred pounds, on isolated cumulus clouds. In six out of the eight trials, radar observations indicated that rain had formed inside the cloud and on four of these occasions heavy rain was observed visually to reach the ground. One case was doubtful and in one other, in which the cloud extended only 1,000 ft. above freezing level, no change was detected. In all the other experiments the clouds had a vertical extent of more than 10,000 ft. of which at least 4,000 ft. was above freezing level.

One of the most spectacular tests was described in detail. On the afternoon of February 5, 1947, there were 7–8 tenths of cumulus cloud over New South Wales; the base of the clouds was at 11,000 ft., the freezing level at 18,000 ft. and the tops of the clouds uniformly at 23,000 ft. The following is the description of the experiment as given by Kraus and Squires :—

* The list of references is on p. 174.

"At 13.45 hr., 100 lb. of granulated carbon dioxide was dropped into a cloud the top of which was slightly below the general level. After five minutes no visual results were observed. The aircraft flew on, and another test was carried out about twenty miles to the south-west. At 13.56 hr. 150 lb. of 'dry ice' was dropped into a second cloud. The aircraft circled, and in less than five minutes rain echoes from within the cloud were recorded on the aircraft's 10 cm. radar equipment. After the release of a further 150 lb. of 'dry ice', the echoes grew in intensity, and twenty-one minutes after the cloud was first infected an oblique view was obtained which showed heavy rain coming from the base of the cloud. Forty-five minutes later the aircraft descended to 8,000 ft., well below the cloud base, and a pillar of rain covering at least twenty square miles was then seen to reach the ground. Later interrogation of farmers in that vicinity confirmed the occurrence of an isolated rain storm.

"The flight was observed by a 25 cm. radar set at George's Heights in Sydney. Rain echoes appeared on the radar screen in the area of the first drop at 14.03 hr., that is, 18 min. after the release of 'dry ice'. In the second dropping zone, rain echoes were first sighted at 14.12 hr., or 16 min. after the release. It persisted for the rest of the afternoon. No other rain was observed within 100 miles of the aircraft."

The second infected cloud was seen to grow spectacularly and, twenty minutes after seeding, it had a small anvil which later grew to an estimated height of 40,000 ft. The first infected cloud did not grow to such an extent, but these two were the only clouds above the general level of the other tops.

Formation of ice crystals and consequent release of heat.—The exact mechanism of the changes brought about by the granulated carbon dioxide is not certain but is probably the following. Cwilong [2] has found that when clean air is cooled, the water vapour in it will not condense directly into ice crystals until the temperature falls to −41·2° C. or less; with ordinary outdoor air the threshold temperature is −32·2° C.

If the processes of condensation in a growing cumulus cloud are the same as in the Cwilong experiment, then we would expect to find super-cooled water particles in the cloud until the −32·2° C. level is reached, *i.e.*, roughly 16,000–17,000 ft. above freezing level in the tropics and 14,000–15,000 ft. in this country. Once the cloud has reached this level, ice crystals would be expected, and they, falling through parts of the cloud where the up current was not sufficient to support them, would gradually infect some of the cloud below, so that ice crystals and supercooled water drops would later be found much below the −32·2° C. level.

It is not known if this is indeed the case for there are no comprehensive observations as to the first appearance of ice crystals in a growing cumulus cloud. It is known, however, that supercooled water drops are the rule and not the exception, in clouds, for a considerable height above freezing level.

It seems safe to assume, therefore, that the cumulus clouds which were dusted with granulated carbon dioxide were composed of supercooled water drops.

Each granule of "dry ice" would have a temperature of not more than −65°C.[3] As the particle falls through the cloud it will cool below −32·2°C.

by contact, a thin trail of air, supersaturated with respect to ice, or some of the actual supercooled water drops, and will thus leave a trail of ice crystals before it melts. These ice particles will grow at the expense of the supercooled water drops.

The change from the water to the ice state in the cloud will, of course, release heat—the latent heat of fusion—and the denser the original supercooled water cloud, the more heat will be available. This is one reason why the original supercooled water cloud may grow when changed to an ice cloud.

Change in the saturated adiabatic lapse rate of temperature.—Another factor aiding growth of the cloud is the change in the lapse rate of temperature. When saturated air rises, it cools at a slower rate than unsaturated air due to the release of latent heat of condensation. If the temperature is just below freezing, the condensation will most likely be to supercooled water drops and the lapse rate of temperature will be greater than if the condensation were to ice crystals, for in the latter case more latent heat is released. The factors governing the saturated adiabatic lapse rate of temperature are rather complicated, but the writer has recently computed the lapse rates using Brunt's method[4] for temperatures below freezing, for the two cases of condensation to supercooled water and to ice, respectively. The two lapse rates, in conditions usual in this country, are about 0·64°C./100 m. (supercooled water), and 0·55° C./100 m. (ice) at temperatures just below freezing, but the difference between them gradually decreases until it is negligible at heights of 10,000 ft. or more above the freezing level.

It is seen therefore that because of the difference in the two lapse rates of saturated air above the freezing level, the environment may be stable for convective processes where the condensation is to supercooled water, and unstable when the condensation is to ice.

Thus in the supercooled water cloud which has had some of its particles changed to ice, not only will there have been a release of heat to aid further convection but the rate of cooling of the ice parts of the cloud, on further lifting, will be less than for the rest of the cloud and will thus further aid the growth of the cloud.

Order of magnitude of the heat changes in the experiment of February 5.—A few simple calculations may be made to show the order of magnitude of the heating which might be expected from the change from supercooled water to ice particles in the particular case of the experiment described in detail above, and also the difference in the two lapse rates, supercooled water and ice respectively, which would govern the growth of the cloud.

With the aid of a tephigram it is easily seen that the air entering the bottom of the cumulus cloud at saturation at 11,000 ft. will contain approximately 12 gm. of water vapour per kilogramme of dry air. At the top of the cloud at 23,000 ft. the temperature will be about −8° C. and the saturated water-vapour content can only be about 4 gm./Kg. Thus at the top of the cloud there may be as much as 8 gm. of supercooled water per kilogramme of dry air assuming that all the condensed water is carried with the ascending current. This does not allow for any mechanism which may concentrate the condensed water in any one part of the cloud, but this is probably unimportant in a young cloud in which there is as yet no precipitation, for the particles will not be large enough to have an appreciable velocity through the air and will thus move with the various up and down currents.

There may be, therefore, about 8 gm. of supercooled water per kilogramme of dry air in the top of the cumulus cloud under consideration. If we suppose that 7 gm. of this is quickly changed to ice, the heat released will be 7×75 gm. cal. since the latent heat of fusion of ice at –8° C. is 75 gm. cal./gm.

The heat released is absorbed by :—

7 gm. of ice
1 gm. of supercooled water
4 gm. of water vapour
1 Kg. of dry air.

Thus if t° C. is the resultant rise in temperature of the whole :—

$$7 \times 75 = t\,[(7 \times 0{\cdot}5) + (1 \times 1) + (4 \times 0{\cdot}47) + (10^3 \times 0.24)]$$

since the specific heats of ice, water, water vapour at constant pressure and air at constant pressure are respectively, 0·5, 1·0, 0·47, 0·24.

Hence $t = 2{\cdot}1$° C.

This would be the local rise in temperature due to the sudden change from water to ice if there were no loss of heat by other means. But of course much of the heat would be transferred by eddy diffusion to other parts of the cloud unaffected by the carbon dioxide granules, and so the rise in temperature of the ice part of the cloud will probably be considerably less than this figure.

In such a sudden change there would also be a small amount of heat released by further condensation from the water vapour direct to ice, since the saturation vapour pressure over ice is less than over supercooled water, but this will be negligible compared with the heat released by the freezing of the free water.

At freezing level, in the cloud, the two lapse rates of temperature will be about 0·53° C./100 m. for condensation to supercooled water and 0·47° C./100 m. for condensation to ice. At the top of the cloud, at 23,000 ft., the rates will be 0·59 and 0·54° C./100 m. respectively. Thus if part of the cloud just above the freezing level, becomes changed to ice particles and moves upwards by convection, when it reaches the top of the cloud, 5,000 ft. above, it will be, taking the mean of the difference of the lapse rates, about 0·8° C. higher in temperature than the surrounding cloud which is still in the form of supercooled water drops even though there was no such difference between water and ice parts, at freezing level. This of course neglects any loss of heat there may have been by conduction or diffusion, in the process.

It is seen, therefore, that the temperature differences caused by the changing of the supercooled water cloud to a part-ice cloud is of the order of 1° C. This is not large but there are many occasions when such a temperature difference would tip the balance in favour of further instability, and probably this was the case in the New South Wales experiments which were made on days when the meteorological conditions were thought to be most favourable.

Formation of rain in the cloud.—The above argument can explain the growth of the cumulus cloud and thus, indirectly, the formation of rain in it, since the deeper the layer of cumulus cloud the more likely the fall of rain from it.

But the report of the experiment says that less than five minutes after the "dry ice" had been dropped, "rain echoes from within the cloud were recorded on the aircraft's 10 cm. radar equipment".

The strength of radar echoes from hydrometeors is governed by three factors:—

(i) the distance of the reflecting drops from the radar instrument,

(ii) the diameter of the reflecting drops,

(iii) the number of reflecting drops per unit volume.

The radar signal, in fact, varies as Nd^6/r^2 where $N =$ number of drops per unit volume, $d =$ diameter of the drops, $r =$ distance between the cloud and the radar set.—Ryde[5].

The rain echoes observed therefore mean that either the diameter of the reflecting drops or their number had increased greatly within 5 minutes of the seeding of the cloud with "dry ice", since presumably the aircraft remained at approximately the same distance from the cloud. The formation of ice crystals of itself would not be expected to make any significant increase in the radar echoes (Ryde, *ibid.*).

But the total volume of the cloud particles is not increased by more than a small fraction by the transition from supercooled water to ice and thus Nd^3 remains almost unchanged in the process. Hence it is possible to say that the diameter of the drops must have increased within the cloud within a few minutes of sprinkling the "dry ice," and to call the echoes "rain echoes" is probably correct.

This is strong confirmation of the theory put forward by Bergeron[6], that moderate or heavy rain falls from clouds containing a mixture of supercooled water drops and ice crystals.

It is not possible to say exactly how the presence of the ice particles aids the growth of the cloud particles to dimensions sufficient for them to fall out as precipitation. Probably the different rates of fall of the ice particles and the supercooled water drops allows the former to grow at the expense of the latter by collision, and the ice particles will also tend to grow by direct condensation because the air, originally saturated with respect to supercooled water, will be supersaturated with respect to ice (Bergeron, *ibid.*). Indeed, once the process has started, it may mean the partial evaporation of the supercooled water-drops into the air, now saturated with respect to ice, and recondensation of this water vapour directly on to the ice particles.

From the data available, it is not known how soon actual rain fell from the bottom of the infected cumulus cloud. After 21 minutes, when the cloud had developed an anvil and had probably reached a sufficient height above freezing level to produce its own ice crystals (i.e. above the $-32{\cdot}2^\circ$ C. level, about 34,000 ft.), rain was seen falling from the cloud, but it may have started quite soon after the "dry ice" was released. It is certain, however, that the continuance of the rain was due to normal shower-cloud processes ; once the cloud was induced to grow and could produce its own ice crystals, presumably it could continue to produce rain so long as the heating at the ground continued, which caused the initial convection to bring up water from lower levels.

Turbulence within the cloud.—The rapid changes after the sprinkling of the carbon dioxide give an indication of the remarkable degree of turbulent mixing present within the cloud.

The aircraft presumably could sow the dry ice only over a narrow lane. As explained above, these granules may infect quite a deep layer of the cloud before they melt, but even so, only a comparatively small volume of the cloud can have been reached initially. Yet within eight minutes the cloud had grown considerably. It is inferred, therefore, that within five minutes or so turbulent mixing must have spread the ice crystals formed by the cooling by the carbon dioxide through a large volume of the cloud.

Conditions favourable for the stimulation of clouds.—The foregoing discussion indicates that the conditions suitable for the stimulation of a spectacular growth in a cumulus cloud must lie within rather narrow limits. The environment must be unstable for condensation processes to ice above the original cloud though, of course, stable for condensation to supercooled water, and there must be sufficient free water in the cloud to liberate heat on freezing, sufficient to start off further convection. If the lapse rate of temperature in the environment lies between the two saturated lapse rates, for condensation to supercooled water and to ice respectively, then only a very small impetus is required to make the cloud grow further once ice is induced to form in the cloud. If, however, there is a check in the lapse rate of the environment, above which the air is once more unstable for moist ascent, then the amount of heat which can be liberated by the change from supercooled water to ice is the important factor in deciding whether further growth of the cloud is possible.

Generally speaking, tropical or warm climates will be more favourable for carrying out such experiments than temperate climates. The difference between the two saturated adiabatic lapse rates of temperature for condensation to ice and supercooled water respectively, is slightly greater when the freezing level is high than when it is low, and there is also more water vapour in a hot climate (other than desert) which may be turned into liquid on ascent in a cumulus cloud.

As stated before, the Australian experiments were carried out on days which were specially selected as being considered likely to be favourable. The results of further experiments are awaited with great interest and, in particular, information as to the exact time of the induced rain relative to the growth of the cloud ; whether it actually falls before the cloud can produce its own ice crystals or whether the large growth of the cloud is necessary for the rain formation. It would also be interesting to discover if rain can be induced from a comparatively shallow layer of stratocumulus cloud just above the freezing level and which lies under an inversion or is otherwise prevented from growing upwards.

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DIURNAL VARIATION OF EVAPORATION FROM NATURAL SURFACES

BY E. J. SUMNER, B.A.

Part II

In **Part I** a method of determining the diurnal variation of evaporation from a grass surface was indicated, and the final results for Kew set out in diagrammatic form. The values arrived at were shown to be in good agreement with those obtained elsewhere by other means, and this might have been used to justify the method. However, it is felt that some analysis of the factors involved should be given and an attempt made to estimate the probable error.

The limiting factor in the application of the energy method, and the one over which there is still much controversy, is the ratio R associated with the name of I. S. Bowen[1*]. The error in its use is twofold : that inherent in the ratio itself, and that involved in its computation from inadequate climatological data.

Bowen's ratio.—In deriving equation (6) it is assumed, among other things, that eddy diffusion is the only agency at work in the vertical transport of heat and moisture in the atmosphere, and that the steady state exists. Neither of these assumptions is justified ; heat is also transported by the exchange of long-wave radiation from one moist layer to another, and equilibrium is seldom attained. It may be remarked in connexion with the latter point that any departure from the steady state would act similarly on the transport of moisture as on the transport of heat, and that, as a result, R would not be subject to very great errors on this account. Also, a rough estimation by the author gave a very small percentage error for both the numerator and the denominator of the ratio due to departure from equilibrium, and it is considered that inaccuracies from this cause may be ignored.

The effect of radiative diffusion is more debatable. Although it can probably be neglected by comparison with eddy diffusion in the free atmosphere, within the semi-boundary layer next to the earth's surface, where the flux of heat and moisture by diffusion is mainly due to molecular processes, it may not be negligible although its absolute value is unknown. Sverdrup[2], using a value for the radiative diffusivity equal to that of the molecular diffusivity of heat, and assuming the coefficient of eddy diffusion to vary linearly with height, calculated that R was too low by about 30 per cent. for a water surface. A similar calculation overland, assuming a power law for the diffusion above the boundary layer, gives more or less the same value. However, experiments by Cummings and Richardson in America indicate a very much smaller error, which suggests that the value for the radiative diffusivity near the earth is much lower than the corresponding value for molecular diffusivity. Even if 30 per cent. is of the right order, since R averages about 0·2 in the present calculations, then $(1 + R)$ is only in error by about 5 per cent. and the evaporation results are 5–6 per cent. too high.

The ratio may, of course, be applied to any surface provided all the items in (6) are known. In the case of a water surface the surface temperature T_Q

* The list of references is on p. 178.

may be easily measured and e_G is the saturation vapour pressure at this temperature. For the earth neither e_G nor T_G are measurable owing to technical difficulties, and readings either a little below (more usually in the case of temperature) or a little above the surface are the ones normally taken. The following discussion is concerned with the way in which various difficulties due to inadequate information were met.

Surface temperature.—At Kew, for 1927, temperatures at 10 cm. and 20 cm. below turf were available, and these were extrapolated to the surface assuming homogeneous soil conditions. The phase of this resultant temperature variation, which reached a maximum at 1515 was very much in doubt, although its amplitude was considered to be fairly accurate. Wright[3], from whose paper the data were taken, had pointed out that the observed changes of phase with depth were not consistent with the normal heat conductivity equations, and for this, and other reasons given below, a phase change of one and a half hours (22½°) was made. T_G at a particular time was calculated using this hypothetical temperature curve, and e_G was taken as the saturation vapour pressure at this temperature. In order to get some idea of the error involved using these values we must consider the relationship between them and the temperature and humidity in the grass a few centimetres above the ground, as the following considerations will show.

The subject is one of great complexity, and one on which much observational work remains to be done. However, it is known that the actual temperature of the grass may differ considerably from the air temperature within it, being generally higher in the day-time, and lower at night near the top whereas lower down this state of affairs may be reversed although the magnitude of the difference is considerably less. Also, the distribution of air temperature within the grass is influenced by its depth, type, luxuriance of growth, and whether the leaves are vertical or not. Early in the year when the grass is short there is probably little modification of the temperature profile from what one would expect with a uniform surface, but later when the grass has grown the temperature at the surface is less during the day than higher up and more at night. In other words, the " effective " surface of the earth is

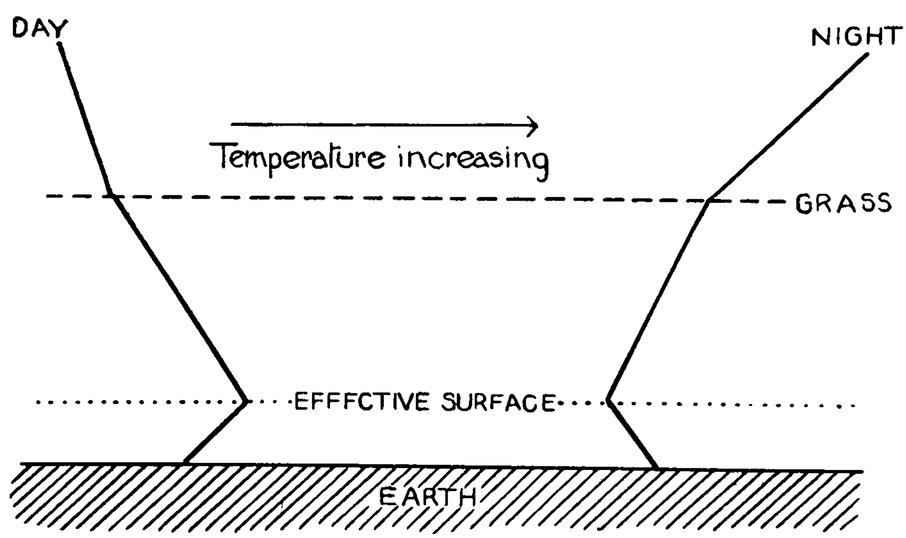

FIG. 3.—POSITION OF THE EFFECTIVE SERVICE

HYPOSTEREOGRAMS

FIG. 1.—VIGOROUS UP-CURRENT IN A CUMULUS CLOUD

FIG. 2.—ALTOCUMULUS AND CUMULUS SHOWING UNIFORM CLOUDBASE OVER THE SEA

[*To face p.* 176

HYPOSTEREOGRAMS

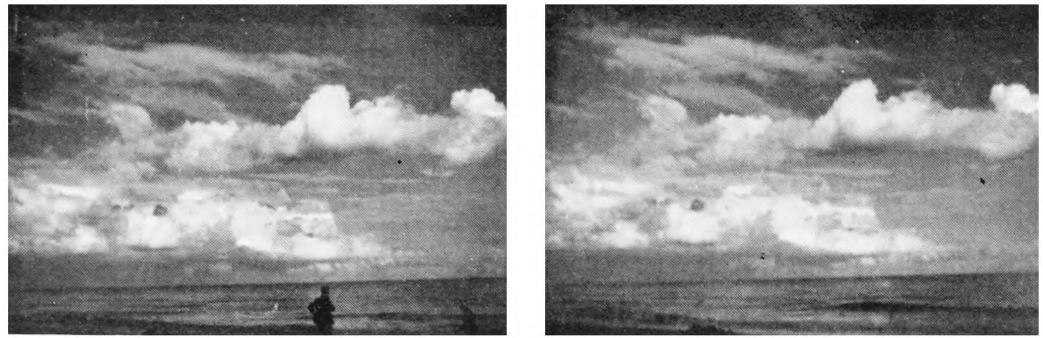

FIG. 3.—DISTANT STORM

FIG. 4.—CIRRUS

raised, being somewhere between the surface and the top of the grass. Fig. 3 illustrates this ; it is not intended to convey the magnitude of the effect, nor is the effective surface necessarily the same by day as by night.

Strictly speaking, it is the temperature and vapour pressure at this "effective" surface which are required in evaluating Bowen's ratio. Curves given by Geiger [4] for a grainfield suggest a maximum difference between the surface temperature and the effective temperature of 1° C. or even less for vegetation over one metre high in summer. It is probable that for turf an error of 1–2° C. is the maximum at all times. Temperature differences of this order make the computed evaporation about 5–10 per cent. too high in the day-time, but at night the percentage error may be great since $e_G - e_A$ in the denominator of R becomes very small making the numerical value of the ratio vary enormously depending on what effective temperatures are used. For this reason, the magnitude of the rate of dew deposition is very much in doubt, especially in spring and autumn when it is probably less than indicated.

The exact time at which the effective surface temperature reaches its maximum is not known, but observations made by Best[5] at 2·5 cm. above closely-cropped grass for clear days in March (1931–3) gave a time of 1400 and an extrapolated surface maximum was found to be at 1330.

Taking into account all the above points it seems that the diurnal curve got by extrapolating to the soil surface and altering the phase by one hour and a half (so as to give a maximum between 1330 and 1400) gives a good enough approximation to the effective temperature, especially as the difference $T_G - T_A$ is then found to have a maximum nearer midday in agreement with Best's observations.

Surface vapour pressure.—Readings of vapour pressure near to the earth's surface are few and far between. In spite of the large evaporation of plants during the day-time and the relatively high leaf temperature, absolute saturation is seldom obtained in the adjacent air. However, Geiger quotes observations by O. Stocker which showed a very steep humidity gradient above a cover of vegetation. For example, an observation taken in a meadow near Freiburg on a hot almost windless day (when the air temperature was as high as 29° C.), at 2 cm. above the ground, among grass, gave the humidity as 96 per cent., whereas at 100 cm. in the free air it was only 57 per cent. Other observations show equally high humidities among vegetation.

The saturation vapour pressure at the surface temperature (not the effective temperature) is evidently representative of that at the effective surface to a high degree of accuracy except possibly during periods of drought in summer and autumn.

Other terms.—Most of the complications in the previous section were due to the presence of a covering of vegetation having different thermal characteristics to the soil. The evaluation of H, the heat storage, presented the same difficulties, and a similar device was employed to surmount them.

In the experiments conducted by Wright it was found that grass interfered with the normal process of heat conduction and it was suggested by comparison with observations taken below bare soil that the time taken to transmit heat through the grass was about an hour and a half. Thus the heat storage deduced from soil temperatures must only be used in conjunction with values of the other elements for an hour and a half previously. Accordingly H was calculated from equation (3) using the same hypothetical surface temperature as before.

The heat stored in the grass itself was neglected and no account was taken of the lack of homogeneity of the soil. The effect of an increase in H on the total evaporation is very small although it alters the profile of the diurnal curve somewhat, making both the evaporation and the deposition slightly less.

The maximum errors arising from all the causes so far discussed are cumulative, but together they represent only 10–15 per cent. of the total evaporation. An added source of error, and one which can easily equal the previous ones, arises in the determination of the insolation at places where continuous pyrheliometer readings are not available, which is more often the case. At Kew pyrheliometer readings were taken only once a day within half an hour on either side of noon when the sky was clear, and this provided a rough check on the theoretical values used. It is not proposed to enter into the intricacies of the computation here ; details are to be found elsewhere—see Brunt[6], Richardson[7], Ångström[8].

Another error is in the reflectivity of a grass surface, which in the present work was taken as 20 per cent. of the incoming short-wave radiation at all seasons. This figure is probably too high, but, since it reduces the evaporation whereas the other errors tended to increase it, some compensation is provided.

Conclusion.—There seems to be a wide-spread misconception among meteorologists that the amount of water lost by evaporation over land is negligible by comparison with that from the sea, and some authors in recent times have ignored it completely. Having regard to the diversity of types of grasses, cultivated crops, etc., and the fact that only a single year's values have been computed, it is impossible to generalise the results found for Kew, but it is manifest that land surfaces covered with living vegetation lose a considerable amount of evaporated water, especially during the growing season. For example, the total evaporation at Kew for 1927 was about 41 cm. (about half the rainfall) which is equivalent to just over 1·1 mm./day averaged over the whole year. This may be compared with 1·87 mm./day obtained theoretically by Frost[9] for the Atlantic Ocean in these latitudes, and Jacobs' average figures of 2·2 mm./day for the Atlantic at 50°N.[10]

The energy method is tentative in application, and the accuracy of the results is impaired by lack of observational data. More investigation is required before one can predict the diurnal variation of evaporation with any degree of confidence, although the favourable comparison between existing results and those found here encourage the author to think that sufficiently accurate values can already be found for practical purposes.

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THUNDERSTORM OF JUNE 27, 1947

This thunderstorm attracted particular attention in the London area owing to the darkness and severe squall which accompanied it. Mr. E. Gold wrote the following account of the storm in London :—

" An outstanding feature of the storm here was that underneath the very black cloud which was moving eastwards there was practically no rain and no wind. The rain could be seen to the south-west against what appeared to be a rather bright sky but did not begin at Victory House until the western edge of the dark cloud was practically overhead. Then the rain began to fall in torrents and the wind rapidly increased. The dark cloud was really very black and it was impossible to read without artificial light, even in my room on the 7th floor. The intensity of the rain, no doubt combined with splashing from the roofs, reduced visibility so much that it was practically impossible to see across Kingsway at roof level, i.e. visibility was less than about 30 yards."

At Kingsway the squall gave a maximum gust of SSW. 64 m.p.h. at 1120 G.M.T., with a sharp rise of pressure of 2 mb. At Kew Observatory the peak of the squall was 230° 53 m.p.h. at 1130. Mr. G. Seligman also noted the squall at Wimbledon. Rainfall exceeded 1 in. over most of London and amounted to 1·66 in. at Greenwich. Its duration at Kingsway was 70 min. At South Farnborough the extreme was only SSW. 19 m.p.h. at 1050 G.M.T., and there was no sharp rise of pressure. At Dunstable the extreme was SSW. 20 m.p.h. and pressure rose sharply 4 mb., with a double peak, the second one at a secondary squall. The squall can be attributed to cooling by precipitation, probably including the melting of very heavy hail, with the stones too small to reach the ground. Wet-bulb temperature fell with the squall at Dunstable to 61° F., some degrees less than the wet-bulb potential temperature at any height. The freezing level was at 12,000 ft., where there was a very strong southerly wind. The worst squalls accompany strong upper winds, but the dynamical problem is complex. The descent of cold air must always involve some spreading out at a low level.

The cloud structure at Dunstable (as in London) showed some evidence of an upper cold front. Just before the rain black mammillated clouds were moving from west-south-west at an estimated height of fully 7,000 ft., possibly 8,000 ft., though the storm itself was approaching from the south. The dark cloud had a straight edge to westward but the brighter region soon receded to the north-west horizon as the storm area spread west, probably the result of the northward movement of the widest part of the storm.

The thunderstorm was one of a series which broke out over Spain, south-west France and the Bay of Biscay (shown by atmospherics only in the Bay) on the previous late afternoon and evening, and moved quickly northward in the upper current. It was a fairly typical high-level storm, but there were some unusual features on the sea-level charts. The main front was off Scilly at 1200 and moving very slowly (see Fig. 1), but further east there was a large horizontal gradient of temperature, associated with exceptional heat on the continent. According to reports in the Press, the maximum temperature of 101° F. at Brussels on the 27th was a record for June. At Kew the minimum of 67° F. on the night of the 26th–27th was the highest on record for June. The temperature at 950 mb. (about 2,000 ft.) at Downham Market rose from 72 to 77° F. between 1800 and midnight and then fell. The southerly current over England (backing SE. in the south) fell off rapidly in the night and was

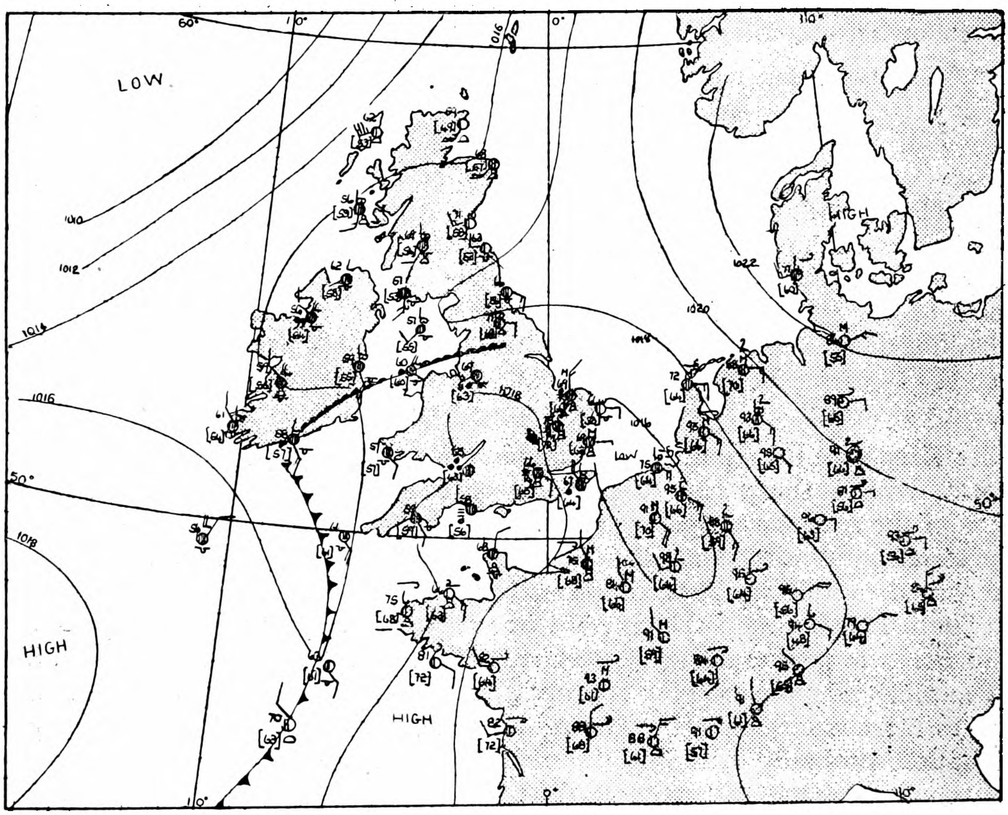


FIG. 1.—SYNOPTIC CHART AT 1200 G.M.T., JUNE 27, 1947
Dew-point temperatures are given in brackets.

replaced by a weak NW. wind over the Midlands, quickly spreading over eastern England. This was confined to a very shallow layer but it was accompanied by an advection of colder air with frontogenetic action near the east coast, though it is difficult to locate a definite front. The upper frontal action observed at London and Dunstable was probably related to the diffuse frontogenesis to eastward lower down.

A wedge of high pressure developed over the Bay of Biscay during the night of the 26th–27th and by 1200 on the 27th there was an elongated anticyclone, as shown on Fig. 1. The 700 mb. contours (Fig. 2) show that it was a very shallow anticyclone. At 1800 there was a shallow cold anticyclone from the Midlands to the English Channel, which moved to the north-east and intensified, developing a central pressure of 1027 mb. off Norway by 0600 on the 29th. The air in which it formed was greatly cooled by precipitation falling into it from above, and this may have given the trigger action which started the anticyclonic development, though it is impossible to prove this in the present state of our knowledge.

The thunderstorms over Spain and south-west France on the previous evening finally developed into an area of continuous rain with little or no thunder, and this moved rapidly northward over western England and Wales during the morning. The thunderstorms which affected the eastern districts of England developed over north France early on the 27th near the east boundary of a region of widespread rain, which accentuated an already steep horizontal temperature gradient. The storms moved quickly north and one had already

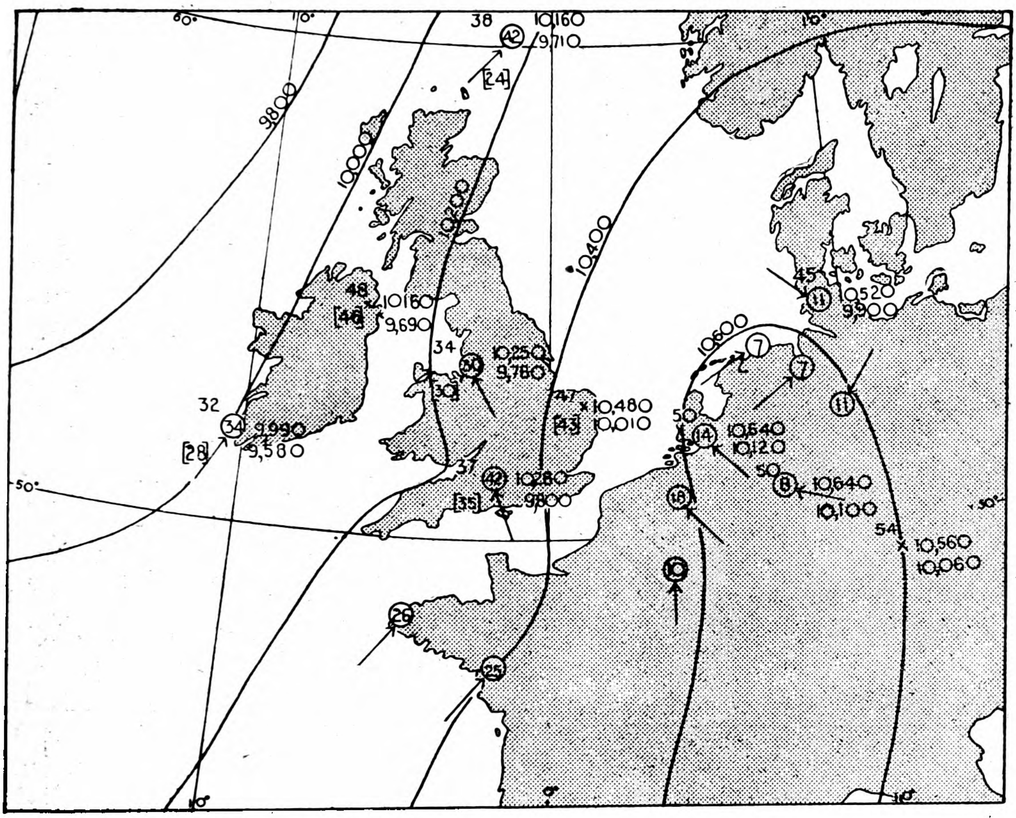


FIG. 2.—UPPER AIR CHART AT 1200 G.M.T., JUNE 27, 1947

Figures on right of stations are (top) heights of 700 mb. surface above sea level and (below) heights above 1000 mb. surface. Figures on left of stations are dry-bulb temperatures and (in brackets) wet-bulb temperatures at 700 mb. Wind velocities are given in knots inside station circles. Heights are given in feet.

reached West Raynham (north Norfolk) by 1000 G.M.T. There were a number of scattered early storms, including a brief one in London 50 min. before the main one. The main storm was much larger than the earlier ones and its front boundary was orientated north-west to south-east with a length of about 100 miles, though the length of the most intense part of it was less. Judging from the duration of rain in relation to the speed of movement, the width of the belt (in direction south-west to north-east) was 40 miles in the London-Dunstable region, but only some 20 miles at South Farnborough. Its vertical extent was very great, the top probably being at least up to the tropopause at 41,000 ft. Radar echoes up to 40,000 ft. were observed by the Royal Aircraft Establishment, South Farnborough, when the storm was near

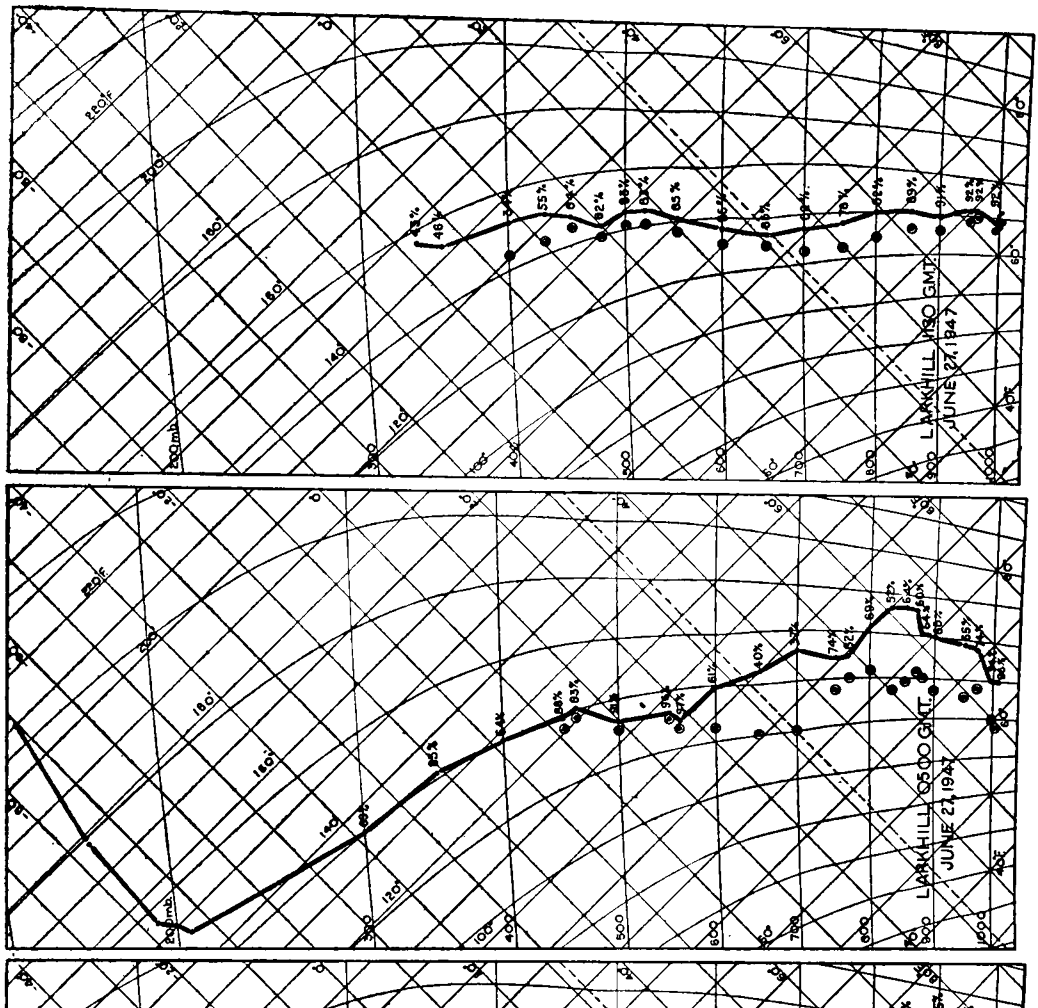


FIG. 3.—TEPHIGRAMS OF UPPER AIR ASCENTS AT COLTISHALL AND LARKHILL ON JUNE 27, 1947

the south coast at 1000 G.M.T., and to just above 40,000 ft. from East Hill, Dunstable, when the storm was in the Cambridge-Mildenhall area. The storm moved north at a speed of just over 40 knots, derived both from the autographic records and from the successive sets of observations of atmospherics. This is a lower speed than might have been expected from the Larkhill winds at medium levels at 1200 (see Table I) but these were probably in excess of the wind in the storm area. The geostrophic wind at 700 and 500 mb. cannot be measured with accuracy owing to the eastward decrease of gradient, but it is consistent with a mean wind between the two levels little in excess of 40 knots.

TABLE I—UPPER WINDS AT LARKHILL

Pressure	0600 G.M.T.		1200 G.M.T.		1800 G.M.T.	
mb.	°true	kt.	°true	kt.	°true	kt.
950	220	10	190	9	260	6
900	220	10	190	7	260	8
850	220	15	200	12	260	10
800	220	22	200	21	250	12
750	210	23	190	26	250	18
700	200	30	170	42	250	22
650	200	32	150	60	240	29
600	180	40	170	57	240	33
550	180	42	190	57	230	38
500	190	43	180	52	230	44
450	190	46	170	63	230	49
400	190	44	—	—	240	46
					210	46

There were no wind observations at Downham Market.

The storm was still active over Yorkshire at 1500 G.M.T. but after it went over the North Sea it rapidly lost intensity and only a few atmospherics were recorded. Since the storm was a high-level one the decrease in intensity after leaving the land must have been largely accidental. There was some decaying medium cloud behind the storm, but the evening was brilliantly fine. The fine weather moved northward from France, and since the temperature gradient was east-west it cannot be explained in frontal terms.

The tephigrams (Fig. 3) show marked latent instability aloft. The cloud observation at Coltishall only refers to the outlying clouds, and the tops of even the earlier storms were probably much higher. The base of the main cumulonimbus masses was probably not below 7,000 ft. The most interesting feature is the change at Larkhill between 0600 and 1200. The wind was light up to 5,000 ft. and most of the cooling must have been due to the rain. The wet-bulb temperature had only fallen slightly at certain levels, while at some levels it had risen. By 1800 dry-bulb and wet-bulb temperatures had risen slightly up to 600 mb. (14,000 ft.). Higher up temperature rose slightly between 0600 and 1200 and fell slightly by 1800, with a temporary veer of wind. The trough at 700 mb. (Fig. 2) was over a tongue of cold air which did not extend much higher up, and was due partly to precipitation.

