.O. 567

THE METEOROLOGICAL MAGAZINE

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M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 967, JANUARY 1953

CHARTS OF UPPER AIR TEMPERATURE AND ISOBARIC HEIGHT

By D. DEWAR, B.Sc.

Not many years ago a research worker contemplating a study of upper air climatology would have found that he could make little progress owing to lack of data; now he may well find that his first problem is how to use the wealth of observational material that has been collected as a result of the introduction of daily radio-sonde observations by most of the meteorological services of the world. The broadcasting since January 1949 of CLIMAT TEMP messages giving, at five standard pressure levels, monthly mean values of temperature, dew point and height of the isobaric surface provides valuable summaries of some of these observations.

After the formation of the Upper Air Climatology Branch of the Meteorological Office, it was realized that a useful contribution to the study of the general circulation of the atmosphere could be made by tabulating and plotting these monthly mean values as part of the routine work. Some account of the development of the work and the present procedure is given below.

Preparation of charts.—After discussion with other branches of the Meteorological Office it was decided that the charts should give isopleths of temperature and height on the isobaric surfaces for 700, 500, 300, and 200 mb. A Mercator projection was adopted for the base maps so that the monthly charts could be compared with the charts of average height of isobaric surfaces, published in *Geophysical Memoirs* No. 85. The units chosen were metres and degrees Centigrade in preference to British units of feet and degrees Fahrenheit.

Up to December 1950 the charts were drawn on reproductions of the base maps used for the charts of *Geophysical Memoirs*, No. 85[1], to which had been added the location of upper air stations broadcasting CLIMAT data. The boundary of these maps was at 100°W. and divided the United States roughly in two, a division which, while very satisfactory for the Admiralty chart on which the maps had originally been based, was not so convenient for drawing isopleths over America. A revised map was brought into use in January 1951 with the boundary of the map changed to 180°, and a circumpolar map for the northern hemisphere, extending to 55°N., was added to get a better idea of the run of the isopleths in high latitudes and to allow stations outside the northern limit of the Mercator map to be plotted.

Data used for the charts.—For the early charts the data used for plotting were obtained from teleprinter messages supplied by the Central Forecasting Office at Dunstable, and the values published by the United States Weather Bureau

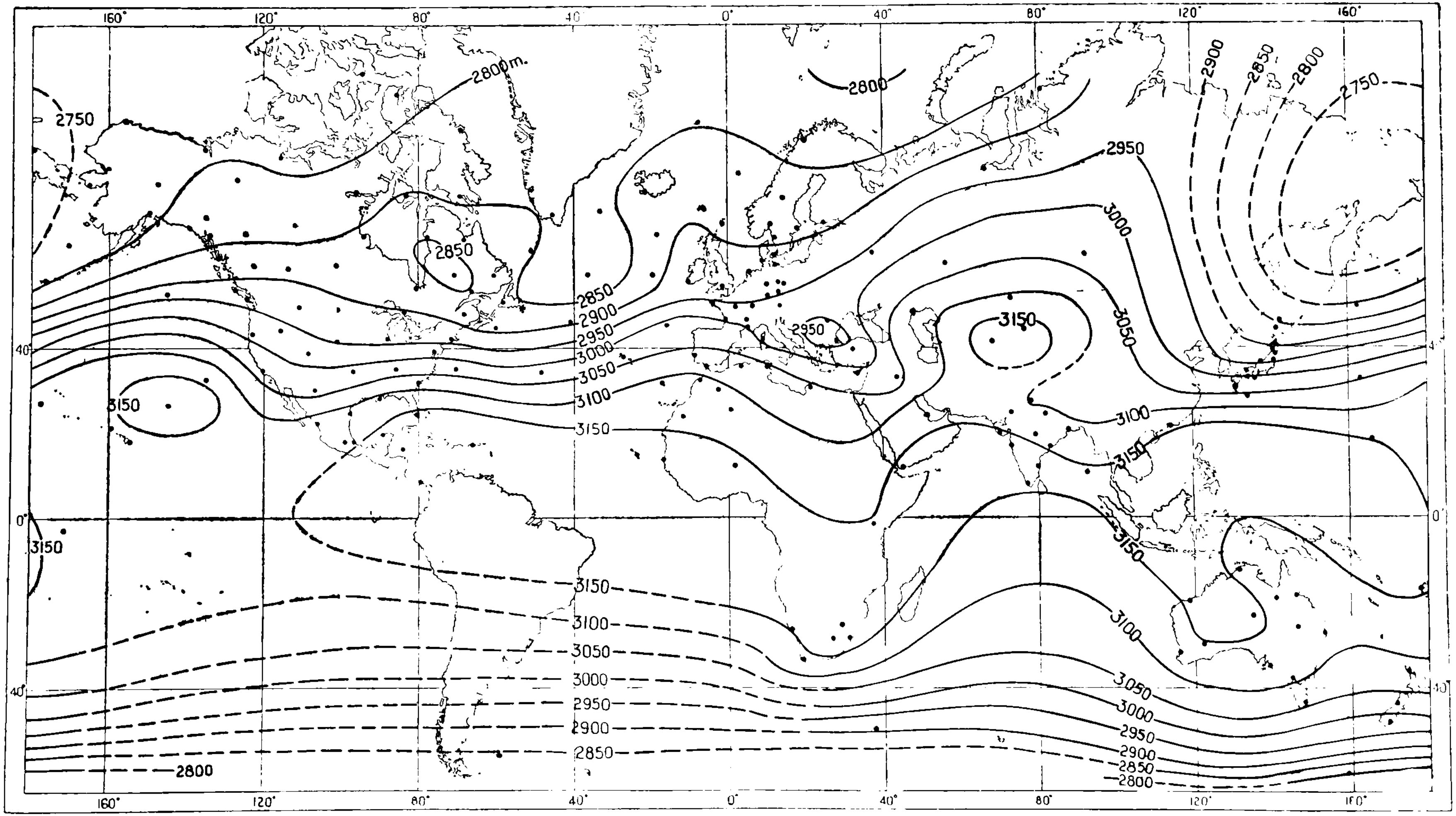

FIG. I—CONTOURS OF MEAN HEIGHT OF 700-MB. PRESSURE SURFACE, MARCH 1952
(Tropical and temperate zones)

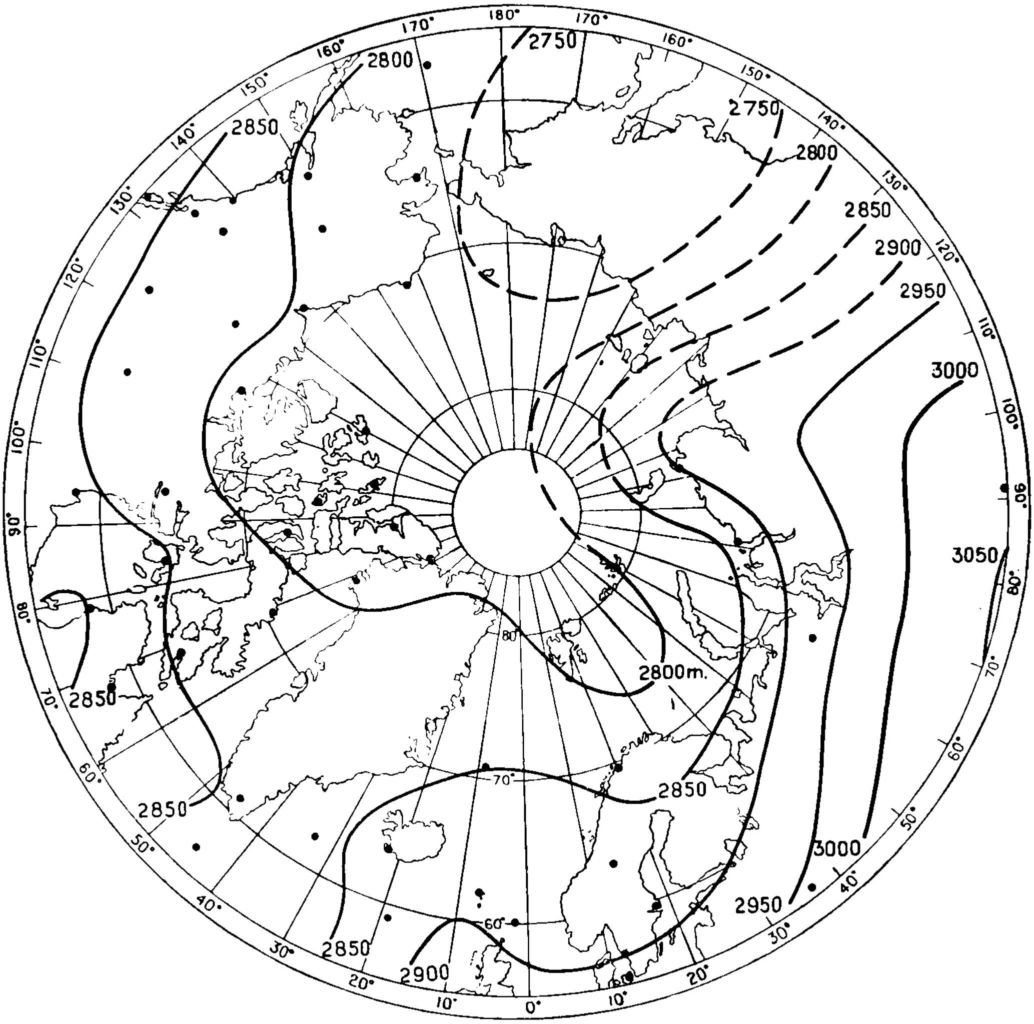

FIG. 2—CONTOURS OF MEAN HEIGHT OF 700-MB. PRESSURE SURFACE, MARCH 1952
(Arctic region)

in "Monthly climatic data for the world", supplemented by values worked up from data sent to the Upper Air Climatology Branch from British radio-sonde stations overseas. No data were received for Russia, Japan, South America and New Zealand and these early charts now seem very incomplete. Through the co-operation of the Directors of the South African and New Zealand Meteorological Services and the Director of the Royal Observatory, Hongkong, it was arranged that copies of CLIMAT data for those countries would be sent by air mail, and these enabled more complete charts to be drawn. More recently values for about twelve Russian stations have been added by working up monthly means from daily values extracted by the Central Forecasting Office Dunstable from the upper air data broadcast for Russian radio-sonde stations. The number of stations for which values are given in "Monthly climatic data for the world" has steadily increased, and it is now possible to draw a fairly complete chart over the world up to the 300-mb. level. Data for South America are still unfortunately non-existent, and there seems to be little hope of being able to do more than draw tentative lines over this region for some time to come. The 700-mb. charts for March 1952, reproduced as Figs. 1 and 2, show stations now being received and the latest type of chart.

Accuracy of data.—Each chart usually shows a few values that have to be rejected as being either obviously wrong or decidedly at variance with adjacent stations. Frequently values cannot be made to fit in with a smooth run of the isopleths, and, as it is difficult to know whether these departures are minor errors or real departures due to local topography, the policy adopted has been to follow the values as far as possible rather than to draw smooth curves.

Values given in the "Monthly climatic data for the world" are plotted in preference to the data received through interception of the broadcast messages, as more stations are given and values for the American stations probably have fewer transmission errors. For the British (home and overseas) stations and for South Africa, Hongkong and New Zealand the values given in confirmatory messages sent by post are used. This system ensures that the best data are used, but unfortunately it entails a delay of about six weeks before charts can be plotted.

Some rather peculiar discrepancies between values for stations in the same area have been found. For the charts up to April 1950 the only station in west Africa giving CLIMAT values was Dakar, and these values were accepted though both heights and temperature were lower than would have been estimated for this area. In May 1950 two other stations in the same latitude (Sal and Niamey) were received, and confirmed the suspicions felt about the Dakar values. Taking Sal and Niamey as correct led to a temperature correction of roughly +2°C. being required for Dakar with height corrections ranging from about 100 m. at 700 mb. to 400 m. at 200 mb. By early 1951 the differences had become smaller, and from June 1951 onwards Dakar values are in fair agreement with Niamey (Sal reports having ceased).

Values for Gibraltar and neighbouring stations were often found to be conflicting in 1950. On the whole the values for Gibraltar appeared high in relation to those for Portela, Casablanca, Colomb-Béchar and Maison Blanche, but differences were not consistent either from level to level, station to station, or month to month. These differences, which it was thought might have arisen through the use of different types of radio-sonde instruments, became less in 1951, and charts for the latter part of that year show generally good agreement between the different stations.

The differences in monthly means that can arise through the use of two types of radio-sonde at Canadian stations are discussed in a paper by T. J. G. Henry[2] and are shown to be appreciable.

Average values.—In addition to plotting the monthly data on charts the values have been entered on special summary forms which allow all the data broadcast to be entered month by month, and provide for monthly and seasonal averages to be computed after five years' data have been entered. When the charts indicate that a value is wrong, a probable value read from the charts is entered in brackets. These five-year averages, when available, will be very useful for the revision of the average charts of temperature over the world being prepared from data now available.

Major features of the charts.—This note has been written primarily to describe the production of the charts. They are being used in the research section for a study of upper air climatology, but in the meantime a brief description of some features noted while they were being drawn may be of interest.

Although in their diversity of detail they are reminiscent of daily synoptic charts certain features are often well marked. Considering first the contour charts, three "waves" extending around the northern hemisphere are frequently recognizable; one crest is normally to be found over the west of the American continent, another over the central Atlantic and another over central Russia. Of the corresponding troughs, that to the north of Japan is the most marked and often it is linked by a region of low isobaric height to the trough in the Labrador region giving, on the circumpolar chart, the impression roughly of a figure eight stretching across the pole.

It is more difficult to generalize for the southern hemisphere as the charts are less complete and features of the distribution less prominent, but the impression obtained is one of a mainly latitudinal run of the lines with a tendency for troughs to be indicated over the oceans and crests over the continents.

The temperature charts up to the 300-mb. level show, as might be expected, warm air in equatorial regions with warm ridges corresponding to the isobaric-height crests. In the northern-hemisphere summer the warmest regions as a rule are over Mexico (at the lower levels) and in a belt extending from India over southern Arabia to central Africa. The high-temperature region over Mexico is most evident at 700 mb. and at 300 mb. the temperature is definitely lower than that over India. During the northern winter the high-temperature area moves southwards to form a broad belt centred roughly over the equator, showing a definite bias for greater warmth in the northern hemisphere.

Of the localized features noticed, the most prominent is the steep gradient over Japan between the area of greater height of the isobaric surfaces over the western Pacific and smaller height to the north of Japan. Though not so striking, the contours from west Africa to India on the 300-mb. and 200-mb. charts suggest that there is a sweep of strong westerly winds over this region between about 20°N. and 40°N. from October to March, and this is borne out by the vector mean winds recently computed for Habbaniya for the period 1948–50. The speeds are given below together with the corresponding values for Larkhill:—

	October	November	December	January	February	March
			knots			
200 mb.						
Habbaniya	64	50	68	73	77	85
Larkhill	35	36	26	33	32	24
300 mb.						
Habbaniya	48	39	59	63	68	70
Larkhill	36	37	27	37	38	24

Another feature often noticed is the steep horizontal temperature gradient over Australia; an example of this is shown in the 500-mb. temperature chart for August 1951, reproduced as Fig. 3, where the intense thermal gradient is particularly noticeable.

The 200-mb. temperature chart deserves special mention; it is the most difficult chart both to draw and to understand and, probably for these reasons, the most interesting. Fairly complete charts are unfortunately only available for about a year, as data for high-latitude stations were not received for earlier charts and the drawing of the charts is still in arrear. Some of the following comments may therefore not apply generally.

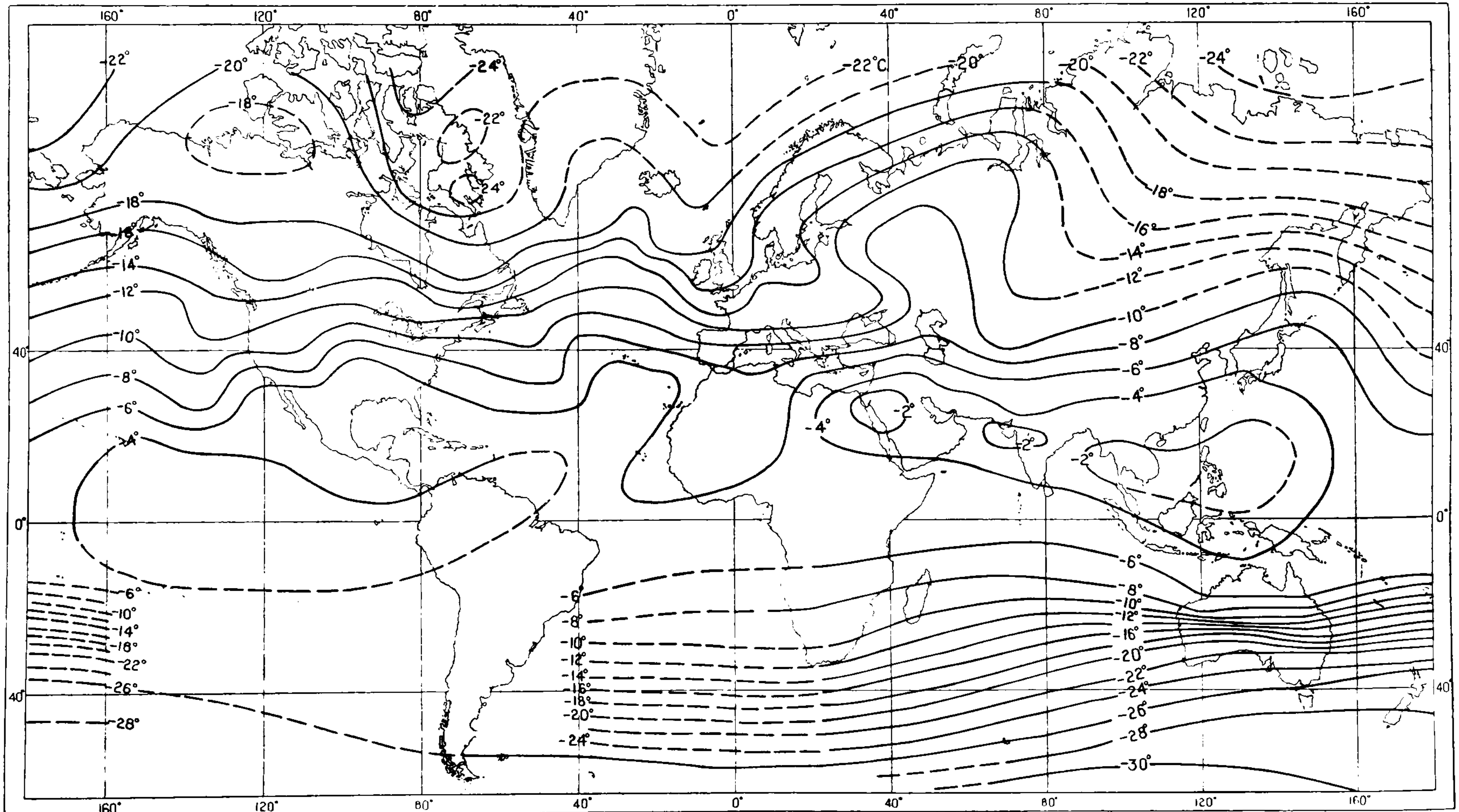

FIG. 3—MEAN TEMPERATURE AT 500 MB., AUGUST 1951
(Tropical and temperate zones)

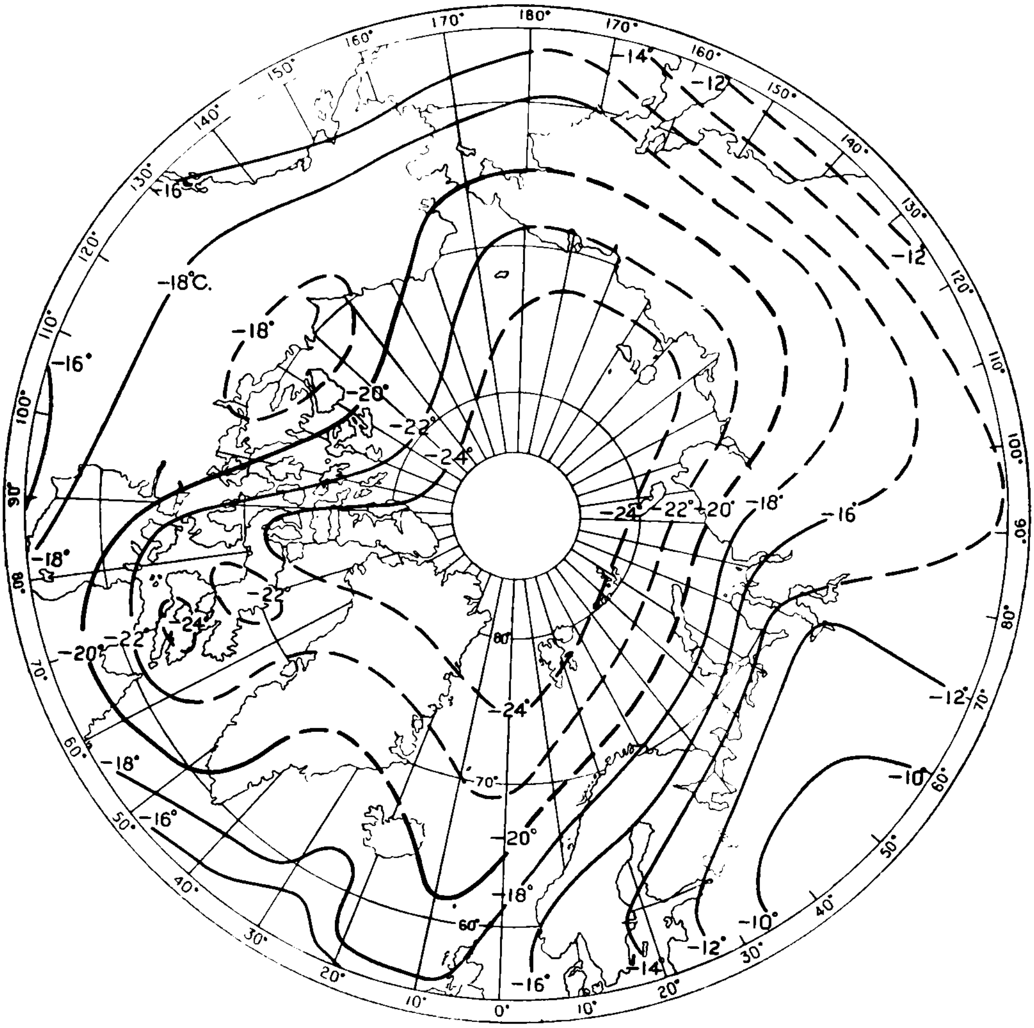

FIG. 4—MEAN TEMPERATURE AT 500 MB., AUGUST 1951
(Arctic region)

The temperature distribution changes almost completely at this level from the pattern shown by successive lower-level charts, and becomes very confused with many warm and cold patches appearing in different parts of the chart, owing to some regions being now in the stratosphere while others are still in the troposphere. The pattern varies considerably from chart to chart with seasonal changes superimposed on these variations; the following paragraph attempts to present the dominant features.

From May to October, generally, the arctic regions show the highest temperature and the antarctic regions the lowest. Equatorial regions have about the same temperature as arctic regions, but are sometimes colder; still colder air is usually found in a belt in the region of 40°N. From November to January the polar regions of the northern hemisphere become the coldest parts of the chart while the antarctic regions become warm; at the beginning of this period a belt of warm air extends from South America to South Africa and then sweeps north-east towards Japan. During February and March this warm belt moves into the equatorial zone with a cold belt to north and another

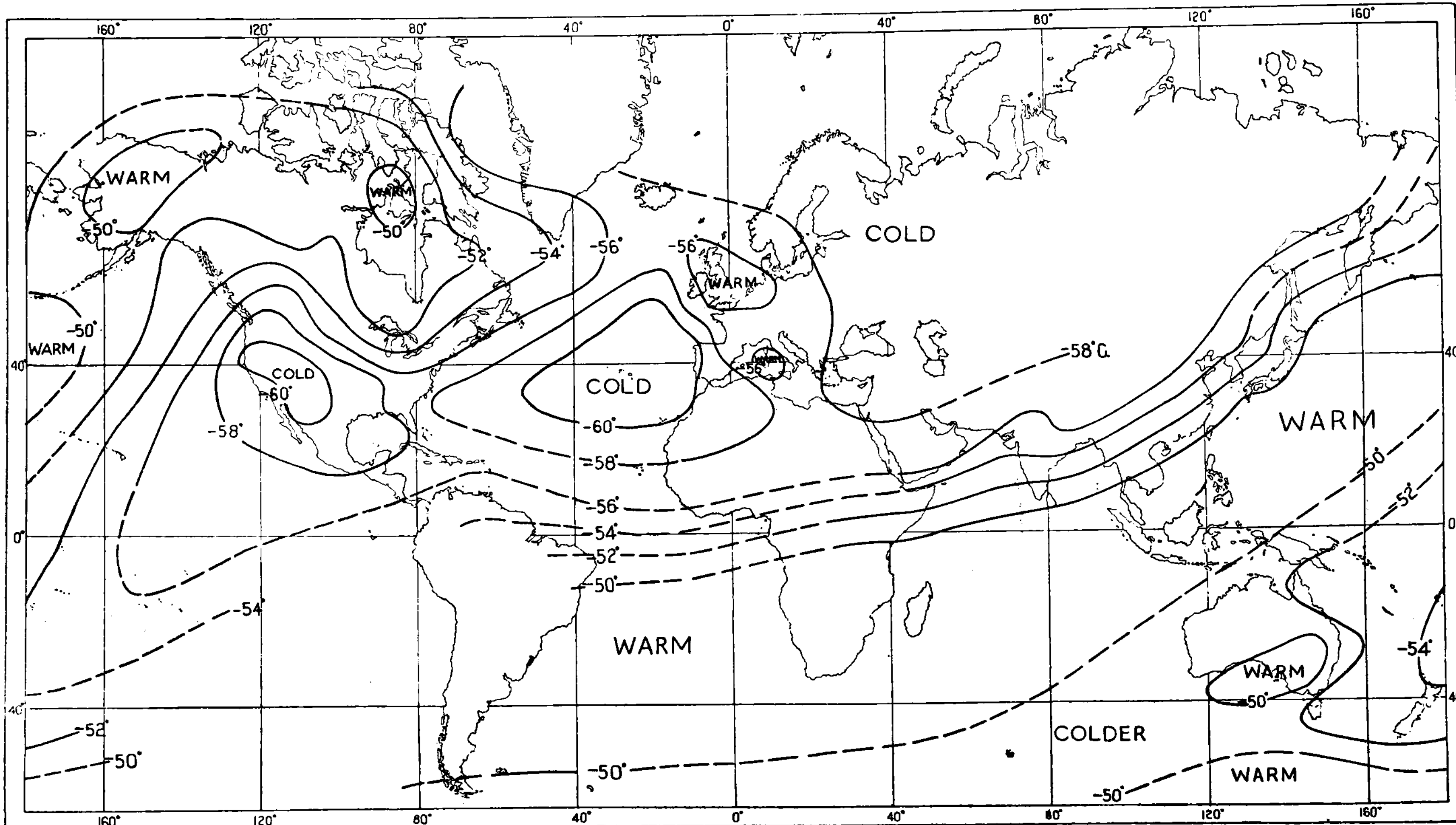

FIG. 5—MEAN TEMPERATURE AT 200 MB., DECEMBER 1950

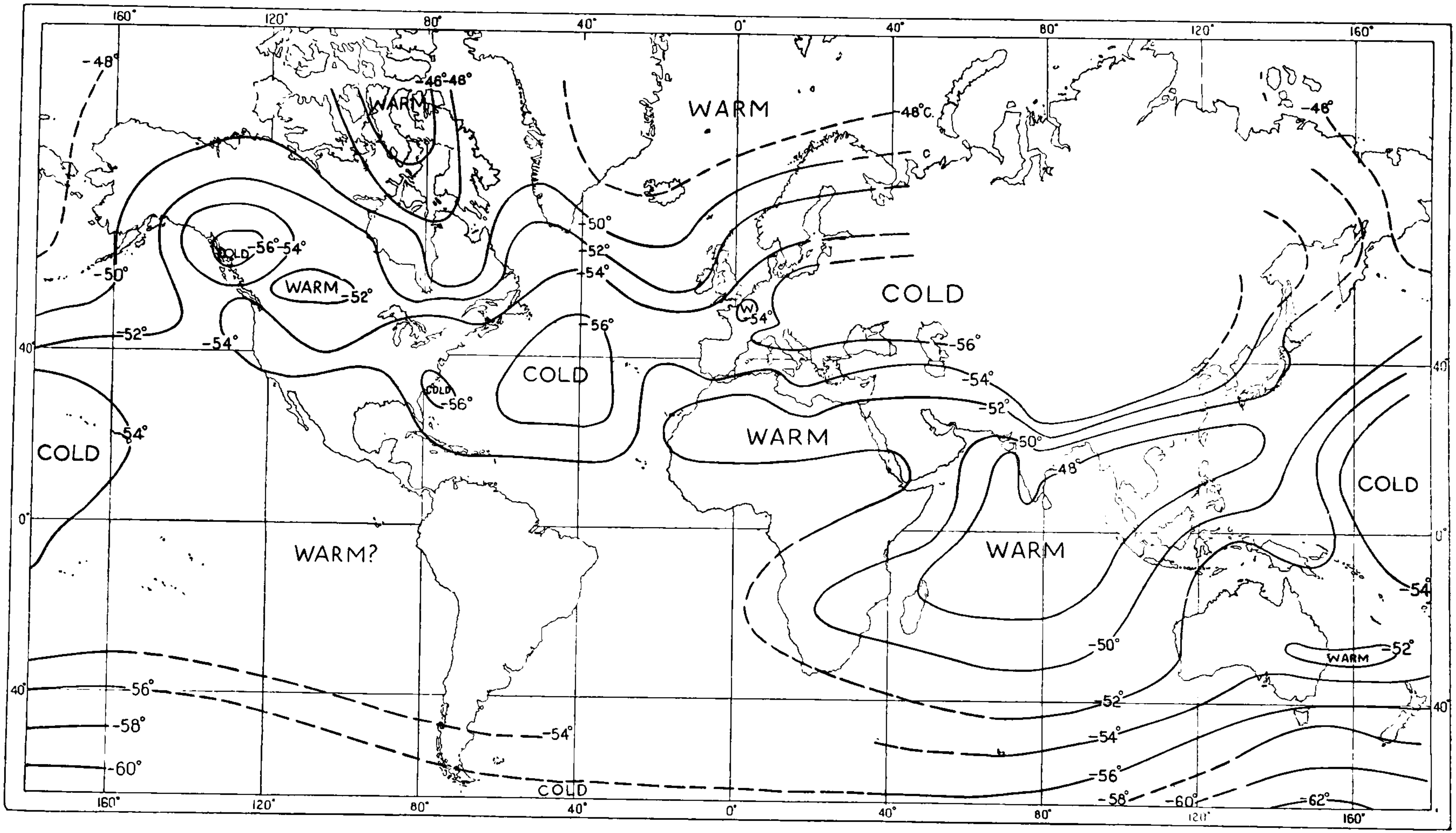

FIG. 6—MEAN TEMPERATURE AT 200 MB., SEPTEMBER 1951
(Tropical and temperate zones)

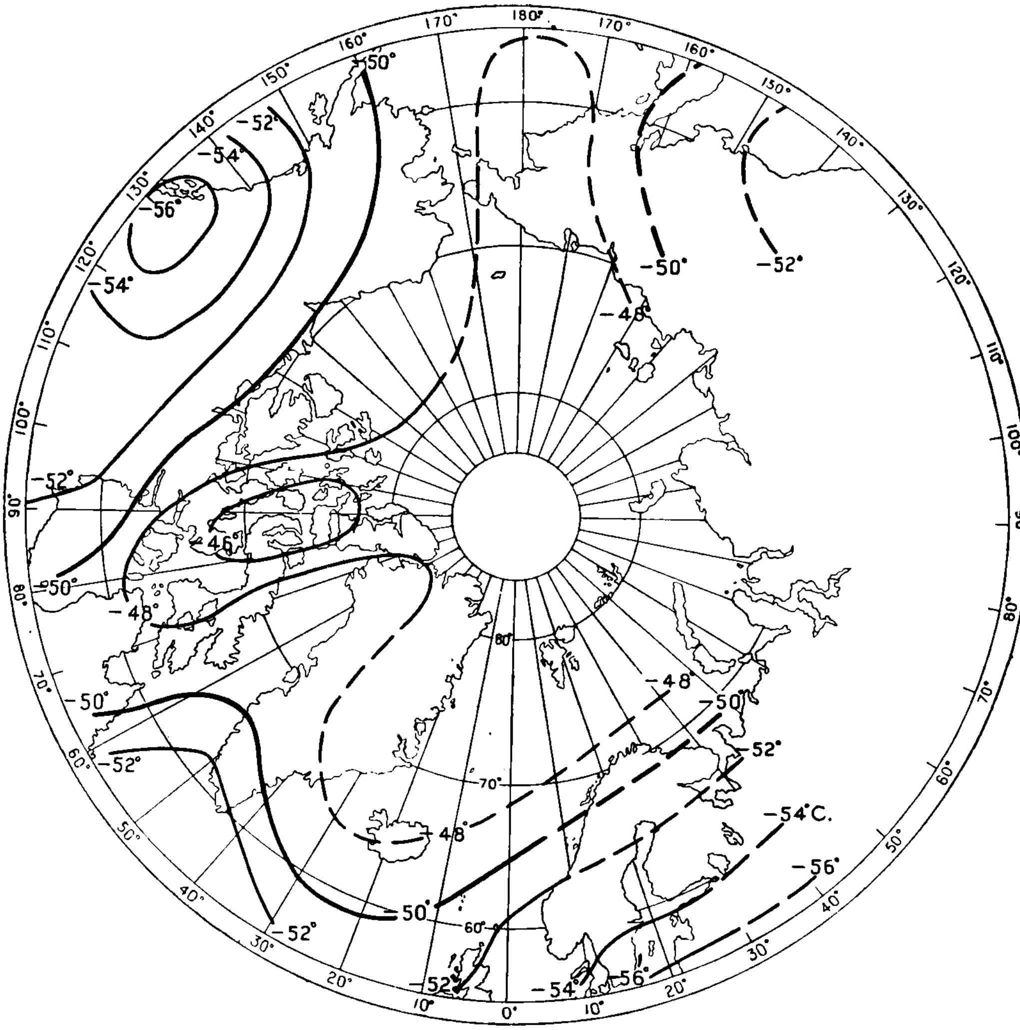

FIG. 7—MEAN TEMPERATURE AT 200 MB., SEPTEMBER 1951
(Arctic region)

to south of it but with warm air again further south. By April the arctic regions are becoming warm again and the antarctic regions cold, and the coldest air is now found in a belt between about 30° and 40°N.

Some of these features are illustrated by the chart for December 1950 (Fig. 5) and the charts for September 1951 (Figs. 6 and 7).

It is worth noting that the 200-mb. charts suggest that at this level the mean position of the thermal equator is south of the geographical equator—a reversal of its position in the lower troposphere.

In this brief description it has only been possible to deal with a few of the many interesting features of the charts; a detailed study of them may lead to the discovery of facts of both theoretical and practical importance.

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SOLAR AND TERRESTRIAL RELATIONSHIPS

By D. H. McINTOSH, M.A., B.Sc.

In the daily publication, *Wetterkarte*, of the Meteorological Service of the United States Zone of Germany for March 14, 1952, Professor Scherhag[1] described remarkable meteorological and ionospheric effects which he associated with the occurrence of an intense solar eruption in the early hours of February 24. The temperature on February 24 at 27 Km. over Berlin rose from −83°F. (−64°C.), which is normal for the season, at 0900 G.M.T. to −53°F. (−47°C.) at 1500 G.M.T. and to °1F. (−17°C.) by next morning. The increase in temperature extended downwards, the temperature at 20 Km. rising from −76°F. (−60°C.). on February 26 to −38°F. (−39°C.) on February 29. The wind at 18 to 30 Km., normally almost always westerly in winter, changed direction to east and increased in speed by the afternoon of the 29th to the remarkable value of over 60 kt. The wind change is considered to have been produced by the development of an intense high-pressure area in the stratosphere over northern Europe. The temperature measurements were made with special American balloons and with radio-sondes of a new type described as having higher accuracy than any others. The ionospheric effects were shown by world-wide interference with radio transmission.

The assumption in this article of a direct link between the solar and meteorological events was made with a degree of certainty which does not appear to be justified. Here, the general problem of solar and terrestrial relationships is reviewed, and comment made on Professor Scherhag's article.

Geomagnetic and ionospheric phenomena.—There is ample visual evidence that the sun passes through a marked cycle of activity of approximately 11 years. These solar variations are reflected in corresponding changes in the earth's magnetic field and in the electron density of the upper atmospheric layers. In both these phenomena the effects of two distinct types of solar radiation are distinguishable: an ultra-violet "wave" radiation, moving with the speed of light, responsible for ionizing the atmospheric layers and giving rise, in conjunction with the tidal motions of the atmosphere, to geomagnetic diurnal variations depending on both solar and lunar time; and a slower-moving "particle" radiation consisting of electrified solar particles whose close approach to the earth causes geomagnetic and ionospheric storms. Both types of radiation are directly correlated with the sun's activity, as measured by the relative sun-spot number. The relations are close for annual mean values, but become increasingly vague as the time interval shortens, so that it is rarely possible to interrelate the respective day-to-day changes. An exception is provided by the occurrence of an intense solar flare. About four minutes after such a flare is first observed there often occurs, over most of the sunlit hemisphere, a characteristic variation of the earth's magnetic field and a radio fade-out, resulting from a sudden intensification of the ionizing wave radiation. The magnetic effect may, exceptionally, last about an hour, and the radio fade-out two or three times as long. If the flare is centrally situated on the sun's disc, there is a much greater than random probability of it being followed after about a day by an intense and world-wide magnetic storm of sudden onset, assumed to be caused by the arrival in the vicinity of the earth of slower-moving solar "particle" radiation emitted simultaneously with the "wave" radiation. This probability by no means amounts to certainty; intense flares have occurred in apparently favourable positions without subsequent storms, while conversely the occurrence of an intense storm in the absence of a flare, or even a sun-spot, has been known. H. W. Newton[2] has demonstrated a statistical connexion between intense flares and "very great" magnetic storms. The "lesser" storms are not associated with flares and have, in contrast to the "very great" storms, a marked recurrence tendency of 27 days, corresponding to the solar rotation period. Because of a lack of close association with visible sun-spots, these storms were attributed by J. Bartels[3] to hypothetical magnetically effective solar emitting areas, which he termed "M-regions". Our knowledge of magnetic and ionospheric variations may perhaps be summarized by the statement that, while a solar origin of their greater part is not in doubt, there remains a good deal of mystery in the phenomena, and their day-to-day changes can rarely be related directly to corresponding solar changes.

Solar and meteorological connexions.—Since we regard the sun as the driving force in all that constitutes weather, it is natural to expect that changes in the condition of the sun will be reflected in corresponding weather variations, and attempts have been made by many authors to confirm this expectation. C. G. Abbott, who has been largely responsible for the increased accuracy of solar-constant measurement achieved in the past 50 years, holds to the opinion that the constant is subject to small variations which cause small weather changes. It is more widely held, however, that the small differences found in the constant result from variations in the transparency of the atmosphere, these being associated with weather anomalies which are therefore the cause, and not the effect, of the measured variations of the constant. Support for this view appears to be contained in Abbot's own finding[4] that there is no sun-spot cycle variation of the solar constant. Changes in the atmospheric transmission properties would be expected to average out over a long period to give such a result, while on the other hand the existence of day-to-day changes in the value of the constant with no long-period change corresponding to sun-spot epoch would be very difficult to explain.

Much of the work in the field of solar and meteorological relationships has recently been reviewed by C. E. P. Brooks[5] who reached the conclusion that a connexion does most probably exist. It is my opinion, having regard to the dependent nature of successive sun-spot numbers, to the properties of both time and space coherence displayed by meteorological data, and to the lack of independence of different meteorological elements, that none of the relations so far claimed carries real conviction. On the analogy of the relationships discussed in the preceding paragraph, it is likely that the use of solar and meteorological data meaned over a fairly long period would have the best prospect of establishing a relationship, and most of the workers have used such material. Recently B. and G. Duell[6], working with daily values, have claimed positive results which appear to have received fairly general acceptance. Their method consisted essentially of finding mean values of barometric pressure under conditions of varying intensity of solar "particle" and ultra-violet radiation. The means were calculated, for instance, at a large number of stations in the series of days extending from 3 days before to 11 days after magnetically disturbed days (5 per month), these means being contrasted with corresponding values round magnetically quiet days. A similar procedure was adopted with days of intense solar flares, and the resulting variations attributed to the influence of the additional ultra-violet radiation associated with flares. Before we can assume that the resulting variations are uniquely, or even partly, related in a direct way to the variations of solar radiation, it is necessary to determine how successfully other random influences have been eliminated by the averaging process. This is readily done by finding the standard error either of the means themselves or of the differences between means, and is a very necessary precaution in an investigation of this nature. The results of such tests which I have applied to the findings of B. and G. Duell are as follows:—

(*a*) The maximum difference found between the means associated with magnetically disturbed days and those round magnetically quiet days was about 4 mb., each of the means being derived from 320 cases. Magnetically quiet and disturbed days tend to occur in separate successions, and calculation shows that only about one in three of either type of day makes an independent contribution to the "true" pressure mean. The standard deviation of the difference of two means, each given by n independent values is $\sqrt{2}\sigma/\sqrt{n}$, where σ is the standard deviation of the individual daily values (about 12 mb. in this case—central Europe in the four winter months November to February). Thus the difference of 4 mb. was only $2\frac{1}{2}$ times the appropriate standard deviation. If such a difference were obtained in a single random sample it would be no more than suggestive of a relationship. Since, however, it was the maximum difference in a series of days at a number of stations in a specially selected season and grouping of years, it must be considered quite insignificant.

(*b*) For stations over north-west Europe, the departures associated with magnetic disturbance from long-period pressure means were represented on charts by the authors. Maximum departures of $+2 \cdot 5$ mb. occurred in west Iceland and of $-2 \cdot 5$ mb. near Riga, both on the second day following the selected days of magnetic disturbance; the appropriate values of σ are about 15 mb. in each case, so that these maximum departures are each less than twice the standard deviation of the means, derived from 320 cases as in (*a*). There is thus no reason to believe that the intensification and slackening of the pressure gradient over north-west Europe following days of magnetic disturbance is due to any cause other than insufficient averaging.

(*c*) Examination in a similar way of the variations in the mean surface pressure following days of intense solar flares shows that they also fail to attain a level of significance; in this case, all 51 cases can be counted independent. However, the corresponding pressure variations at upper levels suggest a possible significance. From the day of an intense solar flare to the succeeding day, the level of the 500-mb. surface in Ireland was found by B. and G. Duell to fall, in the average of 51 cases, by about 130 ft. Examination of a year chosen at random shows that the standard deviation of the difference on successive days of the 500-mb. level at Aldergrove is 300 ft. Thus the standard deviation of the mean of 51 independent cases is about 42 ft., and the actual mean departs from zero by just over three times this amount. Although it must again be noted that this is a maximum value over a wide area, the contrast with the very small changes over the preceding 24 hr. is striking when account is taken of the normal coherence of such changes. The suggestion of a real effect was considered strong enough to warrant testing with fresh data. The mean 500-mb. contour level at Aldergrove was determined for each day from 3 days before to 11 days after 29 Class 3 or 3+ flares occurring between 0900 and 1500 G.M.T. during 1942–51. The variations of these means were found to be insignificant, and the substantial change round the flare day, which occurred in the data used by B. and G. Duell, did not reappear here. The variations in surface pressure at Mauritius in the series of days round 40 intense flares, occurring between 0800 and 1600 L.M.T., were also examined, but again with negative result. Mauritius was chosen because of the small range of random fluctuations there, and because it seems likely that any effect associated with solar flares should be biggest where the distance from the subsolar point is least.

Geomagnetic storm of February 24, 1952.—The description by Scherhag[1] of the geomagnetic, ionospheric and solar disturbances of February 24, 1952, contains some puzzling features which have a bearing on his assumption of a direct link between these events and the accompanying stratospheric rise of temperature. A world-wide geomagnetic storm commenced suddenly at 2126 G.M.T. on February 23, 1952 and continued with varying intensity till February 25. At no time was the magnetic storm, or accompanying ionospheric storm, of more than moderate intensity; periods equally or more disturbed had already occurred in February and occurred again in March. Evidence appears to be lacking of a big solar disturbance in the form of an intense flare on February 24; no visual flare was reported, and the absence of any of the geophysical effects which usually accompany a large flare makes it almost certain that none did occur. The storminess of February 24 was obviously of corpuscular origin and could not be linked with any flare or other solar disturbance which may have occurred that day.

The reported rise of temperature at about 27 Km. over Berlin, amounting to nearly 85°F. in 24 hr. seems very large and apparently is quite exceptional at this level since it received special comment. The intermediate observation, showing a rise of 30°F. in 8 hr. serves both to confirm the observation made later and to show that the rise of temperature took place gradually. It is natural to seek for an explanation of this temperature rise, but a too ready linking of this exceptional event with other events which were not exceptional appears unwarranted, and may only serve to divert attention from the true explanation.

Conclusion.—The present lack of clear proof of a direct link between solar and surface meteorological changes does not necessarily mean that no such link exists, but makes it certain that any direct tropospheric effect of solar variations is very small. There may, however, yet be an achievement in this field of investigation comparable to that of Professor Chapman[7], who, following the failure of many previous investigators, was able to prove the existence at Greenwich of a lunar atmospheric tide of total amplitude only a small part of the error of the individual values used.

Since there are very probably no variations in the solar constant measurable at the ground, the variable part of the sun's radiation must be removed in the upper atmosphere. The influence of such variations is apparent in the regular ionospheric layers (100 Km. and upwards), while it is known by direct observation that the additional ultra-violet radiation associated with solar flares penetrates to the D layer, at a height of about 80 Km. The pressure at 80 Km. is of the order of only 5×10^{-2} mb., and it seems hardly possible that any pressure variations occurring at this level would be apparent at the surface, even if transmitted in full. If the variable component of radiation can penetrate beyond the D layer to the ozone layer, at a height of 20–40 Km., the chance of visible reactions in the troposphere increases proportionally to the greater pressure at these levels. The failure of the ozone content of the atmosphere to show a solar cycle variation or to increase at the time of an intense solar flare may be considered indirect evidence that no effective variation of solar radiation reaches this level. These facts are capable of other interpretation, but it seems certain that the ozone layer represents the only possible link between the sun's variations and surface weather reactions. It should be possible to answer some of these problems with the help of the direct observations at very high levels now becoming available, but it is important that these observations should not be interpreted too hastily or in the light of preconceived theories.

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RELATIVELY HIGH STRATOSPHERE TEMPERATURE OF FEBRUARY 1951

By F. J. SCRASE, Sc.D.

In an article on atmospheric reactions to solar corpuscular emissions H. C. Willett[1] reported what he described as "the first instance of the direct measurement of thermal effects produced in the higher atmosphere by a sudden solar disturbance". He stated that during the 24-hr. period, February 24–25, 1952, the regular twice daily high-altitude soundings taken by the German Weather Service in the western zone of Berlin recorded a rise of temperature of 72°F. (40°C.) at the 20–10-mb. levels in the stratosphere. This sudden heating effect diffused slowly downwards to the 50-mb. level where there was a 22°F. (12°C.) increase a few days later. During the following week a slow return to near normal temperature occurred at all levels. These observations have since been discussed in more detail by R. Scherhag[2] who claims to have confirmed the connexion between the high temperature and solar eruptions by a statistical investigation of the correlation between the daily magnetic activity and the temperature of the upper stratosphere.

Since Willett assumed that the Berlin observations of abnormal heating in the stratosphere were the first of their kind, it may be of interest to report that a similar occurrence had, in fact, been noted a year previously by the writer from the results of high-altitude soundings made at Downham Market (52°36′N., 0°24′E.) and Lerwick (60°08′N., 1°11′W.). About 150 of these soundings to levels between 20 and 30 Km. were made in 1950 and 1951. Temperature was measured by the Meteorological Office radio-sonde, and wind and height by radar. The soundings were all made at night (2200) so

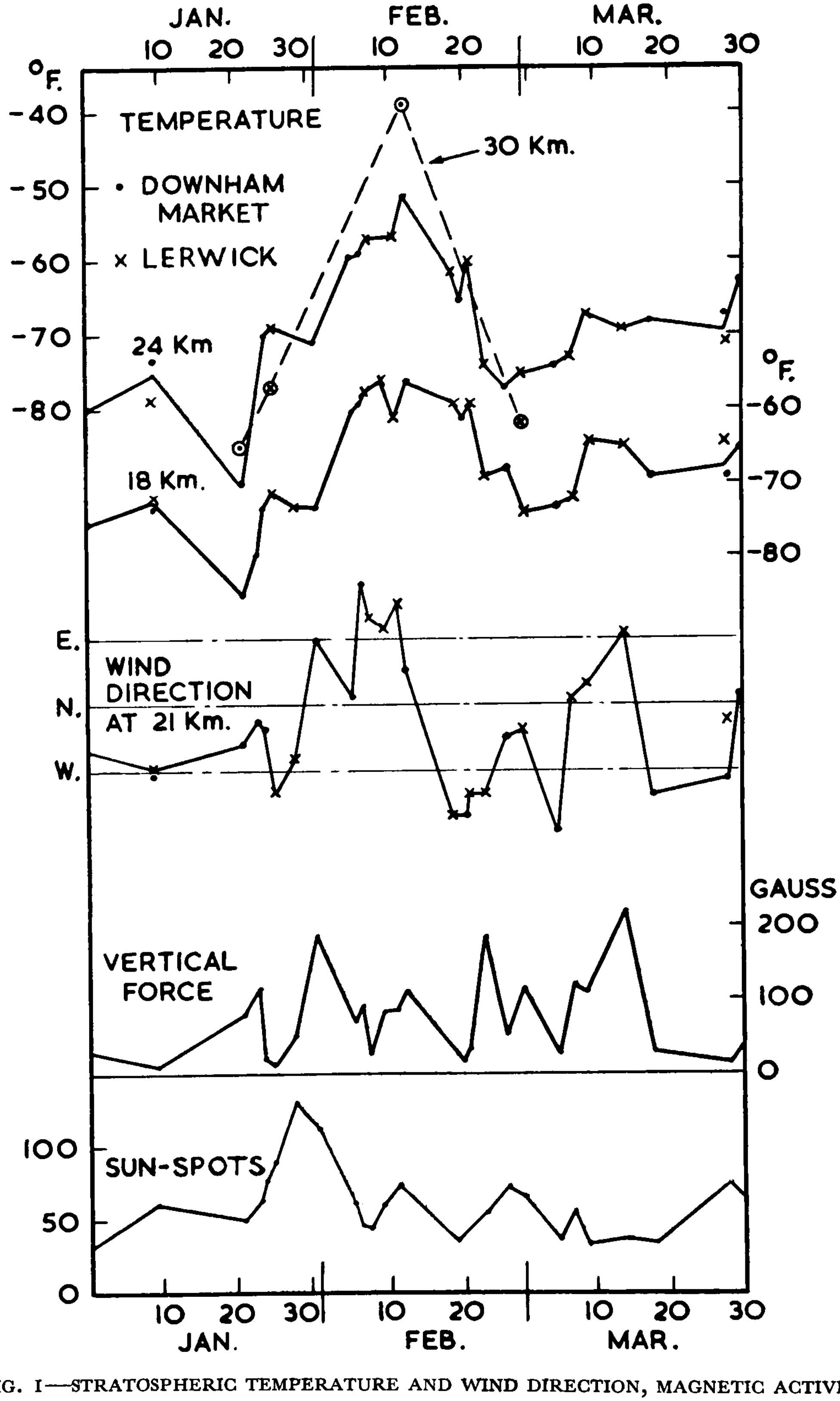
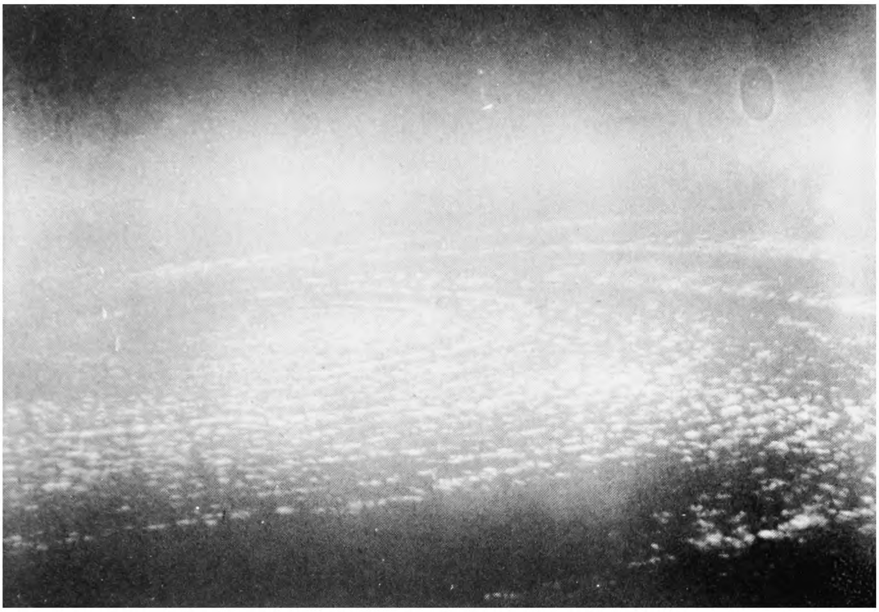


FIG. 1—STRATOSPHERIC TEMPERATURE AND WIND DIRECTION, MAGNETIC ACTIVITY (RANGE OF VERTICAL FORCE AT ESKDALEMUIR) AND SOLAR ACTIVITY DURING THE FIRST QUARTER OF 1951



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CLOUD PATTERN NEAR CAPO CARBONARA, SARDINIA, FROM 35,000 FT.
(See p. 28)

Reproduced by courtesy of "The Aeroplane"

PROPELLER-TIP CONDENSATION TRAILS

The Firefly aircraft was just taking off from H.M.S. *Eagle* whilst she was steaming off the Isle of Wight, on March 8, 1952. (see p. 29.)

FIG. 1—A FRESHLY FORMED PIECE OF CONTRAIL

FIG. 2—DISTRAIL CLEARLY DEVELOPED
(1 min. after Fig. 1)

FIG. 3—DISTRAIL BREAKING UP INTO A ROW OF HOLES
(2 min. after Fig. 1)

FIG. 4—HOLES WELL DEVELOPED
(4 min. after Fig. 1. This picture is incomplete because the film ran out)

CONTRAILS AND DISTRAILS

Condensation trails (contrails) and evaporation trails (distrails) were formed by an aircraft over Wimbledon Common about 10.30 a.m. on September 23, 1952. Photographs were taken looking northwards. The aircraft was passing just behind the tree on the left of Fig. 1; it was in cloud and cannot be distinguished in the photograph.

(see p. 27)

Photographs reproduced by courtesy of R. S. Scorer

SANDSTORM OR HABOOB FROM THE GARDEN OF A HOUSE IN KHARTOUM

(See p. 26)

Photographs reproduced by courtesy of J. Fleming as to eliminate solar-radiation errors. A preliminary survey of the results has been published[3], and a more detailed account, which is to include occurrences of the type now under discussion, is in course of preparation.

The point of immediate interest is that the stratospheric temperatures observed in these soundings during the period February 5–20, 1951, were relatively high compared with the general run of the temperatures before and after this period. The observations at 18, 24, and 30 Km. for the first three months of 1951 are plotted in the upper part of Fig. 1. At the peak of the warm period on February 12, the temperatures at the three heights were about 20°, 25° and 40°F. higher than those outside the period. The differences at specified pressure levels would be still greater. The changes were practically simultaneous at all the stratospheric heights but there were no similar changes in the tropospheric observations.

The soundings during the period February 1–12 were also noteworthy in showing the appearance of an easterly air stream at the levels above 18 Km. It was followed by a reversion to the westerly stream before the summer régime finally set in. The observations of wind direction at 21 Km. are shown in Fig. 1. The changes from the westerly flow of the winter months to the summer easterlies does not usually take place until nearer the vernal equinox.

Possible connexion of the abnormal temperature with solar phenomena was investigated by examining the sun-spot numbers published by the International

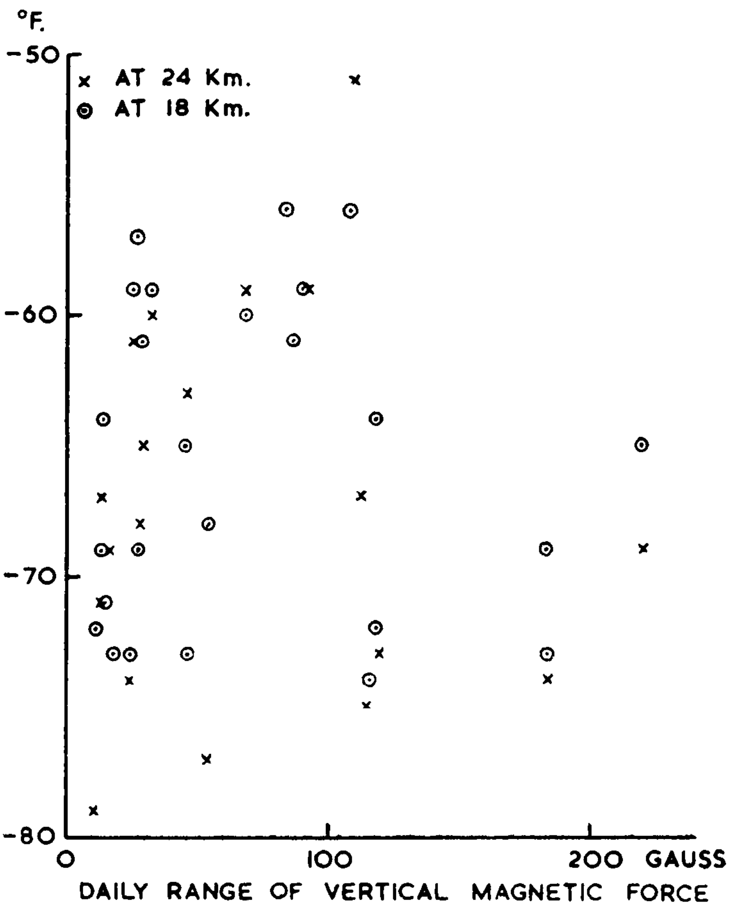

FIG. 2—STRATOSPHERIC TEMPERATURE AND MAGNETIC ACTIVITY

Astronomical Union[4] and the daily range of vertical magnetic force recorded at Eskdalemuir Observatory (55°19′N., 3°12′W.). The range of vertical force may be taken as giving a good indication of solar corpuscular activity. The data for the days of the high-level soundings are plotted in the lower part of Fig. 1. There is clearly little or no connexion with the sun-spot number or the magnetic activity, neither of which was abnormally high. The lack of correlation is, perhaps, more evident in Fig. 2 in which the temperatures are plotted against the daily range of vertical force; the sun-spot data gave a similar result. According to the *Quarterly Bulletin on Solar Activity* for the first quarter of 1951 the only solar eruptions large enough to be estimated as 3 on a scale 1 to 3 of increasing intensity and size occurred on February 19 and 25, and March 24. There is little evidence to indicate that these eruptions caused relatively high temperatures in the stratosphere. Neither does there appear to be any evidence of ionospheric activity to correspond with the high temperatures.

The weather over the British Isles during February 1951 was decidedly abnormal in two respects, namely very low sea-level pressures and high rainfall. The mean pressures were between 10 and 14 mb. below average, and the exceptionally low readings at some places broke previous records. Rainfall over south-east England was nearly double the average, and again at some places records were broken.

For most of the month a westerly type of weather prevailed, with depressions passing over or close to the British Isles. Temperatures were remarkably uniform.

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METEOROLOGICAL OFFICE DISCUSSION

Orographic effects on wind with special reference to the safety of aircraft

The first discussion of the 1952–53 series, held at the Royal Society of Arts on October 20, 1952, dealt with orographic effects on wind with special reference to the safety of aircraft. It was opened by Mr. L. Jacobs who based his statement on the following papers:—

FIELD, J. H. and WARDEN, R.; A survey of air currents in the Bay of Gibraltar 1929–30. *Geophys. Mem., London*, **7**, No. 59, 1933.

ABE, M.; Mountain clouds, their forms and connected air currents. *Bull. cent. met. Obs., Tokyo*, **7**, No. 3, 1941.

BROOKS, F. A.; Mountain top vortices as causes of large errors in altimeter heights. *Bull. Amer. met. Soc., Lancaster Pa*, **30**, 1949, p. 39.

ROUSE, H.; Model techniques in meteorological research. "Compendium of meteorology", Boston Mass., 1951, p. 1249.

It has long been known that air in passing over hilly or mountainous country is uplifted on the windward slopes but that the airflow to the lee can be very irregular, often with violent up-and-down currents. Over fairly rough high ground, with winds of any intensity, marked eddies can form in the lee, either breaking off irregularly and travelling downstream, or remaining in regularly spaced positions, the so called "rotors" first described in detail by Küttner[1,2] from sailplane and other investigations.

In stable air and with a moderate increase of wind with height, standing waves can be set off in the lee of high ground, and with moisture present lenticular cloud is shown at the up currents of the waves. These clouds have long been observed in various parts of the world. Manley[3] has pointed out in his detailed account of the helm wind that observations of the helm bar in Cumberland were made as early as 1777. Local names have been given to these lenticular clouds such as moazagotl in the Riesengebirge Mountains in Germany and turusi on Mount Fuji in Japan.

Many attempts have been made to calculate theoretically the disturbance of the air flow by high ground. Scorer[4,5] has pointed out the inadequacies in the earlier theoretical treatments by Lyra and Queney, and has himself put forward a suitable mathematical theory to explain the formation of the lee waves, assuming dry, isentropic, inviscid, stream-line flow in which the disturbance is only a small proportion of the wind velocity. He has given diagrams of the air flow to be expected over a mountain ridge, showing extension of the lee waves to great heights, and has pointed out that the lee clouds such as helm bar and Küttner's rotors indicate the waves at low levels, while, at the other extreme, the mother-of-pearl clouds observed by Størmer show the lee waves at 70,000–100,000 ft. His theory fits in very well with observations of the lee waves as shown, for example, by the sailplane flights described by Yates[6] in this country and by light-aircraft flights by Radok[7] in Australia. Turner[8,9] has recently given many examples of the effect of the vertical currents of these waves on aircraft in western Europe, sometimes 60–80 miles from the high ground, with up-and-down currents sometimes greater than 2,000 ft./min.

For very disturbed flow to the lee of a mountain an attempt can be made to study the flow round a model placed in a wind tunnel, such studies being supplemented by investigations on the site. This approach to the problem has been made in the four papers which form the basis of this discussion.