C. K. M. DOUGLAS

At Croydon, a violent squall accompanied by a thunderstorm and heavy rain occurred between 1100 and 1115 G.M.T. At 1110 the barometer rose 7 mb. and then fell 5 mb. Temperature dropped 12° F., approximately 1 in. of rain fell in about 15 minutes. The wind which had been light suddenly increased to gale force and gusted up to 73 m.p.h. and, a few minutes before the squall, backed from roughly NW. to S. and then veered rather more

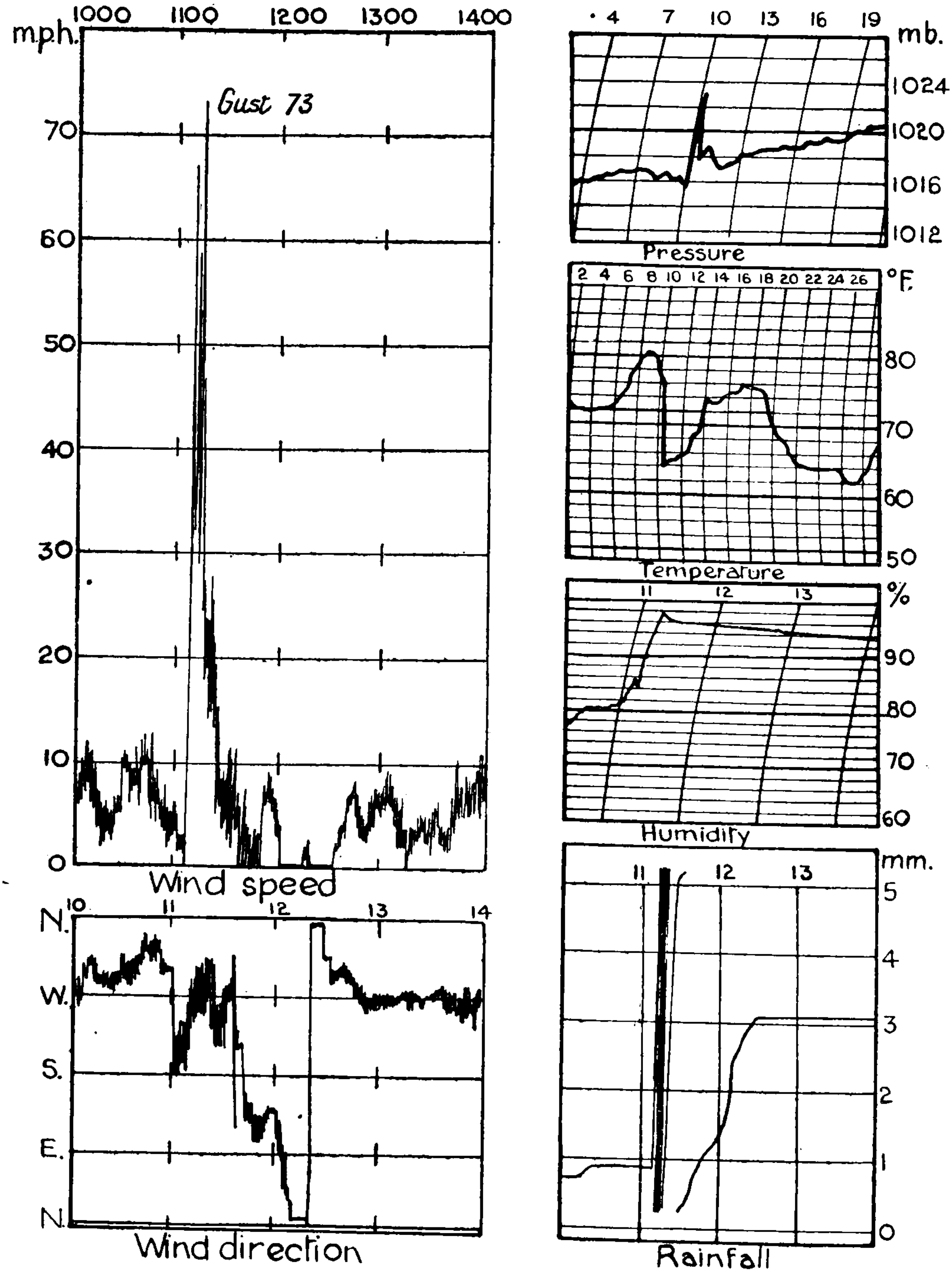


FIG. 4.—AUTOGRAPHIC RECORDS AT CROYDON, JUNE 27, 1947

The barograph is one hour slow ; the thermograph is three-quarters of an hour slow ; the wind-direction graph is about ten minutes slow.

EFFECT OF WATERSPOUT IN ORKNEY, AUGUST 5, 1945
View taken from disturbed area looking south-south-west showing large chunks of earth uprooted by the waterspout.
(see p. 187).

General view looking north-east showing part of disturbed area in the foreground (taken at a distance of 150 yards on August 9.

View taken from the middle of the disturbed area looking south-east down the valley towards Isbister Bay. The burn into which the water drained can be seen in the middle distance.

EFFECT OF WATERSPOUT IN ORKNEY, AUGUST 5, 1945

(see p. 187)

gradually to NW. again. Tracings of the autographic records are shown in Fig. 4.

Mr. H. V. Sims, the meteorological observer at the Grammar School, Earl's Colne, Colchester, writes :—

"On Friday, June 27th, after an ordinary thunderstorm at midday, we were visited by a veritable tornado. Towards 2 p.m. the sky became inky black ; thunder and lightning approached again ; the wind changed in a few minutes from SE. to SW. and increased to gale. Rain started and then suddenly increased to torrential with visibility down to about 20 yards. At the same time we saw a whirlwind cross the playground and, in its midst, waltzed a heavy door wrenched from the gymnasium. This was finally smashed to pieces (the door). Most of my beehives were overturned and the screen, in spite of repairs after the recent accident (and a ½-cwt. block of concrete), was thrown five yards leaving me with only the shade min. intact.

"In the village, the gale brought down many trees, chimneys and roofs. Some lead roofing on the school was stripped right back and smashed the tile roof on which it landed. Part of the roof of the machine shop at the Atlas Works, Earl's Colne, was blown in, luckily without personal damage. I estimate that approximately 0·85 in. rain fell in about thirty minutes. Floods, of course, were widespread for the next hour or two. Unfortunately, I was too excited to observe the behaviour of the barometer."

L. F. LEWIS

METEOROLOGICAL RESEARCH COMMITTEE

The meeting of the Meteorological Research Committee held on July 17 was an unusually interesting one. In the first place, it witnessed the strengthening of the Committee by the addition of two new members, Professor P. A. Sheppard and Professor O. G. Sutton. The Committee already includes many of the most eminent meteorologists in the country, and the Air Ministry may well regard itself as fortunate in acquiring two additional members of such distinction.

In the course of the meeting, the Committee decided to form three sub-committees, each of which will be responsible for one of the three sections into which the research programme is divided, viz. Instruments, Forecasting, and Physical and Dynamical Problems. The primary reason for establishing these sub-committees is to permit of more detailed discussion of highly specialised matters than is possible in full Committee. It is also intended to give an opportunity to those actually engaged on the problems to participate in the discussion of their work by the sub-committees. The view was also widely supported that the sub-committees should hold their meetings at places where investigations are in progress.

Among the other subjects discussed at the meeting on July 17 was the artificial production of rain described by Kraus and Squires in their article in *Nature* of April 12, 1947. Many readers will remember Dr. Kraus as the able and energetic young meteorologist who took a prominent part in developing the Meteorological Reconnaissance Flights during the war, and subsequently served as the Senior Meteorological Officer at the Photographic Reconnaissance Unit at Benson. The physical explanation of the experiments performed by Kraus and Squires does not present any great difficulty, but some members of the Committee expressed surprise that such a limited amount of solid CO_2 should produce rain over an area of many square miles, and that the effect should take place so rapidly. Further information on these points is being sought, both from Dr. Kraus and also from Professor Langmuir, who has been responsible for some similar experiments in America.

ROYAL METEOROLOGICAL SOCIETY

The Summer Meeting of the Society took place on Saturday July 5, when a visit was made to Portsmouth Dockyard.

About one hundred Fellows and their guests left Waterloo Station at 10.45 a.m. and, arriving at Portsmouth around 12.30 p.m., split into two parties, one led by W/Cdr. Poulter and the other by Cdr. Burgess. After having lunched the parties proceeded separately to the Dockyard, one to visit the aircraft carrier, H.M.S. *Illustrious* and the other Nelson's flagship H.M.S. *Victory*.

On boarding the *Illustrious* the party was welcomed by the senior officer on duty and quickly split into parties of ten for a rapid tour of the ship. In an incredibly short space of time we walked the flight-deck, crowded into the tiny meteorological office, visited the bridge and descended by the aircraft lift to the spacious hangers below. Already, so early in the afternoon, we were glad of that lift—'tween-deck ladders on board naval vessels are obviously not constructed for the comfort or convenience of landsmen, especially when they happen to be in a hurry. We would have liked more time to see more but it was enough to enable us to appreciate the vast and detailed organization necessary for the efficient running of a great ship.

Having come to the end of our allotted time on the *Illustrious* we changed places with the other party and proceeded to the *Victory*. This again was of necessity a short visit but an extraordinarily interesting one coming directly after our tour of a modern aircraft carrier.

At about 3 p.m. the two parties joined up and walked through the dockyard to the radar-training ship H.M.S. *Boxer*, where we were received with traditional naval courtesy by the Captain and officers. As soon a the whole party had gathered in the lecture room, the Captain of the ship, Cdr. C. J. Wynne Edwards, D.S.C., R.N., gave us a short talk about the *Boxer*. Built originally as an L.S.T. (Landing Ship, Tank) she had been converted into a Fighter-Direction Ship for use in the Pacific. When the war came to an end she underwent considerable alteration and was fitted out as a training ship for officers and ratings in the use of radar, her present function. Cdr. Wynne Edwards was followed by the Navigation Officer, Lt. W. G. Wright, Royal Australian Navy, who briefly explained the main uses of radar at sea. To implement his talk and make things clearer to the struggling lay minds of some of us, an interesting film, explaining the elementary principles of radar, was shown. Lt. P. G. Satow, D.S.C., R.N., then described the uses of radar in meteorology. At the moment its main use is in following the corner reflectors carried aloft by balloons and so making possible the determination of the speed and direction of the upper winds. Equipment used for this purpose has been fitted in the ocean weather ships now starting operations in the North Atlantic. On trial, as shore equipment, this instrument gave ranges up to 45 miles at a vertical height of 58,000 ft., but its maximum range, when used under Atlantic conditions, is more likely to be of the order of 20 miles. In addition to the determination of upper winds, radar can be of invaluable use to the meteorologist in the detection of rain-bearing clouds. Shower and thunder clouds can be located at a considerable distance and their tracks plotted. The great advantage of being able to do this is obvious. With the full employment of radar in this way the present danger of an aircraft being caught in a suddenly appearing and violent convective storm would be obviated. Great use was made of this during the recent war. Naval forces frequently took cover beneath large rain clouds only steaming out into clear weather long enough to enable the carriers to fly off or fly on their aircraft. It was a pity that time would not allow the speakers to tell us more about this fascinating subject.

A tour of the ship followed, each small party being shown round by one of the ship's officers. One is at a loss how to describe the inner workings of such a ship for it is literally crammed full of the latest types of radar equipment; plan position indicators, direction finders for surface vessels, height finders for aircraft, short-range navigation sets which enable ships to find their buoys at night or in fog, homing beacons for aircraft in thick weather and innumerable other instruments which left us wondering—what next? A somewhat bewildered and very tired—even more and steeper ladders here—party of meteorologists finally found its way to the officers' wardroom where a very welcome tea was being served.

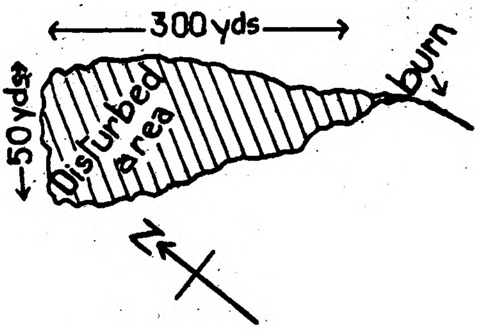
Before leaving the *Boxer* Mr. Shipley thanked Cdr. Wynne Edwards for allowing us the privilege of such a wonderfully interesting afternoon on his ship and voiced the party's appreciation of the kindness shown by his officers in giving up their shore leave for our benefit and instruction.

It was a most successful meeting, greatly appreciated by all those lucky enough to be present. We only regretted the speed with which it was conducted. No doubt there were good and sufficient reasons for that. We were rather left feeling however that we had seen and learned a lot but had also missed much which would have proved equally interesting and instructive.

LETTERS TO THE EDITOR

Waterspout in Orkney

On Sunday, August 5, a waterspout was observed in Orkney between about 0930 and 0955 clock time. It was first noticed crossing the Bay of Isbister (about 5 miles north-west of Kirkwall) travelling in a north-westerly direction, the funnel pendant from a large cumulus cloud but not reaching the ground. In its travel north-west, the waterspout encountered the slopes of Milldoe Hill (735 ft.) at a point near the top where a small burn has its source. The burn runs down to the south-east and drains into the Bay of Isbister. Near the top of the hill, in its travel up the burn, the lower end of the waterspout appears to have reached the ground, because there was considerable disturbance of the surface over an area of length 300 yds., max. width near the top 50 yds. as in sketch below. The edges of the disturbed area were quite sharp though not straight. The top soil which is covered with heather and coarse grass had been torn apart to a depth of 3 or 4 ft., broken up and thrown about into large chunks each weighing several hundredweight. A considerable amount of water had evidently fallen from the spout at this point and flowed down the hill as several large pieces of earth had been washed to the side of the area. Facing p. 184 and p. 185 are photographs of this disturbed area taken on August 9, 1945. The top of the hill was undisturbed, and the waterspout was observed to travel across country in a north-westerly direction



for another 5 miles before finally disappearing at 0955. There were no other traces on the ground except at the place described above.

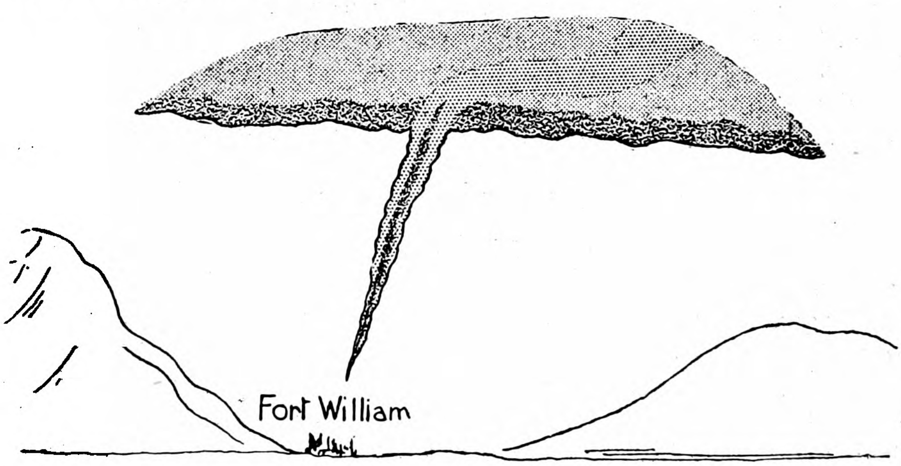
I saw the waterspout myself from Twatt aerodrome from 0950–0955, bearing east and it appeared to be passing behind Greenay Hill (2½ miles away). It disappeared shortly afterwards.

C. S. PORTER

R.N. Air Station, Twatt, Orkney, August 13, 1945.

Waterspout at Fort William

I was at Gairlochy, on the Caledonian Canal, about 2 p.m. on Sunday, August 5, and had been watching the sky over Fort William, where a large black cloud coming from the south-west seemed to indicate a change of weather. Very suddenly a long pointed finger appeared to shoot down from the black cloud in the manner in which I believe a waterspout begins, but the extremity did not reach ground level. It appeared to hang stationary for about 3 minutes although it may have been travelling in my line of sight. Small pieces of cloud seemed to be swirling down one side and up the other. The sketch below gives a rough idea of its appearance.



The weather before the change had been fine with light W. or NW. wind, good visibility, and about 4 or 5 tenths cumulus with well defined outline, and clear blue sky between, except away to the south, where the blue sky became obscured by a fine veil as if of fine cirrus. The extreme tip of Ben Nevis was hidden in cloud. Shortly after the above-mentioned effect, rain started, and continued for an hour or two, with a shift of wind to the NE., moderate and cooler, especially the following day.

GILBERT O. KOLLIEN

5 *Hillview Terr., Edinburgh,* 4. *August* 14, 1945.

[On August 4, 1945, a shallow depression was centred to the north of the Faroes and a cold front crossed Scotland during the day. By the morning of the 5th another centre of low pressure was developing to the east of Scotland on this front which was almost stationary over the North Sea. Ed. *M.M.*]

NOTES AND NEWS

A simple method of making hypostereograms of clouds with a single camera

Binocular vision ceases to produce any perceptible appearance of solidity at distances greater than about two to three hundreds yards. A normal landscape viewed from the air appears, for example, dead flat, the only clues to the height of objects on the ground being afforded by cast shadows. In such cases the retinal images obtained in each eye differ only by amounts that are too small to be resolved. This is also the case with views of clouds, the shapes and positions of which can only be appreciated through similar indirect effects of cast shadows, absorption of light in the atmosphere and perspective.

The stereoscopic camera enables this normal maximum distance of stereoscopic vision to be multiplied many times photographically by the simple expedient of increasing the distance between the lenses. In certain cases two exposures with a single camera, taken the requisite distance apart, may be used. This is the case with objects that remain fixed throughout the time required to make the exposures and to transfer the camera from one position to the other. The use of the stereoscope in this way for the interpretation of aerial photographs will be familiar to most.

Suitable stereoscopic pairs may often be obtained with cloud photographs in an extremely simple manner. The drift of the clouds with the wind is frequently sufficient to provide the requisite displacement between two photographs taken within a few seconds of each other from the same position. The interval between the two exposures may be made sufficiently short so that the clouds do not change appreciably. As it is desirable for the relative displacement between the two pictures to be horizontal (otherwise the photographs would have to be mounted with inclined horizons for viewing) it is necessary for the camera to be pointed in a direction at right angles to the wind. For example, with a N. wind the clouds to be photographed should lie either to the east or west of the observer. The exposures are made in the ordinary way using a panchromatic film and a deep yellow filter, and the interval between the two exposures necessary to produce a good effect of depth under ordinary conditions is about 5 seconds. This is roughly the time required to wind on the film and make the exposures. With low cloud the interval should be shorter and with high cloud longer but its exact length is not in the least critical.

The accompanying plates (facing p. 176 and p. 177) show four pairs of photographs taken in this way for viewing in an ordinary stereoscope. The first pair (Fig. 1) shows a vigorous up current rising vertically from a layer of cumulus cloud. Fig. 2 is of interest as showing the level cloud base over the sea. The cumulus clouds, though of varying sizes, all have their bases on the same level. Fig. 3 is of a distant storm the summits of which are seen to be partially masked by the nearer and lower clouds. Fig. 4 is of cirrus. The depth is not portrayed very markedly—a longer interval between the exposures would have been desirable—but a curtain of falling particles may be observed under many suggesting an explanation of the normal " spun out " appearance of this type of cloud.

In viewing the photographs the landscape should be neglected. In this there is no displacement so that it appears at the back of everything. Figures are a nuisance as they often appear in totally different positions in the two photographs. In photographing clouds, however, it is necessary to seize one's opportunity and it is not always easy to exclude the unwanted figure at the precise moment and in the required direction !

R. A. R. TRICKER

WEATHER OF JUNE, 1947

Pressure was low over the north-east Atlantic, high from the Azores to Spain and relatively high in a wedge across France and central Europe to the Black Sea ; it was also relatively high in the Arctic region from north-east Greenland to Spitsbergen. Mean pressure for the month ranged from 1007·2 mb. on the Atlantic (50° N. 30° W.) to 1021·2 mb. at Horta in the Azores. Differences from the average showed a large area on the Atlantic of more than 5 mb. below average and an area near Spitsbergen of rather more than 4 mb. above average.

Over the British Isles the greater part of June was characterised by depressions or troughs of low pressure travelling north or north-east over the country. Southerly or south-westerly winds predominated, with excessive rainfall on the whole, though less than the average occurred over a large part of the Midlands. Thunderstorms occurred rather frequently and some were severe. It was sunnier than usual in east and south-east England but dull in the west and north of the British Isles. The opening days were exceptionally hot.

Mean temperature exceeded the average, the excess being greatest in the eastern half of England. The first three days were exceptionally hot over much of England ; on the 3rd, temperature reached or exceeded 90° F. at a large number of stations in the eastern half of the country ; at some stations in this area, for example at Kew Observatory with its long meteorological record, it was the hottest June day on record. The month was wet on the whole ; more than twice the average rainfall was received over a small area in the Fens, in the Scilly Isles, around Garvagh, County Londonderry, in a small area in Perthshire and at Kelso. The thunderstorms on the 27th were severe in the south-eastern counties (see p. 179).

Generally speaking the month was dull ; in east and south-east England, however, it was somewhat sunnier than usual. In Scotland the deficiency was marked ; at Leuchars, it was the dullest June since observations were started in 1922 and at Dundee the total sunshine was the lowest in June for at least 30 years.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days' diff. from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	94	35	+2·6	112	+1	91	37
Scotland	80	32	+1·3	147	+5	69	23
Northern Ireland	75	37	+1·7	159	+4	82	28

RAINFALL OF JUNE, 1947

Great Britain and Northern Ireland

Co.	Station	In.	% of Av.	Co.	Station	In.	% of Av.
London	Camden Square	2·74	136	*Glam.*	Cardiff, Penylan	2·62	104
Kent	Folkestone Cherry Gdns.	3·00	151	*Pemb.*	St. Ann's Head	2·86	137
,,	Edenbridge, Falconhurst	2·77	126	*Card.*	Aberystwyth	1·97	80
Sussex	Compton, Compton Ho.	2·45	98	*Radnor*	Bir. W.W., Tyrmynydd	2·84	87
,,	Worthing, Beach Ho. Pk.	2·42	138	*Mont.*	Lake Vyrnwy	4·11	126
Hants	Ventnor, Roy. Nat. Hos.	1·88	103	*Mer.*	Blaenau Festiniog	5·32	82
,,	Fordingbridge, Oaklands	1·75	95	*Carn.*	Llandudno	2·70	142
,,	Sherborne St. John	1·79	84	*Angl.*	Llanerchymedd	3·21	135
Herts.	Royston, Therfield Rec.	2·22	99	*I. Man.*	Douglas, Boro' Cem.	4·99	206
Bucks.	Slough, Upton	2·67	130	*Wigtown*	Pt. William, Monrieth	4·35	185
Oxford	Oxford, Radcliffe	1·08	48	*Dumf.*	Dumfries, Crichton R.I.	3·63	143
N'hant.	Wellingboro', Swanspool	1·34	64	,,	Eskdalemuir Obsy.	4·92	156
Essex	Shoeburyness	2·47	140	*Roxb.*	Kelso, Floors	4·28	203
Suffolk	Campsea Ashe, High Ho.	1·49	79	*Peebs.*	Stobo Castle	2·94	126
,,	Lowestoft Sec. School	0·97	87	*Berwick*	Marchmont House	2·89	125
,,	Bury St. Ed., Westley H.	3·26	155	*E. Loth.*	North Berwick Res.	3·04	183
Norfolk	Sandringham Ho. Gdns.	2·02	93	*Midl'n*	Edinburgh, Blackf'd. H.	2·97	149
Wilts.	Bishops Cannings	1·89	78	*Lanark*	Hamilton W.W., T'nhill	2·78	126
Dorset	Creech Grange	2·13	93	*Ayr*	Colmonell, Knockdolian	3·25	128
,,	Beaminster, East St.	2·45	108	,,	Glen Afton, Ayr San.	3·14	105
Devon	Teignmouth, Den Gdns.	2·68	140	*Bute*	Rothesay, Ardencraig	4·51	147
,,	Cullompton	2·65	125	*Argyll*	Loch Sunart, G'dale	5·73	178
,,	Barnstaple, N. Dev. Ath.	2·45	109	,,	Poltalloch	4·36	143
,,	Okehampton, Uplands	3·63	131	,,	Inveraray Castle	5·78	146
Cornwall	Bude School House	3·14	156	,,	Islay, Eallabus	3·88	148
,,	Penzance, Morrab Gdns.	3·44	155	,,	Tiree	3·69	145
,,	St. Austell, Trevarna	5·13	197	*Kinross*	Loch Leven Sluice	3·82	174
,,	Scilly, Tresco Abbey	4·14	239	*Fife*	Leuchars Airfield	2·55	153
Glos.	Cirencester	1·97	82	*Perth*	Loch Dhu	6·13	147
Salop	Church Stretton	1·53	60	,,	Crieff, Strathearn Hyd.	5·71	216
,,	Cheswardine Hall	1·23	50	,,	Blair Castle Gardens	3·49	176
Staffs.	Leek, Wall Grange P.S.	1·26	48	*Angus*	Montrose, Sunnyside	2·67	161
Worcs.	Malvern, Free Library	1·87	81	*Aberd.*	Balmoral Castle Gdns.	2·00	118
Warwick	Birmingham, Edgbaston	1·57	68	,,	Aberdeen Observatory	1·11	65
Leics.	Thornton Reservoir	1·30	60	,,	Fyvie Castle	1·75	83
Lincs.	Boston, Skirbeck	3·12	171	*Moray*	Gordon Castle	3·22	158
,,	Skegness, Marine Gdns.	2·30	128	*Nairn*	Nairn, Achareidh	3·06	173
Notts.	Mansfield, Carr Bank	1·77	78	*Inv's*	Loch Ness, Foyers	3·81	172
Ches.	Bidston Observatory	2·29	104	,,	Glenquoich	5·46	111
Lancs.	Manchester, Whit. Park	1·89	72	,,	Ft. William, Teviot	6·14	173
,,	Stonyhurst College	2·53	82	,,	Skye, Duntuilm	3·71	143
,,	Blackpool	2·85	131	*R. & C.*	Ullapool	2·96	130
Yorks.	Wakefield, Clarence Pk.	2·93	136	,,	Applecross Gardens	3·34	117
,,	Hull, Pearson Park	1·97	96	,,	Achnashellach	3·72	99
,,	Felixkirk, Mt. St. John	2·16	99	,,	Stornoway Airfield	2·68	122
,,	York Museum	3·32	160	*Suth.*	Lairg.	3·13	150
,,	Scarborough	2·22	121	,,	Loch More, Achfary	4·11	111
,,	Middlesbrough	2·37	125	*Caith.*	Wick Airfield	2·54	141
,,	Baldersdale, Hury Res.	3·96	168	*Shet.*	Lerwick Observatory	2·41	135
Norl'd.	Newcastle, Leazes Pk.	2·61	124	*Ferm.*	Crom Castle	3·75	138
,,	Bellingham, High Green	3·76	163	*Armagh*	Armagh Observatory	3·74	148
,,	Lilburn Tower Gdns.	2·15	105	*Down*	Seaforde	4·48	162
Cumb.	Geltsdale	3·62	134	*Antrim*	Aldergrove Airfield	3·52	146
,,	Keswick, High Hill	3·15	108	,,	Ballymena, Harryville	4·17	143
,,	Ravenglass, The Grove	2·41	92	*Lon.*	Garvagh, Moneydig	5·63	222
Mon.	Abergavenny, Larchfield	1·89	77	,,	Londonderry, Creggan	4·16	148
Glam.	Ystalyfera, Wern Ho.	3·44	91	*Tyrone*	Omagh, Edenfel	4·56	162

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, FEBRUARY, 1947

STATIONS	PRESSURE		TEMPERATURES							RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE	
			Absolute		Mean Values											
	Mean of Day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb			Total	Diff. from normal	Days	Daily mean	Per-cent of poss-ible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	0–10	in.	in.		hrs.	%
London, Kew Observatory	1007·9	−7·1	40	15	32·9	27·1	30·0	−10·7	28·3	82	8·7	1·19	−0·35	11	0·6	6
Gibraltar	1011·3	−8·7	71	42	62·4	52·0	57·2	−1·4	53·2	87	7·5	9·29	—	19	—	—
Malta	1009·2	−6·9	75	44	62·3	52·4	57·3	+2·0	54·8	73	5·6	0·33	—	4	6·9	63
St. Helena	1013·1	−2·8	78	59	70·9	61·9	66·4	+1·2	62·1	97	9·2	4·10	+1·42	19	—	—
Freetown, Sierra Leone	1010·1	+0·8	89	71	85·9	76·6	81·3	+0·6	75·1	80	5·2	0·10	−0·20	1	8·4	71
Lagos, Nigeria	1009·9	+0·2	96	67	92·3	73·6	82·9	+0·4	78·3	82	8·2	0·32	—	4	7·1	60
Kaduna, Nigeria	1008·3	—	98	60	95·1	65·8	80·5	+2·8	65·4	40	3·6	0·03	+0·01	1	9·6	81
Zomba, Nyasaland																
Salisbury, Rhodesia																
Cape Town	1013·6	+0·2	103	51	83·0	63·1	73·1	+2·8	62·9	68	1·8	0·07	−0·51	3	—	—
Germiston, South Africa	1011·7	—	87	55	80·1	59·4	69·7	—	60·1	64	3·5	3·89	—	13	8·9	69
Mauritius	1008·9	−1·9	90	71	86·5	74·3	80·4	+1·1	74·8	79	5·2	4·12	−3·39	16	9·2	72
Calcutta, Alipore Obsy.	1013·0	−0·5	90	52	85·2	60·8	73·0	+1·8	60·0	76	2·0	0·54	−0·45	3	9·2	81
Bombay	1011·1	−1·6	93	62	85·3	68·9	77·1	+1·4	67·4	78	1·1	0·00	−0·03	0	10·3	90
Madras	1012·2	−0·7	88	65	84·9	70·5	77·7	0·0	71·9	87	4·6	0·00	−0·30	0	9·1	78
Colombo, Ceylon	1010·6	−0·2	92	65	87·4	71·9	79·7	−0·7	71·8	87	3·9	1·66	−0·28	2	9·1	77
Singapore	1009·0	−1·2	89	71	85·9	73·0	79·5	−0·7	76·0	85	—	14·93	+8·31	18	—	—
Hongkong	1019·4	+0·8	74	43	62·4	52·1	57·3	−1·8	53·4	79	—	0·51	−1·32	5	4·6	40
Sydney, N.S.W.	1016·6	+2·7	94	61	77·2	67·1	72·1	+0·8	67·7	79	8·1	5·84	+1·64	15	4·9	36
Melbourne	1014·6	+0·1	98	46	83·6	61·4	72·5	+4·9	63·2	59	6·1	1·39	−0·32	7	7·1	53
Adelaide	1013·4	−0·9	105	54	88·5	65·8	77·1	+3·1	64·9	46	5·1	0·77	+0·05	5	8·6	57
Perth, W. Australia	1010·0	−3·0	100	55	86·8	64·5	75·7	+1·6	64·7	49	3·4	0·10	−0·35	2	10·6	80
Coolgardie	1010·8	−1·6	106	57	90·0	65·4	77·7	+1·5	62·1	49	4·0	0·18	−0·67	5	—	—
Brisbane	1014·4	+1·9	86	65	80·6	68·5	74·5	−2·0	69·8	68	7·7	9·77	+3·43	22	4·6	35
Hobart, Tasmania	1016·3	+3·1	88	46	74·4	54·1	64·3	+2·0	56·0	61	5·9	1·24	−0·24	7	8·9	65
Wellington, N.Z.	1018·2	+2·4	82	42	67·7	53·4	60·5	−0·7	56·5	75	7·2	5·75	+2·61	7	7·6	55
Suva, Fiji	1007·3	−0·5	89	70	85·3	73·9	79·6	−0·7	75·8	84	6·6	14·70	+3·98	18	7·0	55
Apia, Samoa	1007·4	−1·0	91	73	87·3	75·5	81·4	+2·4	78·4	82	7·6	10·36	−4·93	14	6·2	49
Kingston, Jamaica	1014·0	−1·3	88	65	85·4	70·1	77·7	+1·2	70·4	74	3·7	2·94	+2·34	8	8·0	69
Grenada, W. Indies	—	—	86	70	84·6	74·8	79·7	+2·6	74·4	77	7·0	0·18	−2·60	6	—	—
Toronto	1009·9	−8·1	43	3	28·9	16·3	22·6	+1·5	18·6	—	9·7	1·00	−1·38	15	2·4	23
Winnipeg	1022·8	+1·0	30	−29	8·4	−9·1	−0·3	−0·4	−5·1	—	6·6	1·24	+0·50	14	3·5	35
St. John, N.B.	1001·7	−12·2	47	4	32·2	18·6	25·4	+5·5	21·2	—	6·6	5·09	+1·19	14	3·6	35
Victoria, B.C.	1019·3	+2·7	59	20	49·7	33·5	41·6	+1·1	36·4	93	5·4	4·56	+1·30	8	4·0	39

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Frontispiece]

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CAPTAIN L. G. GARBETT, C.B.E., R.N.
Director of the Naval Meteorological Service

M.O. 482 AIR MINISTRY

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RETIREMENT OF CAPTAIN L. G. GARBETT, C.B.E., R.N.

Captain L. G. Garbett, Director of the Naval Meteorological Service, retired on August 9. He is succeeded by Captain J. W. Josselyn, D.S.C., R.N.

Captain Garbett's association with meteorology goes back for over a quarter of a century. In 1921, on his retirement from the Navy, he was appointed superintendent of Navy Services in the Meteorological Office. His duties consisted chiefly in acting as Liaison Officer between the Meteorological Office and the Admiralty. At first the work was not very arduous and Captain Garbett took the opportunity to increase his technical knowledge by helping with the lectures and classes then being started at the School of Meteorology under Sir Napier Shaw, Professor of Meteorology at the Imperial College of Science. Thus began a very close and happy association which continued until Sir Napier's death in 1945.

From the first Captain Garbett regarded his role as active, and at a very early stage he seems to have visualised what the Naval Service might ultimately become. The *Annual Reports* on the work of the Division show clearly that his efforts were from the first directed towards the definite object of building up an efficient forecast service within the Fleet, and that all the various activities of the Division had that one end in view.

In the early days Captain Garbett spent much of his time finding out what were the needs of the Fleet and how to provide for them. He began by discussions with the Commander-in-Chief of the Atlantic Fleet. Later in 1925 he visited the Mediterranean Fleet at Malta; in 1929–30 he went to China and the East Indies, in the latter part of 1930 to America and the West Indies, and in 1932 to Africa. The object of these visits was " by conference with the officers of the Fleet and with the Meteorological Services to organise the supply of meteorological information to the Fleet and the use of that information within the Fleet ". One of the incidental results of his visit to the West Indies was the formation of a Meteorological Service in Bermuda with a naval officer as Director. The conferences led to much closer co-operation between the local services and the Fleet to their mutual benefit.

One of the landmarks in the organization of the service was the appointment by the Admiralty in 1927 of a Fleet Meteorological Committee to direct and supervise the development of meteorology in the Navy. Captain Garbett was a member of that committee which, in 1934, made certain recommendations for governing the future policy of meteorology in the Navy. The recommendations were based on proposals which had been submitted by Captain Garbett and " embraced internal organization of meteorological work in the Fleet, selection and training of personnel for meteorological duties, meteorological equipment of H.M. ships and meteorological publications for use in the Fleet."

From then onwards the work rapidly expanded but the increased threat of war accentuated the administrative difficulties, and after prolonged discussion the greater part of the work of the Naval Division was transferred to the Admiralty. On August 1, 1937, a new branch of the Hydrographic Department of the Admiralty was formed, known as the Naval Meteorological Branch, with Captain Garbett as Chief Superintendent.

The outbreak of war naturally brought still further expansion and at the end of 1939 meteorological offices, manned by the Navy, were opened at several shore stations. In 1940 the status of the Branch was raised to that of a Directorate and Captain Garbett became Director of the Naval Meteorological Service (D.N.M.S.). The need for more staff was largely met by the enlistment and training of additional officers for meteorological duties in the R.N.V.R. In 1945, when the Branch reached its greatest strength, a total, including W.R.N.S., of no less than 300 officers and 450 ratings were employed in meteorology.

Such, briefly, is the history of the Naval Meteorological Service which grew up under Captain Garbett's guidance and which owes its success chiefly to his patience, courage and initiative.

In the steps by which he reached his end, the first in importance was the provision of adequate training. To begin with, naval officers attended lectures at Portsmouth and Plymouth and also visited the Forecast Division of the Office. Later on special courses of lectures were arranged, first at Calshot and then in London. When the Naval Meteorological Branch was established in 1937, the Admiralty simultaneously assumed responsibility for the training of officers and ratings. Captain Garbett realised that the needs of the Navy were not entirely met by the existing textbooks, and at his request an " Admiralty Weather Manual " was prepared and plans were put in hand for a series of Handbooks of Weather on the different Naval Stations' designed to give an officer the climatic and synoptic background he needed for forecasting in all parts of the world.

In building up a forecast service in the Navy it was also essential to provide for the broadcast of weather data so that ships could construct their own synoptic charts. Captain Garbett worked to ensure that a uniform Fleet Synoptic Message should be broadcast by shore stations for use on board ship. The first messages in this form were broadcast from Malta as the result of Captain Garbett's visit in 1925, and later on similar broadcasts were started in the Far East, South Africa, Australia, Canada and India. He visualised also that in war a ship might have to forecast from nothing but her own observations, so a special study was made of single-observer forecasting. Lt.-Cdr. (now Capt. Beatty was appointed in 1929 for this work. Some of the early work on the relation of cloud forms to fronts was carried out by Lt.-Cdr. (now Capt.) Josselyn, Captain Garbett's successor.

Captain Garbett realised also that the Fleet had its own contribution to make both to synoptic meteorology and to upper air research. In quite early days he arranged that synoptic reports should be broadcast from ships, particularly from those off the regular trade routes, and these reports began to appear in the *Daily Weather Report*. At first they were made only in the Mediterranean, but later they were extended to other regions. Encouraged by Sir Napier Shaw, Captain Garbett also began to take a personal interest in upper air observations at sea. He translated Teisserenc de Bort's instructions for ballon-sonde observations and made experiments with sounding balloons at sea in H.M.S. *Kellett* and H.M.S. *FitzRoy*, himself designing a special anchor for the meteorograph. Arrangements were made for H.M.S. *Hermes* and H.M.S. *Furious* to take upper air temperature observations on international days. He was also active in equipping H.M. ships for pilot-balloon observations and all ships carrying aircraft were so equipped. A chart showing the distribution of observations and later the observations themselves were published.

Although Captain Garbett's own work was chiefly on the administrative side, he was well aware of the help which scientists could give, and at his suggestion several investigations were undertaken, such as the observation of visibility at sea and the design and exposure of instruments on board ship. When the Meteorological Research Committee was formed, Captain Garbett was appointed a member so that he could keep the Admiralty informed of the latest advances in the science, and bring any special requirements of the Navy to the notice of the Committee.

The success of Captain Garbett's work needs no demonstration. The existence of the Naval Meteorological Service itself is its witness, and he has every reason to look back on the past 26 years as years of great achievement. The Admiralty recognised the value of his work by promoting him to the rank of Captain in 1936 in spite of his being on the retired list—a very unusual step—and by advancing the status of the Branch to that of a Directorate in 1940. For his services during the war he was awarded the C.B.E. in 1942.

Our best wishes go to Captain Garbett in his retirement in Herefordshire, and to Captain Josselyn in his task of carrying on the work of the service which Captain Garbett created.

SPECIFICATION OF WATER VAPOUR IN THE ATMOSPHERE

BY G. A. BULL, B.SC.

Introduction.—It has been realised within the last few years by physicists and meteorologists that the nomenclature of atmospheric humidity needed clarification. There has been a tendency for particular industries to use terms unknown to others or, worse, for terms to be used with different meanings by different industries. Here meteorology is included as one of the industries dealing with atmospheric humidity. Other such industries that may be mentioned are heating, ventilating and air conditioning, ceramic manufacture, chemical engineering, gas making.

On this account the British Standards Association in 1945 set up a sub-committee of its technical committee on units and data to prepare a publication on atmospheric humidity to include definitions, formulae, and constants.

The sub-committee contained representatives of the industries mentioned above and of the Physical Society.

The sub-committee met at frequent intervals during 1945 and 1946 and as a result of its work *British Standard* 1339 : 1946 containing recommended definitions formulae and constants was published in December, 1946, by the British Standards Institution.

The Meteorological Office was not able to accept all the decisions of the British Standards humidity sub-committee and reservations on this account are given where necessary in *British Standard* 1339 : 1946. During the discussion in the sub-committee the Meteorological Office prepared a paper, setting out its views on the subject, which has now been submitted to the International Meteorological Organization for examination by the Commission for Instruments and Methods of Observation.

Consideration, from a rather different angle, has been given to humidity matters by the International Joint Committee on Psychrometric Data. The latter committee is mainly American but has participating organizations in Canada and Great Britain. The Meteorological Office, the National Physical Laboratory, the Physical Society and the Institution of Heating and Ventilating Engineers are the British participating organizations. This body is concerned with the compilation of a set of tables of great exactness covering the properties of air and water-vapour mixtures.

The next section of this note is devoted to a detailed consideration of the memorandum on the specification of water vapour in the atmosphere sent to the International Meteorological Organization by the Director of the Meteorological Office, the third section to the British Standard on humidity definitions and constants, and the fourth to the departure of moist air from the perfect gas laws which is the aspect to which the International Joint Committee on Psychrometric Data has particularly given its attention.

Memorandum by the Meteorological Office on the specification of water vapour in the atmosphere.—The memorandum points out that there are seven main terms in meteorological use relating to water vapour, viz. water-vapour pressure, water-vapour density, relative humidity, absolute humidity, specific humidity, moisture content, humidity mixing ratio, which are used to express five different physical quantities. In addition there are the dew-point temperature, the frost-point temperature and the wet-bulb temperature.

Since two of the seven terms are redundant, it is proposed that five of them should be selected, specified and recommended for general use by the International Meteorological Organization.

The terms recommended are, with indicating letters :—

e = vapour pressure,
d = vapour density,
U = relative humidity,
q = moisture content,
x = mixing ratio.

The terms omitted as redundant are " absolute humidity ", which is identical with " vapour density ", and " specific humidity " which is identical with "moisture content" as defined below. It is to be noted that "humidity" occurs in only one, "relative humidity", with the intention that the word humidity in meteorological usage will refer invariably to "relative humidity".

The specifications are as follows :—

Vapour pressure, e.—The memorandum states that this term is used with its ordinary physical significance. Accepting, as we may for meteorological purposes (see p. 200), the accuracy of Dalton's law of partial pressures, then the vapour pressure is the pressure which the water vapour would exert at the same temperature if the other constituents of the atmosphere were absent. If Dalton's law is not accepted the concept of partial pressure loses its meaning.

Vapour density, d.—This has its ordinary physical definition as the mass of water vapour per unit volume. On the assumption that water vapour is a perfect gas then $e = RdT$ where T is the absolute temperature and R the gas constant for water vapour.

Relative humidity, U.—The memorandum points out that in the past the term relative humidity has been used indiscriminately to mean either of two separate quantities, which, it is true, have almost identical numerical values under conditions occurring in meteorological practice.

These quantities are :—

(i) $U_d = 100\ d/d_t$ where d is the density of water vapour actually in the air, and d_t is the density of saturated water vapour at the temperature t of the air.

(ii) $U_e = 100\ e/e_t$ where e is the partial pressure of the water vapour actually present in the air and e_t is the saturation vapour pressure at temperature t of the air (dry-bulb temperature).

The two ratios are necessarily identical at 0 and 100 per cent., but at intermediate ratios U_e is slightly greater than U_d though the difference is negligibly small at meteorological temperatures. Further information on this matter is given later but we may note here that Callendar's "Steam Tables" show that at a temperature of 126° F. a relative humidity of 50 per cent. on the pressure definition corresponds to a relative humidity of 49·97 per cent. on the density definition, at 153° F. the corresponding value is 49·95 per cent. and at 183° F. it is 49·9 per cent. The discrepancy at a lower temperature than 120° F. is too small for calculation from the tables. For any given temperature the difference is greatest for a relative humidity of 50 per cent.