Field and Warden started their experiments in 1929 with a 1 : 5,000 model of the Rock of Gibraltar, after many accidents had occurred with seaplanes attempting to land in Gibraltar Bay, in the lee of the Rock (top 1,396 ft.), when an easterly wind, the levanter, was blowing.

To study the air flow around the model in the wind tunnel the motion of either flags—short fine silk fibres—or streamers—long woollen strands—were observed and sketched. The flags of equivalent length 800 ft. and equivalent spacing 2,000 ft. were fixed on wires at various equivalent heights up to 7,000 ft., and the positions of the streamers could be adjusted until they illustrated the major eddies. By skewing the model results were obtained with winds from between NE. and SE.; repetition of the experiments with or without a change of observer showed no material differences.

There was good agreement between the flag and streamer methods—as shown by plots on some twenty diagrams. At all levels up to at least 3,000 ft. an area of vortices and eddies extended westward of the Rock for about a mile and a half over the Harbour and Bay and was succeeded further west by a wide region of turbulent winds on a decreasing scale.

Following the model experiments, measurements were made of the horizontal and vertical currents at Gibraltar, by double-theodolite pilot-balloon ascents, from November 1929 to March 1930. In spite of weather difficulties and a lack of easterly winds, 138 balloons were sent up of which 77 were in winds between 72° and 120°, the extreme easterly range found during the period.

In comparing model and site results it must be remembered that the tunnel wind is uniform while winds on the site are liable to vary appreciably with height and time. In spite of this the model observations did, as Field and Warden report, "forecast in a very remarkable way the real winds on the site. In a total of 360 plottings of balloons there were only some 24 instances of discordance, many of them slight."

Vertical velocities calculated from the pilot-balloon ascents, which were mostly made with surface winds of force 3, reached nearly 800 ft./min., and they considered that these velocities probably reached 1,500 ft./min. or more for a short time even on days when the free wind did not exceed force 6. Down currents are stronger than up currents and are considerably more frequent.

While at Gibraltar they made a short study of the banner cloud which forms to the lee of the Rock, and noted that the period of breakaway of small cumulus cloud from the end of the banner (4–5 min.) agreed well with a theoretical estimate of 3 min. previously given by Relf of the National Physical Laboratory.

Abe in his 1941 paper continues to describe work he commenced in the 1920's on the ciné and stereo photography of clouds round the conical-shaped Mount Fuji (12,390 ft. high) in Japan, using his results to judge the associated air currents. He is careful to point out that the first ciné photographs of cloud were taken by Sir Napier Shaw[10] in 1911. His work on cloud photography is voluminous—an earlier 1937 paper contains 500 pages—but the opener pointed out that, in interpretation, there is always the difficulty of allowing for the growth or decay of the clouds. He gives many examples of rotating clouds with vertical, horizontal and inclined axes saying "they are certainly generated by vortices induced on the lee mountainside."

The important feature of Abe's work is his wind-tunnel experiments, using a 1 : 50,000 model of Mount Fuji. He made his first model experiments in 1932[11] but the series of experiments in 1939–41 are more detailed. Abe points out the desirability of equating the Reynolds number for the flow over Mount Fuji with that over the model. He does this by making the assumption that eddy viscosity is applicable to the flow over Mount Fuji and molecular viscosity to the model. By assuming a velocity of 22 m.p.h. for flow over Mount Fuji and adopting a velocity of 2 m.p.h. for the air flow in the wind tunnel he calculated a Reynolds number for both cases of around 4,000. This is a definite assumption and, as mentioned below, it was criticized by Rouse.

To make the air flow visible Abe used smoke of an incense stick in normal experiments, and occasionally little wind vanes. To get a wind shear the air flow was partly interrupted or an extra blower was introduced into the chamber. To simulate a lapse rate the heavy white smoke of "dry-ice" cloud could be introduced into the bottom of the tunnel. He took photographs of the air flow past the model under varying conditions and obtained rough qualitative agreement with the movements and shapes of mountain clouds he had observed on Mount Fuji. In particular he was able to imitate a wing-shaped turusi (lee cloud) in his wind tunnel, with its associated up-and-down currents.

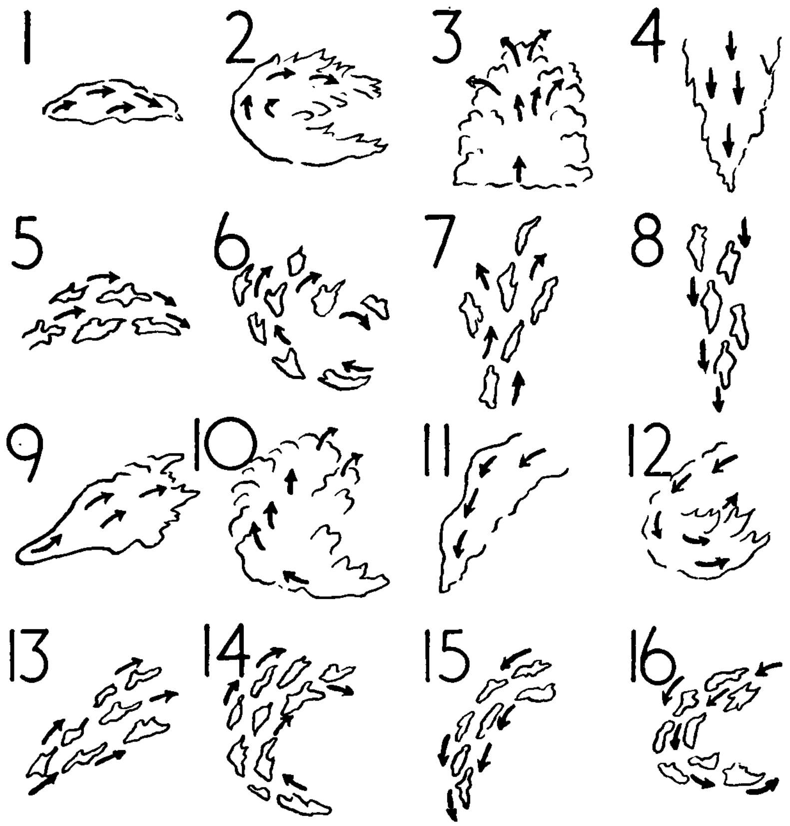

FIG. 1—ABE'S CLASSIFICATION OF MOUNTAIN CLOUDS

He points out that, while the cloud forms generated by Mount Fuji are simple compared with those of other mountains, as its shape is very simple, a classification of the various peculiar types observed might well form a useful foundation for an international classification, as he was convinced that the various shapes gave a good guide to the vertical currents. His main classification is shown in Fig. 1.

Brooks is only indirectly concerned with model experiments in that he applies the well known results of wind-tunnel tests of pressure drop on the camber of aerofoils to get some idea of the equivalent pressure drop likely over a mountain top. With a free stream velocity of 100 m.p.h. over a 14,000-ft. mountain this gives an altimeter error of 700 ft., assuming a double velocity head. He points out that this error is not large enough to explain some of the errors of 2,000–3,000 ft. which he claims have been reported directly by aircraft and indirectly by large pressure changes observed on the tops of mountains and by vortex cloud spouts descending below the main cloud level.

These large pressure changes could arise as the pressure drop in intense vortices (analogous to tornadoes) stemming from the bluff edges of the mountains. He calculated that the tangential velocity of the core of a vortex, of which the outer part was irrotational, would have to be 135 m.p.h. to give a pressure fall at the centre sufficient to bring the total altimeter error on top of the 14,000-ft mountain to 2,000 ft., but stated that this inner velocity could be set up on the outer edge of the vortex by quite moderate winds. He suggests wind-tunnel experiments, possibly using the free surface of a water channel to simulate the natural gradient of density, be carried out to check this theory, followed by investigation by aircraft and smoke generators on the site.

Dr. Rouse, Director of the Iowa Institute of Hydraulic Research, the author of the fourth paper, commenting on Brooks's work, states that he did not doubt that pressure intensities within the eddies were fully as low as Brooks estimates. He did not understand, however, how the velocities involved would permit the altimeter error in an aircraft to occur without the velocity effect becoming even more disastrously apparent. Moreover, measurements he had made indicated that the velocities in the lee of abrupt boundary irregularities, such as walls and cliffs, were invariably lower than that of the deflected wind.

It was as a result of Brooks's work and the discussion on it that the project of research "Theoretical and observational study of air flow over mountain ranges" was initiated by the United States Air Force's Air Research and Development Command in 1950 and is still proceeding.

In Rouse's own paper he points out the use of dimensional analysis and in particular the Π theorem in planning model experiments. For mechanical flow dimensionless parameters, such as the Euler, Froude, Reynolds and Mach numbers, have to be equated for model and site, and normally temperature would also have to be considered. However, if gravitational, viscous or thermal effects are to be neglected, only the Reynolds number need be considered. Rouse criticizes Abe's assumption regarding the viscosity, since Abe was dealing with fairly smooth high ground, but he points out that where the ground is rough—as in Field and Warden's case—the flow is essentially independent of the Reynolds number. The opener mentioned that Abe's 1942 experiments[12] with bluff models satisfied this condition.

Rouse refers to unpublished war-time work using large mountain models in hangars, the air flow being produced by blowers or aircraft propellors, but gives no details. He gives suggestions for future model work pointing out that pitot heads or hot-wire anemometers can be used for measurement and chemical smoke for display of the flow. To simulate thermal stratification experiments could be carried out in water using salt solutions of different concentrations.

It is rather surprising that, in view of Rouse's general recommendation of the use of model experiments, the United States Air Force Research project decided, after preliminary experiments, to discontinue model work owing to lack of dynamic similitude. Only preliminary notes have so far been published on the general work of the research project[13,14]. Measurements are being made at Bishop, California (between the Sierra Nevadas and White Mountains which range up to 10,000–14,000 ft.) using radio-sondes, radar equipment and double-theodolite pilot-balloon measurements. Performance-calibrated sailplanes are being tracked and vertical currents of 4,000 ft./min. have been recorded.

The Bishop lee waves are used by sailplane pilots to climb to record heights of over 40,000 ft. Lee clouds are common at 25,000–35,000 ft. with higher lee clouds estimated at 60,000–80,000 ft. (It should be noted that Austin[15] has reported that in this country wave clouds can be set off to 32,000 ft. over hills less than 800 ft. high, and Ludlam[16] has emphasized that this hill cirrus is indeed quite common in the British Isles, with vertical currents inside the clouds up to 2,000 ft./min.)

These four and other papers appeared to the opener to indicate that the use of models is feasible with heights up to say 2,000–3,000 ft. near very rough terrain, but that such experiments should be supplemented, and, in the case of higher levels and higher ground, superseded by investigation on the site.

Gliders have been increasingly used in recent years for investigation on the site and descriptions of such work have been given by Förchtgott[17-21] in Czechoslovakia, Raspet[22] in the United States and by Yates[6], Bell[23], Fyfe[24], Ludlam[25] and Scorer[26] in this country. Scorer[27] has given a summary of the theoretical and glider work discussed during the July 1952 meeting of the Organization Scientifique et Technique Internationale du Vol à Voile at Madrid.

The opener mentioned that Raspet[28] had detected well marked windward waves as well as lee waves, and that, apart from recent theoretical work by Ringleb[29], he had been unable to trace any other reference to these waves.

The Director said that this discussion is very topical and coincides with the publication of the report of the air crash on January 10, 1952, in the Snowdon area. This is the first public inquiry on aircraft accidents to have a meteorologist on the Board and Mr. Gold with his wide knowledge of meteorology was a most admirable choice. Two general effects on aircraft have to be considered, turbulence and the effect of the flow on altimeter readings. Like other critics of Brooks's paper he was puzzled about his altimeter errors, as these would be fluctuating widely with the movement of the vortices, and velocities as great as Brooks estimated would be enough to break up any aircraft.

Dr. Scorer, Imperial College, emphasized that there was a great deal to be said on this subject so he would restrict his remarks to describing three of the latest results, which he expected to publish shortly.

It is now well recognized that static stability in an air stream extends the effect of a mountain to greater heights than when the lapse rate is adiabatic. It is evident therefore that wind-tunnel experiments must take account of the relationship between kinetic energy and buoyancy energy expressed in the number

$$S = g\beta\frac{d^2}{U^2}$$

which must take the same value in model and full scale ; β represents the static stability $(= dT/Tdz)$, d is a representative length and U is the wind. This number is of paramount importance and the Reynolds number is a secondary consideration. In typical cases we find that very slow running speeds, such as 70 cm./sec., are required, and this makes the control of velocity and temperature profiles extremely difficult. He had abandoned the construction of a projected wind tunnel through lack of time and resources.

To give point to the importance of this stability number it is desirable to distinguish types of flow in the atmosphere. It is thus called aerodynamic flow if it is analogous to ordinary wind-tunnel flow, that is when the lapse rate is adiabatic, and barostromatic if the stratification is stable.

A special result, of great importance, is that if an adiabatic layer, such as a layer of nimbostratus for instance, is sandwiched between two stable layers the flow over a hill cannot be steady and laminar. It is therefore unsteady or contains overturning, but the nature of these disturbances is unknown, and cannot be evaluated by perturbation theory (this theorem may be relevant to the air crash in Snowdonia).

The wavy motions produced by mountains can affect the readings of radiosonde balloons for they drift downwind through the waves as they ascend. In passing from a crest to a trough a fictitious inversion may be recorded.

One of the difficulties of research in the field is in obtaining the right weather. A research team will have to be ready to go to a site at short notice when a suitable forecast is given. There is no need to go outside Great Britain for this, nor to fly at great altitudes, for the nature of the flow near the ground determines the effective shape of the mountain as regards disturbances at great heights. The problem at high levels is simple in comparison with the study of standing and moving eddies in the lee of a hill.

Abe's demonstration in a wind tunnel of how to produce a wing-shaped cloud in the lee of a mountain is not conclusive, for a similar-shaped banner cloud can be explained by perturbation theory with no eddies or vortices in the lee.

Mr. H. S. Turner said that he had been collecting reports in the last 4 years at Northolt of standing waves observed by aircraft pilots, and now had 30 reports indicating that appreciable up-and-down currents, sometimes associated with marked turbulence, can be experienced by aircraft—in one case the aircraft was descending at 1,000 ft./min. over the Rhône Valley when it should have been ascending at 500 ft./min. In every case there was a shallow unstable layer recorded near the ground with a stable layer above. Cases were recorded in all months except June and July, and the most frequent areas were, in descending order, the Rhône Valley, north England and south Scotland, north Wales and the north Irish Sea. He gave a detailed account of the upper air picture on October 6, 1952, when Gloucester reported moderate or severe turbulence at 18,000–25,000 ft. in the Cheltenham area, and he was able to confirm the existence of standing waves by questioning a pilot at Northolt.

Mr. Gloyne mentioned that the flow round hills and valleys was of great importance in agricultural meteorology, and, for example, that hills and valleys of certain angles were self cleaning when snow fell and drifted. The same Brooks mentioned by the opener had also pointed out that orographic flow caused the forward flagging of trees on the tops of hills and the reverse flagging of trees in the reversed flow at the lee foot of the hills. Mr. Gloyne emphasized that the curvature in models was always greater than that on full scale.

Mr. Illsley described the effect of south-westerly winds on landing on the east-west runway at Gibraltar, pointing out that the south-westerly sea breeze was shallow and caused no difficulty but that with deep south-westerly currents the turbulence caused by the Rock made conditions very dangerous. Pilots had been forbidden to turn in the lee of the Rock owing to the danger of stalling in the eddies.

The effect of obstacles on the readings of anemometers was of course well known but he had found some very marked effects with two anemometers, one on the windward and the other on the leeward side of a building at South Cerney, and similar effects due to high ground at Plymouth.

Mr. Bannon very much doubted if Brooks's altimeter error in a vortex is important, for an aircraft would pass through the vortex before the altimeter could be read at all. He wondered if the opener had found any references in the literature to the size or distribution of the vortices to which Brooks was referring. Mr. Jacobs said that Brooks is very careful to avoid giving any idea of the size of the vortices but suggests that the intense ones are confined to near the mountain. He could find no other reference to the size of this "Brooks" vortex although Field and Warden found 6,000 ft. diameter for those in the lee of the Rock of Gibraltar. Dr. Scorer thought that the effect of the descending currents on aircraft in the lee was far more important than any possible altimeter error.

The Director mentioned that the Meteorological Office was in close touch with the United States Air Force project and has pointed out the importance of considering the wind shear and lapse rate.

Mr. Gold wondered if Dr. Scorer could give a description of the physical principles of the formation of the standing waves. He presumed the waves had a small effect on altimeter readings. He would like to know whether there had been any comparative readings of aircraft accelerations and altimeters. In connexion with Mr. Illsley's remarks on anemometers, he pointed out that similar difficulties were found long ago at the Lizard[30]. There was no doubt about the importance of flow over mountains, and he was surprised that there had in fact been so few aircraft accidents—he attributed this to the skill of the pilots. Dr. Scorer referred to the differences between aerodynamic and barostromatic flow, and said it was difficult to give the short physical explanation of the height distribution of wave motion asked for by Mr. Gold. He did not think aircraft accelerations and altimeter errors had been considered, or would be a worth-while investigation, but comparison of actual and altimeter readings of heights of gliders near hills was a profitable investigation, which he had already undertaken in north Wales, and he suggested could be repeated in the lee of the Isle of Man.

Dr. Stagg asked "Where do we go from here?" He pointed out the difficulties of waiting till conditions were just right in nature, e.g. for standing waves, and suggested that large model experiments in hangars as mentioned by Rouse might be the answer using the *S* number proposed by Dr. Scorer. Dr. Scorer thought the answer was to have mobile teams of meteorologists and glider pilots available to go to sites at short notice.

Mr. Wallington considered that more meteorologists should take up gliding. He mentioned that the late Terence Horsley had reported that on one occasion when he had landed after soaring in standing waves, to the lee of the Sidlaw Hills, he found that there had been such intense turbulence at ground level that trees had been uprooted.

The Director asked Mr. Gold how the Court of Inquiry had decided on the exact figures in their recommendations that the safety height over hills be increased so that when, for example, the wind had increased to 60 kt. the clearance should be 4,000 ft. Mr. Gold said that the figures seemed reasonable in the light of evidence available to the Court. There was no doubt whatever that 1,000 ft. is inadequate clearance in conditions that may arise over mountains of 3,000 ft. or more.

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LETTERS TO THE EDITOR

Sandstorms in the Sudan

It was interesting to compare Mr. D. W. Johnston's notes on the relation of visibility to wind in Cyrenaica[1] with corresponding effects on the other side of the Sahara. The haboobs or sandstorms of the Khartoum area are well known; they are associated with line-squalls moving north-westwards from Abyssinia and the eastern Anglo-Egyptian Sudan. Immediately prior to the arrival of a haboob the surface wind is calm, but in a matter of seconds it accelerates to 50–60 kt. and the visibility in blowing sand can fall below 10 yd. During the day-time a haboob can be seen approaching as a wall of sand. The mechanics of blowing sand have always been vaguely associated with instability in the line-squalls. Since the publication of the report on the American thunderstorm project[2] it is now thought that it is the leading edge of the cold down-draught from a thunderstorm cell which actually raises the loose sand. An average drop in temperature of about 20°F. on the arrival of a haboob is a confirmation of this theory.

Mr. Johnston also mentions the effect of vegetation on the initiation of blowing sand, this corresponds to another effect in the Sudan. A large area to the south-east of Khartoum known as the Gezira is now artificially irrigated and forms a large cotton plantation. Older inhabitants in Khartoum are convinced that present-day haboobs are not nearly so heavily sand-laden as those of earlier years.

The two photographs facing p. 17 are of a sandstorm or haboob; they were taken from the garden of my house in Khartoum about 1445 G.M.T. (1645 local time) one afternoon in June 1950.

J. FLEMING

Northolt Airport, March 10, 1952

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Duststorm near Mafraq

In the issue of the *Meteorological Magazine* for August 1952 there is a short note referring to two fine photographs of a duststorm near Mafraq. As it is thought that the note may give the impression that a duststorm is solely a frontal phenomenon, I would like to point out that this is not always the case. My own experience both in India and the Middle East is that many duststorms are associated with the squalls which accompany thunderstorms. The parent thunderstorm may have developed locally and the duststorm may or may not be followed by rain from the associated cumulonimbus cloud especially as the precipitation may evaporate before reaching the ground.

It is significant that, on the occasion in question, thunderstorms were reported in the area and in one of the two photographs there appears to be some cumulonimbus in the vicinity of the duststorm.

R. G. VERYARD

Stanmore, September 10, 1952.

Contrails and distrails

A phenomenon similar to that described by your correspondent H. G. Hopkins in the *Meteorological Magazine* for October was observed over west Wimbledon at about 10.30 a.m. on September 23, 1952. An aircraft caused a condensation trail (contrail) for a short distance in a cloud (there was no shadow, or relative motion of the cloud and the contrail) and on either side was a channel cleared of cloud (distrail). I fetched my camera but a lower cloud intervened before I could record it and the distrail was not visible about five minutes later when the contrail, now very diffuse, was again seen. However, after about two minutes, a second aircraft followed on a similar track—approaching from the south-west, turning to the left over Wimbledon Common and returning towards the south-west. A small length of contrail again appeared (Fig. 1) in about the same place, with a distrail on either side. The distrail developed into a row of holes in the course of the next five minutes (Figs. 2, 3, 4). The motion of the cloud cannot be judged from the position of the trees in the photographs because the camera was not fixed. Unfortunately the film ran out and the last picture is incomplete, but shows clearly the distrail holes. Lower cloud again intervened after a further 1½ minutes. The photographs are reproduced in the centre of this magazine.

A tentative explanation is suggested: the part of the cloud in which the distrail occurred was water cloud which was evaporated by the exhaust heat but did not reform immediately because of this heating and because of the downwash of the aircraft or simply because the surrounding air was not saturated with respect to water; the part in which the contrail formed was ice cloud at the same temperature and because the frost point was not exceeded, except perhaps in a small part of the wake of the aircraft, the cloud was not evaporated but the ice crystals grew through the addition of water vapour by the aircraft. The appearance of the cloud is, if anything, in favour of some explanation of this sort because the contrail part is more fibrous, the distrail part more woolly.

R. S. SCORER

Imperial College, London, S.W.7, November 13, 1952.

[At the time of Dr. Scorer's interesting observation an anticyclone was centred to the west of the Bay of Biscay and a depression to the north of Scotland. A warm front had passed over south-east England during the previous night. The surface isobars over south-east England were curved anticyclonically.

The tropopause height and temperature were about 41,000 ft. (190 mb.) and −80°F. The tropopause was reported by Larkhill as Type II (no inversion but a sharp discontinuity with lapse rate above), less than or equal to 1°F./1,000 ft. at 0300 G.M.T. and Type I (definite inversion) at 1500 G.M.T.

The Mintra level was about 29,700 ft. (320 mb.) at a temperature of −35°F. The vertical temperature distribution as shown by the Larkhill observations had no unusual features in the region between 20,000 and 40,000 ft. The difference between dry-bulb and dew-point readings at the highest level recorded, 350 mb., was 22°F. at 0300 G.M.T. and 16°F. at 1500 G.M.T. The wind above Larkhill at 0900 G.M.T. was 280° 36 kt. at 24,000 ft., 289° 38 kt. at 40,000 ft., and 308° 20 kt. at 50,000 ft.—Ed. *M.M.*]

NOTES AND NEWS

Unusual Cloud Pattern

We are indebted to Mr. R. Noble, 24 Norman Grove, Longsight, Manchester 12, for the aerial photograph of cloudlets arranged in a series of roughly concentric rings which is produced facing p. 16.

The photograph was taken at 38°50′N., 10°00′E., a little to the east of Capo Carbonara, the south-east point of Sardinia, between 0945 and 1015 G.M.T. on August 11, 1952. The photograph was taken from 35,000 ft. and the estimated height of the clouds is 3,000 ft. Mr. Noble estimated the clouds occupied a circle of 20 to 30 miles diameter. No other cloud was visible.

The cloudlets appeared to be stratocumulus just forming but may have been small cumulus.

The general wind direction was NE. on the west side of a trough of low pressure which moved eastwards across the Mediterranean. The clouds appear to have formed in a horizontal eddy presumably produced topographically.

There was apparently no general vertical motion in the eddy as the clouds show little vertical development. They probably formed in a shallow unstable layer, and but for the presence of the eddy would have been in a series of straight lines.

Propeller-tip condensation trails

The lower photograph facing p. 16 was taken aboard H.M.S. *Eagle* on March 18, 1952, and shows a typical example of propeller-tip condensation trails produced by the propeller of a Firefly aircraft. H.M.S. *Eagle* was, at the time, steaming near Nab Tower in the English Channel just to the east of the Isle of Wight.

The air mass over the area was old polar maritime air in the rear of an occlusion which moved north-eastwards along the Channel during the morning of March 16, 1952. This occlusion became stationary and frontolysed over Scotland and the North Sea in the face of an anticyclone which developed over Scandinavia, whilst the air over southern England became stagnant with a slight easterly drift on the 18th. It was very humid, relative humidities being more than 90 per cent. throughout the day at Calshot.

After a clear night the day at Calshot began with fog which cleared between 0700 and 0800, became cloudy with showers in mid afternoon, and again became foggy after dark. Thunder was heard during the afternoon.

Tornado in Northern Ireland

We are indebted to Mr. J. Porter of Garvagh for drawing attention to reports in the *Belfast News Letter* of October 25, and *Northern Constitution* of November 1, concerning a tornado at Upperlands, Co. Derry at 6.15 p.m. on Thursday, October 23, 1952. Considerable damage was done on the farm of Mr. M'Kinistry. A beech tree 4 ft. in diameter was uprooted and sheets of corrugated iron were later found suspended from tree branches 50 ft. above the ground. A metal pot weighing over 1 cwt. was moved nearly a quarter of a mile and corrugated iron roofing half a mile. Men repairing the tower of the church at Tamlaght, two miles distant, saw wreckage flying through the air. One witness spoke of seeing a "mass of something like smoke inside which leaves etc. were swirling". This was probably the funnel of the tornado.

On October 23, there was a very unstable south-westerly air stream over Ireland giving showers and local thunder.

METEOROLOGICAL OFFICE NEWS

Radio-sonde display.—At the exhibition organized by the Radio Industries Council held at Earl's Court at the end of the summer, an exhibit of radio-sonde equipment was staged, in conjunction with Messrs. Whitely's of Mansfield. The complete assembly, consisting of balloon, parachute and radio-sonde transmitter was shown, with ground receiving equipment in console form designed by Messrs. Whitely's for overseas sales. Signals from the radio-sonde could be seen on the cathode-ray tube and measurements taken by members of the public. Office staff attended to answer technical questions, to demonstrate the operation of the instruments and explain the purposes to which upper air observations are applied. The display attracted considerable attention and was valuable in bringing this branch of our work to the attention of the general public. The Office is indebted to Messrs. Whitely for allotting so large a part of their exhibit to meteorological apparatus.

Ocean weather ships.—Following an accident to the Second Engineer in *Weather Watcher*, the Master of the Ship consulted Dunstable Hospital by radio and carried out the treatment prescribed. On the ship's return to the Shore Base, the Medical Officer at Greenock Royal Infirmary stated that the treatment "could barely have been improved on, any refinements being merely academic".

Social and sports activities.—*Party at Harrow.*—On the evening of November 26, the staff of the Climatological Division at Harrow held a birthday party to celebrate the 60th birthday of Mr. R. H. Mathews, O.B.E., Assistant Director (Climatology). The party was planned by the staff as a demonstration to him of their very sincere appreciation of his efforts on their behalf, and of their affection for him. Over 120 past and present members of his Division attended. Mr. Mathews in a short address said how appreciative he was of the means taken by his staff to launch him into old age and how he would treasure the memories of their work and play together during the last four years.

Lawn tennis.—In the Air Ministry lawn tennis championships, the Office staff gained the following successes:

Ladies' Singles: Winner — Miss N. Edwards
Men's Singles: Runner Up — Mr. J. M. Lain
Mixed Doubles: Runners Up — Mr. J. M. Lain and Miss N. Edwards

Cross-Country Running.—The Office won the team race in the Air Ministry Cross-Country Championship held at Hayes, on Saturday, November 29, 1952. Mr. W. R. Bird was second, Mr. I. P. McDonald third in the individual event, and Mr. P. D. Dench second in the handicap.

The running of Messrs. McDonald and Bird did much to enable the Air Ministry Harriers to win the London Business Houses Intermediate Championship held at Parliament Hill Fields earlier in the month.

WEATHER OF NOVEMBER 1952

Mean pressure was above normal over the North Atlantic, north of 45°N., and Scandinavia, and below normal over central Europe. The mean pressure to the west and south-west of Ireland reached 1018 mb., which was as much as 13 mb. above normal in places; mean pressure at the Azores (1017 mb.) was 5 mb. below normal. Over Scandinavia and central Europe mean pressure was between 1010 and 1015 mb. and in the latter region it was 5 mb. below normal.

Mean temperature over the whole of Europe, except Spain, was about 2–5°F. below normal. The values of mean temperature varied from 20°F. in the north of Scandinavia to 35–45°F. in central Europe and 50–60°F. in the Mediterranean region.

In the British Isles the weather was exceptionally cold, particularly during the latter half of the month. As far as can be estimated at present it was the coldest November over Great Britain as a whole since 1925. Snowfall was the heaviest in November since 1919 and in some southern districts for a much longer period; for example at Oxford for 72 years. Less than the average sunshine occurred in Ireland but over most of Great Britain there was an excess; at Southport it was the sunniest November since records began in 1896.

The first week was unsettled generally, and rather mild in the south and west. On the 2nd a small disturbance moved from north of Ireland to the southern North Sea giving rain in most places. On the 4th another depression off north-west Ireland and associated troughs moved east; rain occurred generally and was heavy locally (3·04 in. at Blaenau Festiniog, Merionethshire, and 3·63 in. at Borrowdale, Cumberland). On the 5th a depression south of Iceland moved east-south-east and troughs moved across the British Isles giving further rain, with gales at exposed places in the north-west. Thereafter a deep depression moving south over the North Sea gave widespread severe north-westerly gales; gusts up to 80 kt. occured in the north-west Midlands and considerable damage occurred in some places. The north-westerlies persisted until the 11th but temperature was still not very low. By the 13th a ridge of high pressure extended from the Atlantic across Scotland to Russia; this distribution was temporarily broken on the 14th and 15th by a small depression moving south to south-west England and giving some rain in most places and a thunderstorm at Guernsey. A good deal of fog occurred from the 14th to the 16th. During the 17th and 18th another weak disturbance moved south-south-west from the north of Scotland giving showers, wintry in some parts. Thereafter a depression over France moving west gave considerable rain in the south and on the 20th and 21st a complex depression moving eastward over the country gave substantial rainfall and some wet snow. In the rear of this disturbance there was an outbreak of northerly winds of Arctic origin followed by a ridge of high pressure; snow lay 5 in. deep at Dyce, near Aberdeen, on the 23rd and exceptionally hard frost for November was registered on the mornings of the 24th and 25th. Air temperature fell to 17°F. at Midleton, near Cork on the 24th and to 5°F. at Dalwhinnie, 7°F. at Moor House, Westmorland (1,830 ft.), and 10°F. at Kielder Castle on the 25th. Subsequently a depression moved east-south-east from south-west Ireland and later turned east-north-east along the English Channel to west Germany giving considerable precipitation in southern districts. Heavy rain in Sussex (2·04 in. at Heathfield in the 24 hours to 0900 on the 28th) caused serious flooding. In the closing days a trough of low pressure over northern France spread a little north giving further precipitation in the south on the 29th. In a belt across the country covering parts of East Anglia, the Midlands, the hills in the south-west and most of south Wales, during the last four days there were successive falls of sleet or snow which lay on the ground. Snow lay 10 in. deep at Whipsnade, in the Chilterns on the 30th, with drifts up to 8 ft. in the the vicinity. At Tredegar, Monmouthshire (1,028 ft. above M.S.L.), it lay 6 in. deep from the 27th to the 30th and on the evening of the 29th a train travelling from Merthyr Tydfil to Abergavenny ran into a 10 ft. drift at Pen-y-Wern. In the north severe frost and valley fog occurred; on the morning of the 29th air temperature fell to 10°F. at Moor House and 12°F. at Eskdalemuir, while the maximum temperature at Renfrew on that day was only 24°F., the lowest maximum there in November since records began in 1921.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	62	10	−3·2	118	−1	116
Scotland	57	5	−3·3	77	−1	123
Northern Ireland ...	57	20	−2·3	85	−3	85

RAINFALL OF NOVEMBER 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·85	163	*Glam.*	Cardiff, Penylan ...	4·00	99
Kent	Folkestone, Cherry Gdn.	4·54	140	*Pemb.*	Tenby, The Priory ...	3·86	89
,,	Edenbridge, Falconhurst	4·46	126	*Radnor*	Tyrmynydd	4·73	71
Sussex	Compton, Compton Ho.	5·09	134	*Mont.*	Lake Vyrnwy	4·25	74
,,	Worthing, Beach Ho. Pk.	4·12	129	*Mer.*	Blaenau Festiniog ...	7·46	70
Hants.	Ventnor Cemetery ...	6·08	185	,,	Aberdovey	4·21	93
,,	Southampton, East Pk.	3·71	118	*Carn.*	Llandudno	2·47	85
,,	Sherborne St. John ...	3·74	131	*Angl.*	Llanerchymedd ...	3·77	90
Herts.	Royston, Therfield Rec.	3·74	161	*I. Man*	Douglas, Borough Cem.	3·60	76
Bucks.	Slough, Upton... ...	2·93	132	*Wigtown*	Newton Stewart ...	2·94	59
Oxford	Oxford, Radcliffe ...	3·81	166	*Dumf.*	Dumfries, Crichton R.I.	2·13	58
N'hants.	Wellingboro' Swanspool	2·91	135	,,	Eskdalemuir Obsy. ...	3·96	68
Essex	Shoeburyness	4·23	199	*Roxb.*	Kelso, Floors	4·08	177
,,	Dovercourt	4·45	207	*Peebles*	Stobo Castle	2·95	89
Suffolk	Lowestoft Sec. School...	4·21	179	*Berwick*	Marchmont House ...	3·41	114
,,	Bury St. Ed., Westley H.	4·12	179	*E. Loth.*	North Berwick Res. ...	2·32	104
Norfolk	Sandringham Ho. Gdns.	3·27	132	*Midl'n.*	Edinburgh, Blackf'd. H.	2·07	92
Wilts.	Aldbourne	4·76	163	*Lanark*	Hamilton W. W., T'nhill	2·15	60
Dorset	Creech Grange... ...	4·64	113	*Ayr*	Colmonell, Knockdolian	2·54	51
,,	Beaminster, East St. ...	4·95	125	,,	Glen Afton, Ayr San. ...	3·66	67
Devon	Teignmouth, Den Gdns.	5·15	161	*Renfrew*	Greenock, Prospect Hill	2·16	36
,,	Cullompton	3·91	114	*Bute*	Rothesay, Ardencraig...	2·61	51
,,	Ilfracombe	4·53	115	*Argyll*	Morven (Drimnin) ...	2·72	40
,,	Okehampton Uplands...	6·06	114	,,	Poltalloch	2·54	45
Cornwall	Bude, School House ...	4·45	125	,,	Inveraray Castle ...	3·50	41
,,	Penzance, Morrab Gdns.	6·60	144	,,	Islay, Eallabus... ...	2·69	50
,,	St. Austell	5·78	117	,,	Tiree	2·06	43
,,	Scilly, Tresco Abbey ...	6·01	174	*Kinross*	Loch Leven Sluice ...	2·11	59
Glos.	Cirencester	3·81	128	*Fife*	Leuchars Airfield ...	1·99	87
Salop	Church Stretton ...	3·67	118	*Perth*	Loch Dhu	2·82	32
,,	Shrewsbury, Monksmore	2·34	104	,,	Crieff, Strathearn Hyd.	2·02	47
Worcs.	Malvern, Free Library...	3·30	131	,,	Pitlochry, Fincastle ...	1·97	53
Warwick	Birmingham, Edgbaston	2·54	107	*Angus*	Montrose, Sunnyside ...	2·04	77
Leics.	Thornton Reservoir ...	2·00	88	*Aberd.*	Braemar	3·06	80
Lincs.	Boston, Skirbeck ...	2·79	139	,,	Dyce, Craibstone ...	3·55	109
,,	Skegness, Marine Gdns.	2·55	118	,,	New Deer School House	4·29	133
Notts.	Mansfield, Carr Bank...	2·51	103	*Moray*	Gordon Castle	4·09	142
Derby	Buxton, Terrace Slopes	3·66	78	*Nairn*	Nairn, Achareidh ...	2·55	113
Ches.	Bidston Observatory ...	2·44	98	*Inverness*	Loch Ness, Garthbeg ...	3·27	78
,,	Manchester, Ringway...	2·13	82	,,	Glenquoich	8·28	68
Lancs.	Stonyhurst College ...	2·46	55	,,	Fort William, Teviot ...	4·27	52
,,	Squires Gate	1·96	59	,,	Skye, Duntuilm ...	4·40	73
Yorks.	Wakefield, Clarence Pk.	1·21	57	,,	Skye, Broadford ...	5·60	65
,,	Hull, Pearson Park ...	3·08	141	*R. & C.*	Tain, Tarlogie House ...	2·81	95
,,	Felixkirk, Mt. St. John...	1·71	70	,,	Inverbroom, Glackour...		
,,	York Museum	1·48	71	,,	Achnashellach	7·93	92
,,	Scarborough	4·09	166	*Suth.*	Lochinver, Bank Ho. ...	6·90	137
,,	Middlesbrough... ...	3·37	159	*Caith.*	Wick Airfield	3·57	114
,,	Baldersdale, Hury Res.	2·34	64	*Shetland*	Lerwick Observatory ...	2·88	68
Norl'd.	Newcastle, Leazes Pk....	3·23	137	*Ferm.*	Crom Castle	1·70	49
,,	Bellingham, High Green	3·81	111	*Armagh*	Armagh Observatory ...	2·47	87
,,	Lilburn Tower Gdns. ...	4·32	129	*Down*	Seaforde	2·86	75
Cumb.	Geltsdale	3·42	104	*Antrim*	Aldergrove Airfield ...	3·01	93
,,	Keswick, High Hill ...	3·21	57	,,	Ballymena, Harryville...	3·59	89
,,	Ravenglass, The Grove	1·68	38	*L'derry*	Garvagh, Moneydig ...	4·27	109
Mon.	Abergavenny, Larchfield	3·87	101	,,	Londonderry, Creggan	3·71	90
Glam.	Ystalyfera, Wern House	5·36	82	*Tyrone*	Omagh, Edenfel ...	3·23	85

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

Wt-33. K15.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 968, FEBRUARY 1953

ANOMALY CHARTS AND FORECASTING

By R. W. JAMES, M.Sc.

Introduction.—It is normal to regard an instantaneous pressure pattern as consisting of an overall mean flow and one or more perturbations in that flow. It is therefore important to consider whether it is possible to disentangle perturbations from the mean flow, and present the pattern of each separately.

A chart of pressure meaned over any period, gives rigorously the pattern of mean geostrophic flow for that period, but careful thought must be devoted to whether a mean flow, so obtained, is physically significant. A chart of mean pressures over a 24-hr. period is certainly a mean chart, but such a mean would not be held to have any real relevance to atmospheric processes, for the period of meaning is shorter than the time during which a perturbation influences any one point.

In long-term forecasting the five-day mean chart is much used for "smoothing out" the perturbations, but here again the period of meaning is rather too short to give a physically significant mean flow. The pressure at a point may be unusually low for a period of three days or longer owing to its proximity to the path of a migrating low, and hence the 5-day mean pressure at that point will not be truly representative of what the pressure would have been in the absence of a perturbation. It is true that, in a five-day period, a given point might have been traversed by two perturbations of opposite sign. In this way the average may be "kept straight" but this presupposes a specific perturbation pattern, which is presupposing too much.

The only way to keep the average straight is to take a meaning period long compared with the time for which a single perturbation influences any one point. The longer the meaning period, of course, the slighter the disturbing influence of any one perturbation on the mean, but there is a limit to the length of period to be taken, for the mean flow itself changes seasonally, and in transitional periods it may change rapidly. Hence a suitable meaning period must be long compared with the life of a single perturbation, but must be short enough for changes in the mean flow to be inappreciable. In some circumstances both these conditions cannot be met simultaneously. We have been considering migratory perturbations, the effect of which is felt at a single point for only a day or so. However, it is possible to have a stationary perturbation in the mean flow dominating a region for a matter of weeks.

According to the principles enunciated above, it would be necessary to study such a perturbation with a mean chart extending over months, but then we could no longer neglect the seasonal variation in the mean flow. This difficulty is surmounted by taking as our mean flow some seasonal mean based on a number of years' observations. Three-monthly means might be considered adequate for the purpose, although a more refined elimination of seasonal trend would be obtained by using monthly mean charts.

An anomaly chart could be prepared by "gridding" a current synoptic chart with a seasonal mean field. This procedure is simple to apply as a synoptic routine, for no more is required than a set of mean seasonal overlays. It suffers, however, from the drawback that migrating and stationary perturbations both appear on the anomaly chart and are not separated. The short-lived migrating anomalies can be eliminated by meaning anomaly charts over a suitable period, say 10–30 days. This is entirely analogous to eliminating passing perturbations from current synoptic charts by meaning over five-day periods, or longer.

Once a chart of the "semi-permanent" anomalies is obtained, it is possible to produce a chart containing only the transient anomalies by gridding an anomaly chart against a "semi-permanent" anomaly map covering the relevant period. In general this double-gridding process is tedious, and takes a great deal of labour. In most circumstances it should be possible to separate the transient from the semi-permanent anomalies by examination of serial charts.

Normally the mean surface flow is weak compared with the surface flow in perturbations. The raw surface chart may be regarded as virtually an anomaly chart, the mean flow element in it being so weak as to occasion only a slight distortion of the perturbation pattern.

The same is not true of upper-level charts. Here gradients associated with the mean flow tend to be stronger than those due to perturbations. Perturbations are frequently so weak in relation to the general flow at 300 mb. that they are manifest only as trough or wedge distortions in the latter. The "true" structure of a weak perturbation can in this way be distorted almost out of recognition by a strong general flow, and in such cases the anomaly chart becomes of real value in disentangling the perturbation from the mean flow.

It might well be that forecasters are hampered in their interpretation of high-level charts by this swamping effect of the mean flow. The anomaly chart should therefore prove of value in interpreting the high-level structure of atmospheric vortices.

Anomaly Charts.—Fig. 1 shows the contour pattern over the United States at 0300 G.M.T. on April 19, 1949. Contours are drawn at 200-ft. intervals. The broken lines show the mean contours for March–May, derived from "Upper winds over the world"[1]. The conspicuous feature of this chart is a closed centre of low pressure over the Great-Lakes region. Gridding gives the anomaly pattern displayed in Fig. 2. It will be seen that the anomaly pattern is very much simpler than that of the contour chart from which it is derived. The normal north-south pressure gradient has been almost completely eliminated. Contour heights are close to normal everywhere except in the region of the cold low.

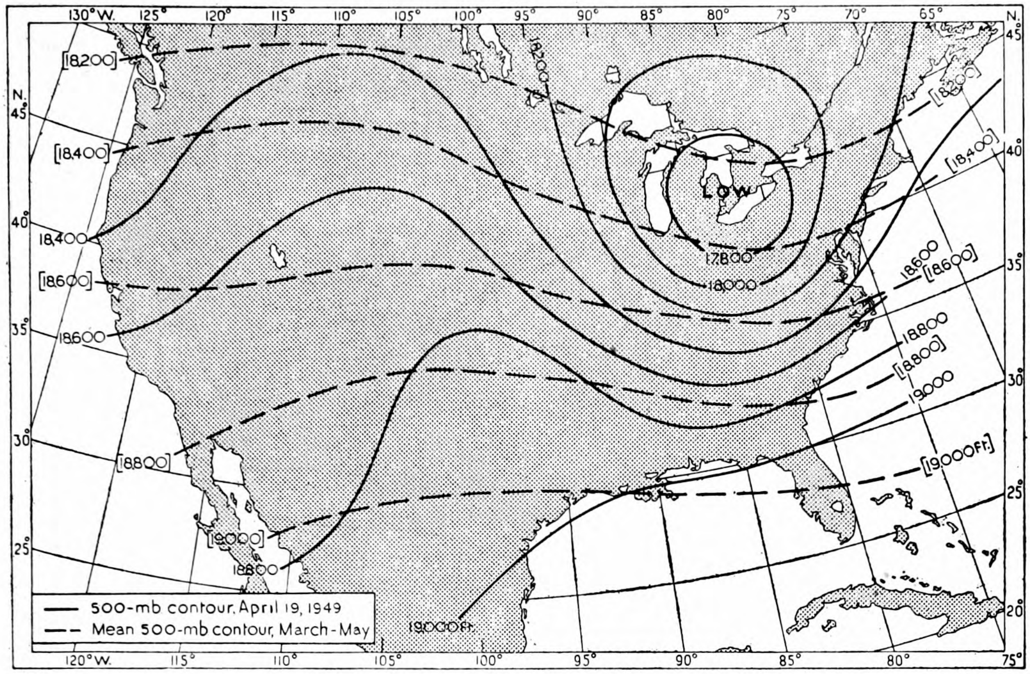

FIG. 1—500-MB. CONTOURS, 0300 G.M.T., APRIL 19, 1949

It seems reasonable, therefore, to take the anomaly pattern as representative of the structure of the cold low as such. The vortex covers something less than the eastern half of the United States, and is roughly circular. The outer limit of the vortex may be taken as the line of zero anomaly.

The central contour anomaly is −700 ft. indicating a pressure anomaly of −13 mb. approximately.

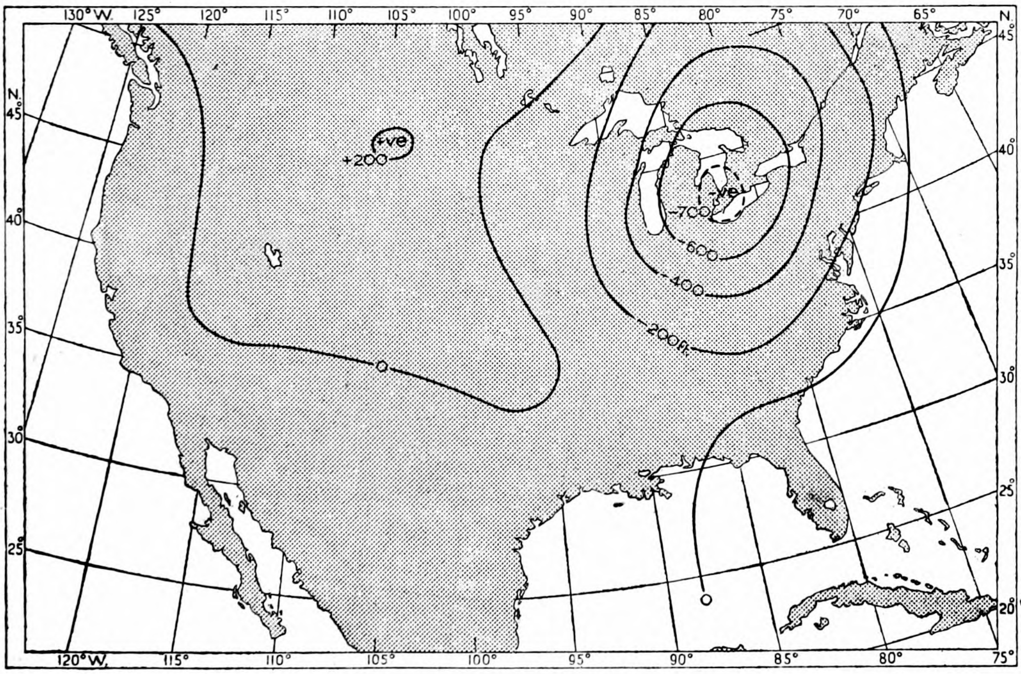

FIG. 2—500-MB. CONTOUR ANOMALY PATTERN, 0300 G.M.T., APRIL 19, 1949

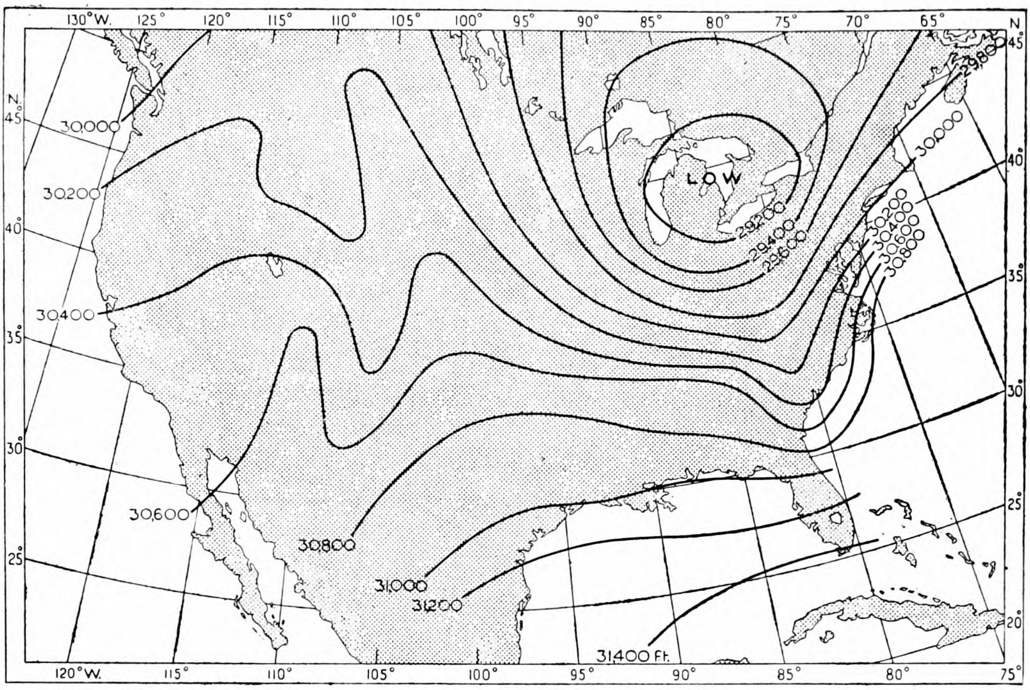

FIG. 3—300-MB. CONTOURS, 0300 G.M.T., APRIL 19, 1949

Fig. 3 shows the 300-mb. contours for the same time, and Fig. 4 the contour anomaly at 300 mb. Again a more clear-cut pattern is seen in the contour anomaly, dominated by the eastern vortex. The vortex at the 300-mb. level has a slightly greater extent along the north-south axis, and covers a slightly wider area, but its relation to the 500-mb. section is clear. The central anomaly is −900 ft., representing an intensity of −11 mb. There is a slight decrease in

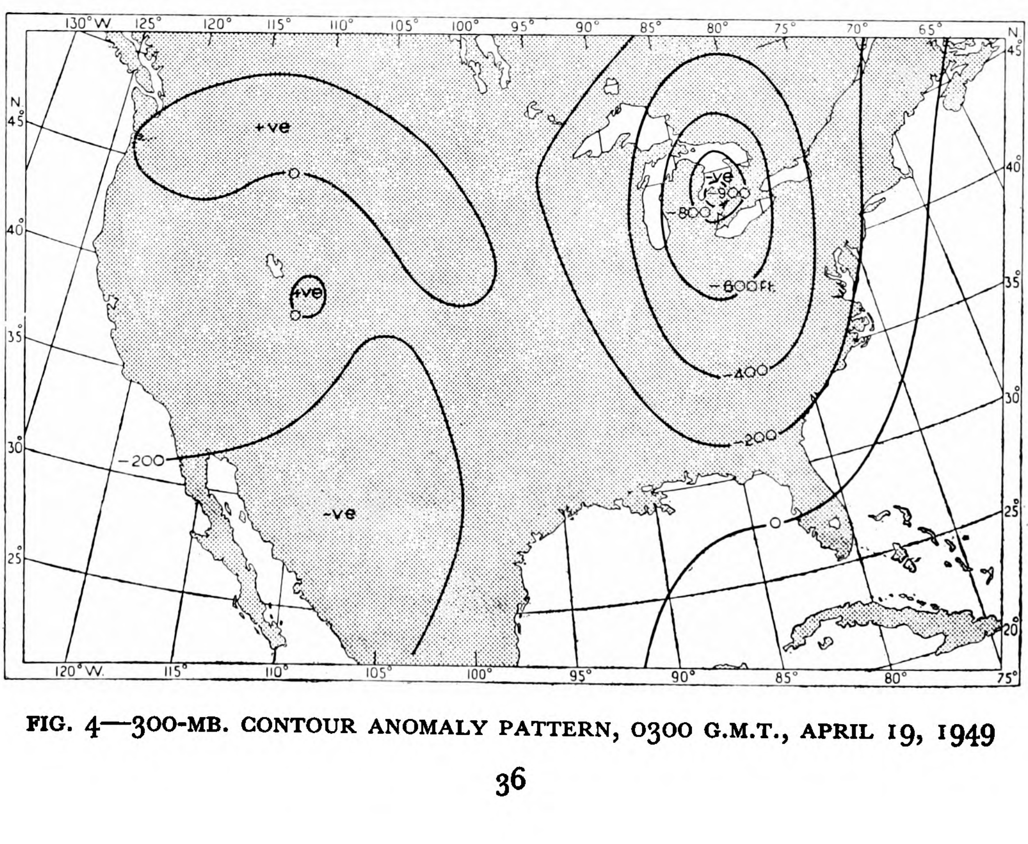

FIG. 4—300-MB. CONTOUR ANOMALY PATTERN, 0300 G.M.T., APRIL 19, 1949

intensity between the 500-mb. and 300-mb. levels, but the vortical geostrophic winds increase in this range proportionately to the increase in contour anomaly.

Similar patterns are found at other levels.

An examination of the situation illustrated, and others, convincingly demonstrates that it is possible to disentangle a perturbation field from a mean flow, and to analyse the horizontal and vertical structure of individual vortices. The anomaly chart purports to display the vortical structure as such, and, from this point of view, might be studied with profit so as to gain a clearer picture than is possible with the raw contour maps, which inevitably include the distortions associated with the mean flow.

The use of such charts puts emphasis on the high-level morphology of pressure patterns, and it seems likely that the structure of a vortex is related to its subsequent evolution.

The relation of horizontal pattern to stage of maturity and future development is well known in the case of frontal lows, and is an indispensable part of the forecaster's machinery. It may equally be possible to trace a characteristic evolutionary change in the vertical structure of pressure patterns, thereby making use of vertical structure as a guide to future development. That there is a characteristic evolution in the vertical structure of systems is, of course, widely known. Anticyclones characteristically first appear as cold wedges of little depth, and develop into warm highs of great vertical extent. On inception the frontal low is "warm" and shallow. There is a steady vertical extension with the occlusion process.

Goldie[2] has made these qualitative findings rather more explicit by presenting "characteristic" vertical structures corresponding to early and late stages of occlusion. He finds that in the natural occlusion momentum remains approximately constant with height up to about 8 Km. (Clayton-Egnell law) and falls off rapidly at higher levels. A similar structure of momentum is found to be characteristic of the developed warm high.

The author[3] has been able to confirm Goldie's broad findings by means of a parametric approach to the measurement of vertical structure. This parametric approach can be used to examine quantitatively such characteristic evolutionary developments as the occlusion process, and the transformation of a migrating cold high into a warm, stable system.

The bearing of these structural features on the evolution of pressure patterns is a question which must be left to future synoptic research. However, enough is known from a limited number of cases studied, to express the belief that high-level structure is an important element in the evolutionary process, and hence a key in the forecasting of development in the field of pressure. In an examination of vortical structure the anomaly chart may be expected to play an important role.

The anomaly-pattern technique can, of course, be applied to other meteorological elements, such as temperature, thickness pattern, etc.

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UNUSUAL AUGUST WEATHER OVER SOUTHERN SPAIN AND PORTUGAL

By A. WARD

The most marked feature of the weather over southern Spain and Portugal during the summer months is the almost complete lack of rain; over very large areas the average monthly rain in August is less than 0·2 in.[1] Much of the rain which does occur is in the nature of isolated upper-level thunderstorms, either produced *in situ* by the diurnal heating of the ground or carried over from north Africa by a southerly upper wind. The storms occur in the evening or during the early part of the night, and are generally quite local and of short duration. However, during the period August 27–29, 1952, inclusive, practically the whole area was affected by outbreaks of thundery rain or thunderstorms, and in places, particularly over an area to the north-east of Gibraltar, falls of over 1 in. were recorded.

Synoptic situation.—Throughout the period an anticyclone was centred north of the Azores with a ridge extending to the east-north-east over northern France and the Low Countries. Shallow and indefinite depressions persisted over Spain and Portugal until, on the morning of August 29 when a considerable fall in pressure occurred over south-western France and the southern Bay of Biscay, a more definite depression developed in the Bay, and a westerly gradient was established across the Iberian Peninsula. The synoptic chart for 0600 G.M.T. on August 28 is reproduced in Fig. 1.

Fair or fine weather was reported over most of the Iberian Peninsula on the 26th and during the night of the 26th–27th. Reports of thick medium cloud at Madeira and isolated cumulonimbus over French Morocco on the evening of the 26th indicated increasing instability to the south-west and south. During the morning of the 27th thick, unstable medium cloud, with outbreaks

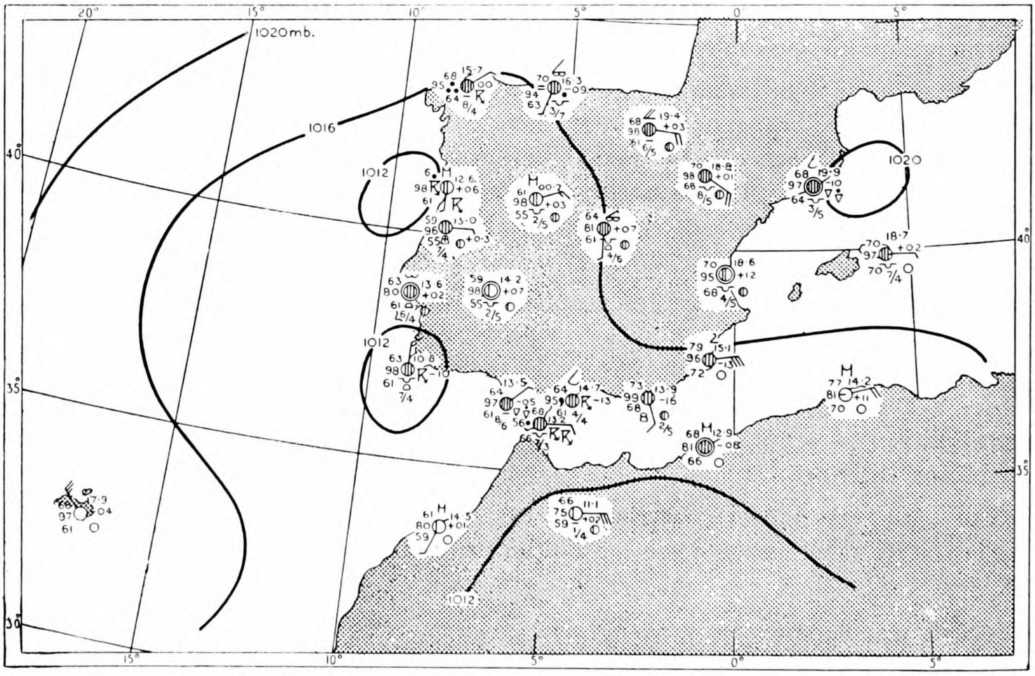


FIG. 1—SYNOPTIC CHART, 0600 G.M.T., AUGUST 28, 1952

of thundery rain, spread quickly north-east over southern Spain and by the evening had covered most of central, eastern and southern Spain. The area of thundery outbreaks continued to spread, and by midday on the 28th covered practically the whole of Spain and Portugal. During the 29th clearing conditions moved slowly north-east across the peninsula and the thundery outbreaks moved into southern France.

The lack of information precludes the construction of a detailed rain chart over the period, but it is evident that, over a very large area, the rainfall exceeded 0·5 in. The area of heaviest fall was to the north-east of Gibraltar where, in places mainly in the foot-hills and on the southern slopes of the Sierra Nevada, falls of over 1 in. in 24 hr. were recorded. The available climatological data for this area[1] indicate a mean August rainfall of about 0·2 in., with a maximum 24-hr. fall of 0·1 in. or less. The total rainfall at Gibraltar during the period was 0·3 in.

Upper air temperature and moisture content.—The unusual rainfall is mainly attributed to a cold pool, which developed in a pronounced cold trough off the Portuguese coast on August 26, moved eastwards to a position near Lisbon by 0300 G.M.T. on the 27th, and after remaining almost stationary for 24 hr. slowly increased in temperature and moved north-eastwards into the Bay by 0300 G.M.T. on the 30th. The 1000–500-mb. thickness chart for 0300 G.M.T. on August 28, with the approximate movement of the cold pool marked by crosses, is reproduced in Fig. 2. The exceptional depth of the cold air, indicated by a closed 18,200-ft. thickness line near Lisbon, was undoubtedly due to the marked southward penetration of cold air on the 25th and 26th

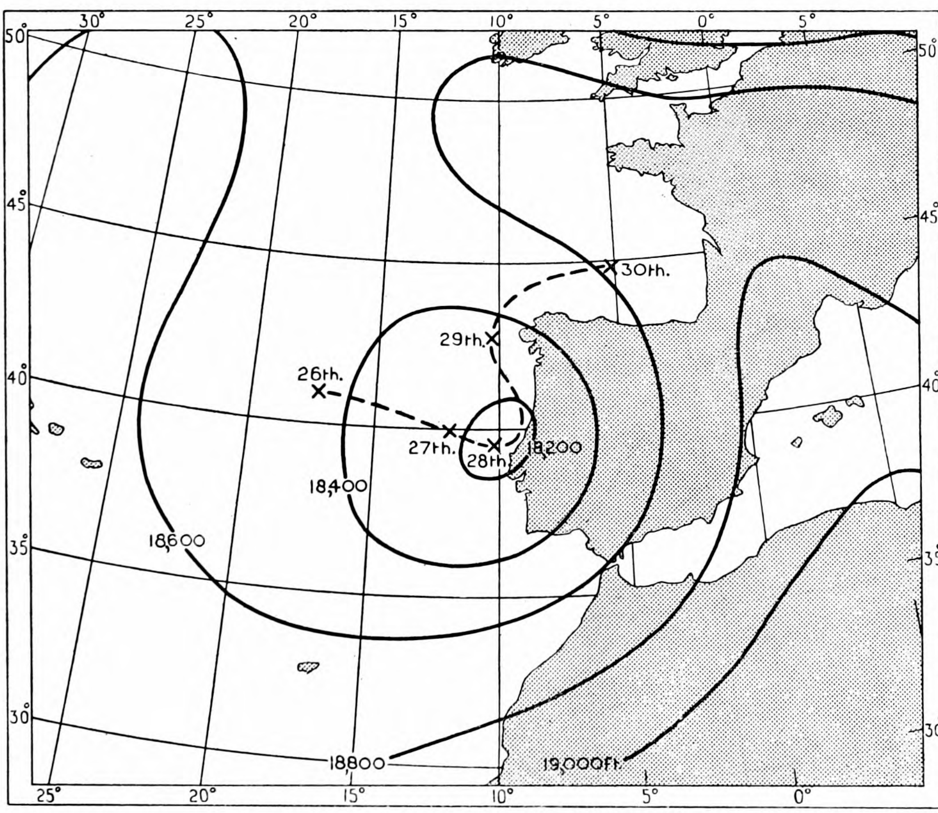
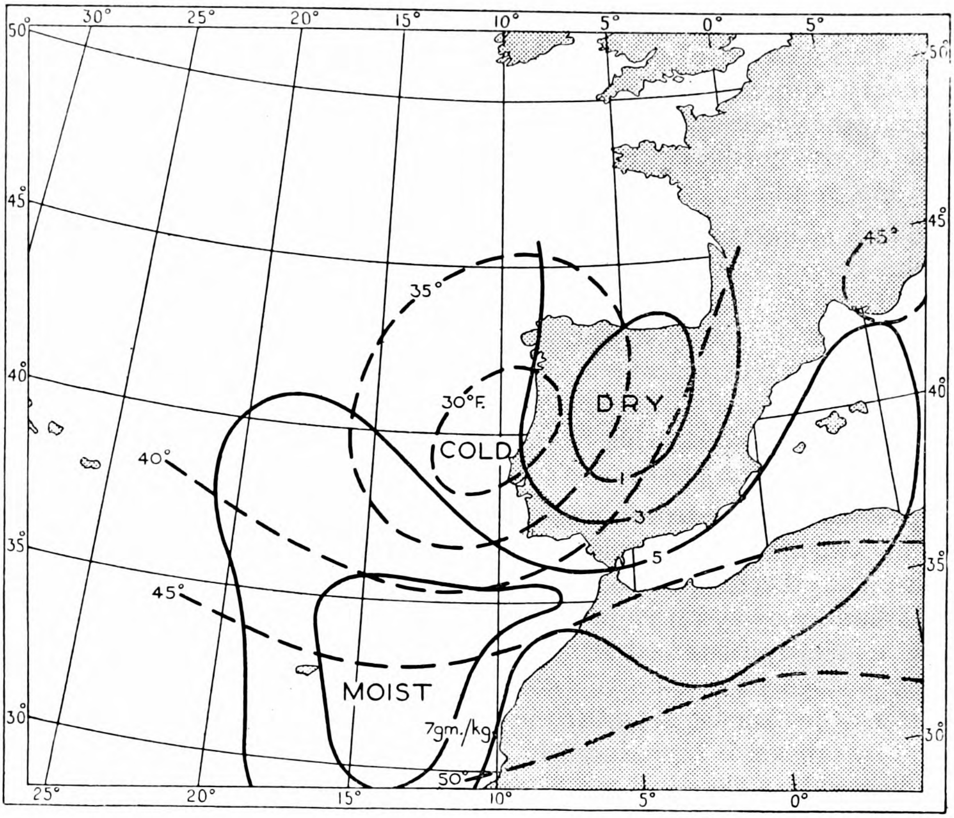


FIG. 2—1000–500-MB. THICKNESS CHART, 0300 G.M.T., AUGUST 28, 1952



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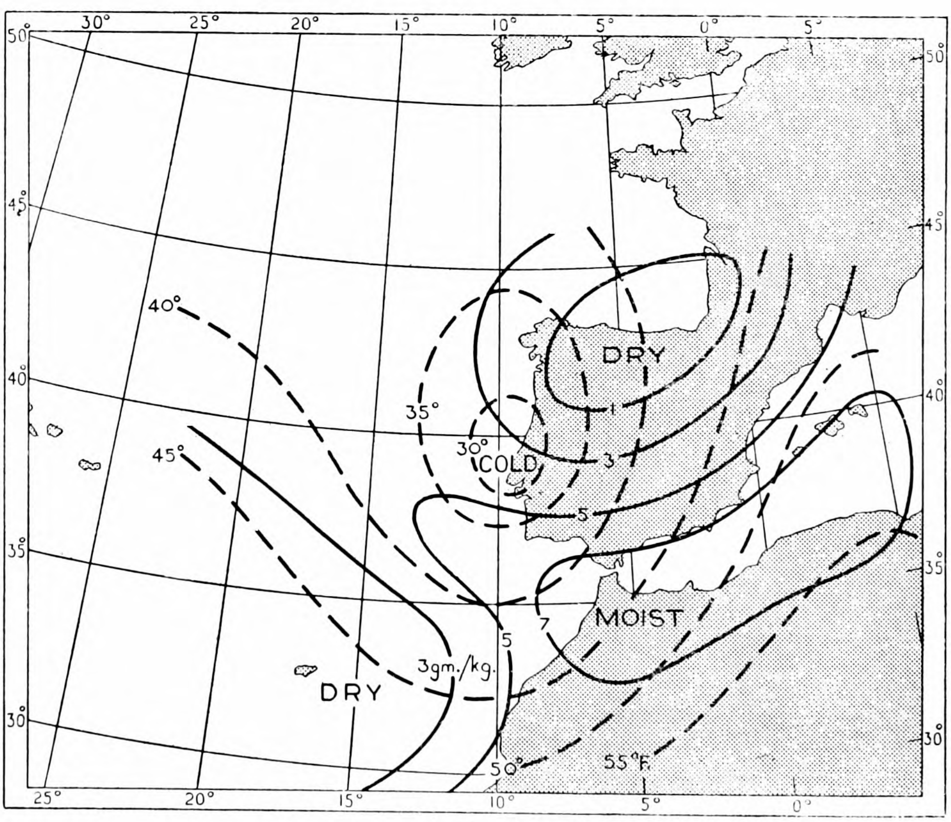

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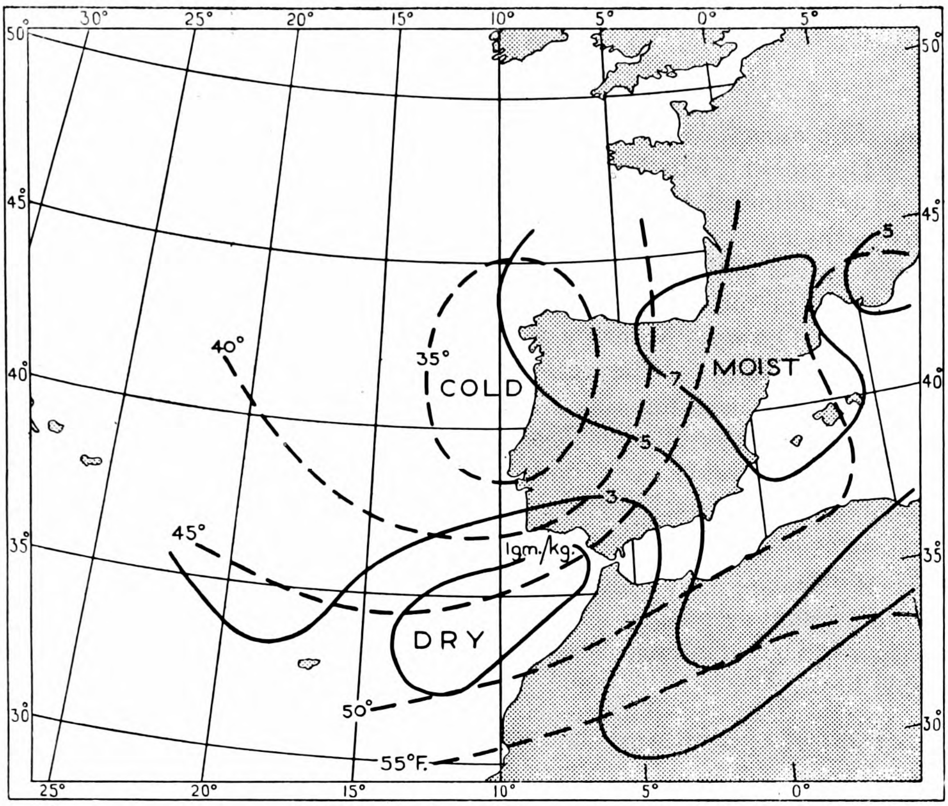

0300 G.M.T., August 29, 1952

FIG. 3—700-MB. TEMPERATURE AND MOISTURE-CONTENT CHARTS FOR AUGUST 27–29, 1952

- - - - - - - - - Isotherms. ———————— Isopleths of humidity mixing ratio.

Saturation humidity mixing ratio at 700 mb.

°F.	gm./Kg.	°F.	gm./Kg.	°F.	gm./Kg.
25	4	35	6	45	9
30	5	40	7·5		

behind a slow-moving depression over the Bay of Biscay. The 1000–500-mb. thickness at Lisbon was over 400 ft. below the mean value for August[2].

Cold pools of similar intensity have occasionally developed off the Portuguese coast in August in previous years, notably in 1947, but on these earlier occasions it appears that the air was too dry to give other than isolated thundery outbreaks.

During the period under discussion, however, the cold pool was associated with a pocket of very moist air aloft; the thundery outbreaks were closely related to the north-eastward movement of this moist air and the subsequent improvement to the incursion of drier air from the south-west. Selected 700-mb. temperature and moisture-content charts, based on all the upper air data available, are reproduced in Fig. 3.

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DOES A COLD AUTUMN HAVE ANY INFLUENCE ON THE WINTER FOLLOWING?

By R. F. M. HAY, M.A.

The question must have occurred to many people recently (this is being written in early December), whether a cold autumn such as we have just experienced tends to be followed by a cold winter or otherwise. A similar problem in seasonal sequences was recently investigated by Glasspoole.* For the south Midlands it was anticipated that some useful information might be obtained from a study of the long homogeneous temperature record of the Radcliffe Observatory, Oxford. Monthly values of mean temperature for this station have been published for the period 1815–1930. For the purpose of this note these values were used together with the series for the same station since published in the *Monthly Weather Report*, which were made directly comparable with the aid of monthly corrections kindly supplied by the Radcliffe Meteorological Station. The data used here refer to the period 1821–1950; autumn is defined as September, October and November, winter as December, January and February.

As the decadal means for autumn and winter for this period showed a range of up to 1·5°F., a first step was to obtain smoothed decadal means as given in Table I.

TABLE I—DECADAL MEAN TEMPERATURE DURING AUTUMN AND WINTER

Oxford — Period: 1821–1950

Decade	Autumn	Winter	Decade	Autumn	Winter
	°F.	°F.		°F.	°F.
1821–30	50·3	38·9	1881–90	49·2	38·9
1831–40	49·9	39·0	1891–1900	49·5	39·0
1841–50	49·5	39·0	1901–10	49·5	39·5
1851–60	49·4	39·2	1911–20	49·4	40·0
1861–70	49·4	39·5	1921–30	49·8	40·0
1871–80	49·2	39·2	1931–40	50·3	39·4
			1941–50	50·7	39·3

Smoothed values were obtained by the usual $(a + 2b + c)/4$ method, and the deviations of each autumn and the following winter from this long-period mean were corrected for each year for the difference of the appropriate smoothed decadal mean from the long-period mean. In practice a value of the smoothed decadal mean appropriate to each year was used by simple interpolation from the above table. In this way a large part of the effect of secular change was eliminated.

Frequency distributions of temperature deviations for autumn and winter at Oxford (related to smoothed decadal means as described) are shown in Fig. 1. The autumn curve has almost a "normal" distribution. The curve for winter on the other hand is distinctly "skew" and has two additional interesting maxima. These are taken to indicate a preference for a winter type of pressure distribution giving mild winters with a mode in the temperature deviations at +2·3°F. and for a less common type, though one which gives severe winters, with another mode at −5·3°F. These curves were drawn to assist in defining classes of autumn and winter temperature deviations, from

*GLASSPOOLE, J.; Seasonal weather sequences over England and Wales. *Met. Mag., London*, **78**, 1949, p. 193.

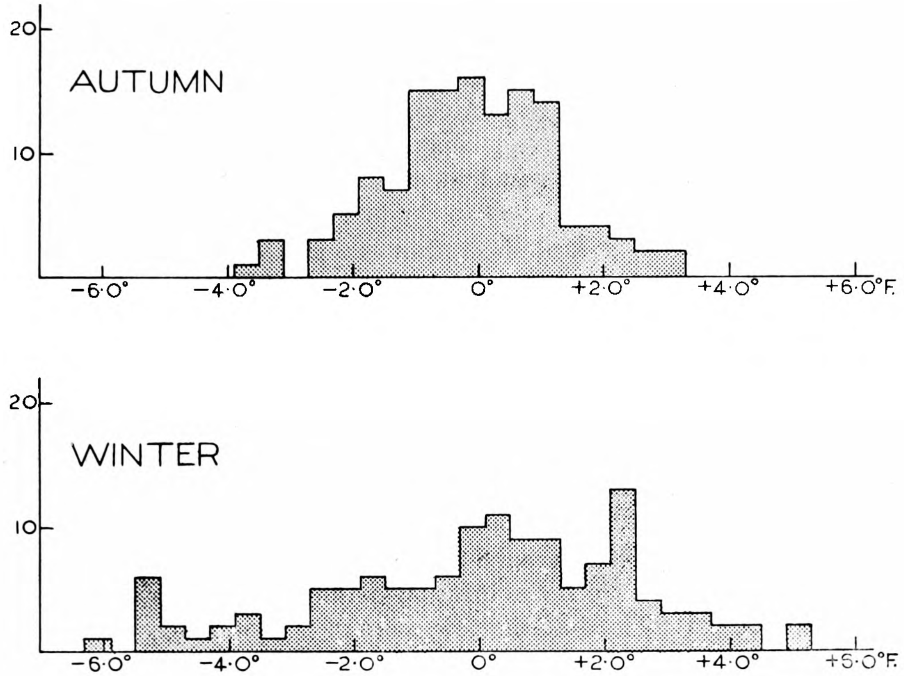

FIG. I—FREQUENCY DISTRIBUTION OF DEVIATIONS OF MEAN DRY-BULB TEMPERATURE FROM SMOOTHED DECADAL MEANS, OXFORD 1821–1950

which the data given in Table II were obtained. The definitions adopted for both autumn and winter were: "average" not more than 0·9°F. from the mean, "above" or "below" more than 0·9°F. but not more than 2·9°F. from the mean, and "much above" or "much below" more than 2·9°F. from the mean.

TABLE II—CONTINGENCY TABLE BETWEEN ASSOCIATED TEMPERATURE DEVIATIONS DURING AUTUMN AND THE FOLLOWING WINTER

Oxford — Period: 1821–1950

	FOLLOWING WINTER					
AUTUMN	Much below	Below	Average	Above	Much above	Totals
Much above	..	..	..	1	1	2
Above	2	3	8	11	3	27
Average	10	15	23	16	7	71
Below	2	5	9	9	1	26
Much below	2	1	..	1	..	4
Totals	16	24	40	38	12	130

It is at once obvious that the information here is of no direct value for long-range forecasting. Autumns classified as "below" and "much below" are almost equally likely to be followed by cold or warm winters. There does appear to be some evidence that autumns "above" and "much above" average are followed by winters "above" or "much above" more often than by winters "below" average. As there were not enough occasions in all classes for a χ^2 test to be applied to the table as it stands, the data for "much above" and "much below" were joined with their respective "above" and "below" classes for this purpose. Application of the test showed no statistically significant difference in the class frequencies from expected values, i.e. there is no significant association between characteristics of autumns and following winters when simply expressed as "above" and "below" normal. In preparing Table II the years which contributed to each class were noted. Most interest attached to the cell relating autumns above average with winters above average which included 11 out of 27 autumns in this class, namely those for the years 1824, 1834, 1847, 1865, 1866, 1921, 1929, 1938, 1945, 1947, and 1949. However, the influence of minor climatic change is evident here since no year between 1866 and 1921 contributed to this cell, while 4 years in the last 12 contributed.

The smoothed decadal means show that the period of mild winters in the first three decades of the present century has ended. The rate of fall of the decadal means has, however, become less and the fall seems unlikely to persist through another decade. At Oxford autumn decadal temperatures have increased by 1·3°F. in the last 30 years, though the recent autumn suggests this process may be ending. The autumn of 1952, relative to the appropriate smoothed decadal mean, was the coldest in the 130 years' series (deviation −3·9°F.), although in relation to the long-period mean the autumns of 1829, 1840, 1887 and 1919 were slightly colder.

In conclusion no reliable inference regarding the temperature of the winter of 1952–53 can be drawn from the unusual coldness of the past autumn. The most that can be stated is that the few cases of exceptionally cold and warm autumns in the past 130 years have been mostly followed by cold and warm winters respectively. Since sea temperature is very conservative and winter temperature in Great Britain is to some extent influenced by sea-surface temperature this result is not surprising; its violation is brought about by the incidence of easterly winds which, as was well seen in February 1947, can greatly reduce the warming influence of the narrow seas within a few weeks.

ACCURACY OF 100-MB. WINDS

By D. H. JOHNSON, M.Sc.

Summary.—The results of a statistical test applied directly to the wind reports show that for British land stations the standard vector errors in reported winds at the 100-mb. level are generally less than 6 kt.

Introduction.—A notable feature of the wind field at the 100-mb. level is its steadiness in space and time. This provides an opportunity to establish directly an upper limit to the observational error in the wind reports. Bannon[1] has already estimated from the performance of the radar equipment that high-level wind errors should be small. This is confirmed in the present paper.

Estimates of wind errors from instrumental performance.—Estimates of the errors in winds measured with the GL. Mk III radar equipment in use at British land stations have been made by Bannon[1]. These apply to measurements of wind over 1-min. intervals, and were deduced from the basic errors of the radar instrument as functions of height and of the mean wind speed up to the level in question. Bannon's estimates of the root-mean-square vector error in the measurement of winds at 50,000 ft. are reproduced in Table I. These values are expected to vary slightly with the skill of the operators and the state of efficiency of the instrument.

TABLE I—ROOT-MEAN-SQUARE VECTOR ERRORS IN WINDS AT 50,000 FT. TO THE NEAREST KNOT (DUE TO BANNON)

	Mean wind (kt.)						
	10	20	30	40	50	60	70
Root-mean-square error (kt.)	2	2	3	4	5	6	7

Errors at 100 mb.—The appropriate pressure level for each radar observation of wind is determined from a graph drawn to show the pressure level reached by the radio-sonde at any chosen time. Winds are calculated from radar observations made at 1-min. intervals, but it is the practice in the British Meteorological Office to ascribe to a given pressure level a wind averaged over a period of either 2 or 3 min. At 100 mb. the random errors in the measurement of pressure are known to be large. Harrison[2] has given the probable error at 200 mb. as 5 mb. It follows that winds at 100 mb. cannot be measured so accurately as winds at 50,000 ft. Additional errors may arise in the computation and transmission of the data.

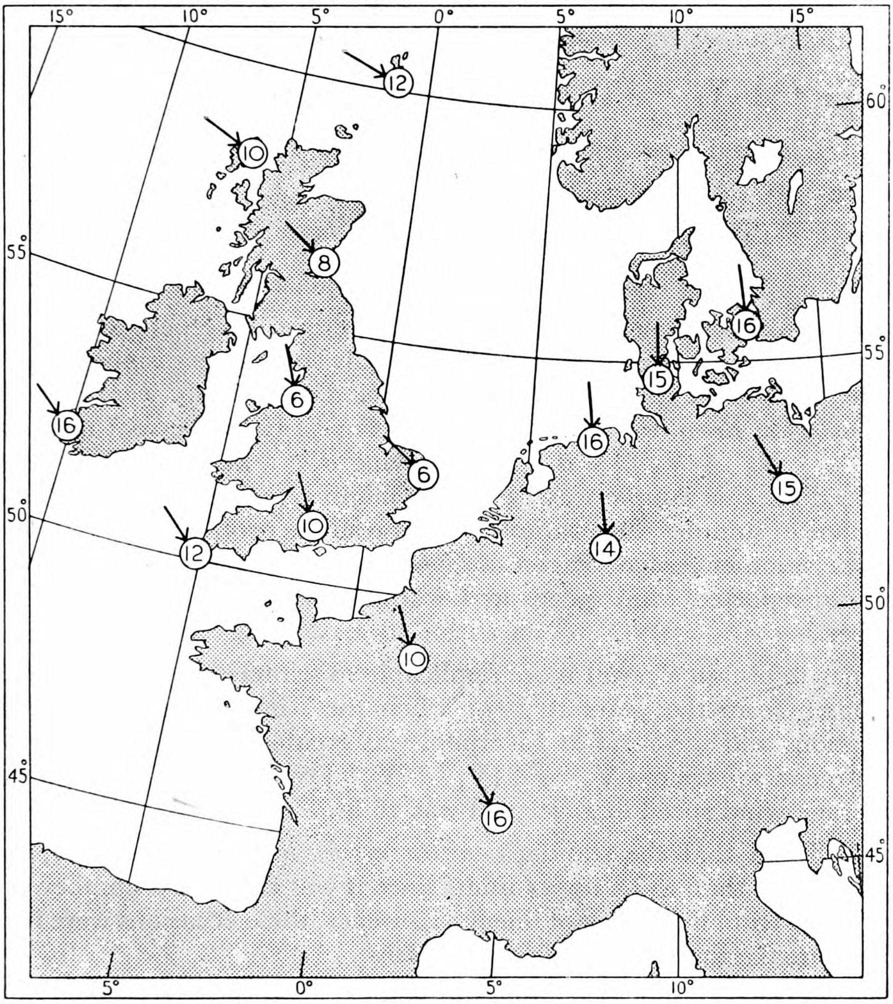

FIG. 1—WINDS (IN KNOTS) AT THE 100-MB. LEVEL, 1500 G.M.T., MARCH 17, 1952

A feature of the 100-mb. wind reports is the general coherence of the observations both in space and time with the suggestion of a steadiness in the wind exceeding that of lower levels. An example of the general coherence in space is shown in Fig. 1. Such smooth flow patterns are regularly to be seen on the working charts, which itself implies that the total effect of the vector errors discussed above must be small. It was decided to utilize this property of the flow to estimate statistically an upper limit to the total standard vector error of the reported winds rather than to attempt to estimate the magnitude of the component errors individually.

Statistical test.—Three stations A, B, C, are required, spaced at equal intervals along a line.

Let the true (vector) winds at A, B, C, be $\mathbf{V}_1$, $\mathbf{V}_2$, $\mathbf{V}_3$

Let the measured winds at A, B, C, be $\mathbf{V}_1'$, $\mathbf{V}_2'$, $\mathbf{V}_3'$

Let the (vector) errors in winds at A, B, C, be ε_1, ε_2, ε_3

Then the wind at B may be estimated from the winds at A and C by linear interpolation with an error η

Thus $$\mathbf{V}_2 = \tfrac{1}{2}(\mathbf{V}_1 + \mathbf{V}_3) + \eta$$

or $$\mathbf{V}_2' + \varepsilon_2 = \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3') + \frac{\varepsilon_1}{2} + \frac{\varepsilon_2}{2} + \eta\,.$$

Thus $\left\{\mathbf{V}_2' - \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3')\right\} = \frac{\varepsilon_1}{2} + \frac{\varepsilon_3}{2} - \varepsilon_2 + \eta.$

Now ε_1, ε_2, ε_3 and η are independent and $\overline{\varepsilon_1{}^2} = \overline{\varepsilon_2{}^2} = \overline{\varepsilon_3{}^2} = \sigma^2$ (say).

Therefore

$$\overline{\left\{\mathbf{V}_2' - \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3')\right\}^2} = \tfrac{3}{2}\sigma^2 + \eta^2$$

and hence $\sigma\sqrt{(3/2)}$ is less than the root mean square of $\left\{\mathbf{V}_2' - \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3')\right\}$.

The three British upper air stations at Aldergrove, Liverpool and Downham Market are approximately collinear and equally spaced; occasions were chosen from the first half of 1951 when reports of wind at 100 mb. were given in the *Daily Aerological Report* for all three stations. For 74 cases the root mean square of $\left\{\mathbf{V}_2' - \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3')\right\}$ was 6 kt., implying $\sigma < 5$ kt. The mean Liverpool wind speed for this sample was 13 kt. As might be expected there was a preponderance of summer observations, so this result is probably more representative of the summer season; Part 1 of *Upper air data 1946–50*[3] gives the average of 100-mb. reported wind speeds at Larkhill as 13 kt. in June and 27 kt. in December.

In order to obtain a result more applicable to winter observations, occasions were chosen from the years 1950–51 when the winds were available for all three stations and the wind at Liverpool was greater than 19 kt. For 78 cases the root mean square of $\left\{\mathbf{V}_2' - \tfrac{1}{2}(\mathbf{V}_1' + \mathbf{V}_3')\right\}$ was 7 kt. implying $\sigma < 6$ kt. The average wind speed at Liverpool was 26 kt.

It is believed that the standard vector errors in the winds were, in fact, appreciably less than those upper limits since it was clear on a number of occasions that the wind field was not linear. However, these occasions were included in order to make the test completely objective.

Conclusions.—These tests, made directly on the reported winds, indicate that the standard vector error of 100-mb. wind reports from British land stations must be small both in summer and winter. They confirm the order of magnitude of the errors in winds at 50,000 ft. deduced by Bannon from the basic errors of radar.

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METEOROLOGICAL OFFICE DISCUSSION

Short-range weather forecasting

The discussion on Monday, November 17, 1952, held at The Royal Society of Arts, was opened by Mr. V. R. Coles who based his statement on two articles from the "Compendium of meteorology":—

DUNN, G. E.; Short range weather forecasting, p. 747.

BUNDGAARD, R. C.; A procedure of short-range weather forecasting, p. 766.

Mr. Coles said that both articles indicated that the problem of weather forecasting can be divided into three sections:—

(i) Analysis of current information

(ii) Construction of forecast charts

(iii) Forecasting the weather from the completed forecast charts.

Both Dunn and Bundgaard are mainly concerned with the construction of forecast charts, though they point out that on many occasions the problem of forecasting the weather is more difficult.

Although surface forecast charts—prebaratics—and upper air forecast charts—prontours—must obviously be closely integrated, the writers point out that there is some advantage in a semi-independent preparation of the prebaratic and prontour charts. This procedure ensures that well marked features on the upper charts are given full weight on the forecast charts and are not obliterated without good reasons.

After the prebaratic and prontour charts have been prepared more or less independently, they are adjusted to be mutually consistent.

The first step in the construction of all forecast charts is extrapolation of recent trends, and the prebaratic is considered first. Extrapolation from working charts over the last 24 hr. leads to the first approximation to the prebaratic and this approximation is then adjusted in the light of current tendencies. To this end isallobaric charts for 3 hr. and 12 hr. are maintained, the 12-hr. charts being adjusted for diurnal variation of pressure. New systems cannot, of course, be forecast by the extrapolation procedure, and the latest tendency field must be carefully watched for indications of the formation of wave disturbances on fronts and the development of new anticyclones.

Having located a wave disturbance the forecasting problem is to decide whether it is likely to develop into a large depression. At this stage in the preparation of the prebaratic chart the methods recommended by the two writers diverge, Dunn making use of the 700-mb. contour chart to decide how the surface systems can be expected to develop and move, whilst Bundgaard describes how Sutcliffe's expression for the divergence of the thermal wind enables the thickness chart for 1000–500 mb. to be used to determine areas of cyclonic and anticyclonic development and to forecast the movement of surface systems. Bundgaard points out that Sutcliffe's work calls for some modification of Scherhag's earlier rules for determining the development of surface systems from the topography of the 500-mb. contour chart. Several of these rules are quoted in Bundgaard's article.

Dunn then describes the semi-independent preparation of the 700-mb. forecast chart, other levels being constructed in a similar manner. The process is again one of extrapolation of recent trends, with adjustment in the light of the latest tendency field, followed by comparison with the independently prepared prebaratic.

Bundgaard describes the preparation of prontour charts by the building-up process, and is therefore concerned particularly with the forecasting of the thickness patterns. He describes in detail the preparation of the 1000–500-mb. forecast thickness, or pre-thickness chart. Again, extrapolation of recent trends is the first step followed by a correction for current tendencies, due weight being given to the motion of cold pools, warm ridges, etc. Bundgaard points out that though the thickness lines move, to the first approximation, with the gradient wind through the isobaric layer, care must be taken to make allowance for non-advective dynamical and thermodynamical effects. The completed pre-thickness chart is then compared with the prebaratic for consistency and the prontour chart obtained by the graphical addition of pre-thickness and prebaratic charts.

The problem of forecasting the weather from the completed forecast charts is not dealt with in great detail in either article, though Bundgaard devotes some time to the problem of objective forecasting, taking as an illustration the forecasting of rainfall amount.

The Director, before inviting general discussion, referred to the fact that forecast manuals were now being prepared in which the forecasting of pressure patterns and of the weather would be separately treated. In connexion with objective forecasting he asked what success the method had achieved.

Mr. Sharp said that the forecasting devices we had heard about were all empirical, and that the forward step made when fronts were recognized was of an entirely different nature, being the recognition of something factual, something real and fundamental. Mr. Sharp suggested the next big step forward would be similar, and would come from the appreciation of fundamental processes in the upper atmosphere above 500 mb.

Dr. Stagg asked if there was anything in practice we could learn from Dunn and Bundgaard's methods and whether sufficient attention was paid to cold pools. Mr. Coles replied that pre-thickness charts had been prepared independently of the prebaratics for some time at Dunstable as an experiment, but it was probably true to say that they were not so good as pre-thickness charts prepared after the completion of the prebaratic.

Mr. Sawyer said that a study of the extensive literature on methods of "objective" forecasting suggested that results achieved up to the present had been roughly of the same standard as those obtained by conventional methods. An attempt at Dunstable to estimate rainfall from prebaratic charts by computing Sutcliffe's expression for cyclonic development had given rainfall patterns which looked reasonable in relation to the chart. However, important features of the rainfall distribution obtained in this way were often dependent on minor details of the prebaratic chart which could not be relied upon. Perhaps the best way of improving rainfall forecasts was to apply statistical methods to specific recognizable synoptic types, rather than to such "objective" methods which are expected to apply with westerlies and easterlies alike.

Dr. Sutcliffe said that we could no longer blame all our forecasting troubles on our lack of a theoretical understanding of depressions and anticyclones. In fact we had now a tolerably good idea of how and why these systems developed,

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MAMMATUS CLOUD, ANDORRA, JULY 15, 1952
(see p. 57)

Reproduced by courtesy of Bath & Wilts. Chronicle & Herald

GLAZED FROST, LANSDOWN, BATH, SOMERSET, 11.15 a.m., NOVEMBER 30, 1952

Reproduced by courtesy of METPHOTO

CLOUD CLEARANCE LANES BY AIRCRAFT NEAR RYE, SUSSEX

The photograph was taken about 1730 on August 17, 1952, a few seconds after three piston-engined aircraft had passed through the cloud. The lanes slowly filled in and after five minutes had disappeared.

Reproduced by courtesy of METPHOTO

AIRCRAFT CONDENSATION CLOUD IN SHADOW

Reproduced by courtesy of J. W. Wilkins

TYPICAL FOG CONDITIONS, RICHMOND PARK, SURREY, 1500, DECEMBER 7, 1952

(see p. 57)

but the theory suggested that prediction had inherent limitations. It may be that the general standard of short-range forecasting had not improved very much, and so far as we could see at present there may be little prospect of a radical improvement, but there was a great difference, he said, between uncertainty based on ignorance, which led to guesswork, and uncertainty based on scientific understanding, which permitted the forecaster to give the maximum amount of useful advice appropriate to the problem in hand. It was very valuable to study methods used in other countries, but the conclusion was that at present there were no revolutionary ideas waiting to be picked up, little more than interesting variations in technique. Until something new was discovered the practical forecaster could justifiably regard his duty as that of extracting the extra few per cent. of efficiency by conscientious work in the light of available knowledge. Dr. Sutcliffe commented on numerical methods, and indicated that research was going well in the Office as well as in other countries but we had no right as yet to expect revolutionary improvements in forecasting by these methods.

Dr. Farquharson stressed the value of having trained scientists as forecasters, who could assess the relative value in the day-to-day problem of results achieved by research. It was better that a trained scientist should make an *ad hoc* selection of what was likely to be useful to him in the practical problem rather than that small pockets of staff should be employed on various lines suggested by research which might possibly be useful. The Forecast Division was at present engaged in two experiments: in one the upper air forecaster was attempting to work independently of the surface forecaster in the preparation of prebaratics; in the other the quantitative forecasting of rainfall in the London area was being attempted. The Forecast Division was very much alive to needs and did its best to meet outstation requirements; it would be interesting to hear what outstations had to say about this.

Mr. Robins criticized the prebaratics prepared by the Forecast Division, indicating that too little attention seemed to be paid to isallobaric, and too much to upper air, fields.

Mr. Douglas said that great weight was attached to tracks and barometric tendencies by the forecasters at the Central Forecasting Office, and three-dimensional analysis should not be regarded as a rival technique. Its function was rather to explain the changes in progress, and failing some miraculous advance in forecasting this was the criterion by which scientific ideas should be judged. A better understanding of the underlying physical processes leads to some improvement on pure extrapolation. The significant features of the tendency field can be picked up while the chart is being plotted. If isallobars are drawn this must be done on a separate chart before the prebaratic is made, at the same time as the isobaric chart is being drawn up and analysed. Hitherto the demand for the 3-hourly isallobaric chart has not been strong enough to justify it. Isallobaric charts for longer time intervals are difficult to interpret physically and are therefore more purely empirical. The factors which make progress in forecasting a slow process also limit the standard attainable by any forecaster. In view of the large element of chance in 24-hr. forecasting, an outstation forecaster will sometimes make a better guess than Dunstable. A reasonable measure of consistency in the forecasts issued must be maintained, but within these limits our outstations have always enjoyed considerable freedom.

Cmdr Frankcom asked if use were made of ships' barometric-tendency reports and whether the establishment of ocean weather ships had improved the accuracy of forecasts. Mr. Coles, in his reply, stated that he considered ships' observations to be vital and that tendency reports were necessary.

Dr. Scorer pleaded for greater attention to be paid in textbooks to the aspect of diurnal variation of the various weather elements.

Mr. Gold stressed that the step from forecast charts to weather forecasts was on occasions much more difficult than from analysis to forecast charts, and suggested that a special study of forecast errors associated with "wrong placing" on the forecast charts was needed.

Several following speakers protested about the mutilation of forecasts by the Press and B.B.C.

The Director, in summing up, said that post-mortems on forecasts were held daily at Dunstable and that major errors were investigated in an attempt to prevent their recurrence. He said that the forecasting monographs which were being prepared would give attention to all aspects of diurnal variation. He stated that considerable effort was spent in trying to ensure that the Press and B.B.C. did not mutilate the forecasts.

METEOROLOGICAL RESEARCH COMMITTEE

The 22nd meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on October 3, 1952.

The papers discussed at this meeting included one by Mr. D. H. Johnson[1] on the accuracy of the measurement of the winds at 100 mb., and another by Mr. R. Murray[2] on jet streams over the British Isles during June 14–18, 1952. A paper by Mr. A. G. Matthewman[3] on cloud in relation to warm and quasi-stationary fronts near Bircham Newton in winter aroused much interest as it threw doubt on the idealized warm-front cross-section model which has adorned meteorological textbooks for the last 30 years.

The Sub-Committee also reviewed the progress made in research.

The 22nd meeting of the Physical Sub-Committee was held on October 9, 1952.

The Committee considered the results of work done during the previous winter on the measurement of visual range and of slant visibility and on the relation of these measurements to other conditions.

Interesting papers on turbulence in the lowest layers were discussed. They included one by Mr. Rider[4] dealing with the evaporation from a growing crop of oats in terms of the Richardson number at some low level and another by Mr. Lander and Dr. Robinson[5] describing some measurements of the small-scale fluctuations of wind and temperature near the ground.

The 14th meeting of the Instruments Sub-Committee of the Meteorological Research Committee was held on October 23, 1952.

The Committee reviewed the instrumental aspects of the investigation of visibility and visual range carried out last winter. Current methods of measuring liquid water content in cloud[6] were also considered.

Three reports dealing with the development of a technique for measuring atmospheric density at high altitudes by means of the scattering back of light from a pulsed searchlight beam were examined and a recommendation made regarding the next step in this work.

ABSTRACTS

1. JOHNSON, D. H.; A note on the accuracy of 100-mb. winds. *Met. Res. Pap., London,* No. 739, S.C. II/112, 1952.

Winds at 100 mb. are generally coherent in space and time, e.g. over west Europe on March 17, 1952. Hence winds at 3 collinear equally spaced stations can give the root-mean-square error at the middle one. For British stations it is appreciably below 6 kt.

2. MURRAY, R.; The jet streams over the British Isles during June 14–18, 1951. *Met. Res. Pap., London,* No. 743, S.C. II/114, 1952.

A long-wave trough with associated depression north of Scotland is shown by surface and 300-mb. charts. Vertical wind and temperature sections show a cold frontal zone and two jet streams. One moved rapidly south-east over Europe, dying out on June 16, the other moved south-east across the British Isles at about 5 kt., becoming dominant on June 15. Their average lateral speed, 7·9 kt., compares with a geostrophic component of 6·5 kt. Changes in wind maxima are related to changes of mean thermal gradient of troposphere. A model for tropopause structure and development during jet streams is put forward.

3. MATTHEWMAN, A. G.; On the three-dimensional structure of fronts: Part II—Cloud in relation to warm and quasi-stationary fronts near Bircham Newton in winter. *Met. Res. Pap., London,* No. 747, S.C. II/115, 1952.

Vertical cross-sections were drawn for 49 surface warm fronts or warm occlusions. Frontal cloud development is tabulated in relation to distance of surface front, height and thickness of frontal zone, shear of geostrophic and actual wind, relations between speeds of warm or cold air and of front, and ageostrophic motion of front. A definite relation was found only with forward wind component relative to front (correlation 0·5).

4. RIDER, N. E.; The evaporation from an oat field during the late spring and summer of 1951. *Met. Res. Pap., London,* No. 724, S.C. III/127, 1952.

The aerodynamic formula for evaporation from gradients of wind speed and specific humidity is extended to include zero displacement (height of effective surface above the ground, calculated from wind speeds at three heights) and Richardson number (for departure from adiabatic). The revised equation is applied to observations at various points in an oat field near Cambridge, recorded automatically at heights up to 160 cm. depending on the crop height. The apparatus is fully described and illustrated, specimen records shown, and a number of values of daily water loss computed (ranging from 0·05 to 5·65 mm.). Values are estimated as up to 15 per cent. too low.

5. LANDER, A. J. and ROBINSON, G. D.; Some observations of the small-scale fluctuations of wind and temperature near the ground. *Met. Res. Pap., London,* No. 740, S.C. III/138, 1952.

Records were made on cloudless days, wind 1–2 m./sec., 25 cm. over short grass, with small vertical and horizontal hot-wire anemometers and a resistance thermometer. Half-hourly profiles were taken of air and earth temperature, humidity and wind, with solar radiation and fluxes of atmospheric and terrestrial radiation. Theory and errors of flux of heat and linear momentum are discussed, and the estimated fluxes, eddy conductivity and eddy viscosity tabulated. The heat flux found is 30–50 per cent. of that calculated from radiation and soil temperature; the remainder is attributed to movements small compared with the instrument. The frequency distributions of the fluctuations are not normal and much of the heat flux is associated with large vertical currents. The turbulence is shown to be anisotropic.

6. MURGATROYD, R. J.; Methods of measuring liquid water content in cloud. *Met. Res. Pap., London,* No. 737, S.C. I/66, S.C. III/136, 1952.

The stringent instrumental requirements for use in aircraft are summarized. Existing methods discussed include: impaction, absorbent cylinders, capillary collector, resistence of absorbent paper, rotating cylinders, rotating disc, orifice-type icing-detectors, heated wires or cylinders, heated intake and hygrometer, transmitted or scattered light, etc.

HONOURS

The following awards were announced in the New Year Honours List, 1953:—

KNIGHT BACHELOR

Professor Harold Jeffreys, Cambridge University

O.B.E.

Mr. J. C. Cumming, Principal Scientific Officer, Meteorological Office

M.B.E.

Cmdr. J. Hennessy, R.D., R.N.R., Senior Nautical Assistant, Meteorological Office

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 11—Duststorms of the Anglo-Egyptian Sudan. By M. H. Freeman, M. Sc.

Duststorms are the most important meteorological phenomena affecting the air routes over the Anglo-Egyptian Sudan. They are caused by an increase in the surface wind and occur in both winter and summer, but the two types are generated somewhat differently. In winter the gradient wind steadily increases and visibility is gradually reduced by blowing dust. In summer the duststorms are usually associated with thunderstorms and are known as haboobs; the wind increases in a sudden squall and visibility drops almost instantaneously from good to less than 1,100 yd.

The Report describes each type and discusses the physical processes involved. Statistics, based on the four-year period 1944–48, are given of frequency, duration, severity, time of onset and maximum wind speed. Methods of forecasting each type are considered. A particularly severe kind of haboob of long duration is discussed in detail in view of its importance to aviation. The Report was first written in 1948, and the principles outlined in it have been successfully used in the Anglo-Egyptian Sudan for some time.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on November 19, 1952, with the President Sir Charles Normand in the Chair, the following papers were read:—

*Ludlam, F. H.—Orographic cirrus cloud**

Mr. Ludlam said observations by aircraft pilots show that ridges or hills of 1,000 ft. in height can produce atmospheric waves disturbing the air flow up to 30,000 ft. leading to the air at these high levels being displaced vertically some 2,000 ft. at speeds of 1 m./sec. or more. At temperatures of about —40°C. or less, if the humidity is sufficiently high, cloud droplets may form which subsequently freeze and form cirrus clouds which trail down wind. A number of observations made from Dunstable of cirrus trails forming over the Chilterns, Cotswolds and the Black Mountains were vividly described. The azimuths and elevations of the commencements of the trails were measured by theodolite. The rate of displacement of details observed by theodolite, supposing the clouds were at a height where temperature was about —40°C., agreed with the Larkhill wind soundings. Orographic cirrus forms less readily in the middle of the day, as is to be expected from Dr. Scorer's theory of orographic wave formation which shows such waves form less readily when the air near the ground is made unstable by solar heating.

In the course of the discussion doubt was expressed about the orographic origin. Mr. Gold asked if these cirrus clouds had been seen at midday and how Mr. Ludlam knew the clouds were not at a higher level than where temperature was —40°C. It was also pointed out by Dr. Farquharson and others that cirrus cloud has been observed at high levels from aircraft close to the cloud which could not be seen from the ground. Mr. Schove thought all cirrus was frontal in origin. Dr. Scorer said he had seen orographic cirrus

* *Quart. J.R. met. Soc., London,* **78**, 1952, p. 554.

at midday, and Prof. Sheppard described seeing cirrus form over the coastal mountains of south-west Ireland and spread inland. Mr. Ludlam said these clouds were observed at midday and when there were no obvious fronts. He pointed also to the mother-of-pearl clouds seen over southern Norway, which were at a much greater height than his orographic cirrus and were universally admitted to be of orographic origin. In thanking Mr. Ludlam, the President pointed out that the orographic theory of the formation of mother-of-pearl cloud was accepted by few meteorologists until the sail-plane observations in the Moazagotl wave of strong vertical currents at very great heights had been made.

*Sawyer, J. S.—A study of the rainfall of two synoptic situations**

Mr. Sawyer described the detailed analysis he had made of the rainfall associated with a small depression which moved eastwards across Northern Ireland and the English Midlands on March 14, 1949, the relation between the rainfall and the distribution of Dr. R. C. Sutcliffe's development function, and the effects of orographic lifting. A similar analysis for the rainfall connected with the warm front of February 14, 1950, is described in his published paper. Rates of rainfall were computed from the records of 50 autographic rain-gauges, and used to form a composite picture of the mean rate of rainfall in relation to the track and position of the centre of the depression. A chart of the distribution of the total rainfall was drawn using all the 24-hr. rainfall observations. The onset of the measurable rain was abrupt at most stations but no single moving line represented the onset of rainfall. The rain area had three discontinuous boundaries, one in the south, one in the centre, and one in the north, which overlapped at their ends and moved eastwards across the country. The main rain belt in front of the centre of the depression maintained a fairly constant position with respect to the depression but was not closely connected with the warm front. Most of the rain fell behind the warm front in the south-west and ahead of it in the south-east. The radar echoes observed from East Hill (near Dunstable) agreed well with the distribution of the rate of rainfall derived from the autographic records.

Sutcliffe's cyclonic development function was calculated at 6-hr. intervals and used to determine vertical velocities and so, on various assumptions, the rate of rainfall. The map of total rainfall computed in this way agreed well with the actual one except that its main features were displaced about 100 miles to the north.

Finally, the effects of orographic lifting were computed supposing that the air was saturated and lifted through a height equal to the height of the hills at the foot and decreasing proportionately to zero at 500 mb. This gave values of the right order of magnitude.

Mr. Sawyer's paper was greeted by the President, Dr. Stagg, and Prof. Sheppard as one of great, indeed historic, importance in meteorology. Dr. Stagg inquired about the possibilities of forecasting rainfall by the use of the development function, and commented that in this particular case the vorticity of the thermal wind appeared less important than the vorticity of the surface flow. Mr. Tucker described theoretical work on orographic rain tending to

* *Quart. J.R. met. Soc., London,* **78**, 1952, p. 231.

show that orographic effects would give drizzle and not rain on high ground when drizzle only was falling on lower ground. Dr. Sutcliffe asked Mr. Sawyer for his opinion on forecasting possibilities, and with Dr. Scorer commented on the difficulty of allowing for the degree of stability. Prof. Sheppard thought it was most important to be able to do such calculations at all and the time taken in them was secondary. Dr. Farquharson said he had calculated the development function for three thickness intervals and the values changed with the interval; he inquired which one should be used for calculating rainfall. Mr. Sawyer, in reply, stressed that the charts were approximate and to some extent subjective because of the necessity for interpolating between stations. The uncertainty of forecast charts restricts the possibility of forecasting rainfall amounts by his method. One important point was that in this case they knew there was rainfall but it was clearly possible to have occasions of upward motion without rainfall because the air did not reach saturation. His work on orographic rainfall was admittedly rather rough and assumed that all water condensed, fell to the ground.

LETTERS TO THE EDITOR

Unusual wet-bulb readings

In the March 1947 issue of the *Meteorological Magazine* I reported an occasion when my wet bulb read higher than the dry bulb. This morning at 9.15 a.m. the dry bulb read 30°F. and the wet bulb 31½°F. The muslin was frozen stiff; I had not been to the screen before, so the high reading was not due to wetting the bulb and allowing insufficient time for it to cool. There was no fog and only moderate hoar-frost. There seem to be two possible explanations:—

(i) The water in the muslin had only frozen just before; this does not appear very likely as it was an hour after sunrise on a bright sunny morning after a clear frosty night.

(ii) Water was moving along the wick and turning into ice only when it reached the frozen muslin. The water in the glass container was liquid except for a narrow strip of ice around the edge.

Whatever the explanation, the occurrence indicates another wet-bulb anomaly in the neighbourhood of freezing point about which the observer might be warned.

E. GOLD

8 Hurst Close, N.W.11, December 2, 1952

Postscript.—This morning at 9.10 a.m., the dense fog (visibility 8–10 yd.) having gone and visibility being above 100 yd., my dry bulb, from which a drop of water (melted rime) was hanging, read 33½°F. and the wet bulb, on which the muslin was wet, read 32°F. This low reading was due to the ice on the muslin not having all melted, as I verified; there was an appreciable amount in the folds at the top of the muslin cap. The true difference between the "dry" and the "wet" temperatures was 0·2° or 0·3°F. Two hours later they were 36·3° and 36·0°F. respectively.

This indicates another source of error of which warning might be given in observer's instructions.

E. GOLD

December 8, 1952

Unusual rainbow phenomenon

At 1555 G.M.T. on October 22, 1952, after a heavy shower a brilliant rainbow complex was observed from the Meteorological Office, Northolt. The secondary and some supernumerary bows were clearly seen as well as the primary.

The most remarkable phenomenon, however, was another very faint bow seen rising from the north base of the primary bow but with a definite curvature away from it as in Fig. 1. The length of this unusual arc, which was only visible at times, was 5°. It was coloured red on the side away from the primary

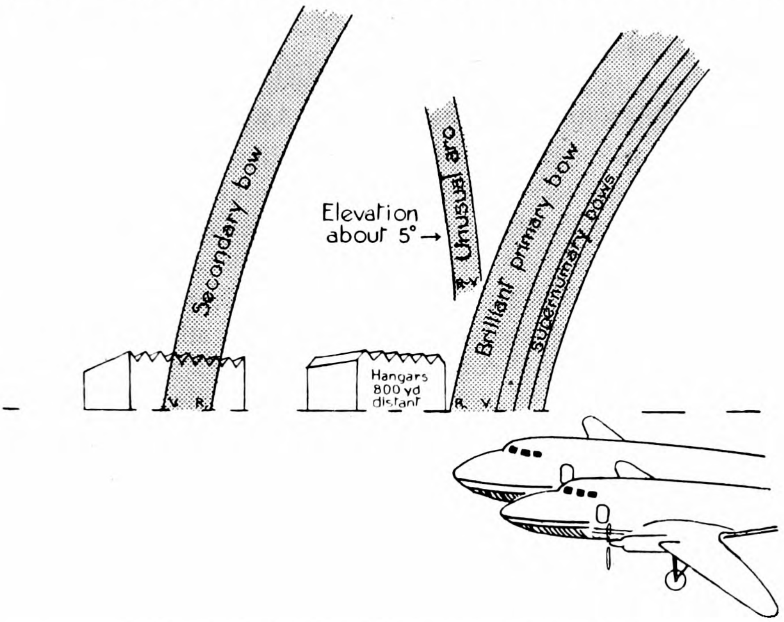

FIG. 1—UNUSUAL RAINBOW PHENOMENON

and violet on the nearer side. In the direction of this arc were an area of wet tarmac and the polished aluminium noses of two aircraft. No horizontal surface such as water in a reservoir could give an additional bow with axis at right angles to the normal but a vertical or spherical reflector could do so. Could it be that the unusual arc was the result of reflection from the aircraft noses? The arc was seen by at least four other members of the staff.

R. K. PILSBURY

Northolt Airport, October 24, 1952.

[An arc such as the one described by Mr. Pilsbury is very rare. An arc, exactly similar in position, curvature and colour order was seen at Wilhelmshaven, Germany, on November 9, 1926*; it was seen over a longer arc as it reached to the secondary bow. It is naturally not easy to determine the curvature of a short arc, but Mr. Pilsbury is certain the curvature of the one seen at Northolt was opposite to the curvature of the normal primary bow.

Pernter and Exner† consider arcs curved in the opposite sense to the primary to be produced by abnormal refraction but give no detailed explanation.

The colour sequence in the arc is opposite to the one which would be expected if the arc were part of a primary bow produced by a solar image displaced

* Wilhelmshaven, Marine-Observatorium. Anomaler Regenbogen. *Met. Z., Braunschweig*, 43, 1926, p. 508.

† PERNTER, J. M. and EXNER, F. M.; Meteorologische Optik. Wien and Leipzig, 1910, p. 599.

in azimuth by reflection as Mr. Pilsbury suggests. Further, it seems unlikely that reflection in a chance surface would produce a solar image at just the right distance in azimuth to give a bow intersecting the main primary at the ground. The order of colours and the intersection at the ground would be expected of a bow formed by reflection of the sun in a horizontal reflecting surface behind the observer. A "reflection" bow would however be curved in the same sense as the primary.

A brilliant rainbow with clearly defined secondary and supernumerary bows was seen from the Meteorological Office, Harrow, at about the same time but the unusual arc was not seen.—Ed., *M.M.*]

NOTES AND NEWS

Waterspout off Stromboli, August 8, 1952

We have received, through the courtesy of Miss D. G. Chambers, extracts from the meteorological log of the Charterhouse Geographical Expedition to Stromboli island in the Tyrrhenian Sea, in August 1952, kept by her nephew J. A. C. Cann.

The most interesting feature of the log is the description of a waterspout seen off Stromboli on August 8 which is very early after midsummer for the occurrence of such violent convective phenomena so far south in the Mediterranean.

The wind blew at force 7 from WSW. during the evening of the 7th with very black cloud to the west. Lightning was seen in the distance. About 0800 G.M.T. on the 8th the wind veered to NW. and died down, and it was calm on the sheltered side of the island at 1000 and 1300, though the smoke of the volcano showed the wind at 3,000 ft. was still NW. The waterspout was sighted at 1310 extending downwards from a cloud to the east-north-east of the island. As it drifted eastwards at an estimated speed of 5–10 m.p.h. the bottom became detached from the sea and by 1400 it had ceased to exist.

Mr. H. H. Lamb, Senior Meteorological Officer, Malta, writes: "A cold front crossed Spain from the Atlantic on the 6th and by 2000 G.M.T. was orientated from east-north-east to west-south-west and approaching Stromboli from the north. The WSW. winds reached gale force before the front passed Stromboli between midnight and 0100 on the 8th followed by a veer and decrease of wind.

"The waterspout seen several hours later does not appear to have been connected with any front. It was presumably chiefly an instability phenomenon though perhaps set off partly by some local influences on the surface winds.

"A curious and surprising feature is that subsidence was already active over a wide region covering the western part of Sicily and most of the the western Mediterranean, that is to say within about 150 miles of the scene of the waterspout.

"Such phenomena are not normally expected in this part of the Mediterranean so soon after midsummer. It is interesting to note, however, that 50 years' statistics of daily frequencies of rainfall in Rome show a small peak giving a frequency of one rain-day about once in 10 yr. for the 5-day period, August 4–8; this is more than double the frequency of rain in most other 5-day periods at that stage of the year though it is nearly equalled about July 26–30. Distinctly greater frequencies occur in the second half of August. These figures appear to be a faint reflection of well marked rainfall singularities affecting western and central Europe though much more rarely affecting the Mediterranean. Although we have no frequency figures for the regions nearest to Stromboli consideration of the statistics for Florence, Rome and Malta suggests that in most years the thunderstorms which bring the first rain should be expected about the middle of September. On the other hand in 1904 and 1933 there was no rainless month even so far south as Malta."

Mammatus

If air ascends in cumulus convection and spreads out at a level well above the condensation level it will contain large cloud droplets in contrast with the air above which it has spread. The base of a cumulus cloud, where the drops have just formed, is somewhat diffuse, unlike the sharply outlined base of stratocumulus formed by the spreading out of cumulus. Evening stratocumulus, which usually forms after the cumulus has all gone, looks different from the cumulogenitus type because their bases are respectively at and above the condensation level of the air of which they are composed.

Any descent of air at the base of a cumulogenitus cloud will lower the base of it simply because it is above the condensation level. The cloudy air will descend at the wet adiabatic lapse rate, and the dry air below at the dry adiabatic lapse rate, and generally an unstable discontinuity of temperature will quickly result. In such a case the base of the cloud assumes a mammatus structure. Though of ominous appearance and resulting from extreme instability there is no reason to suppose that it is a prognostic of precipitation, at any rate not from the region of mammatus itself, because there the air is descending. Mammatus is often produced on the lower outline of precipitation that is actually falling but it is then recognizable as of different origin. The effect of a redistribution of the liquid water within a cloud and just below it in producing mammatus in sinking air has been fully discussed by F. Wagner*, and the process is often important. But if spreading out has occurred no redistribution is required.

Because it is commonly associated with the edges of thunderstorms mammatus is often believed to be a bad omen, but it may be a sign that the precipitation is over, or at least that it is elsewhere. The photograph facing p. 48 shows a display of mammatus which occurred about two hours after the cessation of the rain of a thunderstorm. Mammatus had been visible almost continuously in one part of the sky or another ever since the storm moved away, and the sky cleared to the west as the sun set so that the cloud was illuminated from below, the pendulous parts being bright orange red, the background cloud almost black.

R. S. SCORER

Typical fog conditions

The photograph facing p. 49 was taken in Richmond Park (about 175 ft. above M.S.L.) at 1500 G.M.T. on December 7, 1952, during a period when London and its suburbs were enveloped by a severe fog. In the Park, visibility was 100 yd. while at lower levels transport was completely disrupted owing to visibilities ranging from zero to 50 yd. The depth of the fog, as indicated by the photograph, probably did not exceed 300 ft. while the sky above was partly covered by altocumulus-altostratus.

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* WAGNER, F.; Mammatusform als Anzeichen für Absinkbewegung in Wolkenluft. *Ann. Met., Hamburg*, **1**, 1948, p. 336.

Atmospheric pollution, its origins and prevention. By A. R. Meetham. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. viii + 268, *Illus.*, Pergamon Press Ltd, London, 1952. Price: 35*s.* net.

This book contains a mass of interesting information vitally concerning us all. For the proper understanding of the problem of reducing atmospheric pollution some knowledge of the history, composition and use of fuels is necessary. Following a general account of the problem, seven chapters deal therefore with fuels: the chemistry of fuels, natural fuels, artificial fuels, industrial boilers, power and electricity, industrial furnaces, and domestic fires. The remaining seven chapters deal with atmospheric pollution: its measurement, distribution, changes with time, effects, prevention, and finally the law and its administration.

The chapters on fuels deal inevitably with engineering aspects, but there are many simple drawings which enable the layman to follow the general principles involved. The book contains 81 illustrations and 26 tables. The emphasis is always on the resultant pollution. Much of the pollution arises when fires are started or fuel added. In the early part of the war the Fuel Research Station devised a scheme for eliminating the smoke from the funnels of coal-burning ships, by allowing enough air to enter the fuel to consume all smoke. This principle has been applied on land with considerable success, both in the reduction of pollution and saving of fuel.

Since 1910 the total consumption of coal in Great Britain has decreased appreciably, but owing to improved efficiency the output of power has risen. The amount of coal used a year is now about 180 million tons; of which 65 are consumed for domestic purposes (45 in fires and 20 in the production of gas and electricity); 65 in industrial boilers, including railways; and 50 by other industrial users in furnaces. The railways, consuming some 15 million tons, are amongst the worst offenders in producing smoke pollution; next come the domestic fires. In districts where on the average one open fire is burning per house a group of 380 houses emits about a ton of smoke per week and nearly as much sulphur dioxide. In some districts smoke from special industries is a major problem and the methods necessary to eliminate pollution are outlined. The burning of 180 million tons of coal each year results in 9 million tons of atmospheric pollution, made up of 5·2 as sulphur dioxide, 2·4 smoke, 0·6 ash and 0·5 hydrogen chloride and other chlorides. The most destructive pollution is sulphur dioxide, the cost, apart from its effects on health, amounting to between 20 and 50 million pounds a year by its damage to metals, wool, cotton, leather, paint and building materials.

The book summarizes present knowledge on the subject, with special reference to the recent work of the Department of Scientific and Industrial Research, both at the Fuel Research Station and the Building Research Station. Information is naturally drawn from the report on "Atmospheric pollution in Leicester", published by the Department of Scientific and Industrial Research in 1945, since Dr. Meetham was in charge of the work there during 1937–39, especially to illustrate the effect of wind on smoke concentration and distribution, and on the variation of pollution with time. Meteorologists have an interest from many aspects. The Chairman of the Atmospheric Pollution Committee, 1934–50, was Dr. G. M. B. Dobson. Moreover, from 1915 to 1927 the Committee was under the control of Directors of the Meteorological Office, before being transferred to the Department of Scientific and

Industrial Research. The book should be read by everyone interested in using our fuel resources to the best advantage and in diminishing atmospheric pollution on health grounds or for the financial benefit to the community. It is claimed that the general problem of preventing smoke is not an insoluble one, either technically or economically, and this book explains how this may be accomplished.

J. GLASSPOOLE

Climate and the British scene. By Gordon Manley. *The new naturalist. A survey of British natural history.* 8¾ in. × 6¼ in., pp. x + 452, *Illus.*, Collins, London, 1952. Price: 25*s*. 0*d*.

In his preface Professor Manley says "This is not a meteorological text." This very positive statement might perhaps be construed as meaning that the book is not addressed to meteorologists but to that rather nebulous person, the "general reader". It would be a mistake to imagine however that this is a book from which meteorologists have nothing to learn. It is in fact a very substantial contribution to the climatology of Great Britain. The presentation is lively and unacademic, but it is in no sense a mere re-hash of routine climatological facts. As meteorologists we have all, no doubt, become very familiar with the essential facts about the British climate, and we are all familiar with the essential elements of the British scene. Few people can however have pondered so deeply as Professor Manley has done on the inter-relationship between the one and the other. It is a fascinating study and Professor Manley has handled it in masterly fashion.

The first impulse of any normally constituted reader on picking up this fine book would be to go right through it looking at the pictures. There are over eighty plates, and this fact is in itself a clear indication of the author's realistic method of approach. Pictures are of course essential to any portrayal of the British scene, with all its variations with place and with season, but Professor Manley has managed very cleverly to select pictures which portray the British climate just as clearly as they portray the British scene. The meteorology is often very unobtrusive, but it is there to see, with the aid of the carefully written legends. A good example of this dual role is furnished by Plate 17, a fine colour photograph of Princes Street, Edinburgh, by Cyril Newberry. This is the sort of picture which one might expect to find in any well illustrated book about Edinburgh, but in this context it illustrates not only the buildings, gardens and traffic of Princes Street, but also the characteristic features of springtime in the Scottish capital. The legend reads: "Princes Street, Edinburgh, early May. Springtime: almost calm, slight haze, very light air from S.E. Cautious retention of coats by older Scotsmen". In this sort of way a vivid realism is given to the climatological facts and their relationship to our environment of town and country, mountain, sea-shore and pasture.

About half the plates are in full colour, and this fact must have made the book costly to produce. It is to be hoped that Messrs. Collins's courage in publishing it at the very moderate price of 25*s*. will reap its just reward.

The text is divided into 14 chapters, followed by an appendix of climatological data for representative stations. After an introduction in which the general features of our climate are briefly surveyed, and a chapter on "The makers of the observations" which contains some interesting facts about sources of climatological data from mediaeval times to the present day, we reach Chapter 3 which is devoted to "Some elementary properties of our moist atmosphere". Here, if one may say so, the writing does not seem quite so carefree as in other chapters, and there is a rather bad slip on p. 38 where, in connexion with the condensation of moisture to form cloud, it is stated that "that part of the condensation which takes place below 32° will be directly as ice". Recent work on cloud physics has shown that things are by no means as simple as that. Again, on p. 45, after a perfectly clear description of the mode of formation of rime a reference is given to Plate 13; but Plate 13 is a picture of glazed frost, not of rime, and is in fact so described in the legend.

Chapter 4 gives a good account of the atmospheric circulation over the British Isles, and the author is to be commended for hanging the entire climatological discussion on an air-mass framework. It is to be hoped, however, that in a new edition Professor Manley will eliminate Fig. 10 on p. 60, which might easily lead the reader to imagine that at Parc St. Maur, Paris, and on the summit of the Eiffel Tower, the daily minimum temperature is 0°C. in January and July alike.