Clearly the vapour-density definition is the more fundamental since its value can be directly measured by weighing whereas the ratio of the pressures can only be derived indirectly.

The memorandum therefore proposes that the definition of relative humidity should be based on density.

Moisture content, q.—The term moisture content has been used hitherto without any clearly defined meaning. The Meteorological Office memorandum proposes to define it as the mass of water vapour in unit mass of air, i.e., in unit mass of the mixture of dry air and water vapour. The value of q ranges from zero in the case of dry air to unity in the case of steam (water vapour with no air). It is usually expressed in terms of grams per kilogram, and in these units is identical with $1{,}000\ d/d'$ where d' is the density of the air. An expression sometimes used in the past for this quantity was " specific humidity ".

Assuming, as appears to be very nearly the case under meteorological conditions, that Dalton's law holds and that the density of water vapour is 0·622 times that of dry air at the same temperature and pressure then

$$q = \frac{622e}{P - 0{\cdot}378e}$$

where P is the total pressure.

Mixing ratio, x.—This is defined, in agreement with meteorological practice for some years past, as the mass of water vapour which must be mixed with unit mass of dry air to obtain air of the same constitution as the actual air. Like moisture content it is usually expressed in grams per kilogram and in these units is identical with $1{,}000d/(d'-d)$. In terms of pressure

$$x = \frac{622e}{P - e}$$

The value of x ranges from zero for dry air to infinity for steam.

" British Standard 1339 : 1946, Humidity of the air (Definitions, Formulae, and Constants ".—In this section the specification is briefly reviewed with particular attention to terms not used in meteorology or terms recommended for use with different definitions from those proposed in the Meteorological Office memorandum.

The specification begins by referring to the confusion in terminology and recommending the set of definitions based on majority usage given in the specification. Among these definitions are the following :—

Absolute humidity.—This is identical with vapour density.

Humid volume.—This is a term not used in meteorology but much used in industry. It is that volume of the air in cubic feet which contains 1 lb. of dry air. Alternatively it may be given in cubic centimetres per gram of dry air. The term is not very happily chosen since air has a humid volume if it contains no water vapour at all, while its value becomes infinite for steam. The formula for humid volume is

$$V = \frac{RT}{P - e}$$

where R is the gas constant for dry air and T is the absolute temperature.

Moisture content.—The specification defines this as identical with the " mixing ratio " used by meteorologists. The Meteorological Office did not agree with this definition of moisture content. A serious defect is that its value is infinite in the case of steam which is unreasonable for a " content ".

The quantity so defined is important in industrial drying processes since the mass of dry air remains constant as the air passes through the drying apparatus.

Percentage saturation.—This is another industrial term not used by meteorologists. It is the percentage ratio of the actual mixing ratio to the saturation mixing ratio at the same dry-bulb temperature.

The formula for it is

$$\text{Percentage saturation} = 100\,\frac{d}{d_t}\cdot\frac{d'-d_t}{d'-d}$$

where d_t is the saturation vapour density. Assuming the gas laws and Dalton's law this can be written

$$\text{Percentage saturation} = 100 \frac{e}{e_t} \cdot \frac{P-e}{P-e}$$

The total pressure P is normally taken as 1000 mb. in practice.

When the air is completely saturated its value is 100 per cent. and when the air is completely dry it is 0 per cent. When relative humidity is intermediate between 0 and 100 per cent. the numerical values of relative humidity and percentage saturation are almost identical at low temperatures but above 100° F. the difference is appreciable. The difference between relative humidity and percentage saturation is $U\ (e_t - e)/(P - e)$.

Examples:—

Dry bulb ° F.	Relative humidity %	Percentage saturation %
50	50	49·7
100	50	48
150	50	43

Relative humidity.—The pressure definition of relative humidity was adopted by the sub-committee. The specification points out that the pressure definition is not identical with the mass one, but that the numerical difference between the two is inappreciable at temperatures below 200° F.

The other definitions (dew point, dry- and wet-bulb thermometers, hoar-frost point, saturation vapour pressure, Stevenson screen, total heat and vapour pressure) in the specification do not call for comment.

The notation recommended by the specification differs from the one proposed by the Meteorological Office.

The British Standards Institution (B.S.I.) specification reads :—

P = total atmospheric pressure
t = dry-bulb temperature
t' = wet-bulb temperature
e = actual vapour pressure
e' = saturation vapour pressure at the wet-bulb temperature
e'' = saturation vapour pressure at the dry-bulb temperature
h_W = moisture content
h_V = absolute humidity
ρ = density of moist air (mass of unit volume)
V = humid volume

Formulae with recommended constants are given for the psychrometric relation between vapour pressure and the difference between wet- and dry-bulb thermometers, moisture content (B.S.I. use of term), absolute humidity, density of moist air and humid volume.

The only one of these calling for comment is the value of the constant A in the psychrometric formula $e = e' - A\,P\,(t - t')$ using the notation above. The specification adopts the same values for A as are given in the Meteorological Office " Hygrometric Tables ", except that for the wet bulb in the Stevenson screen the value $4{\cdot}4 \times 10^{-4}$ is recommended instead of the value

$4{\cdot}44 \times 10^{-4}$. This appears to be an improvement since the additional ·04 used in the " Hygrometric Tables " can only justifiably be used if account is taken of the variations of pressure, whereas it is normal practice to take P as fixed at 1000 mb. when calculating relative humidity at ground level.

The effect of departure from the perfect gas laws on the humidity elements.—Meteorologists are generally accustomed to accept the accuracy of the laws of a perfect gas or mixture of perfect gases as applied to the atmosphere and but little reference is to be found in meteorological textbooks to the fact that these laws are not quite accurate. The assumption is fully justified under conditions met with in the atmosphere and within the limits of the accuracy possible in meteorological measurement, but it is desirable that meteorologists should appreciate broadly how justifiable it is.

It has been realised for over a century that Avogadro's, Boyle's, and Charles' laws, summarised in the equation $PV = nkT$ (where P = pressure, V = volume, n = number of molecules, k = Boltzmann's constant, T = absolute temperature) are incorrect particularly near the critical points. The perfect gas laws hold in fact only for a collection of infinitesimally small perfectly elastic molecules influencing one another's motion only when in collision. However, molecules are actually of finite size and do exert attractive or repulsive forces upon one another when not in contact. Numerous modifications of the equation of state allowing for these considerations have been put forward.

The most celebrated of the earlier ones, though not the first, is that of Van der Waals,

$$\left(P + \frac{a}{V^2}\right)\left(V - b\right) = RT$$

in which a and b are constants for a particular gas. The term a/V^2 added to P is intended to make a rough allowance for the inter-molecular forces of attraction or repulsion while b allows for the finite size of the molecules.

Kammelingh Onnes introduced in 1900 the equation of state of the form $PV = RT + A(T)P + B(T)P^2 + \cdots$, in which $A(T)$, $B(T)$, etc., are functions of T called the second, third, etc., virial coefficients, RT being the first. The second virial coefficient can be found from the mutual potential energy of two unpolarised molecules by means of a formula derived in modern textbooks on the kinetic theory of gases or statistical mechanics.

When there is a mixture of gases a further complication arises from the mutual interaction of unlike molecules. The virial coefficients then become functions of the relative proportions of the different kinds of molecule.

Dry air obeys the gas laws very exactly and water vapour less exactly. The properties of water vapour at high temperatures and pressure are of great importance in steam engineering and much research has been and still is being done on them. Several semi-empirical equations of state have been proposed for water vapour. As a specimen of them we may quote Callendar's equation which is

$$PV = 4611{\cdot}7\ T - P\left\{26{\cdot}3\left(\frac{373{\cdot}1}{T}\right)^{3{\cdot}3} - 1\right\}$$

where V is in cu. cm./gm. and P in mb. Tables of the connexion between the pressure and specific volume of water vapour as functions of temperature based on this formula are available as the Callendar " Steam Tables ". Other more complicated equations, with associated tables, have been published by Keenan and Keys, Linde, and others. Use was made of Callendar's " Steam Tables " in the Meteorological Office memorandum to calculate the difference between the numerical values of the two definitions of relative humidity assuming the accuracy of Dalton's law and neglecting the relatively small extent to which dry air departs from a perfect gas.

The equation of state for a mixture of gases is of the form :—

$$PV = RT + P\left\{ \Sigma A_{ij}(T) \right\} + \cdots$$

where A_{ij} is the second virial corresponding to the gases i and j. This includes the terms depending on the interaction of like molecules which appear as terms such as A_{ij}. R is the value of the gas constant which would be calculated in the ordinary way on the basis of Dalton's law. Clearly, if the equation of state is of this form, the concept of " partial pressures ", the associated Dalton's law, and the pressure definition of relative humidity strictly break down. Research into the properties of moist air on these lines is proceeding at the University of Pennsylvania under the auspices of the American Institution of Heating and Ventilating Engineers and the International Joint Committee on Psychrometric Data. An important paper by J. A. Goff entitled " Thermodynamic Properties of Moist Air ", describing the results so far obtained was published in *Heating, Piping and Air Conditioning*, New York, June, 1945. The results of their researches are reassuring so far as conditions at temperatures occurring in the atmosphere are concerned. Thus, their values of humidity mixing ratio at saturation differ by at most 0·3 per cent., from those of " Hygrometric Tables " over the range from 20° F. to 80° F. At −9° F. the difference has increased to 0·5 per cent. It thus appears that the deviations from the perfect gas laws are very small under meteorological conditions.

ABSOLUTE DROUGHTS AND PARTIAL DROUGHTS OVER THE BRITISH ISLES, 1906—40

BY J. GLASSPOOLE, M.SC., PH.D. AND H. ROWSELL, B.SC.

In *British Rainfall*, 1887, the following definitions of absolute and partial drought were introduced :—

> *Absolute drought* is a period of at least 15 consecutive days, to none of which is credited 0·01 in. of rain or more.
>
> *Partial drought* is a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed 0·01 in.

The absolute and partial droughts recorded at 50 representative stations over the British Isles were initially given in the annual volumes of *British Rainfall*; in 1903 the number of stations was increased to 73 and in 1910 to 100 stations. Although it has not been possible to use the same stations throughout, statistics are therefore available back to 1910 and the series back to 1906 has also been used in order to obtain the mean frequencies for the 35 years 1906–40. The procedure adopted was to prepare maps on which were plotted separately for each year the number of absolute and partial droughts at the individual stations. For each of the 100 places used in recent years the number of droughts was written down from the maps and the mean extracted. Fig. 1 shows the

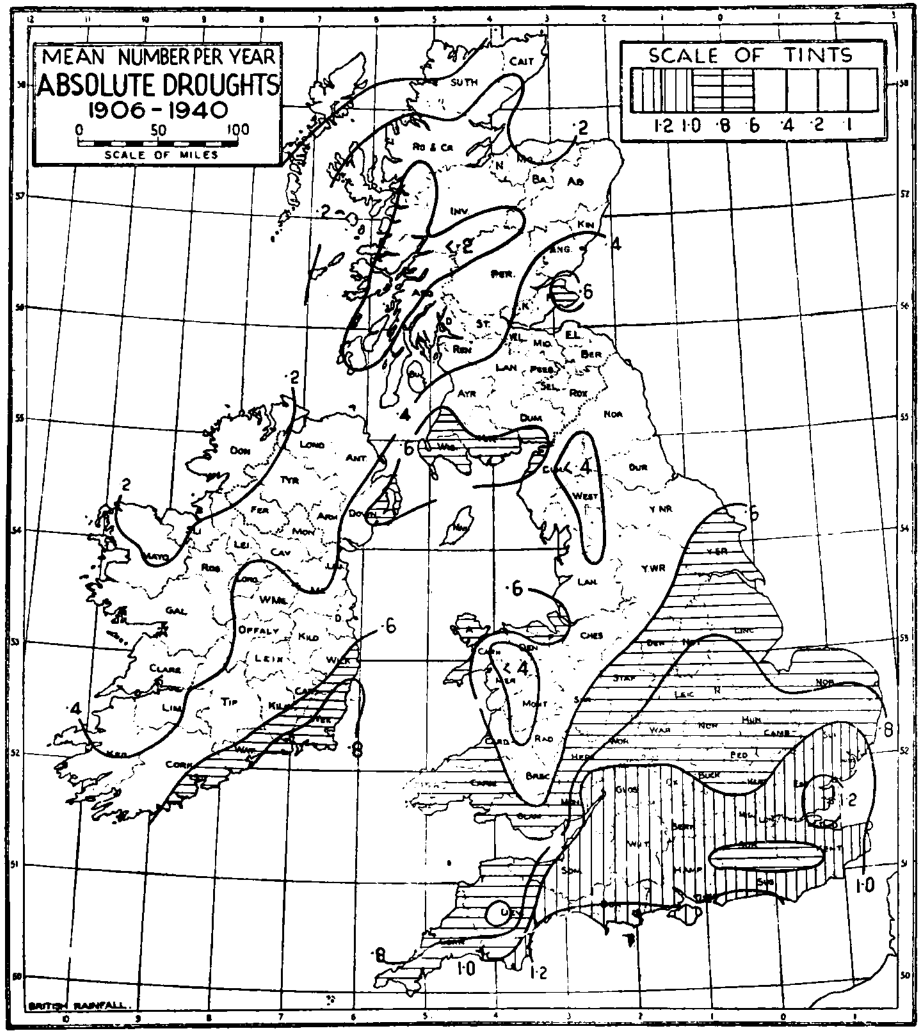

MEAN NUMBER PER YEAR
ABSOLUTE DROUGHTS
1906 - 1940
0 50 100
SCALE OF MILES
SCALE OF TINTS
1·2 1·0 ·8 ·6 ·4 ·2 ·1
BRITISH RAINFALL.

FIG. I

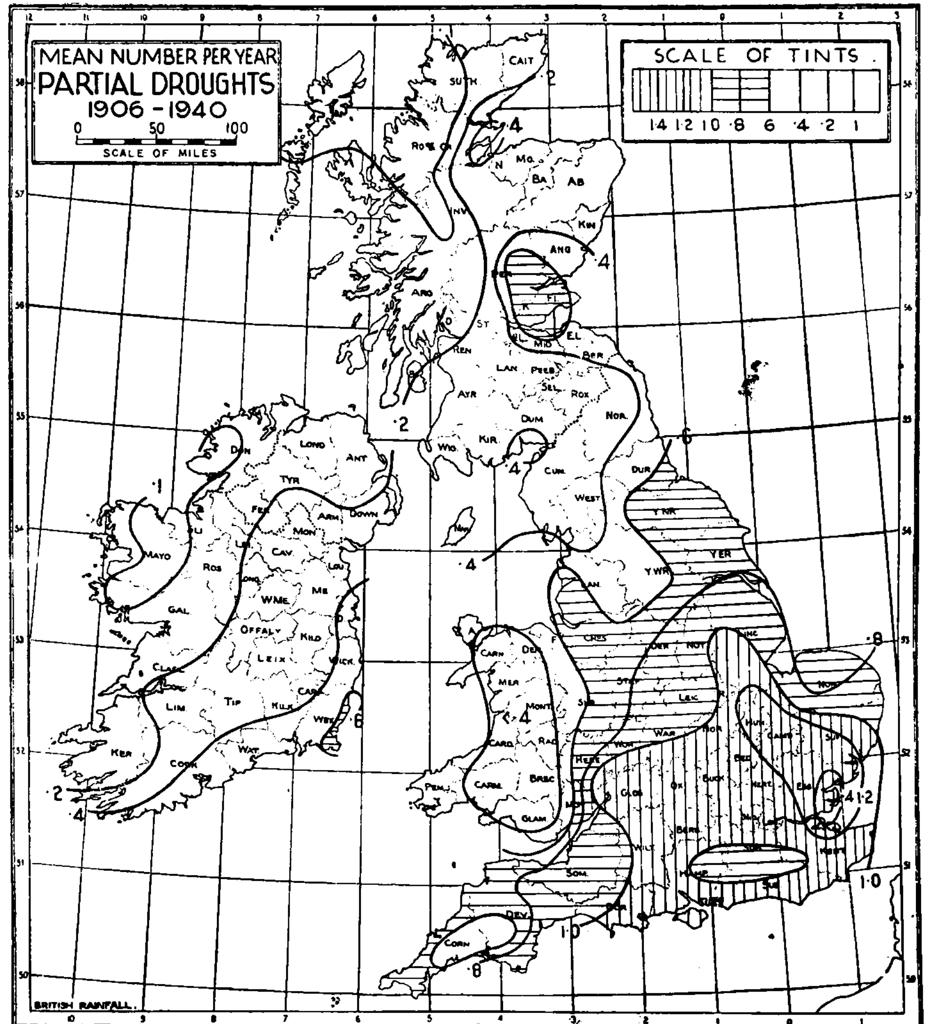

MEAN NUMBER PER YEAR
PARTIAL DROUGHTS
1906 - 1940
0 50 100
SCALE OF MILES
SCALE OF TINTS.
1·4 1·2 1·0 ·8 ·6 ·4 ·2 ·1
BRITISH RAINFALL.

FIG. 2


GREATEST NUMBER IN A YEAR
ABSOLUTE DROUGHTS
1906 - 1940
0 50 100
SCALE OF MILES
SCALE OF TINTS
5 4 3 2 1
BRITISH RAINFALL.

FIG. 3

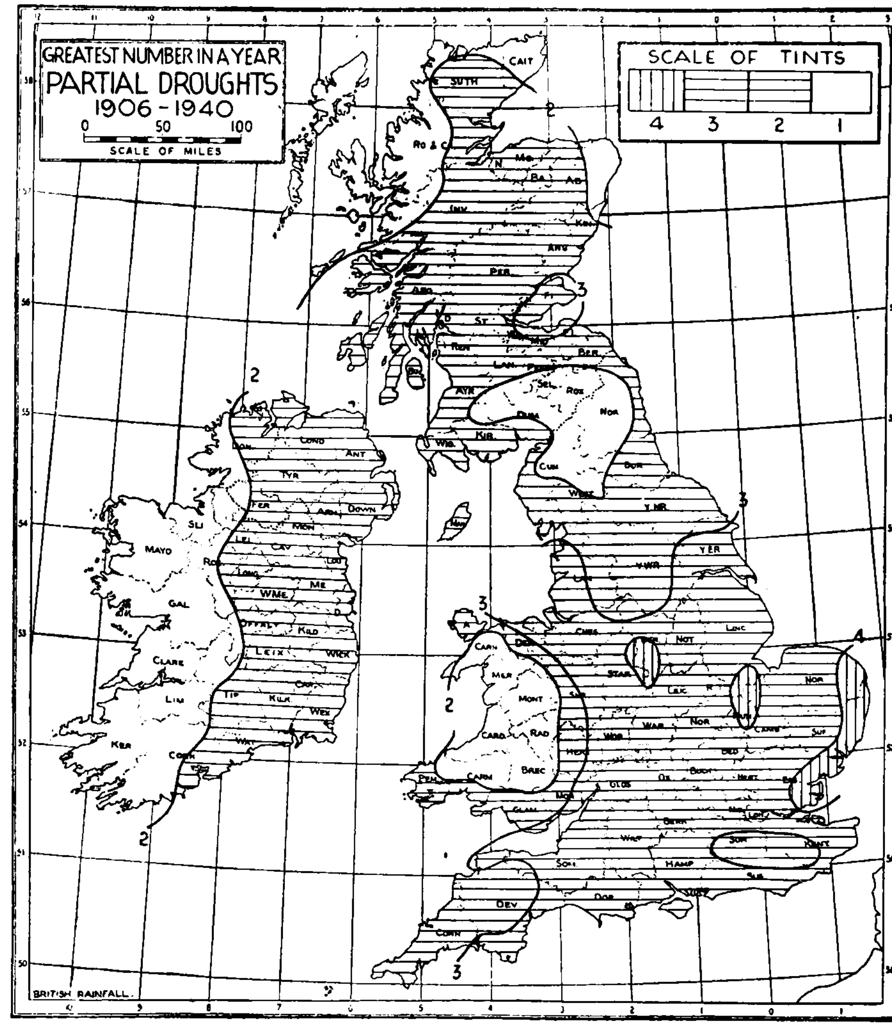

GREATEST NUMBER IN A YEAR
PARTIAL DROUGHTS
1906 - 1940
0 50 100
SCALE OF MILES
SCALE OF TINTS
4 3 2 1
BRITISH RAINFALL.

FIG. 4

resulting distribution of the mean number of absolute droughts per year and Fig. 2 the corresponding mean number of partial droughts.

It will be seen from Fig. 1 that, on the average, the area south of a line roughly from Ross-on-Wye to Oxford and Bury St. Edmunds records rather more than one absolute drought per year, whereas in the extreme north-west of Scotland the frequency is only one in ten years. The map shows the distribution in greater detail than that first given in the *Quarterly Journal of the Royal Meteorological Society, London,* **65**, 1939, p. 381, which is based on fewer records and for the period 1919–38.

From Fig. 2 it will be seen that the frequency of partial droughts is on the whole very similar to that of absolute droughts, rather more than one per year occurring in the south-east of England and only one in ten years in the north-west of Scotland. The extreme south-east of Essex records three partial droughts in two years, while most of the north-western parts of both Ireland and Scotland give fewer than once in five years.

During the 35 years 1906–40 there was no year (see Fig. 3) with more than one absolute drought over much of the north-west of the British Isles, as well as over the Pennines and the mountainous regions of northern Wales. Over more than half the country the greatest number was two, while three occurred in one year mainly in the south of England. Small areas have recorded as many as four ; and five absolute droughts occurred in 1911 at Ashburton (Druid House) in south Devon. The year 1911 gave the largest number of absolute droughts in the series at the 100 representative stations, viz. 137. The next largest numbers were 112 in 1939 and 110 in 1929. The earlier years 1887 and 1901 gave 160 and 112 respectively, and in 1887 the greatest number at any selected station was four. On the other hand only 11 absolute droughts were recorded at the 100 representative stations in 1923 and 1927. The earlier year 1902 gave 10 only.

All stations (see Fig. 4) have recorded at least one partial drought in a year and a few stations in the Midlands and east of England as many as four. The largest numbers at 100 stations were 156 in 1932, 137 in 1911 and 109 in 1921. Since 1887 the only year to give a comparable number was 1887 with 116. The smallest number in the series occurred in 1918 with 14, although the earlier years 1888, 1890 and 1902, gave 8, 6 and 4 respectively.

Since absolute droughts have been recorded at all stations within the period 1906–40, it is clear that all parts of the country are likely to experience at least 15 consecutive days without measurable rain. The duration of the longest absolute drought experienced at each station has been extracted and the values plotted on a map. Further information is provided by the monthly maps of rainfall which show that no measurable rain has been recorded on a number of occasions in different parts of the country. The list to the end of 1943 of individual months for which no rain was recorded somewhere in the country is:—

February, 1891, 1895, 1932 and 1934
March, 1929 and 1931
April, 1893, 1912 and 1938
June, 1921, 1925 and 1942
July, 1911
August, 1940
September, 1894

In June, 1925, there was no measurable rain over an area of 6,410 sq. miles in southern England and Wales, and in February, 1891, over some 3,290 sq. miles in central and east England and south Wales.

In parts of the north of Scotland and north-west of Ireland the greatest number of consecutive rainless days is between 15 and 20. Over most of Scotland, Ireland and northern England and the mountainous districts in Wales the greatest number has never reached 30 days. In the south-east of England the number has exceeded 40 days and along the south-east coast reached as many as 60 days. The longest well authenticated absolute droughts covered 60 days ~~between~~* March 4 and May 14, 1893 at Hastings, Winchelsea, Lewes and Haywards Heath.

(This note was prepared during the war and is published now for comparison with recent droughts.)

* within the period.

LETTERS TO THE EDITOR

Supercooled water on pond ice

The existence of slush and water on the top of pond ice at a very low temperature in January, 1945, is the subject of a letter in the *Meteorological Magazine* for March, 1947, p. 63. The title was chosen intentionally, as the writer was of the opinion that supercooling was the process responsible for the presence of the water. The Editor has added a note to the effect that it would have been interesting to analyse the slush in view of the possibility of dissolved substances having lowered the freezing point. I admit that I did not conduct the experiment, but it appears most unlikely that this is the explanation.

Taking the well known physico-chemical formula $M = sK/Ld$, where M is the molecular weight of the solute, s its weight in grams, L the weight of the solvent, and d the depression in degrees centigrade below freezing point (in the case of ammonium sulphate, one has to choose at random, $M = 132$, $d = 9^{\circ}$ C. on the particular occasion) K is a constant (= 1,870 for water), and taking L as 1,000 gm., it is found that s has to be 635 gm.

Assuming the depth of slush to be 2 in. and that it contained 50 per cent. liquid, and that the area of the pond concerned was $\frac{1}{4}$ acre, the weight of solid needed is about 28 lb./sq. yd. or about 15 tons in all ; this figure is derived by erring on the small side in the calculation. It seems impossible that quantities of soluble substance of this order of magnitude could be deposited on a pond in the country, and particularly over such a limited area, the rest of the pond being free.

Nevertheless, the Editor's remark, though apparently inadequate as an explanation in this case, is interesting, as considerable quantities of dirty-looking solid do get deposited upon snow and ice in winter in places far removed from areas of industrial pollution. On May 26 last, while near the summit of Carnedd Llewelyn examining the last remaining Welsh snow-bed, I found it filthy in appearance, much of it being literally black, as if covered with tar, and the ground around, previously covered by the snow-bed, in the same condition, as I found out after having unwarily sat on it.

S. E. ASHMORE

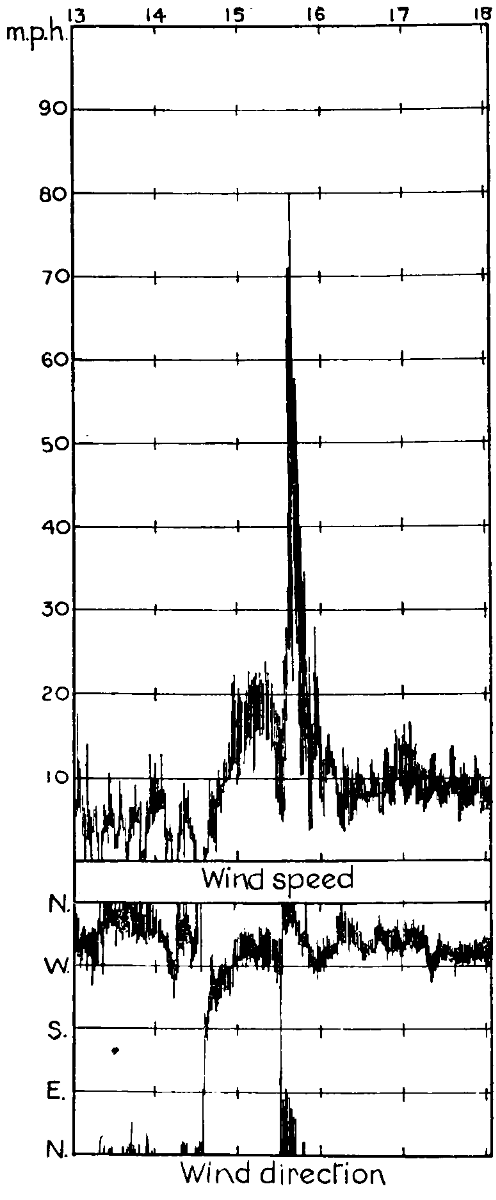
11 *Percy Road, Wrexham. June* 13, 1947.

Severe squall at Kano, northern Nigeria

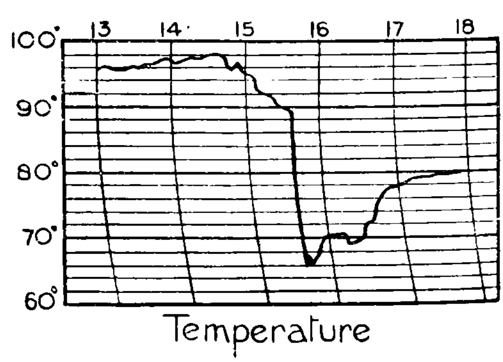
The following notes are on the development of the weather at Kano, on June 12, 1947, culminating in a very severe squall.

Small cumulus began to form at 1100 G.M.T. and had increased to 3 tenths at 4,500–5,000 ft. by 1200. Very rapid development followed, and by 1335, local showers were observed at many points between east and west through south. The shower clouds were isolated, and individually did not cover a large area—6 tenths cumulonimbus were reported at 1400—with base 4,000 ft. and tops in many instances having already reached their maximum vertical development and spreading out to form massive anvils.

At about this time a large isolated cumulus was observed to the north-east, at a distance of some 50 miles. As this cloud, still developing, was borne



SKETCH OF THE OBSERVED CLOUD



AUTOGRAPHIC RECORDS AT KANO DURING THE SQUALL OF JUNE 12, 1947 nearer the airport on the north-easterly upper wind its base was estimated to be at least 5,000 ft. and diameter a little over a mile.

The under surface of the cloud was seen to develop an ominous turbulent annular roll, diameter about half that of the cloud base, and giving to the cloud's under surface an appearance which can be best described as an immense flat-bottomed crater, with the sides of the " crater " protruding downwards from the main base to a distance of between 500 and 1,000 ft. The walls of the " crater " showed evidence of strong downward currents, while the lower edges were swept outwards and upwards.

Surface wind had been light from a westerly point, but shortly before 1500 freshened to SW. 15 to 17 m.p.h. At this time the effects of the cloud were becoming visible to the north-east of the airport, where vast clouds of thick dust were being lifted from the surface. With the closer approach of the cloud, blowing dust arrived at the airport at 1534. The surface wind at this time was still westerly. Six minutes later, at 1540, the squall struck, the wind veering sharply from 300° to 030°, and gusting to 80 m.p.h. Violent gusts were maintained for ten minutes, followed by a rapid moderation and backing, so that by 1600 the wind was again W. 12 m.p.h.

The rain which accompanied the squall was very heavy, but short-lived, soon becoming slight, and ceased at 1630; 0·39 in. were recorded. Thunder occurred, but was not very heavy.

At 1500, when the wind first freshened, the temperature was 96° F., but by 1540 had fallen to 89° F., followed by an almost instantaneous drop to 66° F. as the squall struck.

The path of the squall was narrow, the really heavy squall being contained within a belt of width 200–300 yds. This assumption is based on a survey of the damage caused to buildings in the track of the storm as it passed right across the airport buildings from north-east to south-west. Only in a relatively narrow belt was serious damage caused—corrugated iron roofs, complete with joists, being lifted bodily and carried several hundreds of yards, while similar buildings on each side of the storm track escaped damage.

A. T. DORRELL

Kano airport, Nigeria.

NOTES AND NEWS

First British ocean weather ship—Renaming ceremony

On the afternoon of Thursday, July 31, 1947, in the London Docks, the ceremony of renaming our first ocean weather ship* was performed by the Secretary of State for Air. The ship was the ex-Royal Naval corvette *Marguerite,* and she was to be renamed *Weather Observer.* The extensive work of converting the ship from a war vessel to her new appearance had been carried out at H.M. Dockyard, Sheerness. At about noon on the 30th the ship had arrived up river from that port and had been berthed in Shadwell Basin, London Docks.

The Port of London Authority had kindly allotted, abreast the ship's berth, a large shed in which an exhibition of meteorological instruments was laid out, and where refreshments were arranged for the guests. Decorations were hung round the inside walls of the shed including the national flags of the

* See *Meteorological Magazine,* **76,** 1947, p. 25.

countries interested in the Atlantic ocean weather ship scheme ; Belgium, Canada, Denmark, Eire, France, Holland, Iceland, Norway, Portugal, Sweden, the United Kingdom, and the United States of America. On a flagstaff outside the shed the Union Flag was flown; the ship herself flew masthead flags, a jack, and the Red Ensign, and also her " number " M.P.J.J.

In the forenoon of Thursday, July 31, representatives of the Press visited the ship and were shown the meteorological arrangements in her. A number of photographs were taken, and a radio-sonde balloon was released by the ship's meteorological staff (see photograph facing p. iii of cover). Fortunately the wind was in the right direction to take the balloon and its gear clear of several tall dock cranes and of a near-by church spire. At 11 a.m. Sir Nelson Johnson, Director of the Meteorological Office, addressed a large Press conference in the shed on the quay.

By 3 p.m. a considerable gathering, including many distinguished people, was on the quay. The Secretary of State for Air, Mr. Noel Baker, was introduced by the Director to a number of the guests, and to the Captain and senior officers of the ship. The ship's company had been mustered on the quay alongside their ship, and they were inspected by the Secretary of State, who then made a speech.

After pointing out that the idea of ocean weather ships was not a new one, Mr. Noel Baker went on to mention the International Conference convened by P.I.C.A.O. in London in September, 1946, which resulted in the signing of an agreement by ten countries for providing and maintaining 13 ocean weather ship stations in the North Atlantic. These ships would act as floating " islands " to provide meteorological observations, and to give navigational aid to aircraft in flight. He outlined the work to be done by them, their upper air soundings and other meteorological work, and their use, should occasion unfortunately arise, as air/sea rescue vessels.

The crews of the ocean weather ships would have an arduous and sometimes difficult job, but if their work resulted in improved accuracy of the weather forecasts for the civil air lines operating across the ocean, as well as for shipping, and for agriculture and many other economic purposes ashore, then it would be difficult to estimate the great value of these ships to the peoples of the countries concerned.

At about 3.30 p.m. the Secretary of State, accompanied by the Director and some guests, boarded the ship and the renaming ceremony was performed; this was done by the Secretary of State, after wishing good luck to all who sail in her, pronouncing the ship renamed *Weather Observer* and at the same time cutting a tape which released a Union Flag that had until then covered the vessel's name on her bow.

The party then inspected the ship, being conducted round by the Captain. Other guests visited the exhibition of meteorological instruments in the shed on the quay, while waiting their turn to inspect the ship.

Guests were conducted over the ship in parties of about a dozen. At the end of the inspection by the Secretary of State and party, another radio-sonde balloon was released from the special balloon filling compartment at the after end of the ship. This balloon, like the one launched in the forenoon, also went clear of all obstructions. The successful launching of radio-sonde balloons from a small ship is no easy job; the balloon with its radar target, transmitter aerial and transmitter having about 30 ft. overall length at the launch, requires considerable skill in handling.

Visitors to the ship found plenty to interest them; the navigating bridge with the various "gadgets" in the chartroom and wheelhouse, the motor lifeboats and other rescue arrangements were all interesting. Some found their main interest in the radio and the radar equipment, all of which is of up-to-date Admiralty pattern, or in the engine room with its complicated mass of machinery. The crew's quarters, recreation rooms and cooking arrangements were of interest to others. A large proportion of the visitors were members of the staff of the Meteorological Office, and to them the interest, no doubt, was in the meteorological plotting room, the insrument-preparing room and the balloon-filling compartment.

The ship herself presented quite a striking appearance, with her black hull and with her deck houses, bridge, boats, funnel and masts painted a bright yellow. This colouring is to make the ship conspicuous from the air. Her unusual appearance and rig caused considerable interest in shipping circles on London River.

The vessel's general dimensions are :—

Length O.A. 206 ft., beam 33 ft., draft-loaded, about 16 ft. She is of 725 tons gross, 268 tons net measurement and has a maximum speed of 16 knots, with a single screw, reciprocating steam engines, and oil fired boilers. As a corvette her armament had been one 4-in. gun mounted forward, one two-pounder QF gun mounted aft, six Oerlikon guns (3 either side) and 72 depth charges.

The change in appearance brought about by the conversion from a war-time corvette to an ocean weather ship—truly from "sword into plough-share"—can be seen by comparing the photograph of H.M. corvette *Snowflake*, a sister ship to H.M. Corvette *Marguerite*, facing p. 32 of this year's February issue and the photograph of O.W.S. *Weather Observer* facing p. 216 of this issue.

It can be seen that two specially designed masts have been added, with a radar platform on the lattice-work foremast. The forecastle deck has been carried aft to the mainmast to provide extra cabin accommodation; a deckhouse has been built forward of the bridge, two 30-foot motor lifeboats fitted, and a large balloon-filling compartment built aft. She has also been considerably altered internally.

On Friday, August 1, 1947, the O.W.S. *Weather Observer*, Captain N. F. Israel, D.S.C., sailed from the London Dock at 2 p.m. to complete her radar tests off Portsmouth and then proceed to her station in the Atlantic—Station "J" in latitude 53° 50′ N., longitude 18° 40′ W.

C. H. WILLIAMS

Explosion at Brest

On July 28, one of the seismographs, a short-period vertical-component instrument, and four different types of barograph, including a very sensitive micro-barograph, recorded at Kew Observatory the effects of the explosion of a cargo of nitrate at Brest, some 300 miles away. The whole disturbance lasted about a minute and resembled very closely the observed effects of war-time explosions (bombs, rockets, etc.).

The recordings were simultaneous on all instruments, showing that, as was the case for the most part during the war, the seismograph disturbance was due to the explosion air wave and not to true earth movements. There were no indications of upper air sound waves.

The first pulse recorded by the seismograph was at 16h. 48m. 52s. G.M.T., the largest amplitude at 16h. 49m. 5s. and all four barographs recorded a sudden pulse of about one millibar of very short duration, the mean of the times being 16h. 49m. 6s. ± 15s. It was estimated from these records that the Brest explosion occurred at about 16h. 25m. G.M.T.

Ball lightning

Two accounts of ball lightning have been received recently. The first comes from Mrs. James Carruthers, C.H., reporting that her friend Miss Heron who lives at Castle Douglas, Kirkcudbrightshire, had told her that on July 9, 1947, " it was a close day but with no rain or thunder; about 11 a.m. a nurse, who was looking after an invalid in the house, saw a fire ball apparently running along one of the electric wires outside the house. A moment after, it crashed with a terrific explosion into a very large oak tree in the garden which was shattered and blasted to pieces . . . . Every fuse in the house was smashed, and all the electric communications—telephone, radio, etc.—but no windows were broken."

The second is from Miss B. D. P. Foster who has kept a daily record of rainfall at Penmilder, Liskeard, Cornwall, since August, 1895. She writes:—

" On August 17, about 7 p.m. during a thunderstorm there was a terrifying and apparently simultaneous crash of thunder and a flash of vivid lightning. People in the neighbouring cottages thought their houses had been struck or their chimneys fallen and children were terrified. During the storm a small-holder and his wife (Mr. and Mrs. Coombes) were sheltering by Penmilder gates—they saw a ball, misty coloured, come through the trees and where it touched the trees zigzag lightning shot out. The ball floated on down the hill and hit a telegraph pole . . . the ball was then lost to sight. The trees crackled and the Coombes quite expected to see them on fire, but there was not even any sign of scorching."

[July 9 was a day of widespread thunderstorms in that area of Scotland but no other case of ball lightning has been reported on that date. There were widespread thunderstorms over Cornwall on August 17.—Ed. *M.M.*]

Variations in the frequency of clear and cloudy days with the number of observations

Clear and cloudy days are defined as days on which the mean cloud amount is less than 2 tenths and greater than 8 tenths respectively. As this amount may be based on 2–24 observations, it is of some interest to examine the effect of changing the number of observations on the frequency of clear and cloudy days.

Table I gives the frequencies at 3 stations for some of the more usual combinations of the available observations. Two sets of values are given, based on (*a*) < 2 and > 8 tenths, (*b*) $\leqslant 2$ and $\geqslant 8$ tenths. For each station, values are given for one of the clearer and one of the cloudier months. Table II gives the mean cloud amount for the hours used in Table I.

TABLE I—AVERAGE NUMBER OF CLEAR AND CLOUDY DAYS

Station and Period	Times of observations	Clear < 2 (a)	Clear $\leqslant 2$ (b)	Cloudy > 8 (a)	Cloudy $\geqslant 8$ (b)	Clear < 2 (a)	Clear $\leqslant 2$ (b)	Cloudy > 8 (a)	Cloudy $\geqslant 8$ (b)
		July				*May*			
Valencia 1922–31	0700, 0900, 1300, 1500, 1800, 2100	0·6	0·8	17·4	18·7	0·4	0·7	12·1	12·4
	0900, 1500, 2100	0·6	0·8	16·8	19·0	0·3	0·7	12·1	13·9
	0900, 2100	0·7	0·8	18·1	20·5	0·7	1·2	13·4	15·5
	0900	0·8	1·7	18·8	22·2	1·0	2·2	12·8	18·0
		December				*June*			
Potsdam 1924–33	0200, 0800, 1400, 2000	1·9	2·0	16·8	17·4	3·4	3·6	7·5	8·0
	0800, 1400, 2000	2·1	2·4	17·8	18·2	3·3	3·9	7·2	8·2
	0800, 2000	2·8	3·0	18·8	19·5	3·9	4·7	7·3	8·6
	0800	3·6	4·1	21·1	22·2	6·1	8·5	12·1	14·5
		January				*July*			
Batavia 1927–36	0300, 0900, 1500, 2100	0·4	0·5	15·3	16·8	4·0	4·8	2·3	2·7
	0900, 1500, 2100	0·4	0·5	17·5	19·0	4·3	5·3	2·8	3·6
	0900, 2100	0·7	0·8	17·9	19·0	5·7	7·6	3·9	4·8
	0900	1·9	2·7	19·1	20·4	15·3	17·7	4·9	5·9

TABLE II—DIURNAL VARIATION OF CLOUD AMOUNT

	Month	0200	0300	0700	0800	0900	1300	1400	1500	1800	2000	2100
						tenths						
Valencia	July	—	—	8·3	—	8·1	7·9	—	7·6	7·8	—	8·0
	May	—	—	7·5	—	7·3	7·1	—	7·0	7·0	—	7·2
Potsdam	Dec.	7·1	—	—	7·8	—	—	7·4	—	—	7·3	—
	June	5·3	—	—	6·0	—	—	6·6	—	—	5·5	—
Batavia	Jan.	—	6·9	—	—	7·8	—	—	7·9	—	—	8·1
	July	—	4·5	—	—	3·5	—	—	4·7	—	—	6·6

The following causes lead to changes in the frequencies as the number of observations is increased.

(1) The definitions < 2 tenths and > 8 tenths do not refer to a constant cloud amount as the number of observations is changed. For example, on clear days the mean cloud amount is < 2 tenths at n observations, and the maximum possible mean cloudiness c at the hours of observation is given by $(2n - 1)/2$ tenths, thus:—

n	1	2	3	4	6	8	12	24
c	1	1·5	1·67	1·75	1·83	1·87	1·92	1·96

This effect tends to raise the number of clear and cloudy days with additional observations.

(2) The combination of observations leads to a decrease in the standard deviation of the derived values, as compared with the individual values. Thus, provided that the mean cloud amount for the day lies between 2 tenths and 8 tenths, then, as n increases there is less chance that the mean at n observations will be < 2 or > 8 tenths.

(3) It might be expected that the addition of an observation at a comparatively clear time of day would accentuate the decrease in the number of cloudy days and damp down the decrease in the number of clear days.

In Table I the effect of (1) is eliminated in columns (*b*) which show a fall in frequency in almost every case as *n* is increased. While this is generally true also for columns (*a*), there are more occasions on which the expected change does not take place.