Chapters 5, 6 and 7, which are devoted to a survey of "Sky, temperature and season" from winter to high summer, are among the best in the book, displaying as they do Professor Manley's remarkable capacity for close observation and vivid description. This section is followed by two chapters on "Landscape features and their effect on weather". Here and elsewhere in the book the writing is leavened and adorned with a wealth of literary allusion, as in the following passage taken from a section on town smoke: "Smoke is indeed a gloomy subject: for while there are those who will rhapsodise over the hazy city sunsets across the Thames, there are many more who deplore the vanished glories of a sunny little Manchester from which the green and gold Pennine slopes were visible on many April mornings two centuries ago. It is possible that the whole country is affected more than we think. Early last century the Ordnance Survey sighted the Welsh Mountains from Bardon Hill in Leicestershire. Ralph Thoresby espied the shipping in the Thames as he rode over Harrow Hill in May 1702. Celia Fiennes saw the Isle of Man from near Chester; Defoe (1726) was informed that from the Cheviot the view extended to the Tyne, and George Smith saw the cliffs beside the North Sea from Crossfell in 1947. But Wordsworth noted the London smoke haze from Hampstead Heath."

Chapter 10, "Mountains and moorlands: the effect of altitude", contains some interesting facts about the repercussions of the climatological effects of altitude on agricultural practice. At the village of Nenthead in Cumberland, for example, at 1,500 ft. the growing season is about ten weeks shorter than in the lowlands, and it is consequently necessary to feed cattle, if any are kept, for six months of the year. Chapter 11, "Snowfall and snowcover", summarizes work to which Professor Manley has made noteworthy personal contributions. In the next chapter, on "Secular variations of the British climate", we have a useful survey of the facts, so far as they are known or surmised, regarding climatic variations since the last phase of the Ice Age, about 15,000 years ago.

Chapter 13, "Instrumental records: the ranges of climatic behaviour", is so to speak, a concession to conventional climatology, containing as it does data relating to extremes of temperature and other elements, "for the benefit of those whose curiosity is better satisfied by figures". The last chapter on

"Climate and man" attempts to assess the effects of climate on human activity, health and behaviour. There is, in particular, an interesting discussion on bracing and relaxing climates.

To summarize, this is a very noteworthy book and a valuable contribution to meteorological literature. Those of us who are professional meteorologists tend perhaps to drift into a narrowness of outlook through excessive concentration on those aspects of meteorology which relate to our daily tasks. Here is an excellent corrective.

E. G. BILHAM

OBITUARY

Edmund Gilbert Dymond, M.A., F.R.S.E.—The news of the sudden death on October 26, 1952, at the age of 52, of Mr. E. G. Dymond came as a shock to his friends in the Meteorological Office in which he served during the war.

Mr. Dymond had a distinguished academic career at Cambridge and after graduating in 1922 became a research worker at the Cavendish Laboratory. An International Education Board Fellowship enabled him to go to the Universities of Göttingen in 1924 and Princeton in 1925, when he was elected a Fellow of St. John's College, Cambridge, and appointed a University teacher. In 1932 he became lecturer and Carnegie Teaching Fellow in the Department of Natural Philosophy at Edinburgh University and in 1948 he was appointed Reader in Physics there.

From Edinburgh Mr. Dymond took part in the Wordie expedition to Baffin Bay in 1937, and, in collaboration with Dr. H. Carmichael, published the results of studies of cosmic rays and wind in the upper atmosphere near the north magnetic pole in two papers in the *Proceedings of the Royal Society* in 1939.

At the outbreak of the war Mr. Dymond immediately responded to the call to join the Meteorological Office, where it was realized that his experience of balloon-sounding technique was likely to be of great service. The Office had embarked on a programme for the development, by the National Physical Laboratory, of radio-sonde and radio-wind equipment. Trials of the earlier designs of radio-sonde had pointed the way to improvements, and it fell to Mr. Dymond, who was appointed to Kew Observatory, to develop and perfect what came to be known as the Kew radio-sonde. The thoroughness with which he undertook this work can be gauged by the fact that the design of the mass-production Mark II radio-sonde, now in use in very large numbers, is basically the same as that of the Kew radio-sonde. Having achieved a highly successful instrument Mr. Dymond was not content until he was able to assess its perfomance by an exhaustive series of trials and comparisons, the results of which he reported in a number of *Meteorological Research Papers* during the war. A full and excellent account of his work on the radio-sonde was published in the *Proceedings of the Physical Society* in 1947, and was followed by a more general description of radio-sonde technique in the journal *Research* in 1950.

On his return to Edinburgh after the war Mr. Dymond resumed his research on cosmic rays, one of his objects being to investigate meson production at very high altitudes. For this purpose he applied his war-time experience by using radio-sonde technique. His last published paper, in collaboration with J. D. Pullar on meson production in the atmosphere, appeared in the *Philosophical Magazine* in 1951, but at the time of his death he was engaged in writing up the main results of his post-war work on cosmic rays. He was recently elected to the office of Vice-President (for Scotland) of the Royal Meteorological Society.

Mr. Dymond's high ability as an experimental physicist combined with his special knowledge of radio-sonde design led to his being invited to become a member of the Instruments Sub-Committee of the Meteorological Research Committee in 1951. He travelled down from Edinburgh to attend its most recent meeting only three days before he died. It was a great loss to the Office when he left after the war and his valuable guidance on instrument development problems will now be sadly missed.

Mr. Dymond was quiet and modest in manner and he was generous in giving credit to colleagues working with him or under his direction for their assistance in his work. All those who were associated with him during his period in the Meteorological Office will sadly mourn his death. Our deepest sympathy goes to his widow and his family.

F. J. SCRASE

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—Things looked black for the ocean weather ship sailing schedule at 11 a.m. on Saturday, December 20, 1952, when it was discovered that two members of the meteorological staff of the o.w.s. *Weather Recorder*, due out of Greenock early on the following day, had fallen sick. However, an S.O.S. sent to all offices on the "first-channel" teleprinter broadcast brought in the names of two volunteers by 2 p.m. on the same day. Only one of these could be released from his post and he—an Assistant of 17—travelled from Plymouth to Greenock and was aboard the *Weather Recorder* by 9 a.m. on Monday, December 22, and the ship sailed forthwith.

WEATHER OF DECEMBER 1952

Mean pressure was below normal in Europe and the United States and above normal over the North Atlantic, north of 40°N.; at 55°N., 40°W. the mean pressure, 1010 mb., was 8 mb. above normal. The lowest mean pressure, 1004 mb., occurred just north of Scotland; this pressure is about normal for this region for December. The highest mean pressure, 1024 mb. between Portugal and the Azores, was 4 mb. above normal. Mean pressure in Europe was mainly between 1012 and 1016 mb. and varied from 2 to 5 mb. below normal.

Mean temperature varied between 30° and 40°F. over most of Europe, generally 2–4°F. below normal. In the Mediterranean region and extreme north of Africa mean temperature was between 50° and 60°F., rising to 70–80°F. in west Africa.

In the British Isles the weather was cold on the whole, with considerable snowfall around the middle of the month. Sunshine exceeded the average in most parts of Great Britain, the total at Oxford being the highest for December in a record going back to 1881. Other notable features of the weather were the long spell of dirty fog in the London area during the period 5th to 9th and the widespread, unusually severe gale on the 17th.

In the opening days of the month a ridge of high pressure associated with an anticyclone situated south of Iceland moved south over the British Isles. Frost and local fog occurred, the frost being severe in some places; air temperature fell to 13°F. at Renfrew on the 1st and to 18°F. at Manchester on the 2nd, while the maximum at Renfrew on the 1st was only 30°F., the low temperature being largely due to almost persistent fog. A trough of low pressure moving south-east immediately behind the ridge caused slight rain in the north and east. From the 3rd to the 5th the anticyclone off our north-west coasts moved south-east, being centred over south-east England and the nearby continent on the 6th. Cold mainly dry weather, with frost and local fog, persisted, though a trough of low pressure spreading east brought milder weather with occasional rain to some western districts on the 6th and 7th. These conditions did not reach the south-east, however, until the 9th. In the London area the fog was smoke laden and unusually persistent; at Kingsway, fog (visibility less than 1,100 yd.) lasted from 0000 on the 5th to 1800 on the 9th (114 hr.) while visibility was less than 220 yd. from 0900 on the 6th to 0900 on the 8th and only 40 yd. or less from 0600 on the 7th to 0300 on the 8th. On the 10th a depression off the west of Scotland moved north-east giving rain generally and a gale locally on our north-west coasts. On the 11th and 12th a depression off south-east Iceland moving south-south-east gave showery weather, and on the 12th another disturbance off our south-west coasts moved rapidly east causing further rain. Behind these depressions cold northerly winds prevailed over the British Isles with a gale locally in the north of Scotland and widespread snow which was heavy in places with deep drifts. For example snow was 12 in. deep at West Kirby on the 15th and 16 in. at Bwlchgwyn on the 16th; snow drifts were 5–7 ft. deep at Bwlchgwyn. Thunderstorms occurred at numerous places in north Wales and north-west England on the 15th. On the 16th a very deep depression off north-west Scotland moved east-south-east and later turned south-east giving considerable precipitation on the 16th and widespread, notably severe, north-westerly gales on the 17th. Gusts reached 80 kt. locally in the north-west, while Cranwell, Lincolnshire, recorded a gust of 96 kt., the highest ever registered at an inland station in this country. The depression filled quickly over the Low Countries and a spell of milder, unsettled south-westerly to westerly type of weather set in and persisted until the 25th. Rain fell frequently during this period but temperature rose to 50°F. locally at times and touched 55°F. at Hawarden and Wrexham on the 22nd. From the 25th to the 28th a depression moved south-south-east from the south of Iceland to south-west France; the weather became colder again, with rain or snow at times. Rather widespread fog occurred on the 27th, the fog being thick and persistent locally in south-east and east England and the Midlands. During the closing days a depression moved south-east from east of Iceland to the North Sea. More rain or sleet occurred and there was rather persistent fog in parts of south-east and east England on the 30th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	56	15	−2·5	93	+2	132
Scotland	57	7	−1·8	94	+2	106
Northern Ireland ...	53	16	−2·5	111	+3	103

RAINFALL OF DECEMBER, 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·38	100	*Glam.*	Cardiff, Penylan ...	3·34	67
Kent	Folkestone, Cherry Gdn.	4·32	135	*Pemb.*	Tenby	4·40	88
„	Edenbridge, Falconhurst	2·79	85	*Mer.*	Aberdovey	4·98	105
Sussex	Compton, Compton Ho.	3·83	91	*Radnor*	Tyrmynydd	6·34	77
„	Worthing, Beach Ho. Pk.	3·27	109	*Mont.*	Lake Vyrnwy	6·09	86
Hants.	Ventnor Cemetery ...	4·38	130	*Mer.*	Blaenau Festiniog ...	11·28	89
„	Southampton (East Pk.)	2·40	66	*Carn.*	Llandudno	3·21	111
„	Sherborne St. John ...	2·40	73	*Angl.*	Llanerchymedd ...	3·92	89
Herts.	Royston, Therfield Rec.	2·01	87	*I. Man*	Douglas, Borough Cem.	5·57	113
Bucks.	Slough, Upton... ...	2·30	91	*Wigtown*	Newton Stewart ...	4·40	81
Oxford	Oxford, Radcliffe ...	2·16	88	*Dumf.*	Dumfries, Crichton R.I.	3·61	84
N'hants.	Wellingboro' Swanspool	2·39	102	„	Eskdalemuir Obsy. ...	5·24	75
Essex	Shoeburyness	2·03	110	*Roxb.*	Kelso, Floors	..	..
„	Dovercourt	2·44	113	*Peebles*	Stobo Castle	4·16	109
Suffolk	Lowestoft Sec. School...	2·79	120	*Berwick*	Marchmont House ...	4·28	152
„	Bury St. Ed., Westley H.	2·14	89	*E. Loth.*	North Berwick Res. ...	1·90	88
Norfolk	Sandringham Ho. Gdns.	2·48	98	*Midl'n.*	Edinburgh, Blackf'd. H.	2·74	117
Wilts.	Aldbourne	3·43	106	*Lanark*	Hamilton W. W., T'nhill	3·12	72
Dorset	Creech Grange... ...	3·69	84	*Ayr*	Colmonell, Knockdolian	3·66	66
„	Beaminster, East St. ...	3·75	78	„	Glen Afton, Ayr San. ...	5·27	82
Devon	Teignmouth, Den Gdns.	3·33	79	*Renfrew.*	Greenock, Prospect Hill	7·59	102
„	Cullompton	4·10	93	*Bute*	Rothesay, Ardencraig...	7·18	132
„	Ilfracombe	4·29	89	*Argyll*	Morven (Drimnin) ...	7·24	92
„	Okehampton Uplands...	4·84	69	„	Poltalloch	6·43	101
Cornwall	Bude, School House ...	4·00	92	„	Inveraray Castle ...	9·60	97
„	Penzance, Morrab Gdns.	4·51	79	„	Islay, Eallabus... ...	5·83	98
„	St. Austell	5·31	87	„	Tiree	5·18	99
„	Scilly, Tresco Abbey ...	3·78	81	*Kinross*	Loch Leven Sluice ...	2·96	75
Glos.	Cirencester	2·88	86	*Fife*	Leuchars Airfield ...	1·79	72
Salop	Church Stretton ...	3·22	91	*Perth*	Loch Dhu	7·68	76
„	Shrewsbury, Monksmore	2·72	111	„	Crieff, Strathearn Hyd.	2·85	64
Worcs.	Malvern, Free Library...	2·26	82	„	Pitlochry, Fincastle ...	2·23	55
Warwick	Birmingham, Edgbaston	2·84	106	*Angus*	Montrose, Sunnyside ...	2·09	75
Leics.	Thornton Reservoir ...	2·65	99	*Aberd.*	Braemar	4·11	115
Lincs.	Boston, Skirbeck ...	1·61	75	„	Dyce, Craibstone ...	2·87	85
„	Skegness, Marine Gdns.	1·54	70	„	New Deer School House	3·28	96
Notts.	Mansfield, Carr Bank...	1·98	68	*Moray*	Gordon Castle	2·30	86
Derby	Buxton, Terrace Slopes	5·57	98	*Nairn*	Nairn, Achareidh ...	2·01	98
Ches.	Bidston Observatory ...	2·84	107	*Inverness*	Loch Ness, Garthbeg ...	4·25	92
„	Manchester, Ringway...	3·03	99	„	Glenquoich	12·34	84
Lancs.	Stonyhurst College ...	5·27	109	„	Fort William, Teviot ...	8·58	84
„	Squires Gate	3·75	120	„	Skye, Broadford ...	7·83	87
Yorks.	Wakefield, Clarence Pk.	1·72	71	„	Skye, Duntuilm ...	6·62	106
„	Hull, Pearson Park ...	1·81	75	*R. & C.*	Tain, Tarlogie House ...	2·18	77
„	Felixkirk, Mt. St. John...	1·57	65	„	Inverbroom, Glackour...	8·71	119
„	York Museum	1·64	73	„	Achnashellach	9·39	99
„	Scarborough	2·58	108	*Suth.*	Lochinver, Bank Ho. ...	5·75	103
„	Middlesbrough... ...	1·85	95	*Caith.*	Wick Airfield	3·62	118
„	Baldersdale, Hury Res.	2·92	76	*Shetland*	Lerwick Observatory ...	5·79	121
Norl'd.	Newcastle, Leazes Pk....	3·71	158	*Ferm.*	Crom Castle	3·42	83
„	Bellingham, High Green	3·53	97	*Armagh*	Armagh Observatory ...	3·47	111
„	Lilburn Tower Gdns. ...	4·40	167	*Down*	Seaforde	..	..
Cumb.	Geltsdale	3·51	92	*Antrim*	Aldergrove Airfield ...	3·54	103
„	Keswick, High Hill ...	5·10	76	„	Ballymena, Harryville...	4·66	105
„	Ravenglass, The Grove	4·58	100	*L'derry*	Garvagh, Moneydig ...	4·99	124
Mon.	Abergavenny, Larchfield	2·81	63	„	Londonderry, Creggan	5·78	132
Glam.	Ystalyfera, Wern House	5·99	72	*Tyrone*	Omagh, Edenfel ...	4·99	118

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

Wt-33. K15.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 969, MARCH 1953

MR. R. H. MATHEWS, O.B.E., B.A.

After nearly 40 years of Government service, Mr. R. H. Mathews, Assistant Director for Climatology, retired from the Meteorological Office on January 31, 1953. Having graduated with honours in mathematics at East London College, University of London, Mr. Mathews started his career in September 1913 in the Customs and Excise Department. Came World War I, and in August 1917 he was released for active service in the Gunners. On demobilization in January 1919 Mr. Mathews returned to Excise duties, but on April 1, 1920, he transferred to an appointment as Junior Professional Assistant in the Meteorological Office.

After a period of training in outstation work at the R.A.F. School of Navigation at Calshot, Mr. Mathews was posted to the Forecast Division, where he was concerned with meeting the meteorological requirements for the civil air routes to the Continent. With the increasing demands for forecasting facilities from the R.A.F., it became necessary early in 1922 to provide a 24-hr. roster for Service and civil aviation, and M.O.6, which was then the Aviation Branch, was expanded to meet this requirement. As a Senior Professional Assistant Mr. Mathews served on the M.O.6 roster until November 1928. It was during this period that, in collaboration with Mr. H. L. B. Tarrant, Mr. Mathews organized the Meteorological Office Social and Sports Club, and himself played in the Meteorological Office football team which won the Air Ministry Championship year after year.

At the end of 1928 Mr. Mathews was posted to Leuchars, another R.A.F. station, where, to gain yet more experience in meeting the ever increasing demands of military aviation, he took full advantage of the opportunity to make familiarization flights. It is of interest to note that it was at Leuchars that "sferic" observations were first made by the Meteorological Office. Using radio direction-finding equipment designed by the now famous Sir Robert Watson Watt with teams at Leuchars and Datchet, the pioneer work on thunderstorm location was started. By contributing to the success of this work, Mr. Mathews assisted in no small degree in laying the foundations of the elaborate programme of "sferic" observations which we maintain today.

At the end of 1933 Mr. Mathews volunteered for duty in Iraq, and, as Assistant Superintendent, went to Hinaidi to take charge of the meteorological office there which served civil airlines as well as the R.A.F. This post enabled Mr. Mathews to acquire a knowledge of staff work which was to stand him in good stead in the exacting years of World War II. During this period plans were made by the Iraq Government for the establishment of an Iraq Meteorological Service, and in May 1936 Mr. Mathews accepted an invitation to inaugurate the Service as its first Director. He remained in Iraq for a three-year tour. Here he was nick-named "the Gremlin" by the R.A.F.—a name which stuck to him to the end of his service with the R.A.F.

In January 1937 Mr. Mathews was posted as officer-in-charge of the meteorological office at the R.A.F. Cadet College, Cranwell, where for over a year he maintained the high standard which had already been set by his predecessors for inculcating in the minds of the cadets, destined to be the R.A.F. Commanding Officers of the future, the necessity of being "weather conscious". With the increasing menace of Hitlerism in the troubled days before World War II, a considerable expansion of the R.A.F. was planned. Part of this expansion included the creation of a number of new Groups in Bomber Command. One of these was No. 5 Group, a Group which was to become famous during the war for its precision bombing. Mr Mathews was posted to Grantham as Senior Meteorological Officer of No. 5 Group in March 1938. It was in this capacity, in which he served until shortly after VE Day, that he was able to put to such good use the long experience which he had acquired over the years of providing meteorological information and guidance to the R.A.F. All will have heard of the "dam-busting" and other valiant achievements of the squadrons in No. 5 Group, but many may not have realized how much the success of these efforts depended on the harmonious team work and mutual understanding of meteorological and operations staff which Mr. Mathews excelled in developing. It was in No. 5 Group that, under the direction of such brilliant Commanders as "Bomber" Harris, Slessor and Cochrane, the tactical use of weather, good and bad, was again and again employed in bomber operations with such gratifying results, and it was for his contribution to the planning of such operations that Mr. Mathews was appointed an O.B.E. in 1943. With promotion to Principal Technical Officer and Acting Group Captain in May 1945, Mr. Mathews was assigned for meteorological duties in connexion with the planning of a special operation overseas in which No. 5 Group was to take part, but the ending of World War II rendered this operation unnecessary.

In November 1945 Mr. Mathews became Chief Meteorological Officer, Transport Command, under his old chief, Sir Ralph Cochrane. Four years at H.Q. Transport Command, which included several flights overseas, saw the end of his long association with the R.A.F., and in January 1949 Mr. Mathews took up office at Harrow on promotion to Assistant Director in charge of climatology.

In this new capacity he piloted the publication of the "Climatological atlas of the British Isles" which, owing to the war, had been so long delayed. During his four years at Harrow, Mr. Mathews took a very special interest in the welfare of his staff, and fathered, with much success, the social and sports activities of all the staff at Harrow.

At a ceremony in Victory House on January 30 the Director expressed the good wishes of the staff of the Office to Mr. Mathews, and presented him on their behalf with a cheque for buying a greenhouse, an inscribed copy of the

"Climatological atlas of the British Isles" and an album of signatures. The Director referred to the high opinion of Mr. Mathews's work expressed by high R.A.F. officers, and to his genial personality and ability to get the best out of his staff. Mr. Mathews, in reply, paid tribute to the zeal, friendliness, and cordial collaboration between all ranks which prevailed in the Meteorological Office, and referred to the need for constant encouragement of the junior staff on the quality of whose work the success of the Office as a whole was dependent.

LONDON FOG OF DECEMBER 5–8, 1952

By C. K. M. DOUGLAS, B.A. and K. H. STEWART, Ph.D.

Fog was fairly widespread over eastern England during the period December 5–8, 1952. The fog was thickest in the London Basin in which visibility over large areas was below 20 yd. for many hours on end and was often below 10 yd.

The primary cause of the persistent dense fog was the complete absence of any pressure gradient for an exceptionally long period. All the observations in the London area on December 5–7 reported almost nothing but calm, and the absence of wind was not confined to the Thames Valley but was also very noticeable on adjacent high ground. Very sluggish air movement due to drainage may have affected the details of fog density, but even the most detailed synoptic charts throw no light on this problem. Precisely how rare the prolonged calm was could only be found from wind statistics. At first sight it may seem surprising that it should be rare, in view of the frequency of quasi-stationary anticyclones and belts of high pressure, but a closer examination of such cases shows that the region of complete calm rarely remains stationary for long. Small irregular movements of the centre or ridge are frequent, with small pressure changes close to the centre of the same sign as larger changes in the periphery zone. A geostrophic wind of only 10 kt. may be important in relation to the persistence of very dense fog, as distinct from fog of a more normal type, and a very light wind did in fact give rise to a temporary improvement on December 8.

The anticyclone reached the London area from the north-west in the early hours of December 5 and then became stationary. The situation at 1800 on the 6th is shown in Fig. 1. The western end of the belt of high pressure can be regarded as the original anticyclone, and the eastern end as another and more mobile system. Though pressure remained high in that area for some days, there was no region of prolonged calm. The pressure on the Continent did not rise high enough to produce a southerly gradient in the London area, and at Manston and Felixstowe the pressure on December 6–8 was on the whole identical with that over London Airport. The thickness pattern on the chart showed a pronounced thermal wedge to the west of Ireland, which was unfavourable for any development of the sea-level trough off our north-west coasts. The thermal gradient over south-east England was weak, and the axis of the ridge remained stationary over the London area till December 8, and on that day it was somewhere near the North Downs.

The air mass originated in high latitudes, but it was over open water between December 1 and 4, and though it was cold and dry these features were less pronounced than on some days with N. or NW. winds in December 1950, and again on December 15, 1952. The air which was over London on the 5th had

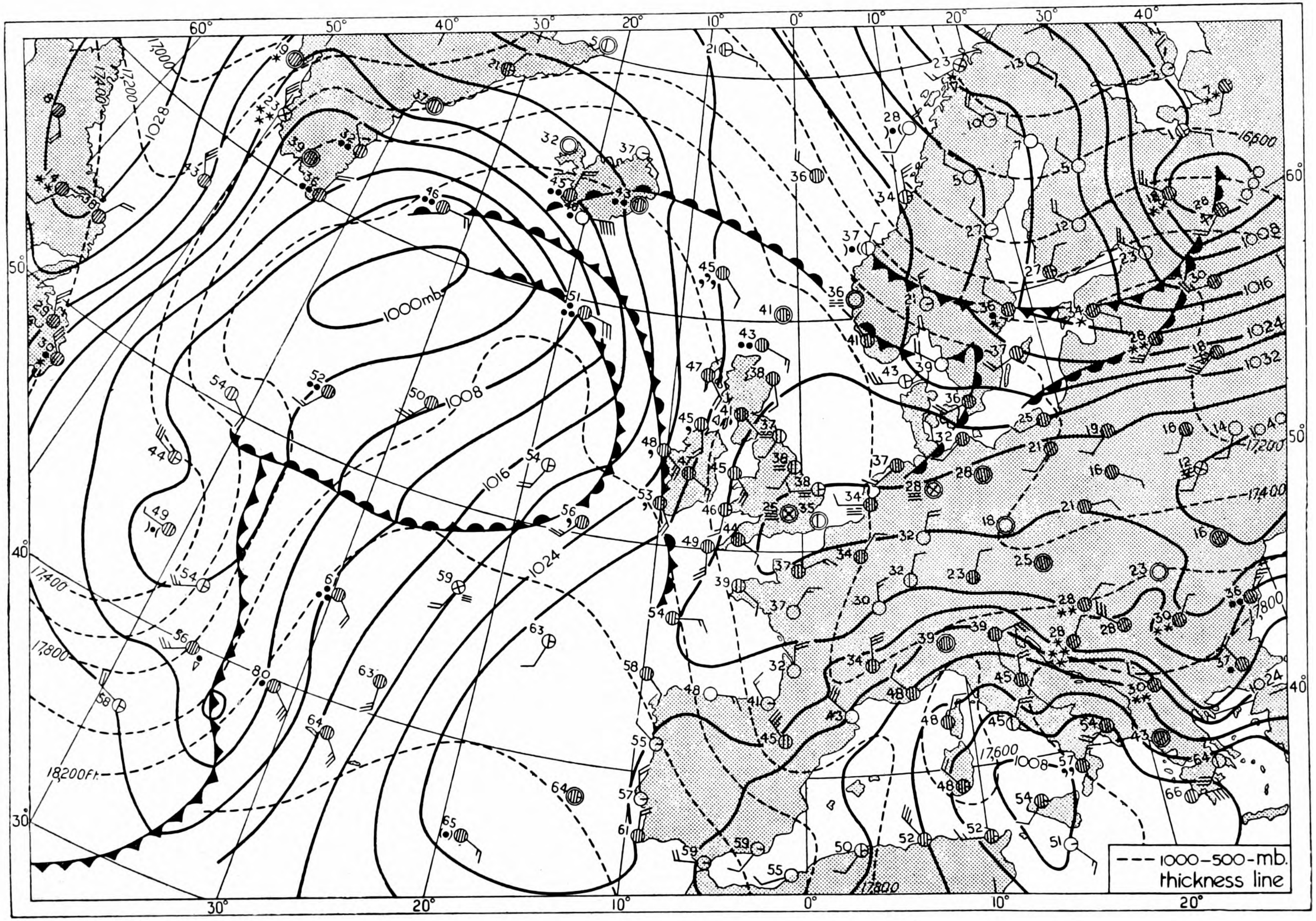
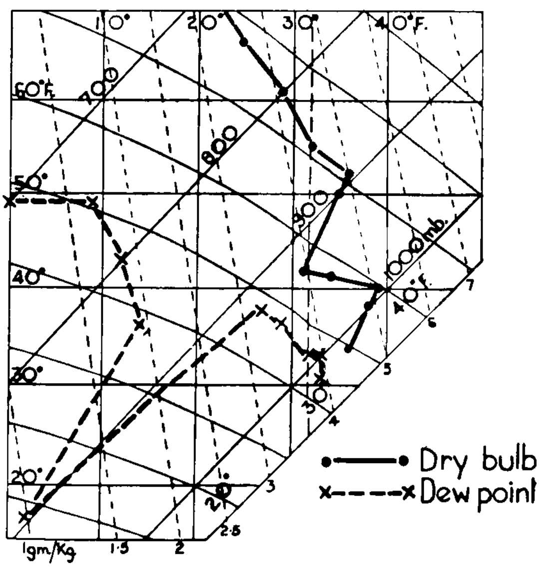


FIG. 1—SYNOPTIC CHART, 1800 G.M.T., DECEMBER 6, 1952

given inland maxima of about 40°F. on the 4th with dew points about or a little below freezing point. There were some stratocumulus clouds on the 4th, but the clear skies on the axis of the ridge on the 5th–8th were almost inevitable in the absence of thicker and more general previously existing clouds. The fog on the 5th was mainly an urban fog, but on the next three days there was dense rime-producing water fog extending to rural areas. The photograph facing p. 81, reproduced from *The Times*, shows the shallow nature of the fog in the region of Box Hill; Ranmore Common (616 ft. above M.S.L.) was clear of the fog. The 400-ft. hills to the north of London were well covered with fog to beyond St. Albans. By about 11 a.m. the fog in the higher rural areas cleared to mist with weak sunshine, but this does not necessarily imply that a comparable clearance would have occurred in the Thames Valley in the absence of smoke, taking into account the shortness of the days and the low elevation of the sun. A light wind brought an improvement to much of London on the 8th, but the fog was again very dense in the evening and night. On the 9th there was a general SW. wind of force 2–3, but in the north-east districts of London the fog was slow to clear.

The coldest days were December 6 and 7 when London Airport had minima of 23° and 22°F. and maxima of 29° and 31°F. In central London the temperature, as would be expected, was not so low with minima some 6°F. and maxima 2 – 3°F. higher.



0300 G.M.T., December 6, 1952 0300 G.M.T., December 7, 1952

FIG. 2—TEPHIGRAMS OF RADIO-SONDE ASCENTS AT LARKHILL

On December 5 and 6 the subsidence inversion at Larkhill and Hemsby was distinct from the surface radiation inversion, but by the 7th the two inversions were closer together, and in the London area this process may well have been more complete. The 0300 soundings at Larkhill on December 6 and 7 are reproduced in Fig. 2; the dew points below the main inversion were affected by advection from the English Channel, especially on the 7th, and cannot be regarded as representative of the air over London.

A low subsidence inversion increases stability, and the dryness aloft favours radiation from the top of the fog, but if the dry air comes exceptionally low a light wind may dissipate the fog. It is possible that this happened on December 8 when the improvement began remarkably early in parts of London. There was better evidence for it on December 26, 1944, when the fog cleared over a large area and the air was very transparent above 400 ft. More recently, a similar development occurred in parts of southern England on January 20, 1953.

Taking into account both density and duration, the only closely comparable fog in the London area in recent decades was that of November 27–December 1, 1948. The foggy spell of November 22–27, 1936, was more prolonged but the fog was for the most part not of comparable density on low ground, mainly owing to its greater thickness in the vertical. The 1948 fog was associated with an anticyclone which spread from the Continent, and on November 28–30 the pressure distribution over much of England resembled that in the recent foggy period, though it developed quite differently. In the earlier period the fog was far more extensive, the temperature and water content were higher, and the inversion (the amalgamated ground radiation and subsidence inversions) was much larger. When a southerly geostrophic wind of 17 kt. developed on December 1 the fog cleared quickly in London, except locally in the north, but much more slowly in parts of northern England where the air had traversed a large area of comparatively level country, though the gradient there was stronger.

There was an even longer spell of dense and persistent fog in the Glasgow area on November 16–21, 1925. The geostrophic wind was not so persistently low as in the case of the two prolonged London fogs, but the local topography in the Clyde Valley favours a dense fog with almost no surface wind even with an appreciable geostrophic wind from certain directions. In the London area the Downs are a barrier against S. winds, but its effectiveness is limited, though of course it varies according to the strength of the temperature inversion.

The prolonged calm inversion conditions which brought fog also led, of course, to high concentrations of smoke and other atmospheric pollution in and around the built-up area of London. The average smoke content (as measured by filter-paper gauges) for the 6th and 7th at stations in central London ranged from 2 to 4 mgm./m.^{3}, and the concentration of sulphur dioxide was about one part per million of air. These values are some 10–15 times the normal (non-foggy) December ones. The smoke content at Kew Observatory, where it is measured every hour, rose to a maximum of over 2·3 mgm./m.^{3} in the late evening of the 5th, but fell to somewhat lower values on the succeeding days.

These amounts of pollution are not exceptional for foggy weather although they are large by comparison with average winter conditions, and are quite high enough to account for the obvious dirtiness and general unpleasantness of the fog. The direct effect of the pollution on visibility must have been small; in order to get visibilities as low as 5 yd. there must be at least 200 mgm./m.^{3} of suspended matter in the air, and since "smoke" contributed at most only 4 mgm./m.^{3} it is clear that at least 98 per cent. of the suspended matter was made up of the water droplets of the fog. It is likely, however, that the atmospheric pollution had important indirect effects in reducing the visibility. By providing an abundance of nuclei for the formation of water droplets, the pollution probably caused the droplets of the London fog to be smaller, more numerous and more stable than those of the fog in the surrounding country, and so produced a denser and less easily cleared fog. That some such mechanism must operate is clear from climatological maps, which show maximum frequencies of fog and dense fog in industrial areas. The present case, however, is not an ideal one in which to study the mechanism, because the area in which pollution favoured fog coincided very closely with that where synoptic conditions favoured it too.

A detailed investigation of the fog is being made by the Meteorological Office.

GALE OF DECEMBER 17, 1952

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

A very severe gale was experienced over Scotland and northern England on December 17, 1952. A number of walls and chimneys were blown down and roofs damaged over a wide area. The damage seems to have been particularly heavy in Lancashire and the Isle of Man.

The chart for 0600 on December 17 is reproduced in Fig. 1, and includes the track of the centre, which split into two portions after 1800 on the 16th, one centre moving eastward between Orkney and Shetland, and the other moving south-east over Scotland. This is shown as a separate centre on some of the hourly charts, but not on all, owing to topographical complications. The depression was complex in its early stages, and seems to have been composed of two systems which both formed near south Greenland. For this reason the movement of the centre of gravity of the system was rather slow in its warm-sector stage, although there was a fairly strong thermal wind over a wide belt. By 0600 on the 16th its central pressure had fallen to 974 mb. and it was just becoming occluded. Pressure fell to 960·9 mb. at Sule Skerry at 0300 on the 17th, but by 0600 the northern centre was beginning to lose depth. Subsequently the northern centre filled quickly and the southern one moved south-east and filled less rapidly, but by 0600 on the 18th it had a central pressure of 990 mb. Between this depression and an advancing ridge of high pressure to westward, with its crest at 26°W. at 0600 on the 17th, there was a steep NW.–N. gradient wind with an exceptional concentration of isobars in the neighbourhood of the Hebrides. The gale spread south-eastwards, but owing to the filling of the depression it had lost its severity by the time it reached southern England.

The anemogram for Bidston, Liverpool, shows an hourly mean wind of 45 kt. (52 m.p.h.) between 0800 and 0900 and the mean was not often below 43 kt. (50 m.p.h.) between 0700 and 1400. Gusts exceeding 70 kt. (80 m.p.h.) occurred in all hours between 0650 and 1530; the highest was 75 kt. (86 m.p.h.) at 1320. At Stornoway the mean speed was 55 kt. from 0400 to 0500 and about 52 kt. between 0330 and 0700. There were many gusts exceeding 70 kt., and the highest was 80 kt. at 0450.

In addition to the general gale, there was a most extraordinary gust of 96 kt. (111 m.p.h.) during a brief squall at Cranwell at 0640 in the morning, shown in Fig. 2. During this unique gust the anemometer pen was being watched by two observers, Mr. R. Needham and Mr. K. Hodgson. There were four gusts of 57 kt. just before it, and several of 53–63 kt. just after it. During the

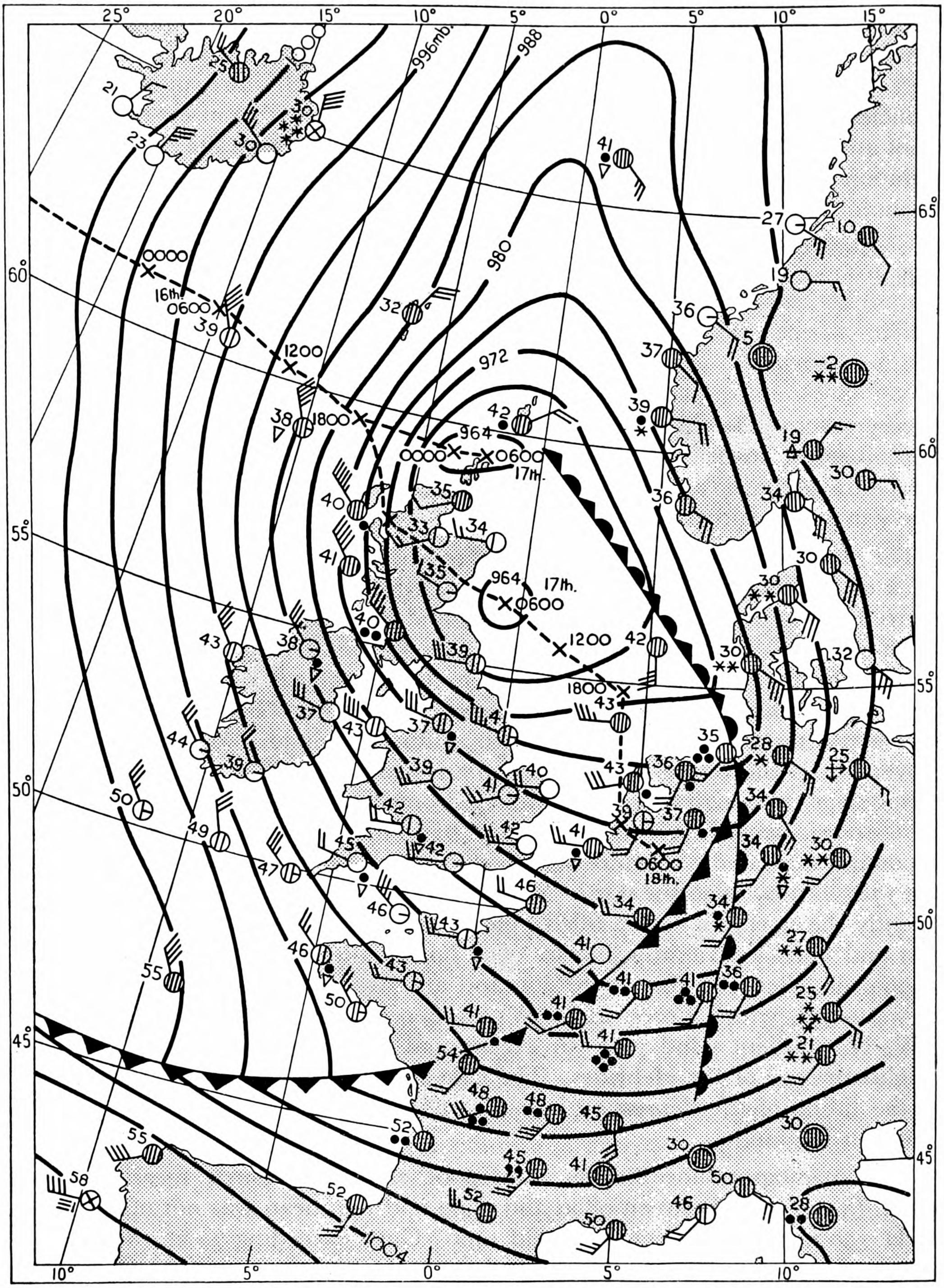


FIG. 1—SYNOPTIC CHART, 0600 G.M.T., DECEMBER 17, 1952

squall pressure rose 1·5 mb. in 5 min. and 0·8 mm. of rain fell in just over 5 min. at a rate of 10 mm./hr. The rainfall trace is given in Fig. 3. Mr. J. Newton, the Meteorological Officer at Cranwell, was approaching the office in his car at the time and it was almost blown off the road. He describes the shower as a "wall of water" which suggests that a descending squall was somehow concentrated into an exceptionally narrow zone. The writer has no

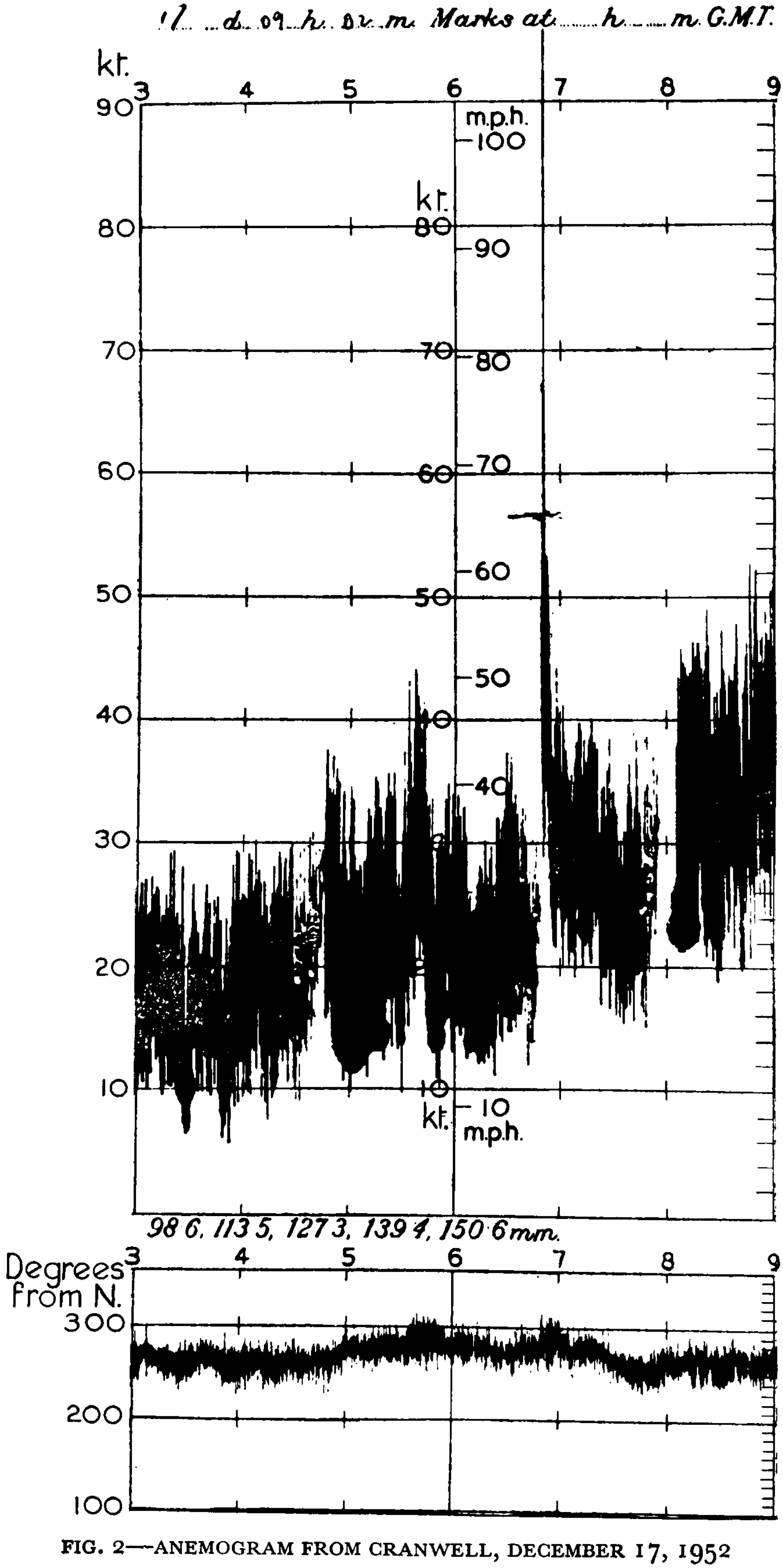


FIG. 2—ANEMOGRAM FROM CRANWELL, DECEMBER 17, 1952

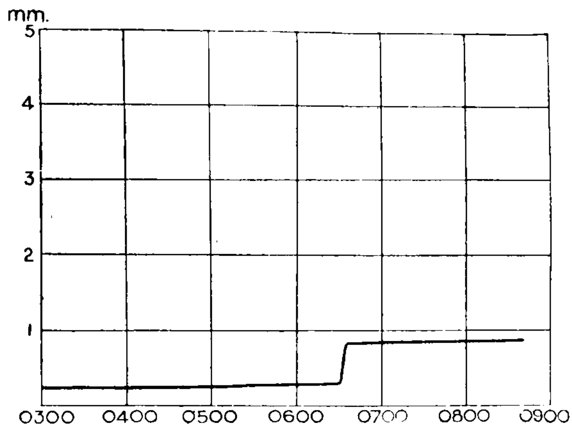


FIG. 3—HYETOGRAM FROM CRANWELL, DECEMBER 17, 1952

knowledge of anything closely similar having been recorded in this country. The squall occurred well ahead of the main gale, but the geostrophic wind was up to about 70 kt. There was a small trough of low pressure, but such troughs are very characteristic of unstable currents. The Hemsby wind sounding at 0900 showed a speed of only 46 kt. at 2,000 ft. increasing to 57 kt. at 5,000 ft., but decreasing to 31 kt. at 14,000 ft., then increasing to 69 kt. at 27,000 ft.

FÖHN TEMPERATURE IN SCOTLAND

By E. N. LAWRENCE, B.Sc.

In the May 1952 *Meteorological Magazine*[1], there was a description of an example of the föhn effect over Scotland. That the gain in air temperature in the case described was only 5°F. was probably due mainly to the fact that the air before the uplift was far from saturation point (precipitation is presumed to occur on windward slopes) and partially to the gradient wind being south-easterly rather than south-westerly with the lesser likelihood of a great proportion of the air being lifted to a height about that of the Cairngorms.

The following example, which occurred on February 18, 1945, shows a temperature of at least 60°F. in north-east Scotland at 0300, a time which precludes any insolation. The moist south-westerly air stream had almost a maximum length of mountainous track over the Grampians, and precipitation was widespread on western slopes.

From the morning of February 15, 1945, (or earlier) until the morning of the 18th, a south-westerly air stream from the Azores to Scotland persisted. The average pressure gradient for this period was sufficiently high to bring air from the vicinity of the Azores to Scotland. Throughout this period the North Atlantic was covered by a complex low-pressure area between the winter anticyclones of Eurasia and North America. On the morning of the 18th, the main depression was centred just south of Iceland with its warm sector extending south-east from the centre and covering the whole of the British Isles. There was a double cold front, but neither front was associated with any significant wind veer (or marked change in surface air) and the south-westerly air stream extended from the Azores to the British Isles. Between the Azores and Newfoundland, a further young depression was moving eastwards. Fig. 1 shows the situation at 0300 on February 18, 1945.

Theoretical estimates of the dry-bulb temperature and dew point at Dallachy, Morayshire (57°39′25″N., 3°04′00″W., 37 ft.), have been calculated from the Aldergrove radio-sonde ascent (see Fig. 2) on the assumption that air represented by the Aldergrove radio-sonde ascent at 1700 on February 17 reached the area of Dallachy at about 0300 on the 18th, and that the average mechanical uplift of air due to the mountains was 3,000 ft. The latter is a reasonable assumption as much of the land in the vicinity of the track is over

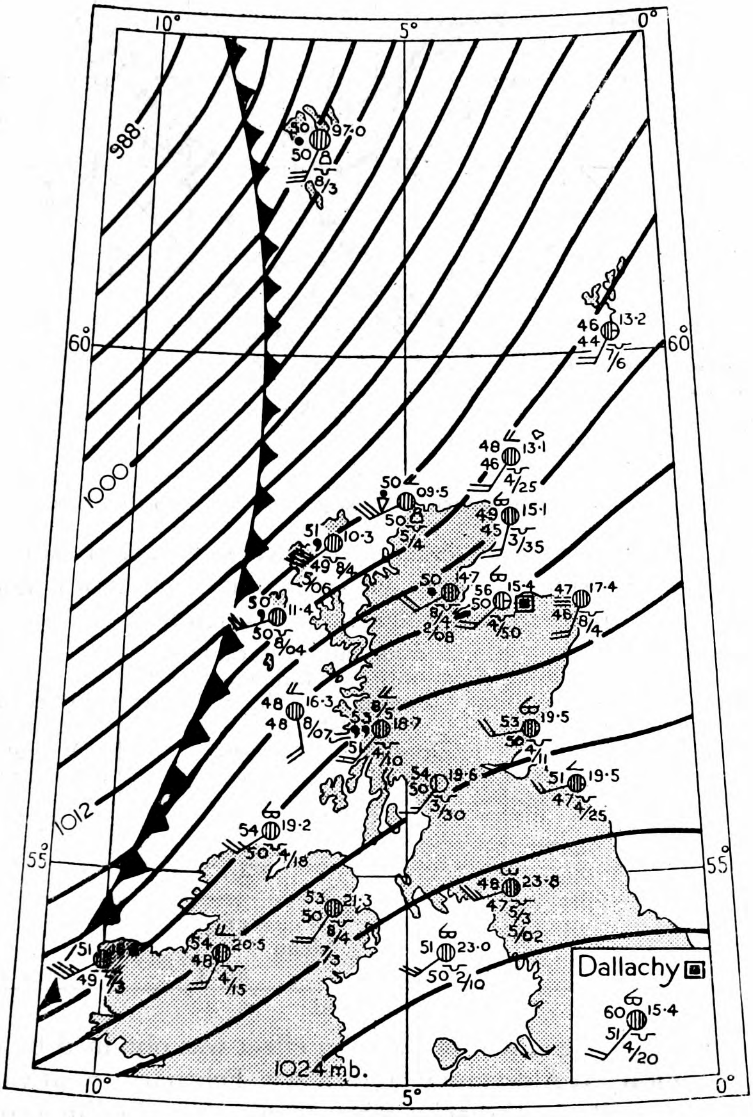


FIG. I—SYNOPTIC CHART, 0300 G.M.T., FEBRUARY 18, 1945

2,000 ft. and the highest points just over 4,000 ft. (see Figs. 3 and 4). Furthermore, the Aldergrove ascent shows that the air above 3,000 ft. was very stable, thus reducing turbulent mixing with layers of air above the mountain-top level. It was assumed that air at various levels was lifted mechanically to an average height of 3,000 ft., and that after saturation was reached further lifting resulted in precipitation. The air then descended at the dry adiabatic lapse rate. The results are given in Table I.

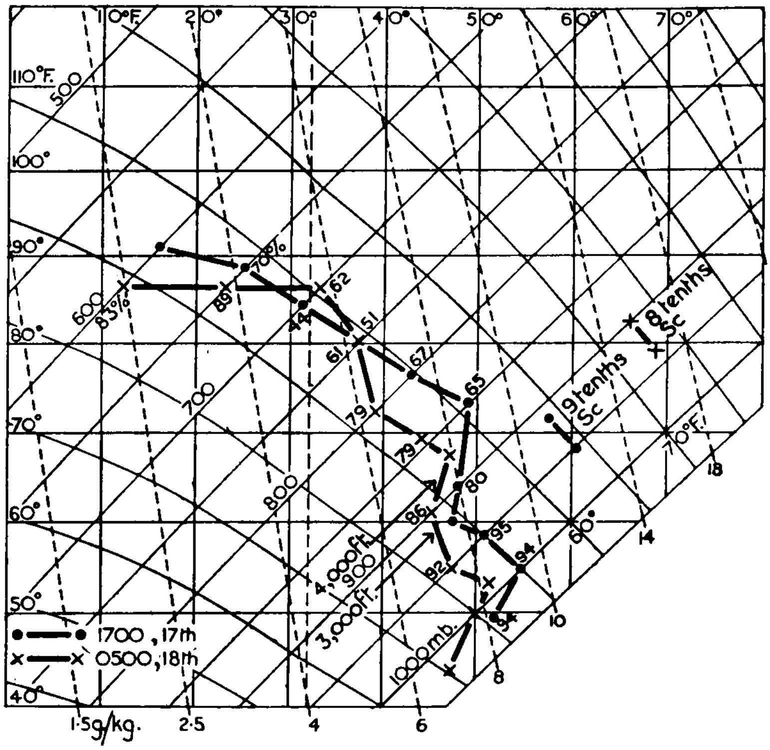


FIG. 2—TEPHIGRAMS OF ASCENTS AT ALDERGROVE

TABLE I—CALCULATED AND OBSERVED TEMPERATURES AT DALLACHY ASSUMING ASCENT OF AIR FROM VARIOUS LEVELS AT ALDERGROVE TO ABOUT 3,000 FT. AND DESCENT TO SURFACE AT DALLACHY

Conditions at Aldergrove 1700 G.M.T., February 17, 1945			Air from various levels above Aldergrove after lifting to 3,000 ft. and descending to the surface at Dallachy		Surface observation at Dallachy at 0300	
Pressure level	Temperature	Relative humidity	Dry-bulb temperature	Dew point	Dry-bulb temperature	Dew point
mb.	°F.	%	°F.	°F.	°F.	°F.
915	47	90*	62	50		
950	51	95	62	50		
1000	55	94	62	51		
1018	52	94	58	46		
			Mean			
			61	49·3	60	50·5

* Estimated

A further check on the extent of the föhn effect was obtained by comparing the absolute humidity at Aldergrove (1700 G.M.T. February 17) at various levels with values computed for Dallachy after lifting. The loss in water content produced by mechanical uplift was calculated and compared with the observed rainfall. For this calculation, it was assumed that the surface layer was lifted to a height of 2,500 ft., that at 8,000 ft. the air was undisturbed (vertically) by the orographic uplift, and that intermediate layers were lifted in inverse proportion to their height. The computation was carried out for the levels, 1000, 950, . . . 750 mb. and the values of the absolute humidity so obtained were subtracted from the corresponding values for Aldergrove, giving a difference in water content of approximately 0·95 gm./Kg. for the lowest 2,000 ft. and 0·45 gm./Kg. for the next 1,700 ft. and thereafter zero. Hence for a column

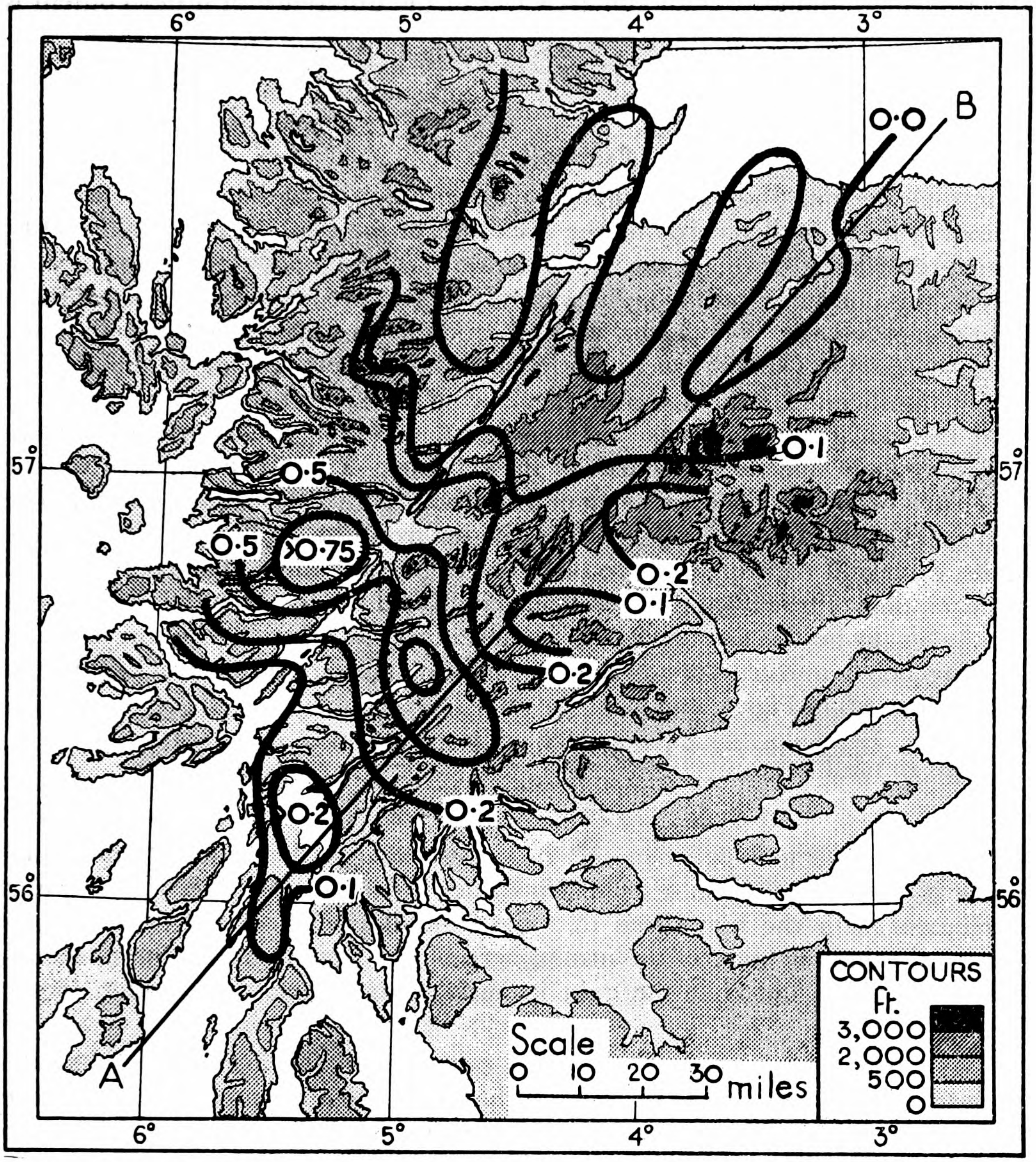


FIG. 3—RAINFALL OF FEBRUARY 17–18, 1945, OVER PART OF SCOTLAND
The rainfall measurements are given in inches

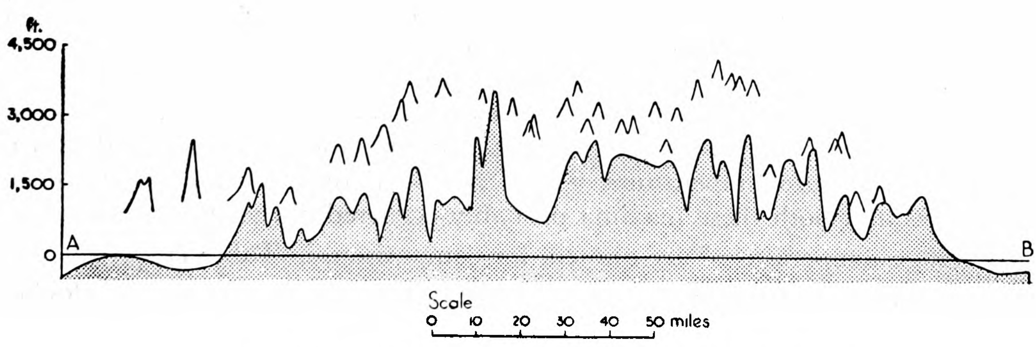


FIG. 4—CROSS-SECTION ACROSS THE GRAMPIANS
Mountain peaks within ten miles of the line AB are also indicated

8,000 ft. high and cross-sectional area 1 cm.[2] the difference in water content is

$$\frac{2000 \times 0{\cdot}95 + 1700 \times 0{\cdot}45}{1000} \times 30{\cdot}48 \times \frac{1{\cdot}2928 \text{ gm.}}{1000}$$

$= 0{\cdot}112$ gm.

$= 0{\cdot}04$ in. ($1{\cdot}12$ mm.) of rainfall.

This quantity must now be compared with actual rainfall data. There were no autographic rainfall records in the area except for Greenock (Prospect Hill) which recorded 0·01 in. for the 24-hr. period ending at 0900 G.M.T. February 18, but at this point orographic uplift was only slight. Hence recourse was made to rain-gauge records. The 24-hr. rainfall amounts in inches along the air track over Scotland to Dallachy were plotted and the isohyets drawn. In the absence of any significant frontal discontinuities during the 24-hr. period, it was assumed that the rate of rainfall was fairly constant, and that the hourly rates were approximately one twenty-fourth of these values. The mean speed of the air layer to 8,000 ft. was assessed as 30 m.p.h. (roughly the geostrophic speed). The 170 miles of track over Scotland were divided from the south-west into 30-mile units, each unit corresponding to one hour in journey time. The mean rainfall for each unit of track was assessed from Fig. 3 and the total for the six divisions was taken to be the assessment of the actual rainfall from a column of air of height 8,000 ft. and cross-sectional area 1 cm.[2] in passing over the track indicated by the line AB in Figs. 3 and 4.

$$\text{Thus rainfall} = \frac{0{\cdot}15 + 0{\cdot}39 + 0{\cdot}19 + 0{\cdot}13 + 0 + 0}{24} \text{ in.}$$

$= 0{\cdot}04$ in.

The close agreement between this quantity and the theoretically calculated value of the rainfall (also 0·04 in.) is rather fortuitous, but the figures are in agreement with the hypothesis that the rainfall was produced from a comparatively shallow layer of the atmosphere by orographic uplift due to mountainous terrain, and that the gain in surface air temperature is due to the föhn effect.

The above computation was carried out also on the assumption that the undisturbed level was at 4,000 ft., and that owing to air compression above the mountains the mean wind speed of the layer to 4,000 ft. was increased to 35 m.p.h. over the Scottish section of the track. Under these conditions the corresponding values for the calculated and observed amounts of rainfall were 0·03 in.

February 18, 1945, was associated with record temperature at several places in this area of north-east Scotland. Throughout the century (since 1901) for any time of the day in February, a temperature record of 60°F. was not exceeded at Inverness, Nairn, Gordon Castle (about 2 miles from Dallachy) or Aberdeen except on February 18, 1945, when Gordon Castle and Nairn reported maximum temperatures of 61°F. and 62°F. respectively. The evidence suggested that both these maxima probably occurred during the afternoon.

Average temperatures[2] are quoted, for comparison, in Table II.

That the south-westerly air stream over the north of the British Isles on February 18, 1945, was both unusually warm and moist may be seen from the following comparison between the air and sea temperatures[3] over the sea area to the west of Ireland and over the North-West Approaches for February and

TABLE II—AVERAGE MAXIMUM AND MINIMUM TEMPERATURE

	Temperature in February		Temperature in July	
	Average minimum	Average maximum	Average minimum	Average maximum
	°F.	°F.	°F.	°F.
Aberdeen	35·2	43·3	51·2	62·2
Wick	36·1	43·1	49·8	58·9
Gordon Castle ...	33·8	44·9	50·0	65·1

the observations of dry-bulb temperature and dew point respectively on the synoptic chart for 0000 on February 18, 1945.

Absolute maximum temperature observed at sea[3]:—

	Air temperature	Sea temperature
	°F.	°F.
West of Ireland	52	51
North-West Approaches	52	49

Temperature observed at 0000 on February 18, 1945:—

	Air temperature	Dew point
	°F.	°F.
Aldergrove	55	52
Oban	54	51

It might be expected that the frequency in winter of high temperature produced by föhn-effect situations would be quite high, because warm damp SW. winds are so frequent over north Scotland, particularly during the winter. On the occasion described the record temperatures were probably produced by the coincidence of an unusual vertical temperature distribution (inversion from 3,000–5,000 ft.) with extremely high temperature and dew point in the air over the Atlantic. The inversion is believed to have reduced mixing with drier air above, thereby increasing the amount of water condensed and the latent heat liberated in the uplifted air.