Any modifications caused by diurnal variation are most easily seen in columns (*b*). Only at Batavia is the variation sufficiently marked for any effect on the frequencies to be expected. Here, the January 0300 observation is comparatively clear; when this is added to the observations at 0900, 1500 and 2100 the frequency of cloudy days drops from 19·0 to 16·8. Also when the "cloudy" July 2100 observation is added to the "clear" 0900 observation there is a marked drop in the frequency of clear days.

In conclusion it may be stated that the total effects from these three causes are small and that, provided more than one observation a day is used, the variations in frequency are not important from any practical point of view.

W. H. HOGG

REVIEWS

Further researches into the physical reality of some long-periodic cycles in the barometric pressure of Batavia, by H. J. de Boer. Batavia, Koninklijk Magnetisch en Meteorologisch Observatorium. Verh. No. 30. 8vo. $9\frac{1}{2}$ in. × $6\frac{1}{4}$ in. pp. 28. Surabaya, H. van Ingen, 1947.

De Boer has made a new periodic analysis of the pressure curve at Batavia by a method which resembles that of Fulvirch (i.e. auto-correlation) but is much simpler. The mean lengths of the periods so found are

2·34, 3·36, 5·97, 7·32, 8·47, 11·12 and 15·87 years.

The work is then extended to other stations and maps are constructed showing the distribution of the $2\frac{1}{3}$-, 11- and 16-year oscillations over the globe. The author also includes maps of the Brückner cycle of 36 years. His method of presentation is to compute the amplitude and phase of the oscillation by harmonic analysis. To show the relative importance of the oscillations at any particular station he also uses a "development coefficient", which is the ratio of the amplitude found by harmonic analysis to the standard deviation of the pressure. The pressure oscillations of 11 years and 36 years are found to be similarly distributed over the globe. Both oscillations originate in the tropics and propagate thence in various directions becoming less intense relatively and converging towards the north and south poles. The supposition is that they are both of solar origin.

De Boer regards the 16-year cycle as being a consequence of the interaction of the 11-year and 36-year cycles, and he seeks to derive it by supposing, following Seidel's suggestion, that the amplitude of the 11-year cycle varies in a 36-year rhythm. His map computed on this principle agrees in its main features with the map of the 16-year oscillation which he has earlier derived from the observations themselves, except that there is a discrepancy in phase amounting to 70°.

The paper, which ends with a discussion of errors in harmonic analysis with limited numbers of ordinates, follows on from previous works quoted in the list of references and should be read in conjunction with them.

J. WADSWORTH

Industrial Experimentation, by K. A. Brownlee, London, 2nd edn. 8vo. $9\frac{1}{2}$ in. × 6 in., pp. 151. London, H.M. Stationery Office, 1947. Price 2*s*. 6*d*.

It may seem strange, in a meteorological publication, to recommend a book on the design and interpretation of industrial experiments. The meteorologist, unlike the industrialist, is unable to control the elements he studies. He cannot design experiments; his part is to interpret the results of the experiments conducted by Nature in the atmosphere. " Industrial Experimentation " will enable him to interpret his data and to give quantitative estimates of the correctness of his conclusions.

Two admirable features of the book are the very clear summary of the fundamental concepts of statistics and the attention given to tests of significance. The analysis of variance is treated in much detail, and is applied to correlation and to the planning of experiments. In simple correlation, it is used to check the linearity of the relation between two variables. The chapters on the design of experiments have been considerably amplified in this second edition. Although they do not appear to be of direct application to meteorology, nevertheless some of their contents may be of service; for example the use of logarithms in the analysis of variance and the warnings against the rigid use of significance levels.

The book is concerned only with practical details and no knowledge of mathematics is assumed beyond an acquaintance with algebraic symbols. In the main, the author succeeds in presenting each new idea clearly and separately. He errs, however, in allowing explanations of method to become submerged in numerical computation. Not only is this confusing in a first reading, but it also makes the book less valuable for further (spasmodic) reference. A generalised account, uncomplicated by arithmetic, with the specific examples following, would be a clearer arrangement in the chapters on the " chi-square " test and the analysis of variance. Perhaps this could be remedied in a further edition. In general, the reasonableness of the methods and the similarity of approach to the various problems make up for the lack of theoretical exposition, and instructions are not confused by alternative procedures. An exception to this is found in the treatment of partial regression coefficients. Since no explanation is given for the sets of equations employed, it would seem better to replace these by the easily remembered formulae involving correlation coefficients. Generally, fewer computational errors arise in applying set formulae than in solving simultaneous equations.

The reviewer would like to see specific references to theory where this cannot be found in textbooks of statistics. One interesting example is the use of a modified Poisson series to account for the distribution of time intervals between rare events.

There is much of interest in K. A. Brownlee's book and the advantages of clear print and a well set-out table of contents make it practicable for reference. It is worth possessing if only because of its tables for significance tests. These have been carefully selected and are clear and easy to use.

N. CARRUTHERS

WEATHER OF JULY, 1947

At the beginning of the month a depression approached Iceland from the Atlantic and moved slowly east. On the 4th a depression in mid Atlantic moved rapidly east to the north of Scotland; subsequently it followed a complicated track over Scotland and was associated with rather unsettled cold weather over the British Isles. On the 13th, a wedge of high pressure over the North Sea stretching north from an anticyclone over France moved east and pressure became high in a belt extending from westward of Portugal across England to Scandinavia. Temperature rose considerably and thundery conditions prevailed. From the 20th to 22nd an almost stationary depression was situated west of Ireland, while a trough of low pressure moved slowly north-east across England. Later a weak trough of low pressure associated with a depression over the Azores moved north-east over England becoming almost stationary over central Ireland and northern England. A spell of very warm weather ensued in south-east and east England and heavy rain at times in the vicinity of the trough. Finally an anticyclone developed over the British Isles and the closing days of the month were mainly fine apart from local mist or fog. The average pressure distribution for the month shows a high extending from Bermuda to the west of Portugal (1026 mb. near its centre) with a depression, less than 1010 mb., covering southern Greenland, Iceland and the Faeroes. Pressure was more than 2·5 mb. below the average in a belt from the south of Greenland to the Azores and more than 2·5 mb. above average in an area extending north to Nova Scotia and Newfoundland and east to 40° N. 40° W. Pressure was somewhat above normal over Germany and most of the Baltic.

The weather in the British Isles was distinguished by a cold spell from the 5th to the 11th followed by warm conditions, with frequent and sometimes severe thunderstorms during the remainder of the month. A maximum temperature of 90° F. was registered at Cheltenham on the 27th and in London (Greenwich) on the 28th. The general rainfall was not very different from the average but the distribution was variable owing to heavy local falls during thunderstorms. These were widespread and severe locally on the 15th, 16th and 28th. At Wisley, Surrey, on the 16th, 4 in. of rain fell in about 75 minutes, a " very rare " fall, while hailstones about the size of grapes were observed. In Perthshire two persons were killed by lightning on the 16th and there was considerable flooding and other damage. On the early morning of the 28th, at Ballykelly, Northern Ireland, 1·67 in. fell in 60 minates causing serious flooding. Sunshine was generally below the average except in north-east and east Scotland and locally in eastern districts of England, where it exceeded the average.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	90	40	+ 1·6	95	+ 1	88	34
Scotland	80	36	+ 1·3	99	— 2	105	30
Northern Ireland ..	79	40	0·0	118	+ 2	78	23

RAINFALL OF JULY, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·78	75	*Glam.*	Cardiff, Penylan ..	2·77	90
Kent	Folkestone, Cherry Gdns.	2·92	139	*Pemb.*	St. Ann's Head ..	3·10	119
,,	Edenb'dg, Falconhurst	1·85	80	*Card.*	Aberystwyth	5·21	171
Sussex	Compton, Compton Ho.	1·59	56	*Radnor*	Bir. W. W., Tyrmynydd	3·42	83
,,	Worthing, Beach Ho. Pk.	1·29	63	*Mont.*	Lake Vyrnwy	4·56	125
Hants.	Ventnor, Roy. Nat. Hos.	1·64	81	*Mer.*	Blaenau Festiniog ..	8·86	104
,,	Fordingb'dg, Oaklands	1·41	71	*Carn.*	Llandudno	1·54	69
,,	Sherborne St. John ..	1·30	58	*Angl.*	Llanerchymedd ..	2·37	83
Herts.	Royston, Therfield Rec.	1·84	73	*I. Man.*	Douglas, Boro' Cem. ..	3·39	111
Bucks.	Slough, Upton ..	2·19	114	*Wigtown*	Pt. William, Monreith..	3·18	113
Oxford	Oxford, Radcliffe ..	1·70	72	*Dumf.*	Dumfries, Crichton R.I.	4·81	147
N'hant	Wellingboro', Swanspool	1·82	79	,,	Eskdalemuir Obsy. ..	4·50	110
Essex	Shoeburyness	1·79	98	*Roxb.*	Kelso, Floors	2·87	109
Suffolk	Campsea Ashe, High Ho.	1·77	77	*Peebles.*	Stobo Castle	2·37	82
,,	Lowestoft Sec. School ..	1·50	66	*Berwick*	Marchmont House ..	2·73	90
,,	Bury St. Ed., Westley H.	2·32	93	*E. Loth.*	North Berwick Res. ..	1·73	67
Norfolk	Sandringham Ho. Gdns.	1·61	63	*Midl'n.*	Edinburgh, Blackf'd. H.	1·92	68
Wilts.	Bishops Cannings ..	1·98	80	*Lanark*	Hamilton W. W., T'nhill	2·20	77
Dorset	Creech Grange.. ..	1·37	56	*Ayr*	Colmonell, Knockdolian	3·43	109
,,	Beaminster, East St. ..	3·11	120	,,	Glen Afton, Ayr San. ..	4·51	107
Devon	Teignmouth, Den Gdns.	1·69	73	*Bute*	Rothesay, Ardencraig ..	3·90	98
,,	Cullompton	1·65	61	*Argyll*	Loch Sunart, G'dale ..	4·87	105
,,	Barnstaple, N. Dev. Ath.	2·49	92	,,	Poltalloch	5·34	129
,,	Okehampton, Uplands	3·13	92	,,	Inveraray Castle ..	8·89	179
Cornwall	Bude School House ..	2·33	95	,,	Islay, Eallabus ..	5·94	174
,,	Penzance, Morrab Gdns.	2·09	77	,,	Tiree	3·50	97
,,	St. Austell, Trevarna ..	3·34	100	*Kinross*	Loch Leven Sluice ..	2·44	85
,,	Scilly, Tresco Abbey ..	2·59	117	*Fife*	Leuchars Airfield ..	1·57	60
Glos.	Cirencester	2·56	99	*Perth*	Loch Dhu	6·90	143
Salop	Church Stretton ..	3·58	136	,,	Crieff, Strathearn Hyd.	4·78	161
,,	Cheswardine Hall ..	5·64	208	,,	Blair Castle Gardens ..	4·66	182
Staffs.	Leek, Wall Grange, P.S.	3·36	105	*Angus*	Montrose, Sunnyside ..	1·51	57
Worcs.	Malvern, Free Library	1·40	61	*Aberd.*	Balmoral Castle Gdns...	2·46	96
Warwick	Birmingham, Edgbaston	3·95	170	,,	Aberdeen Observatory	1·44	51
Leics.	Thornton Reservoir ..	2·69	108	,,	Fyvie Castle	2·06	63
Lincs.	Boston, Skirbeck ..	1·49	68	*Moray*	Gordon Castle	2·41	75
,,	Skegness, Marine Gdns.	1·47	67	*Nairn*	Nairn, Achareidh ..	1·82	71
Notts.	Mansfield, Carr Bank	2·12	81	*Inv's*	Loch Ness, Foyers ..	2·86	95
Ches.	Bidston Observatory ..	4·52	175	,,	Glenquoich	6·51	101
Lancs.	Manchester, Whit. Park	2·85	86	,,	Ft. William, Teviot ..	4·63	95
,,	Stonyhurst College ..	3·56	92	,,	Skye, Duntuilm ..	3·33	89
,,	Blackpool	2·47	85	*R. & C.*	Ullapool	2·01	65
Yorks.	Wakefield, Clarence Pk.	1·80	71	,,	Applecross Gardens ..	3·55	89
,,	Hull, Pearson Park ..	·88	38	,,	Achnashellach	4·74	97
,,	Felixkirk, Mt. St. John	1·61	59	,,	Stornoway Airfield ..	3·06	106
,,	York Museum	2·59	103	*Suth.*	Lairg	2·98	95
,,	Scarborough	1·53	43	,,	Loch More, Achfary ..	3·64	68
,,	Middlesbrough.. ..	2·13	83	*Caith.*	Wick Airfield	·88	33
,,	Baldersdale, Hury Res.	3·64	114	*Shet.*	Lerwick Observatory ..	1·56	68
Norl'd	Newcastle, Leazes Pk.	2·86	112	*Ferm.*	Crom Castle	3·61	104
,,	Bellingham, High Green	4·11	125	*Armagh*	Armagh Observatory ..	3·24	112
,,	Lilburn, Tower Gdns...	2·65	107	*Down*	Seaforde	4·06	127
Cumb.	Geltsdale	5·30	154	*Antrim*	Aldergrove Airfield ..	3·80	136
,,	Keswick, High Hill ..	3·54	92	,,	Ballymena, Harryville..	4·18	122
,,	Ravenglass, The Grove	3·46	92	*Lon.*	Garvagh, Moneydig ..	3·62	112
Mon.	Abergavenny, Larchfield	1·96	79	,,	Londonderry, Creggan	4·37	119
Glam.	Ystaeyfera, Wern Ho. ..	4·85	106	*Tyrone*	Omagh, Edenfel ..	3·76	111

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, MARCH, 1947

Stations	Pressure: Mean of day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Mean values Min.	Mean values ½ Max. and Min.	Mean values Diff. from normal	Mean values Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Daily mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hrs.	%
London, Kew Observatory	1002·7	−10·2	58	23	45·9	36·0	40·9	−2·2	38·3	87	7·9	4·66	+2·97	26	1·9	16
Gibraltar	1016·3	−0·8	76	49	67·4	54·9	61·1	+3·5	56·6	84	7·1	5·83	—	15	—	—
Malta	1015·9	+1·7	75	46	66·7	53·7	60·2	+3·1	56·1	63	5·1	0·04	—	1	9·0	76
St. Helena	1014·5	−1·6	74	60	70·2	62·2	66·2	+1·1	62·5	96	9·0	6·39	+2·37	28	—	—
Freetown, Sierra Leone	1010·9	+1·7	90	70	84·5	76·4	80·5	−0·4	75·8	83	5·8	3·50	+2·34	4	8·0	66
Lagos, Nigeria ..	—	—	95	69	91·3	73·5	82·4	+1·0	79·7	83	8·0	7·90	—	7	6·4	53
Kaduna, Nigeria ..	1009·3	—	100	58	95·0	64·5	79·7	−1·9	60·0	22	2·8	0·20	−0·34	1	9·6	80
Zomba, Nyasaland ..																
Salisbury, Rhodesia ..																
Cape Town ..	1015·3	+0·8	99	55	79·9	60·9	70·4	+2·3	61·2	75	3·3	2·53	+1·65	6	—	—
Germiston, South Africa	1015·6	—	83	48	75·8	55·4	65·6	—	56·8	69	4·0	4·70	—	12	8·5	70
Mauritius	1013·9	+2·0	89	66	84·0	72·3	78·1	+0·1	72·0	77	5·8	1·84	−6·75	19	8·4	69
Calcutta, Alipore Obsy.	1010·0	−0·1	100	63	93·2	71·5	82·3	+2·1	72·1	83	3·0	1·30	−0·08	4	8·7	73
Bombay	1010·5	−0·4	92	66	86·8	73·5	80·1	+0·6	71·2	77	2·7	0·00	−0·02	0	8·3	69
Madras	1010·5	−0·4	92	72	90·2	74·7	82·5	+1·4	75·6	81	4·0	0·12	−0·22	1	10·6	88
Colombo, Ceylon ..	1010·6	+0·5	91	71	88·5	74·5	81·5	−0·3	75·1	90	5·8	6·45	+2·17	12	7·6	63
Singapore	1009·2	−0·5	91	72	87·5	74·5	81·0	−0·2	77·6	84	—	17·12	+9·72	20	—	—
Hongkong	1017·6	+1·6	79	50	68·2	58·5	63·3	0·0	59·3	80	6·8	2·85	−0·09	9	4·4	37
Sydney, N.S.W. ..	1016·7	+0·4	87	70	76·3	63·9	70·1	+0·8	64·8	74	5·7	2·55	−2·43	9	7·0	57
Melbourne	1014·5	−2·4	98	47	75·9	56·6	66·3	+1·8	58·2	61	5·8	5·73	+3·55	17	5·9	48
Adelaide	1016.0	−1·1	100	50	79·5	58·2	68·9	−1·0	59·1	50	6·3	2·36	+1·34	9	6·3	52
Perth, W. Australia ..	1014·1	−1·2	98	54	84·6	62·6	73·6	+2·4	62·9	48	2·2	0·48	−0·33	4	9·6	78
Coolgardie	1015·3	+0·4	96	49	84·3	60·1	72·2	+0·3	60·0	59	3·7	0·96	+0·02	5	—	—
Brisbane																
Hobart, Tasmania ..	1012·7	−1·5	85	44	69·6	52·8	61·2	+1·9	54·9	68	7·6	3·21	+1·51	13	5·9	48
Wellington, N.Z. ..	1021·9	+4·7	76	43	65·3	52·9	59·1	−0·2	55·6	78	7·1	1·99	−1·34	8	6·4	52
Suva, Fiji	1010·1	+1·7	90	71	85·1	73·5	79·3	−0·8	75·9	88	8·1	20·99	+6·50	29	4·0	33
Apia, Samoa ..	1010·3	+1·1	91	71	87·3	74·9	81·1	+1·8	78·3	81	6·4	13·40	−0·58	21	6·6	54
Kingston, Jamaica ..	1015·1	+0·2	91	68	87·7	71·3	79·5	+2·4	71·3	66	2·8	0·18	−0·84	3	8·8	73
Grenada, W. Indies ..	1013·8	+0·8	86	71	84·7	75·3	80·0	+2·2	72·7	81	6·8	0·94	−1·72	11	—	—
Toronto	1011·0	−6·3	55	12	37·3	24·5	30·9	+1·3	26·4	—	7·3	2·52	+0·11	14	4·3	36
Winnipeg	1019·1	−0·1	41	−10	26·3	6·2	16·3	+1·3	9·2	—	6·2	0·72	−0·44	13	5·1	43
St. John, N.B. ..	1007·7	−6·4	51	11	39·6	25·3	32·5	+4·1	26·8	—	6·1	2·78	−1·76	12	5·4	45
Victoria, B.C. ..	1016·2	+0·3	65	27	53·3	36·0	44·7	+1·2	38·6	95	5·3	2·24	−0·19	12	5·5	46

[*To face page* 216.

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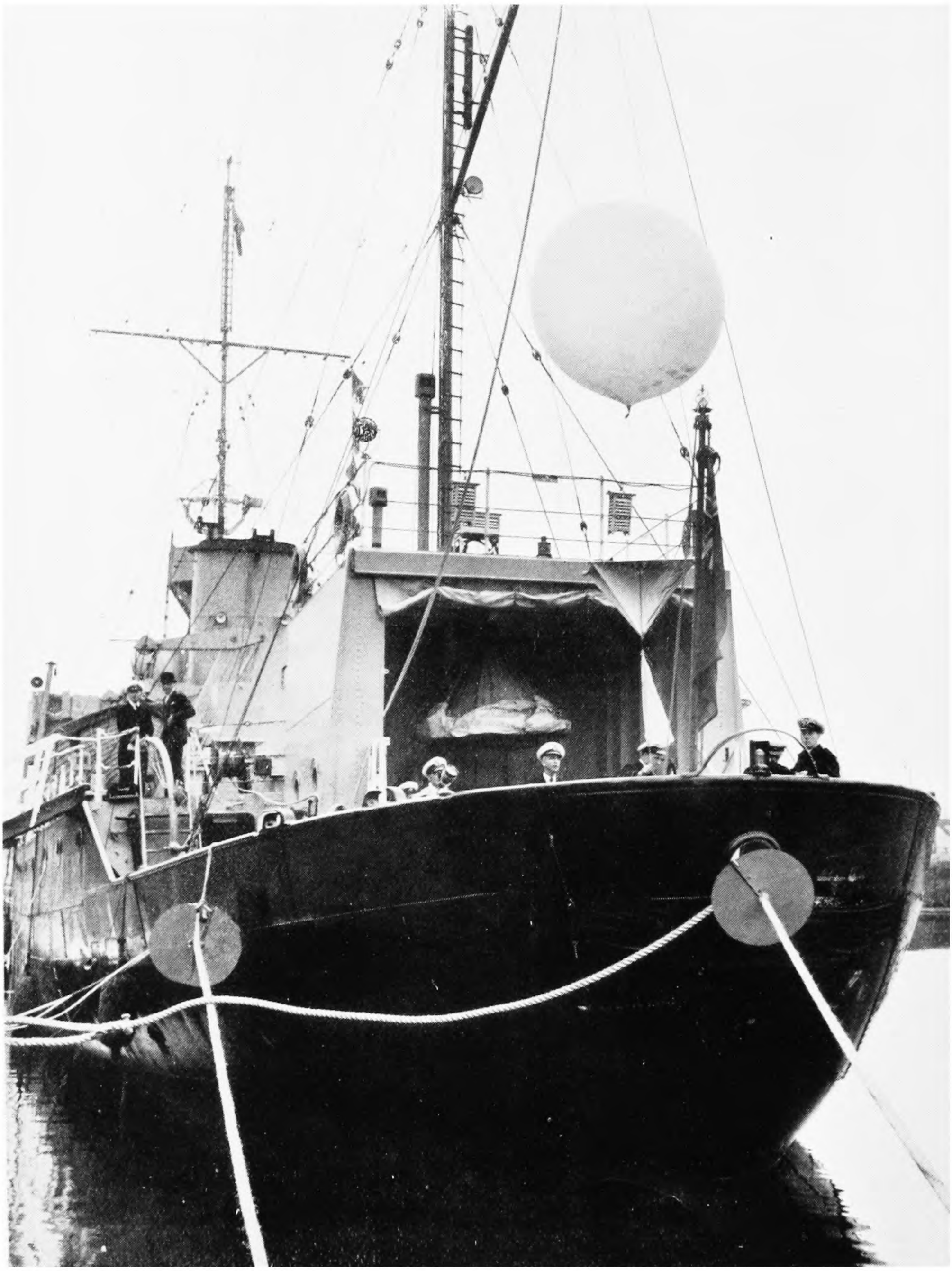
O.W.S. *Weather Observer*
(see p. 207)



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LAUNCHING OF A RADIO-SONDE BALLOON FROM THE *Weather Observer*

(see p. 208)

M.O. 482 AIR MINISTRY

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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'.nd 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 predetermined 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

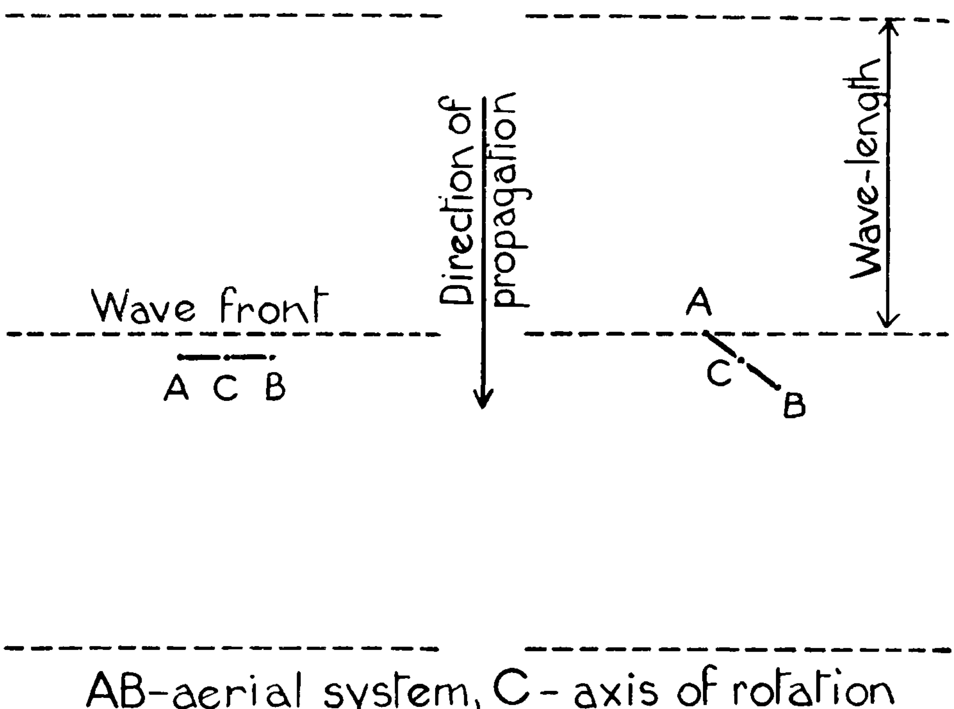


FIG. I—AERIAL SYSTEM IN PLANE OF WAVE FRONT (Plan)

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.

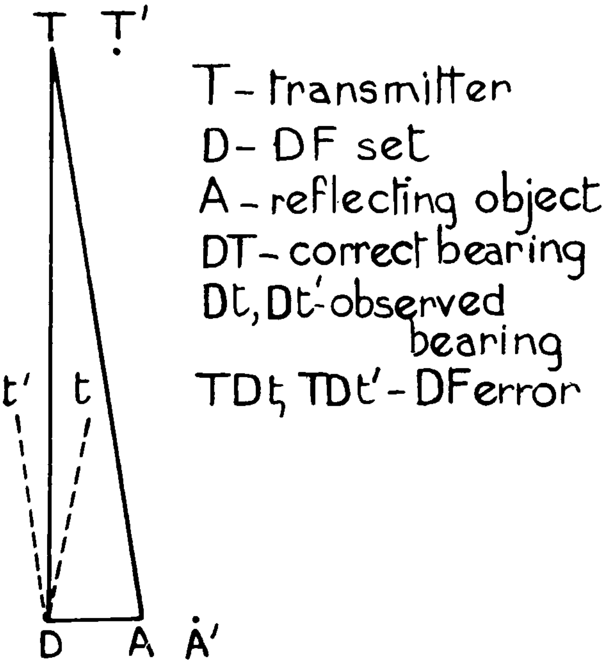


FIG. 3

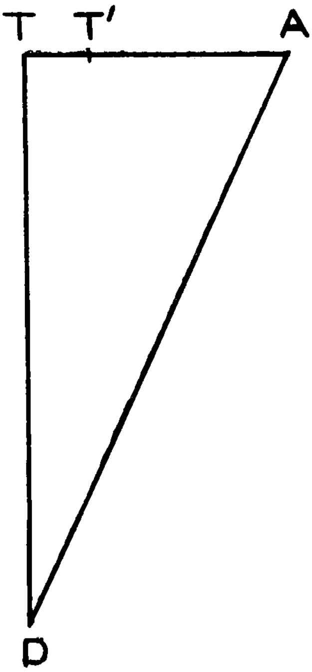


FIG. 4

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 aerials 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 aerials 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 pinnace when the land approaches were impassable.

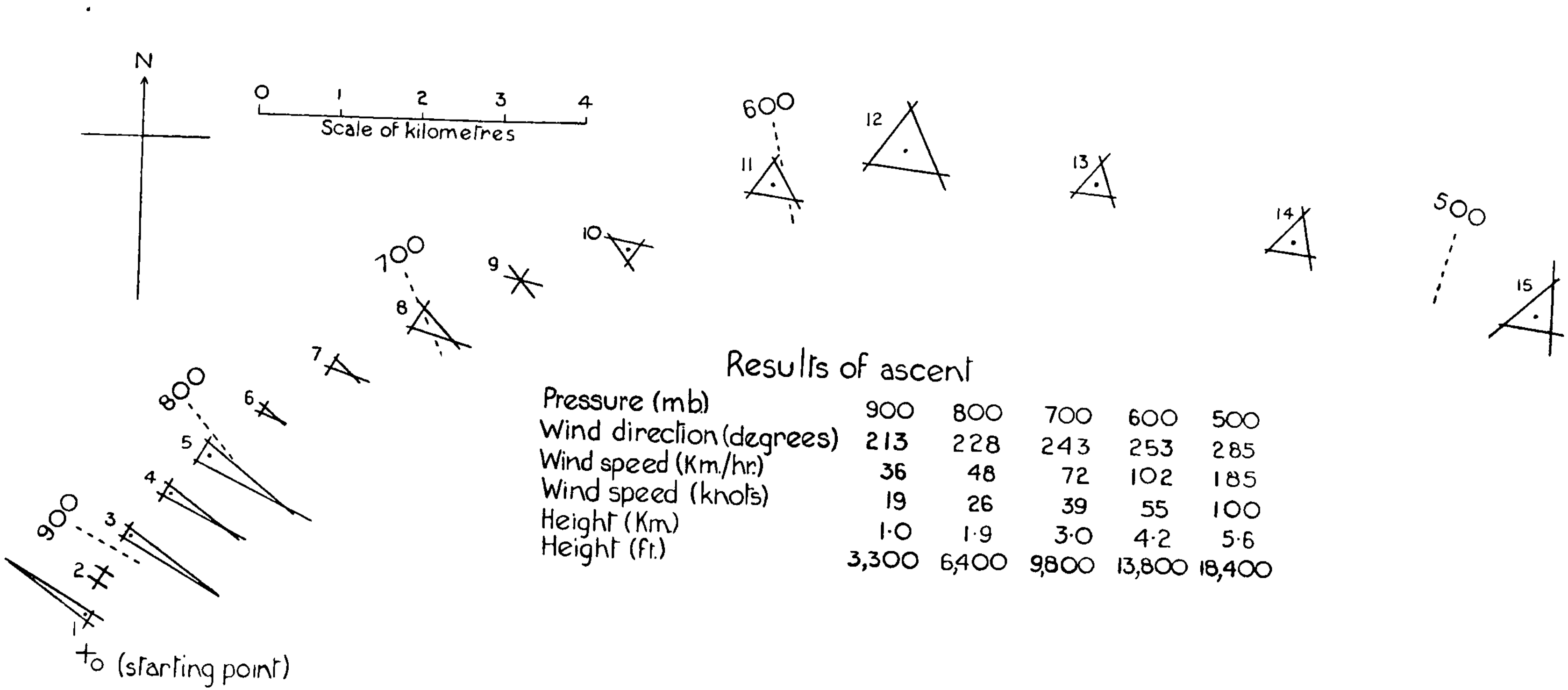
Nor must we forget the drivers, who had their full share of these hardships, and without whose services the work could not have been done.

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



Results of ascent

Pressure (mb)	900	800	700	600	500
Wind direction (degrees)	213	228	243	253	285
Wind speed (Km/hr.)	36	48	72	102	185
Wind speed (knots)	19	26	39	55	100
Height (Km)	1·0	1·9	3·0	4·2	5·6
Height (ft.)	3,300	6,400	9,800	13,800	18,400

FIG. 5—GRAPH OF D.F. BEARINGS
(½ 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.

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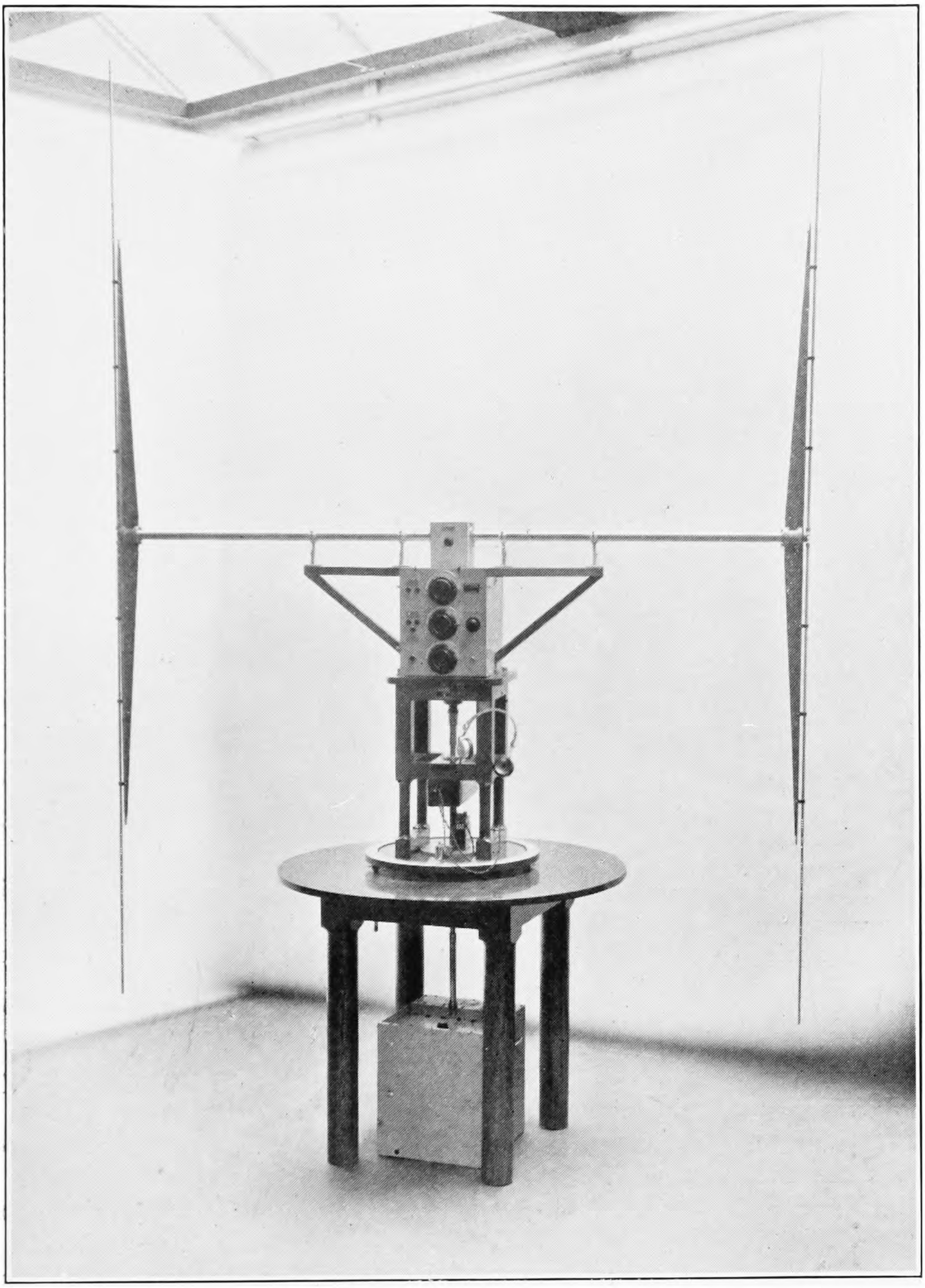
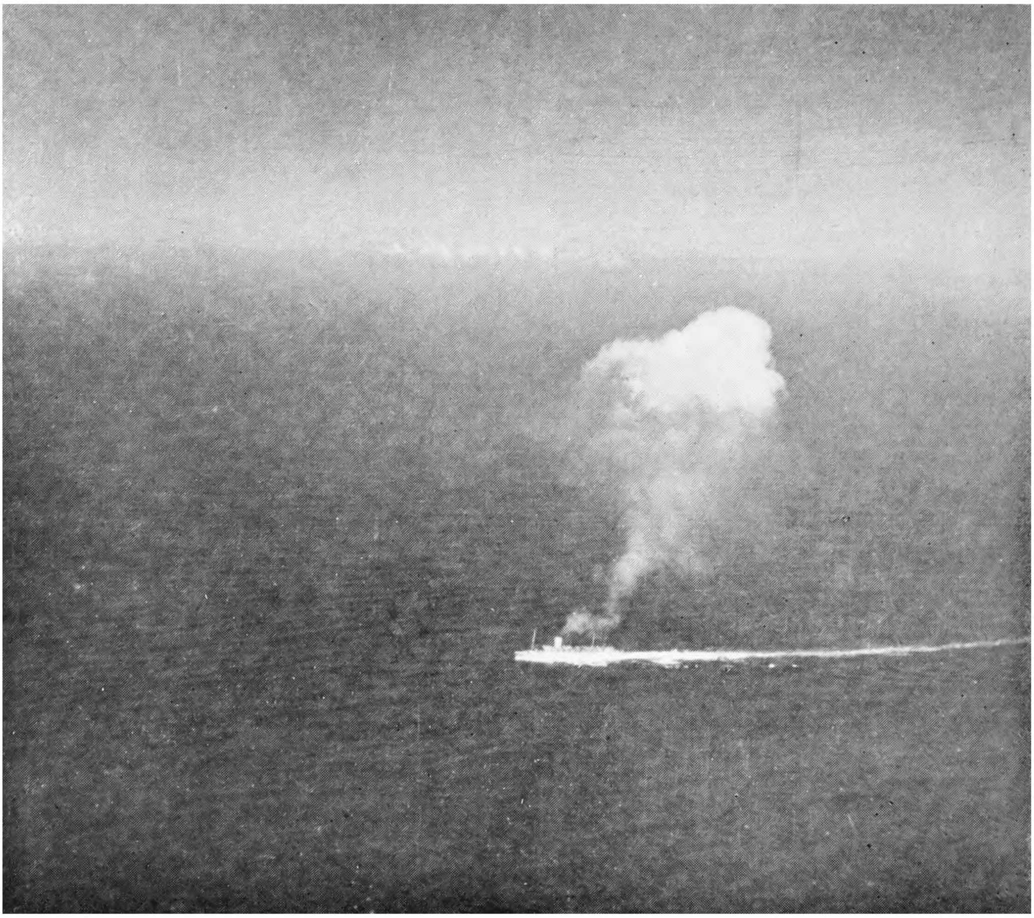


COMPLETE DIRECTION FINDER

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.

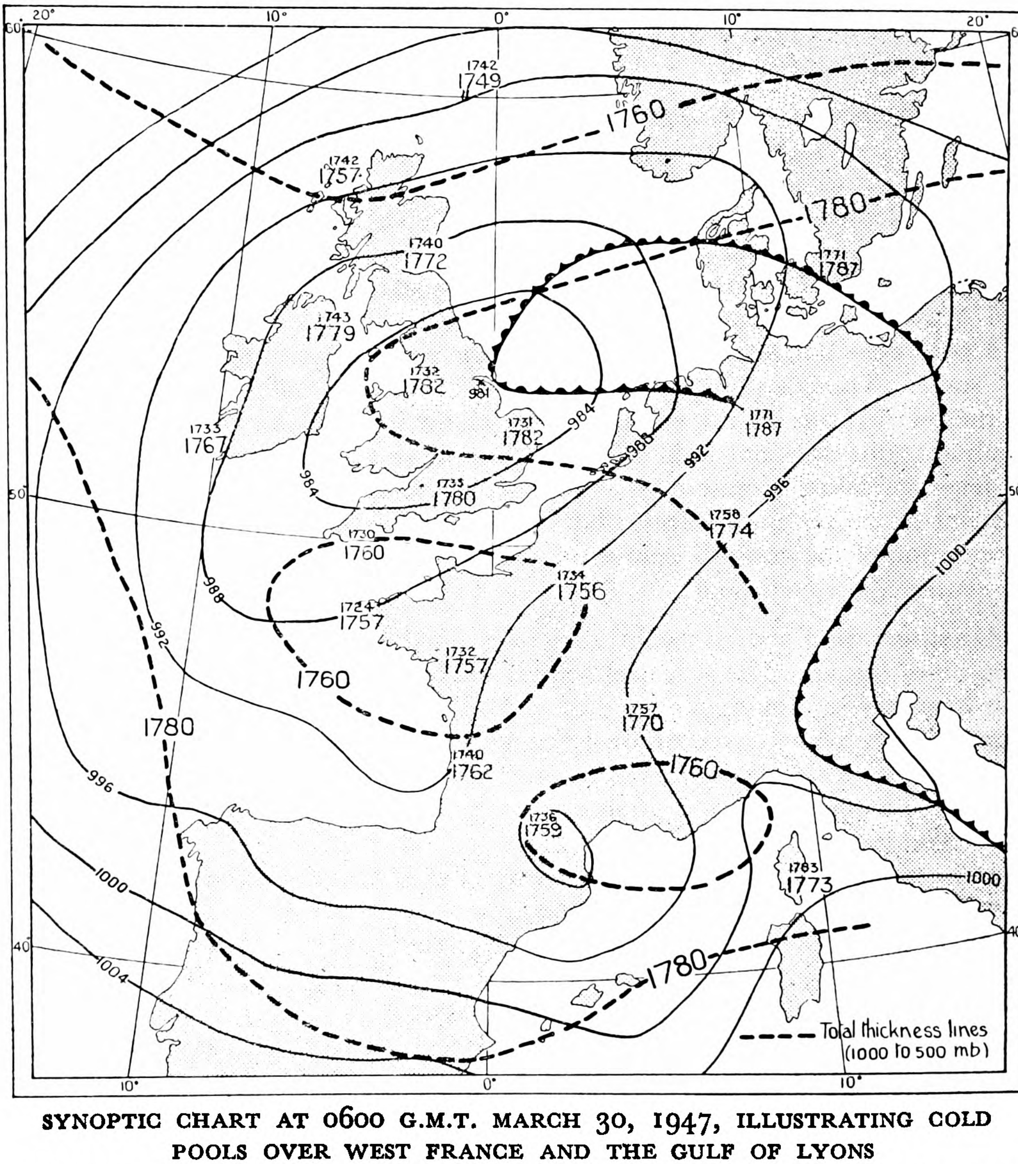
There is first a tongue of cold air with a trough on the thickness lines, and then the cold air is cut off to northward and a pool of cold air is left. It was pointed out by R. C. Sutcliffe, in 1942, in a memorandum circulated officially, that since the thermal wind is parallel to the thickness lines 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 rotary circulation of an occluded depression brings cold air from the rear round the south side and often brings relatively warm air round the north side. This distorts the isotherms, but cannot in itself bring the cold trough or pool over the sea-level centre. A supplementary process is that the advance of the depression is retarded and somehow the upper trough or depression comes over it. This is one of those baffling mutual interactions which are so frequent in the atmosphere, probably involving a critical phase and a dynamical instability. Any slight reduction of the speed of travel favours the



SYNOPTIC CHART AT 0600 G.M.T. MARCH 30, 1947, ILLUSTRATING COLD POOLS OVER WEST FRANCE AND THE GULF OF LYONS

The observed total thickness is plotted in tens of feet and the smaller figures above them are heights above mean sea level.

advance of cold air round the south side (often of warm air round the north side) and so reduces the thermal wind over the centre, leading to a further reduction of speed. A deepening of the system also tends to reduce the thermal wind over it, and at the stage when the upper trough is developing behind the sea-level centre there is probably another mutual interaction, i.e. a reduction of speed favours deepening.

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 anticyclonic 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-

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* 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.

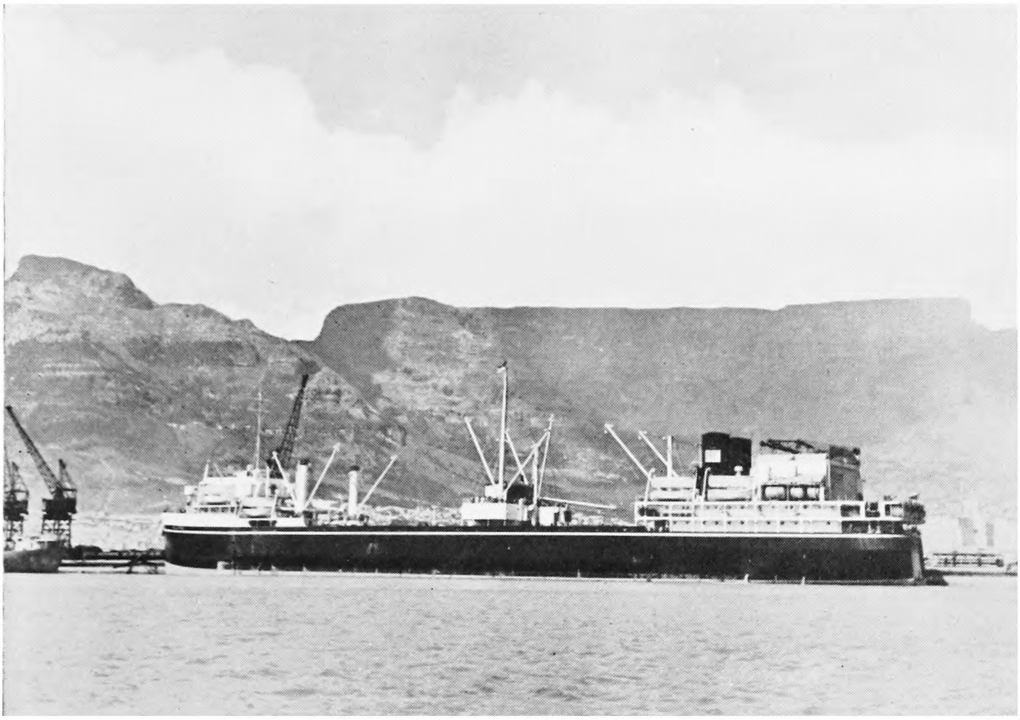
The company's chief object in carrying a meteorologist was to guard the safety of the aircraft and their crews against weather hazards, since the only previous attempt to use aircraft for whale-spotting in Antarctic waters (by a Norwegian company in 1929) had ended in disaster, with the loss without 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.

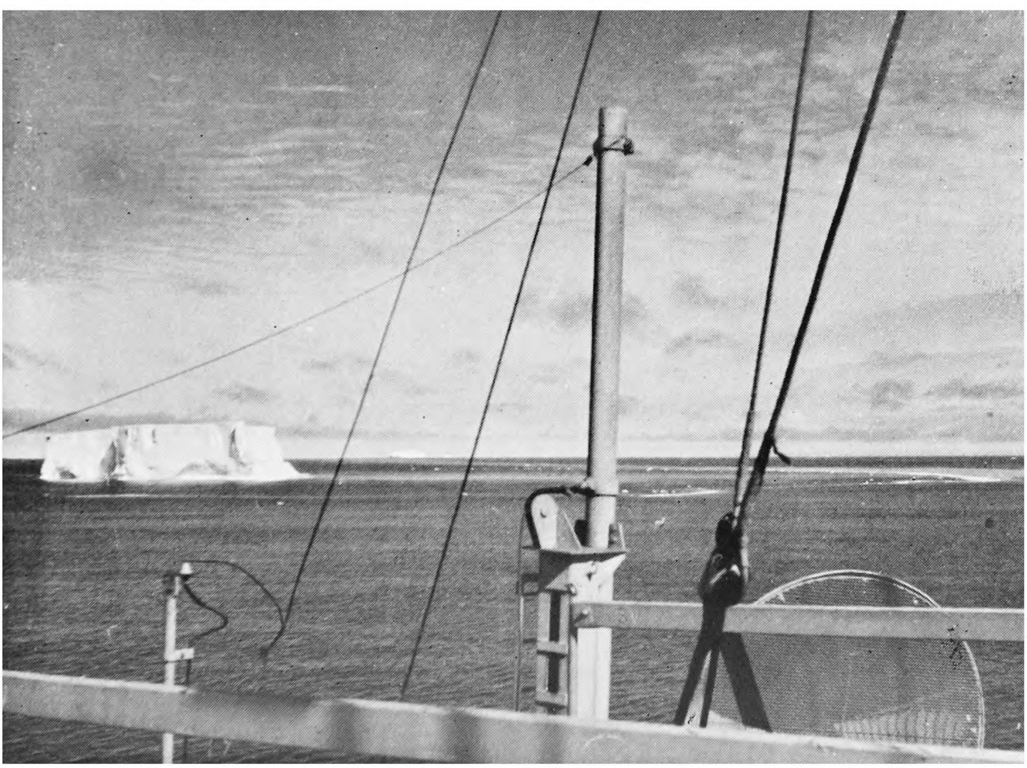
The voyage took us north through the Hebrides and across to Norway to pick up the skilled whaling crew, and from there south with calls at Southampton, the Canary Islands and Cape Town. This enabled us to stock up with fuel oil and the most enviable stores of food and drink for the five-month



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.



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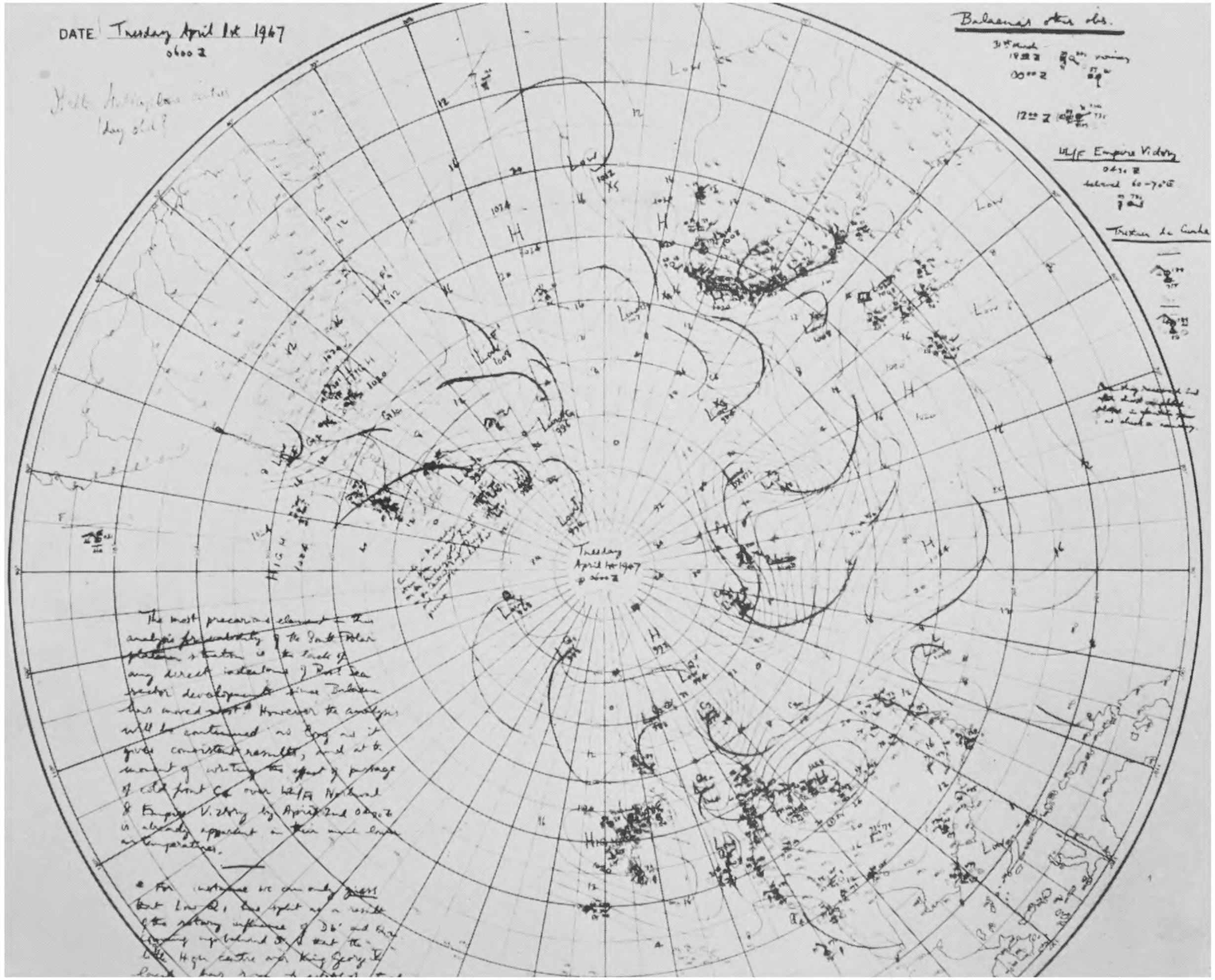
BRILLIANT SUMMER MORNING IN ANTARCTIC WATERS, JANUARY 1947

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 meterological 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 4½ 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 **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 **V**, viz. u, v, w. Since these are inclined to the axis of rotation at angles, $\pi/2$, ϕ, $\pi/2-\phi$ 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.*]

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* 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	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage 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.
London	Camden Square ..	·08	4	*Glam.*	Cardiff, Penylan ..	1·11	26
Kent	Folkestone, Cherry Gdns.	·03	1	*Pemb.*	St. Ann's Head ..	1·02	31
,,	Edenbridge, Falconhurst	·12	5	*Card.*	Aberystwyth	·47	12
Sussex	Compton, Compton Ho.	·54	17	*Radnor*	Bir. W. W., Tyrmynydd	·57	11
,,	Worthing, Beach Ho. Pk.	·70	31	*Mont.*	Lake Vyrnwy	·49	10
Hants	Ventnor, Roy. Nat. Hos.	·77	39	*Mer.*	Blaenau Festiniog ..	·37	3
,,	Fordingbridge, Oaklands	·68	26	*Carn.*	Llandudno	·38	13
,,	Sherborne St. John ..	·59	24	*Angl.*	Llanerchymedd ..	·58	16
Herts.	Royston, Therfield Rec.	·02	1	*I. Man.*	Douglas, Boro' Cem. ..	·31	8
Bucks.	Slough, Upton	·30	14	*Wigtown*	Pt. William, Monreith	·09	2
Oxford	Oxford, Radcliffe ..	·59	26	*Dumf.*	Dumfries, Crichton R.I.	·27	7
N'hant	Wellingboro', Swanspool	·00	0	,,	Eskdalemuir Obsy. ..	·03	1
Essex	Shoeburyness	·53	30	*Roxb.*	Kelso, Floors ..	·22	7
Suffolk	Campsea Ashe, High Ho.	·69	35	*Peebles.*	Stobo Castle	·03	1
,,	Lowestoft Sec. School ..	·15	7	*Berwick*	Marchmont House ..	·12	4
,,	Bury St. Ed., Westley H.	·12	5	*E. Loth.*	North Berwick Res. ..	·20	6
Norfolk	Sandringham Ho. Gdns.	·03	1	*Midl'n.*	Edinburgh, Blackf'd. H.	·19	6
Wilts.	Bishops Cannings ..	·52	17	*Lanark*	Hamilton W. W., T'nhill	·03	1
Dorset	Creech Grange.. ..	1·23	43	*Ayr*	Colmonell, Knockdolian	·06	1
,,	Beaminster, East St. ..	1·02	33	,,	Glen Afton, Ayr San. ..	·00	0
Devon	Teignmouth, Den Gdns.	1·20	53	*Bute*	Rothesay, Ardencraig ..	·03	1
,,	Cullompton	·81	27	*Argyll*	Loch Sunart, C'dale ..	·24	4
,,	Barnstaple, N. Dev. Ath.	·32	10	,,	Poltalloch	·09	2
,,	Okehampton, Uplands	·95	22	,,	Inveraray Castle ..	·18	3
Cornwall	Bude School House ..	·32	11	,,	Islay, Eallabus	·00	0
,,	Penzance, Morrab Gdns.	·84	26	,,	Tiree	·16	4
,,	St. Austell, Trevarna ..	1·77	49	*Kinross*	Loch Leven Sluice ..	·15	4
,,	Scilly, Tresco Abbey ..	1·23	45	*Fife*	Leuchars Airfield ..	·50	16
Glos.	Cirencester	·42	14	*Perth*	Loch Dhu	·02	0
Salop	Church Stretton ..	·67	20	,,	Crieff, Strathearn Hyd.	0·5	1
,,	Cheswardine Hall ..	·74	22	,,	Blair Castle Gardens	·04	1
Staffs.	Leek, Wall Grange, P.S.	·65	18	*Angus*	Montrose, Sunnyside ..	0·7	3
Worcs.	Malvern, Free Library	1·18	41	*Aberd.*	Balmoral Castle Gdns...	·81	27
Warwick	Birmingham, Edgbaston	·63	23	,,	Aberdeen Observatory	·00	0
Leics.	Thornton Reservoir ..	·21	7	,,	Fyvie Castle	·14	4
Lincs.	Boston, Skirbeck ..	·00	0	*Moray*	Gordon Castle	·53	17
,,	Skegness, Marine Gdns.	·06	2	*Nairn*	Nairn, Achareidh ..	·32	13
Notts.	Mansfield, Carr Bank ..	·16	6	*Inv's*	Loch Ness, Foyers ..	·51	17
Ches.	Bidston Observatory ..	·29	9	,,	Glenquoich	·03	0
Lancs.	Manchester, Whit. Park	·37	11	,,	F. William, Teviot ..	·01	0
,,	Stonyhurst College ..	·21	4	,,	Skye, Duntuilm ..	·20	4
,,	Blackpool	·53	15	*R. & C.*	Ullapool	·09	3
Yorks.	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	*Suth.*	Lairg	·24	8
,,	Scarborough	·61	22	,,	Loch More, Achfary ..	·28	5
,,	Middlesbrough ..	·46	17	*Caith.*	Wick Airfield	·06	2
,,	Baldersdale, Hury Res.	·19	5	*Shet.*	Lerwick Observatory ..	·03	1
Norl'd	Newcastle, Leazes Pk.	·04	1	*Ferm.*	Crom Castle	1·21	29
,,	Bellingham, High Green	·36	10	*Armagh*	Armagh Observatory ..	·56	15
,,	Lilburn, Tower Gdns.	·25	9	*Down*	Seaforde	·77	21
Cumb.	Geltsdale	·11	3	*Antrim*	Aldergrove Airfield ..	·34	9
,,	Keswick, High Hill ..	·02	0	,,	Ballymena, Harryville..	·26	6
,,	Ravenglass, The Grove	·22	5	*Lon.*	Garvagh, Moneydig ..	·31	8
Mon.	Abergavenny, Larchfield	·87	29	,,	Londonderry, Creggan	·49	11
Glam.	Ystalyfera, Wern Hos...	·63	10	*Tyrone*	Omagh, Edenfel ..	·45	11

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, APRIL, 1947

STATIONS	PRESSURE		TEMPERATURES							RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION			BRIGHT SUNSHINE	
			Absolute		Mean Values											
	Mean of day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb			Total	Diff. from normal	Days	Mean	Per-cent. of poss.
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hrs.	%
London, Kew Observatory	1017·5	+4·1	65	32	56·3	41·7	49·0	+1·9	44·9	72	6·5	1·68	+0·23	11	5·3	39
Gibraltar..	1022·9	+6·5	76	47	68·6	58·0	63·3	+2·4	59·1	78	4·5	0·07	—	2	—	—
Malta	1020·8	+7·4	79	48	69·0	54·4	61·7	+0·8	56·6	56	4·1	0·14	—	3	9·1	69
St. Helena	1014·9	−1·7	72	58	69·4	61·1	65·3	+1·0	61·6	96	8·6	4·04	+0·82	24	—	—
Freetown, Sierra Leone..	1011·0	+1·8	89	71	85·1	77·4	81·3	+0·1	77·3	83	5·6	3·12	−0·94	6	6·7	55
Lagos, Nigeria	1010·8	+1·4	95	69	90·0	72·8	81·4	−1·4	80·2	88	8·7	4·40	—	10	5·0	41
Kaduna, Nigeria ..	1008·1	—	98	69	94·4	73·8	84·1	+1·9	71·3	57	5·9	1·44	−1·64	1	6·9	56
Chileka, Nyasaland ..																
Salisbury, Rhodesia ..																
Cape Town ..	1018·0	+1·6	87	44	72·1	54·2	63·1	−0·1	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	8·3	72
Mauritius	1015·6	−1·7	85	63	81·5	70·7	76·1	+0·3	71·2	81	5·1	5·45	+0·33	24	7·5	65
Calcutta, Alipore Obsy ..	1004·5	−1·9	108	74	99·3	79·5	89·4	+3·8	78·7	79	2·5	0·47	−1·71	3	9·7	77
Bombay	1007·3	−1·5	99	72	89·0	77·1	83·1	0·0	75·3	78	8·2	2·52	+2·47	7	6·9	55
Madras	1006·7	−1·7	105	77	96·7	80·5	88·6	+3·3	79·4	76	4·9	1·03	+0·40	2	10·4	84
Colombo, Ceylon ..	1009·1	+0·4	89	73	87·7	77·3	82·5	−0·2	76·5	83	6·8	4·83	−4·90	16	7·2	59
Singapore	1008·3	−0·6	93	71	87·5	74·2	80·9	−0·7	77·3	85	—	8·83	+1·20	18	—	—
Hongkong	1013·7	+1·1	83	60	73·8	64·9	69·3	−1·5	65·2	82	—	2·38	−3·27	14	3·2	25
Sydney, N.S.W.	1017·9	−0·5	78	51	70·9	57·3	64·1	−0·6	63·6	97	6·7	7·37	+1·85	19	5·5	49
Melbourne	1019·2	−0·3	87	41	69·1	51·7	60·4	+0·9	54·2	75	6·6	3·29	+1·12	17	4·9	44
Adelaide	1019·8	0·0	88	46	72·5	54·7	63·6	−0·3	56·0	55	5·4	1·71	−0·01	11	6·3	57
Perth, W. Australia ..	1015·0	−3·4	85	48	75·6	57·5	66·5	−0·3	59·8	63	5·2	3·96	+2·31	11	6·9	62
Coolgardie	1017·4	−0·9	88	48	74·8	54·2	64·5	−0·5	55·1	70	4·7	1·33	+0·37	8	—	—
Brisbane	1015·2	−2·4	85	56	78·2	61·8	70·0	−0·3	62·9	65	4·3	6·54	+2·77	12	7·9	69
Hobart, Tasmania ..	1019·1	+4·3	75	42	64·0	48·3	56·1	+0·9	51·1	76	6·4	0·88	−0·97	12	5·5	50
Wellington, N.Z. ..	1017·6	−0·5	72	41	61·6	49·6	55·6	−0·2	53·2	81	7·3	5·05	+1·17	11	4·6	42
Suva, Fiji	1011·1	+0·5	89	68	85·5	74·6	80·1	+1·5	76·1	84	6·1	11·25	−0·96	16	7·1	61
Apia, Samoa	1010·1	+0·2	91	72	88·9	74·3	81·6	+2·7	78·2	79	4·8	4·78	−5·37	17	7·8	66
Kingston, Jamaica ..	1015·3	+1·2	90	68	87·1	70·2	78·7	+0·3	72·2	72	2·7	0·55	−0·69	3	9·3	75
Grenada, W. Indies ..	1014·4	+1·9	86	72	84·8	75·9	80·3	+1·4	75·4	78	7·0	1·10	−1·06	8	—	—
Toronto	1017·5	+1·4	68	27	50·3	34·1	42·2	+0·1	35·7	75	7·0	2·33	+0·04	12	4·4	33
Winnipeg	1016·1	−0·6	83	15	44·4	26·3	35·3	−2·4	27·4	—	6·3	1·35	−0·05	7	6·4	47
St. John, N.B.	1018·1	+4·7	57	19	44·7	29·2	36·9	−2·1	31·7	—	6·8	4·35	+0·84	13	6·0	45
Victoria, B.C.	1019·4	+1·9	74	29	58·2	40·6	49·4	+1·5	41·8	93	5·1	2·62	+1·10	14	7·3	54

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Frontispiece]

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MR. E. GOLD, C.B., D.S.O., F.R.S.

M.O. 482 AIR MINISTRY

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ERNEST GOLD, C.B., D.S.O., F.R.S.

On October 31, 1947, Mr. E. Gold retired from the Meteorological Office after 41 years' service. His career may be regarded as starting when he went up to St. John's College, Cambridge, at the beginning of the century. He used his time to such good purpose that in 1903 he emerged as Third Wrangler and followed this up by obtaining a First Class in the Natural Science Tripos in the following year.

Mr. Gold came to the Meteorological Office in June, 1906, and was appointed Superintendent of Instruments. Shortly afterwards he was elected a Fellow of St. John's College, Cambridge, but he remained with the Meteorological Office. The following year, however, he was appointed Schuster Reader in Dynamical Meteorology, and returned to Cambridge for three years. During this period he carried out his well known investigation into the radiative equilibrium in the stratosphere and produced the first scientific explanation of its isothermal condition. His paper in the *Proceedings of the Royal Society* is one of the classics of meteorology, and was probably largely instrumental in securing his election as a Fellow of the Royal Society a few years later.

After his return to the Meteorological Office in 1910, Mr. Gold held the post of Superintendent of Statistics, which covered what is now called Climatology.

Shortly after the outbreak of the first world war, Mr. Gold was commissioned as a Captain in the Royal Engineers (Meteorological Service). He eventually rose to the rank of Lt. Colonel and Commandant of the Meteorological Service in France. He was mentioned in dispatches in December, 1915, awarded the D.S.O. in January, 1916, and the O.B.E. in January, 1919.

On his return to the Meteorological Office he was given the rank of Assistant Director, and was made responsible for all questions connected with observations and instruments.

During the interval between the wars, however, much of his effort and interest were devoted to international meteorology, in which he was destined to play a leading part. When the International Meteorological Organization (I.M.O.)

formed a new Commission in 1920 to deal with questions of synoptic meteorology, Mr. Gold was elected its President, and held the post until October, 1947. During this period, the Commission for Synoptic Weather Information (best known as the C.S.W.I.) met on ten occasions and passed some 400 resolutions, which played a fundamental part in ensuring the development of meteorological practices on uniform lines in all countries. The degree of initiative taken by the C.S.W.I. is indicated in the fact that as early as 1929 it was considering the possibility of applying facsimile reproduction methods to synoptic meteorology.

Mr. Gold also served as a member of three other Commissions of the I.M.O., viz. the Aerological Commission, the Commission for Aeronautical Meteorology, and the Commission for the Projection of Meteorological Charts. He was, in addition, President of the Meteorological Sub-Commission of the International Commission for Aeronautical Navigation from its formation in 1919 until its functions were taken over by the International Civil Aviation Organization in 1946. It would be difficult to exaggerate the importance of the part which Mr. Gold has played in international meteorological affairs during the last 28 years.

On the outbreak of the second world war, he was within a short distance of retiring age, but the war seemed to urge him to new heights of attainment, and gave him full opportunity to display his brilliant gifts of initiative, scientific ability and organising skill. It is not too much to say that the efficiency of the meteorological services during the war was in large measure due to Mr. Gold's efforts. His services were recognised by the award of the C.B. in 1942, and the American Medal of Freedom with Silver Palm in 1946.

Turning now to the personal aspect, those who have had the good fortune to work with Mr. Gold have found him not only an able scientist and administrator, but also a colleague possessing great human understanding and sympathy. He was always ready to put his sound judgment and experience at the disposal of his colleagues, and anybody seeking his advice was sure of a sympathetic hearing. Two of his outstanding qualities were the thoroughness with which he examined every problem which came before him, and the dialectical skill which he displayed in argument. A man of strong character and great ability, he enjoyed the confidence of all who worked with him. Such natural gifts would have gained eminence in any profession, and the Meteorological Office counts itself fortunate that Mr. Gold chose a meteorological career. All his many friends will wish him health and happiness in his well earned retirement.

METEOROLOGY AT THE BRITISH ASSOCIATION

The British Association for the Advancement of Science, which had dispersed from Dundee when war broke out in 1939, returned to Dundee this year for the annual meeting and assembled under the Presidency of Sir Henry Dale, O.M., F.R.S. The general theme of the meeting, "Swords into Ploughshares", was illustrated in the President's inaugural address by reference to the advances made in physical and medical sciences under the stress of war-time requirements, and the developments in aeronautics, radio and other fields of technology, which have peace-time uses. The first meeting of Section A (Mathematics and Physics) was devoted to a discussion on the peace-time application of nuclear fission which was opened by Dr. J. D. Cockcroft, C.B.E., F.R.S., who described the construction and initial operation of the atomic pile recently completed at Harwell, and was continued by other speakers who referred to peace-time uses of the pile for producing radio-active isotopes, providing particles for bombarding atomic nuclei in order to learn more about their structure, and as an eventual source of industrial power.

In his presidential address to Section A, Sir Edward Appleton, K.C.B., F.R.S., dealt with applications of radio to meteorology and astronomy. By means of the cathode-ray oscillograph the wave form of lightning discharges and the changes at different distances from the discharge have been studied. It has been found that in a thunderstorm the leader stroke from cloud to ground, which is of a discontinuous nature, is the origin of a series of electro-magnetic pulsations of relatively high quasi-frequency, and the main discharge, which takes place as a return stroke along the ionised trail blazed by the leader, is the origin of the main atmospheric wave form of lower quasi-frequency. It is interesting to note that the apparently greater number of atmospherics heard on a radio receiving set at night does not imply that thunderstorms are more frequent at night, but is due to the reception of atmospherics from greater distances owing to ionospheric reflection. The cathode direction-finding technique*, used for locating thunderstorms by obtaining simultaneous cross-bearings from three or four well separated receiving stations was later described in some detail by Dr. R. L. Smith-Rose, who also referred to the narrow-sector recorder type of apparatus designed some twenty years ago. It is necessary to use frequencies in the band 10–30 Kc./sec. (wave-length 30–10 Km.) for receiving atmospherics in order to avoid interference by normal radio-communication, broadcasting, and navigational aids. Visual observations on the cathode-ray direction finder are restricted to the strongest flashes; these occur some 5 to 10 times a minute and emanate from storm areas at ranges up to 1,000 miles. Centres of activity are sometimes associated with cold fronts and at other times concentrated towards the apex of the warm sector† suggesting that here the ascensional velocity of the warm air is greatest; in partly occluded depressions the majority of atmospherics emanate from the non-occluded part. Future developments indicated by Dr. Smith-Rose include photographic recording to overcome the present limitations on the rate at which measurements can be made. The outstanding technical problem however is the provision of means for rapidly transferring the angular data to a plotting centre and transforming them into locations on a map. The eventual use of a single observing station to determine not only the bearing but also the range of an atmospheric is hardly more than an interesting speculation at present; in certain limited circumstances the distance of a flash may be measured from an examination of the wave form but this does not seem possible under all conditions.

Another application of radio to meteorology referred to by Sir Edward Appleton was the detection of radar echoes from falling rain. Raindrops scatter energy from a beam of radio waves, the scattering being more pronounced the shorter the wave-length. If pulses of centimetric waves are used, the echoes

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* See *Met. Mag. London*, **76**, 1947, p. 78.

† See *Met. Mag. London*, **76**, 1947, p. 161.

from heavy rainstorms can be detected by this back-scattered radiation which can be displayed on cathode-ray tubes from which the range, bearing, and elevation or height, of the precipitation may be read.*

The apparatus is similar to that developed during the war for detecting the movements of aircraft and shipping. On many occasions reflections appeared on the set from objects at considerable distances; at Bombay, for example, where during the monsoon ships were normally detected up to ranges of 20 miles, abnormal conditions in the hot season disclosed ships commonly at distances of 200 miles (in one case at 700 miles), and parts of the Arabian coast 1,000 to 1,500 miles away. This phenomenon, which also affects television, is due to super-refraction, an account of which was given by Dr. H. E. G. Booker. Radio rays are subject to refraction in the same way as optical rays; they are never quite straight since the density and refractive index of the air decrease with height; in a well mixed air mass downward curvature of the rays, equal to about one fifth of the earth's curvature, is produced. Abnormal propagation of radio waves due to super-refraction is widespread at centimetric wave-lengths, moderate at metric wave-lengths, exceptional at decametric wave-lengths, and unknown at longer wave-lengths. This result is not due to the variation of refractive index with wave-length but arises because, when an atmospheric radio duct is formed by certain conditions of temperature and humidity gradient in the lowermost layers, it acts as a wave-guide such as is used for piping centimetric waves to and from a radiator; such a pipe is an efficient conductor only of waves which are below a certain wave-length, and the longer the wave-length the larger the pipe that is required. In the atmosphere long waves respond only to the crude average of atmospheric gradients whereas sufficiently short waves are affected by the fine structure. In the British Isles a typical duct involving super-refraction of centimetric waves extends only to a height of some hundreds of feet. The meteorological conditions for super-refraction in such a layer are high potential temperature and relatively dry air aloft; this necessitates fine, non-turbulent weather and abnormal propagation is usually associated with nocturnal inversions and with anti-cyclonic conditions over the sea (damp surface). An equatorial climate, being turbulent, is not favourable for abnormal propagation; in a tropical climate, it is most intense; in a temperate climate it is occasionally experienced; little is known of conditions in polar regions.

Dr. E. G. Dymond described the Kew radio-sonde, the development of which was started at the National Physical Laboratory and was taken over by the Meteorological Office at the outbreak of war. The entire radio-sonde weighs 1,400 gm. (3 lbs.), of which 300 gm. is in the special battery with lead negatives replaced by zinc and having an operating capacity of 1½ hrs. It is flown suspended from a balloon of seamless latex rubber which is inflated with hydrogen to a diameter of about 5 ft. expanding to 15 ft. or more before bursting at heights of 60,000–65,000 ft. and occasionally 80,000 ft. The power of the transmitter, although only 30–40 mw., is sufficient to give measurable signals at ranges of 100 miles from the starting point since the instrument is then at high elevation. The accuracy of the radio-sonde is necessarily less than that attained

* Such apparatus is being used by the Meteorological Office at East Hill and similar, though lighter, apparatus is being developed by the Ministry of Supply for installation in aircraft to enable pilots to detect cumulonimbus cloud in darkness.

by normal instruments on the ground, not only because of the need to keep cost and complexity to a minimum, but also due to the extreme temperature range to which it is subjected in flight (from perhaps +80°F. to −90°F. in 40 min.). Average probable errors in pressure, temperature and relative humidity are 5 mb., 1°F. and 10 per cent., the last figure only being attained in the lower layers of the atmosphere because the gold-beater's skin which is used for measuring humidity ceases to function efficiently at extremely low temperatures.

The application of radio to wind measurement was discussed by Mr. H. L. Wright. The need for observations of upper winds at ever increasing heights in order to meet the growing demands of aviation and the obvious limitations of the purely visual method of wind measurement by theodolite led to the development of the radio wind-measurement technique.* In this, the bearing of a signal emitted from an airborne radio-sonde transmitter is received on rotatable aerial systems at three stations set at the corners of a triangle with sides some 20–30 miles long. By plotting the three simultaneously observed bearings at a central control station, speeds and directions of upper winds are determined to the bursing height of the balloon. The height of the transmitter at any instant is determined by calculation from values of pressure, temperature and humidity registered by the radio-sonde. The radio direction-finding method is expensive in manpower. Moreover, the observed bearings are subject to inaccuracies, the source of which it is not possible to identify in every case. A more accurate method of wind measurement is by use of radar equipment whereby the range and elevation as well as the bearing of a free balloon carrying a metallised reflector (frequently the same balloon carries also a radio-sonde transmitter) can be determined from a single observing station with a consequent reduction in use of manpower. The probable vector error of winds found by radar is only 1 or 2 knots which is about half the error in the direction-finding method. The main disadvantage of the radar method is that in very strong winds the balloon is carried out of range of the equipment (at present 40 miles) before reaching the desired extreme height. Radar wind-measurement equipment has now been installed at almost all British radio-sonde stations in the United Kingdom and overseas, and observations of upper winds are made every 6 hours at the principal stations and every 12 hours elsewhere. In the British ocean weather ships essentially similar radar equipment is in use with the addition of stabilising compensation for the ship's motion.

The use of radio for obtaining information on conditions in the ionosphere was described by Sir Edward Appleton. The ionosphere, in which air is relatively strongly ionised owing to the absorption of ultra-violet light, consists of three layers, the D layer at 60–70 Km. which is weakly ionised, the E layer at 100 Km., and the F layer at 230 Km. The structure of the ionosphere is observed by projecting radio waves vertically upwards and measuring the group-time of flight of the waves up to the reflecting layer and back; in this way the equivalent height of the layer is determined. As the frequency is increased the waves penetrate further into the layer from which they are reflected until ultimately a critical frequency is reached; from the value of the critical frequency the maximum ionization in the layer can be deduced. The D layer acts chiefly

* See *Met. Mag. London,* **76**, 1947, p. 217.

as an absorbing region but the reflection of extremely low frequency waves from it has been detected. Using these methods it has been found that the ionization in the E layer starts to increase at sunrise, reaches a maximum at noon, and sinks to a low value through the night. The ionization in the F layer shows a similar solar dependence but does not always reach its maximum at noon nor decay so rapidly at sunset. Ionization waxes and wanes with sunspot activity; and observations have shown that the density increased by as much as 50 to 60 per cent. from the sunspot minimum of 1934 to the sunspot maximum of 1937. This implies a still greater increase, 120 to 150 per cent., in the intensity of ultra-violet light, a result which is in striking contrast to the constancy of solar radiation received at ground level during the same period. The percentage increase in the diurnal variation of the earth's magnetic field from 1934 to 1937 was also about 50 to 60 per cent., and the equality of this increase with that in ionization affords confirmation of Balfour Stewart's theory that the small daily regular changes of terrestrial magnetism are due to currents flowing in the upper atmosphere, the conductivity of which is proportional to ionization concentration. The currents arise from a species of dynamo action due to the rhythmic tidal motion of the ionised layer across the earth's permanent magnetic field. The forced oscillations of 730 cycles a year due to the sun are manifested in the semi-diurnal variations of pressure seen on barograms at equatorial stations. Using radio methods it has been shown that the E layer rises and falls by the unexpectedly large amount of 1 Km. with lunar tidal motion (about 705 cycles a year) twice during a lunar day.

Another application of radio for obtaining information on conditions at high atmospheric levels arises from the influence exerted by the earth's magnetic field on the refracting properties of an ionised layer constituted by free electric charges of electronic mass. The ionosphere is a doubly-refracting medium in that a radio wave entering it is split up into two characteristic components in opposite senses. Under certain conditions this magnetic influence causes an incident radio pulse to split into two separate reflected pulses which arrive back at the ground with slightly different delay times. Use of this method has shown that the intensity of the magnetic field at a height of 300 Km. is about 10 per cent. less than that at the ground.

Dr. A. B. Lovell described the use of radio to detect meteors. When a meteor enters the atmosphere it produces a dense trail of electrons at 80–120 Km. above the earth's surface which scatter energy from an incident radio beam. Simultaneous radio and visual watches indicate that a 3rd magnitude meteor produces about 10^{10} electrons per cm. path and the distribution of intensities leads to the result that the same mass of meteoric material exists in each magnitude. Meteoric showers can of course be detected in daylight by radar observations; such observations revealed a vast meteor shower, which began on May 1, 1947, and was still continuing 53 days later; the intensity and duration of this shower make it unique compared with any hitherto found by visual observations. Mr. J. S. Hey referred to the use of Army radar apparatus operating on 5 m. for meteor detection. During the Giacobinid shower of 1946, stationary echoes were recorded broadside to the meteor trail and also fast-moving echoes were shown arising from ionization immediately around the approaching meteor; from these echoes the velocity of the meteor was deduced to be 23 Km./sec. (about 50,000 m.p.h.).

Sir Edward Appleton and Mr. Hey referred to the curious solar phenomenon revealed by radio that whereas the radio-waves emitted at a black-body temperature of 6,000°K. (to which the visible and thermal radiations from the sun correspond), should be of so slight an intensity as to be undetectable, extremely strong radio-emissions are in fact observed during period of solar activity, especially on 5 m. The intensity is more than a million times stronger than that to be expected and the effective solar temperature corresponding to peak intensities is nearly 10^{12}°K. Sudden large increases in intensity of solar radio emissions were observed to coincide with the great sunspots of 1946, and were associated with large scale "fade-outs" of radio communication on long-distance links. Mr. M. Ryle described experimental work at the Cavendish Laboratory, Cambridge, on solar radiation on wave-lengths of 1·7 m. and 3·75 m., the results of which indicate an equivalent black-body temperature of about 10^{10} K. increasing considerably during the passage of large sunspots. By varying the spacing between the aerials of the receiving system the diameter of the source can be determined, and it has been found by this method that the source of these powerful emissions is only some 10′ of arc in diameter, little larger than the sunspot itself, and implies that in this small region the effective temperature is about 10^{10}°K.

The meeting provided ample evidence of the peace-time applications of radio developments during the war and of the manifold uses of radio in meteorology, not only for obtaining day-to-day information about the earth's atmosphere both at moderate levels and at heights unattainable by other means, but also for increasing our knowledge of the external influences affecting the atmosphere. There can be no doubt that further work along the lines described, for which there is still much scope, and other new developments, which cannot fail to continue, will increase the debt which meteorology already owes to radio physics.

H. L. WRIGHT

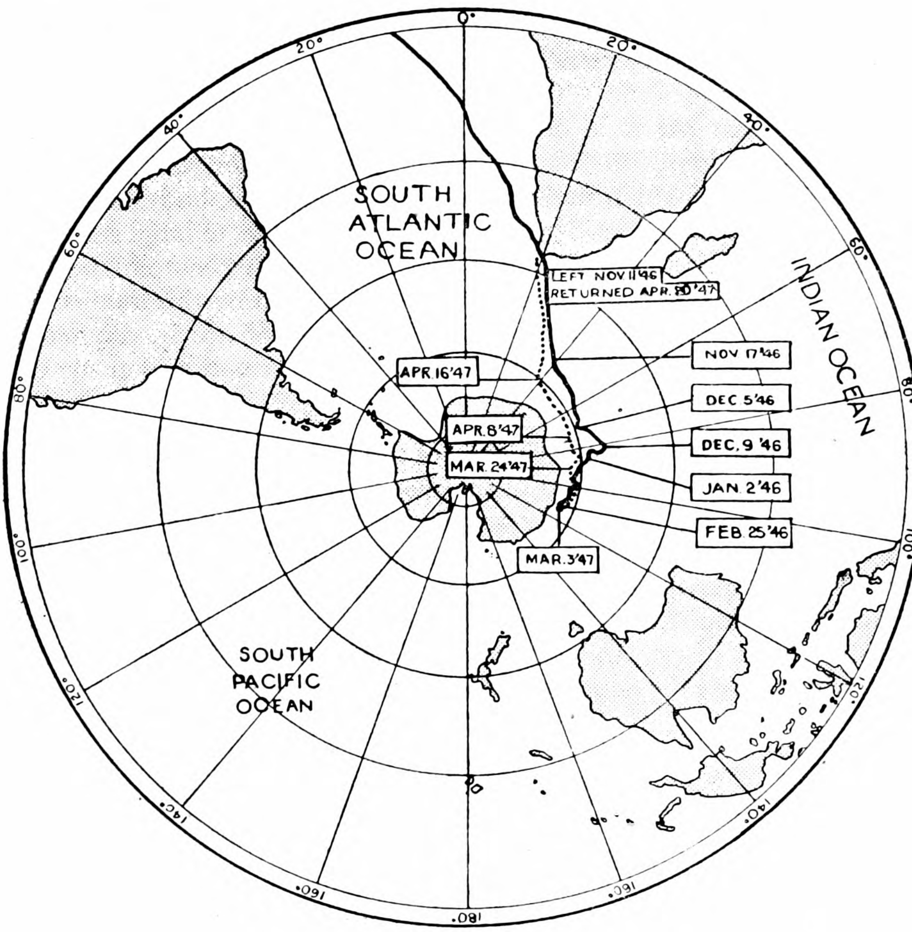
A METEOROLOGIST IN THE ANTARCTIC

BY H. H. LAMB, M.A.

Part II

The 1946–7 whaling season, whilst Europe shivered in a bitter winter, was a fine summer in the Antarctic. Weather was rated fit for unrestricted flying up to a 6-hour range on 53 of the 141 days which the *Balaena* spent on the whaling grounds, and fit for restricted flying on 37 other days—together over 63 per cent. of the days of the season. Even so sunshine was notably a rarity over the wide spaces of the Southern Ocean, where quiet, overcast weather is typical of the best conditions. Sunshine however, became more frequent near the coast of Antarctica, particularly between 104 and 108°E.

We had sailed south-east from the Cape of Good Hope on November 11, 1946, to reach the first ice on the 16th and start fishing for sperm whales near 55°S. 40°E. on the 17th. From this point the factory proceeded on erratic and variable courses, governed by the whaling operations, but in a general south-easterly direction, halting occasionally where many whales were found. A point near 65°S. 115°E., off the coast of Antarctica in the Australian sector, was the furthest point reached, about the beginning of March. The taking of the large blue and fin whales was restricted by international agreement, for the sake of the preservation of the species, to the period December 8, 1946, to April 7, 1947. During the last few weeks of the season we worked our way westwards, keeping to the edge of the pack-ice as before. The ship called in at Cape Town, homeward-bound, on April 20, after a crossing of the Roaring Forties and Fifties which involved four days of continuous storm, in which some damage was sustained by the vessel from the heavy seas.



VOYAGE OF THE WHALING FACTORY SHIP *Balaena*, 1946–7

Storms did not hinder us as often as had been feared on the whaling grounds south of 55°S. in eastern Antarctic waters. There were only 30 days on which the wind exceeded force 5, which was the critical value for the Walrus aircraft alighting on open sea; and often ice shelter was available. Only the bigger swells get past the first lines of drift ice and broken pack. All the smaller ripples are combed out, and the strange, smooth billows of a big swell which rumple the icefields on certain days are amongst the oddest sights of the Antarctic. In these conditions the Walrus could alight on the lagoons and sheltered bays in the ice with wave heights up to 10 to 20 ft.

Ice formation on the aircraft was avoided by flying in snow or cloud as little as possible. Anti-icing paste is not handy for use on biplanes with many struts and cross-wires. That icing is possible and might be serious was shown by the heavy growths of ice which formed on the masts and rigging of the ship on eight isolated days with fog between mid November and mid April. The amounts on these eight days alone suggested that direct ice deposit from fog and stratus on the steeper parts of the windward coasts of Antarctica might be comparable with the total precipitation of types normally counted in annual rainfall figures.

The network of meteorological observing stations, from which regular reports could be used to deduce the weather patterns over the waters traversed in the whaling voyage, was always sparse; and the factory was sometimes 1,500 miles or more from the nearest observing station. To this sparse network could be added reports from our own aircraft and occasionally from one of our whale-boats on longer whaling reconnaissances up to 500 miles from the factory; but the promised reports from the other factories in Antarctic waters did not in general materialise, owing to the highly competitive nature of the whaling industry and the precautions which are taken to keep secret each vessel's movements, until the season is over.