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2. London, Meteorological Office. Averages of temperature for the British Isles for periods ending 1935. London, 1936.
3. London, Meteorological Office. Monthly meteorological charts, Home Waters. London, 1939.

HIGH-LEVEL CLOUD IN THE TROPICS

By C. S. DURST, B.A.

During a flight on March 18–19, 1952, in a Comet aircraft from Wadi Seidna airfield (Khartoum) to Entebbe and thence to Livingstone, it was observed that there appeared to be a continuous sheet of cirrus or cirrostratus at about 45,000–50,000 ft. extending from 10°40′N., 32°40′E. to 16°10′S., 27°30′E., a distance of over 1,600 nautical miles. Seen from between 30,000 and 35,000 ft. it looked very thin when observed at a small angle with the vertical, indeed it often could not be recognized above the aircraft, but when observed at a small angle of elevation it appeared quite definitely as a comparatively thick sheet all round the horizon with a layer of clearer air below.

On the return trip the first appearance of high cirrus, though not dense, was at 1220 G.M.T. on March 21 at about 15°S. The veil did not seem to be so continuous as on the outward trip but it was present at about 45,000 ft. At about 7°S. there was the appearance of a definite thin veil of cirrostratus far above the cirrus thrown off by large cumulonimbus with all the appearance of a clear layer in between. This persisted to about 3°S. On March 22 cirrus was seen above the aircraft soon after leaving Entebbe and appeared to be rather patchy until 6°N. However, at 7°N. there was no cirrus veil. The veil was renewed again between 9° and 10°N. but was again very patchy.

Some photographs of the cloud are reproduced in the centre of this magazine. I am informed by officers of the British Overseas Airways Corporation and others who have travelled by Comet in the tropics that this cirrus layer is the rule rather than the exception.

It has been the custom to think that cirrus cloud seen in the tropics was either directly associated with the cumulonimbus of the tropical thunderstorms, or was the residual cloud from these storms which persisted after the violent convection had ceased. But the great extent of the cirrus or cirrostratus, which in the case reported above extended for 1,600 nautical miles (and even beyond the limits of normal rainfall in March), makes it most improbable that it is to be attributed to the residual cloud of convectional storms.

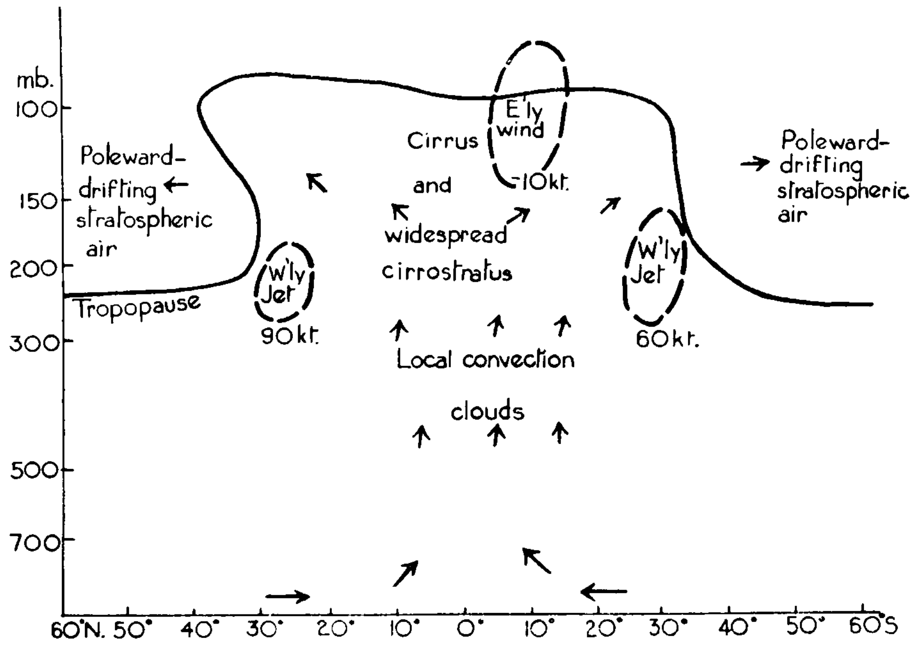
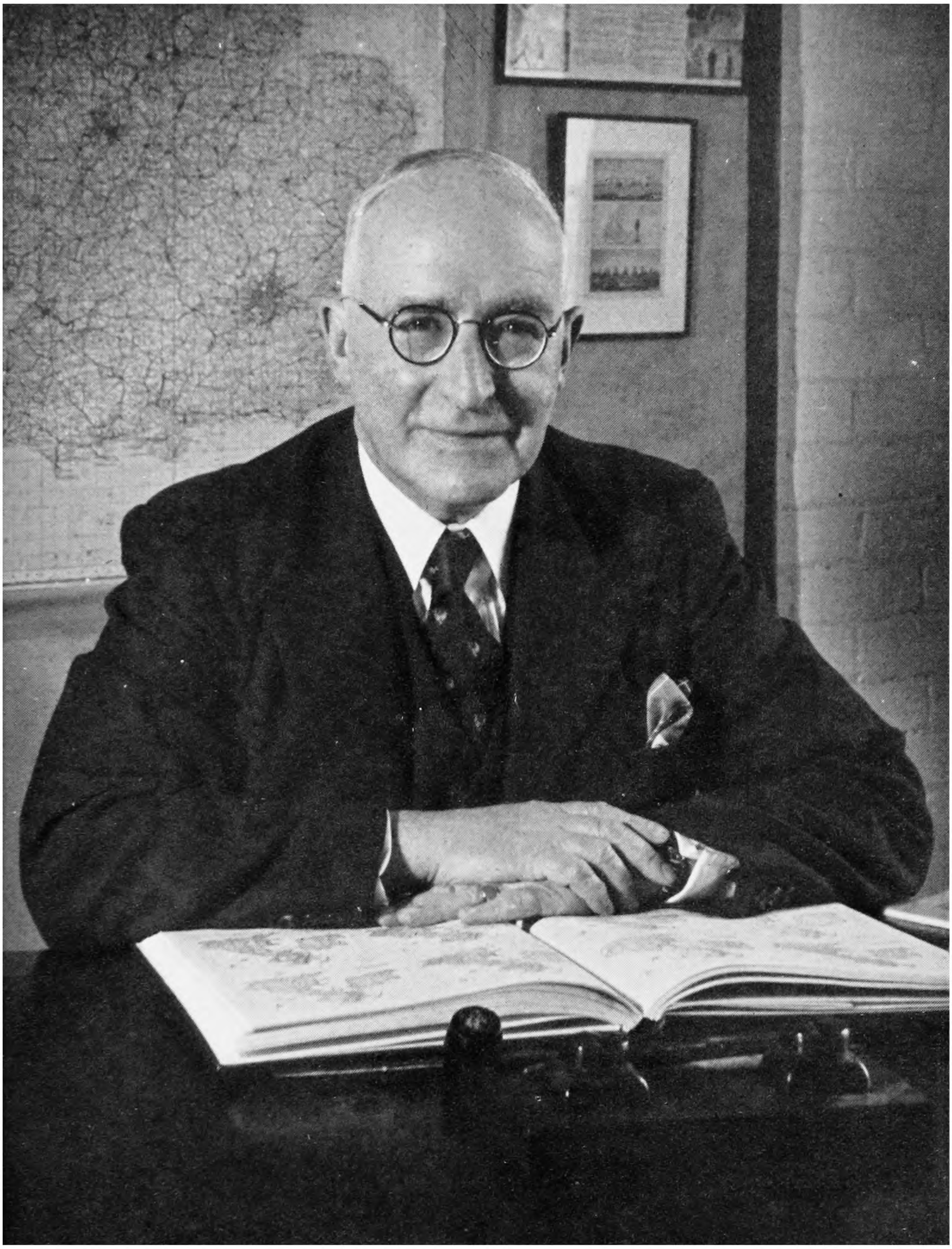


FIG. 1—SCHEMATIC DIAGRAM OF THE GENERAL VERTICAL CIRCULATION

The section of the atmosphere postulated by Frost[1] shows an abrupt rise in the normal level of the tropopause at about 30°N. and 30°S. at the equinoxes, the equatorial tropopause being above the 100-mb. level (say 55,000 ft.) the extratropical tropopause being below the 250-mb. level (say 35,000 ft.). At the positions where the tropopause starts to rise abruptly there are the two semi-permanent jet streams with maximum speeds at about 40,000 ft. (200 mb.). Moreover, it has been supposed that the general circulation of the atmosphere is such that air flows towards the equator near the surface, rises between the tropics and flows outwards high up in the atmosphere.

It is therefore suggested that the cirrus seen at high levels is the result of condensation as the intertropical air rises. When this suggestion was put



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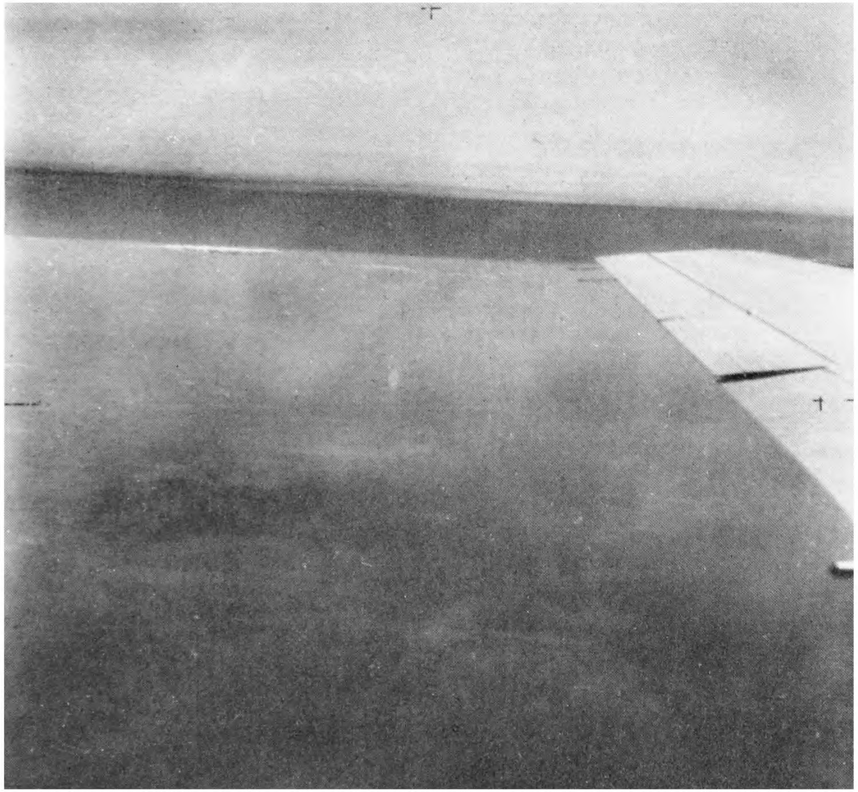
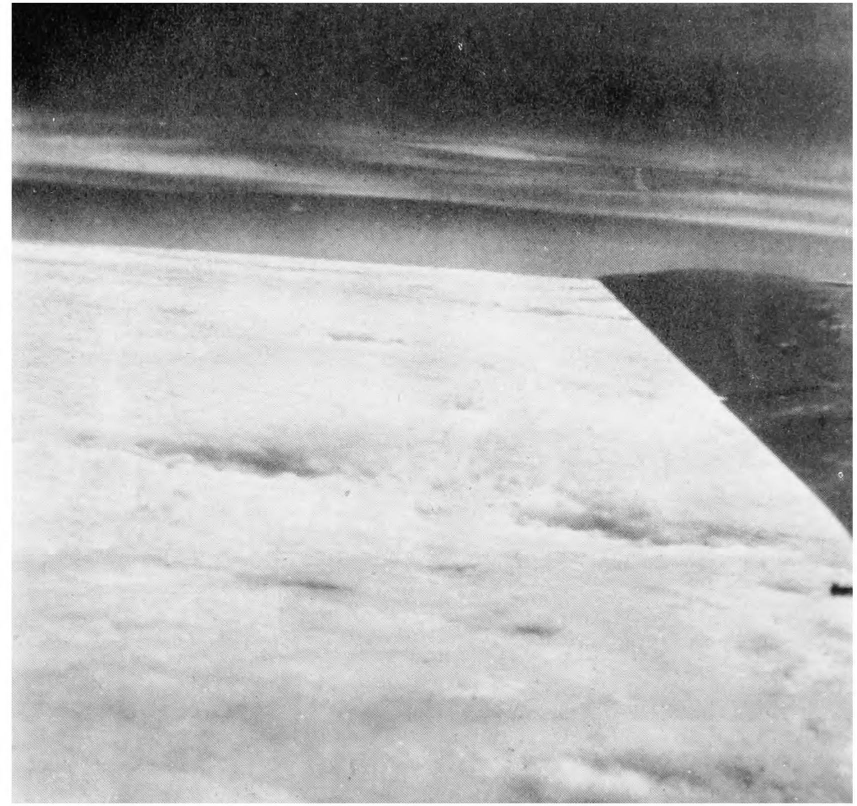
R. H. MATHEWS, O.B.E., B.A.



10°40′N. 32°40′E. from 32,500 ft. 0635 G.M.T., March 18, 1952

This photograph, taken over the Sudan, shows a dust haze stretching up to about 18,000 ft. with the top of a rising column revealed by a cloud at the top of the dust. Some 20,000 ft. above the top of the dust is the sheet of cirrostratus.

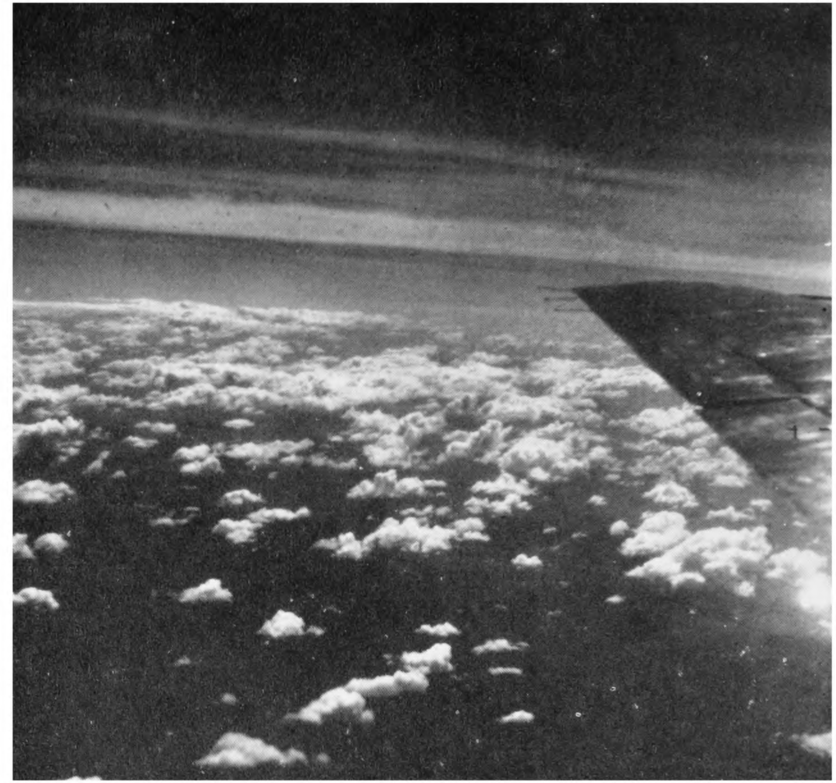


08°18′N. 32°45′E. from 33,000 ft. 0657 G.M.T., March 18, 1952

This photograph, taken over the Sudan, shows a sheet of altostratus or altocumulus cloud, one of a number of patches, an individual patch extending over some thousand square miles. The altocumulus layer has been measured at a height of about 16,500 ft. above M.S.L. Above can be seen the cirrus or cirrostratus layer, the height of which was estimated by eye to be 45,000 ft. or more.

04°20′S. 30°53′E. from 30,000 ft. 0736 G.M.T., March 19, 1952

This photograph shows a mass of cumulus and cumulonimbus cloud beneath. The aircraft had climbed through and past cumulus and cumulonimbus cloud over Lake Victoria and during the ten minutes preceding this photograph had passed by a big cumulonimbus head on the starboard side towering above the aircraft. Cirrus and cirrostratus had been passed through at 30,000 ft. Above these convectional clouds can be seen in the photograph the cirrus or cirrostratus far above the aircraft.



03°00′N. 33°00′E. from 34,600 ft. 0745 G.M.T., March 18, 1952

This photograph, taken over Uganda, shows typical cumulus cloud with base 6,000 ft. above M.S.L. (3,000 ft. above ground level) and tops to 11,000 ft. but mainly 7,000 or 8,000 ft. It was notable how the cumulus could be seen to hang over the hill tops of the broken country beneath. Above is the cirrus or cirrostratus veil the height of which was estimated at 45,000 ft. or more. The measurements from the photographs gave an approximate value of 43,000 ft. for the height of the cirrostratus cloud.

CIRRUS AND CIRROSTRATUS CLOUD IN THE TROPICS

Reproduced by courtesy of A. F. Kersting

TOP OF THE FOG FROM BOX HILL, LOOKING TOWARDS RANMORE COMMON, DECEMBER 8, 1952 forward objection was raised that the condensation would happen not only in the layers between 45,000 and 50,000 ft. but throughout the whole of the atmosphere up to the tropopause. It has, however, been observed by Frith on a number of occasions, from aircraft of the Meteorological Research Flight, that when cirrus was visible from the ground it was invisible when the aircraft was amongst it, the reason being that the ice needles of which it was composed were too sparse to be noticeable at a close view. Therefore it is possible that the Comet was, in fact, among ice needles during the flight from 10°N. to 16°S. This supposition is supported to some extent by the observation that the cloud was not easily visible except when one was looking through a great quantity of it, i.e. when the line of vision was nearly horizontal. Fig. 1 is intended to show in a very schematic manner how the general vertical circulation would take place if the speculation I have put forward above is true.

It is to be noted that in many of the photographs[2] taken from a Comet when flying from Calcutta to Karachi in September 1951 high cirrus cloud far above the aircraft (flying at 40,000 ft. or so) was visible to the southward. It is probable that this cloud, too, is the expression of the general rising of the air in the intertropical region.

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1. FROST, R.; The upper air circulation in low latitudes in relation to certain climatological discontinuities. *Prof. Notes Met. Off., London,* **7**, No. 107 (in the press).
2. HURST, G. W.; Cloud photographs taken from Comet aircraft. *Met. Mag., London,* **81**, 1952, p. 173.

METEOROLOGICAL OFFICE DISCUSSION

Cold pools

The discussion on December 15, 1952, was opened by Mr. S. E. Virgo, who based his statement on the following papers:—

BUSCHNER, W.; Untersuchungen über Verlagerung, Aufbau und Dynamik zweier winterlicher Kaltlufttropfen. *Ber. dtsch. Wetterdienstes, U.S. Zone, Bad Kissingen,* **4**, No. 23, 1951.

FONTAINE, P.; Les "gouttes d'air froid" sur l'Europe, la Méditerannée et l'Atlantique Est. *Météorologie, Paris,* Serie 4, No. 22, 1951, p. 98.

In his introduction the Director remarked that it was fitting that a German paper was being considered on this occasion, the first discussion since the formation of a unified Meteorological Service for the Western Zones of Germany.

Mr. S. E. Virgo first summarized Buschner's paper. Buschner asserts that, in general, a moving cold pool is steered in the direction of the gradient wind at the surface. He considers that cold pools in winter move at about 60 per cent. of the speed of the gradient wind, and he attributes the difference to losses of energy caused by changes of temperature and pressure within the cold pool, by radiation, and also by vertical motions.

Buschner analyses the vertical structure of cold pools by means of vertical cross-sections of temperature, pressure and relative humidity constructed from radio-sonde reports. In his temperature cross-sections he plots the difference between temperatures within the cold pool and those in the undisturbed air outside. In the examples of cold pools in motion which he examines the maximum cooling, about 15°C., occurs at about 650 mb. The upper limit of the negative temperature anomaly occurs at about 400 mb.; above that level the air above the cold pool is warmer than its surroundings, though this heating is not of such a magnitude as to compensate for the cooling at lower levels.

Although there are no marked pressure tendencies at the surface, the pressure cross-sections show increasing anomalies up to the base of the stratosphere, and indeed the sag in the 400-mb. surface within the cold pool on December 15, 1946, amounts to about 800 ft. Moreover there is no change in sign of the pressure anomaly right up to the greatest heights attained by the radio-sondes. In other words, the pressure at any level within the cold pool is lower than in the surrounding air at the same horizontal level, but there is nevertheless complete compensation at the surface.

The cross-sections of anomalies of temperature and pressure are symmetrical, but the cross-section of relative humidity is not symmetrical. There is a tongue of drier air ahead of the axis of the cold pool, suggestive of descending air, and a tongue of moister air behind, suggestive of rising air. This pattern is confirmed by the distribution of cloud and precipitation. There is a cloudless area ahead of the cold pool, and an area of much cloud and snowfall behind.

Buschner asserts that the observed temperatures can only be maintained if the losses due to radiation from the cloudless area ahead of the cold pool are offset by heating caused by downward motion, and with the aid of a radiation diagram he calculates this rate of descent. He then refers to a theorem by Lettau which attributes large-scale downward motions of air to outflow across the isobars in the frictional layer near the earth's surface, and he applies Lettau's formula to obtain an estimate of the downward motion in advance of the cold pool. The rate of descent obtained by this method is significantly higher than that obtained from the radiation calculation. Buschner explains the difference by supposing that the cold pool moves against the air stream, and he is able to calculate from the temperature distribution the up-wind component which would resolve the discrepancy; he finds that it is of the order of 30 per cent. of the speed of the gradient wind. This is in fair agreement with his earlier observation that the cold pool moves at a rate equal to 60 per cent. of the speed of the gradient wind.

The cause of the stagnation of a cold pool is the development of an area of falling tendencies ahead of it; this destroys the strong gradient which is steering the system, and also causes an area of low pressure to appear at the surface under the cold pool. The cold pool then becomes symmetrical, with ascending air, cloud and precipitation occurring vertically above the centre of low pressure.

Fontaine's paper is mainly statistical. He classifies the cold pools which affected the eastern Atlantic and the continent of Europe during the years 1946–49 into three categories according to their origin and trajectory: 51 per cent. fall into the Atlantic category, 33 per cent. into the Mediterranean category, and only 16 per cent. into the continental category. This analysis gave point to a suggestion made by speakers later in the discussion, that Buschner's cold pools were of a rather special kind.

Fontaine also recognizes a correlation between frequency of occurrence of cold pools, and storminess and hail. He draws attention to the number of cold pools which become retarded on the Atlantic between the Azores and Portugal. In the second part of his paper, Fontaine endeavours to find a correlation between the behaviour of cold pools and solar activity.

Mr. Douglas remarked that the Germans introduced "cold drops" in the 1930's, and they were associated with comparatively straight currents at sea level, while "cold pool" is a wider generic term which came into existence at the Central Forecasting Office during the 1939–45 war. Recent extensive research by Mr. Sumner has shown that the "cold drops" are one class in a very large and complex set of entities. Great caution is needed in making generalizations about their relation to weather, and there is sometimes precipitation ahead of cold pools from the east. (Communicated later) Examples of such precipitation occurred in southern England on October 31, 1946, January 28, 1947, and February 20, 1948, the last two with important snowfalls. All three cases were associated with small but increasing troughs of low pressure at sea level, and in 1947 the snow started in Germany. If the absence of any falling tendency of sea-level pressure is made a condition, one is left with a rather small sub-class, and notably so when a cold pool reaches France or southern England from the east. When there is subsidence ahead of a "cold drop", it is a similar phenomenon to the subsidence commonly found behind a cold front but ahead of the related cold tongue in the 1000–500-mb. thickness field. Sea-level pressure is usually rising, but if there is a fall over a large area the belt of subsidence may only be represented by a weakness in the general fall.

Mr. Jacobs pointed out that the slow-moving surface depressions in the Azores region, which he and Mr. Murray had described in "Aviation meteorology of the Azores", were associated with upper cold pools. He had looked through the *Daily Weather Reports* and *Daily Aerological Records* for 1952 and had found that the frequency of these stagnant lows, which could occur anywhere within the region southern Ireland–Bermuda–Azores and southward to Madeira–Portugal was roughly similar to that for the two years previously studied, 1943–45. The lows form as the last wave on a north-east–south-west polar front, which becomes blocked by the build-up of the North American and European highs to the north and then drifts east to south-east, deepens and quickly occludes. The longest periods of bad weather in the Azores region occur with these lows, and the frequent showers or thunderstorms and often strong to gale force winds can be accompanied by drizzle and very low stratus cloud once the centre of the low gets to the south of the Azores. The lows usually persist for one or two weeks, about 4–6 times a year in autumn, winter and spring (when the highs are well developed), but may dominate a whole season as in the autumn of 1945. The upper cold air is often renewed by the arrival of polar lows or of old occluded lows from Florida. The type ends either by the low filling or moving away north-eastwards as the northern highs weaken. Mr. Virgo said that Fontaine had given no reason why he obtained a correlation between strong winds and cold pools, but this might have been analogous to the frequent occurrence of strong winds with the Azores lows.

Mr. Wallington mentioned the large number of cold pools which Fontaine recorded near the east coast of Spain. He pointed out that upper air data from Spain are sparse, and wondered whether the east coast of Spain was in fact a favourable place for cold pools, or whether the number had been artificially increased by the way in which the charts had been drawn.

Mr. Hawson said that at the Central Forecasting Office each cold pool was treated on its merits. The movement of a thickness line might be affected by advection, insolation and vertical motion, and each of these processes was considered separately. He thought that the ratio of the speed of movement of the cold pool to the speed of the gradient wind could vary between very wide limits.

Dr. Sutcliffe referred to the possible confusion in terminology. In the paper discussed, and generally in German literature, the Kaltlufttropfen was defined as a cold pool having little or no associated pressure irregularity at the surface. It occurred over the continent with easterly surface winds and was rather a rare phenomenon. The cold pool, as understood in English literature, was defined as a cut-off region with closed isotherms or thickness lines and could be associated with any surface pressure pattern (as far as the definition was concerned) and was a very common phenomenon. The distribution of convergence, divergence and vertical motion in the neighbourhood of a cold pool or cold drop presented a complex dynamical problem for which there could be no universally valid solution, but on the whole Dr. Sutcliffe's experience confirmed the tendency for the rainfall to lie to the east and so to be behind the westward-moving system. If there were little variation in the surface pressure gradient over the region, the dynamical problem would be little affected by eliminating this gradient (by adding an equal and opposite geostrophic wind at all heights). We should then have a purely thermal wind field, and, in accord with development theory, cyclogenesis and upward motion would normally be found to the east of the thermal trough. Over the sea cold pools were most commonly associated with marked cyclonic circulations, and the German type of "cold drop" was very important because, if it should drift over the sea, it was liable to give rise to important cyclonic activity.

Mr. C. V. Smith spoke of Sumner's recent statistical and synoptic study of cold pools, not yet published. In effect, Sumner has defined a cold pool as the area lying within a closed line in the 1000–500-mb. thickness pattern. He was concerned with only the more intense features, those which were associated with two or more closed thickness lines, and which appeared on at least two successive 0300 G.M.T. charts. His data were for a five-year period, and for a sector which covered the Atlantic and Europe as far as 30°E.

Charts have been produced showing where the pools were located. The greatest concentration is over Europe at all seasons; over the Atlantic there are areas in which pools of the intensity specified by Sumner never occur. Cold pools occur mostly in spring and early summer. Rex and Brezowsky have discerned a maximum blocking of the upper westerlies about this time. A cold pool (especially if it is formed by the cut-off process) is frequently associated with the low vortex (at the 500-mb. level) of the typical blocking pattern formed by the concomitant high and low vortices. Persistence of the pool may then be in part linked with the persistence of this pattern.

The greater number of the cold pools studied by Sumner were formed by the cutting-off of the cold air at the southernmost extremity of an upper cold trough. This was usually of large amplitude and slow moving, though with some relative motion between the northern and southern parts of the trough which resulted in the northern portion shearing forward leaving a closed vortex to the south-west. On the surface this process was associated with a marked anticyclonic development across the area directly below the middle of the upper trough and with the maintenance of a cyclone to the south in association with the developing cold pool. Warm advection from the west across the top of the anticyclone completed the cutting off. There were, however, many variants of this basic model, depending mainly on the degree of development of the surface systems. The predominant agency in removing cold pools was warming *in situ*. The average persistence was three days.

Any configuration of surface isobars could be associated with an upper cold pool. Sumner's data gave about 200 cases for the five-year period of which one fifth to one sixth were of the cold-drop type described by Buschner. The most commonly occurring surface feature was the cyclone.

Statistics have been produced concerning the weather within the area of the cold pools. There were occasions when it was completely fine or completely overcast, but these extremes were rare. Generally, partly cloudy conditions obtained. Precipitation could occur with any associated surface features.

The central thickness (1000–500 mb.) of the pools studied was invariably below—usually 400–500 ft. below—the normal for the time and place, with some tendency to "relax" to an anomaly of about −450 ft. if greater or less than this value.

Mr. Bannon recalled some points made by Scherhag in a lecture. He said that cold pools of the kind described by Buschner are a special type. They die out quickly as soon as they move out over the sea. Mr. Bannon placed little reliance on the 60-per-cent. rule.

Mr. Sawyer said that the disappearance of continental cold pools is often associated with strong cyclogenesis over the sea, a fact which might be important to forecasters.

Mr. Gold was sceptical about Buschner's radiation calculations.

Mr. Boyden said that Lettau's formula for vertical velocity depends upon the curvature of the isobaric surfaces in the frictional layer. The curvature is derived from the configuration of the surface pressure chart. Mr. Boyden failed to see how this could be used to compute vertical motion in a cold pool which makes no impression on the surface pressure chart.

Dr. Sutcliffe agreed that surface frictional convergence and divergence were unlikely to be the main cause of the observed fields of motion in this type of system, any more than in others. The absence of associated surface pressure features over the cold land in winter was probably due to the damping of development by vertical stability over the relatively warm sea—cyclogenesis could take place more freely.

Mr. Kirk referred to the statement that anticyclonic conditions may occur ahead of the cold pool and cyclonic conditions behind it. In the following mathematical argument, he shows that an explanation may be based on the relationship between the winds and the temperature field. It is convenient to examine temperature change along the path of the air in terms of changes related to the constant-pressure surface. Thus

$$\frac{dT}{dt} = \left(\frac{\partial T}{\partial t}\right)_p + \mathbf{V}_{\text{H}} \cdot \nabla_p T + \frac{\partial T}{\partial p}\frac{dp}{dt} \qquad \ldots (1)$$

where T denotes temperature, p denotes pressure, a suffix H denotes the horizontal component, and a suffix p denotes differentiation along the constant-pressure surface.

If Q is the heat received by unit volume then from the principle of the conservation of energy

$$\frac{dQ}{dt} = c_v \frac{dT}{dt} + p \frac{d}{dt}\left(\frac{1}{\rho}\right),$$

where c_v is the specific heat at constant volume and ρ the density, or

$$\frac{dQ}{dt} = c_p \frac{dT}{dt} - \frac{1}{\rho}\frac{dp}{dt}, \qquad \ldots (2)$$

c_p being the specific heat at constant pressure. Substituting from (1) in (2) and rearranging terms, we derive

$$\left(\frac{\partial T}{\partial t}\right)_p = \frac{1}{c_p}\frac{dQ}{dt} - \mathbf{V}_H \cdot \nabla_p T + \frac{1}{g\rho}\left\{\frac{\partial T}{\partial z} + \Gamma\right\}\frac{dp}{dt} \qquad \ldots (3)$$

where Γ is the dry adiabatic lapse rate. If the velocity of the isotherms is $\mathbf{c}$ and the temperature field moves without intensification or weakening, then

$$\left(\frac{\partial T}{\partial t}\right)_p + \mathbf{c} \cdot \nabla_p T = 0 .$$

Hence, substituting in (3),

$$(\mathbf{V}_H - \mathbf{c}) \cdot \nabla_p T = \frac{1}{c_p}\frac{dQ}{dt} + \frac{1}{g\rho}\left\{\frac{\partial T}{\partial z} + \Gamma\right\}\frac{dp}{dt}$$

If colder air approaches and the wind is moving faster than the isotherms, then ahead of the cold air $(\mathbf{V}_H - \mathbf{c}) \cdot \nabla_p T$ is positive. If the non-adiabatic term can be regarded as of secondary importance then dp/dt must be positive since $\partial T/\partial z + \Gamma$ is essentially positive. Hence, since dp/dt may be used as a criterion for development, we should expect anticyclonic conditions ahead of the cold air. A similar argument suggests the necessity for cyclonic activity in the rear of the cold pool.

These results therefore follow from

(i) the assumption that the motion is essentially adiabatic

(ii) the assumption that the cold pool moves as an entity slower than the wind.

Mr. Boyden remarked that the drawing of contours was to some extent subjective, especially over those areas where radio-sonde data were few. He thought forecasters ought to be sure that they had good evidence before they cut off the end of a long cold tongue and made it into a cold pool. He hoped that this discussion would not lead to the appearance of large numbers of cold pools on charts.

Dr. Stagg stressed the need for exact definitions of the terms "gouttes d'air froid", "Kaltlufttropfen" and "cold pools". The precise meanings of all these terms were by no means evident from the discussion; and unless they were clearly defined, confusion was bound to follow.

Mr. Virgo gave his reason for translating the "Kaltlufttropfen" of Buschner's paper as "cold pool". He said that Douglas had defined a cold pool in terms of at least one closed thickness line, and by this definition the "Kaltlufttropfen" of Buschner's paper were "cold pools".

Mr. Veryard said that, in the Mediterranean, rain was associated with cold pools all the time they lasted.

The Director, in closing the Discussion, commented that it was clear that the definition of the term "cold pool" had not yet become standardized.

METEOROLOGICAL RESEARCH COMMITTEE

Joint Meteorological Radio Propagation Sub-Committee

The Joint Meteorological Radio Propagation Sub-Committee—a joint sub-committee of the Meteorological Reseach Committee and of the Tropospheric Wave Propagation Committee of the Radio Research Branch—has been dissolved. Matters primarily of meteorological interest which were formerly dealt with by the Sub-Committee will in future be considered by the Physical Sub-Committee of the Meteorological Research Committee. Matters having primarily a radio interest will be considered by the Tropospheric Wave Propagation Committee.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

A century of London weather.

Many inquiries are received in the Meteorological Office from the Press, the general public, gardeners and students requiring comparisons of current weather with the weather experienced in the past. Printed and manuscript weather observations made in London since 1841 have now been assembled in one cover for the first time in a form designed to give quick and reliable answers to the questions experience has shown to be most frequently asked.

Averages and extremes of temperature, rainfall and sunshine are supplemented by weather details of perennial interest. Coloured diagrams enable the reader to see at a glance how each individual month, season and year compares with the average and with each other, and thus to obtain a broad picture of weather trends in London over the past century.

London fogs are compared with those of 50 years ago, while temperature readings each day for a hundred years have been examined to see whether any periods of the year have in fact been subject to warm or cold spells with any significant regularity.

The more orthodox tabular summaries will be of value to students and to the investigator who wishes to relate weather conditions to his own particular problem.

GEOPHYSICAL MEMOIRS

No. 88—Humidity of the upper troposphere and lower stratosphere over southern England. By J. K. Bannon, B.A., R. Frith, Ph.D. and H. C. Shellard, B.Sc.

This Memoir gives details of the first series, made anywhere in the world, of observations of humidity in the upper troposphere and lower stratosphere. The observations were made on 130 flights, mainly in Mosquito aircraft, over southern England, usually to heights of 38,500 ft. or above. The observations are analysed with respect to their height above or below the tropopause thus emphasizing any humidity differences between troposphere and stratosphere. Correlation coefficients are given between humidity (frost-point temperature) and other parameters at various levels. The humidity is also analysed at fixed levels to show the variation between different synoptic types, between different seasons and between different air masses. Changes in humidity in passing through frontal surfaces are discussed and attention is drawn to some observations made near jet streams. Because of the height limitation of the aircraft, observations penetrating well into the lower stratosphere were only possible when the tropopause was at its normal height or lower.

No. 89—*Temperature and humidity gradients in the first* 100 *m. over south-east England.* By A. C. Best, M.Sc., E. Knighting, B.Sc., R. H. Pedlow, B.Sc. and K. Stormonth, B.Sc.

Using temperature and humidity elements at four different heights on a lattice tower the vertical gradients of temperature and of absolute humidity in the lowest 100 m. of the atmosphere have been recorded over a period of three years at a site near the coast of south-east England.

From these records meân hourly values of temperature and humidity at each height, and of the vertical gradients, have been extracted for each month. The diurnal variation of these atmospheric parameters is examined. Tables are also given showing the effect of cloud cover upon the gradient of temperature and humidity and also the frequency of gradients of specified magnitudes.

The effect of snow cover is briefly considered. The vertical gradient of temperature and humidity in a radiation fog is discussed and one such occasion is examined in detail.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on December 17, 1952, the President, Sir Charles Normand, in the chair, the following papers were read:—

*Roper, R. D.—Evening waves**

An explanation was given of lifts encountered by gliders flying in the evening from Camphill, Derbyshire, which carried them to heights greater than those which they had been able to attain all day. This phenomenon was previously described as an "evening thermal", and was observed at Camphill with a moderate or fresh W. or NW. wind following a sunny day. Haze was common up to about 2,000 ft., and often a lenticular or roll cloud was stationary over or on the hills to the west. Some good examples of these clouds were shown on slides in colour. The author considered the explanation to lie in the rapid change of lapse rate in the lowest layers in the evening which makes conditions suitable for standing waves to occur. An appendix by Scorer showed that an evening inversion at 2 Km. would be associated with a standing wave of wave-length 5 Km. in these meteorological conditions in the evening when most of the shallow convective layer had had time to disappear.

In the subsequent discussion, to which Mr. Gold, Dr. Scorer and others contributed, it was shown that standing waves were quite frequent near many gliding centres and lifts up to 20,000 ft. were known. Probably more cases of such lifts to great heights would have been recorded if the ascent had not been terminated due to the onset of darkness or the pilot's shortage of food or oxygen. An essential condition for the formation of standing waves was the existence of strong vertical wind shear and stability in the lowest layers. Since the amplitude of these standing waves often amounted to several thousands of feet, down-draughts from them constituted a serious menace to aircraft flying near mountains. It was significant that on the occasion of the aircraft crash near Snowdon on January 10, 1951, the wind speed at 30,000 ft. was 155 kt. Mr. Gold

* *Quart. J. R. met. Soc., London,* **78**, 1952, p. 415.

asked whether it was possible to define the magnitude of wind and temperature gradients in the vertical which would be favourable or would prevent the formation of standing waves, and Dr. Scorer believed this would be possible. "Evening thermals" were defined as standing waves which were able to develop in the evening when convection had weakened. As a result of this work stratocumulus hitherto believed to be formed by the spreading out of cumulus at the end of the day can now be ascribed to the development of standing waves. On many occasions standing waves develop without associated cloud.

*Sheppard, P A. Charnock, H. and Francis, J. R. D.—Observations of the westerlies over the sea**

Sheppard, P. A. and Omar, M. H.—The wind stress over the ocean from observations in the trades†

In the past, investigations of wind structure in the first few hundred metres have assumed the existence of a boundary layer at the top of which the wind merges smoothly with the general air flow above, assumed to be geostrophic. No turbulent transfer of momentum in the vertical takes place therefore at this level. Hence the frictional drag exerted by the earth's surface on the moving air may be calculated by balancing the momentum thus extracted with that acquired by virtue of the cross-isobaric flow. This principle has been successfully applied for many years to the wind structure over land surfaces but seems to have had little application to winds over the sea.

These two papers, presented by Prof. Sheppard, describe a practical investigation undertaken at the Scilly Isles for the temperate-latitude westerlies, and, for reasons which emerged later, a theoretical investigation on similar lines for the trade winds. At Scilly a series of accurate pilot-balloon observations were made at half-hourly intervals during a winter spell of westerlies. Some valuable results concerning the finer structure of the westerlies near the surface were obtained, but the main outcome of this work was to show that the principle of momentum balance referred to above could not be applied to these winds; there was no boundary layer, for the baroclinic structure of the atmosphere led to a continued velocity gradient, probably up to the tropopause in many cases. This requires little or no cross-isobaric flow at the surface—which was confirmed by the observations. It is interesting to note that the climatological charts for the North Atlantic Ocean also show no cross-isobaric flow in the westerlies.

The trade winds, however, normally show a reversal of velocity gradient at a height of a few hundred feet, whence it may be inferred that there is a boundary layer into which momentum is transported from above. Cross-isobaric flow is a characteristic of the trade winds, both for individual observations and in the mean. The investigation described in the second of these papers used reported pilot-balloon ascents for certain tropical islands and led in the main to reasonable and consistent values for the surface drag.

A lively and interesting discussion followed. Mr. F. H. Ludlam and Mr. J. S. Sawyer raised the question as to how far the turbulence measured by the half-hourly observations of horizontal wind was applicable to the scale of

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* *Quart. J.R. met. Soc., London*, **78**, 1952, p. 563.
† *Quart. J.R. met. Soc., London*, **78**, 1952, p. 583.

turbulence involved in vertical momentum transport. Dr. R. C. Sutcliffe welcomed the employment of an observational method specifically for the determination of the drag coefficient over the sea. He pointed out the possibility of interaction between the upper and surface levels in the trade winds, and suggested that some downward transport of momentum might be effected by general subsidence arising from a large-scale meridional circulation. Dr. E. T. Eady also suggested that the large-scale circulations were important in this problem and saw no reason why they should be inconsistent with cross-isobaric flow against the pressure gradient.

Prof. Sheppard in reply said that we had as yet no definite knowledge on these points. It was planned to extend the work by using the Scilly observational technique at a tropical location in the not too distant future.

The President, Sir Charles Normand, in closing the discussion, congratulated Prof. Sheppard on his recent appointment to the only Chair of Meteorology in a British University, and expressed his confidence that we could look forward to many papers describing work of the same high quality from Prof. Sheppard's Department in the coming years.

INSTITUTION OF WATER ENGINEERS

Symposium on hydrology

In 1951 the Hydrological Research Group of the Institution of Water Engineers was reformed with revised terms of reference—"The study of hydrology, especially those branches relating to rainfall, run-off, percolation and evaporation, the scope of the studies to include methods of measurement of the phenomena and interpretation of the records, including the appropriate use of statistical methods". After several meetings the Group decided, as a first step, to hold a discussion so that all those interested in hydrology from any of the various aspects could make their contribution. In order to stimulate a discussion the Group prepared a symposium setting out briefly present-day knowledge, the problems involved and the uncertainties. The Discussion was held on November 12, 1952, the meeting being arranged under the auspices of the South-Eastern and Land-Drainage Sections of the Institution of Water Engineers.

The Symposium consisted of four papers: "Hydrological measurements" (divided into four sections: precipitation, evaporation and percolation, run-off, and ground-water levels and storage); "Estimation of yield (overground)"; "Estimation of yield (underground)"; and "Some observations on pumping tests carried out on chalk wells".

Reference can be made only to some of the points raised in the Discussion by the 34 contributors. Mr. N. E. Rider (Meteorological Office) referred to the work now being carried out at Cambridge in measuring dry-bulb and wet-bulb temperatures and wind changes near the surface of the ground. One of the objects is to evolve a simple method of determining evaporation applicable to specific cropped areas for periods of a day or longer. Dr. F. Pasquill (Meteorological Office) paid tribute to the neat way in which Dr. Penman had avoided using surface temperature, which is difficult to measure, but had used quantities normally specified in climatological records: duration of bright sunshine, air temperature, vapour pressure and wind speed. Dr. Pasquill emphasized the importance of continuing the fundamental research work at Cambridge and also of considering incoming radiation as a measure of the heat loss due to evaporation over long periods. Mr. D. J. Schove referred to long-term climatic variations by quoting from his paper "The climatic fluctuations since A.D. 1850 in Europe and the Atlantic"*, but hesitated to apply past fluctuations to forecast future rainfall trends. Capt. W. N. McClean advocated the use of the 33 years, 1913–46, for future averages, because it covered three sun-spot periods. Mr. A. Bleasdale (Meteorological Office) pointed out that the run-off characteristics of a drainage area might change with time. Thus following the heavy rain of August 15 in the Lynmouth area the beds of upland streams were found to have been scoured out. As a result there was some evidence of better drainage of bogs and of streams flooding and falling more quickly. Similar changes in land use or of field drainage might affect relationships between rainfall and run-off over a period of years. Mr. G. Santing referred to experiments carried out in Holland with four large percolation gauges with bare soil, dune vegetation, leafed trees and conifers. The percolation was least with conifers. Many speakers stressed the importance of securing more run-off records, deploring the recent suspension as a measure of economy of the Inland Water Survey Committee.

The afternoon session was devoted to underground hydrology, but it was apparent that this was closely related to surface hydrology. The fullest use of underground water would benefit the supply engineer, and in some cases provide storage in the ground for winter rains to the advantage of the drainage engineer.

The papers and the discussions are being published in the May 1953 number of the *Journal of the Institution of Water Engineers*. The discussion is being considered in detail by the Hydrological Research Group in order to prepare a comprehensive report for submission to the Institution of Water Engineers with a view to publication.

J. GLASSPOOLE

LETTER TO THE EDITOR

Forecasting ground frost

From investigations made at Munster, a low-lying station in Germany, R. Faust† proposed the formula

$$T + \frac{D}{2} < 79$$

for the forecasting of ground frost on radiation nights, where T and D are screen temperature and dew point respectively in degrees Fahrenheit at 1400 local time. G. J. Jefferson‡ examined the applicability of the formula to Hullavington, Wiltshire.

A test has now been made for St. Athans, Glamorgan, a low-lying station, 150 ft. above M.S.L., in fairly level country two miles from the coast. The observations used were for the whole of 1945 and the period November 1949 to May 1951.

* *Quart. J.R. met. Soc., London,* **76**, 1950, p. 147.
† FAUST, R.; Ein Hilfsmittel zur Nachtfrostvorhersage. *Ann. Met., Hamburg,* **2**, 1949, p. 105.
‡ JEFFERSON, G. J.; Forecasting ground frost. *Met. Mag., London,* **80**, 1951, p. 295.

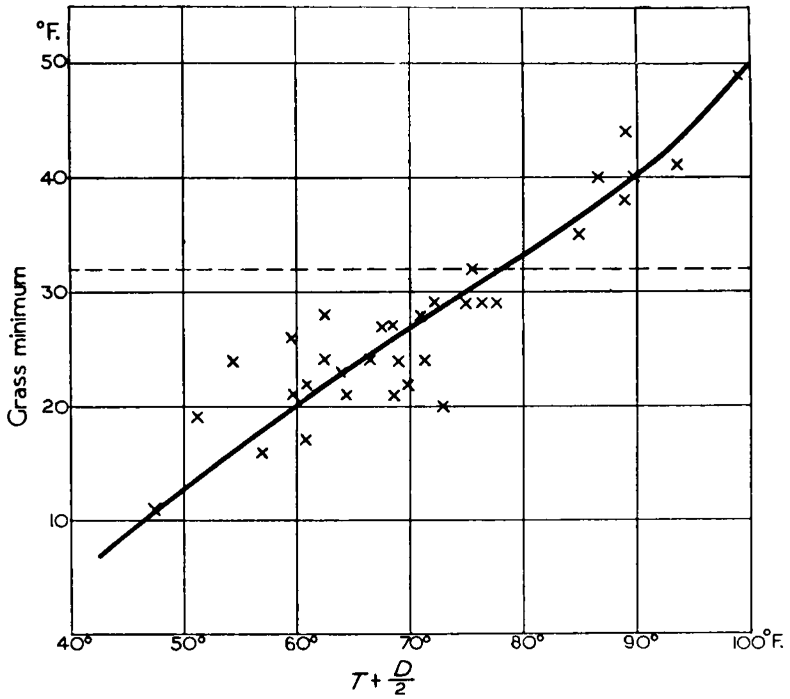


FIG. 1—RELATION OF MINIMUM GRASS TEMPERATURE TO SCREEN TEMPERATURE AND DEW POINT

A similar curve, Fig. 1, was obtained to that given by Jefferson with a constant 78 almost the same as the value 79 given by Faust. A curve, not reproduced, was also drawn for screen minimum temperature. This curve was almost the same with a constant of 66 in place of 78.

W. E. JAMES

Llandow, Glamorgan, August 18, 1952

REVIEW

The Climate of the Gold Coast. By H. O. Walker and A. D. Swan. *Notes Gold Coast met. Serv., Accra,* No. 1, 1952, British West African Meteorological Services, Lagos, 1952.

The author's intention is to describe the climate of the Gold Coast for any person interested in this region but it is not intended for the professional meteorologist.

Only five years' observations (1947–51) for 13 stations have been used as a basis for this study but mainly over 20 years' observations for the discussion of rainfall. Owing to the small and regular changes of temperature and humidity, the short period gives a sufficiently accurate picture of these important elements of climate; the tables based on the longer periods show the large monthly and yearly variations of rainfall as well as illustrating the seasonal variations described in the section on rainfall. Plans for the future will provide data on short-period rainfall intensities and evaporation.

An elementary discussion is given of the air masses affecting the Gold Coast, and of the intertropical convergence zone—it is a pity that maps are not provided for illustrating the seasonal pressure and wind distributions and the associated movements of the zone; they would also have clarified the description of the rainfall seasons over the region.

Brief but useful descriptions are given of cloud, sunshine, thunderstorms and visibility with tables of mean values for the first three; it does not seem worth while giving two tables (for 0900 and 1500) showing mean amount of low cloud as well as the four tables (for 0300, 0900, 1500 and 2100) of means of total cloud amount.

In the section on relative humidity and the specification of water vapour in the atmosphere, it is stated that the wet-bulb thermometer measures the temperature to which the liquid water cools; is not the theory that heat is supplied to the water in order to evaporate it, the heat being drawn from the air passing over the wet bulb and from the thermometer itself? It is suggested that for a future edition, data on wet-bulb temperatures (in addition to relative humidity) would be very useful.

For the person visiting the Gold Coast for the first time a study of this short note, and the appropriate tables, would give him an adequate idea of what weather to expect—this would even apply to the professional meteorologist!

J. PEPPER

ERRATA

November 1952, PAGE 330, FIG. 4; Insert an additional 20 per cent. line over south-eastern Australia joining the points: 35°S., 136°E.; 36°S., 141°E.; 37½°S., 145°E.; and 38½°S., 147°E.

January 1953, PAGE 22, line 47; *for* "inside" *read* "beside".

February 1953, PAGE 46, line 9; *for* "$\frac{\varepsilon_1}{2} + \frac{\varepsilon_2}{2} + \eta$" *read* "$\frac{\varepsilon_1}{2} + \frac{\varepsilon_3}{2} + \eta$."

OBITUARIES

Mrs. Lempfert.—We regret to announce the death on January 10, 1953, of Mrs. Lempfert (Marjorie Hayward, F.R.A.M., Professor of the Royal Academy of Music) wife of Mr. R. G. K. Lempfert, C.B.E., formerly Assistant Director of the Meteorological Office.

Mrs. Lempfert will be remembered by many of the older staff of the Meteorological Office for her contributions, musical and other, to the success of many Annual Soirées.

Francesco Vercelli.—We regret to report that the distinguished Italian geophysicist Professor F. Vercelli, Director of the Geophysical Observatory and of the Thalassographical Institute of Trieste, died, aged 69, on November 24, 1952.

Professor Vercelli contributed to research in several branches of geophysics. In oceanography he investigated the transmission of solar radiation through sea and lake water and the effects of wind and pressure variations on the tides, and led oceanographic expeditions in Italian naval vessels to various parts of the Mediterranean and Red Sea. He devised a method of harmonic analysis and applied it to the prediction of pressure changes. He sought for the sun-spot cycle in tree-ring records. His earliest geophysical work was concerned with the temperature in tunnels in connexion with the construction of the Simplon tunnel; later he founded a seismological station at Trieste and took part in seismic and electromagnetic prospecting for oil in the Po Valley.

He was appointed Director of the Geophysical Institute of Trieste in 1920. When the Institute was divided in 1949 he became Director of both the Geophysical Observatory and the Thalassographical Institute. His last years were devoted to preparing a second edition of his book on meteorology "L'Aria" and to writing a large work on oceanography, "Il Mare".

NEWS IN BRIEF

Dr. P. R. Crowe, Reader in Geography in the University of London, has been appointed Professor of Geography in the University of Manchester with effect from April 1953. Dr. Crowe worked in the Climatology Branch of the Meteorological Office during the war. His meteorological researches have dealt with the trade winds and with the analysis of rainfall data in Great Britain and the United States of America.

METEOROLOGICAL OFFICE NEWS

Social and sports activities.—In appreciation of the local forecasts issued to them during 1952 the Union Castle Line and the Cunard White Star Company invited the staff of Eastleigh Meteorological Office to lunches on the *Edinburgh Castle* and the *Queen Mary* followed by conducted tours of the ships.

The Meteorological Office Social and Sports Committee announce that the Evening Party will be held in the Air Ministry Restaurant, Whitehall Gardens, on Tuesday, March 24.

Miss B. Edwards, Miss N. Edwards and Mrs. J. Sugden were selected for the Civil Service ladies netball team in a representative match against Oxford University at Oxford on January 24. The Civil Service won the match with 21 goals to 11.

WEATHER OF JANUARY 1953

Mean pressure over most of the North Atlantic, north of 40°N., and west Europe was above normal, the greatest excess being 11 mb. just to the west of Ireland (1017 mb.). Mean pressure over Sweden, Finland, southern Europe, the Mediterranean and the Azores was below normal, the greatest deficit being 9 mb. in Finland (1001 mb.) and 9 mb. in the Azores (1015 mb.). The lowest mean pressure, 996 mb., occurred off the north coast of Norway, and the highest, 1023 mb., in France.

Mean temperature over most of Europe and Scandinavia was below normal. It varied from 9°F. in the north of Sweden to 30–40°F. in Europe and 45–55°F. in the Mediterranean region. The greatest deficit of temperature occurred in the south of France where mean temperature was 7°F. below normal. Mean temperature was above normal over the United States generally, the largest excess being 10°F. in the west.

In the British Isles the weather was dry; it was somewhat milder than usual in Scotland but rather cold in England and Wales, particularly in the south. Sunshine was below the average in most parts of England and Wales but exceeded the average in Scotland, particularly on the coast of Fifeshire; it also exceeded the average in extreme south-west England. An unusually severe north-westerly to northerly gale occurred on the 31st.

A depression over north-east France moved away south-east on the 1st and a ridge of high pressure moved over the British Isles from the west. Thereafter a belt of high pressure became established from Scandinavia across the British

Isles to east of the Azores and maintained cold, mainly dry weather, though some scattered precipitation occurred at times. Fog occurred locally at times, particularly in the Clyde area from the 2nd to the 4th; at Renfrew the fog was persistent and day temperature only reached 27°F. on the 2nd and 25°F. on the 3rd. Good sunshine records were obtained locally in the west and north during the first four days. On the 5th and 6th a trough of low pressure moved south-east across the country giving rain in the west but snow in the east and parts of the Midlands. Cold northerly winds prevailed behind the trough, with wintry showers. Subsequently a ridge of high pressure moved slowly south-east and was followed by another trough which gave further slight precipitation except in the south-east. On the 9th an anticyclone off our south-west coasts spread north-east and later moved to Germany. Troughs of low pressure caused slight rain in the west and north and temperature rose, but the rise was only temporary in the south-east. Cold weather with widespread fog prevailed over much of south-east and east England and the Midlands from the 13th to the 15th. Subsequently pressure was high from south Russia to France, while troughs associated with a depression south of Iceland approached our west coasts; milder weather spread to all districts and there was slight rain locally in the west and north. Between the 17th and 23rd another anticyclone moved from the Atlantic to Germany and a spell of dry, cold weather, with a good deal of fog ensued in the south but rather mild conditions persisted in the north with rain at times, particularly from the 21st to the 23rd. Good sunshine records were obtained on the 18th and locally on the 19th and 20th, but sunshine was variable due to the incidence of fog. On the 24th, 26th and 27th troughs of low pressure gave slight rain in places in the south and east and heavier rain locally in the north. Pressure continued high to the south of the British Isles and on the 28th a small disturbance moved rapidly from the south-west of Iceland across the north of Scotland giving rain there. On the 30th a depression south of Iceland moved east-north-east and later turned south-east to Denmark, becoming very deep; rain fell generally on the 30th and wintry showers on the 31st. A widespread severe north-westerly to northerly gale prevailed. The *Princess Victoria* foundered in the North Channel with heavy loss of life during the afternoon of the 31st. During the evening and night there were strong north-westerly gales in the North Sea and a high spring tide; exceptional floods and coastal damage occurred with consequent heavy loss of life from Yorkshire to the Thames Estuary and in Holland. During the gale, on Costa Hill, Orkney, several gusts exceeded 105 kt. and the highest reached 109 kt.; and at Milltown, near Lossiemouth, several gusts exceeded 93 kt.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	58	11	−1·0	46	−5	85
Scotland	58	9	+1·8	63	−2	107
Northern Ireland ...	54	16	+0·1	44	−3	93

RAINFALL OF JANUARY 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·92	49	*Glam.*	Cardiff, Penylan ...	1·11	30
Kent	Dover	1·06	50	*Pemb.*	Tenby, The Priory ...	1·76	47
,,	Edenbridge, Falconhurst	1·27	52	*Radnor*	Tyrmynydd	2·14	34
Sussex	Compton, Compton Ho.	1·43	45	*Mont.*	Lake Vyrnwy	2·17	38
,,	Worthing, Beach Ho. Pk.	1·18	51	*Mer.*	Blaenau Festiniog ...	6·67	65
Hants.	Ventnor Cemetery ...	1·33	51	,,	Aberdovey	2·07	53
,,	Southampton, East Pk.	0·92	34	*Carn.*	Llandudno	0·96	40
,,	Sherborne St. John ...	0·81	35	*Angl.*	Llanerchymedd ...	2·34	74
Herts.	Royston, Therfield Rec.	1·28	74	*I. Man*	Douglas, Borough Cem.	2·25	67
Bucks.	Slough, Upton	0·81	44	*Wigtown*	Newton Stewart ...	1·96	48
Oxford	Oxford, Radcliffe ...	0·85	47	*Dumf.*	Dumfries, Crichton R.I.	1·23	38
N'hants.	Wellingboro' Swanspool	0·98	53	,,	Eskdalemuir Obsy. ...	2·52	47
Essex	Shoeburyness	0·85	63	*Roxb.*	Crailing	0·72	37
,,	Dovercourt	0·68	43	*Peebles*	Stobo Castle	1·14	38
Suffolk	Lowestoft Sec. School ...	0·96	57	*Berwick*	Marchmont House ...	0·99	44
,,	Bury St. Ed., Westley H.	1·10	61	*E. Loth.*	North Berwick Res. ...	0·57	33
Norfolk	Sandringham Ho. Gdns.	1·23	63	*Midl'n.*	Edinburgh, Blackf'd. H.	0·32	18
Wilts.	Aldbourne	1·45	63	*Lanark*	Hamilton W. W., T'nhill	1·32	40
Dorset	Creech Grange... ...	1·10	34	*Ayr*	Colmonell, Knockdolian	1·52	35
,,	Beaminster, East St. ...	1·15	33	,,	Glen Afton, Ayr San. ...	2·55	50
Devon	Teignmouth, Den Gdns.	0·53	18	*Renfrew*	Greenock, Prospect Hill	3·64	56
,,	Cullompton	0·60	19	*Bute*	Rothesay, Ardencraig ...	3·42	76
,,	Ilfracombe	1·01	31	*Argyll*	Morven (Drimnin) ...	5·12	81
,,	Okehampton	1·27	25	,,	Poltalloch	4·16	82
Cornwall	Bude, School House ...	1·22	40	,,	Inveraray Castle ...	7·06	86
,,	Penzance, Morrab Gdns.	1·42	37	,,	Islay, Eallabus	3·14	67
,,	St. Austell	1·43	33	,,	Tiree	3·03	71
,,	Scilly, Tresco Abbey ...	1·65	53	*Kinross*	Loch Leven Sluice ...	0·77	24
Glos.	Cirencester	0·77	31	*Fife*	Leuchars Airfield ...	0·49	27
Salop	Church Stretton ...	0·79	30	*Perth*	Loch Dhu	4·90	54
,,	Shrewsbury, Monksmore	0·60	31	,,	Crieff, Strathearn Hyd.	0·70	17
Worcs.	Malvern, Free Library ...	0·46	21	,,	Pitlochry, Fincastle ...	0·87	25
Warwick	Birmingham, Edgbaston	0·97	48	*Angus*	Montrose, Sunnyside ...	0·81	41
Leics.	Thornton Reservoir ...	1·15	58	*Aberd.*	Braemar	1·01	32
Lincs.	Boston, Skirbeck ...	0·86	53	,,	Dyce, Craibstone ...	1·20	51
,,	Skegness, Marine Gdns.	0·64	37	,,	New Deer School House	1·63	70
Notts.	Mansfield, Carr Bank ...	0·39	18	*Moray*	Gordon Castle	1·74	86
Derby	Buxton, Terrace Slopes	2·60	58	*Nairn*	Nairn, Achareidh ...	1·05	58
Ches.	Bidston Observatory ...	0·81	38	*Inverness*	Loch Ness, Garthbeg ...	2·44	55
,,	Manchester, Ringway ...	1·28	54	,,	Glenquoich	14·18	103
Lancs.	Stonyhurst College ...	2·34	55	,,	Fort William, Teviot ...	6·24	64
,,	Squires Gate	1·48	57	,,	Skye, Duntuilm ...	3·85	73
Yorks.	Wakefield, Clarence Pk.	0·46	24	,,	Skye, Broadford ...	7·56	100
,,	Hull, Pearson Park ...	1·15	64	*R. & C.*	Tain (Mayfield) ...	1·70	70
,,	Felixkirk, Mt. St. John ...	0·88	44	,,	Inverbroom, Glackour ...	6·47	120
,,	York Museum	0·47	27	,,	Achnashellach	8·64	95
,,	Scarborough	1·10	55	*Suth.*	Lochinver, Bank Ho. ...	3·66	86
,,	Middlesbrough... ...	0·78	49	*Caith.*	Wick Airfield	2·80	114
,,	Baldersdale, Hury Res.	0·99	30	*Shetland*	Lerwick Observatory ...	4·20	99
Norl'd.	Newcastle, Leazes Pk....	0·78	39	*Ferm.*	Crom Castle	1·25	88
,,	Bellingham, High Green	1·38	48	*Armagh*	Armagh Observatory ...	0·94	37
,,	Lilburn Tower Gdns. ...	1·43	69	*Down*	Seaforde	1·33	42
Cumb.	Geltsdale	2·08	74	*Antrim*	Aldergrove Airfield ...	1·48	54
,,	Keswick, High Hill ...	2·32	46	,,	Ballymena, Harryville...	1·63	44
,,	Ravenglass, The Grove	2·74	82	*L'derry*	Garvagh, Moneydig ...	1·47	43
Mon.	Abergavenny, Larchfield	0·64	19	,,	Londonderry, Creggan	1·46	41
Glam.	Ystalyfera, Wern House	2·31	37	*Tyrone*	Omagh, Edenfel ...	1·79	51

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

Wt-33. K16.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 970, APRIL 1953

GALE OF JANUARY 31, 1953

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

An exceptionally severe NW.–N. gale affected the north and east of the British Isles and most of the North Sea on January 31, 1953. The associated floods caused serious loss of life and immense damage on parts of the east coast, and in Holland, with its larger vulnerable area, the catastrophe was much worse. The storm itself was especially severe in north Scotland, and that was the only part of the British Isles which suffered much inland damage. On the north-east coast of England force 10 was reported. The storm was at least as severe as that of January 15, 1952, and on that occasion the depression moved east-north-east and the worst of the storm was from SW.–W. There is no evidence in our records of any equally severe northerly gale.