Reports from the Falkland Islands and the stations in their dependencies farther south on the islands in the Atlantic sector and in Graham Land therefore constituted the only information available from high latitudes apart from our own observations. These stations and Tristan da Cunha, which also occupied a key position, were more than 4,000 miles away; yet their importance is such that the loss of these reports due to a radio fade-out could be felt even in the Australian sector 180 degrees of longitude away. And their loss for several days in succession would render an interruption of the forecasting service necessary. Fortunately this seldom happened.

One was in this way driven to map the weather over a very wide area every day; for, no matter how far east we went, the Falklands group of reports could never be dispensed with. Ultimately the maps covered more than half the southern hemisphere, and in an experimental series which lasted from March 20 to March 27, 1947, they were completed right across the South Pole, without any serious inconsistencies coming to light in the observations culled from widely separated sectors. In many longitudes south of about 62°S. in the Indian Ocean and Australian sectors our weather was obviously influenced by the topography of the unknown land, at distances ranging from 30 to 200 miles farther south. This was awkward for forecasting at first, but one soon learnt what to expect; since the orographic effects seemed to be as regular and dependable in their occurrence as orographic effects are everywhere. Thus, whilst the weather maps prompted interesting conclusions about the weather patterns over Antarctica as a whole and about the south polar anti-cyclones, the observations made on the factory near the coast of Antarctica almost inevitably suggested ideas about the geography of the unknown land.

This process of reasoning back from observed meteorological effects to a diagnosis of the nature of the geographical features causing them may be unique. The chief of the tentative conclusions was the hypothesis of a major topographical barrier running through East Antarctica from near 80°S. 80°E. towards the coast near 100°E. This may be either a great range of mountains or the main crest of the ice-cap; and it will be interesting to see whether its existence is ever confirmed by eye observation. Since returning to England I have learnt that a German expedition in 1939 found that the ice-cap reached the hitherto unknown height of 15,000 ft. near 80°S. in Queen Maud Land (Atlantic sector);

this area lies on a direct extension of the line of the supposed great topographical barrier in East Antarctica, which served well as a basis for many successful weather forecasts for the eastern whaling grounds visited by *Balaena* between 80° and 115°E. Singularities in the wind régime observed off shore also suggested ideas about the general form of the unknown coast line, the most interesting being the suspected existence of an inlet or fjord near 107°E., just west of the hill ranges of the Budd Coast, which were sighted between 109° and 114°E.

A few further points may be mentioned in conclusion. The meteorological task on this expedition had been undertaken with great diffidence as to what might be possible, and forecasting was begun on an explicitly experimental basis. Gradually the disinterested work of independent checkers showed that the results were justifying the attempt. The standpoint which produced this result was a conviction about the basic soundness of the existing theories of fronts and depressions, which were rigorously applied, and a completely open mind with regard to whatever local factors and influences might come to light. Both aspects of this position brought rewards. The former led to a further vindication of the accepted theories, and demonstrated their application to new regions of the earth, showing indeed a regularity which made up for the lack of a close network of weather observing stations. It would not however have been possible to complete the weather maps over the vast expanses of the Southern Ocean but for an assumption, that the subtropical anticyclones (located happily in latitudes where reporting stations and ships are more plentiful) control the weather patterns of the Far South, where the depressions are steered by the currents of warm air guided into higher latitudes by these anticyclones. During the greater part of its life history, and particularly at its prime, the influence of one of these high-pressure centres was assumed to be paramount over wide areas and all else secondary. The assumption worked well, and agrees with the evidence that the weather over the limitless Southern Ocean is by no means so uniform and devoid of characteristic differences in different longitudes as was formerly supposed. This discovery may suggest a greater emphasis on the study of the rôle of stable anticyclones in controlling the weather patterns over wide areas in the northern hemisphere. Over the Southern Ocean the typical régime is wave disturbances, first formed near the western extremities of the anticyclones about 30°S., travelling south-east and occluding and deepening, then sometimes coalescing in high latitudes with older, fully occluded centres, to form the deepest depressions and worst storms of the Southern Ocean.

The necessarily open-minded attitude to the occurrence of local effects led to hints of geographical discovery in a peculiarly interesting and quite unforeseen manner. One weather phenomenon which came as a surprise was the observation of large cumulus and cumulonimbus clouds on over 30 days in the far south. These were considered to occur in most cases in air streams of very cold origin over Antarctica which had spent long over open sea and were in some cases returning towards the continent. The cloud tops were estimated at 17,000 to 20,000 ft. on one or two occasions, and showers of small hail fell. Nevertheless, stratus and stratocumulus clouds prevail, and the upper air temperatures observed suggest successive shallow air masses separated by stable layers, which may well represent successive frontal surfaces, to correspond with the bunches of occlusions commonly seen on the surface maps, as the normal structure of the lower atmosphere over the southern parts of the Southern

Ocean; deep adiabatic layers only occur after the air masses have been modified by considerable heating from the sea surface, and after various stages of transition from successive parallel belts of stratiform cloud, with or without snow and fog, to well scattered cumulus were observed in northward-moving air masses between 50° and 60°S.

STATISTICS OF *Balaena's* OBSERVATIONS SOUTH OF 50°S.

	Barometric pressure	Air temperature	Beaufort wind force
	mb.	°F.	
Average value ..	982	28·7	3·9
Highest value ..	1013	37·8	11
Lowest value ..	960	12·1	0

A selection of photographs will be found at the end of this number.

HIGH PILOT-BALLOON ASCENTS AT PIARCO, TRINIDAD

BY J. C. W. WICKHAM.

Twelve months' experience of pilot-ballooning at Piarco, Trinidad, has shewn that, with 100-gm. balloons and the standard Meteorological Office Mk. IV theodolite, it is possible, fairly frequently, to follow balloons and obtain values of the wind speed and direction to theoretical heights (i.e. assuming a constant rate of ascent) of well over 40,000 ft.; indeed, on occasions, 90-in. balloons have been followed well above this height. This might be thought surprising when one considers that Trinidad lies in a maritime air mass and is subject to tropical weather.

There are three British stations in the south-eastern Caribbean Sea: Piarco (Trinidad), Pearl's airfield (Grenada) and Seawell airfield (Barbados). From a comparison of ascents made at these stations it is evident that on the average the Trinidad balloons can be followed to much greater heights than can the others. It is found that by careful choice of time, either immediately after dawn or one to two hours before sunset, high ascents can often be made in clear skies.

The table shows pilot-balloon ascents in excess of theoretical heights of 40,000 ft. made at Piarco between September, 1946, and February, 1947. The number of these ascents is so far limited and it is impossible to generalise from them, but the following statements about the winds above 40,000 ft. can be made from those available:—

(1) Approximately 60 per cent. of these winds lie between 220° and 320°.
(2) Approximately 70 per cent. have a westerly component.
(3) Of the remaining 30 per cent. 3 out of 4 lie between 360° and 90°.

In Trinidad the dry season extends from January to May; the presence of haze in the lower atmosphere when this season is well established, and of abundant cirrus in the last two months of the dry season rendered ascents to 40,000 ft. impossible from the end of February, 1947, to the time of writing (June, 1947). The haze in the lower atmosphere does not extend very often above 10,000 ft. and balloons which ascend beyond this height are rarely lost in haze; this is because the elevation of such ascents is practically always relatively

PILOT-BALLOON ASCENTS IN EXCESS OF THEORETICAL HEIGHTS OF 40,000 FT. MADE AT PIARCO, TRINIDAD, BETWEEN SEPTEMBER, 1946, AND FEBRUARY, 1947

Date	Sept. 19		Sept. 20		Oct. 1		Oct. 11		Oct. 16		Oct. 25		Nov. 3		Jan. 9		Jan. 27		Feb. 11		Feb. 19	
Time (G.M.T.)	1100		1100		1100		1100						1100		1300		1100		1300		1100	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
5,000	100	18	110	13	130	12	120	7	100	17	120	15	100	15	090	23	060	8	070	17	090	22
10,000	100	15	110	14	110	14	090	13	090	6	110	8	120	12	070	12	110	9	030	8	250	8
15,000	090	16	090	19	060	15	050	2	100	13	100	12	110	10	140	15	100	1	080	19	200	8
20,000	090	18	100	13	090	9	030	10	070	7	130	6	310	1	220	7	030	12	070	17	050	6
25,000	130	22	090	13	070	5	180	6	090	2	350	4	300	5	230	25	030	10	350	20	250	8
30,000	080	10	130	15	170	16	150	14	320	10	320	19	280	14	230	20	320	18	070	10	250	8
35,000	110	9	340	5	210	9	210	15	330	11	300	25	290	16	270	30	240	18	170	14	200	12
40,000	050	22	340	16	230	20	250	28	300	20	290	31	290	22	200	14	230	16	270	6	210	8
45,000			140	13			250	28	280	20	310	34			220	12	330	17	070	10	330	5
50,000			120	29			220	10	280	22	230	25			360	3	060	8	080	15	330	10
55,000							220	23	290	27	310	20			360	25	290	22	140	19	260	18
60,000									280	30							290	16	040	35		
65,000																	020	6				
70,000																	090	15				
Maximum height (ft.)	40,500		50,700		41,000		54,750		62,750		55,750		40,500		55,400		70,700		63,000		55,000	
How lost	Behind Cu		Behind Cu		Behind Cu		Behind Cu		Behind Cu		Near sun		Burst		Behind cloud		Burst		Burst		Behind cloud	

high, and the effective haze thickness consequently relatively shallow. Practically all the balloons which are reported lost in haze are lost below 10,000 ft. and their angle of elevation is relatively low (12–15°).

It would seem then that the two conditions for high ascents are a light wind and/or an early reversal with height. If there is a light wind the balloon rises more nearly vertically and so passes through a lesser haze thickness than would be occasioned by a strong or moderate wind.

The peculiar wind structure of this area allows these conditions to be satisfied fairly frequently both in summer and in winter, because in winter when the trade winds are strong the reversal to a westerly wind occurs at a comparatively low height (8,000–15,000 ft.), while in summer when the reversal takes place above 20,000 ft. the easterly winds of the lower layers have decreased in speed.

It seems that above the dry-season haze top (8,000–10,000 ft.) there is very pure air and little cloud apart from cirrus, while in the wet season the cloud-free air is absolutely clear and unless the balloon bursts early the skilful observer has a very good chance of an ascent to a theoretical height of 10 miles.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held at 49 Cromwell Road on October 15, Prof. G. M. B. Dobson, President, in the Chair, the following papers were read :—

Sverre Petterssen, P. A. Sheppard, C. H. B. Priestley and K. R. Johannessen—An investigation of subsidence in the free atmosphere.

This paper gives the results of an investigation carried out at Dunstable during the latter part of the war at the request of the Meteorological Research Committee. It includes a theoretical discussion of subsidence and a large number of statistical tables giving the magnitude of the subsidence at different levels and its relation to other factors. Prof. Sheppard, who introduced the paper, concentrated mainly on the statistics, and emphasised that the investigation was concerned only with prolonged subsidence of substantial amount over large areas. It aimed at presenting the facts rather than at discussing their implications.

During the discussion which followed the value of such statistics was emphasised. The apparent large subsidence at 300 mb. (Tables XI and XII) was commented on. Both Sir Charles Normand and the President pointed out that humidity observations at high levels are not sufficiently accurate to be used for computations of subsidence. The absence of a correlation between subsidence and barometric tendency (Table XIV) was attributed to the concentration on substantial subsidence rather than on its earlier stages. Table XIII shows a marked relation between subsidence and high pressure, and this implies a rise of pressure at an earlier stage. Reference was also made to the complex problems presented by low cloud sheets and the inversions above them.

G. D. Robinson—Notes on the measurement and estimation of atmospheric radiation.

The paper concerns measurements of infra-red temperature radiation in cloudless conditions at Kew Observatory using two radiometers, one of them constructed by Mr. W. H. Dines and first described in the *Meteorological Magazine* in 1920.* Some 10 to 15 per cent. of the radiation received from the atmosphere

* *Met. Mag. London*, 55, 1920, p. 189.

may, on occasion, originate in the first one or two metres and since distances of this order are involved when calibrating the instruments, a number of corrections must be applied, a fact which was not realised when Dines' measurements were made, since the emissivities of short atmospheric paths had not then been measured. The corrections are developed, and on applying them it is shown that consistent results are obtained with two very different types of radiometer. Measurements of atmospheric emission are then compared with computations made from Elsasser's radiation chart using temperatures and humidities given by radio-sonde ascents. The divergences between computed and observed values are discussed and it is shown that they may be referred to two causes. The first is a variable radiation due mainly, but possibly not entirely, to particulate matter, the second is the over-estimation of the emissivity of long path lengths of water vapour. Using a modification of a technique due to F. A. Brooks new emissivities are estimated from the measurements, and the construction of a simplified empirical chart radiation chart using them is described. Finally a method of estimating the outward nocturnal radiation without the use of a radiometer is explained.

In the discussion which followed the reading of the paper, both Dr. J. M. Stagg and Prof. D. Brunt said that the surprising feature was not that observations differed from computations made from Elsasser's radiation charts, but that the divergences were as small as those actually found. Prof. Brunt explained several assumptions underlying Elsasser's method, and showed how, in the case of the widths of the lines of the water-vapour spectrum, the recent measurements have shown that the assumption was considerably in error.

LETTER TO THE EDITOR

Record high temperature for Vienna

On August 5, 1947, a maximum temperature of 100·3°F. was recorded at the R.A.F. Meteorological Office, Schwechat airport, Vienna, which is about eight miles south-east of the centre of the city. This was the highest official temperature ever recorded in Vienna or its environs since the beginning of records in 1775. The previous maximum temperature recorded was 98°F. in July, 1857. This was recorded at the old Central Institute of Meteorology, Vienna. The exposure at Schwechat is no doubt slightly more conducive to high extremes than the Vienna exposure due to the bare and flat nature of the surrounding land and also to the fact that it is at a slightly lower altitude. The present Central Institute of Meteorology is at Hohe Warte, Vienna. The Hohe Warte site only recorded 95°F. on August 5, 1947, but even so, that was the highest recorded at that site.

A pronounced feature of the synoptic chart for August 5, which strongly contributed to the extreme heat over central and south-east Europe that day, was the existence of an anticyclone over the Black Sea. This anticyclone together with a trough of low pressure which covered the western Mediterranean resulted in the establishment of a strong south to south-westerly upper current which very probably originated from north Africa. Contour charts at 500 and 700 mb. and radio-pilot balloon ascents for Vienna confirmed that a strong south to south-westerly current had become well established aloft.

A cold occlusion passed Vienna at 1635 G.M.T. The maximum temperature was recorded between 1330 and 1400 G.M.T. when the relative humidity was only 19 per cent. The approach of the front and the accompanying southerly drift ahead of it appears to have given the mercury the extra kick required to break the record. This effect was noticed at Klagenfurt on July 30, 1947 when, just prior to the passage of a very weak cold front, the temperature, which had mounted steadily to reach 94°F., suddenly rose to 96°F. in a matter of a few minutes to the accompaniment of a slight southerly wind, then dropped rapidly as the wind changed to light northerly.

The general warmth over the area was also believed to be largely due to the föhn effect induced by the south-westerly current passing over the Alps. The synoptic situation prevailing that day was more representative of winter than summer. In winter the föhn brings fair, very mild conditions to the Vienna area. Snow melts under maximum temperatures of about 50°F. The added effect of this föhn to a normal hot summer day undoubtedly helped to produce the record maximum temperature.

A. H. GORDON
T. M. DAVIES

A.H.Q. (Rear), Austria, September 22, 1947.

NOTES AND NEWS

Diurnal variation of thunderstorms

Following Mr. Bishop's interesting paper in the May 1947 issue of the *Meteorological Magazine*, some further figures in regard to the diurnal variation of thunderstorms in other parts of the British Isles may be of use. These figures have already been published in *Summer Thunderstorms*, 1932, the second report of the Thunderstorm Census Organization, and are reproduced by permission.

The wide variation in the hours of thunderstorm maxima and minima between different districts of the British Isles suggested that some indication of storm travel might be obtained from a detailed examination of hourly frequency. Accordingly an analysis of about 10,000 records of the times of storms in the two winters (January to March) of 1925 and 1926, and in the two summers (April to September) of 1931 and 1932, was made. These data provided 92 sets of hourly percentage figures, and distinction has been made between coastal and inland districts, a coastal district being defined as wholly within ten miles of the open sea. Summer storms only are considered first.

The sets of percentage figures are shown graphically in Fig. 1 in which the arrangement of the sets is roughly geographical. The districts, E 7, E 4, etc., are those used in the Thunderstorm Survey and are fully specified in the " List of Stations ". The main divisions are lettered as follows :—

A: England, London County.
B: England, South-eastern Counties.
C: England, South Midland Counties.
D: England, Eastern Counties.
E: England, South-western Peninsula.
F: England, West Midland Counties.
G: England, North Midland Counties.
H: England, North-western Counties.
J: England, Yorkshire.
K: England, Northern Counties.
L: South Wales.
M: North Wales and Isle of Man.

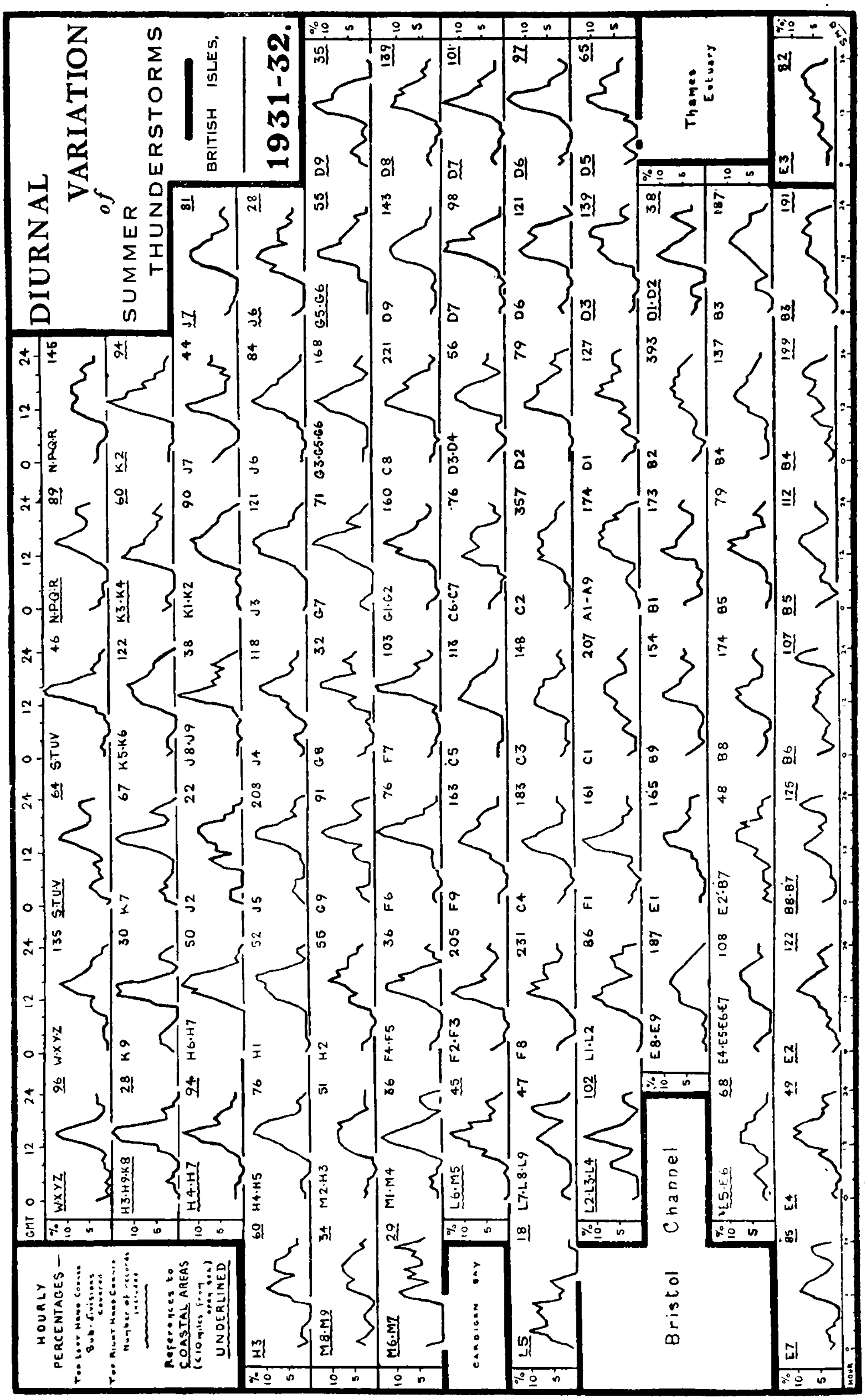

DIURNAL VARIATION of SUMMER THUNDERSTORMS
BRITISH ISLES,
1931-32.
HOURLY PERCENTAGES
Bristol Channel
Thames Estuary

FIG. 1

N P Q R: Southern Scotland.
S T U V: Northern Scotland.
W X Y Z: Ireland.

Each main division is subdivided into nine numbered parts. References to coastal areas are underlined, and the number of records included in each group is given at the top right-hand corner of each graph.

Obviously, the period under discussion is far too short, but the movements of the times of maximum storm frequency across the country can be interpreted along the following lines:—

(*a*) A line of maximum storm frequency advances north-eastward from the Bristol Channel area about 1200 G.M.T.; the eastern portion of this line joins another line moving northward over Hampshire and Sussex, and the combined line moves north-eastward until it arrives over the counties of Lincoln, Huntingdon and Cambridge, and north-east Essex at 1700. The northern part of the line goes to sea off Spurn Point about 1800 while the southern portion runs off the coasts of Norfolk and Suffolk from 1900 to 2000.

(*b*) A secondary line moves northward out of the Thames Estuary from 1100 to 1200 and becomes a contributory cause of the maxima at 1400 and 1500 in Norfolk and Suffolk.

(*c*) Similar phenomena make their appearance over the Mersey and Humber Estuaries around 1400, and in both cases the lines move inland.

(*d*) The night storms present an entirely different picture: the lines of maximum intensity run roughly east and west, and their northward travel is most noticeable over the eastern half of southern England. Storms previously formed on the continent strike the Sussex coast around 2000 and travel up to Norfolk producing a maximum there from 0200 to 0300 the following morning.

A combination of circumstances produces an absolute maximum around 2200 in the Isle of Wight and New Forest area. This is interesting in that it appears to be the latest absolute maximum in any part of the country.

So far only summer storms have been discussed, but the analysis agrees well with results which have been obtained by an independent method. Table I shows comparative results for summer and winter, the main maxima being printed in heavy type.

TABLE I—DIURNAL VARIATION OF SUMMER AND WINTER THUNDERSTORMS IN THE BRITISH ISLES, EXPRESSED AS THE PERCENTAGE PER HOUR OF THE TOTAL

Coastal regions (within 10 miles of the open sea)												
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Summer (1931 and 1932)	1·7	1·8	1·7	**2·0**	1·6	**1·7**	1·4	1·8	2·2	3·4	4·8	6·8
Winter (1925 and 1926)	4·1	3·5	3·2	4·1	4·4	**4·5**	3·2	2·6	2·1	1·5	0·9	1·1
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Summer (1931 and 1932)	8.7	**9.4**	9.2	7.6	6.6	5.3	4.6	4.0	3.9	**4.4**	3.5	2.4
Winter (1925 and 1926)	1.7	3.1	5.0	5.4	**5.6**	5.0	7.0	7.9	**8.2**	6.7	5.3	3.9
Inland regions (more than 10 miles from the open sea)												
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Summer (1931 and 1932)	2·0	1·7	1·5	1·0	**1·1**	**1·1**	1·0	1·2	1·6	3·3	5·0	7·0
Winter (1925 and 1926)	3·2	2·1	1·5	1·3	**1·4**	1·0	0·8	0·7	1·1	1·7	1·7	2·9
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Summer (1931 and 1932)	8·7	9·7	**10·0**	9·0	7·9	6·1	4·7	3·8	**3·9**	3·5	3·0	2·2
Winter (1925 and 1926)	4·4	7·6	8·8	**9·2**	8·7	8·5	7·7	6·2	4·9	**5·2**	5·1	4·3

As would be expected, the main maximum frequency in inland areas occurs in the summer around 1500 and in the winter an hour later. In coastal areas the summer maximum occurs at 1400 while in winter the afternoon maximum at 1700 is surpassed by the evening maximum at 2100.

The evening maxima occur generally in both summer and winter, in both inland and coastal areas, around 2100 and 2200. The early morning maxima occur in both seasons and in all areas from 0400 to 0600, and are most pronounced on the coast in winter.

S. MORRIS BOWER

"Range" of values in a series of observations

We were recently asked what was the difference to be expected between the highest and lowest values in a series of *n* observations. This problem is of some interest and does not appear to have been discussed before.

It is well known that the standard deviation σ_d of the differences between two independent series of observations with standard deviations σ_1 and σ_2 is given by $\sigma_d^2 = \sigma_1^2 + \sigma_2^2$. Consequently, if we have a single series of observations with a near normal distribution and standard deviation σ, and take a number of pairs at random, the standard deviation σ_d, of their differences should be $\sigma\sqrt{2}$. In a series of *n* observations there are $n(n-1)/2$ possible pairs, and the distribution of the differences between these pairs (all differences being zero or positive) should give half a normal frequency curve with standard deviation of $\sigma\sqrt{2}$.

To test this, the mean temperatures of 100 Januaries at Greenwich, 1841–1940, were used and the 4,950 differences were tabulated. The results are shown by the vertical columns in Fig. 1. The distribution of the individual mean

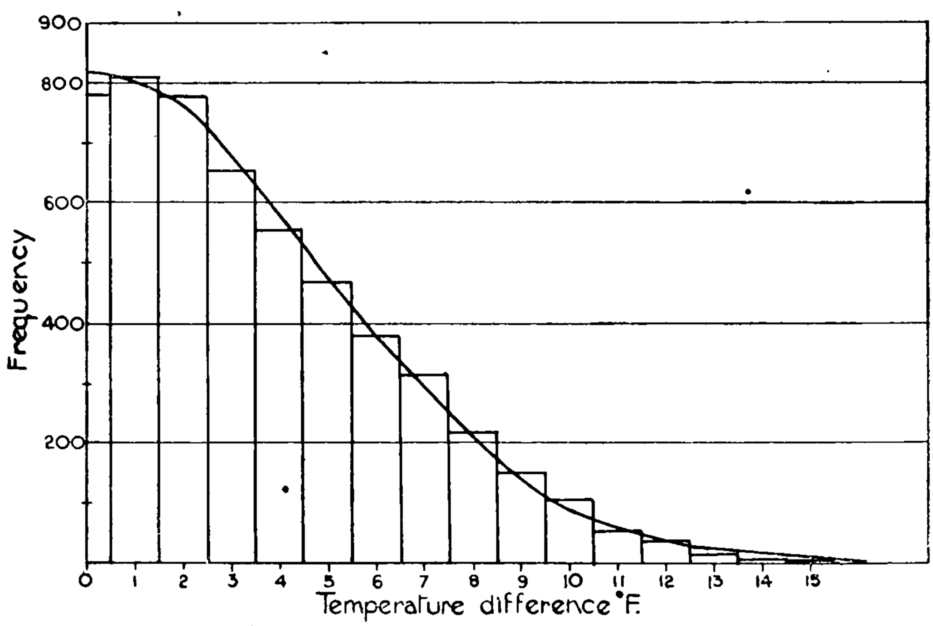


FIG. 1—DISTRIBUTION OF DIFFERENCES BETWEEN PAIRS OF VALUES OF AVERAGE TEMPERATURES AT GREENWICH IN JANUARY, 1841–1940
(Total frequency: 4,950)

values has a fairly high degree of skewness with a standard deviation of 3·41°F. The curved line in Fig. 1 shows the normal curve with a standard deviation of $3{\cdot}41\sqrt{2} = 4{\cdot}82$°F. In spite of the skewness of the original distribution, the agreement is good.

To find the range to be expected between the highest and lowest values in any series of length n, we need to find the value which has an even chance of being exceeded once in $n(n-1)/2$ trials, i.e. which has a probability of $1/[n(n-1)]$. These values were found for a number of series selected at random with the results, (Range)/(standard deviation) shown in Table I. The agreement between observation and theory is reasonably good. Table II gives the expected range, in terms of the standard deviation of the original series, for periods of different lengths. It should be noted that Table II is not applicable to daily values since these are not independent; a continuous set of n daily maximum temperatures in this country may be taken to be roughly equivalent to $n/3$ independent observations, but the interdependence of daily minima appears to vary in different seasons, and that of other elements has not been examined.

TABLE I

Station	Position	Element	Month	Period	(range)/σ Observed	(range)/σ Computed
		Daily Mean		*years*		
Bukit Jeram	3°N. 101°E.	Pressure	Jan.	7	2·8	2·8
			July	7	2·8	2·8
		Minimum temperature	Feb.	9	3·9	3·1
			Aug.	9	3·3	3·1
Malacca	2°N. 102°E.	Maximum temperature	Feb.	9	3·3	3·1
			Aug.	9	2·7	3·1
Bukit Jeram	3°N. 101°E.	Maximum temperature	Mar.	10	3·0	3·2
			Sept.	10	3·3	3·2
Suva, Fiji	18°S. 178°E.	Pressure	Jan.	12	3·1	3·4
			July	12	3·3	3·4
		Maximum temperature	Jan.	14	3·7	3·6
			July	14	3·8	3·6
Apia, Samoa	14°S. 172°W.	Minimum temperature	Jan.	14	3·3	3·6
			July	14	3·2	3·6
		Pressure	Oct.	21	4·1	4·0
Cumberland Bay	54°S. 36½°W.	Maximum temperature	Feb.	21	3·7	4·0
			Aug.	23	4·0	4·1
Malacca	2°N. 102°E.	Maximum temperature	Jan.	22	4·3	4·0
		Pressure	Jan.	25	3·5	4·1
			July	25	4·4	4·1
Iba	15°N. 120°E.	Mean temperature	Jan.	25	4·1	4·1
			July	25	4·3	4·1

TABLE II—RATIO OF EXTREME RANGE TO STANDARD DEVIATION

Series of n independent observations

No. of years	(range)/σ	No. of years	(range)/σ	No. of years	(range)/σ
7	2·80	18	3·85	50	4·74
8	2·97	20	3·95	60	4·88
9	3·11	25	4·15	70	5·00
10	3·24	30	4·31	80	5·10
12	3·43	35	4·44	90	5·18
14	3·59	40	4·55	100	5·25
16	3·73	45	4·65		

C. E. P. BROOKS
N. CARRUTHERS

OBITUARY

Dr. Ellsworth Huntington. We regret to record the death in October, at the age of 71, of Dr. Ellsworth Huntington, well known for his books on the influence of climate on human affairs. Dr. Huntington was educated as a geographer and spent the years 1900 to 1906 exploring in Asia, where he was impressed by the evidence for former considerable population in areas which are now waterless. In " The pulse of Asia " he developed the theory that these migrations were due to large-scale climatic pulsations. In " Civilization and climate " he maintained that the ideal climate for human progress was found in the storm belts of temperate regions, and this idea was expanded in a long series of readable books, ending with " Mainsprings of civilization " in 1945.

NEWS IN BRIEF

The L.G. Groves Memorial Prize for Meteorology has been won this year by Mr. J. S. Sawyer, Senior Scientific Officer in the Meteorological Office. The prize is to be awarded annually on July 1, beginning in 1947, for the most important contribution made during the past year either to the science of meteorology or to the application of meteorology to aviation.

The L.G. Groves Memorial Award for Meteorological Air Observers has been won this year by Warrant Officer P. G. Rackliff, R.A.F.V.R. Meteorological Assistant. The award is to be given annually on July 1, beginning in 1947, to an officer employed on flying duties or a member of aircrew who, in either case, has been employed on meteorological air observer duties for meritorious work or devotion to duty.

Miss A. Tobitt, Meteorological Assistant at Dunstable, has been awarded the Henry van den Burgh Prize for commercial geography in the London Chamber of Commerce examinations in which she gained the highest number of marks for the whole country.

REVIEWS

Science from shipboard. Prepared under the guidance of the Boston–Cambridge Branch of the American Association of Scientific Workers. Size: $7\frac{1}{4}$ in. × $4\frac{1}{2}$ in. pp. 268. *Illus.* Science Service, Washington, 1943.

A long voyage by sea may suggest to many a dull monotony of sea and sky. Both, however, are frequently changing and the waves, the clouds, the stars and the various forms of sea life are interesting things if only one knows what to observe. " Science from Shipboard " was prepared to provide such knowledge. It describes itself as " a simple manual of information and instruction " and, indeed, the elements of meteorology, astronomy, zoology, technology and physiology all find a place in this pocket-size volume. The style is friendly but concise ; the 138 illustrations, mainly diagrammatic, are clear and, in places, amusing.

The largest section, " Waves, Wind and Weather " is contributed by the well-known climatologist, Dr. Charles F. Brooks. This includes an explanation of the main climatic regions of the world ; gives homely devices for estimating direction and velocity of wind, cloud heights and temperature from on board ship ; describes the weather changes in the path of a storm ; and shows how storm warnings may be seen "written" in the waves as well as in the sky. The section concludes with descriptions of climatic changes to be encountered on four of the main transport routes from the United States.

In the sections on astronomy are included short notes on the solar system with a monthly guide to the positions of the brighter planets, comprehensive star charts (for use in southerly as well as in northerly latitudes), and simple details of time measurement and of navigation. Other sections deal with sea life, oceanic birds and the constitution and changing nature of coast-line and islands. The volume concludes with "Your Ship", a description of the structure of a ship, and the working of its engines, and "Yourself", an attempt to explain the sensations one experiences on shipboard.

N. CARRUTHERS

A hőmérséklet napi ingadozása, mint bioklimatikus tényező (Daily range of temperature as a bioclimatic factor), by V. Grubich. *Időjárás, Budapest*, **51**, 1947, pp. 84–90. (English summary, p. 103.)

Starting from the hypothesis that temperature in itself can be regarded only as a "static" factor having no stimulating effect on the human body, Dr. Grubich has proceeded in this paper to the logical assumption that the daily range is the temperature condition exercising the greatest biological control. Because the average daily range, whilst following the yearly trend of temperature, is yet greater in summer than in winter, the author concludes that the former season has more stimulating conditions and is therefore the time most favourable for violent exercise. Furthermore, he shows that higher altitudes have a smaller daily range than do the lowlands, and so advances the opinion that the climate of the lowlands has the greater stimulating effect on human beings.

Temperature range is in fact a measure of climatic stimulation. Thus a mild climate, characterised by higher average temperatures and a lower temperature range, is far less stimulating to human beings than is a climate in which the reverse conditions operate. The difference between the temperature and temperature range when comparing the above climatic extremes is not apparent however when yearly means are considered. It is necessary to compare the monthly mean values in order to differentiate between the two differing temperature régimes. This seems such an obvious necessity that one wonders why Dr. Grubich bothered to mention the yearly values which can mean very little anyway.

Several graphs are included in the paper showing the percentage distribution of daily temperature range and these do help to build up a more detailed idea of the climatic differences which are the subject of the paper.

After considering the differing effects, from a biological point of view, of increasing and decreasing temperatures the author goes on to talk of the abruptness of the temperature transition from winter to spring in March and from summer to autumn in September. This is more marked during the latter transition period, especially in the true continental climates, when the fall in temperature can be very abrupt and may, as the author suggests, be connected with the prevalence of colds during this period. He concludes, however, by conceding that other factors such as changes in atmospheric humidity may be of importance in this case.

We feel too that he might well have added the same proviso to his statements regarding temperature range and human stimulation since it is certain that humidity changes can, in many cases, play a part of equal importance with that of temperature changes in influencing human exertions.

L. G. CAMERON

WEATHER OF SEPTEMBER, 1947

At the beginning of the month a belt of high pressure extended from mid Atlantic north-eastwards to Norway. The eastern end of this belt gradually moved southwards and by the 10th the belt ran almost west to east from south of the Azores to northern Italy. This persisted until the 16th, when a depression north of Scotland, which gave the only considerable rainfall of the month in London on the 17th, split it into two parts. A deep depression passed north of Scotland on the 23rd after which anticyclonic conditions again spread over Great Britain, with a temporary break on the 28th–29th. The average pressure for the month shows an anticyclonic belt extending from the Great Lakes of America across the Azores and central Europe, exceeding 1023 mb. in mid Atlantic, with a depression (1003 mb.) from Denmark Strait to Spitsbergen. Pressure was above normal from the Great Lakes to Russia, the excess reaching 5 mb. east of Newfoundland, and below normal over the Arctic, the deficiency exceeding −5 mb. between north-east Greenland and Bear Island; pressure was also slightly below normal in the western Mediterranean.

In the British Isles the weather was unsettled and wet in the north-west and dry in the east and south. In England and Wales it was unusually warm; as far as can be estimated mean temperature was, with two exceptions namely 1929 and 1933, the highest for September since before 1901; in 1929 the mean temperature was higher than in 1947 but in 1933 it was about the same. Rainfall exceeded the average in western, northern and central districts of Scotland, over most of north-west England, in the Tees valley and in an inland area in south Devon. On the other hand less than half the average occurred over some parts of England and less than a quarter at Lowestoft. Rain occurred very frequently in the north-west and north, measurable rain being reported on 27 days at a number of stations in north-west Scotland. The long drought which occurred throughout most of August was not terminated in parts of England until the 11th or even the 17th; at Wye, Kent, there was no measurable rainfall from July 29 to September 16 inclusive, a period of 50 days. Sunshine exceeded the average in the Shetland Isles and in the eastern and Midland districts of England but was below the average in the west of the British Isles.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	88	30	+3.1	78	−1	106	41
Scotland	78	26	+1.6	135	+3	93	29
Northern Ireland ..	76	39	+2.0	110	+3	78	25

RAINFALL OF SEPTEMBER, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·40	77	*Glam.*	Cardiff, Penylan ..	2·27	74
Kent	Folkestone, Cherry Gdns.	1·37	58	*Pemb.*	St. Ann's Head.. ..	1·98	69
,,	Edenbridge, Falconhurst	1·68	74	*Card.*	Aberystwyth	2·29	80
Sussex	Compton, Compton Ho.	2·15	77	*Radnor*	Bir. W. W., Tyrmynydd	3·12	81
,,	Worthing, Beach Ho. Pk.	1·54	72	*Mont.*	Lake Vyrnwy	2·97	79
Hants.	Ventnor, Roy. Nat. Hos.	1·42	57	*Mer.*	Blaenau Festiniog ..	8·19	104
,,	Fordingbridge, Oaklands	1·24	58	*Carn.*	Llandudno	1·87	88
,,	Sherborne St. John ..	1·10	54	*Angl.*	Llanerchymedd ..	3·56	121
Herts.	Royston, Therfield Rec.	1·15	61	*I. Man.*	Douglas, Boro' Cem. ..	2·77	85
Bucks.	Slough, Upton	1·15	65	*Wigtown*	Pt. William, Monreith..	4·09	140
Oxford	Oxford, Radcliffe ..	1·15	67	*Dumf.*	Dumfries, Crichton R.I.	2·79	103
N'hant	Wellingboro', Swanspool	1·30	72	,,	Eskdalemuir Obsy. ..	4·61	125
Essex	Shoeburyness	1·41	84	*Roxb.*	Kelso, Floors	1·28	67
Suffolk	Campsea Ashe, High Ho.	·86	45	*Peebles.*	Stobo Castle	2·40	95
,,	Lowestoft Sec. School ..	·41	21	*Berwick*	Marchmont House ..	1·33	55
,,	Bury St. Ed., Westley H.	1·12	56	*E. Loth.*	North Berwick Res. ..	1·08	52
Norfolk	Sandringham Ho. Gdns.	1·08	52	*Midl'n.*	Edinburgh, Blackf'd. H.	1·27	62
Wilts.	Bishops Cannings ..	1·36	62	*Lanark*	Hamilton W. W., T'nhill	4·16	155
Dorset	Creech Grange ..	1·79	65	*Ayr*	Colmonell, Knockdolian	3·84	111
,,	Beaminster, East St. ..	1·67	65	,,	Glen Afton, Ayr San. ..	6·16	158
Devon	Teignmouth, Den Gdns.	2·16	110	*Bute*	Rothesay, Ardencraig ..	4·93	122
,,	Cullompton	2·19	97	*Argyll*	Loch Sunart, G'dale ..	9·08	145
,,	Barnstaple, N. Dev. Ath.	1·45	54	,,	Poltalloch	—	—
,,	Okehampton, Uplands	3·33	103	,,	Inveraray Castle ..	10·77	168
Cornwall	Bude School House ..	1·71	69	,,	Islay, Eallabus	5·98	143
,,	Penzance, Morrab Gdns.	1·47	50	,,	Tiree	5·12	138
,,	St. Austell, Trevarna ..	2·00	63	*Kinross*	Loch Leven Sluice ..	3·05	119
,,	Scilly, Tresco Abbey ..	1·51	59	*Fife*	Leuchars Airfield ..	2·02	105
Glos.	Cirencester ..	1·77	80	*Perth*	Loch Dhu	8·60	150
Salop	Church Stretton ..	1·53	73	,,	Crieff, Strathearn Hyd.	4·52	158
,,	Cheswardine Hall ..	1·42	70	,,	Blair Castle Gardens ..	4·27	180
Staffs.	Leek, Wall Grange, P.S.	1·53	61	*Angus*	Montrose, Sunnyside ..	1·77	89
Worcs.	Malvern, Free Library	·86	45	*Aberd.*	Balmoral Castle Gdns...	2·60	108
Warwick	Birmingham, Edgbaston	1·59	89	,,	Aberdeen Observatory	1·67	75
Leics.	Thornton Reservoir ..	1·00	55	,,	Fyvie Castle	3·12	120
Lincs.	Boston, Skirbeck ..	1·29	73	*Moray*	Gordon Castle	3·50	140
,,	Skegness, Marine Gdns.	1·02	56	*Nairn*	Nairn, Achareidh ..	3·25	154
Notts.	Mansfield, Carr Bank ..	1·47	80	*Inv's*	Loch Ness, Foyers ..	4·94	168
Ches.	Bidston Observatory ..	2·23	93	,,	Glenquoich	12·90	149
Lancs.	Manchester, Whit. Park	2·11	89	,,	F. William, Teviot ..	9·32	146
,,	Stonyhurst College ..	4·73	124	,,	Skye, Duntuilm ..	7·85	171
,,	Blackpool	4·03	141	*R. & C.*	Ullapool	5·80	160
Yorks.	Wakefield, Clarence Pk.	1·04	65	,,	Applecross Gardens ..	6·81	136
,,	Hull, Pearson Park ..	·94	55	,,	Achnashellach	10·08	147
,,	Felixkirk, Mt. St. John	1·56	86	,,	Stornoway Airfield ..	6·72	179
,,	York Museum ..	1·96	120	*Suth.*	Lairg	6·02	213
,,	Scarborough	1·34	75	,,	Loch More, Achfary ..	13·58	236
,,	Middlesbrough.. ..	2·29	138	*Caith.*	Wick Airfield	3·89	156
,,	Baldersdale, Hury Res.	3·40	136	*Shet.*	Lerwick Observatory ..	4·89	162
Nor'ld	Newcastle, Leazes Pk.	1·68	85	*Ferm.*	Crom Castle	2·85	102
,,	Bellingham, High Green	1·68	70	*Armagh*	Armagh Observatory ..	2·68	109
,,	Lilburn, Tower Gdns. ..	1·14	48	*Down*	Seaforde	2·66	97
Cumb.	Geltsdale	3·23	115	*Antrim*	Aldergrove Airfield ..	2·86	115
,,	Keswick, High Hill ..	5·24	124	,,	Ballymena, Harryville	3·77	121
,,	Ravensglass, The Grove	3·51	104	*Lon.*	Garvagh, Moneydig ..	2·87	97
Mon.	Abergavenny, Larchfield	1·39	59	,,	Londonderry, Creggan	3·99	121
Glam.	Ystaeyfera, Wern Ho ..	2·77	63	*Tyrone*	Omagh, Edenfel ..	3·63	119

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, MAY, 1947

STATIONS	PRESSURE: Mean of day M.S.L.	PRESSURE: Diff. from normal	TEMPERATURES: Absolute Max.	TEMPERATURES: Absolute Min.	TEMPERATURES: Mean values Max.	TEMPERATURES: Mean values Min.	TEMPERATURES: Mean values ½ Max. and Min.	TEMPERATURES: Mean values Diff. from normal	TEMPERATURES: Mean values Wet bulb	RELATIVE HUMIDITY	MEAN CLOUD AMOUNT	PRECIPITATION: Total	PRECIPITATION: Diff. from normal	PRECIPITATION: Days	BRIGHT SUNSHINE: Daily Mean	BRIGHT SUNSHINE: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	ins.	ins.		hrs.	%
London, Kew Observatory	1015·6	0·0	86	39	66·0	48·6	57·3	+2·6	53·4	71	7·4	1·35	−0·37	15	5·2	34
Gibraltar	1014·2	−1·9	82	47	72·5	58·7	65·6	+0·1	60·0	75	5·8	0·83	—	8	—	—
Malta	1013·9	−0·6	79	54	72·7	59·7	66·2	+0·3	61·0	59	3·9	0·02	—	2	9·9	71
St. Helena	1015·9	−2·3	80	57	68·1	59·2	63·7	+1·4	59·6	97	8·5	4·35	+1·67	19	—	—
Freetown, Sierra Leone	1011·1	+1·5	90	70	85·0	77·0	81·0	+0·5	77·1	81	7·2	4·23	−7·24	7	6·6	53
Lagos, Nigeria ..	1010·9	+0·8	92	70	87·9	72·3	80·1	−1·7	78·6	89	7·4	9·30	—	16	4·5	36
Kaduna, Nigeria ..	1008·8	—	99	63	91·2	71·1	81·1	+1·2	73·4	72	7·6	6·40	+0·63	15	8·5	67
Chileka, Nyasaland																
Salisbury, Rhodesia ..																
Cape Town ..	1018·7	+0·6	89	37	67·6	50·7	59.1	+0·2	52·6	85	6·0	3·47	−0·28	16	—	—
Germiston, South Africa	1023·0	—	73	33	66·9	42·4	54·7	—	46·2	56	1·2	0·02	—	2	9·7	90
Mauritius	1016·6	+0·3	84	61	80·1	66·7	73·4	+0·8	68.4	78	3·4	1·30	−2·62	13	8·7	78
Calcutta, Alipore Obsy.	1003·5	−0·1	103	73	97·0	80·4	88·7	+2·6	81·1	79	5·3	5·83	+0·27	9	8·1	61
Bombay	1007·2	−0·2	93	76	91·1	80·1	85·6	−0·2	77·6	77	3·8	0·00	−0·55	0	9·9	76
Madras	1006·0	+0·6	107	79	99·0	81·9	90·5	+0·7	78·9	69	3·7	0·02	−1·82	1	11·0	87
Colombo, Ceylon ..	1009·1	+0·7	89	73	88·0	77·0	82·5	−0·3	77·2	86	7·0	18·02	+7·08	21	8·5	69
Singapore	1008·6	−0·1	91	72	88·4	75·6	82·0	0·0	79·7	88	—	5·24	−1·40	14	—	—
Hongkong	1009·8	+0·7	88	69	81·9	73·6	77·7	+0·3	74·5	90	—	7·30	−4·77	16	4·2	32
Sydney, N.S.W. ..	1023·3	+4·7	82	48	69·5	54·7	62·1	+3·3	57·7	75	5·7	4·54	−0·64	10	5·9	57
Melbourne	1022·1	+2·9	76	35	67·1	48·3	57·7	+3·6	50·7	73	6·3	0·47	−1·69	7	4·8	47
Adelaide	1023·0	+2·8	81	42	70·6	51·7	61·1	+3·1	53·8	63	5·8	1·12	−1·60	12	6·5	64
Perth, W. Australia	1018·5	+0·1	80	40	67·7	51·6	59·7	−1·0	54·9	69	5·6	9·90	+4·93	16	5·7	55
Coolgardie	1020·2	+1·1	88	36	70·2	49·4	59·8	+2·1	50·8	64	3·4	1·30	−0·03	6	—	—
Brisbane	1022·1	+3.5	80	46	73·5	57·7	65·6	+1·0	60·2	71	4·7	2·18	−0·63	17	6.9	64
Hobart, Tasmania ..	1017·9	+2·6	76	37	62·0	47·6	54·8	+4·3	48·1	67	7·0	3·44	+1·54	11	4·5	46
Wellington, N.Z. ..	1020·9	+5·3	68	39	58·0	46·5	52·3	+0·9	49·1	80	6·1	2·36	−2·32	10	5·3	54
Suva, Fiji	1011·9	−0·8	87	64	81·7	71·8	76·7	+0·2	72·3	81	7·3	13·59	+3·52	20	4·7	42
Apia, Samoa ..	1010·5	−0·6	90	69	87·0	74·2	80·6	+2·2	77·2	80	5·9	10·26	+4·19	16	7·1	62
Kingston, Jamaica ..	1014·6	+1·5	91	71	88·4	73·5	80·9	+1·2	74·1	72	3·5	1.94	−2·45	6	9·1	70
Grenada, W. Indies	1013·8	+1·2	87	74	85·5	77·3	81·4	+1·7	77·4	82	7.7	0·82	−3·37	15	—	—
Toronto	1011·9	−3·0	80	30	61·5	42·9	52·2	−1·6	44·6	77	6·9	3.37	+0·58	18	5·5	37
Winnipeg	1013·3	−0·5	74	20	57·4	35·0	46·2	−5·8	36·9	81	6·6	0·85	−1·15	13	7·6	49
St. John, N.B. ..	1013·2	−0·7	72	30	57·7	41·4	49·5	+1·8	44·8	80	7·1	6·98	+3·27	20	5·8	39
Victoria, B.C. ..	1016·2	−0·5	85	36	66·1	44·8	55·5	+2·5	46·5	93	4·9	0·45	−0·68	5	9·4	62

[*To face page* 264

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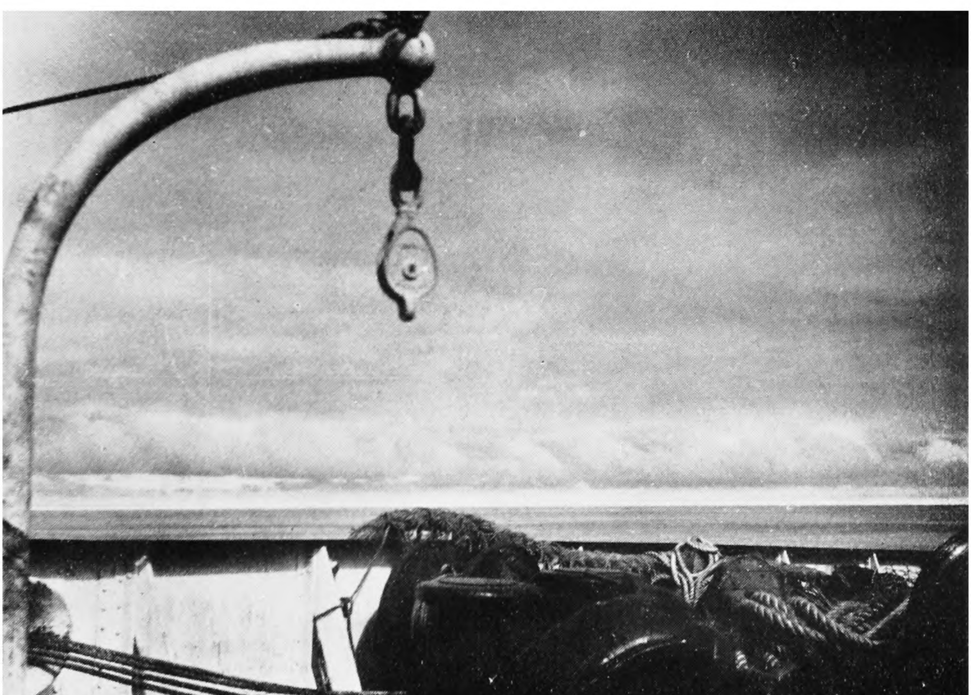
FINE DAWN OVER THE ICE FRINGE, SOUTHERN OCEAN

The water is 2,500 fathoms deep here, but the still surface mirrors the pale blue and gold light of the sky and is almost as bright. Against this background the ice looks dark and the impression is of coastal shallows.

[0230 L.T., November 26, 1946, at 57°S. 55°E.]



Reproduced by courtesy of H. H. Lamb

MOST TYPICAL CLOUD STRUCTURE IN ANTARCTIC WATERS

Cumulus penetrating a layer of stratus or stratocumulus at no great height above it. The cumulus is often concentrated along a line, as here, which may represent the vestiges of a decaying front.

[1200 L.T., January 26, 1947, at 63°S. 98°E.]

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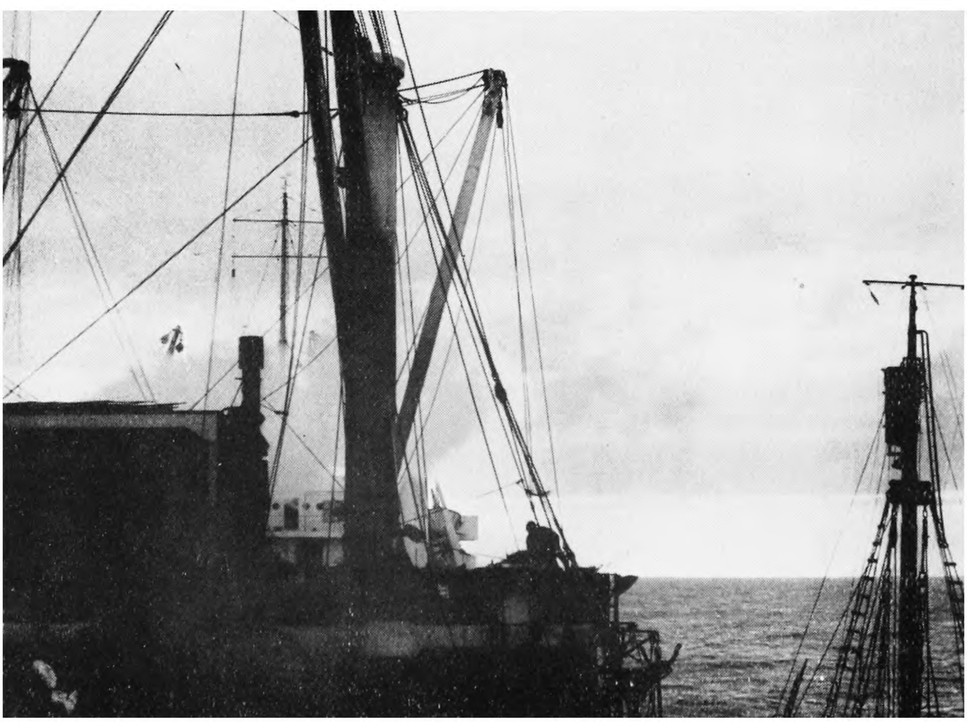
CUMULONIMBUS ANVIL CLOUD

A somewhat rare occurrence, but actually observed on about 23 per cent. of the days of the season in Antarctic waters. The top of this anvil was estimated to be at 12,000 to 15,000 ft.

[1100 L.T., April 5, 1947, at 63°S. 84°E.]



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CHARACTERISTIC EDGE LINE OF A FRONTAL CLOUD SHEET

The frontal cloud consists of altostratus, and altocumulus at about 12,000 ft., which advanced from the east leaving clear only the western horizon, towards which the picture is taken.

[1900 L.T., January 11, 1947, at 63°S. 89°E.]

M.O. 482 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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METEOROLOGICAL OFFICE LIBRARY

BY C. E. P. BROOKS, D.SC. AND G. J. EVANS, B.SC.

The Meteorological Office Library forms part of the Climatology Branch and is housed in the Meteorological Office building at Headstone Drive, Harrow. It has grown steadily since its formation in 1870, and now includes about 35,000 volumes and 10,500 pamphlets in addition to manuscripts, photographs and lantern slides. The contents are not limited to pure meteorology; the aim of successive librarians has always been to collect as much as possible of all published meteorological literature and in addition a representative selection of books on subjects such as physics, mathematics, geography, oceanography, etc., which are likely to be required by the scientific staff in the course of their work. Books and periodicals are obtained in a variety of ways of which the most important is the exchange of publications between the Meteorological Office and other scientific institutions. Some 300 such exchanges are in existence, the great majority being international in character. Book lists, periodicals and abstracts are scanned for references to new books and papers of interest, and if no exchange is possible these are obtained either by a request for an author's copy or by purchase. Many books or reprints are presented directly to the office by the authors themselves.

The Library has a very complete system of cataloguing. All books, reprints and all articles of interest in periodicals, even if no reprint is received, are entered in at least two catalogues:

(1) The "Author Catalogue", in which each entry is on a separate card, arranged alphabetically under authors, and for each author under the first significant word of the title. The number of cards is now approximately 58,000.

(2) The " Subject Catalogue " is on foolscap sheets in loose-leaf covers, classified under subjects and arranged in chronological order. From about 1914 until 1935 the subject classification used was that of the Royal Society's " International Catalogue of Scientific Literature ".

With the advance of meteorology, this classification became obsolete and on January 1, 1936, the Library changed to the Universal Decimal Classification (see below).

Besides these two main catalogues, there are various subsidiary ones. The largest is the " Climatic Index ", in which all publications dealing with any aspect of the climate of a town or country are entered on foolscap sheets in a loose-leaf catalogue, arranged geographically under continent, country, division of country, down to the larger towns. By consulting this catalogue anyone writing an account of the climate of a district can find references to all the literature together in one place.

The " Climatic Index " includes mainly works on the classical descriptive aspect of climate based on monthly averages and extremes. In recent years the synoptic aspect has become important, and a second catalogue has been commenced—"A Regional Bibliography of Synoptic Climatology". This is subdivided geographically, thus assembling together the forecasting problems common to the area concerned. It is of inestimable value to the synoptic meteorologist requiring information concerning an unfamiliar part of the world. There is also a " Bibliography of Upper Air Data " arranged on similar lines but as a card catalogue. It contains details of upper air temperature, pressure, humidity and winds.

The above-mentioned organization is designed chiefly to facilitate the work of individuals attending the library in person. To assist those members of staff unable to use these facilities, the library prepares a bibliography of literature received each month. This monthly *Meteorological Bibliography* forms the basis for the six-monthly bibliography issued by the Royal Meteorological Society. It is supplied to the Heads of Branches in the numbers requested by them, and it is also sent to the main foreign meteorological services. It contains titles and references of all books and papers received during the month and is classified under subjects and numbered. Anyone wishing to borrow any paper noted need only quote the year and month of the bibliography and the number of the entry.

The library also maintains a large selection of photographs and lantern slides which can be borrowed free of charge by members of staff requiring them for lecture purposes. A " Dictionary " catalogue of the lantern slide collection may be borrowed to assist in the choice of slides. The photographic collection has recently been subdivided into subjects, using the Universal Decimal Classification as the basis for the subdivisions.

The Universal Decimal Classification (U.D.C.) which is now the basis of our classifications is a development of a " decimal classification " devised by Melvil Dewey in 1873. The guiding principle is that all knowledge forms one unit, which is divided into ten main classes numbered 0·0, 0·1, . . . 0·9. Each of these is divided in turn into ten sections, giving for example the subclasses 0·10, 0·11, etc. These are further subdivided until the requisite fineness of classification is attained. Natural sciences and mathematics form the class 0·5; this is divided into nine different sciences, of which geophysics forms the division 0·55. Meteorology as a branch of geophysics has the number 0·5515.

On this theory every number begins with 0, and this figure with the decimal point can be taken for granted, but for convenience in reading long series of figures the practice has been adopted of using the point not as a decimal point but as a punctuation to divide the figures into groups, generally of three figures. The number for Meteorology in this practice is 551.5.

The subdivisions of 551.5 were examined by a Commission of the International Meteorological Organization, which in 1935 recommended an extensive revision. The details can be found in the *Quarterly Journal of the Royal Meteorological Society, London*, **62**, 1936, p. 134. Here we may quote the main subdivisions.

551.50	Practical meteorology (methods, data, forecasts).
1	Structure, mechanics and thermodynamics of the atmosphere in general.
2	Radiation and temperature.
4	Atmospheric pressure.
5	Wind.
7	Aqueous vapour and hydrometeors.
8	Climatology.
9	Various phenomena and influences.

This classification is limited strictly to meteorology, making no provision for the many works which deal with the relations between meteorology and other branches of knowledge, such as agriculture. These borderline cases are a difficulty in any scheme of classification. Let us take for example a paper by R. J. Kalamkar, " Micro-climatology in relation to crops ". A meteorologist would naturally wish to include this under meteorology, an agriculturist under agriculture. In the Universal Decimal Classification the problem is handled in a very simple and ingenious way. The number for microclimatology is 551.584, that for crops is 633. If we connect these two numbers by a symbol meaning " relationship ", we have a number for microclimatology in relation to crops. The colon : has been assigned for this purpose, giving the number 551.584: 633. The order of the two related series is reversible and a general library would also include the entry 633: 551.584.

In this way all works on agricultural meteorology are brought together for consultation; the same applies to other subjects. Thus there have been built up bibliographies of meteorology in relation to air transport, civil engineering, water engineering, medicine and a variety of other associated sciences.

In the twelve years which have elapsed since this classification for 551.5 was designed, further advances have occurred, especially in the application of radio and radar to meteorology, and at Toronto last September the Commission of Bibliography and Publications proposed a number of modifications, which are now awaiting acceptance.

In order to bridge as far as possible the break caused by the change of classification in 1936, we prepared "A selected bibliography of meteorological literature, 1901–1935 ", which aimed at giving a list, classified according to the U.D.C., of the more important papers published during those years. This bibliography, which runs to 151 foolscap pages, has proved of great value as a source of rapid reference; copies are available for loan.

The library can assist the staff of the Meteorological Office in five main ways:—

1. By the issue on loan of specific publications. When these are not available in the Meteorological Office Library every effort is made to borrow them from some other library with which we have contacts, such as the Science Library or National Central Library. Members of the staff are asked to take care to give adequate references when requesting publications. Much trouble can be caused to the staffs of the libraries concerned by insufficient or incorrect references. The author, title of work (if known), title of periodical, place of publication, volume number, year and pages of references, should be given whenever possible.

2. By the issue on loan of publications containing specific information or by the provision of bibliographies of special subjects. Here again precision in stating requirements may save a great deal of time and trouble.

3. By keeping track of the special interests of members of the staff engaged on research and calling their attention to publications likely to be of use to them.

4. By the circulation of the *Meteorological Bibliography* referred to above.

5. By the issue on loan of lantern slides, films and photographs. Borrowers should state the full scope of any proposed lecture or display so that in the event of any slide or photograph being out on loan to another borrower, a suitable substitute can be selected from stock. The stock of photographs and lantern slides held is extensive and covers a very wide field. The sizes of the photographs vary considerably but many are suitable for use with an epidiascope.

If a publication is already on loan, the name of the intending borrower is added to a waiting list for the publication. Publications are issued on loan in the first instance for a period of 14 days to staff at home and of one month to staff overseas. Applications for an extension of loan must, in the case of staff in this country, be made after 10 days. Failure to do this may prejudice goodwill arrangements between other libraries and ourselves. Extensions will be arranged providing no waiting list has accrued in the meantime. In general it is expected that the one month from date of receipt to date of return allowed to overseas staff will be sufficient to meet their needs.

The Library does not usually make abstracts of meteorological literature, the general opinion being that abstracts prepared, so to speak, in the void are of comparatively little value, and that it is more useful to make surveys of the literature when required for some special purpose, and devote them to that purpose.

The Library services to other institutions and to scientists not on the staff, are naturally more limited. Loans of books are only made in special circumstances, but a great many technical inquiries are answered. Lantern slides may be borrowed at a charge of 4*s*. for each 20 slides, or part of 20, plus postage. Intending borrowers must state the date by which slides are required.

The purpose of the Library is to be of the utmost assistance to all members of the Meteorological Office, by acting not only as a repository of books, but also as an information bureau. If it is to serve this purpose fully, the co-operation of other members of the staff in making known their needs is necessary, and is always welcomed.

FUNDAMENTAL PROBLEMS IN METEOROLOGY

COMPILED BY THE METEOROLOGICAL RESEARCH COMMITTEE

The Meteorological Research Committee has recently compiled a list of the problems which, in the view of members, are fundamental problems in the science of meteorology today. Some of these problems are suitable for attack by independent workers and steps have accordingly been taken to distribute the list to research workers in the Universities and University Colleges in this country. It is hoped that this action will stimulate interest in meteorological research.

The full list of problems is given below.

Dynamical or mathematical problems

1. Investigation of the formation, persistence and movement of anticyclones and wedges.

2. "Further outlooks" deduced from pressure distribution over northern hemisphere.

   Mathematical examination is needed for these two problems in addition to the empirical study in the Meteorological Office.

3. Large scale air movements in the stratosphere and the extension of dynamical treatment to the stratosphere.

   The north or south movement of air in the stratosphere is of great scientific interest in meteorology.

4. Determination of the rate of travel of waves in the atmosphere.

5. Factors governing the travel of depressions.

6. Energy transformations in relation to the development of pressure systems.

7. Investigation of convergence and divergence and geostrophic departure of the wind.

8. Application of statistical methods to vector quantities.

9. Equations of motion.—(*a*) Solution of the equations allowing for the variation of the Coriolis force—extension of Grimes' solution*. See also classic paper by Guldberg and Möhn†.

(*b*) Solution of equations for accelerated motion with constant uniform pressure field and its application to forecasting wind.

(*c*) Solution of equations for accelerated motion by expressing the pressure variation as exponential or circular functions (Fourier series) of the time.

(*d*) Investigation as to the reality of the oscillatory motion arising from geostrophic acceleration. See a paper by Hesselberg on atmospheric oscillations‡.

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*GRIMES, A.; The movement of air across the equator. *Mem. Malayan met. Serv., Singapore.* No. 2, 1937.

†GULDBERG, C. M. AND MÖHN, M.; Studies on the movements of the atmosphere. The mechanics of the earth's atmosphere. 3rd collection". *Smithson. misc. Coll., Washington, D.C.*, **51**, No. 4, 1910, p. 122.

‡HESSELBERG, TH.; Uber oszillatorische Bewungen der Luft. *Ann. Hydrogr., Berlin*, **43**, 1915, p. 311.

(*e*) The effect of friction; decay of atmospheric oscillations (see the paper by Hesselberg, in which it is assumed that the friction is proportional to the velocity); further investigation of the solution for unsteady motion and its extension to include initial departures from appropriate solution for steady state.

(*f*) Investigation of the effect of the movement of air across the isobars on the pressure distribution.

Physical problems

10. The distribution of temperature in the stratosphere.

11. Possible use of water-vapour content to identify air masses in the stratosphere.

12. Possible use of ozone content to identify air masses in the stratosphere.

13. Structure of fronts in the upper troposphere and stratosphere as indicated by temperature, humidity, ozone and winds.

14. Reliable climatological data for upper air from 0 to 25 Km. for each month and all possible parts of the world.

To include temperature, pressure (density), humidity, winds, height of tropopause and giving both average values and variations from day to day and year to year.

Much of this could be compiled now and is badly wanted. Data for less explored parts of the world and humidities of the upper air could be added as they become available. Some work is in hand in the Meteorological Office.

15. Radiation in the atmosphere. (As programme for Gassiot Committee)

(*a*) Measurement of absorption coefficient of atmospheric gases under atmospheric conditions.

(*b*) Theoretical discussion of absorption and radiation of heat by the atmosphere.

(*c*) Calculation of equilibrium temperature for any height, at any latitude and any season including diurnal variation of temperature.

(*d*) Rate at which air masses at different levels would acquire new temperature if transported to different latitudes.

(*e*) Measurement of water vapour at all heights, seasons and latitudes.

(*f*) Measurement of ozone at all heights, seasons and latitudes.

16. Physics of condensation and sublimation of water vapour in the atmosphere.

17. Formation of rain and snow from cloud.

18. Latent heat of vaporization of supercooled water.

Apparently no data available.

19. Factors affecting coalescence of water drops having diameters in the range 1μ to 7 mm.

Affects development of fog, cloud and rain.

20. Factors affecting the change of state from supercooled water in droplet form to ice.

Affects development of clouds and ice accretion on aircraft.

21. Nature of sublimation nuclei.

22. Radiation from small particles floating in the atmosphere and the consequential effects of the temperature of the particles being different from that of the ambient atmosphere.

Effects of radiation on the lapse rate and stability in a cloud layer.

23. The transfer of air downwards by the drag of a falling raindrop.

The mixing resulting from this process may affect the structure and composition of the lower atmosphere.

24. The fundamental theory of turbulence and its relation to the distribution of eddy velocities in space and time.

The theory of atmospheric diffusion and turbulence has been largely built up on R_ξ the correlation of the eddy velocity of the same particle at various intervals of time ξ. This correlation is not directly observable, nor of itself important. In view of the conditions of continuity and conservation of momentum and vorticity, it seems probable that some relation must exist between R_ξ and the correlation of wind at one point at various intervals of time and at one instant at various points in space. Knowledge of such relations would enable studies in diffusion to be directly linked with wind observations and studies of " bumpiness ". It would also lead to an understanding of the diffusion of water vapour by eddies too large to be observed except in wind variations.

25. The balance between radiation, diffusion and turbulence in the lowest layers of the atmosphere.

(*a*) With reference to fog and dew.

(*b*) With reference to air flow from water surface to land surface and *vice versa*. Kew already have in hand the simultaneous investigation of the diffusion of heat, water vapour and momentum and the flux of radiation. Similar work is also in hand at Rye and Cambridge.

26. Physics of thunderstorms.

Forecasting problems

27. Investigation of factors which govern the formation and dispersal of low stratus cloud.

28. Relation between horizontal temperature gradient and large-scale instability.

Treatment of thunderstorm development to include horizontal temperature gradient as well as vertical temperature gradient.

Instrumental problems

29. Development of a method of measuring air temperatures on high-speed (jet) aircraft which will avoid the application of large airspeed corrections.

30. Design of a new method of humidity measurement in radio-sondes at all heights.

31. Design of a relatively cheap instrument to measure atmospheric ozone.

ZONAL DISTRIBUTION OF HUMIDITY IN THE EARTH'S ATMOSPHERE

BY G. A. TUNNELL, B.SC.

In a recent issue of the Hungarian publication *Idojárás*, Prof. J. Száva-Kováts* has given the results of an investigation into the variations of average water content of the earth's atmosphere with variations in latitude. A variety of data has been used. Prof. Száva-Kováts has given averages of relative humidity and vapour pressure for zones of 5-degree intervals of latitude for land areas and sea areas. A land area or sea area is defined as one which is more than 50 per cent. respectively either land or sea. In addition, the total content of atmospheric moisture has been determined by means of Süring's formula:—

$$a_z = a_0 \; 10^{-z(1+z/20)/6}$$

where a_z is the vapour pressure at a height of z Km. above the earth's surface and a_0 is a constant. The stratosphere has been neglected. An examination of upper air data will show that this formula for averages of vapour pressure is only approximately true and certainly it is a great assumption to apply it to the whole world. However assumptions like this have to be made to get the order of magnitude of the phenomena. Table I gives the results of these calculations.

The second of Prof. Száva-Kováts' tables is given in Table II and it can be seen that the relative-humidity and vapour-pressure data can be used to divide the earth into climatic zones.

Zonal distribution of vapour pressure

(1) Tropical belt in which vapour pressure is higher throughout the year over continents than over the sea.

(2) Two subtropical belts of moderate vapour pressure where throughout the year continental air has less vapour than the sea air, especially in winter.

(3) Two belts of moderate width in which vapour content is small and where the vapour content of continental air is considerably smaller in winter and somewhat bigger in summer than that of the air over the open sea.

(4) Two polar regions of low vapour content where continental and sea air do not seem to differ.

Zonal distribution of relative humidity

(1) Tropical, humid zone where little difference can be found between the humidity of continental and sea air.

(2) Two dry subtropical belts where continental air is much drier than oceanic air during the whole year.

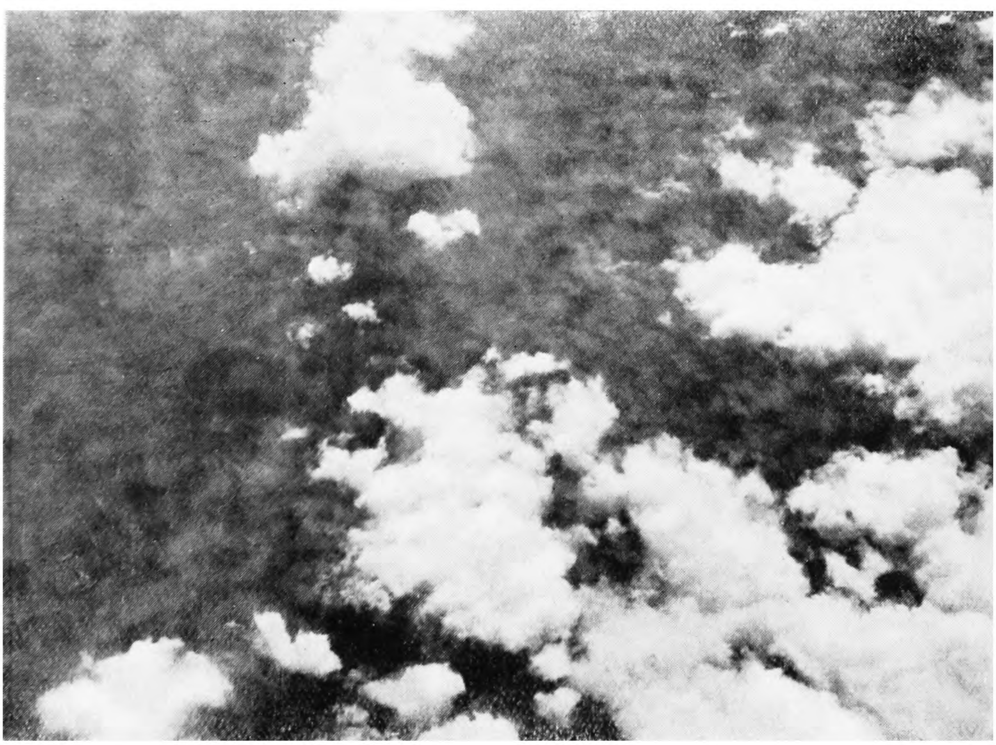
(3) Two humid territories in temperate latitudes inside which there are small differences between continental and oceanic conditions in winter. The continental section of this zone joins with the subtropical zone in summer.

*SZÁVA-KOVÁTS, J. ; A légnedvesség övenkénti eloszlása a Földön. *Időjárás, Budapest*, **51**, 1947, p. 9.

Photograph by R.A.F.

APPROACH OF A WARM FRONT, 1425, JUNE 27, 1945

This photograph, taken from 15,000 ft. looking westwards at 50°5′N. 10°30′W. off south-west Eire shows the preliminary stages of a warm front above lenticular strato-cumulus.



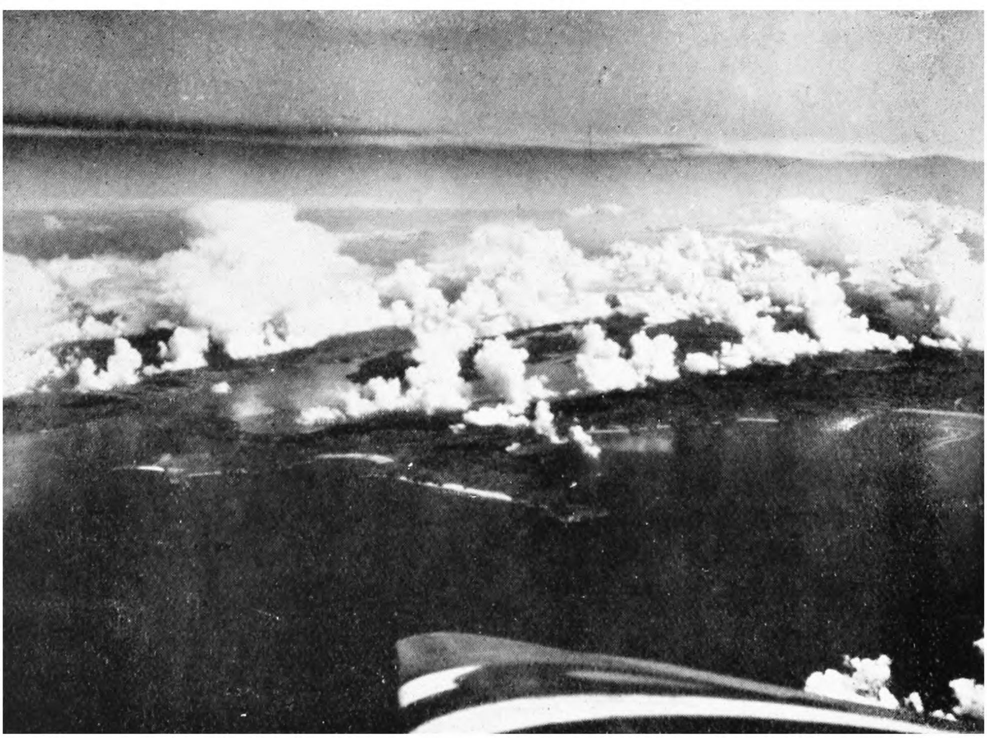
Photograph by R.A.F.

CIRROCUMULUS OVER COBLENZ, 1240, SEPTEMBER 9, 1943

This photograph, taken from 29,000 ft., is a close-up of clouds usually seen from the ground as very tiny dots high in the sky.

Photograph by R.A.F.

FAIR-WEATHER CUMULUS OVER THE ENGLISH CHANNEL, 1605, AUGUST 28, 1944
This photograph, taken from 29,000 ft. looking north-eastwards along the coast of Kent, shows cumulus in fairly regular rows casting shadows on the sea below. The wind at 2,000–3,000 ft. was westerly about 20 kt.



Photograph by R.A.F.

CUMULUS AND CUMULONIMBUS ON AUGUST 20, 1944, AT 1305
This photograph, taken from 29,000 ft. looking east-north-east towards Brest when the surface wind was almost calm, shows reflections of the cumulus clouds in the sea and the control of growth of cumulus on a fine day by sea breezes. The bank of cloud in the distance is associated with a quasi-stationary front over the southern coast of England.

(4) In polar regions conditions are wetter in summer and drier in winter with little difference between continental and sea surfaces.

It is seen that these divisions fit into the general climatic divisions of the earth which are decided ultimately by the movement of the sun and the dynamics of the atmosphere.

TABLE I—AVERAGE AMOUNT OF WATER VAPOUR IN THE ATMOSPHERE

Latitude	Surface Area	Total amount of water present		Average amount of water present	
		January	July	January	July
	10^3 Km^2	Km.^{3}	Km.^{3}	Kg./m.^{2}	Kg./m.^{2}
90—85°N.	971	0·8	11·4	0·71	9·86
85—80°N.	2,902	3·2	30·2	1·10	10·52
80—75°N.	4,814	7·1	55·5	1·49	11·63
75—70°N.	6,691	13·4	90·8	2·02	13·60
70—65°N.	8,511	22·4	137·2	2·66	16·33
65—60°N.	10,270	35·9	191·4	3·51	18·72
60—55°N.	11,953	55·9	248·8	4·69	20·83
55—50°N.	13,542	84·2	308·8	6·35	22·81
50—45°N.	15,026	123·0	378·3	8·04	25·17
45—40°N.	16,400	179·4	466·2	10·85	29·42
40—35°N.	17,647	257·6	564·4	14·90	31·99
35—30°N.	18,761	349·0	644·0	18·91	34·30
30—25°N.	19,730	441·4	715·8	22·70	36·35
25—20°N.	20,551	560·7	796·2	27·62	38·83
20—15°N.	21,214	711·0	878·9	33·43	41·60
15—10°N.	21,716	846·5	955·5	39·01	44·23
10— 5°N.	22,053	944·6	1000·8	42·83	45·58
5— 0°N.	22,224	995·6	1012·7	44·79	45·87
0— 5°S.	22,224	1010·7	988·0	45·63	44·77
5—10°S.	22,053	993·6	938·5	45·34	42·43
10—15°S.	21,716	940·5	831·0	43·51	40·30
15—20°S.	21,214	844·5	676·0	40·03	31·50
20—25°S.	20,551	743·1	549·9	36·45	26·63
25—30°S.	19,730	656·0	474·4	33·61	23·97
30—35°S.	18,761	564·4	403·9	30·19	21·50
35—40°S.	17,647	462·6	327·6	26·22	18·70
40—45°S.	16,400	345·2	253·4	21·18	15·92
45—50°S.	15,026	249·5	193·4	16·22	13·70
50—55°S.	13,542	182·9	149·6	13·58	11·84
55—60°S.	11,953	147·6	119·0	12·50	9·94
60—65°S.	10,270	109·7	81·5	10·85	7·91
65—70°S.	8,511	77·3	40·5	9·22	4·75
70—75°S.	6,691	54·7	16·7	8·32	2·51
75—80°S.	4,814	35·4	6·4	7·45	1·35
80—85°S.	2,902	20·0	2·0	6·95	0·70
85—90°S.	971	7·7	0·7	6·60	0·57
	509,950†	13,077·1†	14,539·4†	25·64‡	28·51‡

These data are for the atmosphere below the stratosphere.

† Total. ‡ Average.

It is of interest to examine Table II more closely. The zone extending 10°N.–10°S. is the zone of equatorial rains in which there is no geostrophic wind control. Further north to 22½°N. and further south to 22½°S. are zones with one cold season, two hot seasons and a distinct wet season. The uneven distribution of land and sea makes these zones unsymmetrical. Over land and sea the summer (July) vapour pressure in the northern zone is higher than the summer (January) vapour pressure in the southern zone, probably because the

TABLE II—ZONAL DISTRIBUTION OF HUMIDITY OVER CONTINENTAL AND SEA SURFACES

	Latitude	Vapour Pressure				Relative Humidity			
		January		July		January		July	
		Continental	Sea	Continental	Sea	Continental	Sea	Continental	Sea
		mm.	mm.	mm.	mm.	%	%	%	%
Polar	90—85°N.	—	0·2	—	2·0	—	80·1	—	85·9
	85—80°N.	0·1	0·4	2·3	4·4	80·0	80·3	82·0	85·5
	80—75°N.	0·3	0·6	5·0	4·9	80·1	80·7	80·2	84·2
	75—70°N.	0·4	1·0	5·9	5·7	80·2	81·7	77·0	82·4
Temperate	70—65°N.	0·6	1·7	7·1	6·7	80·4	82·8	75·0	82·4
	65—60°N.	0·9	2·3	8·4	7·8	80·7	83·6	73·8	83·7
	60—55°N.	1·1	2·9	9·7	8·6	81.6	84·5	72·5	84·9
	55—50°N.	1·4	3·9	10·8	9·3	81·8	84·2	70·1	85·5
	50—45°N.	1·8	5·1	11·9	10·5	78·3	82·7	65·7	84·3
	45—40°N.	2·6	6·4	12·8	12·9	72·2	80·3	61·4	81·6
Subtropical	40—35°N.	3·8	8·2	13·6	15·4	68·1	78·1	60·2	78·4
	35—30°N.	5·3	10·3	14·5	16·6	66·5	76·7	61·4	75·5
	30—25°N.	6·7	12·1	15·5	17·3	65·4	76·4	63·5	74·7
	25—20°N.	8·3	14·2	16·7	18·3	64·6	76·7	66·4	76·0
	20—15°N.	11·3	16·7	18·5	19·3	64·3	77·6	69·2	78·6
	15—10°N.	15·3	18·6	20·5	20·0	65·8	79·2	76·2	82·5
Equatorial	10— 5°N.	19·0	19·8	21·5	20·3	72·8	81·9	83·5	84·8
	5— 0°N.	21·0	20·4	21·6	20·6	81·7	84·5	85·0	85·0
	0— 5°S.	21·6	20·5	20·8	20·2	85·1	85·2	83·5	84·2
	5—10°S.	21·3	20·4	18·8	19·2	83·4	85·2	79·1	82·3
Subtropical	10—15°S.	19·6	19·9	16·0	17·6	78·8	84·6	72·6	80·1
	15—20°S.	16·6	18·7	12·4	14·9	71·1	82·9	66·8	78·5
	20—25°S.	13·4	17·2	9·0	12·8	64·3	80·2	63·6	77·9
	25—30°S.	12·5	15·8	7·3	11·5	61·6	78·0	63·9	78·0
	30—35°S.	11·8	13·9	6·8	9·9	62·3	77·1	68·3	78·9
	35—40°S.	10·8	11·8	6·0	8·1	65·1	77·8	73·3	80·7
Temperate	40—45°S.	9·5	9·3	5·1	6·7	68·5	80·6	77·2	82·4
	45—50°S.	7·9	7·0	4·5	5·5	72·9	83·1	80·8	83·7
	50—55°S.	6·6	5·8	4·1	4·6	77·0	84·1	82·8	84·5
	55—60°S.	—	5·2	—	4·0	—	84·9	—	85.0
	60—65°S.	—	4·5	—	3·1	—	85·1	—	84·2
	65—70°S.	3·9	3·7	1·6	1·9	82·7	84·0	81·7	82·4
Polar	70—75°S.	3·4	3·3	0·8	1·0	81·9	82·4	80·3	80·7
	75—80°S.	3·0	1·5	0·4	0·3	81·3	81·8	79·4	80·0
	80—85°S.	2·8	—	0·2	—	80·8	—	78·7	—
	85—90°S.	2·7	—	0·2	—	80·6	—	78·2	—

The horizontal lines dividing the zones are an approximate average division.

more extensive monsoon climates bring northwards greater amounts of moisture. The winter vapour pressures are slightly higher over land in the south and lower over the sea. These are the zones of SE. trades, NE. trades and monsoons. However, there is far more maritime influence in the southern zone, and the impression is given that sea temperatures control the southern zone while the great land heat controls the northern one.