The very exceptional nature of the gale in the Orkneys is shown by the anemometer trace at the Electrical Research Association station at Costa Hill, reproduced in Fig. 1 (facing p. 112). It shows a mean speed of about 90 m.p.h. for an hour, and gusts up to 125 m.p.h. The trace is considered reliable. The Dines anemometer at the same station with its head 80 ft. above the ground went out of action at 0910 after gusting to over 110 m.p.h.

The record from Costa Hill was obtained from an electric cup generator anemometer on a 30-ft. high mast driving a recording milliammeter. The instrument has been calibrated in a wind tunnel to a speed of 150 m.p.h. Costa Hill is situated at the extreme north point of Orkney, 59°09′N. 3°12′W., and the anemometer installation is on the summit 500 ft. above M.S.L. The ground slopes gradually to a cliff nearly 500 ft. high overlooking the sea ½ mile to the north of the summit. There are also at the site a Dines pressure tube anemometer and 4 cup contact anemometers fitted at 3 levels to a 120-ft. mast, but these unfortunately ceased recording for various reasons at an early stage of the gale. The cup contact anemometers registered the following mean winds between 0800 and 0840:

at 110 ft.	at 80 ft.	at 80 ft.	at 50 ft.
84 m.p.h.	85·5 m.p.h.	99 m.p.h.	101 m.p.h.

The installation was set up and is operated by the Electrical Research Association, to whom thanks for lending records and permission to publish are due, as part of the Association's investigation into the generation of electricity by wind power on a commercial scale.

The meteorological office at Grimsetter airport, Orkney, 84 ft. above M.S.L., reported winds not much less than those at the very exposed Costa Hill. The mean wind at Grimsetter was over 60 kt. from 0918 to 1200, and at 1018 was 68 kt. with gusts to the limit of the anemometer at 93 kt.

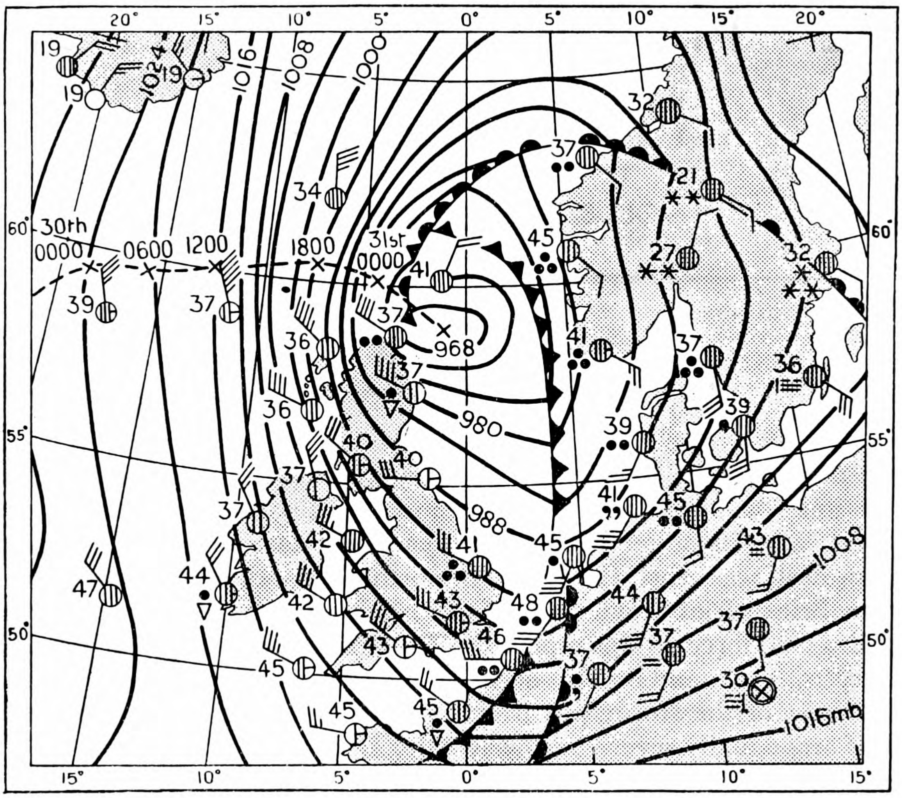


FIG. 2—SYNOPTIC CHART, 0600 G.M.T., JANUARY 31, 1953

The depression formed on January 29 as a warm-front wave, breaking away from a quasi-stationary depression just north of the Azores. A closed centre only appeared at about 1200 on the 29th, at $54\frac{1}{2}$°N. 27°W., with central pressure 1003 mb. It moved north-east and then east-north-east on the track shown in Fig. 2. At 1800 on the 30th, when its central pressure had dropped to 979 mb., it still had an open warm sector with south-west–north-east isobars in it. There was a force 9 northerly wind to the west of it, with a steep and increasing gradient between the depression and an advancing and intensifying anticyclone. By midnight a small central region was occluded and the depression had already turned east-south-east. The lowest pressure recorded was just below 970 mb. in the Orkneys at 0500, but it probably fell some millibars lower over the North Sea at noon. When it reached Denmark at 1800 it was beginning to fill up.

Though the depression assumed the general character of an intense travelling vortex, the maximum winds and gradients occurred behind the trough, and some distortion of the isobars can be seen on both the 0600 and 1200 charts (Figs. 2 and 3). This was related to the cutting in of colder air, and with a movement of the associated fronts against the component of geostrophic wind across them. These fronts consisted of the occlusion and part of what had

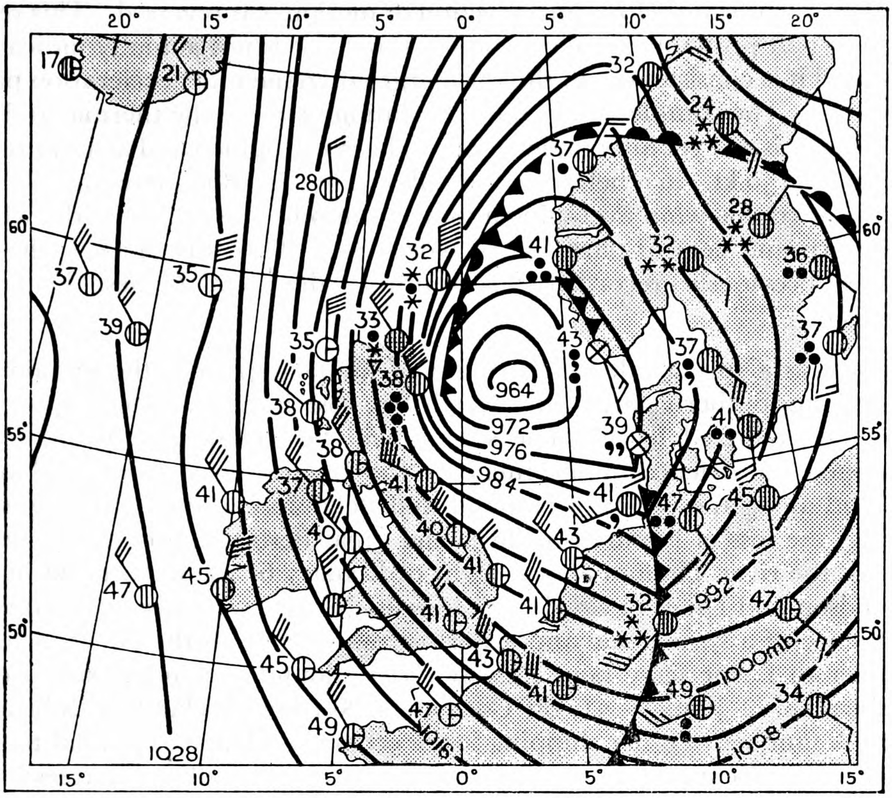


FIG. 3—SYNOPTIC CHART, 1200 G.M.T., JANUARY 31, 1953

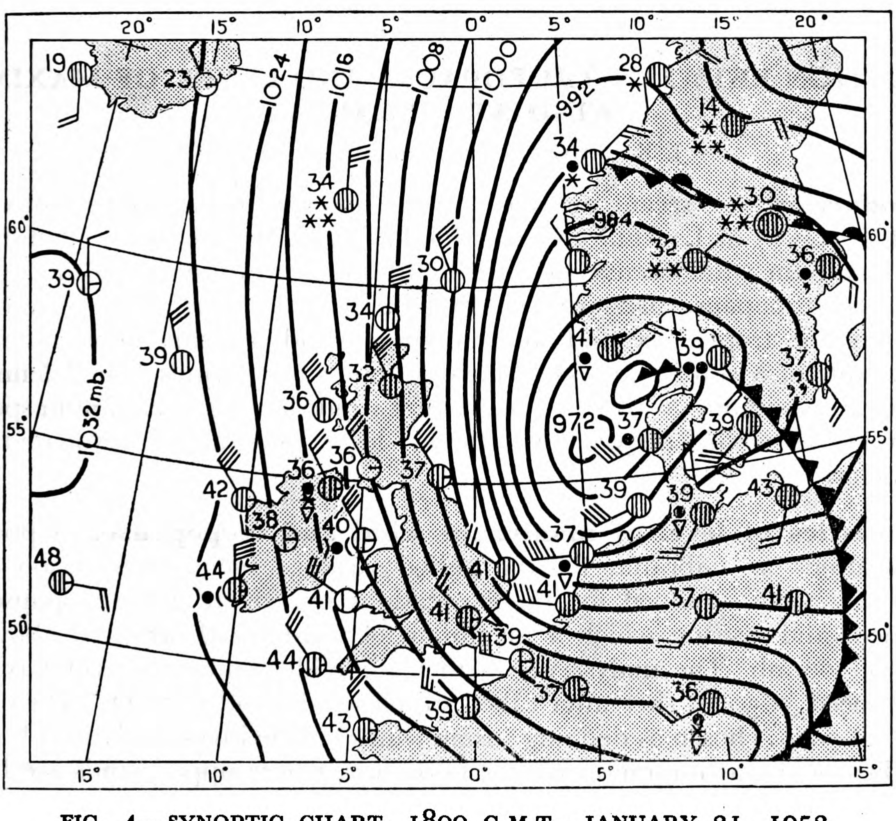


FIG. 4—SYNOPTIC CHART, 1800 G.M.T., JANUARY 31, 1953

been the warm front before the direction of motion was reversed. This reversal of motion had probably started by 0600, though it is not actually indicated on Fig. 2, and it is consistent with the very large component of acceleration parallel to the front. The complex mutual inter-relation between the thermal and dynamical factors is not yet fully understood. The geostrophic wind at 1200 reached 175 m.p.h. (150 kt.) in a belt over 100 miles wide. At 1800 there was a long belt with a geostrophic wind averaging about 140 m.p.h. (120 kt.) over the whole of the western and central parts of the North Sea. This was much higher than anything previously recorded this century; the next highest being only 100 m.p.h.

There was a spring tide on the night of January 31, and the sea along the coasts of the southern part of the North Sea rose in many places to over 6 ft. above the predicted levels. The sea, as will be well known to all readers, overtopped the defences along much of the English coast from Yorkshire to Kent and along the coasts of Holland and Belgium causing extremely serious flooding, the loss of hundreds of lives and great destruction of property. The floods in the river Thames on the night of January 6, 1928, discussed in detail by Doodson and Dines in *Geophysical Memoirs* No. 47, were also associated with coincidence of a spring tide and a north-westerly gale in the North Sea. The Stranraer to Larne ferry boat *Princess Victoria* foundered in the storm during the afternoon of January 31, off Co. Down, Northern Ireland, with heavy loss of life. A number of other shipping losses occurred. The exceptional nature of the gale over Scotland is shown by the widespread felling of trees. Many owners had all their timber blown down and the total quantity laid is believed to be many times the annual felling quota.

RELATION BETWEEN TROPOPAUSE AND LEVEL OF MAXIMUM WIND AT GIBRALTAR

By J. K. BANNON, B.A. and M. P. JACKSON

Introduction.—A recent analysis[1] of occasions of strong winds (maximum wind $\geqslant$ 70 kt.) at Larkhill and Lerwick has shown that over the British Isles the maximum wind occurs most frequently at a pressure 20–40 mb. greater than the tropopause pressure, but that in general the relation between the levels of the tropopause and the maximum wind is small. This note gives the results of a similar analysis for Gibraltar, strong winds being defined as having a maximum $\geqslant$ 50 kt. Occasions of winds having a maximum speed of $<$ 50 kt. occurring above the 500-mb. level were also investigated with inconclusive results.

Statistics of level of maximum wind and tropopause.—Upper air observations at Gibraltar for the period 1948–51 inclusive for 1500 G.M.T. each day were analysed for those occasions on which the tropopause was reached, and also on which a maximum of wind speed occurred above the level of 500 mb. The analysis was further subdivided for occasions of maximum wind speed $\geqslant$ 50 kt. (hereafter called strong winds) and $<$ 50 kt. The critical speed of 70 kt. chosen as defining strong winds for the investigations at Larkhill and Lerwick[1] was impracticable for Gibraltar, where upper winds are lighter than over the British Isles.

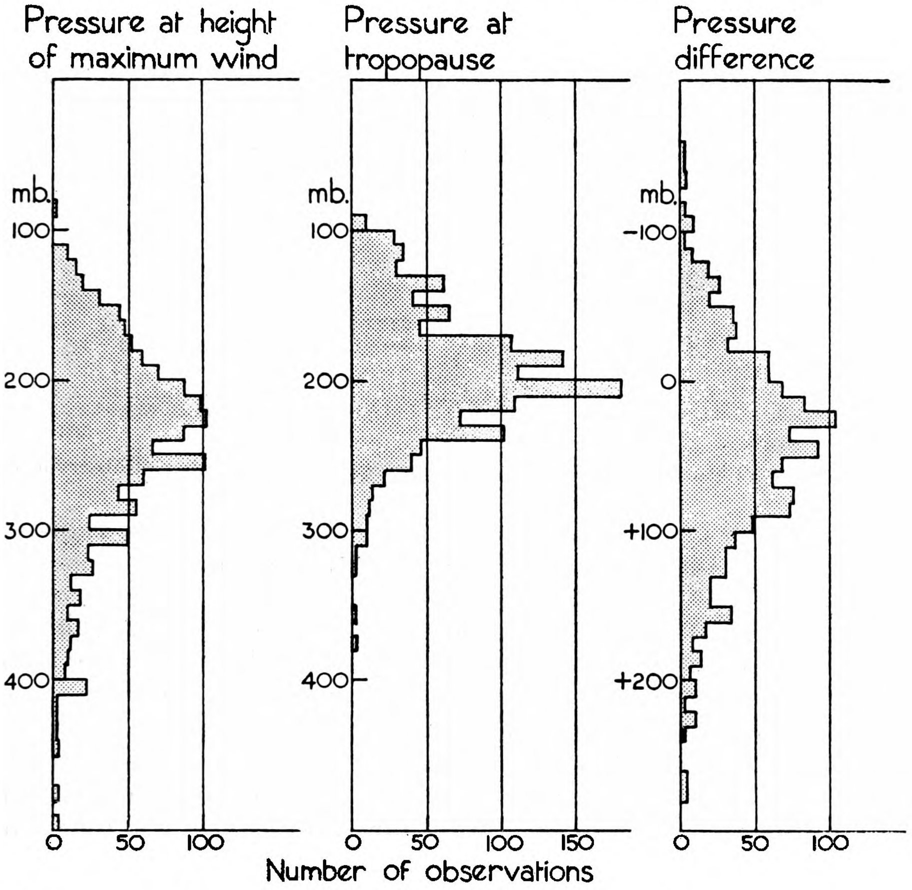
Frequencies for 10-mb. intervals of pressure were then obtained for occasions of both strong and light winds for:—

(*a*) pressure at the level of maximum wind

(*b*) pressure at the tropopause

(*c*) the difference between (*a*) and (*b*).

These are shown for occasions of strong winds in Fig. 1. Similar histograms for light winds are not given here; in all three the frequency distributions were much "flatter" than for strong winds, especially in (*c*).



Mean (mb.)	238	194	45
Standard deviation (mb.)	67	44	69

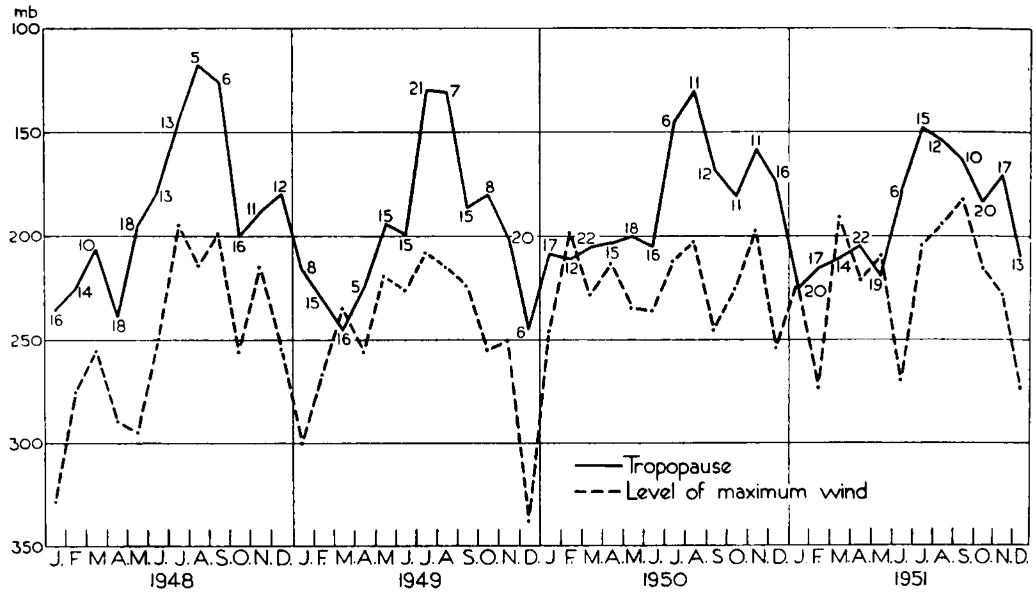
Correlation coefficient between pressure at maximum wind level and at tropopause 0·15

Maximum wind ⩾ 50 kt., Gibraltar 1948–51

FIG. 1—FREQUENCY DISTRIBUTIONS OF PRESSURE AT THE LEVEL OF MAXIMUM WIND AND AT THE TROPOPAUSE AND THEIR PRESSURE DIFFERENCE

Fig. 2 shows mean monthly values of tropopause pressure and pressure at the level of maximum wind for each month of the period 1948–51 for occasions of strong winds. The number of observations available for each month is given. A similar diagram for light winds showed little relation between the two curves and is not reproduced here.

Discussion.—It is seen that for strong winds there is even less relation between the levels of the tropopause and the maximum wind at Gibraltar than there is over the British Isles[1]. Fig. 2 shows that, as at Larkhill and Lerwick, there is some similarity between the month-to-month variation of the monthly mean pressures of these levels, but Fig. 1 and the correlation coefficient quoted there of 0·15 between the levels shows that the relationship is, in general, slight. Compare similar correlations of 0·43 for Larkhill and 0·18 for Lerwick.



Maximum wind ⩾ 50 kt., Gibraltar 1948–51; the figures give the number of observations for each month

FIG. 2—COMPARISON OF MONTHLY MEANS OF THE PRESSURE AT THE TROPOPAUSE AND AT THE LEVEL OF MAXIMUM WIND

In summer at Gibraltar the tropopause is high, often being as high as over the tropics. In winter the tropopause is not much higher on the average than over southern England. It is not surprising to find, therefore, that the relation between tropopause and maximum wind level is much greater in winter than in summer. Table I gives the correlation coefficients between the pressures of the tropopause and at the level of the maximum wind (strong winds) for the four months, January, April, July and October, and the means of these pressures. It is seen that the relation between the two levels is similar at Gibraltar in January to that over southern England[1]; in July there is no relation.

TABLE I—STATISTICS OF TROPOPAUSE PRESSURE AND PRESSURE AT THE LEVEL OF MAXIMUM WIND AT GIBRALTAR

Maximum wind ⩾ 50 kt. occurring above the 500-mb. level

	January	April	July	October
	Number of occasions			
Mean tropopause pressure (mb.)	215	217	163	200
Mean pressure at level of maximum wind (mb.)	267	243	208	235
Correlation between tropopause pressure and pressure at maximum wind	0·43	0·27	−0·03	0·19

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REDUCTION OF AVERAGES OF VAPOUR PRESSURE TO SEA LEVEL

By G. A. TUNNELL, B.Sc.

Introduction.—In preparing world maps of average mean of day atmospheric water-vapour pressure it is necessary to examine its variation with height, because data are drawn from stations at many different levels and variations due to differences in altitude often mask differences in the horizontal field.

It is possible to derive a formula for the variation in the vertical of long-period averages by which the component due to altitude alone can be removed. A satisfactory formula would be one which would remove variations due to height, but would leave horizontal variations caused by the presence of high land, for example the fall in vapour pressure associated with a "rain-shadow area". By means of this formula maps of average vapour pressure reduced to sea level could be constructed.

Sir Napier Shaw[1] gave the following formula used by Kaminsky in the production of the "Climatological atlas of the Russian Empire", which agrees with the Hann formula (discussed below) up to about 1,000 m.

$$e_0 = e\,(1 + 0{\cdot}0004\,h)$$

where e_0 is the vapour pressure at M.S.L. and e the vapour pressure at height h (in metres) above M.S.L.

In the preparation of the "Climatological atlas of the British Isles" neither the Hann nor the Kaminsky formula proved satisfactory. For this reason a new analysis was carried out and is now explained.

Previous work.—The variation of vapour pressure with height was first considered by Lt. Col. Richard Strachey[2] who pointed out in 1861 that, contrary to Dalton's suggestion, water vapour does not exist as a separate atmosphere independent from the rest of the constituents of the air, and that its variation with height indicates it is not even approximately in static equilibrium. To support this, results obtained by Dr. Hooker on the Himalayan Mountains and Mr. Welsh in four balloon ascents were quoted.

J. Hann, using data from Strachey's paper and additional information, suggested[3,4] in 1874 and 1894 that the variation of average vapour pressure with height could be represented by a formula of the form

$$e = e_0 10^{-\gamma h}$$

where γ is, in principle, a function of h; Hann took it to be 1/6,500 which was the average value over the height range he used.

In the latest (1939) edition of the "Hann-Süring, Lehrbuch der Meteorologie"[5], formulae for the free air are distinguished from those for land stations. The formula given for land stations is

$$e = e_0 10^{-h/6300}.$$

This formula is in almost universal use in the reduction of vapour-pressure averages to sea level and is known as the Hann formula; $1/\gamma$ or 6,300 is known as Hann's constant.

The presence of the land surface influences the magnitude of the vapour pressure at mountain stations and formulae for the free air differ from those for land stations. K. L. Bhatia[6] states, in a paper in which aeroplane observations over the Peshawar plain are compared with those at Cherat (4,272 ft.), that vapour pressure at Cherat is, in general, higher than in the free air at the same level. The present paper is concerned exclusively with land stations.

Theory of the present analysis.—Data for British Columbia averaged over July, August and September 1941 were plotted against height. For heights up to over 1,000 m. above sea level the relationship was almost linear. Mean-of-day values showed less scatter about the straight line than averages for individual hours.

Data were then analysed from five areas. Mean-of-day averages for January, April, July and October over as long a period as possible were taken for Argentina[7], Ceylon[8], east Africa[9-11], southern Germany[12] and western Canada[13,14]. These areas were chosen because good data were available, their distribution of vapour pressure was convenient and they have widely differing climates. It was decided to fit the following equation to the data for each area.

$$e = ah + b\lambda + c\phi + d \qquad \text{......} (1)$$

where λ and ϕ are position co-ordinates which may be with respect to any convenient axes in a horizontal plane, and a, b, c and d are constants (regression coefficients) derived from the analysis. Equation (1) may be rewritten

$$e - \bar{e} = a(h - \bar{h}) + b(\lambda - \bar{\lambda}) + c(\phi - \bar{\phi}) \qquad \text{......} (2)$$

where a bar indicates an average value. At the point $\bar{\lambda}$, $\bar{\phi}$

$$e - \bar{e} = a(h - \bar{h}) \qquad \text{......} (3)$$

$$\text{i.e. } e = e_0(1 - \alpha h) \qquad \text{......} (4)$$

where $e_0 = \bar{e} - a\bar{h}$ and $\alpha = -a/(\bar{e} - a\bar{h})$. Equation (4) gives conditions along a vertical line over the point $(\bar{\lambda}, \bar{\phi})$. It is assumed that for long-period averages this relationship holds everywhere, giving a method of finding e_0 when e is known.

Equation (2) contains the first four terms of a Taylor series about the point $(\bar{\lambda}, \bar{\phi}, \bar{h})$ representing the vapour pressure at any point (λ, ϕ, h). By arranging for the isopleths of vapour pressure to be almost linear it is necessary for the remaining terms of the Taylor series to be negligible. The good agreement obtained indicates that this is justified. The value of α is determined at the point $(\bar{\lambda}, \bar{\phi})$ in each area. This linear form of the equation is very convenient; logarithmic formulae or polynomials would involve considerably more computation and the degree of agreement obtained could hardly be improved.

An equation of the form of equation (3) could be obtained from a simple correlation of vapour pressure with height, but the additional terms in equation (2) serve to make a correction for the fact that vapour-pressure values are dependent on their position in a horizontal plane.

Results of the analysis.—The results obtained from the analysis are given in Table I, which indicates that the terms in λ and ϕ have materially improved the fit and that α is very consistent except in western Canada. Here, July alone has a value of α consistent with the remaining areas, and January with 0·00063 has a value 2·5 times the most probable value of α. The reasons for this difference will be considered later.

It will be seen that very consistent values were obtained, and 0·00025 has been taken as the most probable value of α which seems (for long-period, mean-of-day averages) to be a universal constant.

TABLE I—STATISTICAL PARAMETERS AND COEFFICIENTS OBTAINED FROM THE ANALYSIS OF LONG-PERIOD AVERAGES

R is the multiple correlation coefficient of equation (1); r_{eh} is the correlation coefficient of vapour pressure with height.*

	Range of latitude	Range of longitude	Height of highest station		R	r_{eh}	a	α	Type of daily mean	Period
	°	°	m.					× 10⁻⁵		yr.
Argentine (43 stations)	28·5	15·4	1,269	January	0·81	−0·45	−0·0043	−22	Mean of hourly values	10
				April	0·97	−0·57	−0·0041	−26		
				July	0·94	−0·68	−0·0024	−25		
				October	0·96	−0·60	−0·0031	−23		
Ceylon (16 stations)	3·7	1·9	1,881	January	0·99	−0·99	−0·0070	−27	Estimated from half maximum plus minimum dry-bulb and wet-bulb temperatures	14–21
				April	0·99	−0·99	−0·0082	−27		
				July	0·98	−0·96	−0·0072	−26		
				October	0·99	−0·99	−0·0073	−26		
East Africa (39 stations)	21·8	6·1	1,386	January	0·94	−0·89	−0·0056	−22	Corrected to mean of 24 hr. from diurnal curve	Variable, mainly >10
				April	0·90	−0·84	−0·0066	−25		
				July	0·89	−0·76	−0·0060	−29		
				October	0·85	−0·77	−0·0068	−29		
Southern Germany (52 stations)	2·4	8·3	1,618	January	0·96	−0·88	−0·0010	−24	Mean of vapour pressure measured at 0700, 1400 and 2100 local time	50
				April	0·93	−0·92	−0·0014	−23		
				July	0·96	−0·95	−0·0018	−23		
				October	0·97	−0·96	−0·0017	−23		
Western Canada (21 stations)	16·5	23·7	1,079	January	0·96	−0·52	−0·0030	−63	Derived from averages of dew points at 0130, 0730, 1330, 1930 E.S.T.	3–8
				April	0·98	−0·43	−0·0024	−33		
				July	0·90	−0·51	−0·0030	−22		
				October	0·98	−0·54	−0·0035	−38		

* The standard error in fit for the simple correlation between e and h is $\sigma_e(1 - r_{eh}^2)^{\frac{1}{2}}$, and for equation (1) is $\sigma_e(1 - R^2)^{\frac{1}{2}}$, where σ_e is the standard deviation of the vapour-pressure averages[15]; $(1 - r_{eh}^2)^{\frac{1}{2}}$ and $(1 - R^2)^{\frac{1}{2}}$ are therefore a measure of the deviation of the observations from respectively a straight line or a plane and indicate the improvement in fit due to the additional terms in equation (1). R is always positive.

The final reduction formula is then

$$e = e_0(1 - 0{\cdot}00025h). \qquad \dots\dots\dots (5)$$

Formulae for reduction from great heights.—In equation (5) e_0 becomes infinite at 4,000 m. This has led to an investigation of the range of height for which the equation is valid, because there are areas from which the only data available are from stations at great heights. Many are above 4,000 m. but there are no networks of stations sufficient to carry out a statistical analysis; 95 per cent. of the stations used are below 1,300 m. above M.S.L. and equation (5) can be said to hold over this range only. If the true law is of the form

$$e = e_0' \exp(-\beta h), \qquad \dots\dots\dots (6)$$

which holds according to Hann up to approximately 9 Km., then equation (5) is the result of an analysis of variates of the form

$$e = e_0' \exp(-\beta h) + \Delta, \qquad \dots\dots\dots (7)$$

where Δ is a random variable and β is a constant for values of h distributed between sea level and 1,300 m.

The following analysis is carried out to find the relationship between e_0 derived from equations (5) and (6) and to find a value of β corresponding to $\alpha = 0{\cdot}00025$ and hence to find the corresponding value of Hann's constant.

The analysis is carried out with the assumption of ideal conditions, i.e. an infinite homogeneous population of stations, no horizontal gradient of vapour pressure, and random errors distributed normally about $e = e_0' \exp(-\beta h)$. The least square condition of best fit for an equation of the form $e = ah + d$ to variates of the form of equation (7) is that

$$\sum_{n=0}^{N} \left[\left\{e_0' \exp(-\beta h_n) + \Delta_n\right\} - \left\{ah_n + d\right\}\right]^2 \qquad \dots\dots\dots (8)$$

must be a minimum with respect to a and d under the above ideal conditions, where the suffix n refers to the nth station of a total of N stations.

After partially differentiating expression (8) with respect to a and d, equating to zero, integrating and putting $d = e_0$ and $a = -\alpha e_0$, the following is obtained:

$$\frac{e_0'}{e_0} = \frac{\beta}{\exp(-\beta H) - 1}\left(\alpha\frac{H^2}{2} - H\right), \qquad \dots\dots\dots (9)$$

where H is the range of height over which the stations are distributed. Equation (9) gives

$$\beta = \frac{1 - \exp(-\beta H)\left\{\beta H + 1\right\}}{\exp(-\beta H) - 1}\left[\frac{\alpha/2 - 1/H}{1/2 - \alpha H/3}\right]. \qquad \dots\dots\dots (10)$$

β can be found easily from equation (10) by the method of successive approximations.

If α has the value 0·00025 and $H = 1{,}300$ m. then $\beta = 0{\cdot}295 \times 10^{-3}$ and $e_0'/e_0 = 1{\cdot}008$. It can be seen that e_0' and e_0 are, to a high degree of approximation, equal. This leads to a number of expressions for e:—

$$\left.\begin{aligned} e &= e_0 \exp(-0{\cdot}000295\, h) \\ e &= e_0\, 10^{-0{\cdot}000128h} \\ e &= e_0\, 10^{-h/7800} \\ e &= e_0\,(1 - 0{\cdot}00025\, h) \end{aligned}\right\} \qquad \dots\dots\dots (11)$$

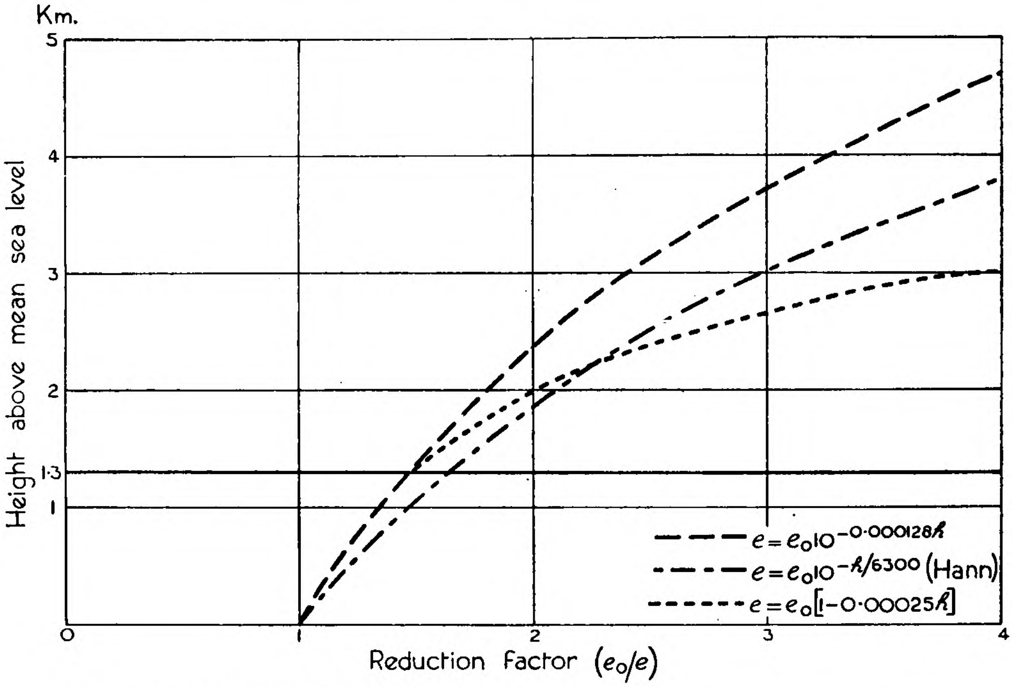

FIG. 1—FACTOR FOR REDUCTION OF VAPOUR PRESSURE TO SEA LEVEL

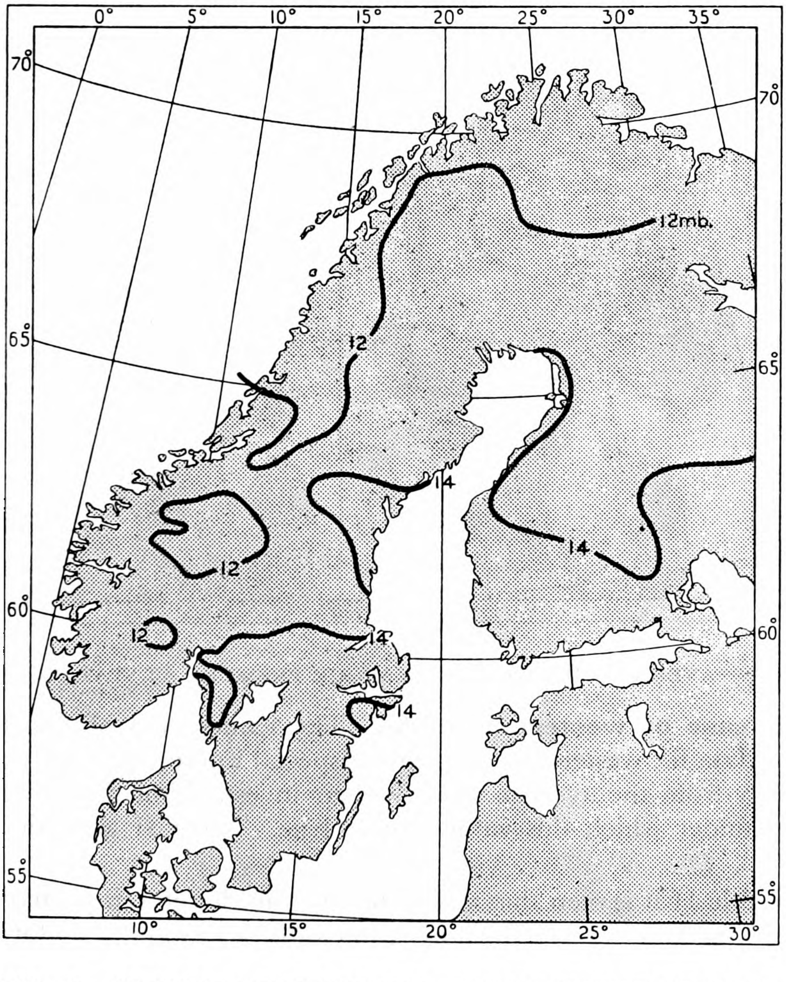

FIG. 2—AVERAGE MEAN-OF-DAY VAPOUR PRESSURE AT M.S.L.

The last of these expressions is accurate for stations less than 1,300 m. above M.S.L.

Fig. 1 gives the variation with height of the reduction factor for reducing vapour pressure to M.S.L. Up to 1,300 m. the linear and logarithmic formulae do not differ greatly, but they diverge fairly rapidly above. This diagram also indicates the relationship between formulae (11) and Hann's formula. Hann's formula gives values of e_0 about 10 per cent. lower than the linear formula at 1,300 m. and under-corrects for height at all levels.

Figs. 2 and 3, giving average mean-of-day vapour pressure for Scandinavia for July at sea level and at station level, demonstrate how the effects due to topography may be removed, leaving true horizontal variations.

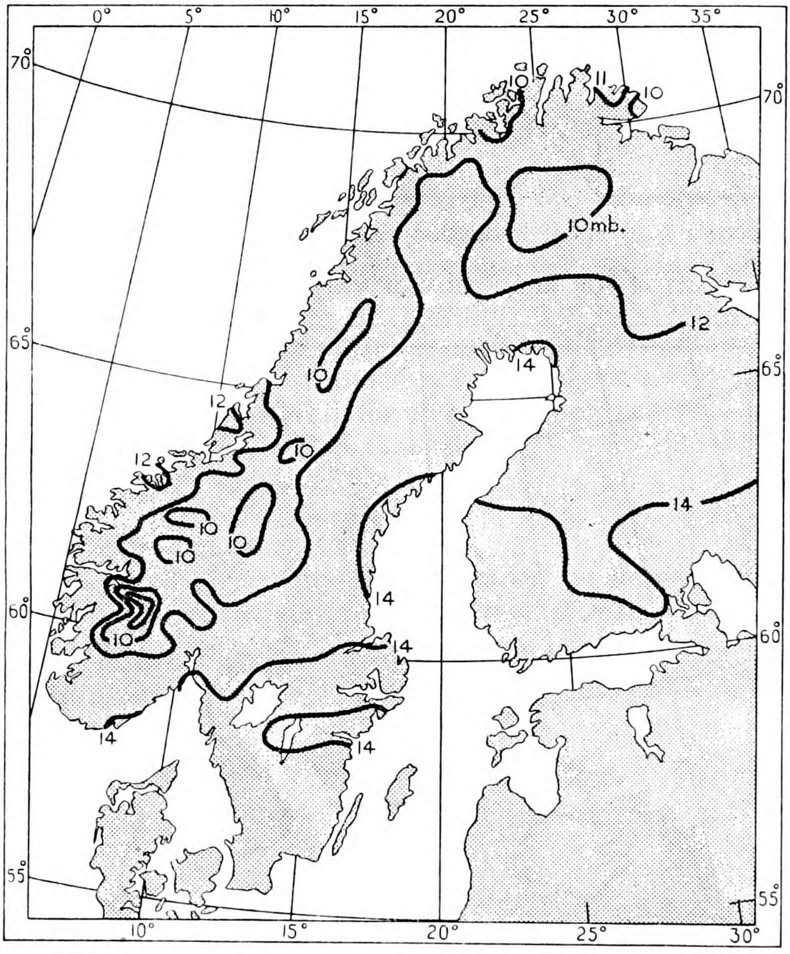

FIG. 3—AVERAGE MEAN-OF-DAY VAPOUR PRESSURE AT STATION LEVEL

Special case of western Canada.—The values of α obtained from the analysis of data for western Canada are of special interest because they diverge considerably from the average value. Their investigation throws light on the conditions under which this value of α is true. Table II gives details of the analysis.

From Table II it is seen that while the magnitudes of a in January and July are almost identical that for April is significantly lower and that for October is higher. The values of α are variable with a maximum in January and a

TABLE II—VALUES FOR WESTERN CANADA

	a	$\bar{h}$	$\bar{e}$	e_0	α
		mb.	mb.	mb.	
January	−0·003029	−1·3592	3·4810	4·8401	0·000626
April	−0·002376	−1·0662	6·0333	7·0996	0·000335
July	−0·003028	−1·3585	12·6286	13·9871	0·000216
October	−0·003492	−1·5666	7·6429	9·2095	0·000379

These values are the results of computation and do not show the accuracy with which they are known.

minimum in July. This indicates that in January and July the rates of fall of vapour pressure with height are identical, but there is a fundamental change in e_0. July represents the normal state consistent with other parts of the world, but in January there is a significant difference.

Let e in January be a linear function of what it would be if the variation in the vertical were normal; then

$$e = L \exp(-\beta h) + M \qquad \text{(12)}$$

where L and M are constants.

By similar calculations to those giving e_0'/e_0 and β

$$L = \frac{\frac{1}{12}\alpha'' \beta^2 H^3 e_0''}{\frac{1}{2}\beta H\{1 + \exp(-\beta H)\} - \{1 - \exp(-\beta H)\}}$$

and $$M = e_0'' \left[\frac{\frac{1}{12}\alpha'' \beta H^2\{\exp(-\beta H) - 1\}}{\frac{1}{2}\beta H\{1 + \exp(-\beta H)\} - \{1 - \exp(-\beta H)\}} + \left(1 - \frac{\alpha'' H}{2}\right)\right]$$

where α'' and e_0'' are values of α and e_0 corresponding to a situation in which equation (12) describes the variation of vapour pressure in the vertical. Putting $\alpha'' = 0{\cdot}00063$, $\beta = 0{\cdot}295 \times 10^{-3}$ and $H = 1{,}100$ m. (the limit of altitude of stations analysed) then

$$\left.\begin{aligned} L &= 2{\cdot}46\, e_0'' \\ M &= -1{\cdot}44\, e_0'' \end{aligned}\right\} \qquad \text{(13)}$$

By equations (6) and (12), a remains unchanged.

Therefore $\alpha'' e_0'' = \alpha e_0$

$$e_0'' = 0{\cdot}40\, e_0. \qquad \text{(14)}$$

From equations (12), (13) and (14) we have

$$e = 0{\cdot}984\, e_0 \exp(-\beta H) - 0{\cdot}58 e_0,$$

i.e. to a sufficient degree of approximation

$$e = e_0\,[\exp(-0{\cdot}000295h) - 0{\cdot}6]. \qquad \text{(15)}$$

Equation (15) is consistent with the two linear equations

$$e = e_0\,(1 - 0{\cdot}00025h) \text{ and}$$

$$e = e_0''\,(1 - 0{\cdot}00063h)$$

i.e. $e_0\,(1 - 0{\cdot}00025h) - 0{\cdot}6\, e_0 = e_0''\,(1 - 0{\cdot}00063h)$.

The explanation now suggested for these differences is as follows. During the summer there is, over western Canada, a freely mixing atmosphere during which the law $e = e_0 \exp(-\beta h)$ holds for long-period averages of vapour pressure. During winter the intense radiation cooling causes a deep inversion in the lower layers which suppresses free vertical mixing; however, above the inversion free mixing continues.

The law followed in winter is of the form

$$e = e_0 \left[\exp\left(-\beta h\right) - \delta\right]$$

where $e_0\delta$ is the reduction in vapour pressure due to the inversion.

Vapour pressure at sea level at the position $(\bar{\lambda}, \bar{\phi})$ in the area being considered is $e_0(1 - 0{\cdot}6)$ or $0{\cdot}4e_0$, i.e. it is 0·4 times the normal vapour pressure at sea level.

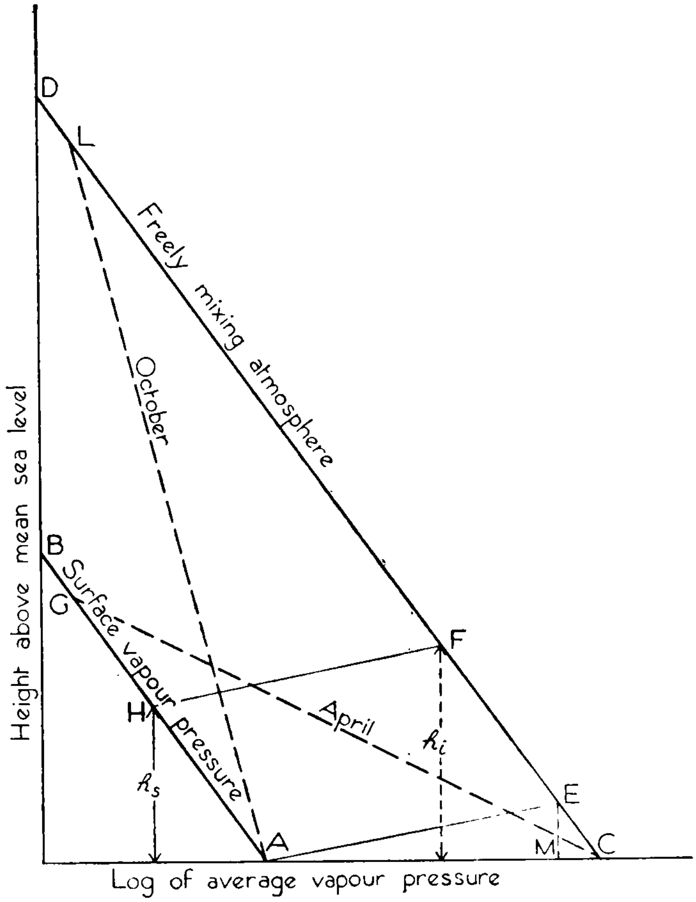

FIG. 4—GENERALIZED DIAGRAM OF VARIATION OF AVERAGE VAPOUR PRESSURE WITH HEIGHT OVER WESTERN CANADA

In Fig. 4, in which the logarithm of average atmospheric vapour pressure is plotted against height above sea level the line AB represents the variations in the vertical of vapour pressure at screen level, AED represents the distribution in the vertical above a sea-level station while HFD represents it above a station h_s m. above M.S.L. (AB is not strictly a straight line). There is a layer with an increase in vapour pressure with height $(h_i - h_s)$ m. thick (dependent on height of station above M.S.L.). The line CD represents a freely mixing atmosphere without the inversion and the point C represents e_0 the sea-level vapour pressure in a freely mixing atmosphere. ME represents the height of the top of the inversion above a sea-level station.

Fig. 5 gives data for Norman Wells[16], one of the northerly stations used in the analysis. The averages used for this diagram are for a short period and for a place well north of the central position for which the above equations hold. However the diagram is sufficient to show the mechanism described above and in Fig. 4. It will be seen that the point E in the diagram corresponds to the top of the temperature inversion. This is true for all stations for which data are available: Fort Smith, Fort Nelson and Norman Wells.

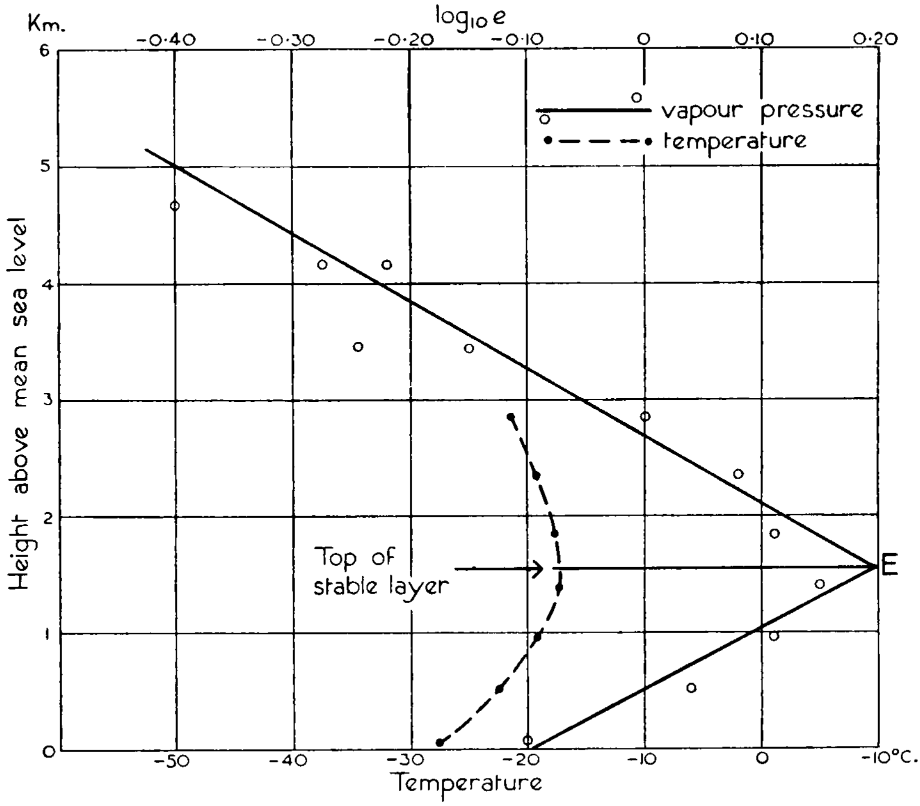

FIG. 5—VARIATION OF VAPOUR PRESSURE AND AIR TEMPERATURE AVERAGES WITH HEIGHT OVER NORMAN WELLS

From Table II and Fig. 4 we see that for April *a* is of smaller magnitude and for October of larger magnitude than the values for January and July. The explanation of this is that October is a transitional month, and the inversion layer AE has formed at lower stations but not at higher ones and the curve runs approximately from A towards the line CD, for example, AL. In April the inversions AE have wholly or partially broken down at the lower stations and the curve of vapour pressure with height runs from some point on CD towards the line AB, for example CG. Thus in the two seasons in which there is a homogeneous structure the variation in the vertical is identical, but in the seasons during which the situation is not homogeneous there are differences. This hypothesis suggests that formulae (11) are true for a freely mixing atmosphere, but when mixing is suppressed by a steep inversion the law breaks down.

Average temperature-height curves for the three stations for which data are available[16] support this theory. For example, in April, at Norman Wells (a low-level station) the only sign of the winter inversion is a slight decrease in the lapse rate at about 1,100 m., but in October the lapse rate has decreased between about 1,500 m. and the surface. There are no data for high-level stations.

Thickness of the inversion.—Some idea can be obtained of the thickness of the inversion from the following considerations.

If the vapour pressure at the top of the inversion is e_i

then $e_i = e_0 \exp(-\beta h_i)$

where h_i is the height of the top of the layer above M.S.L.

If e_s is the vapour pressure at the surface and h_s is the height of the station above sea level

$$e_s = e_0\{\exp(-\beta h_s) - 0 \cdot 6\}.$$

Therefore $h_i = -\frac{1}{\beta}\left[\log_e k + \log_e\{\exp(-\beta h_s) - 0 \cdot 6\}\right] - h_s$

where $k = e_i/e_s$. If average values in January at Norman Wells are taken, where $h_s = 89$ m., $k = 1 \cdot 9$, and $\beta = 0 \cdot 295 \times 10^{-3}$, then $h_i = 1{,}200$ m., which is of the correct order (see Fig. 5). However, this is no more than a rough check.

Conclusions.—(1) The variation in the vertical of the long-period average mean-of-day vapour pressure can be represented very accurately by the following equation:—

$$e = e_0(1 - 0 \cdot 00025h)$$

where h is less than 1,300 m.

(2) If the true variation of average vapour pressure with height is

$$e = e_0 \exp(-0 \cdot 000295h)$$

the linear equation would be an almost perfect fit up to about 1,300 m. The exponential form may therefore be used as an extrapolation formula to reduce averages from great heights to sea level.

(3) The special case of western Canada shows that the above formulae are true for a freely mixing atmosphere but when free mixing is suppressed by a deep inversion they are not applicable.

(4) It is necessary to note that these relationships apply to averages of daily means only. No simple relationship has been found between diurnal variation of vapour pressure and height.

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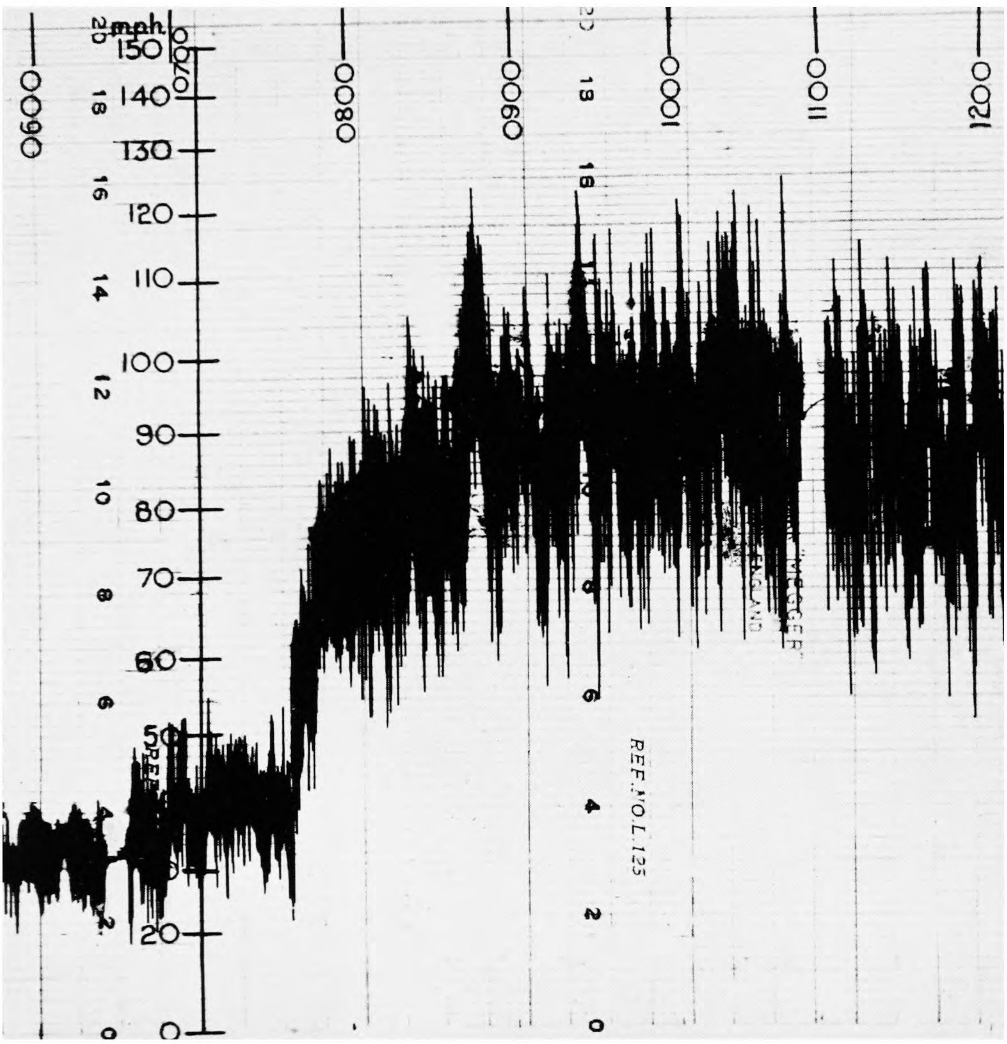
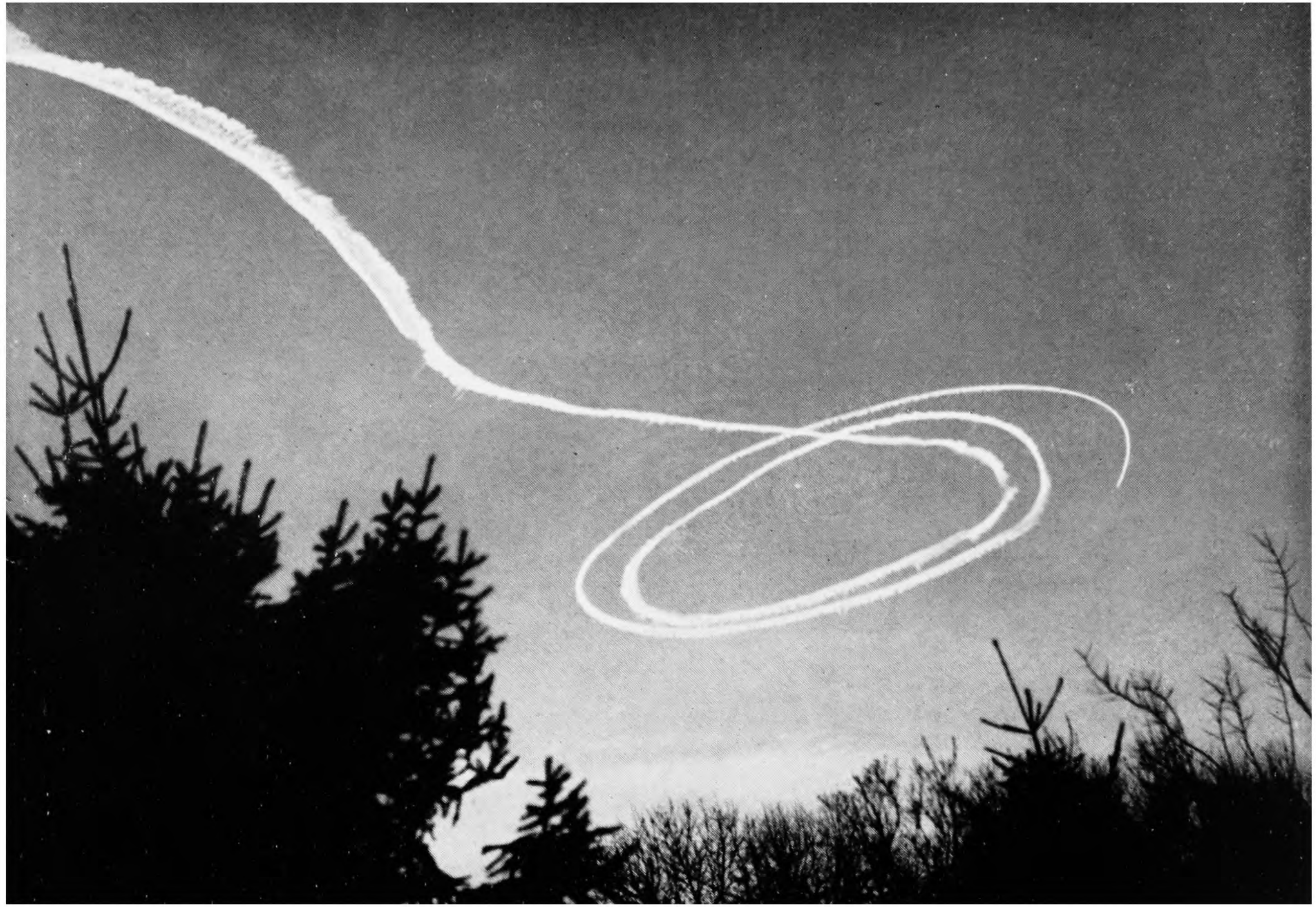


FIG. 1—TRACE FROM THE ELECTRIC CUP GENERATOR ANEMOMETER AT COSTA HILL, ORKNEY

The scale which has been added on the left-hand side is derived from wind-tunnel calibrations and is not linear. On two occasions the clock seems to have "jumped"—at about 0630 and 1100

see p. 97

CONDENSATION TRAILS
Apparent wind shear effect
see p. 125



CONDENSATION TRAILS
Apparent wind shear effect
see p. 125

AFTERNOON VALLEY FOG, 1430 DECEMBER 27, 1952

see p. 125

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FORECASTING OUTBREAKS OF POTATO BLIGHT

By L. P. SMITH, B.A.

During the last three years the reporting stations of the Meteorological Office have been helping the Provincial Plant Pathologists of the National Agricultural Advisory Service in England and Wales to solve the problem of forecasting outbreaks of potato blight. An official report on the investigation by the Ministry of Agriculture and Fisheries summarizing the results obtained, has recently been published[1]. Similar work on a smaller scale has previously been done in Scotland.

Blight is a fungus disease which attacks the potato haulms, spreads rapidly under warm moist conditions, and finally kills the plant; late in the season, spores may be washed on to the potatoes themselves, causing subsequent deterioration during storage. The spread of blight may be prevented by spraying, but to obtain maximum benefit the time of spraying is important, and therefore the forecasting of outbreaks is a very essential service.

Previous work on the disease indicated that a period of 48 hr. during which the temperature in a Stevenson screen did not fall below 50°F. and the relative humidity did not fall below 75 per cent. was a good indicator of a blight outbreak some 7–21 days later. For this reason it was suggested by the Agricultural Meteorology Branch of the Meteorological Office that the plant pathologist might make use of the hourly observations taken at official stations. In doing so, it was realized that:—

(i) The criteria assume a constant relationship between screen climate and climate within the crop (or eco-climate)—an assumption which is by no means valid throughout the life of the crop, or during very wet or very dry spells.

(ii) The reporting stations are not all situated in areas where potatoes are grown.

Nevertheless it was agreed to test the criteria over a period of years to ascertain what degree of help could be obtained by the use of existing observations, and in 1950 arrangements were made to supply "Potato blight warnings" to plant pathologists, and for the latter to carry out widespread surveys of the potato crops to determine the dates of outbreaks and progress of the disease.

The results of the first year were very encouraging. Most of the reports from the stations correctly forecast the outbreak of blight. The disease occurred early in the south and west, and reached epidemic proportions in some areas. The stations which failed to give warnings were situated in non-representative areas where the break-down of the criteria was not unexpected. Some of the northern stations did not give warnings of the later outbreak in their area, but, on the other hand, they did not give any misleading false alarms at earlier stages.

Following this initial success, the investigation was intensified in 1951, broken critical periods or "near misses" being included in the warning system and assessment surveys of the disease increased. 1951 was not a "blight year", the outbreaks in most regions being at least a month later than in 1950, but a very warm moist period in September caused a rapid build-up of the disease which rapidly killed off the haulms before lifting, but was too late to affect yields.

Nearly every station gave warnings during the September period, but during the summer there were several partial failures, and it was obvious that a firm screen-crop climate relationship was not present in a marginal year. Experience furthermore indicated that undue weight could not be placed on a warning, or absence thereof, from a single station, and an "operation room" method, whereby the meteorological warnings and disease reports were considered on country-wide maps and charts, was evolved, necessitating twice-weekly consultations between the Agricultural Meteorology Branch at Harrow and the Plant Pathology Laboratory at Harpenden.

This method was extended in 1952, and charts were prepared showing the current incidence of both warnings and outbreaks. When a flush of warnings occurred copies of the chart were circulated by the Laboratory to all provincial pathologists in the form shown in Fig. 1.

1952 was a blight year in the west, but not elsewhere. Early outbreaks in the west were correctly forecast, and a minor flush of warnings in mid June gave warning of sporadic outbreaks on early crops. The second flush of warnings occurred in early August, and enabled a correct forecast of mid-August blight on main crops to be made and circulated.

Preventive spraying is not usually needed if the blight outbreaks occur after mid August; a later attack cannot adversely affect the yield of the crop to any great extent, although it may impair its keeping qualities. In assessing the value of a station warning, it is therefore necessary to judge its performance in allowing a forecast to be made of an outbreak before mid August; in 1952, three stations gave premature warnings, and three others gave no warnings of a significant outbreak. All the other stations either gave valid warnings, or gave no false alarms.

The conclusions of the three-year investigation were to the effect that, although complete accuracy was impossible, the warnings issued by the meteorological stations, assessed by an operations chart method, gave a very reliable guide for the issue of blight forecasts. A few of the stations used were unsuitable, by reason of their site, and will probably be omitted in future plans. Research is going on with a view to obtaining more precise criteria on which to base the warnings, and on the "follow-up" weather which succeeds a warm moist spell and which determines a slow spread or rapid build-up of the disease.

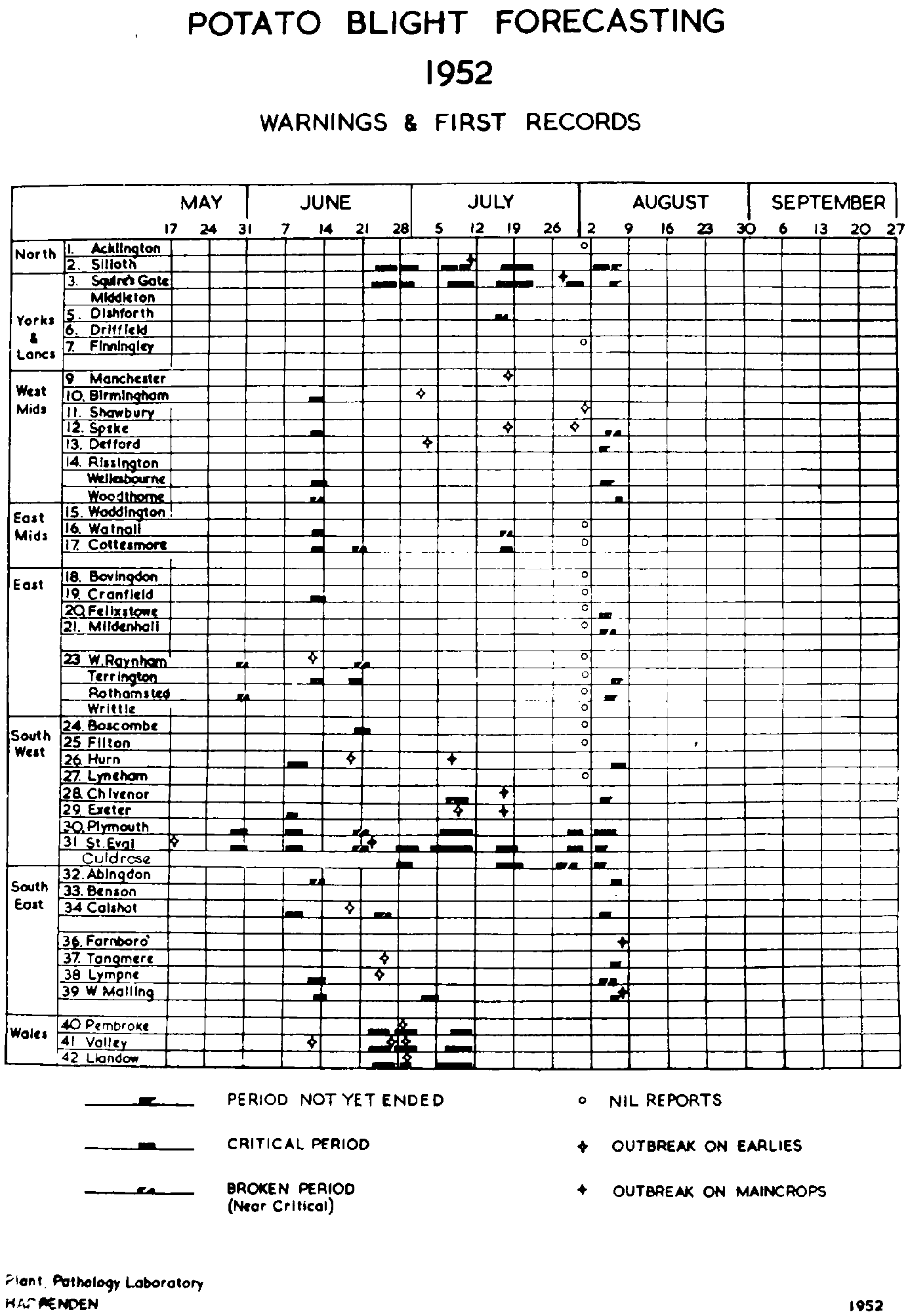

FIG. I—CHART AS CIRCULATED BY THE PLANT PATHOLOGY LABORATORY WHEN A FLUSH OF WARNINGS OCCURRED

The whole investigation is an excellent example of what can be done by close co-operation between scientists to protect our supply of food, and the official report concludes with a note of appreciation and thanks to all the many participators in the scheme.

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METEOROLOGICAL OFFICE DISCUSSION

Atmospheric circulation at high altitudes in the tropics and subtropics

The discussion on January 19, 1953, held at the Royal Society of Arts was opened by Mr. J. K. Bannon and Mr. N. E. Davis.

Mr. Bannon described recent work in the Upper Air Climatological Branch in summarizing observations of winds at high altitudes in the tropics and subtropics. Up to a few years ago knowledge of such winds was very slight, and was derived from a few pilot-balloon observations and observations of cirrus cloud; this knowledge has been summarized in *Geophysical Memoirs* No. 85, "Upper winds over the world"[1]. During the last two or three years an increasing number of radar or radio wind stations have been in operation in low latitudes, and a start has been made to use the observations from these stations to revise *Geophysical Memoirs* No. 85. Charts for the zone 40°N.–40°S. were shown for four levels between approximately 30,000 and 55,000 ft., namely 300 mb., 200 mb., 150 mb. and 100 mb. for each of the months January, April, July and October. On each chart was plotted the vector mean wind for the month for each station, the great majority of the data so summarized being for 1951. Each vector mean was, in general, computed from 15 or more daily observations. In regions of strong wind observations were often missing as the radar or radio targets were carried out of range before reaching the greater heights. The strong winds occurred for the most part at latitudes greater than 20°, however, and it was possible, therefore, to obtain a good idea of the winds in these regions from temperature data using the geostrophic relation. There were very few observations from the southern hemisphere, and most of the description applied to the northern hemisphere only.

For January the charts showed a strong W. wind belt between 20° and 40°N., the greatest speeds occurring between the levels 200 mb. and 150 mb. There was also a moderate easterly stream (up to 30 kt. in the mean) over equatorial regions, but this stream ceased over the central Pacific. The maximum speeds in the easterlies occurred about the 150-mb. level. The strong westerlies increased eastwards across north Africa. Over Iraq the mean maximum wind was about 100 kt. This stream emerged from Asia near the south of Japan (30°N.) where the maximum mean wind was nearly 200 kt., and a branch of this current could be seen near the Hawaiian Islands. Over the Pacific it is likely that there was a northerly branch also, associated with the polar front. The stream was seen again, much intensified, over the United States and the Caribbean Sea; this stream probably divided over the Atlantic Ocean also, the true subtropical branch flowing east to north-west Africa and the other branch, associated with the polar front, north-eastwards towards Iceland and the British Isles. It was not known if the strong subtropical westerly stream was continuous across the Pacific and Atlantic Oceans as observations were lacking; but this seemed likely, at any rate in the mean.

North–South cross-sections of the January mean flow were shown for longitudes 45°E. (Iraq), 80°W. (United States and Caribbean Sea), 140°E. (Japan) and 160°E. (Marshall Islands). These emphasized the differences in zonal flow in different longitudes. At 80°W. the mean flow had two maxima; the more southerly at about 27°N. was the true subtropical stream, and was not, in general, associated with any front. The more northerly was probably associated with the polar front. At 45°E. only one core could be found in the current, about 28°N., and at 140°E. the maximum was very pronounced at about 30°N. though there may have been a secondary maximum near or to the north of 40°N.

In July, the subtropical westerlies were much lighter than in January, and the equatorial easterlies correspondingly stronger. Over North America strong westerlies were well to the north of 40°N., but they could be found along the Mediterranean Sea and then at about 40°N. to Japan with maximum mean speeds about 50 kt. This stream probably passed to the north of the Hawaiian Islands, but it was not known if it was continuous across the Pacific and Atlantic Oceans. The height of this stream was much the same as in January. The corresponding mean stream over Australia was quite strong (maximum speed about 100 kt.) it being the winter season there. This stream probably extended round the southern hemisphere.

The easterly belt was extensive in July and mean speeds exceeded 40 kt. to the south of Asia and over central Africa where the winds were more steady in direction and speed. The easterlies were lighter and more variable in other equatorial regions and the strong steady easterlies appeared to be associated with the Eurasian land mass. As in January, maximum speeds in the easterlies occurred about the 150-mb. level.

A peculiarity of the July flow over the Caribbean Sea and also over the Marshall Islands was a slow westerly stream some 700 miles wide and 20,000 ft. deep, centred between 200 mb. and 150 mb. and embedded in a general easterly current.

The mean flow in April and October appeared in general to be intermediate between that in January and July.

Mr. N. E. Davis discussed statistics providing information on the wind variation at a particular place or height or over a particular route.

The first is the standard vector deviation σ which is defined by $\sigma^2 = [(\mathbf{V}-\bar{\mathbf{V}})^2]$ where the square brackets denote a mean taken over a large number of observations, and $\bar{\mathbf{V}}$ is the mean vector wind. The standard vector deviation is a measure of the variability of wind and consequently a measure of the intensity of disturbances. The standard vector deviation shows a maximum in temperate latitudes (especially near the British Isles) and a minimum near the equator, so that the upper air circulation over the tropics is such that the disturbances in it are less intense than over middle latitudes.

The standard vector deviation may be used as a yardstick for measuring the success of forecasting. If $\mathbf{V}_f$ is the forecast value and $\mathbf{V}$ the true value, then if $[(\mathbf{V}_f - \mathbf{V})^2] < \sigma^2$ the forecast is better than giving the normal $\bar{\mathbf{V}}$ for the season. In temperate latitudes where σ is large $[(\mathbf{V}_f - \mathbf{V})^2]$ is normally considerably less than σ^2, but in the tropics where σ is 20 kt. or less worthwhile forecasts of upper wind may be more difficult to achieve.

The standard vector deviation though it describes how intense disturbances are does not give any information as to how rapidly they occur. This is given by a second statistic r_t the correlation of wind with time, defined by

$$r_t = \frac{[(\mathbf{V}_t - \bar{\mathbf{V}}) \,.\, (\mathbf{V} - \bar{\mathbf{V}})]}{\sigma^2}$$

where $\mathbf{V}_t$ is the wind t hours after the observation of $\mathbf{V}$ for the same place and height. Values of r_t calculated by Mr. Durst for various places show that it depends only on t, and is independent of height and place except that the values are probably slightly lower in the tropics. The equation of r_t is of the form $e^{-\lambda t}$ where λ depends on what might be termed the eddy spectrum of atmospheric disturbances. The value of r_t falls to $\frac{1}{2}$ for t slightly greater than 24 hr.

A third statistic is the correlation of wind with distance defined by

$$r_l = \frac{[(\mathbf{V}_1 - \overline{\mathbf{V}}_1) \cdot (\mathbf{V}_2 - \overline{\mathbf{V}}_2)]}{\sigma_1 \sigma_2}$$

where $\mathbf{V}_1$ and $\mathbf{V}_2$ are simultaneous observations of wind at the same height for two places distant l apart, and σ_1 and σ_2 are the corresponding standard vector deviations. Values of r_l, calculated by Mr. Durst from a number of pairs of places, show that the correlation of wind with distance and consequently the scale of disturbances is less in the tropics than in temperate latitudes. The form of r_l is very similar to that for r_t. In fact, if (for temperate latitudes) the scales of r_t and r_l are such that $t = 6l/100$ then the curves coincide. This is a curious result and must mean that the average speed of upper air disturbances (at least over Europe) is 14–15 kt., which is in broad agreement with figures given by Namias and Clapp[2] and Flöhn[3]. In the tropics the average speed is less since r_l is smaller.

Thus disturbances in the upper air in tropical regions are smaller and less intense than in temperate latitudes and move more slowly. Hence their form will be more rapidly changed by vertical motion, so that the conventional methods of forecasting by estimating the advection of the disturbances and making allowance for vertical motion are less likely to give a good forecast than in temperate latitudes.

Suppose however we have an observation of wind at a point, then it can be modified by means of the equation $\mathbf{V}_t = r_t \mathbf{V} + (1 - r_t)\overline{\mathbf{V}}$ to give an estimate of the wind at some future time t which will be more accurate than giving either the actual observation unmodified or the normal. For the standard error in using the equation is $\sigma \sqrt{(1 - r_t^2)}$ which is less than σ; while the standard error in using the actual observation $\mathbf{V}$ for the wind t hours later is $\sigma\sqrt{\{2(1-r_t)\}}$ which is greater than $\sigma\sqrt{(1 - r_t^2)}$. In fact for $r_t<\frac{1}{2}$, $\sigma\sqrt{\{2(1 - r_t)\}}$ becomes greater than σ so that giving a latest actual observation more than 24 hr. old is worse than giving the normal for the season.

A similar equation can be set up for the average wind over a route. In this case since an adverse wind at one point is to some extent counteracted by a more favourable wind at another, the standard error in modifying the wind over a route is considerably less than the error for the wind at a point, and indeed for temperate latitudes is comparable with that achieved in standard methods of forecasting. In the tropics, since the standard deviation of wind is less than in temperate regions, the method would attain an accuracy sufficient for all normal route flying. Unfortunately it is impossible in the tropics to determine the average wind on any particular occasion within 5 kt., unless radar wind stations are situated at least every 500 miles.

First reports from Comet and Canberra aircraft which have flown at high levels in tropical regions indicate that cumulonimbus can and does reach up to the tropopause level which is over 50,000 ft., while the amount of cirrus and cirrostratus is much greater than previously realized. These clouds are produced by the vertical motion resulting from the convergence of air at low levels. If the reason for this convergence on a particular occasion could be found or even if it could be measured a great stride would have been made in tropical meteorology. Since convergence can only be determined from accurate measurements of wind this problem is the same as the one described before.

As a possible means of making some progress in tropical meteorology Mr. Durst has suggested that a Tropical Year should be organized in which a concentration of surface and upper air stations would be set up in a limited area to study the motion of the air in the tropics and determine the cause of weather disturbances in the tropics.

The Director, in opening the general discussion, referred to Mr. Davis's remarks regarding a Tropical Year, analogous with the former Polar Years, and said that the International Council of Scientific Unions was proposing to arrange a Geophysical Year in 1957–58, when efforts would be made to obtain special observations from all over the world. The Meteorological Office would press for special consideration to be given to tropical problems, and he hoped that before this date the Meteorological Office would be able to formulate specific problems for investigation in this international project. The Director also asked if the peculiar westerly belts embedded in the easterlies over the Caribbean and south-west Pacific in July were real, or if they could have arisen from the method of analysis. Mr. Bannon replied that as far as could be ascertained these mean westerlies were real, though their physical significance was obscure.

Dr. Robinson inquired how many pairs of observations were used to compute r_l and if much interpolation was required; Mr. Davis replied that little interpolation was necessary as data were used from several pairs of stations at various distances apart.

Mr. Wallington suggested that the regression equation for a wind forecast might be extended by a third term which would take account of a conventional forecast.

The Director then intervened to point out that the statistical technique for forecasting winds had not yet been approved for general use; it was still under test.

Mr. Gilchrist, in showing cross-sections along 80°W. for two days of January 1951 when there was a well defined maximum of wind velocity in the subtropics, pointed out differences between this maximum and the polar jet stream, namely, it occurred at about 200 mb. with a very pronounced vertical shear immediately under it, was not associated with a frontal system, and was not related to the tropopause in the usual way. By means of diagrams showing the 200-mb. winds at Miami and Bahrein in January and at Aden and Albrook Field (Panama Canal) in July, he drew attention to the fact that the subtropical flow across Arabia and southern Asia in both summer and winter was much steadier than in other parts of the world.

Mr. Jenkinson described a simple technique for deriving charts of isotachs and stream-lines from charts of temperature at fixed pressure levels using the geostrophic winds from the surface isobars added vectorially to the thermal winds from successive layers of the atmosphere. An example was shown of mean isotachs for January for the Middle East at the 200-mb. level computed by this method; the maximum wind was shown as 120 kt. between Bahrein and Habbaniya. Mr. Jenkinson also drew attention to the advantages of using the cosine of the latitude as horizontal co-ordinate when computing geostrophic zonal winds in low latitudes (James[4]); he claimed that qualitatively, if not quantitatively, correct results could be obtained by this method even over the equator, and as an example quoted a calculated mean easterly component of 50 kt. at 100 mb. over Singapore for July.

Mr. Hay described the main features of the air flow at high levels over Singapore and Hongkong based on two years' observations at both places. In the upper troposphere at Singapore easterlies prevailed all the year, reaching a maximum (mean vector wind) near the 50,000-ft. level in the monsoon periods (December–February, June–August) when 60 kt. was exceeded in many ascents. Typical ascents for these months showed a gradual increase of wind becoming more rapid with height up to near 50,000 ft., then an abrupt change to light westerlies. Decisive evidence for appreciable horizontal thermal gradients over Singapore was not yet available above 30,000 ft. However, the extreme differences noted between ascents at this level in a single year amounted to 16°F. Over Hongkong the wind régime was very similar to that over Bahrein; at the highest levels (100 mb.) easterlies prevailed from May to October, but at 300 mb. their duration was a month less with some interruptions by westerlies which lasted a few days. The easterlies were weaker than at Singapore (maximum mean vector winds 30–40 kt.). Typical ascents at Hongkong in summer showed a gradual increase of easterlies up to 60 mb., but the narrow belt of strong easterlies and the return to westerlies above, so common at Singapore, were not observed.

Prof. Sheppard said he thought the work described by Mr. Bannon was valuable and defended the use of climatic mean values to describe the general circulation of the atmosphere. He then offered an explanation of some of the peculiarities noted in the mean flow. First, he referred to the meridional flow towards the equator at low altitudes, the currents upwards over the equator and the return flow away from the equator in the upper troposphere; the principle of conservation of angular momentum then explained the strong W. winds in the upper troposphere in the subtropics, though friction reduced the speeds considerably. Next, he postulated that by irregularities in the distribution of land and sea and seasonal changes in insolation, the zone of up-currents is displaced to one side of the equator. The equatorward flow in the upper troposphere from the top of this up-current will then result in an easterly current, angular momentum being at least partly conserved. This would explain the strong constant easterlies to the south of Asia during the northern summer.

Mr. Gold said he was surprised that there were no observations shown on the charts for Australia. Mr. Bannon replied that several radar or radio wind stations were now in operation in the Australian area, and that it was understood that many more would be set up in the coming year. Mr. Gold wondered if the range of latitude over which there was a flow toward the equator in the upper troposphere, as postulated by Prof. Sheppard, was sufficient to generate the strong equatorial easterlies at high altitudes in July. Regarding the cross-section shown by Mr. Gilchrist for a particular day in January he pointed out that the discontinuity in lapse rate marked on the figure as a continuation of the polar tropopause surface sloped downwards towards the south, indicating wind increasing with height above it, with the conventional distribution of temperature.

Mr. Dewar showed diagrams of the mean vector winds at various levels up to 100 mb. for each month of the year at Aden, Bahrein and Habbaniya, emphasizing the change-over to easterlies at the first two stations in the summer.

Mr. Dight doubted whether the strong subtropical westerlies in the upper troposphere increased steadily across Asia in winter as Mr. Bannon had implied. He thought the great mountain mass of the Himalayas must have some effect on the flow. Mr. Bannon replied that Chaudhury[5] and Yeh[6] had noted the influence of the Himalayas, and that these mountains undoubtedly must have an important effect on the flow; he had purposely simplified the picture for demonstration purposes.

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METEOROLOGICAL RESEARCH COMMITTEE

The twenty-third meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on November 20, 1952.

The Committee considered the problem of long-range forecasting and reviewed the methods put forward at different times.

The Committee also considered a paper by Dr. Sutcliffe[1] on the formation of new anticyclones, one by Dr. Goldie[2] on the storm of January 14–15, 1952, as a moving vortex, and two by Mr. Sawyer[3,4] on rainfall in the British Isles, the first dealing with rainfall resulting from depressions which passed eastwards between Scotland and the Faeroes, the second dealing with rainfall of depressions which moved eastward between the Bristol Channel and the Scottish Border.

ABSTRACTS

1. SUTCLIFFE, R. C., The formation of new anticyclones. *Met. Res. Pap., London,* No. 755, S.C. II/120, 1952.

In Atlantic and western Europe 42 new anticyclones were classified by 500-mb. contour and 1000–500-mb. thickness into 4 types—simple sinusoidal oscillation with and without pre-existing high to the south, anticyclonic wave disruption and complex types. Examples are illustrated and discussed. The upper air patterns however lead to development of ridges from pre-existing high-pressure centres much more often than to closed new highs, and this problem is discussed.

2. GOLDIE, A. H. R., The storm of January 14–15, 1952, as a moving vortex. *Met. Res. Pap., London*, No. 758, S.C. II/122, 1952.

Calculations are given of the vortical intensity and kinetic energy of this depression in comparison with others of a similar type, i.e. solid rotation to a maximum speed V_m at R from centre, and $V \, . \, r$ = const. to a further distance S. Kinetic energy per unit thickness, $\pi \rho R^2 V_m{}^2 \, [\frac{1}{4} + \log_e(S/R)]$ is greatest in midwinter when it is 4–7 times that of a West Indian cyclone. Reduction of mean speed of jet stream by 10 kt. would provide the energy, and some support for this is found in profiles of upper winds on January 14–15 with distance from isobaric centre, but convection from surface layers is also necessary.

3. SAWYER, J. S., Rainfall in the British Isles resulting from depressions which pass eastward between Scotland and the Faeroes. *Met. Res. Pap., London*, No. 748, S.C. II/116, 1952.

Rainfall charts were drawn for 61 frontal depressions, and expressed as averages, standard deviations and medians, and charts are drawn for types classified by fronts crossing the British Isles. Rainfall was investigated in relation to various parameters and a few significant correlations found, but none of these are likely to improve on forecasts based on synoptic experience.

4. SAWYER, J. S., Rainfall of depressions which moved eastward across the British Isles between the Bristol Channel and the Scottish Border. *Met. Res. Pap., London*, No. 762, S.C. II/124, 1952.

Average rainfall and standard deviation of 45 depressions are charted for British Isles, with profile across track and frequency distributions. Amount was correlated with various parameters, giving a regression equation R (mm.) $= 15 \cdot 9 - 0 \cdot 18V - 0 \cdot 23(p - 1000) - 0 \cdot 092(\theta - 90)$, V = speed of depression in knots, p = central pressure of depression, θ = orientation of track in degrees from north; total correlation 0·60.

LETTER TO THE EDITOR

Barograph records of deep depressions

The barograph trace from Reykjavik, Fig. 1, for January 18, 1944, shows an unusually deep depression of the type described by Mr. C. K. M. Douglas in the *Meteorological Magazine* of April 1952. The depression, Fig. 2, which moved from the north-west Atlantic Ocean to the Arctic Ocean along the Denmark Strait was well occluded with the warm sector to the west of the British Isles. From the steepness of the gradients prevailing at the time, the fairly small curvature of the isobars and the barograph reading of approximately 943 mb. at Reykjavik, the central pressure of the low (down to the 930's at least) appears to have been comparable with extreme values for the Denmark-Strait area.

The trace is typical of the passage of a deep Atlantic depression and is V shaped rather than cusp-like, as with the trace of a more rapidly moving tornado or the smaller but more intense hurricane illustrated in the *Meteorological Magazine* of July 1952.

The symmetry of the trace illustrated here is commonly found in air-mass depressions, either of the tropical or polar type, and is unlike the steep fall followed by a steeper rise associated with the young frontal cyclones of temperate latitudes, of which the storm over north Scotland described by Mr. Douglas in

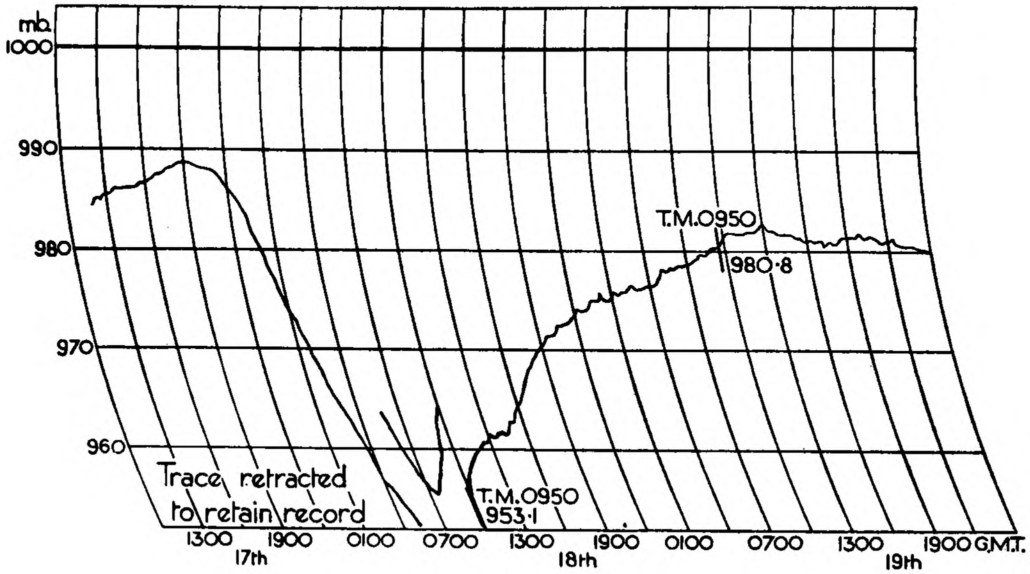


FIG. 1—BAROGRAPH TRACE FROM R.A.F. METEOROLOGICAL OFFICE, REYKJAVIK, JANUARY 18, 1944

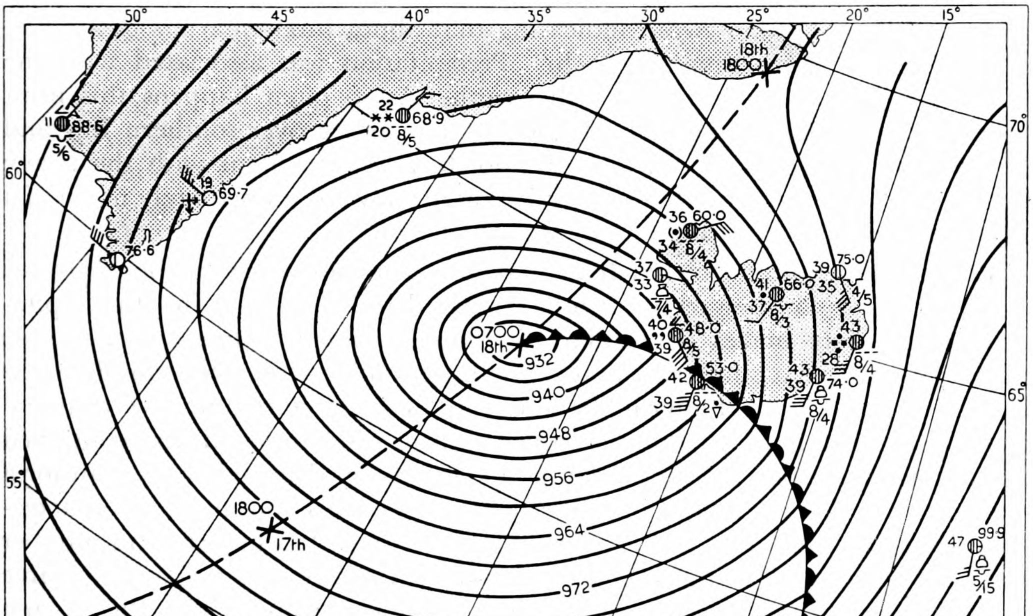


FIG. 2—SYNOPTIC CHART, 0700 G.M.T., JANUARY 18, 1944

the April 1952 issue of the *Meteorological Magazine* is an example. The latter type of low, when well occluded, is more likely to give a symmetrical trace of the type shown here, and when associated with a great deceleration of movement would of course give the reverse trace of a fall followed by a gradual rise.

E. N. LAWRENCE

July 29, 1952

NOTES AND NEWS

An unusually prolonged fall of "frozen drizzle"

The rather familiar expression "raining cats and dogs" may savour of exaggeration, and it is less of an exaggeration to say that it was "raining ice" during the afternoon and evening of Saturday, November 29, 1952, when "frozen drizzle" was observed near London over the remarkably protracted period of some 10 hr.

"Frozen drizzle" at the conclusion of a winter cold spell in the southern half of England is, in my experience, less rare than is commonly supposed. But it is normally a very transient phenomenon and often requires for its detection a favourably located, expectant observer. Invariably in the past I have detected it with the first drops of precipitation preceding a period of general rain. I would emphasize that I refer throughout this note to spherical droplets of clear ice, easily identifiable as such. The most protracted fall previously observed, of perhaps a dozen observations over the years, was one of about five minutes' duration as I was walking across the old Waterloo Bridge late one evening. It must be extremely unusual for the phenomenon to persist over a period of about 10 hr.

The observations were made at Ickenham, near Uxbridge, Middlesex—the extreme western edge of suburban London. The late afternoon of Saturday November 29 and the early hours of Sunday were extremely wet in the London area, the *Daily Weather Report* indicating that about three-quarters of an inch of rain fell in approximately 10 hr. Precipitation was associated with the approach of a warm front from the south. As so often happens this front failed to make any substantial advance at the surface over southern England against the very cold air mass to the north, and coincident with the heavy rain in southern England there was substantial snowfall immediately north of a line from Bristol to London.

Precipitation commenced at Ickenham as slight snow early in the afternoon but at about 1630 changed its form to "frozen drizzle". This form of precipitation in quantity makes a peculiar "swishing" noise which is unmistakable although somewhat similar to that made by granular snow. So complete was the freezing process that after half an hour in the precipitation my overcoat and hat remained quite dry. From about 1700 rain predominated and continued at varying intensities until the small hours of Sunday, November 30. But for a very considerable portion of the time the frozen pellets continued to be detectable, and intermittently as the rain waned the ice pellets increased in number until the "swishing" sound was easily audible. In spite of the quantity of free water falling at times, large sections of the pavements were quickly "iced", not with a smooth glassy icing but with a definitely granular layer, crunching underfoot almost like spilled sugar, and from time to time slippery enough to provide the children with slides of a yard or two, as they hurried home in the rain—there was no earlier snow or ice persisting. Admittedly during the later evening the frozen precipitation was almost entirely absent for appreciable periods and it was therefore with considerable surprise that I awakened at 0220 to the characteristic, eerie, swish-swish-swish. I verified that the precipitation was almost wholly pellets of frozen rain or drizzle. This was probably the final phase of the precipitation.

It is reasonably easy to visualize the thermal state of the lower atmosphere which will permit the phenomenon to occur over a short period. But to attempt to envisage the thermal distribution which will permit such a delicate balance that appreciable frozen droplets will co-exist with raindrops qualifying for an entry in the register as "heavy rain" is an interesting speculation. It is astounding that such a balance could be maintained over such a prolonged period.

F. H. DIGHT

Valley fog

The photograph of valley fog (facing p. 113) was taken by Mr. J. B. Tuke from Eastcombe, Stroud, Gloucestershire at 1430 on December 27, 1952. It shows fog filling the Toadsmoor valley. The valley bottom is at about 400 ft. above M.S.L., the photograph was taken from about 650 ft. and the top of the fog is at about 550 ft. The existence of well defined valley fog at such a late hour with the slopes above the fog in bright sunshine is particularly interesting.

Condensation trails

The photographs of a condensation trail in the centre of this magazine were taken by Mr. J. B. Tuke from Eastcombe, Stroud, Gloucestershire, at 1610 on November 10, 1952. The area of the upper photograph is to the left of that for the lower one, and the direction left to right is south-east to north-west; the whole trail pattern drifted south-eastwards. Interesting features are the twisting of the trail, the comb-like structure and the remarkable "kink" in the photograph on the left-hand page.

Mr. J. K. Bannon has commented as follows: The twisting and comb-like structure of the trail are frequently seen. The slope of the trail after a few minutes depends on several factors including turbulence, distribution of humidity and nuclei, fall-out of particles and distortion by wind shear. The large "kink" in the upper photograph appears to be mainly in a horizontal plane, and was probably produced by a shallow layer of SW. wind. The Larkhill upper wind observation made at 1500 shows a wind of 83 kt. at 450 mb. and 67 kt. at 200 mb. from NW. with little variation of direction with height and little vertical shear. There was a strong NW. jet stream with axis off the Norfolk coast at the time, so horizontal shear may have been large though observations are insufficient to prove it. If there was a large horizontal shear dynamic instability may have set up a thin local horizontal eddy producing the "kink".

Radio fadeouts

The following extract from the radio overseer's report of *Weather Explorer*, Voyage 41, emphasizes some of the difficulties which can be produced by radio fadeouts.

"Communications for the first three weeks of the voyage were good, but from the 26th to 30th January (both dates inclusive) serious fadeouts occurred, commencing at about 1800Z and lasting for six to eight hours. During these periods, no contact could be made with any station in the U.K. on 3, 4, 6 or 8 mc/s. Observations and upper air data were delayed and were usually relayed via the Azores on 6543 kc/s. Attempts were made to contact G.P.O. radio stations on M/F and H/F, but were not successful, although communication on M/F was good."

The vessel was on duty at the time at station "India" in position 59°N. 19°W., distant about 750 nautical miles from Dunstable. During the same voyage the ship's radar followed a balloon and target to a range of 156,000 yd.

This was the voyage during which the gale (discussed on p. 97) occurred in which the *Princess Victoria* was lost. The Master's report mentions that on January 30 the "wind at 1330 was 320° 25 kt., at 1350 was 50 kt., at 1400 was 72 kt., at 1445 50 kt. and at 1500 was 45 kt."

REVIEW

Plant environment and the grower. By S. A. Searle. $8\frac{3}{4}$ in. × $5\frac{1}{2}$ in., pp. vi + 50, *Illus.* C. F. Casella & Co. Ltd. in collaboration with A. Gallenkamp & Co. Ltd., London, 1952. Price 5*s.* 0*d.*

Mr. Searle's pamphlet is an account of meteorology and soil physics applied to horticulture both glass-house and outdoor. Particular attention is paid to methods of measuring the elements concerned such as soil water content. The work is intended for horticulturists but makes interesting and instructive reading for meteorologists unfamiliar with the application of their science to horticulture.

G. A. BULL

OBITUARY

Frederick William Crewe.—It is with great regret that we record the death on February 25, 1953, of Mr. F. W. Crewe, Experimental Officer, radio-sonde unit, meteorological office, Larkhill.

Mr. Crewe was appointed to the staff of Lerwick Observatory in 1935 and spent his first four years there. During the early part of the war he served for short periods at several synoptic stations, but he was posted to Larkhill in March 1943 and remained there until his death. He was well known to nearly all the staff in the radio-sonde field and was well liked and highly esteemed by his seniors and juniors alike. The Meteorological Office can ill spare such men.

Mr. Crewe leaves a widow and one son to whom we offer our deepest sympathy in their loss.

WEATHER OF FEBRUARY 1953

Mean pressure was above normal over most of the North Atlantic and west Europe and below normal over most of North America. The greatest excess of pressure was 10 mb. over south-west Ireland where mean pressure reached 1022 mb. The lowest mean pressure 997 mb. occurred just south-east of Greenland where it was 5 mb. below normal; mean pressure was also below normal over the eastern Mediterranean to the extent of 2–4 mb.

Mean temperature was below normal over Europe and above normal over North America; it varied from 7°F. in northern Scandinavia to 30–40°F. in west Europe and 40–50°F. over the Mediterranean, and was generally 2–5° below normal in these regions.

In the British Isles the weather was mainly dry, particularly in south and east Scotland, north-west England and Northern Ireland. It was sunny on the whole in Scotland but, apart from Cornwall, most parts of England and Wales had rather less sunshine than usual. The first half of the month was cold, the cold weather lasting until the 13th in Scotland and Ireland but persisting over the 16th in England and Wales; from the 18th onwards conditions were very mild.

During the opening days a depression over north-west Germany moved away south-east and became less deep. Meanwhile an anticyclone off our western seaboard moved in over the country. Northerly gales occurred locally at first but these died down as the depression moved away. Cold weather prevailed with some wintry showers. On the 3rd and 4th a depression east of the Faeroes moved south-east to the Baltic and the anticyclone receded westward; some slight precipitation occurred. Thereafter northerly winds prevailed, with wintry showers. Sunshine was good on the whole during the first week. On the 8th and 9th a trough of low pressure associated with a depression south of Iceland moved over the British Isles giving widespread snow, and on the 10th a deep depression moved east over our southern districts giving further considerable precipitation in England and Wales. Behind this disturbance a cold north-easterly air stream gave further snow in many districts on the 11th and 12th. On high ground in northern England and Wales, snow lay to a considerable depth blocking many roads. For example at Malham Tarn, Yorkshire (1,297 ft.), snow lay 2–3 ft. deep with drifts up to 10 ft. on the 12th to 14th; at Bwlchgwyn, Denbighshire (1,267 ft.), level snow was 17 in. deep on the 11th, 12th and 13th and the whole meteorological station was buried under huge drifts; at Buxton (1,007 ft.) level snow was 14 in. deep on the 12th with heavy drifts; at Lake Vyrnwy (995 ft.) level snow was 12½ in. deep on the 12th with drifts 5–6 ft. On the 13th a small depression moved south-east from Iceland to the Shetlands and on the 14th turned south-south-west across northern and western England; more snow fell over much of England, but it became milder in Scotland, Ireland and the extreme west of England and Wales. Snow was lying over quite a large area from about the 8th until the 16th and at some places until the 17th or 18th. A ridge of high pressure moved south-east over the British Isles on the 15th and 16th giving early morning frost, hard locally in England and Wales (minimum temperature 18°F. at Cranfield on the 15th and 19°F. at Cranfield and 20°F. at Mildenhall on the 16th), but milder weather persisted in the north and west. Subsequently pressure was high to the south and low to the north of the British Isles, and a very mild south-westerly to westerly type of weather was established; considerable rainfall occurred at some places in the north-west, particularly on the 22nd and 24th but measurements were small in the south. Gales were recorded at times in the extreme north-west and north. On the 26th the ridge of high pressure over France spread north and by the 27th anticyclonic conditions prevailed over the whole country; sunshine records were good in many places during this period but they were variable, partly due to the incidence of fog. Day temperature exceeded 55°F. at numerous places between the 21st and 28th; it reached or slightly exceeded 60°F. at a few, for example, at Ross-on-Wye on the 26th, at Tangmere, London Airport and Bristol on the 27th, and at Dyce on the 28th. The minimum, 50°F., at Dyce on the morning of the 26th was notably high for February in that locality.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	62	13	+0·1	81	−3	97
Scotland	61	14	+1·7	70	−1	109
Northern Ireland ...	59	20	+1·6	47	−2	96

RAINFALL OF FEBRUARY 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·48	89	*Glam.*	Cardiff, Penylan ...	1·96	67
Kent	Dover	2·36	123	*Pemb.*	Tenby	3·09	107
,,	Edenbridge, Falconhurst	1·35	61	*Radnor*	Tyrmynydd	2·85	54
Sussex	Compton, Compton Ho.	2·03	77	*Mont.*	Lake Vyrnwy	3·87	85
,,	Worthing, Beach Ho. Pk.	1·06	54	*Mer.*	Blaenau Festiniog ...	8·26	101
Hants.	Ventnor Park	1·09	50	,,	Aberdovey	2·78	93
,,	Southampton (East Pk.)	1·42	62	*Carn.*	Llandudno	1·85	95
,,	Sherborne St. John ...	1·74	80	*Angl.*	Llanerchymedd ...	2·67	105
Herts.	Royston, Therfield Rec.	1·62	105	*I. Man*	Douglas, Borough Cem.	2·18	68
Bucks.	Slough, Upton... ...	1·58	93	*Wigtown*	Newton Stewart ...	1·33	35
Oxford	Oxford, Radcliffe ...	1·58	96	*Dumf.*	Dumfries, Crichton R.I.	0·97	30
N'hants.	Wellingboro' Swanspool	1·54	96	,,	Eskdalemuir Obsy. ...	2·04	41
Essex	Shoeburyness	1·20	98	*Roxb.*	Crailing...	1·05	57
,,	Dovercourt	0·99	78	*Peebles*	Stobo Castle	1·21	44
Suffolk	Lowestoft Sec. School...	1·36	97	*Berwick*	Marchmont House ...	1·31	63
,,	Bury St. Ed., Westley H.	1·06	71	*E. Loth.*	North Berwick Res. ...	0·75	48
Norfolk	Sandringham Ho. Gdns.	1·93	117	*Midl'n.*	Edinburgh, Blackf'd. H.	0·72	43
Wilts.	Aldbourne	1·61	75	*Lanark*	Hamilton W. W., T'nhill	1·16	40
Dorset	Creech Grange... ...	2·07	72	*Ayr*	Colmonell, Knockdolian	1·49	39
,,	Beaminster, East St. ...	2·05	68	,,	Glen Afton, Ayr San. ...	1·92	44
Devon	Teignmouth, Den Gdns.	1·64	62	*Renfrew.*	Greenock, Prospect Hill	3·36	63
,,	Cullompton	3·01	108	*Bute*	Rothesay, Ardencraig...	2·61	65
,,	Ilfracombe	2·69	97	*Argyll*	Morven (Drimnin) ...	4·48	85
,,	Okehampton	2·25	51	,,	Poltalloch	2·91	61
Cornwall	Bude, School House ...	1·65	66	,,	Inveraray Castle ...	6·43	95
,,	Penzance, Morrab Gdns.	1·89	57	,,	Islay, Eallabus... ...	2·82	67
,,	St. Austell	2·01	52	,,	Tiree	3·26	95
,,	Scilly, Tresco Abbey ...	1·70	61	*Kinross*	Loch Leven Sluice ...	1·36	48
Glos.	Cirencester	1·56	69	*Fife*	Leuchars Airfield ...	0·66	38
Salop	Church Stretton ...	2·14	92	*Perth*	Loch Dhu	4·21	57
,,	Shrewsbury, Monkmore	1·49	95	,,	Crieff, Strathearn Hyd.	0·94	27
Worcs.	Malvern, Free Library...	1·35	75	,,	Pitlochry, Fincastle ...	1·04	35
Warwick	Birmingham, Edgbaston	1·23	73	*Angus*	Montrose, Sunnyside ...	0·89	48
Leics.	Thornton Reservoir ...	1·62	97	*Aberd.*	Braemar	1·37	48
Lincs.	Boston, Skirbeck ...	1·65	113	,,	Dyce, Craibstone ...	1·26	55
,,	Skegness, Marine Gdns.	1·80	118	,,	New Deer School House	1·78	84
Notts.	Mansfield, Carr Bank...	1·52	79	*Moray*	Gordon Castle	1·80	94
Derby	Buxton, Terrace Slopes	2·19	58	*Nairn*	Nairn, Achareidh ...	1·42	88
Ches.	Bidston Observatory ...	0·98	58	*Inverness*	Loch Ness, Garthbeg ...	2·99	87
,,	Manchester, Ringway...	1·17	62	,,	Glenquoich	10·80	104
Lancs.	Stonyhurst College ...	1·80	54	,,	Fort William, Teviot ...	7·85	105
,,	Squires Gate	0·78	37	,,	Skye, Broadford ...	6·30	98
Yorks.	Wakefield, Clarence Pk.	1·53	90	,,	Skye, Duntulm ...	4·15	90
,,	Hull, Pearson Park ...	1·95	117	*R. & C.*	Tain, Mayfield... ...	1·89	83
,,	Felixkirk, Mt. St. John...	1·65	98	,,	Inverbroom, Glackour...	4·52	89
,,	York Museum	1·65	109	,,	Achnashellach	7·68	112
,,	Scarborough	1·82	108	*Suth.*	Lochinver, Bank Ho. ...	3·81	95
,,	Middlesbrough... ...	1·71	132	*Caith.*	Wick Airfield	1·56	69
,,	Baldersdale, Hury Res.	1·49	51	*Shetland*	Lerwick Observatory ...	4·04	128
Norl'd.	Newcastle, Leazes Pk....	1·73	113	*Ferm.*	Crom Castle	1·04	35
,,	Bellingham, High Green	2·05	81	*Armagh*	Armagh Observatory ...	1·43	64
,,	Lilburn Tower Gdns. ...	1·69	85	*Down*	Seaforde	1·04	34
Cumb.	Geltsdale	1·06	41	*Antrim*	Aldergrove Airfield ...	1·00	41
,,	Keswick, High Hill ...	1·96	40	,,	Ballymena, Harryville...	1·65	51
,,	Ravenglass, The Grove	1·49	49	*L'derry*	Garvagh, Moneydig ...	1·63	52
Mon.	Abergavenny, Larchfield	1·64	51	,,	Londonderry, Creggan	1·53	48
Glam.	Ystalyfera, Wern House	4·85	94	*Tyrone*	Omagh, Edenfel ...	1·59	53

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

Wt-33. K16.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 971, MAY 1953

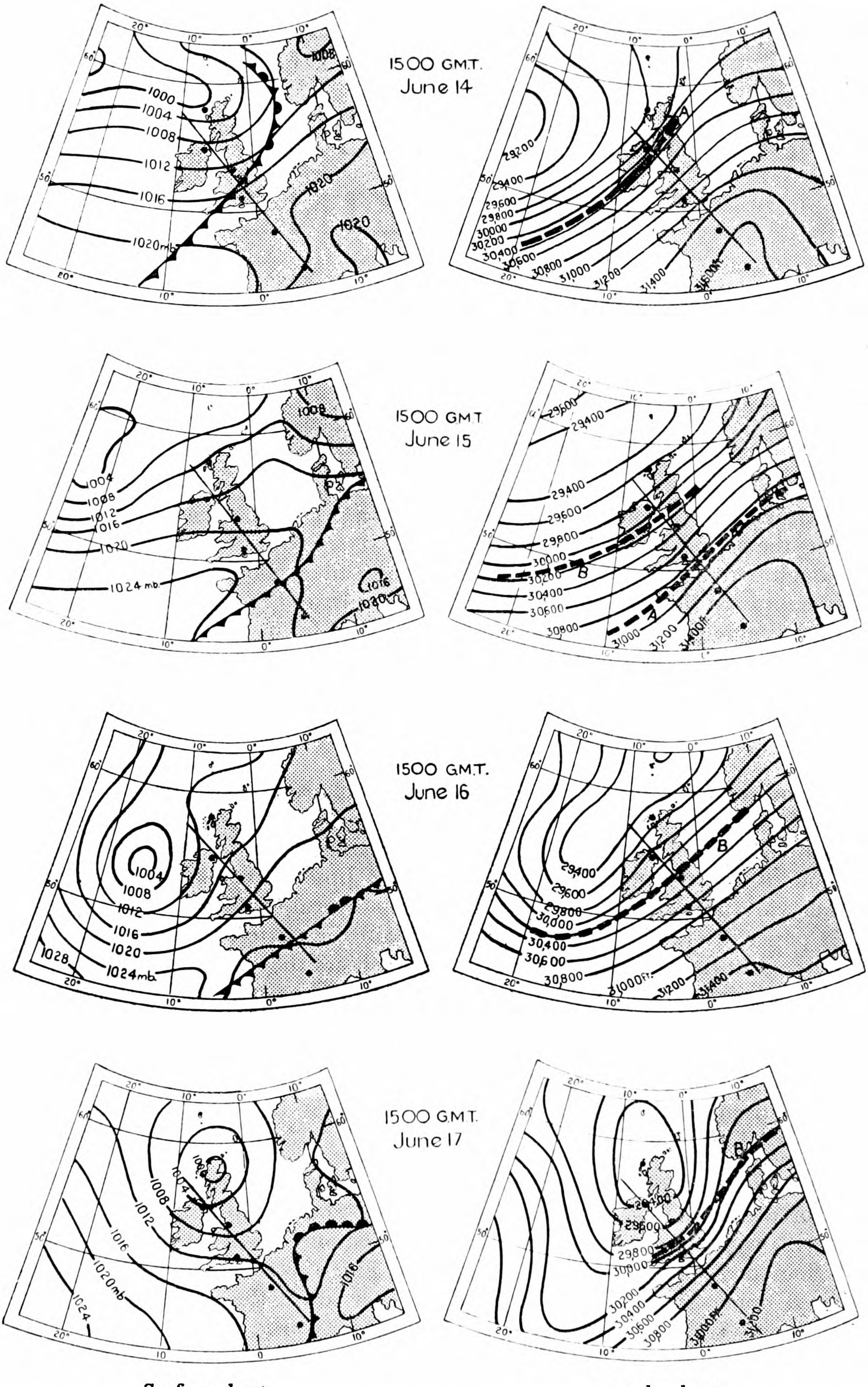
JET STREAMS OVER THE BRITISH ISLES DURING JUNE 14–18, 1951

By R. MURRAY, M.A.

Summary.—It is shown that the strong upper flow over the British Isles during the period June 14–18, 1951, was associated with two distinct jet streams, although both existed together for only a short time. Both jet streams occurred on the forward side of a major long-wave trough, and apparently in association with the same generalized frontal zone of a cold front. The lateral movement of the jet streams is shown to have been roughly related to the geostrophic advection at the surface perpendicular to the jet-stream axis. The nature of the tropopause and variations in the height and intensity of the jet-stream axes are discussed.

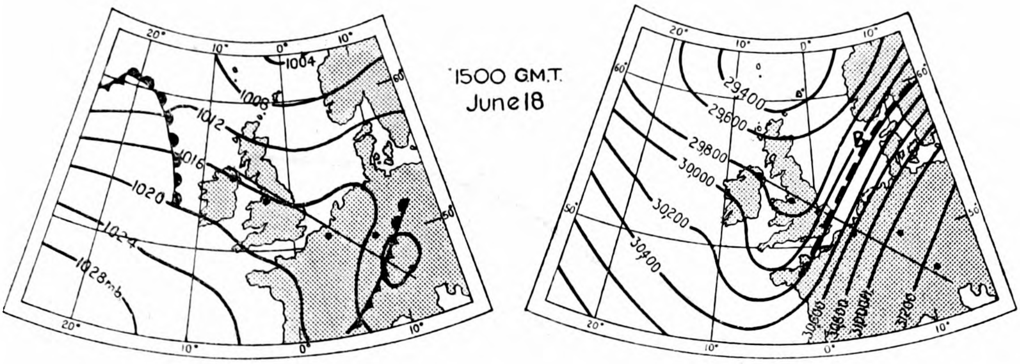
Introduction.—Inspection of the upper air charts for the period June 14–18, 1951, when a strong SW. air flow existed in the upper troposphere over the British Isles, showed that a single wind maximum occurred on June 14, 16, 17 and 18, but the position was uncertain on June 15 owing to the apparently erratic variations in wind speed reported by several of the aerological stations. This paper attempts to describe and explain the pattern of behaviour of the wind field during this five-day period, and shows that two distinct jet streams actually co-existed for a time on June 15, 1951. The period analysed afforded a good opportunity for the examination of certain questions connected with jet streams. One is concerned with the lateral movement of a jet stream; another is the nature of the tropopause near and especially on the low-pressure side of a jet stream; yet another is the variation of the height of a jet-stream axis along its length.

The wind and temperature fields were investigated with the help of cross-sections drawn at six-hourly intervals from 0900 G.M.T., June 14 to 1500 G.M.T., June 18, 1951. For most of the period the section shown on the charts of the first four days of the period illustrated in Fig. 1 was employed; this section utilized upper air observations from some or all of the stations, Stornoway, Aldergrove, Liverpool, Larkhill, Trappes and Lyons. The main flow backed somewhat during June 18 so that a rather differently orientated section was used at 0900 and 1500 G.M.T. on that day (see Fig. 1). The sectional analysis ceased with the movement of the jet stream away from England over the Continent later on June 18.



Surface charts   300-mb. charts

FIG. 1—SURFACE AND 300-MB. SYNOPTIC CHARTS, JUNE 14–18, 1951



Surface chart 300-mb. chart

FIG. 1—*continued*

Synoptic situation.—The general synoptic developments may be followed by means of Fig. 1 which shows the surface and 300-mb. maps daily at 1500 G.M.T. A depression moved north-east some 200 miles off north-west Scotland on June 14. Its cold front crossed England as a weak katafront[1] and reached northern France about midnight on June 14; for the next four days the surface front over France and Germany was often ill defined, but broadly associated with a belt of shallow lows and some thundery outbreaks rather typical of summer weather over the Continent. A minor trough swept east across Scotland some 200–300 miles behind the primary front, but without having any obvious effect on either the pressure or the weather of England. Meanwhile, during June 14, cyclogenesis occurred some 200 miles south of Iceland in the elongated trough extension from the depression off north-west Scotland. This new centre, after about 24 hours of consolidation *in situ*, moved 300 miles southwards, then turned east and was near north-west Ireland at midnight on June 16; thereafter it travelled steadily north-east across north Scotland. A cyclonic vortex also formed at 300 mb. on June 14 and subsequently followed much the same track. The cold trough to the south of the upper low moved east at the average rate of five degrees longitude per day, reaching the British Isles on June 18 in a form sharper than existed previously; this cold trough was essentially a long-wave feature in the westerlies.

Movement and behaviour of the jet streams.—The jet-stream picture can be seen from sections shown in Figs. 2–6. A single wind maximum, A, just under the tropopause is shown in Fig. 2 (1500 G.M.T., June 14); it moved south and is shown just north of Larkhill in Fig. 3 (0900 G.M.T., June 15). However, a second wind maximum, B, appeared for the first time north of Aldergrove; this new wind maximum is not shown by direct wind observations, but is based on geostrophic wind computations made with a scale similar to that described by Matthewman[2]. Fig. 4 (1500 G.M.T., June 15) shows wind maximum B, as a major feature, well substantiated by wind reports in addition to geostrophic computations, while wind maximum A is shown as a weakening system south of Larkhill. At 2100 G.M.T., June 15, wind maximum B was situated south of Aldergrove and wind maximum A over France and Germany (a section from Jever to Munich located wind maximum A south of Jever with indications of another wind maximum to the north of Jever). By 0300 G.M.T. on June 16 wind maximum B was just north of Liverpool, with A only a weak residual centre south of Trappes. Henceforth only wind maximum B existed; Fig. 5 (1500 G.M.T., June 16) and Fig. 6 (1500 G.M.T., June 18) are typical sections.

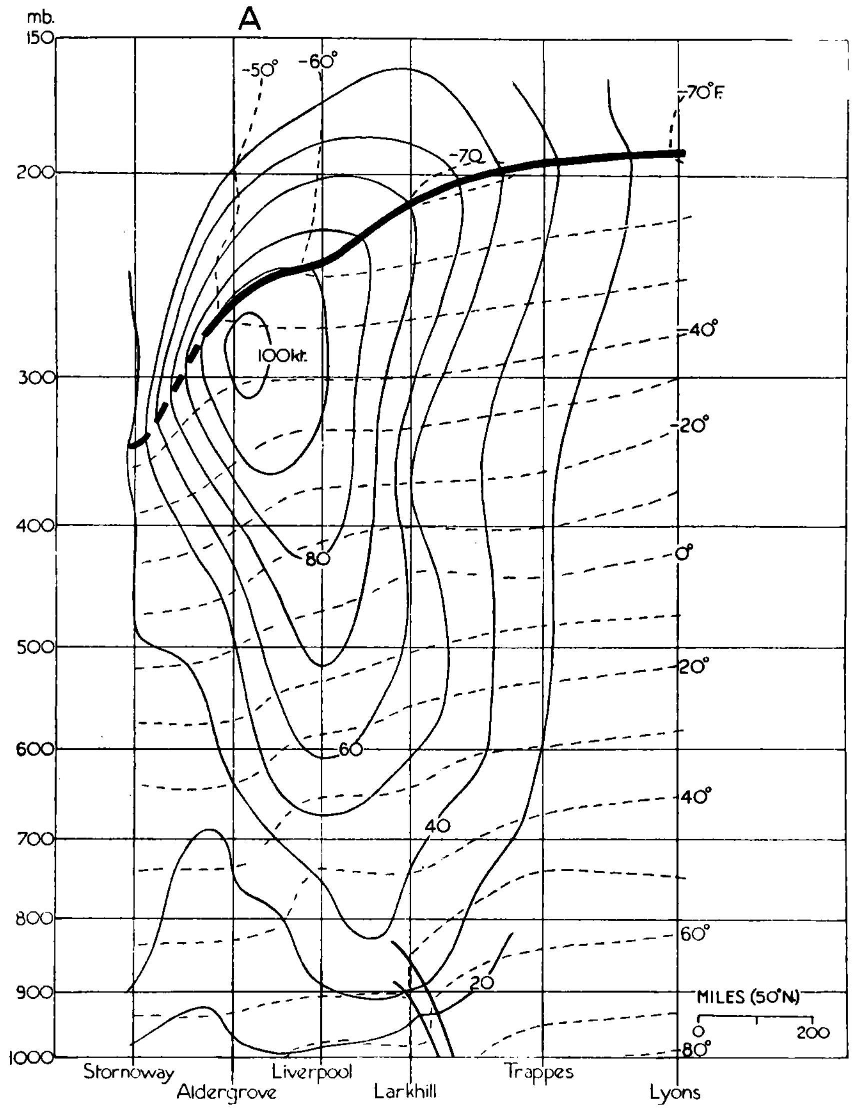


FIG. 2—CROSS-SECTION, STORNOWAY–LYONS, 1500 G.M.T., JUNE 14, 1951
Isotherms are drawn as thin broken lines; isokinetics as thin continuous lines

Additional evidence for the existence and behaviour of the two jet streams is contained in Fig. 7 which shows the time variation of the maximum wind speed on the section Aldergrove–Liverpool–Larkhill, based on reported winds at six-hourly intervals. The movement and change in intensity of wind maxima A and B are obvious on this diagram.

Thus the sequence of events appears to have been as follows. Jet stream A moved south-east into Europe, weakening rapidly during June 15 and disappearing completely early on June 16. Meanwhile jet stream B extended across the British Isles and moved slowly south-east, rapidly becoming the dominant system on June 15. The sequence is shown in Fig. 1 where the broad broken lines give the estimated positions of the jet-stream axes.

Tropospheric thermal field.—The thermal field during the entire period was typical of that associated with jet streams—the main feature being the broad baroclinic zone. Although the latter was a persistent feature, a great

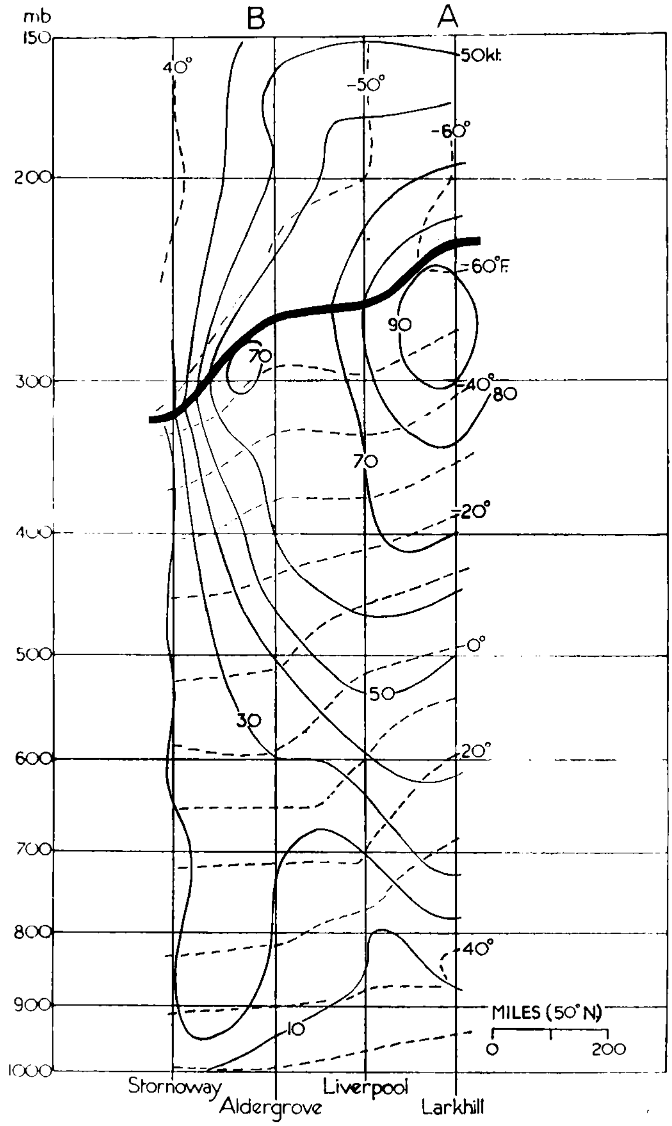


FIG. 3—CROSS-SECTION, STORNOWAY–LARKHILL, 0900 G.M.T., JUNE 15, 1951
Isotherms are drawn as thin broken lines; isokinetics as thin continuous lines

deal of complexity occurred within the zone itself. Sometimes, as in Fig. 4, several subsidiary zones could be drawn within the main baroclinic zone, although it was rarely possible to maintain the continuity of these subsidiary zones for long. Even at the same time neighbouring soundings through the broad baroclinic zone occasionally showed markedly different detailed structure; for instance, compare the soundings over Larkhill and Trappes at 1500 G.M.T., June 16 (Fig. 5). On the other hand, a narrow sloping zone is shown at 1500 G.M.T., June 18 (Fig. 6), supported also by the observations six hours earlier; however it is noteworthy that the "front" as drawn accounts for only a rather small fraction of the baroclinity that existed with the broad baroclinic zone. The transient nature of the temperature lapse-rate discontinuities within the broad baroclinic zone suggests that the analysis of the fine details (as has been done mainly for illustrative purposes in Fig. 4 for example) is of dubious value; the significant reality on the synoptic scale appears to be the broad baroclinic zone itself.