From 22½° to 40°N. and S. are zones which contain much of the world's desert areas. Again there is the smoothing maritime influence in the southern hemisphere. The vapour pressure in the north is lower over land than over sea. The difference is greater in winter than in summer because of the great summer evaporation due to the high temperatures. However, these high temperatures cause a fall in relative humidity. The effects in the southern hemisphere are similar but less in magnitude.

Further polewards from 40°N. or S. are the temperate regions of depressions in which land and sea areas are similar, except in continental areas very far from the sea in the northern hemisphere where the high temperature in summer lowers the relative humidity and raises the vapour pressure. The remaining zones are the polar areas whose atmospheric water content is controlled by seasonal temperatures.

Prof. Száva-Kováts has examined humidity gradients and shown that discontinuities in gradient occur at the edges of climatic zones. This gives good backing to the use of humidity data in identifying air masses. If an air mass moves from one climatic zone to another it will take the characteristics of its first zone to the second. This investigation has shown that it is sound for humidity characteristics to be used in identifying the sources of air masses.

Finally the balance between evaporation and rainfall has been considered, with the resulting movement of water vapour which must take place to make up deficits in some places and surpluses in others.

According to these estimates the average water-vapour content of the earth's atmosphere is 13,808 $Km.^3$ of liquid water while the total annual rainfall as well as annual evaporation are each 511,080 $Km.^3$ of liquid water. Thus average rainfall and evaporation are 37 times the average water content of the earth's atmosphere.

Table III (Prof. Száva-Kováts' Table IV) shows the variations of the water economy of each zone from the average for the earth and gives the deficits and surpluses of the zones. It is doubtful whether in this table the evaporation data can be very reliable especially over areas like the Sahara desert; because so long as land surfaces can supply moisture freely then estimates of evaporation become feasible; but when areas are not giving moisture freely then their supplies of atmospheric moisture are complex. These difficult surfaces are spread over great areas in all continents.

The following conclusions are given by the paper concerning the water economy of the main climatic zones.

(1) There is little rainfall or evaporation in polar regions.

(2) Temperate regions show a great excess of rainfall over evaporation and are transition regions between the polar lack and subtropical surplus of evaporation.

(3) Subtropical zones are characterised by a great lack of rainfall and surplus of evaporation.

(4) The equatorial zone is marked by its rainfall surplus and lack of evaporation.

The movements of moisture given in the table are an expression of average conditions. The movement of water vapour to the equatorial regions is not true, for example, during the wet season in the African Sudan. At this time of the year moisture most definitely moves away from equatorial regions

TABLE III—WATER CIRCULATION OF THE ATMOSPHERE

Latitude	$\frac{R}{v}-37$	$\frac{E}{v}-37$	$\left(\frac{R}{v}-37\right)v$	$\left(\frac{E}{v}-37\right)v$	R	E	Balance and movement
				10^3 *cubic kilometres*			
90—80°N.	−17·7	−30·9	− ·40	− ·70	·44	·14	=+ 1.87
80—70°N.	−10·0	−28·8	− ·85	− 2·40	2.25	·68	+20·23
70—60°N.	+ 3.7	−20·9	+ ·73	− 4·04	7·89	3·11	
60—50°N.	+18·8	+ 0·6	+ 6.56	+ ·21	19·47	13·12	=+18·36
50—40°N.	+13·1	+ 0·6	+ 7·52	+ ·34	28·74	21·51	
40—30°N.	− 1·7	+ 1.6	− 1·55	+ 1·45	32·23	35·04	
30—20°N.	−10·9	+ 2·2	−13·77	+ 2·76	32.73	49·24	= −33·83
20—10°N.	− 8.3	+ 0·2	−14·07	+ ·33	48·67	63·18	
10— 0°N.	+ 4·4	− 5·8	+ 8·76	−11·46	81·89	61·69	=+20·20 { +13·60
0—10°S.	− 4·6	− 1·8	− 9·19	− 3·53	63·53	69·16	+ 6·60
10—20°S.	− 6·8	+ 2·9	−11·22	+ 4·77	49·68	65·61	
20—30°S.	− 8·4	+ 5·8	−10·26	+ 7·02	34·57	51·95	= −46·63
30—40°S.	+ 1·6	+10·3	+ 1·46	+ 9·05	33·99	41·67	
40—50°S.	+35·9	+10·2	+18·71	+ 5·31	37·98	24·62	
50—60°S.	+54·1	−10·4	+16·21	− 3·11	27·29	7·98	=+39·19
60—70°S.	+19·1	−23·0	+ 2·96	− 3·55	8·68	2·16	+40·03
70—80°S.	−19·6	−33·6	− 1.11	− 1·90	·98	·19	=+ 0·84
80—90°S.	−32·3	−35·7	− ·49	− ·54	·07	·02	

E = Average annual evaporation of liquid water over whole zone.
R = Average annual rainfall received by the whole zone.
v = Average water-vapour content of atmosphere over whole zone.

If E_0, R_0, v_0 are average conditions for the earth, then

$$R_0=E_0=37v_0$$

$$\text{or} \quad R_0/v_0=E_0/v_0=37$$

Therefore R/v—37 and E/v—37 are the differences from the average earth conditions of each zone where E, R, v are the values for the particular zone. The last column (Balance and movement) gives the excess of rainfall over evaporation, a negative sign implying an excess of evaporation over rainfall. More details of the annual rainfall over the earth for 5-degree zones of latitude can be found in a paper by W. Meinardus.*

to subtropical regions. It is very necessary in this case not to particularise from average figures because the equatorial region is the richest in moisture of any zone, and any exchange of air mass at the surface must lead to a loss of moisture by the equatorial zone. The belt of tropical rains has a seasonal movement and it must be true that there is always a flow of moisture into this belt.

ERRATUM

August, 1947, PAGE 179, line 26; *for* " at 1130 " *read* " at 1115 ".

*MEINARDUS, W.; Die Niederschlagsverteilung auf der Erde. *Met. Z., Braunschweig*, **51**, 1934, p. 345.

METEOROLOGICAL RESEARCH COMMITTEE

The 51st meeting of the Meteorological Research Committee was held on October 30, 1947.

Following the circulation to Universities of the list of fundamental problems (see p. 269) a request had been received by the Committee for a member to give a talk at one of the Universities on the mathematical problems of meteorology. This was arranged.

The papers considered by the Committee included one, by R. J. Murgatroyd, on some anomalous sound-reception experiments carried out during the war. The work described in this paper marks a big advance on other observations of this type, partly due to the fact that the explosions were deliberately organised for this purpose.

Another paper, by Dr. A. H. R. Goldie, dealt with the estimated distribution of temperature, pressure and wind up to 45 Km. on the basis of the most recent observations, and there was also a discussion of the diurnal variation of upper air temperatures as measured by the Kew Mark I radio-sonde following a report by J. Piegza.

Messrs. J. S. Sawyer and D. Dewar contributed a paper giving seasonal charts of the mean height of the tropopause over the earth. There were also two papers by F. Pasquill dealing with the measurements of evaporation from a field by means of measurement of the gradient of humidity in the lowest few feet of the atmosphere and computation of the upward flux of water vapour.

METEOROLOGICAL OFFICE DISCUSSIONS

The Meteorological Office held the opening Monday evening discussion of the present session in the lecture theatre of the Science Museum on November 17, 1947. Mr. R. H. Clements opened the discussion, which dealt with the paper by J. Bjerknes and J. Holmboe entited " On the theory of cyclones ", published in the first number of the *Journal of Meteorology**.

Mr. Clements explained that in this paper the tendency equation was invoked to demonstrate that large-scale pressure variations at the surface depended on the integral of the horizontal divergence. Choosing first a simplified trough pattern, the longitudinal and transversal divergence terms were estimated qualitatively using the concept of isobaric channel flow, resulting in the requirement of a mean relative zonal wind greater than a certain critical value for eastward transport of the trough. The application to baroclinic westerly currents was given.

The main portion of the paper was devoted to suggesting a mechanism for cyclogenesis postulating vertical motion as the trigger factor. The tendency equation was used to define two limiting cases between which actual cases were likely to lie, and by choosing a reasonable in-between case an explanation was offered for the formation and intensification of a wave disturbance in a baroclinic westerly current with a low level of non-divergence. Tentative explanations were also put forward for the seasonal cycle, the damping out of waves in the stratosphere and the development of tropical storms.

**J. Met., Milton Mass.* 1, 1944, p.1.

Closed systems in the lower levels were then considered and it was demonstrated how closed cyclonic isobars tended to pile up air to the east and oppose eastward motion. The general cyclone pattern with closed isobars below and sinusoidal isobars above was then discussed leading to an explanation of the life history of a cyclone.

The Director then threw the meeting open to discussion asking whether the work in the paper had been tested in the synoptic field. Dr. Sutcliffe, whilst recognising that the paper was an important contribution and, in particular, noteworthy for the absence of any mention of ideal fronts, nevertheless considered that the treatment was too idealised. Mr. Sawyer was highly sceptical of qualitative treatment generally, saying that in reaching conclusions borne out by facts one was not entitled to assume that the methods used were therefore correct. Mr. Matthewman subsequently put this objection in more concrete form by pointing out that although the authors had dealt with the divergence of gradient winds the divergence of non-gradient winds brought other terms into the picture, and these terms were potentially important. Mr. Bannon was dissatisfied with the scant respect the paper showed for vertical motion. Mr. Miles gave a brief account of some work that had been carried out in America on the slopes of the axes of tropical storms as far as it touched on the paper under discussion.

In the course of the discussion and in his closing remarks, Mr. Clements said he could find cases in which the critical speed was exceeded with no motion of the trough; that he was dissatisfied with the whole concept of isobaric channel flows, in particular showing that the assumption of zero transversal divergence in some cases meant that the longitudinal divergence was also zero. He was also in some difficulty about the limits set down in the cyclogenesis section of the paper as they did not allow upward motion with falling pressure and *vice versa*.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society, held at 49 Cromwell Road, on November 19, with Prof. G. M. B. Dobson, President, in the Chair, the following papers were read:—

N. P. Sellick—Note on the dynamics of development.

It had been hoped that Mr. Sellick, Director of the Rhodesian Meteorological Service, who had been visiting this country on his way back from meetings in Canada and the United States, would have been present to read his "Note on the dynamics of development" but unfortunately he had been unable to extend his stay sufficiently. In his absence Dr. Sutcliffe gave a brief account of the paper.

The author had dealt with a hypothetical case in which a horizontal slice of air rotating with constant angular velocity was, by the imposition of a uniform field of convergence, constrained to increase its rate of rotation to another steady value. An average convergence of 10^{-5} sec.$^{-1}$ was required to change a rotation of 5×10^{-6} to $7{\cdot}41 \quad 10^{-6}$ sec.$^{-1}$ in six hours in the average latitude chosen (where $2\omega \sin \phi = 10\ ^{1}$ sec.$^{-1}$).

From the equations of motion the associated pressure field was determined, and it was shown that a fall of pressure of 5·4 mb. at the centre of a depression of 400 Km. radius was required. It was thus inferred that the average divergence in the column of air above would be only $2 \cdot 5 \times 10^{-7}$ or roughly 1/40 of the convergence required to produce the circulation. Thus in this case, which illustrated a general principle, the amount of divergence involved in creating circulation was much greater than that involved in creating pressure changes.

Mr. Gold and Prof. Sheppard joined in the discussion, and amongst the points to which attention was drawn were the highly artificial assumptions made as well as the rather sudden jump from a rotating slice to the whole atmosphere. Dr. Sutcliffe thought however that the paper did illustrate a very important principle of general application which was by no means so widely known as it might be.

S. Petterssen and W. C. Swinbank—On the application of Richardson's criterion to large-scale turbulence in the free atmosphere.

Mr. W. C. Swinbank introduced this paper by referring briefly to Reynolds' original work on the eddy motion of incompressible fluids. Reynolds, by considering the various forms of energy involved in such motion, showed that the kinetic energy of eddying will increase if the rate of working of the shearing stresses exceeds the rate at which eddying energy is degraded into heat energy. L. F. Richardson adapted Reynolds' treatment to the case of a compressible fluid, in particular to the atmosphere, where the eddies must do work as they expand. By considering all the forms of energy involved in a large atmospheric block, including radiation, heat transfer and potential energy as well as those considered by Reynolds, Richardson had derived a criterion showing that the kinetic energy of eddying will increase if the work done by the shearing stresses exceeds the work done against gravity, and *vice versa.*

Twelve diagrams were then shown each referring to a layer of air 50-mb. deep, and extending in all from 900 to 300 mb., in which were plotted simultaneous observations of vertical wind shear and lapse rate of temperature. The observations totalled over 1,500, and covered a period of 3 months. It was obvious from the diagrams that, if Richardson's criterion were correct, turbulence in the troposphere would be nearly always decreasing. Using as a principle that over a long period of time there would be no net change in the turbulent state of the atmosphere it was clear that observation could be reconciled with theory only by modification of Richardson's analysis. This could most obviously be done in respect of his rather arbitrary assumption that the coefficients of eddy diffusion of heat and momentum were identical. The speaker explained how, by dropping this assumption and using the principle that there is no net change of turbulence over a long period, the data had been re-analysed to determine the ratio of these coefficients. It turns out that the ratio of the coefficient for heat to that for momentum is remarkably constant at about 0·65 throughout the troposphere.

The discussion that followed could have left Fellows in no doubt that turbulence is an aptly named subject. The whole gamut of turbulent processes was covered, ranging from references to " eddies " of synoptic dimensions by Prof. P. A. Sheppard and Mr. E. T. Eady (who finds an application of a form of Richardson's criterion to large-scale air-mass behaviour) to a contribution from Mr. E. L. Deacon referring to turbulence in a shallow layer near the ground. Dr. R. C. Sutcliffe (questioning whether the criterion could be applied to 50-mb. layers) was of the opinion that shearing stresses were not primarily responsible for creating turbulence, but rather that turbulence was diffused upwards to all levels from the earth's surface. Mr. E. Gold and Mr. J. S. Sawyer asked whether Richardson had taken account of turbulence advected into the layers under consideration, and Dr. J. M. Stagg, welcoming an investigation into turbulent problems in the free atmosphere, suggested that the data might have been further analysed to see whether the ratio of the coefficients varied with stability.

ROYAL ASTRONOMICAL SOCIETY

A geophysical discussion on atmospheric turbulence was held by the Royal Astronomical Society on October 24, 1947, with Professor D. Brunt in the Chair.

The discussion was opened by Prof. O. G. Sutton who outlined briefly the difficulties encountered and the methods adopted in dealing with turbulence in the atmosphere. The standard equations of motion for a viscous fluid contain terms depending on the products of eddy velocities and for this reason are intractable mathematically. A more fundamental difficulty however arises from the fact that the pattern of flow varies with the speed. The viscosity of a fluid may be regarded either as the characteristic governing the velocity profile in the fluid, or as an agency for diffusing momentum or it may be related to the shearing stresses. If we postulate the existence of an eddy coefficient in the turbulent flow in the atmosphere, observations show that it is many times greater than the corresponding molecular coefficient, but that it is of the same order of magnitude whether we consider transfer of heat or momentum. This is satisfactory but the theory fails when it is found that the eddy coefficient is a function of position, i.e. of distance from the boundary.

An alternative treatment due to Prandtl introduces the idea of a mixing length analogous to the mean free path in kinetic theory, and development of this idea relates the mixing length to the shearing stress in the air.

Prof. Sutton concluded by stressing the need for more attention to be paid to turbulence in the free air, remote from boundary influences.

Prof. Sheppard then gave a short discussion of the problem of the aerodynamic drag of the atmosphere and boundary-layer profiles. Laboratory experiments have led to a relation between the velocity u at a distance z from a rough boundary surface, a length characteristic of the roughness, the shearing stress in the fluid at the surface and a constant known as Kármán's constant. This relation indicates that u varies as $\log z$. A similar relation has been found in the lowest layers of the atmosphere but without measurement of the drag of the atmosphere on the earth's surface and it was not possible to say that the relation was the same as in laboratory work. In some recent work Prof. Sheppard has measured the drag at the earth's surface, and from this has been able to show that, under adiabatic conditions, the law for the velocity profile determined in the laboratory applies also to variation of wind with height in adiabatic conditions in the lowest layers of the atmosphere.

This was followed by a short discussion by Mr. F. Pasquill of some recent experimental work on evaporation from the surface of a field. His results indicated that wind velocity and water-vapour density both follow a logarithmic

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LIGHTNING AT WUNSTORF, JUNE 5, 1947

These photographs were taken looking south from the meteorological office at Wunstorf, near Hanover. The top photograph was taken at 0152, the bottom at 0158 as the thunderstorm moved from south to north over the airfield.

METEOROLOGICAL OFFICE DISPLAY TRAILER IN THE LORD MAYOR'S SHOW, 1947
(see p. 284)

law in respect of their variation above the surface. From these results the rate of evaporation from the grass surface can be computed. These showed reasonable agreement with evaporation measured by other methods.

Mr. Pasquill also dealt briefly with the turbulent diffusion of spores and pollen, and outlined a method of computing this diffusion using the normal turbulence theory.

A number of speakers took part in the general discussion which followed. Amongst these was Mr. E. L. Deacon who demonstrated a slide giving results of some experimental measurements of temperature and velocity gradient which strongly emphasised the importance of the Richardson number in turbulent flow in the lowest layers of the atmosphere.

A. C. BEST

MEETING OF THE ROYAL GEOGRAPHICAL SOCIETY

On November 10, 1947, Mr. H. H. Lamb of the Meteorological Office gave a lecture to the Royal Geographical Society under the title " Topography and weather in the Antarctic ". Mr. Lamb was the meteorologist loaned to United Whalers Ltd. for the 1946–7 Antarctic whaling expedition, in which he accompanied the floating factory *Balaena* to the southern ice. The task included forecasting weather for whale-spotting reconnaissance flights by the expedition's Walrus aircraft over the remotest tracts of the Southern Ocean and some of the least known stretches of the coast of Antarctica.

The distinctive feature of this task was the experimental establishment of a weather forecasting service in regions over 1,500 miles from the next regular observing and reporting stations and close to unknown land. This land was seen on several days and, in bright weather, several ranges of coastal mountains up to about 4,000 ft. high were sketched. When the vessel was in 65°S. 112°E. the coastal mountains were probably only 25 to 30 miles away. Careful and accurate identification of cloud features in the manner familiar to experienced meteorological observers provided some useful checks in cases of doubtful appearance of land and helped to give an idea of the height of the coastal mountains, when these were boldly seen.

This does not appear to be one of the most mountainous stretches of the coast of Antarctica, but naturally orographic effects were noticeable in the weather off shore. It was essential for forecasting purposes to make some assumptions about the shape of the unknown land and its coast. This basic need of the forecasting work could only be supplied by reasoning from the observed effects on winds and weather, which luckily appeared very marked and regular. Geographical interest has been attached to this unusual process of reasoning back from meteorological effects to diagnose the nature of the land-relief acting as cause. The results could only be put forward as suggestions to explorers as to what to look for; but they may in the meantime be justified as provisional working assumptions for geographers and others, since the weather forecasting work on the *Balaena* for which they were first used gave results that exceeded expectations. Certain information received since from Admiral Byrd's recent expedition and a German expedition in 1939 also tends to support this work.

A tentative outline of the coast of Antarctica between 100° and 120°E. was shown; and, by indirect reasoning from the *Balaena* daily weather maps, the existence of a major topographical barrier in East Antarctica between about 70°S. 97–100°E. and 80°S. 80°E. was mooted. This barrier, which is probably the main crest of the Antarctic ice-cap, may continue as the backbone of East Antarctica to near the Greenwich meridian in 80°S.

Other points of interest included:

(i) suggested regional differences of climatic character in different longitudes around Antarctica, on which of course local effects are superimposed;

(ii) controlling influence of the subtropical high-pressure cells, which steer the disturbances of higher latitudes and thereby made possible the completion of the weather maps over the wide spaces of the Southern Ocean; and

(iii) discovery from after-checks that the most reliable of the weather maps were those in the series which were experimentally extended right across the south pole. The gain in understanding of the interrelation of events in different longitudes around the southern hemisphere apparently justified the attempt, in spite of the sparsity of the reports available when the maps were drawn. An objective check of the daily weather forecasts issued for 24 to 36 hours ahead on the whaling grounds throughout the expedition suggests the same conclusion.

LETTERS TO THE EDITOR

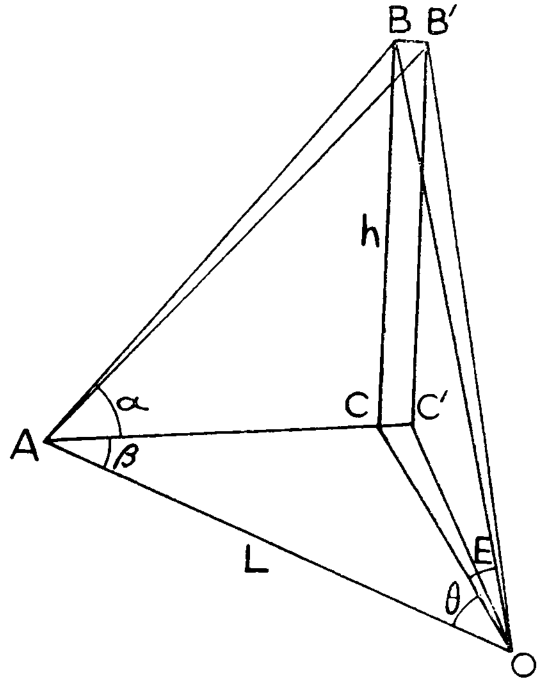
An azimuthal method of measuring cloud height with a searchlight

In the *Meteorological Magazine* for May, 1947, p. 102, Mr. Bilham describes an azimuthal method of measuring cloud height with a searchlight. He claims that this gives much higher accuracy for cloud heights above 2,000 ft. than the usual method using a vertical beam and measuring the elevation of the spot of light. There seems to be a serious fallacy in the theory, however, namely the assumption that because it is possible to measure the elevation of the spot of light to the nearest whole degree it is also possible to measure its azimuth with the same accuracy.

That this is not so is evident from the figure, which is based on Fig. 2. of Mr. Bilham's article. BB′ represents the uncertainty in the position of the spot of light, and by analogy with the ordinary cloud searchlight this subtends one degree at the eye, i.e. angle BOB′ = 1°. But the corresponding uncertainty in the azimuth is angle COC′ = angle BOB′ × OB/OC = angle BOB′ × secE. The following table shows values of E and sec$E$ for various values of the azimuth (taking $\alpha = 80°$, $\beta = 45°$):

Azimuth θ	20	30	40	50	60	70	80	90	100	110	120
Elevation E	69·8	75·8	78·9	80·6	81·7	82·3	82·7	82·8	82·7	82·3	81·7
sec$E$	2.90	4·08	5·19	6·12	6·93	7·46	7·87	7·98	7·87	7·46	6·93

The values of sec$E$ give the error (in degrees) to be expected in measuring θ, and it is seen that this amounts to 6–8° for azimuths greater than 50°, i.e. cloud heights greater than about 4,300 ft. (using a 1,000-ft. base line). If the errors shown in Fig. 3 of Mr. Bilham's article are multiplied by the corresponding values of sec$E$ they no longer show any improvement on the errors of the "elevation" curve. Similar considerations show that the accuracy of the azimuthal method with a 200-ft. base line is likely to be much less than that claimed, which is based on an error of only one degree in the azimuth.



A—Searchlight.
BB′—Spot of light on cloud.
C, C′—Points, on ground, vertically below B, B′.
O—Point of observation.

A qualitative assessment of the relative accuracy of elevation and azimuth measurements is given by imagining the sky covered by a network of latitude and longitude lines with the " north pole " at the zenith. Latitude would then correspond to altitude and longitude to azimuth. If a cloud searchlight spot was seen against such a network in latitude 80°, its longitude could clearly be measured much less accurately than its latitude owing to the longitude lines being much closer together.

J. R. BIBBY

[The same difficulty in the use of the method proposed by Mr. Bilham has also been pointed out by Rear Admiral Schuyler, U.S.N. (Retd.), 1506, 34th St., N.W., Washington, D.C.—Ed. *M.M.*]

[It is certainly true, as Mr. Bibby points out, that the advantage of the azimuthal method will be nullified if the probable error of a measurement of azimuth is substantially greater than the probable error of a measurement of elevation. The same point was made by Mr. F. Graham Millar of the Meteorological Service of Canada in a document presented to the Commission for Instruments and Methods of Observation at the recent Toronto meeting. There has been some delay in starting the trials at Dunstable, and we therefore do not yet know what precision in measuring the azimuth of the spot of light produced by the beam is realisable. I hope this information may shortly be available.—E. G. BILHAM]

A simple method of making hypostereograms of clouds with a single camera

In your August number Mr. Tricker described a method of taking stereoscopic photographs of clouds by taking advantage of the drift of the clouds. The method is not new. It was described by me in an article in the *Quarterly Journal of the Royal Meteorological Society, London,* **43,** 1917, p. 81, and a stereoscopic pair of photographs of a cumulonimbus cloud, taken in 1911, appeared opposite the same page.

C. J. P. CAVE

Stoner Hill, Petersfield.

NOTES AND NEWS

Presentation to Mr. E. Gold

The presentation of a farewell gift from the Staff of the Meteorological Office to Mr. E. Gold on his retirement, was made by the Director before the Monday evening discussion on November 19, 1947, in the lecture theatre of the Science Museum.

The gift consisted of a barograph, Plutarch's " Parallel Lives of the Greeks and Romans " (6 volumes), an attache case fitted as an escritoire, and a cheque.

The Director, before making the presentation and expressing the good wishes of the Staff to Mr. Gold for his well earned retirement, gave the address on Mr. Gold's career summarised in the November number of this magazine.

Mr. Gold, returning thanks, referred to numerous events, grave and gay, in the history of the Meteorological Office during the past 40 years. He said one of his first connexions with international meteorology had been a request to Sir Napier Shaw, who was about to attend the meeting of the International Committee in 1913, to obtain a symbol for sleet. Sir Napier Shaw, however, returned to say that sleet could not be recognised as such and had had to be called " rain and snow mixed". Recalling the introduction of the millibar he recited a poem on the virtues of " Miss Milly Bar". He thanked by name all his personal assistants and typists throughout the years.

Turning to the gifts, he said he had always had an affection for barographs since Sir Douglas Haig's barograph had played the game by him when he had had to adjust it on the night before the battle of Loos in 1915. As for Plutarch, he would greatly appreciate those volumes of the lives of great men, while the escritoire would be like the archdeacon's gaiters which he would never be without, even in bed. He said that when, in 1575, Queen Elizabeth visited his native city of Coventry, in accepting the gifts of the townspeople, she told the mayor that the best of them was the spirit in the hearts of the givers. Similarly he too appreciated much more than the gifts the good wishes of the givers which they conveyed.

Lord Mayor's Show procession, November 10, 1947

The Meteorological Office has produced exhibits illustrating its work at numerous exhibitions, shows and displays, but had not, before the Lord Mayor's Show of 1947, taken part in a moving pageant.

The Lord Mayor of London-elect, Sir Frederick Wells, selected "The Country comes to Town" as the theme for the Show of 1947. The Meteorological Office, asked to participate, had to conform to the theme and produce an exhibit illustrative of its work for agriculture.

The aspect of this work selected was the preparation of forecasts for farmers. There was no opportunity, since each exhibit can only be seen by individual spectators for some 10 to 20 seconds, of referring to any of the other work performed for agriculture.

The display was mounted on a "Queen Mary" trailer, normally used for transporting aircraft. A partition was built along the centre of the "Queen Mary" painted on each side with four panels. The first of these showed a meteorological reconnaissance aircraft, a weather ship and a radio-sonde station. The second and third consisted of an outline weather map and a farmhouse kitchen respectively, while the fourth showed a harvesting scheme. These were headed :—" Information comes from air, sea and ground—to the forecaster—the farmer hears the B.B.C. weather forecast."

On the floor in front of the panels were fixed, suitably labelled, a Stevenson screen with thermometers and a rain-gauge, while slung from the roof was a radio-sonde.

A forecaster sat at his table spread with charts and coloured pencils under the appropriate heading, while alongside the farmhouse kitchen sat a "farmer" listening to a "wireless set."

To provide the more light-hearted touch, traditional in the Lord Mayor's Show, pilot balloons were released at intervals from the rear of the vehicle.

G. A. BULL

REVIEW

Observations made at secondary stations in the Netherlands Indies, by H. P. Berlage, Jr. Vol. XXIV (1942). 4to. 15 in. × 10½ in. pp. viii + 35. Royal Magnetic and Meteorological Observatory, Batavia [1947]

For many years before the war the Royal Observatory, Batavia, had published annually the observations made at their secondary stations in the Netherlands Indies. These stations, manned by native observers, were well distributed and made a valuable contribution to knowledge of climatic conditions in equatorial islands.

When, in 1942, the Netherlands Indies were overrun by the Japanese, the Director and staff of Research Associates of the Observatory were imprisoned, and it seemed certain that the continuity of records extending over many years would be interrupted. Some stations were in fact destroyed, but the majority continued in operation, and it speaks very highly for the devotion and zeal of the observers that a large amount of climatological data was accumulated.

A special welcome should therefore be accorded the present volume which contains the observations made in Java and Madura in 1942. The records relate to about 100 stations, and the elements represented consist of pressure, temperature, humidity, rainfall, wind and sunshine.

P. H. MEADE

WEATHER OF OCTOBER, 1947

The weather of October was mainly anticyclonic throughout the month over the greater part of Europe. An anticyclone occupied the British Isles and central Europe on the 1st to 5th and persisted over southern and central Europe until the 13th. It receded eastwards on the 14th, but a new anticyclone came in from the Atlantic on the same day and moved gradually eastwards to central Europe by the 18th. From the 20th to the end of the month it lay mainly over Scandinavia. The weather in the British Isles was affected to some extent by a deep depression over Iceland on the 9th, but the only real disturbance was caused by a depression which moved north-eastwards into south-west England on the 22nd and then turned south-east. This gave heavy rain in parts of the south-west, amounting to two inches at Scilly.

The pressure chart for the month shows a large area of pressure exceeding 1020 mb., extending from Ireland to the Black Sea and including southern Scandinavia ; from Scotland to Denmark, pressure was 10 mb. above normal. By contrast, pressure was low (5 mb. below normal) south of Greenland; over eastern North America conditions differed little from normal.

The weather over the British Isles was distinguished by a deficiency of rainfall. In England and Wales it was the driest October in a record going back to 1869. In England and Wales, also, the period June to October 1947 was drier than any similar period back to 1869 ; it ranked with 1921, the total rainfall for the five months being 8·7 in. in 1947 compared with 9·1 in. in 1921. In Scotland the month, though dry, was not nearly so dry as October 1946. The month was generally rather warm, particularly in Scotland and Northern Ireland. Warm days occurred at times, mainly from the 4th to the 13th, temperature reaching 75°F. at Long Sutton, Blandford, Totnes and Ellbridge on the 6th and at Wilmington on the 13th. On the other hand cold easterly winds kept day temperatures low during the last six days, while severe frosts were registered locally on the 21st, 22nd and 30th, for example 22°F. at Milford, Surrey, on the 21st. Sunshine appreciably exceeded the average in the west and south of England and Wales but was deficient on the whole in north-east England. In Scotland it was generally dull but an excess occurred in the extreme north-west, round the Moray Firth and in south Ayrshire. Although anticyclonic conditions prevailed for the most part and the total run of the wind was considerably below the average, mean hourly velocities of gale force were registered at Lerwick on the 12th, at Stornoway on the 11th and 12th, and at Scilly and the Lizard on the 22nd and 23rd.

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

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days' difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	75	22	+1·6	20	—11	108	33
Scotland ..	71	23	+2·8	56	—4	93	25
Northern Ireland..	71	31	+3·4	60	—7	103	27

RAINFALL OF OCTOBER, 1947

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	·07	3	*Glam.*	Cardiff, Penylan	1·15	24
Kent	Folkestone, Cherry Gdns.	·36	9	*Pemb.*	St. Ann's Head	1·77	40
,,	Edenbridge, Falconhurst	·45	13	*Card.*	Aberystwyth	·51	12
Sussex	Compton, Compton Ho.	1·13	25	*Radnor*	Bir. W. W., Tyrmynydd	1·26	19
,,	Worthing, Beach Ho. Pk.	·82	23	*Mont.*	Lake Vyrnwy	1·67	28
Hants.	Ventnor, Roy. Nat. Hos.	1·56	40	*Mer.*	Blaenau Festiniog	1·84	18
,,	Fordingbridge, Oaklands	1·07	26	*Carn.*	Llandudno	·55	16
,,	Sherborne St. John	·73	21	*Angl.*	Llanerchymedd	·40	9
Herts.	Royston, Therfield Rec.	·17	6	*I. Man.*	Douglas, Boro' Cem.	·78	17
Bucks.	Slough, Upton	·13	5	*Wigtown*	Pt. William, Monreith	1·34	34
Oxford	Oxford, Radcliffe	·41	14	*Dumf.*	Dumfries, Crichton R.I.	·99	25
N'hant.	Wellingboro', Swanspool	·19	8	,,	Eskdalemuir Obsy.	1·54	29
Essex	Shoeburyness	·32	14	*Roxb.*	Kelso, Floors	1·07	37
Suffolk	Campsea Ashe, High Ho.	·29	11	*Peebles.*	Stobo Castle	1·16	34
,,	Lowestoft Sec. School	·34	12	*Berwick*	Marchmont House	·97	25
,,	Bury St. Ed., Westley H.	·25	9	*E. Loth.*	North Berwick Res.	1·12	38
Norfolk	Sandringham Ho. Gdns.	·32	11	*Midl'n.*	Edinburgh, Blackf'd. H.	1·22	45
Wilts.	Bishops Cannings	·52	16	*Lanark*	Hamilton W. W., T'nhill	1·48	45
Dorset	Creech Grange	1·91	38	*Ayr*	Colmonell, Knockdolian	1·74	39
,,	Beaminster, East St.	1·02	23	,,	Glen Afton, Ayr San.	2·06	40
Devon	Teignmouth, Den Gdns.	·97	25	*Bute*	Rothesay, Ardencraig	2·29	52
,,	Cullompton	·70	17	*Argyll*	Loch Sunart, G'dale	4·38	67
,,	Barnstaple, N. Dev. Ath.	1·58	35	,,	Poltalloch	..	..
,,	Okehampton, Uplands	2·42	40	,,	Inveraray Castle	5·62	80
Cornwall	Bude School House	1·40	34	,,	Islay, Eallabus	2·77	58
,,	Penzance, Morrab Gdns.	1·81	39	,,	Tiree	1·87	41
,,	St. Austell, Trevarna	2·18	41	*Kinross*	Loch Leven Sluice	1·99	58
,,	Scilly, Tresco Abbey	2·59	68	*Fife*	Leuchars Airfield	1·41	54
Glos.	Cirencester	·43	13	*Perth*	Loch Dhu	5·45	76
Salop	Church Stretton	·33	9	,,	Crieff, Strathearn Hyd.	2·76	70
,,	Cheswardine Hall	·62*	20	,,	Blair Castle Gardens	1·85	60
Staffs.	Leek, Wall Grange P.S.	·45	13	*Angus*	Montrose, Sunnyside	1·55	56
Worcs.	Malvern, Free Library	·44	15	*Aberd.*	Balmoral Castle Gdns.	2·00	56
Warwick	Birmingham, Edgbaston	·40	14	,,	Aberdeen Observatory	1·99	66
Leics.	Thornton Reservoir	·34	12	,,	Fyvie Castle	2·33	61
Lincs.	Boston, Skirbeck	·21	8	*Moray*	Gordon Castle	1·51	48
,,	Skegness, Marine Gdns.	·19	7	*Nairn*	Nairn, Achareidh	1·16	51
Notts.	Mansfield, Carr Bank	·18	6	*Inv's*	Loch Ness, Foyers	2·30	68
Ches.	Bidston Observatory	1·09	33	,,	Glenquoich	8·38	84
Lancs.	Manchester, Whit. Park	·53	16	,,	Ft. William, Teviot	5·54	78
,,	Stonyhurst College	·85	19	,,	Skye, Duntuilm	3·18	58
,,	Blackpool	·49	13	*R. & C.*	Ullapool	2·35	50
Yorks.	Wakefield, Clarence Pk.	·77	27	,,	Applecross Gardens	3·27	55
,,	Hull, Pearson Park	·59	20	,,	Achnashellach	5·47	72
,,	Felixkirk, Mt. St. John	·64	22	,,	Stornoway Airfield	3·08	63
,,	York Museum	·83	31	*Suth.*	Lairg	2·26	61
,,	Scarborough	·58	19	,,	Loch More, Achfary	6·57	84
,,	Middlesbrough	·28	9	*Caith.*	Wick Airfield	1·62	55
,,	Baldersdale, Hury Res.	1·04	26	*Shet.*	Lerwick Observatory	2·61	66
Norl'd	Newcastle, Leazes Pk.	·77	25	*Ferm.*	Crom Castle	2·25	69
,,	Bellingham, High Green	·93	24	*Armagh*	Armagh Observatory	1.94	71
,,	Lilburn, Tower Gdns.	·70	19	*Down*	Seaforde	1.71	48
Cumb.	Geltsdale	·59	16	*Antrim*	Aldergrove Airfield	1.86	62
,,	Keswick, High Hill	·90	16	,,	Ballymena, Harryville	1.86	50
,,	Ravenglass, The Grove	·65	15	*Lon.*	Garvagh, Moneydig	2·16	61
Mon.	Abergavenny, Larchfield	·61	15	,,	Londonderry, Creggan	2.40	65
Glam.	Ystalyfera, Wern Ho.	1·83	27	*Tyrone*	Omagh, Edenfel	1·99	54

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JUNE, 1947

Stations	Pressure: Mean of day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Temperatures: Mean values Min.	Temperatures: Mean values ½ Max. and 2 Min.	Temperatures: Mean values Diff. from normal	Temperatures: Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Daily mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hrs.	%
London, Kew Observatory	1015·1	—1·7	91	46	70·2	54·1	62·1	+2·6	57·5	71	6·9	3·17	+1·02	14	6·5	39
Gibraltar	1016·3	—1·0	86	59	80·3	66·0	73·1	+2·6	68·3	80	4·4	0·03	—	1	—	—
Malta	1015·1	—0·1	89	62	83·1	66·8	74·9	+2·2	67·6	53	1·8	0·00	—	0	12·5	86
St. Helena	1018·3	—1·7	68	52	62·7	56·0	59·3	—0·5	56·2	95	8·7	3·42	+0·60	20	—	—
Freetown, Sierra Leone	1012·8	+2·5	88	69	84·5	75·0	79·7	+0·8	76·0	86	7·7	13·32	—6·72	24	5·4	43
Lagos, Nigeria ..	1012·9	+0·5	92	69	86·1	71·9	79·0	—0·5	77·6	90	8·8	10·64	—	18	3·5	28
Kaduna, Nigeria ..	1011·6	—	91	63	86·7	68·6	77·7	+1·0	72·0	79	7·9	7·33	+0·24	19	8·1	64
Chileka, Nyasaland ..																
Salisbury, Rhodesia ..																
Cape Town ..	1022·3	+2·2	81	36	62·3	46·5	54·4	—1·3	48·5	85	5·2	1·76	—2·74	13	—	—
Germiston, South Africa	1024·3	—	69	25	62·2	38·9	50·5	—	41·8	59	1·7	0·00	—	0	8·5	81
Mauritius																
Calcutta, Alipore Obsy.	998·3	—1·0	99	75	93·7	80·7	87·2	+2·1	80·8	85	8·0	8·96	—2·95	16	5·2	39
Bombay	1004·2	+0·2	95	77	91·9	81·4	86·7	+2·7	79·4	78	6·1	3·61	—16·26	9	6·9	52
Madras	1003·4	—0·4	104	78	100·7	83·0	91·9	+1·9	75·5	56	6·5	0·36	—1·61	2	7·4	57
Colombo, Ceylon ..	1009·3	+0·7	88	74	85·9	80·2	83·1	+1·5	77·2	82	8·8	10·55	+3·23	26	5·0	40
Singapore	1008·9	0·0	92	71	88·4	75·7	82·1	+0·6	78·0	82	—	7·54	+0·67	11	—	—
Hongkong	1006·1	+0·3	92	73	85·8	77·5	81·7	+0·3	78·0	88	—	21·64	+5·94	28	2·8	21
Sydney, N.S.W. ..	1016·4	—1·5	72	40	64·8	48·4	56·6	+1·9	48·3	66	3·7	2·15	—2·59	6	7·2	73
Melbourne	1015·6	—2·9	66	36	58·4	44·0	51·2	+0·8	45·0	75	6·6	1·17	—0·89	12	3·5	37
Adelaide	1018·3	—1·1	72	44	62·1	48·1	55·1	+1·5	49·7	70	6·5	1·90	—1·18	17	3·8	39
Perth, W. Australia ..	1015·0	—3·0	74	40	66·3	53·7	60·0	+3·2	56·1	75	7·0	10·41	+3·47	26	3·9	39
Coolgardie	1017·2	—1·7	81	34	66·4	46·2	56·3	+3·5	48·2	69	4·3	0·48	—0·78	5	—	—
Brisbane	1018·7	+0·4	78	41	71·2	49·2	60·2	0·0	52·9	59	1·8	0·29	—2·50	1	8·9	85
Hobart, Tasmania ..	1008·5	—5·8	67	34	53·1	41·9	47·5	+0·5	43·2	75	7·8	7·50	+5·27	22	3·1	34
Wellington, N.Z. ..	1007·5	—7·4	60	39	52·5	43·5	48·0	0·0	45·5	82	8·6	11·02	+6·25	21	2·8	30
Suva, Fiji	1013·5	—0·1	86	62	79·5	70·6	75·1	+0·4	71·1	82	8·2	13·35	+6·64	22	3·5	32
Apia, Samoa ..	1011·0	—0·6	89	71	86·5	73·8	80·1	+2·3	76·8	83	5·8	11·88	+6·53	19	6·7	59
Kingston, Jamaica ..	1014·0	+0·2	96	73	89·9	76·1	83·0	+1·7	75·2	68	4·2	0·32	—3·78	2	7·9	60
Grenada, W. Indies ..	1014·3	+1·0	87	73	85·5	77·1	81·3	+2·3	77·8	84	7·8	7·00	—1·25	20	—	—
Toronto	1014·3	—0·4	89	42	74·0	55·0	64·5	+0·7	55·0	70	5·1	4·53	+1·87	9	9·0	59
Winnipeg	1010·1	—1·7	80	29	70·4	50·1	60·3	—2·0	51·3	81	6·8	3·68	+0·57	14	6·8	42
St. John, N.B. ..	1015·4	+1·9	81	39	62·5	46·9	54·7	—1·8	50·5	84	7·0	6·26	+2·99	13	6·7	43
Victoria, B.C. ..	1015·3	—1·5	75	41	68·1	48·6	58·3	+1·3	49·3	89	6·9	1·41	+0·57	10	9·1	57