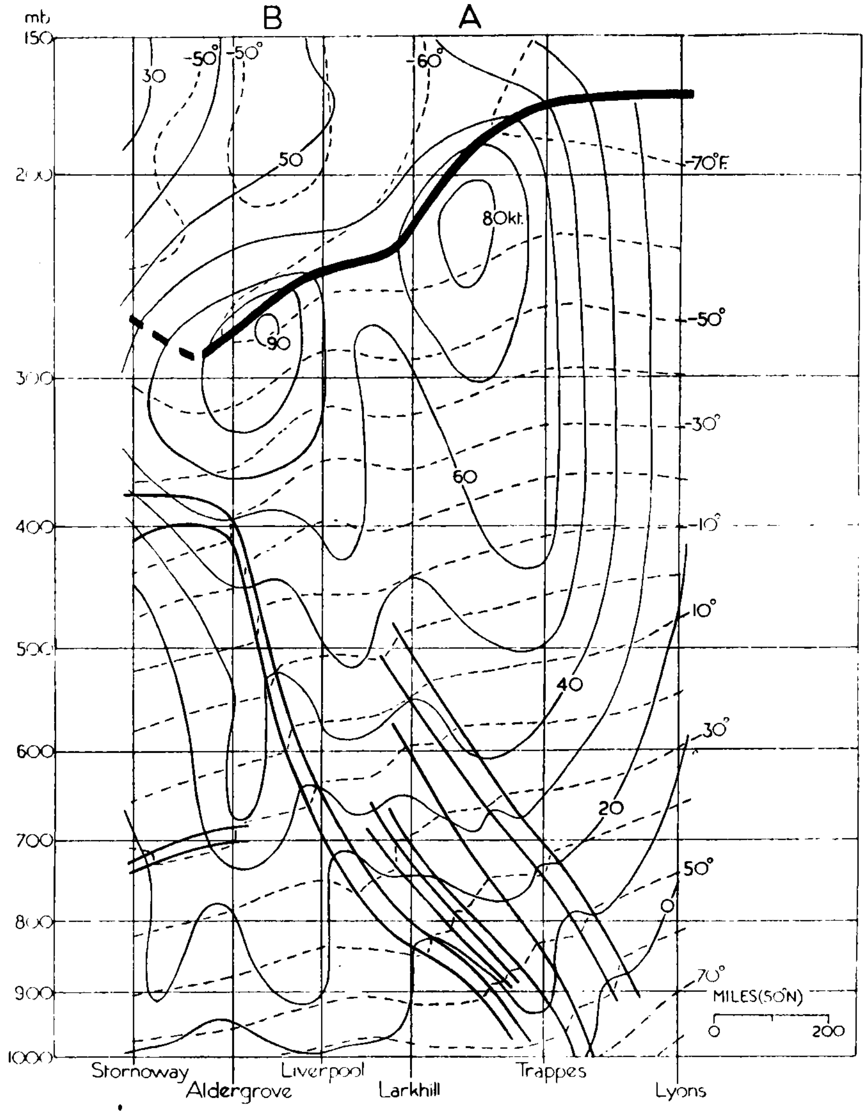


FIG. 4—CROSS-SECTION, STORNOWAY–LYONS, 1500 G.M.T., JUNE 15, 1951
Isotherms are drawn as thin broken lines; isokinetics as thin continuous lines

The behaviour of the generalized frontal zone (i.e. broad baroclinic zone) is interesting and suggestive. On June 14 it was associated both with the surface front which moved into France and with jet stream A over the British Isles. On June 15 the part of the generalized frontal zone in the lower troposphere remained closely associated with the surface front over France, but the upper tropospheric part acquired a double structure with the encroachment of jet stream B (the wavy character of the isotherms in the upper troposphere in Fig. 4 shows this feature). The rapidly weakening jet stream A and its associated baroclinic zone in the upper troposphere moved south and appeared to become detached from the almost stationary part of the baroclinic zone in the lower troposphere over France. Meanwhile as jet stream B developed and moved south its associated baroclinic zone in the upper half of the troposphere also intensified and moved south, so that soon there was re-established a broad, sloping, baroclinic zone throughout the entire troposphere. At this stage the broad baroclinic zone assumed much the same position and general shape

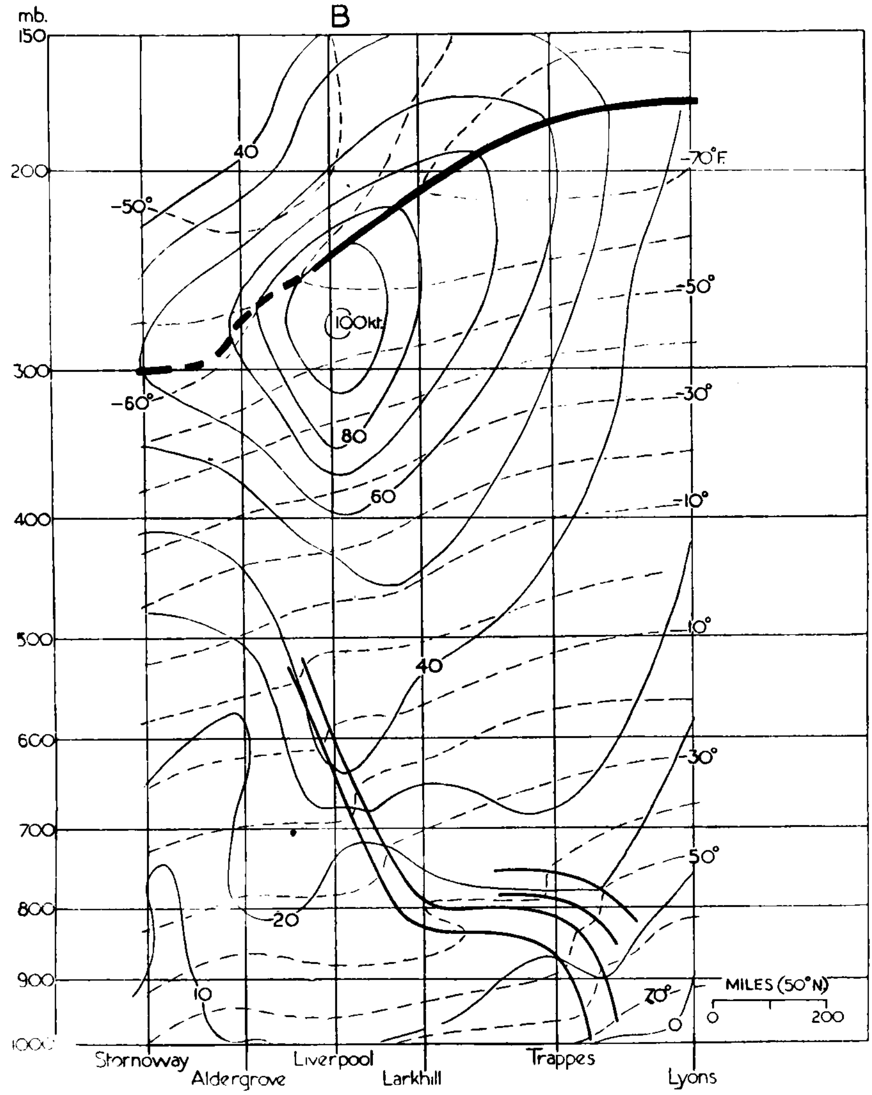


FIG. 5—CROSS-SECTION, STORNOWAY–LYONS, 1500 G.M.T., JUNE 16, 1951
Isotherms are drawn as thin broken lines; isokinetics as thin continuous lines

relative to the surface front over France as the original baroclinic zone had done. Thereafter only the single baroclinic zone and jet stream B existed. It seems as if the stable and necessary features of the forward side of the upper trough in the long-wave pattern during the period were a generalized frontal zone and associated jet stream; the complexity that occurred on June 15 quickly became damped out by these over-riding long-wave requirements.

Lateral movement of the jet streams.—The rate of lateral movement of the jet streams was estimated from the movement of the wind maxima along the Stornoway to Lyons section; for this purpose mean speeds were computed over 12-hour intervals overlapping by six hours.

The surface-pressure difference between points 200 miles on either side of the line of the section Stornoway to Lyons along the jet axes was also measured when the wind maxima A and B could be determined on the sections, and mean pressure differences over 12-hour intervals overlapping by six hours were

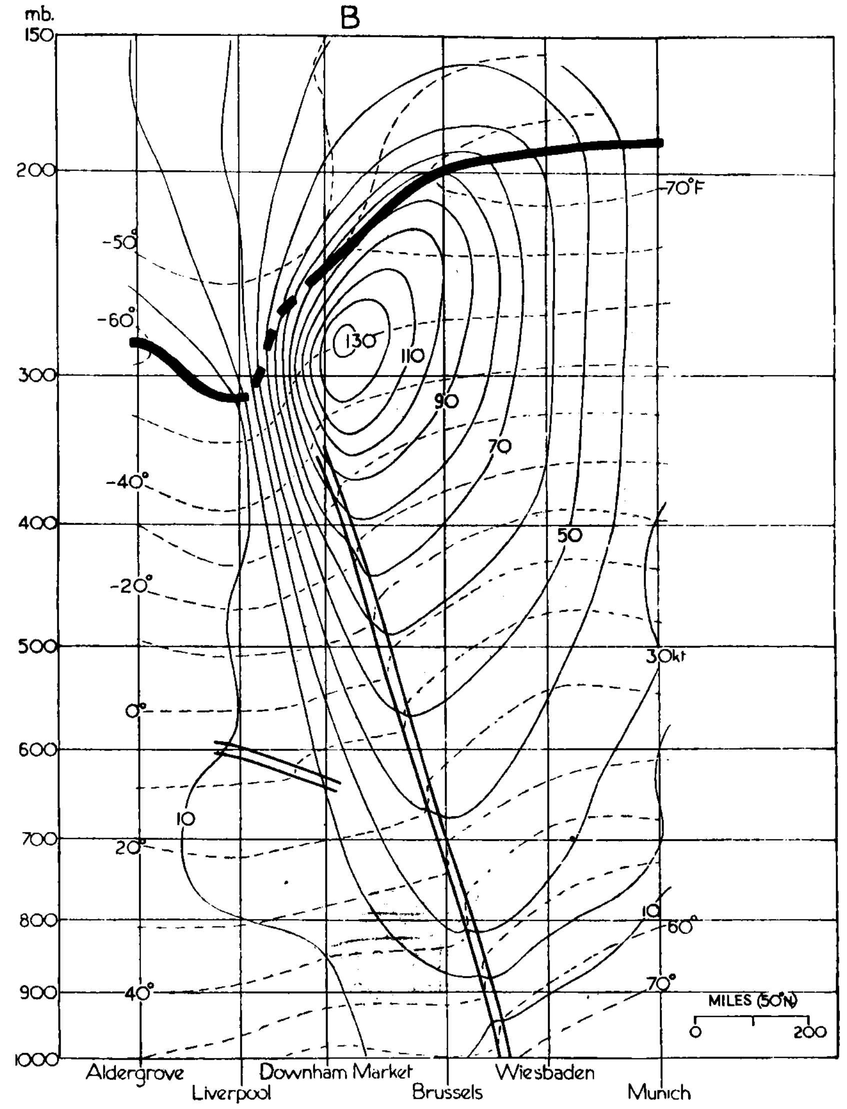


FIG. 6—CROSS-SECTION, ALDERGROVE–MUNICH, 1500 G.M.T., JUNE 18, 1951
Isotherms are drawn as thin broken lines; isokinetics as thin continuous lines

computed as a rough measure of the surface geostrophic advective component operating in a direction normal to the jet-stream axis, that is along the direction Stornoway to Lyons.

On the average the speed of lateral movement of the jet streams (A and B together) was 7·9 kt., compared with 6·5 kt. for the surface geostrophic component. The two quantities were generally in the same sense and never differed by more than 15 kt. at any time, but there was little correlation between their day-to-day variations.

There are at least two points of interest. Early on June 15 jet stream A accelerated and subsequently moved at a greater speed than indicated by geostrophic advection during the phase of rapid decay of the system. A qualitative explanation for this behaviour is that subsidence occurred to the south of the new and dominant jet stream B, thereby decreasing the baroclinity and hence the intensity of the first jet stream farther south. The movement of the weakening jet stream A at a speed greater than suggested by geostrophic advection could then have occurred, because of an ageostrophic component from the cold to the warm air produced by descending motion in the region of vertical wind shear, as suggested by Sutcliffe[3].

The second point to note is that jet stream B moved slowly south-east at about the same speed as the geostrophic advective component and with little change of intensity for nearly two days up to the morning of June 17; thereafter it became quasi-stationary and intensified at about the same time as the geostrophic advective component increased. An ageostrophic component directed north-west against the strengthening surface geostrophic advection would be consistent both with the slowing down and the intensification of the jet stream; such an ageostrophic component might indeed be expected in the present case with the approach of the confluent jet-stream entrance.

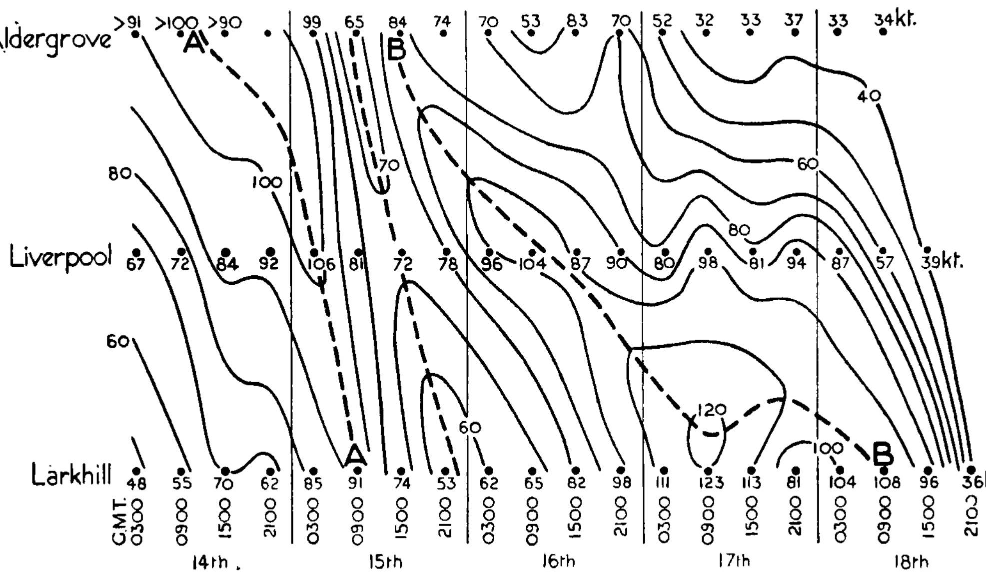


FIG. 7—VARIATION OF MAXIMUM WIND SPEED IN SECTION ALDERGROVE–LIVERPOOL–LARKHILL, JUNE 14–18, 1951

Variations in intensity of the wind maxima.—The variations in intensity of the jet streams A and B are shown in Fig. 8 (constructed from the series of cross-sections).

General subsidence to the south of jet stream B as it extended across the British Isles can be invoked to account for the weakening of jet stream A, as has been suggested in the preceding section.

The first significant intensification of jet stream B on June 17 occurred in a limited region at the base of an upper trough as it travelled north-east across England, as a non-developing wave-like perturbation on the basic jet-stream current. The trough flattened out and lost its individuality to the east of the British Isles later, although it appeared to be partly instrumental in extending the jet stream farther eastwards.

After the passage of the perturbation, the jet stream intensity in the cross-section region weakened temporarily, then increased again with the approach of the markedly confluent jet-stream entrance.

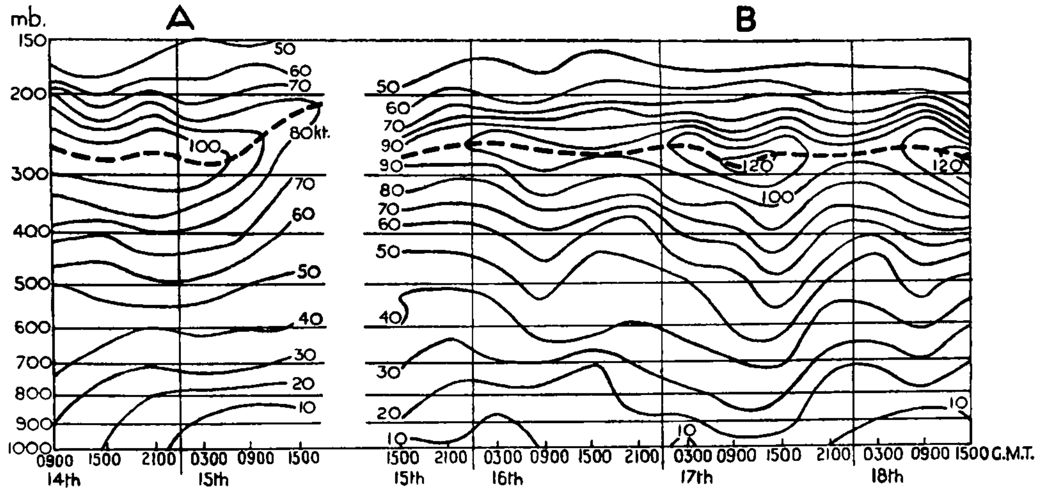


FIG. 8—VARIATION OF VERTICAL DISTRIBUTION OF WIND COMPONENTS PERPENDICULAR TO THE CROSS-SECTIONS AT THE AXES OF THE JET STREAMS A AND B

Variations in height of the wind maxima.—The variations with time of the heights of the axes of the jet streams are also shown in Fig. 8. The time scale of Fig. 8 may be regarded as a distance scale along the axes of the jet streams; the right and left of the time scale refer respectively to the entrance and exit regions of the jet streams.

First, it will be noted that the height of the axis of jet stream A changed but little until the period of decay on June 15 during which it increased rapidly. However, a section from Jever to Munich at 2100 G.M.T. on June 15 showed that the jet axis was just below 200 mb. or at about the same level as at 1500 G.M.T. on the same day over France. There is thus no definite evidence of any variation of the level of jet stream A along its length at any particular time; the higher level reported later on June 15 appears to indicate that the whole of the decadent jet stream was lifted.

Secondly, as regards jet stream B, the height remained fairly constant, the mean pressure at the jet axis during the period being 272 mb. with standard deviation about 9 mb. The probable error in estimating pressure at the jet axis is at least 5 mb., so that the apparent variability of the level of jet stream B may be unreal. Thus in this case too there is no evidence of any material change in the level of the axis of the jet stream along its length.

Tropopause structure.—Several writers[4,5] imply that the high tropopause on the high-pressure side is not continuous with the low tropopause on the low-pressure side of the jet stream. Murray and Johnson[6] have suggested that the tropopause may be continuous or discontinuous, and that the nature of the tropopause may be dependent on the life history of the jet stream.

Most of the cross-sections were readily constructed with the tropopause continuous, using an abrupt change of temperature lapse rate as the criterion to fix the tropopause and not quasi-constancy of potential temperature. Thirty-six temperature soundings on the low-pressure side at distances between 10 and 345 miles from the positions of the jet-stream axes, given on the series of cross-sections, have been examined. Of these soundings 26 gave a definite type I tropopause with an abrupt change from lapse rate to inversion; five showed a little complexity, above the first abrupt lapse-rate change, of the type that could quite easily be explained by small-scale temperature fluctuations and instrumental errors, but no real difficulty arose in deciding the most probable position of the tropopause; the remaining five cases showed some complexity of the type that occurs with a folded tropopause[7]. One of these last five cases occurred at Aldergrove at 0900 G.M.T. on June 16 at 180 miles from the jet axis, but the complexity did not occur at Aldergrove on later ascents, nor down wind on any of the four soundings made at Leuchars on that day. The four other cases occurred at Liverpool between 0900 G.M.T., June 17 and 0300 G.M.T., June 18, at distances between 95 and 125 miles from the axis, at about the time that the jet stream had intensified to 120–130 kt. and was very slow-moving; moreover the Liverpool soundings were situated in that half of the jet stream nearer to the entrance. No soundings were available down wind at about the same distance from the jet axis. However, five soundings (Stornoway 0900 G.M.T., June 15, Aldergrove 2100 G.M.T., June 15 and 0300 G.M.T., June 16, Liverpool 2100 G.M.T., June 16 and 0300 G.M.T., June 17) were located along the line of section in the half sector near the jet-stream exit at distances varying from 70 to 120 miles; these five ascents showed simple type I tropopauses. There is thus evidence to suggest that the tropopause was continuous at one stage, at least in the exit half sector of jet stream B; but that at a later stage in the entrance half sector, when the jet stream was intensifying or had just intensified, it was folded or disrupted over a narrow zone at a distance of about 100 miles from the jet-stream axis.

A model for tropopause structure and behaviour, suggested by this case-history and other work in the literature, may be tentatively put forward. Early in the life history of the jet stream the tropopause is continuous and in some degree sloping. As the jet stream intensifies the slope of the tropopause increases, until the stage may be reached when the tropopause actually folds. The seat of the folding process is near the entrance region, as Sawyer[7] has pointed out, but the folded part of the tropopause will be advected down stream, where it will eventually be disrupted, presumably mainly by turbulence. Later, when the mechanism which produces or maintains the jet stream ceases to operate, the tropopause must become continuous again; this may come about by advection of the continuous tropopause in existence up wind or by some reformation process.

In passing, it may be of interest that the tropopause was on the average about 3,000 ft. above the jet-stream axis (the standard deviation about the mean, based on data from 14 sections, being roughly 1,000 ft.). Experience suggests that this figure is typical of jet streams of moderate intensity, say 90–130 kt.

Concluding remarks.—The most persistent feature of the five-day period appears to have been the slow-moving long-wave trough, dominating the entire troposphere, with a typical baroclinic zone on its forward side (the region analysed by the series of sections). The existence of a jet stream on the forward side of the large-scale trough is quite normal.

The distinctive feature of the period was the formation of two separate wind maxima in association with the broad generalized frontal zone. In this connexion it may be significant that the surface counterpart of the upper trough consisted for a time of a double-centred depression; the original surface low, of which the cold front and jet stream affected the British Isles on June 14, separated into two centres about midday of June 14—one centre moved slowly into the southern Norwegian Sea where it filled up later, while the other centre developed south of Iceland, then swung south and later east towards the British Isles. Apparently the second jet stream B came into existence as a distinct entity in sympathy with the plunging south of the Icelandic low which was clearly instrumental in concentrating the thermal gradient and thus intensifying the upper current in the region south and south-east of the surface low. Nevertheless it would also have seemed reasonable if one continuous jet stream had existed, with the wind maximum being transferred temporarily northwards again early on June 15 owing to the northward advection of the main thermal belt in a limited region to the east of the surface depression. However, accepting the existence of the second and dominant jet stream B, the subsequent motion and behaviour of the first one A appears to be reasonably explicable on dynamical grounds.

Twin wind maxima within a broad tropospheric current are probably more common than was first thought, although they may be somewhat ephemeral and consequently easily missed in a wide aerological network. Certainly, during the five-day period examined, the two jet streams co-existed for little more than 12 hours.

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DIURNAL VARIATION OF RELATIVE HUMIDITY ON SEA-BREEZE DAYS IN ATHENS

By LEON. N. CARAPIPERIS

Introduction.—For some coastal areas, especially in tropical and subtropical regions, the sea breeze has a considerable influence upon the climate. This wind has some of the characteristics of a cold front. When it sets in it affects the normal variation of air temperature and humidity and irregularities appear, the magnitude of which depend on different factors such as the temperature and humidity of the displaced air, the speed of the sea breeze, the height at which the sea breeze disappears, the distance from the sea, etc. The advent of the sea breeze is accompanied by a decrease in temperature and a sudden increase in relative humidity of the coastal places[1–6], while in the places which are at some distance from the sea-shore the influence of the sea breeze upon the temperature and humidity is different and mostly unknown, because only a few cases have hitherto been examined[7–16].

This study is concerned with the influence of the sea breeze on the relative humidity in Athens on days during which the sea breeze blows without interruption.

General characteristics of the sea breeze in Athens.—The sea breeze of the Athens plain blows from SW. or SSW. with great regularity[17]. It occurs on all fine days if the general pressure gradients are weak, and it is fully developed in the warm season when the etesian winds (very persistent NW.–NE. winds blowing over the eastern Mediterranean in summer) are either absent or blowing with little speed over the open sea. Its frequency is greatest from April to October inclusive, and especially great in May, June and October [18,19]. From July to September it is often opposed by the stronger etesian winds.

The sea breeze begins at Athens 3 or 4 hr. after sunrise or earlier, reaches its greatest speed between 3 and 4 p.m., and ceases at sunset or 1–2 hr. later. The strength it attains varies according to the season. During the winter its maximum speed is about 5 m./sec. (at 2 p.m.), in spring and autumn 8 m./sec. (at 3 p.m.) and in summer 12 m./sec. (at 4 p.m.).

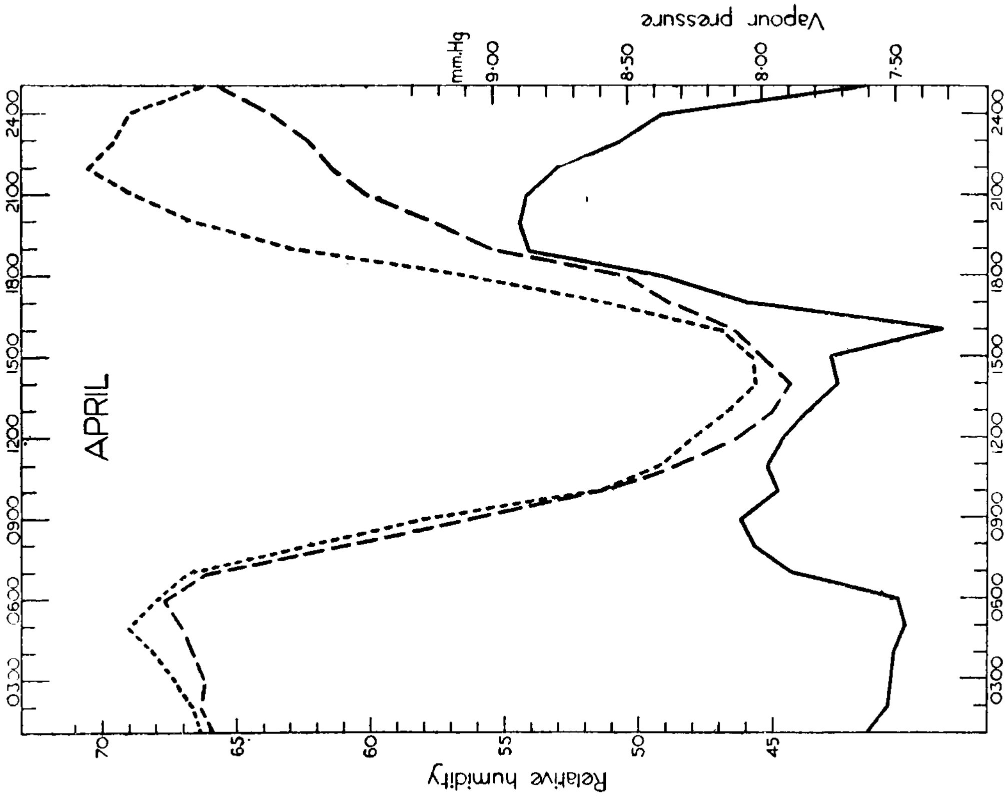
The height to which the sea breeze extends over Athens is not known exactly, but from the upper air data of the radio-sonde station at Ellinikon aerodrome it is concluded that it reaches approximately 500 m. When the etesian winds are absent and the sea breeze is strong, it is felt up to 30 Km. from the coast of Saronikos[17].

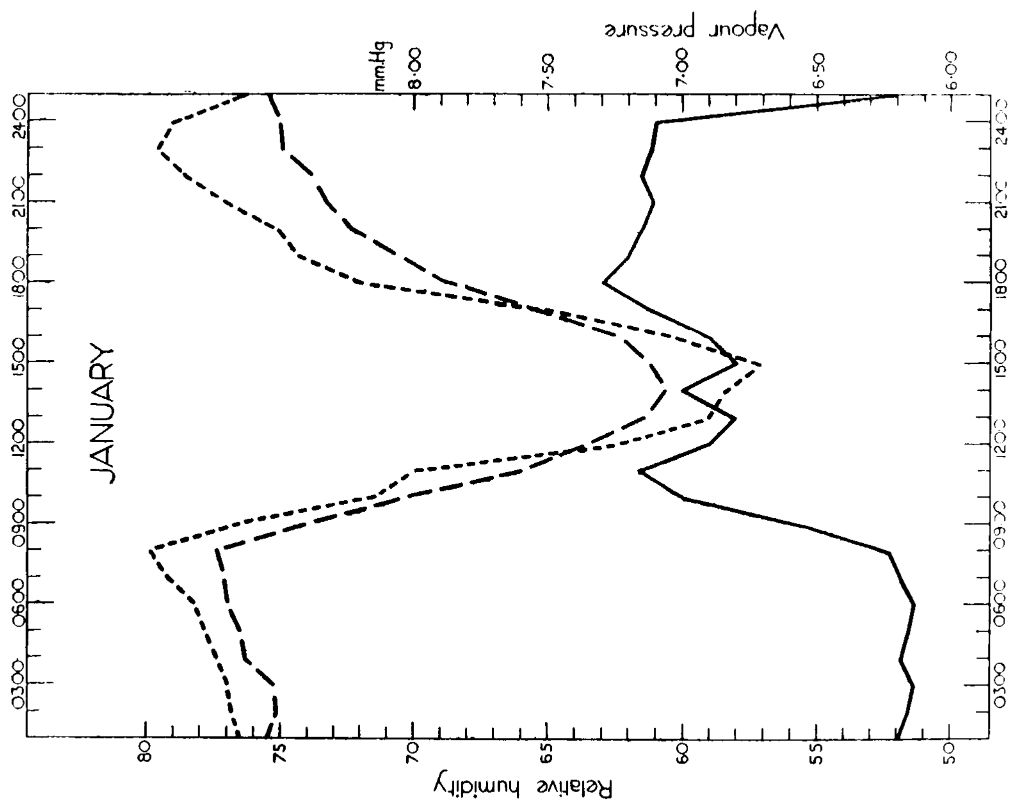
Diurnal variation of relative humidity on sea-breeze days in Athens.—In order to select days during which the sea breeze prevails in Athens without interruption, an examination was made of the records of a Dines's and a Richards's anemographs at the National Observatory, which is about 5 Km. from the sea. The total number of days having an uninterrupted sea breeze during the period 1921–30 was 550, and for these days the hourly values of the relative humidity were calculated from the records of a hair hygrograph.

Fig. 1 gives, for the months January, April, July and October, the diurnal variation of relative humidity on sea-breeze days, of relative humidity on all days (including sea-breeze days), and of vapour pressure on sea-breeze days, computed from observations made during the period 1921–30[20].

The diurnal variation of relative humidity in Athens on all days shows a maximum which occurs at 8 a.m. in January, at 6 a.m. in April and at 4 a.m. in July and October, i.e. the relative humidity shows, in Athens as in most places, a simple diurnal variation in the opposite sense to temperature. On sea-breeze days the diurnal variation of relative humidity in Athens shows mostly a double wave. If the diurnal variation of relative humidity is examined on sea-breeze days in the different months the following results are found:—

Except in the months of June, July and August, the sea breeze converts the simple fluctuation of the relative humidity into a double one. The principal minimum in the months with double fluctuation, occurs 2 or 3 hr. after noon and the principal maximum, except in December, January and February, between 10 p.m. and midnight. The secondary minimum occurs at 1 a.m. and the secondary maximum at 11 p.m. in January, at 5 a.m. in April and at 6 a.m. in October.


APRIL
Relative humidity
70
65
60
55
50
45
Vapour pressure
mm.Hg
9·00
8·50
8·00
7·50
0300
0600
0900
1200
1500
1800
2100
2400


JANUARY
Relative humidity
80
75
70
65
60
55
50
Vapour pressure
mm.Hg
8·00
7·50
7·00
6·50
6·00
0300
0600
0900
1200
1500
1800
2100
2400

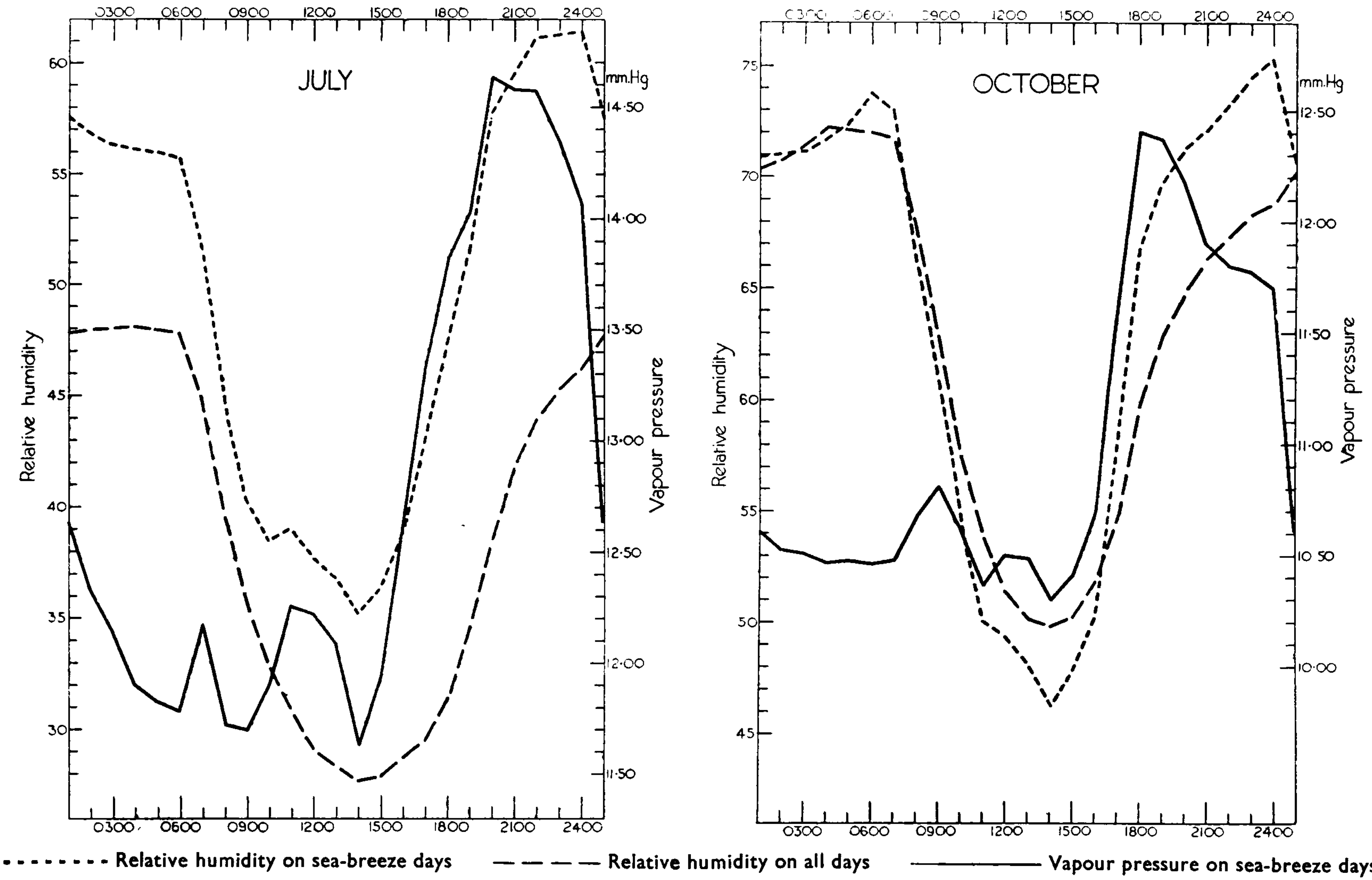


FIG. 1—DIURNAL VARIATION OF RELATIVE HUMIDITY AND VAPOUR PRESSURE ASSOCIATED WITH SEA BREEZE

In all seasons and especially in summer the sea breeze considerably increases the relative humidity in the afternoon and in the late evening.

Except during the winter the principal maximum in the diurnal variation of relative humidity occurs in the evening and not at the time of minimum temperature.

The diurnal amplitude of the relative humidity on sea-breeze days is greater than it is for all days.

The arrival of the sea breeze at Athens is not accompanied by a sudden increase in relative humidity. During the months of July and August, in which the sea breeze has its greatest strength, a small increase of the relative humidity between 10 and 11 a.m. is however observed. In the other months of the warm season the sea breeze only slightly decreases the fall of relative humidity around noon.

From March to September the relative humidity throughout the sea-breeze days is greater than in the case of all days.

Explanation of irregularities and double wave.—After sunrise the air temperature increases, and though the absolute humidity is thereby increased, yet the saturation vapour pressure increases much more rapidly, so that the relative humidity decreases. The advent of the sea breeze does not stop the fall of relative humidity because of the small increase of the vapour pressure in this part of the day. During the months of July and August, when the sea breeze has the greatest strength, the increase of vapour pressure is more considerable and a small increase in relative humidity occurs at the time of the arrival of the sea breeze. Thus the relative humidity from the maximum of the early morning decreases steadily until between 2 p.m. and 4 p.m., when the minimum of vapour pressure and the maximum of air temperature occur. Afterwards the relative humidity begins to increase rapidly at a much greater rate than in the days without sea breeze, because of the fall of temperature and especially because of the great increase of vapour pressure. This increase, which appears in the afternoon of sea-breeze days, is due on the one hand to the decrease of vertical convection currents and on the other hand to the fact that the sea breeze continues to carry over the Athens area large quantities of moisture until sunset and even a little later. The increase of the relative humidity continues until the late evening and the principal maximum in its diurnal variation appears between 11 p.m. and midnight. After that time because the vapour pressure falls much more rapidly than the saturation vapour pressure, the relative humidity decreases. About one hour later, because the temperature decreases steadily and the vapour pressure ceases to fall, the relative humidity increases. Thus the second minimum of relative humidity appears, after which it begins to increase until about the time of the minimum of temperature.

In summer, and especially in July and August, the second maximum and minimum of the diurnal variation of relative humidity disappear, because the vapour pressure from the principal maximum of the late evening falls steadily during the night until the minimum of the morning, and the temperature on summer nights falls little. In addition, this continuous fall of relative and absolute humidity is due to the fact that in summer after the sea breeze either the etesian wind or the land breeze blows[18], and these winds carry drier air masses over the Athens area than the sea breeze.

By courtesy of the Daily Mail

MOCK SUN, PETT'S WOOD, KENT, 1500 G.M.T. FEBRUARY 25, 1953

By courtesy of K. E. Woodley

RIME ON *Distylium Racemosum*, KEW, 1330 G.M.T., DECEMBER 7, 1952
(see p. 158)

By courtesy of K. E. Woodley

RIME ON *Pinus Wallichiana*, KEW, 1350 G.M.T., DECEMBER 7, 1952
(see p. 158)

By courtesy of R. K. Pilsbury

THICK FOG, NORTH HARROW, 1800 G.M.T. DECEMBER 7, 1952
(see p. 158)

The great increase of relative humidity in the afternoon on sea-breeze days is also demonstrated from the upper air data of the radio-sonde station at Ellinikon. Fig. 2 shows the variation with height of the relative humidity computed from observations made at 5 p.m. in July and August of the years 1947, 1948 and 1950. From this diagram it is clearly concluded that the relative humidity on sea-breeze days is much greater, especially in the lower layers of the atmosphere, than on etesian days up to a height of about 600 m.

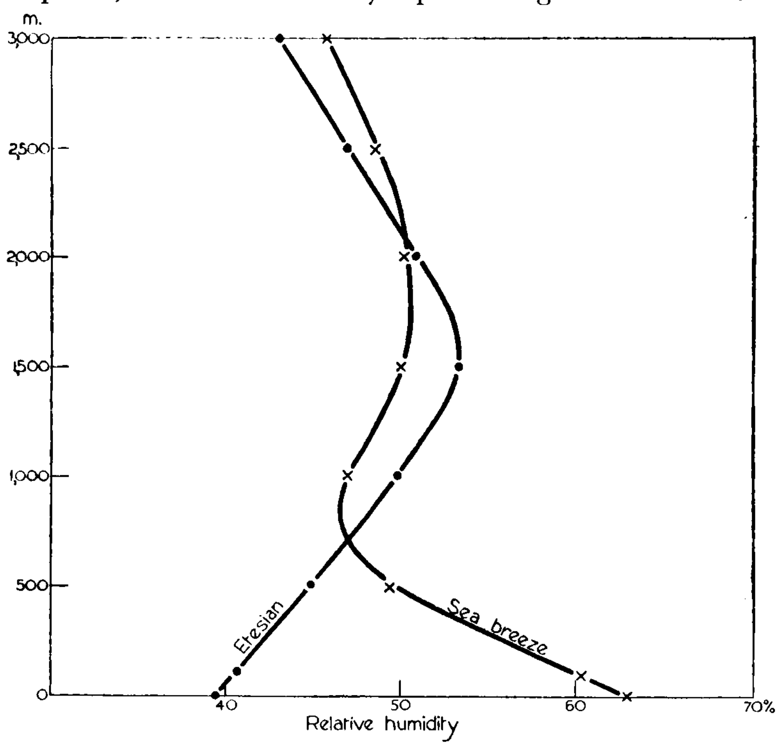


FIG. 2—VARIATION OF RELATIVE HUMIDITY WITH HEIGHT
Time of observation: 1700 Period: July, August, 1947–48, 1950

Eginitis[21] mentioned that in the diurnal variation of relative humidity in Athens there sometimes appears a double wave which was not however attributed to the sea breeze by the author. Also the explanation which was given by Angot[22] is not complete.

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"SELECTED" SHIPS

By Cmdr C. E. N. FRANKCOM, R.N.R. (Retd)

It is common knowledge that in order to obtain adequate meteorological information from the oceans the assistance of voluntary observers aboard merchant ships has to be obtained. It is true to say that practically all the meteorological information that has been obtained from the oceans during the last 100 years has been thus provided by these seagoing amateur meteorologists. This information has been supplemented by that provided by Naval vessels, from the occasional voyages by special research ships, and, of recent years, by the ocean weather stations which have been established in the Atlantic and Pacific.

The arrangements for obtaining observations over the oceans under the "selected" ship scheme are co-ordinated by the Maritime Commission of the World Meteorological Organization. There are at present some 2,300 "selected" ships in the world, of which 500 are British. All these ships make observations, as far as the exigencies of the officers' duties permit, at the main synoptic hours (0000, 0600, 1200 and 1800) and they are, in principle, supplied with tested instruments. Every effort is made by the Marine Branch of the Meteorological Office constantly to improve, as far as possible, the network of observations over the oceans. That these efforts are successful can be shown from some figures concerning the network in the eastern part of the North Atlantic. In 1939 there was a total of 360 British "selected" ships, and in the eastern Atlantic (north of 35°N. and east of 40°W.) a total average of 52 reports a day was received at Dunstable from British and foreign "selected" ships. A map showing the distribution of "selected" ships on March 4, 1953, is given as Fig. 1. During the war it was impracticable, for military reasons, for merchant ships to keep meteorological log-books or to transmit radio weather messages. British "selected" ships resumed making their observations on November 1, 1945, and by the end of that year the average number of reports received in the eastern North Atlantic was 20.

Figures for the years 1946 to 1952 are as follows:—

1946 ...	54	1950 ...	90
1947 ...	80	1951 ...	105
1948 ...	81	1952 ...	118
1949 ...	82		

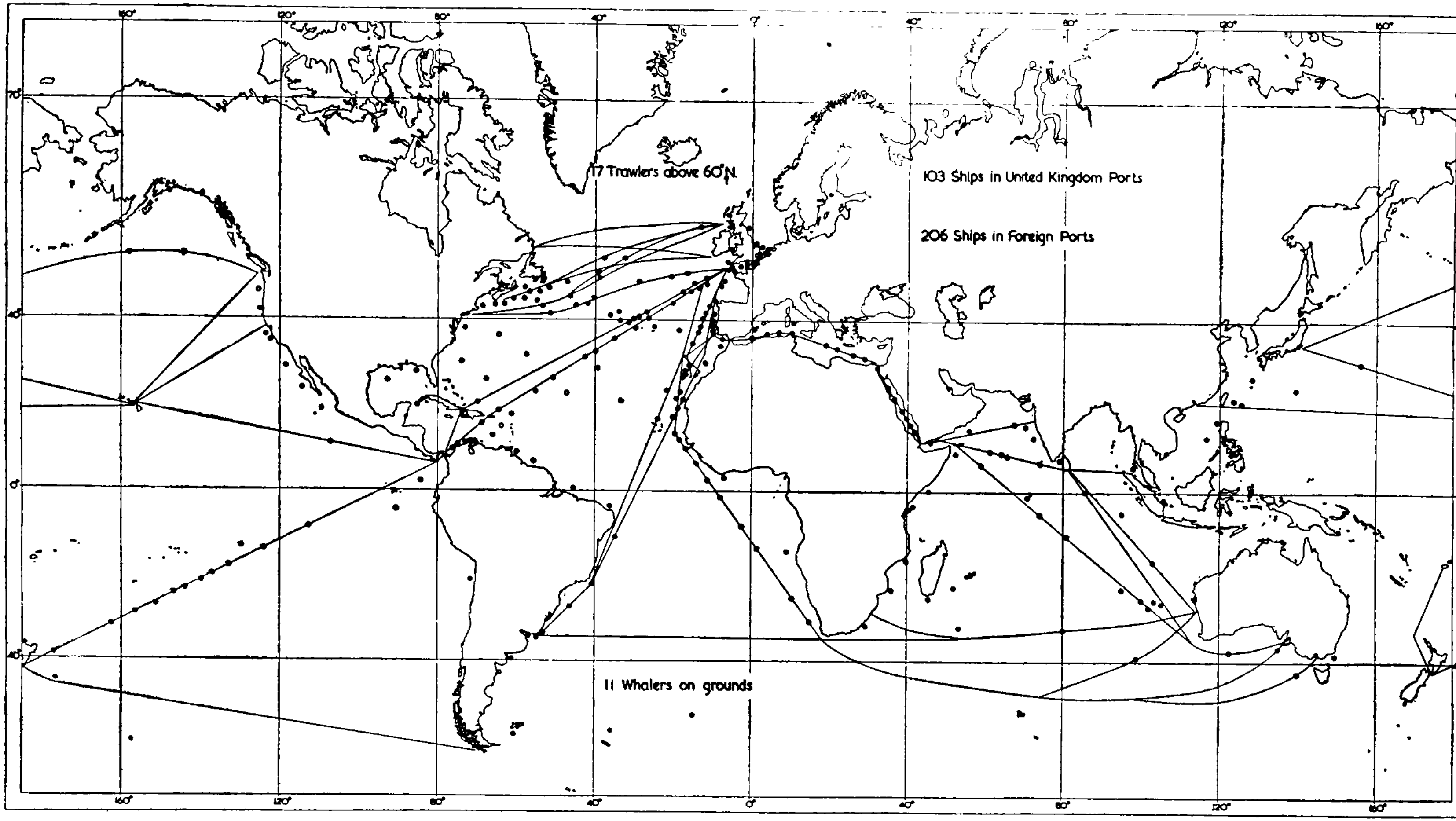

FIG. 1—THE POSITIONS OF BRITISH SHIPS WHICH MADE METEOROLOGICAL OBSERVATIONS ON MARCH 4, 1953
A day picked at random

Thus there has been a gradual increase in the number of reports received throughout the years. It seems from these figures that the meteorological network at sea in the eastern Atlantic is relatively good, but one has to remember that these total reports on a given day represent approximately only a quarter of the number of ships, and all those ships are moving, and the ships themselves tend to be concentrated on the main shipping tracks. There are therefore, inevitably, considerable gaps in the network, but in the eastern North Atlantic it is fortunate that these gaps are, to some extent, closed by the presence of the ocean weather ships.

A similar picture prevails in the western North Atlantic, where it seems that the network is at times, and in some parts, even denser than in the eastern portion of that ocean. Here again the gaps are, to some extent, filled by the presence of weather ships.

In the other oceans of the world the picture is by no means so good, but the World Meteorological Organization is doing its best to encourage those countries which operate "selected" ships to concentrate on recruiting for this work vessels which trade to the more unfrequented parts of the world. A particular example of this is in the Southern Ocean, where success has attended the recruiting of whaling ships, for which a special "position cypher" has been arranged so that they do not have to disclose their position to rival whaling ships when they send their weather messages by radio. This season 11 British whaling ships have been recruited.

From a study of the meteorological log-books sent in by British "selected" ships the quality of the observations is high. The observers in these ships are encouraged by every possible means to make their observations accurately, but there are, nevertheless, certain difficulties inherent in ships' observations which are, to some extent, unavoidable, so that inaccuracies are bound to occur from time to time. This particularly applies to air and sea temperature and humidity.

The radio officers of the ships play an important part in this work, but one difficulty is that many of the ships only carry one radio operator, and the messages have to be transmitted when he is on watch. Statistics show that during the year 1952 about 77 per cent. of the messages to Dunstable were received within two hours of making the observation and about 57 per cent. within one hour.

It is of interest that 93 of the present "selected" ships were carrying out duties as "selected" ships before 1939. These figures perhaps emphasize the enormous shipping casualties which the United Kingdom suffered during the last war, because the general tendency is for any ship to remain a "selected" ship once it has been recruited.

METEOROLOGICAL OFFICE DISCUSSION

The application of wave-length ideas in forecasting

The discussion on Monday, February 16, 1953, held at the Royal Society of Arts, was opened by Mr. E. J. Sumner who based his statement on tests made and forecasting experience gained in the Forecasting Research Branches, Dunstable.

He said that wave-length concepts derive from the Rossby wave-speed formula, which is applicable to the long waves of the atmosphere. These are amongst the most persistent and frequently recurring features of upper flow patterns, and are therefore especially important in extended forecasting. Although there is no exact and invariable correspondence between upper and lower patterns, as a rule they are sufficiently interdependent to make the forecasting of the former of some importance in preparing surface prebaratics. This is especially so in respect of the larger scales of motion; in particular, long waves have thermal and contour patterns which are more or less in phase at all heights. Thus the wave form, which is clearly delineated at the 500-mb. level, becomes stronger with height up to the tropopause; thereafter, with the usual temperature-gradient reversal in the stratosphere, the long-wave pattern fades with increasing height.

An example of a well defined long-wave train encircling the northern hemisphere (500-mb. contour, surface and 1000–500-mb. thickness charts for 0300 G.M.T. on December 12, 1950) was shown illustrating the above characteristics. Other characteristic features remarked on were the strong flow in the centre of the "waving stream" (the meandering jet) with relatively slack areas to north and south, and the presence of smaller waves superimposed on the long-wave pattern. The importance of distinguishing between short and long waves was emphasized, since the formula in question refers only to the latter.

The shorter waves may be divided into two broad classes, namely, short stable waves and short unstable waves. The former may take the form of the merest ripple on 500-mb. charts, the thermal and contour patterns in the lower layers being in anti-phase. They are usually very mobile, the associated surface systems being steered by the upper flow and may deepen or intensify to a moderate extent. The latter have phase differences between the thermal and contour patterns, intermediate between long and stable short waves. These unstable features too tend to be steered by the upper current, at least in the early stages of growth. Mr. Sumner said that the above indications were very rough; it was not always possible to distinguish between stable and unstable waves by simple inspection of contour and thermal patterns, nor was it always possible to segregate waves according to scale, especially when the smaller were growing rapidly. At such times they were liable to disrupt pre-existing long waves, although this was not invariable; they may merely "phase in" with or accommodate themselves to the established régime, temporarily distorting the long-wave profile. The occurrence of these instabilities coincides therefore with a rather critical period in forecasting.

Rossby[1] adopted a simple sinusoidal model of the long waves, and, assuming a barotropic, inviscid atmosphere, arrived at the following formula:—

$$c = U - \frac{\beta L^2}{4\pi^2} \qquad \ldots \quad (1),$$

where c is the wave speed (positive, eastwards; negative, westwards), U the mean zonal wind, L the wave-length and β the rate of change of Coriolis parameter with latitude. The basic theory has been re-interpreted in recent years by Charney[2], and its practical application to the earth's atmosphere (which in middle latitudes is almost always and everywhere baroclinic) justified in an "equivalent-barotropic" sense. This implies, to a first approximation, the conservation of the mean vorticity of a vertical column of the atmosphere (from top to bottom), and the Rossby formula should be applicable to the mean flow of the baroclinic atmosphere, the mean flow pattern being identified for practical purposes with the 500-mb. chart. Other formulae have been derived for more complex, and in some respects more realistic, models of long waves, but all of them include the two main terms of the Rossby form, modified by other parameters or averaged in some way. It is evident therefore that some empirical modification of the simple formula given in equation (1) is required in practice.

The results of a test of the formula as applied to the movement of pairs of upper troughs at the 500-mb. level[3] showed reasonably encouraging results—correlations between the actual and estimated 24-hr. movement of down-wind troughs of over 0·9 were obtained for the cool seasons of the year when various errors were smoothed out by 3-day averaging. Nevertheless it was not found possible to improve on the forecasts made at the Central Forecasting Office, Dunstable (which then (1950) owed nothing to the Rossby formula) of the 24-hr. movement of upper troughs. Although it seemed probable that the technique could be refined so as to equal or even to improve on present forecasting standards, it was considered best to develop some simple practical technique based on the formula, which the forecaster could absorb into his routine, gaining experience on its use under actual working conditions.

The most convenient form for forecasting is

$$c = \frac{\beta}{4\pi^2}(L_s^2 - L^2) \qquad \ldots \quad (2),$$

where $L_s = 2\pi\sqrt{(U/\beta)}$ is the stationary wave-length (derived from equation (2) by putting $c = 0$). Although empirical adjustments are required in general, experience has shown that the use of a zonal parameter U_2 would give a reasonably good estimate of the wave speed of the down-wind trough of a pair without much modification of the above expression. U_2 is computed at the 500-mb. level for a latitude band 20° wide, just containing a pair of troughs and more or less central to the wave train. (The "minimum pattern" on which measurements can be made consists of two troughs with an intervening ridge.) On comparison with the actual wave-length of quasi-stationary troughs it was found that the computed stationary wave-length over-estimated the true value by about 8° longitude on an average (one year's data). This tentative value should therefore be subtracted from all determinations of the stationary wave-length based on U_2. The measurement of the other parameters[3] was also described, and a method of evaluating the above formula by graphical means presented, the entire procedure taking only 3–4 min.

A slide was shown illustrating the "success" of the formula under simulated forecasting conditions. The more progressive waves moved well in accordance with the formula, but those forecast to be slow-moving or retrogressive still showed a decided tendency to progression. In some cases this was merely a question of shorter-waves interfering with the measurements (made in accordance with a rigid procedure), the long wave being actually quasi-stationary or retrogressive as forecast, but there were some cases of definite failure.

The remainder of the opening statement was devoted to illustrating and describing types of synoptic situations to which wave-length ideas were or were not expected to be applicable. Although the final choice rests with the experienced forecaster, the following simple rules may be put forward as a guide to selecting the best situation in which to apply the formula:

(i) The 500-mb. pattern should consist of at least a pair of troughs and an intervening ridge, with a fairly definite, broad, single, connecting flow between the two. It should be reasonably sinusoidal in form.

(ii) Clearly defined long waves of any amplitude may be tackled, bearing in mind, however, that the smaller amplitude waves tend not to be conserved, and, at the other extreme, that very large amplitude waves are likely to be non-sinusoidal or to be disrupting in some manner.

(iii) The presence of short waves should be smoothed out as far as possible when making measurements and interpreting the results.

(iv) The wave profile should not be changing its form or amplitude too rapidly at the time of forecast.

Straightforward cases of progressive, stationary and retrogressive long waves were shown. One case of forecast progression (April 14–15, 1952) was especially interesting in that the surface low on the western Atlantic associated with the upper trough was almost concentric with a cold pool; it was not therefore evident from thermal steering that a substantial movement eastwards should have occurred, as it did.

Retrogression is almost invariably a discontinuous process in which, for example, the original long-wave trough moves away eastwards declining, while a deepening trough moving round the ridge immediately up wind intensifies and "takes over", settling down further west than its predecessor. This pattern of change may be equally well described as a short unstable wave being steered round the larger-scale trough, which is simultaneously moving westwards.

The formula may also be applied to more complicated patterns, for example to double-wave trains in different latitude bands (two-storey structures). These trains may move independently for a time, but the phasing in of troughs and/or ridges of the adjacent trains is always a possibility (see, for example, the situation in the Atlantic sector on November 18–20, 1952). This eventuality is usually associated with radical and rapid over-all changes of the pattern, which for a time may make computations useless. Another complex type is that of a "block", which in a sense is a persistent two-storey anti-phase wave pattern. Wave-length concepts may be applied to give indications of the movement, east or west, of the block itself. The sustained blocking retrogression of May 5–19, 1950, was illustrated.

Finally, examples of the cutting off of a cyclonic vortex at the "tip" of a trough, the rapid formation of a long wave from a short unstable wave (April 19–23, 1950), and the equally rapid break-down of a long-wave pattern by smaller-scale instabilities (December 17–18, 1950) were shown. In some cases wave-length ideas were definitely suggestive of future developments (e.g. cutting off by differential movement in different latitudes), but during such times of rapid change quantitative estimates were often of dubious value; rapidly growing waves often move very much more slowly than the formula indicates.

In conclusion, Mr. Sumner said that one was always tempted to apply the formula to patterns which were very unlike the Rossby model—to force the atmosphere into a sinusoidal mould—which must lead to errors. Some of these would undoubtedly be anticipated if the full implications of the conservation of vorticity were to be worked out from the actual initial flow pattern, which was now possible with the aid of electronic computing machines. These methods, although likely to supersede such techniques as the above, were still, however, in the experimental stage. Meanwhile wave-length considerations could serve as a simple introduction to modern dynamical ideas; and, incidentally, the value of looking at the large-scale developments on upper air charts in their own right was not negligible.

The Director, opening the discussion, remarked on the contrast between the complexity of actual atmospheric flow and the simplicity of the Rossby model. He thought that the formula would frequently break down owing to new developments. He also noted that whereas the correlation, between actual and estimated 24-hr. movement of troughs in the data shown, was good in progressive cases, it seemed to decrease to practically zero in cases of retrogression. Mr. Sumner, in reply, agreed that developments in the patterns were always likely to occur resulting in errors. The small correlation in cases of retrogression was, in part at least, due to the complex nature of the process (interference by smaller scales of motion) and improved considerably with smoothing.

Mr. Bushby said that one of Rossby's main assumptions was that of the conservation of absolute vorticity. Charney[2,4] had adapted this concept to enable him to predict changes in the 500-mb. contour height, and his methods had been tested at Dunstable. An earlier method was essentially one-dimensional, and assumed that the 500-mb. flow consisted of small sinusoidal perturbations superimposed on a west–east zonal current, constant with respect to time and longitude. However, tests showed this method to be inferior to conventional methods in forecasting changes of contour height, but that it was as good in forecasting the 24-hr. movement of troughs and ridges. Two examples were shown. The second method, utilizing the geostrophic approximation in the vorticity equation, gave instantaneous 500-mb. height tendencies. A modification of Charney's equation by Sawyer and Bushby[5] allowed some account to be taken of baroclinic development, but tests had shown that, although the baroclinic terms were significant, the main effect was often represented by the barotropic term. Only a few situations had so far been examined, but in each case when a grid length of about 160 miles had been used there was reasonable agreement between the computed and actual 500-mb. height tendencies. One example was shown. In his opinion, when the flow was sinusoidal the Rossby formula should give a useful approximation to the movement of troughs and ridges.

Mr. C. V. Smith spoke about down-stream effects. The usefulness of a qualitative assessment of constant-vorticity trajectories was illustrated; such a technique could be employed even when flow patterns did not approximate to the simple sinusoidal model required for a confident application of the Rossby formula, and could be more informative about changes of trough amplitude or orientation of axes. One suggestion that arose from the barotropic approach was that the formation of a major trough in the upper westerlies should give rise to a dependent wave train down stream. Examples of down-stream trough formation were shown (October 28–31, 1949; February 9–15, 1950) in which it seemed that the evolution (e.g. the spacing and amplitude finally achieved) of the flow patterns, initiated by baroclinic developments, was in some large degree determined by inertia processes. Some results were quoted[6]. These suggested that the persistence of a major trough in the upper westerlies for 2–3 days, led to the next down-stream trough having dimensions comparable with that of the up-wind trough. The possible importance of so-called "anchor troughs" for long-range forecasting was also alluded to.

Dr. Forsdyke described the results of the application of long-wave considerations to extended forecasting in the Central Forecasting Office, Dunstable, over the period December 1952 to January 1953. The wave-length computation, regarded simply as indicating progression, slow movement or retrogression of the long-wave pattern, gave the right answer on about 60 per cent. of occasions. The great majority of these were cases of progression which would probably have been forecast in any event. Nevertheless he believed that wave-length considerations often gave useful indications of the broad type of evolution over a 3- or 4-day period. A recent example was discussed showing how the breaking down of a ridge of high pressure across the British Isles from Scandinavia by a small depression moving south-south-east from Iceland was successfully forecast (on broad lines, though not in detail) on the basis of the wave-length computation.

Mr. Murray asked how the use of the Rossby formula compared with extrapolation. Mr. Sumner replied that according to some results of Cressman[7], there was a slight gain in using the formula. However, if waves had only recently formed extrapolation could not be used whereas the formula could. Moreover, the forecaster sometimes had little confidence in continuing a trend because owing to observational uncertainties he was not convinced it was real, e.g. a recent rapid deceleration; wave-length ideas could provide confirmation or otherwise.

Mr. Bannon asked how retrogression, which seemed to be effected by the formation of baroclinic disturbances, could be anticipated on the basis of a barotropic model. Mr. Sumner, in reply, said that the application of such models to the baroclinic atmosphere had subsequently been justified in a mean or "equivalent barotropic" sense. The "eddy" terms, which entered into the vorticity equation after meaning vertically throughout the atmosphere, were probably biggest in association with smaller-scale baroclinic disturbances, but with respect to changes at the 500-mb. level even these seem to be dominated by the (inertia) control associated with the mean terms.

Dr. Stewart, referring to some of the results given by Dr. Forsdyke, said that better results would have been obtained if all troughs had been forecast to be progressive. Dr. Forsdyke agreed that this was statistically true, but that against this the formula gave an indication of the speed.

Dr. Scorer and *Mr. Bushby* then discussed the merits of Fjørtoft's graphical method for integrating the vorticity equation.

Mr. Lumb emphasized the importance of land–sea contrasts in modifying long-wave patterns.

Dr. Stagg said that he was still uncertain about the Rossby formula, and considered that the barotropic approach put the 500-mb. flow pattern in a false position as something apart from the rest of the atmosphere. Also, in his opinion, retrogression was best thought of as a process of cutting-off and trough reformation.

Dr. Sutcliffe spoke on the lead that Professor Rossby had given and the unanimity which at present prevailed in research on numerical methods. It would take some time before any great confidence could be entertained in their use; meanwhile forecasters should begin to apply dynamical concepts, if only qualitatively.

Mr. Gold noted that the formula had only been applied to the motion of a single trough, when there were others in the picture. He also stressed the importance of the effect of mountain ranges on upper-flow patterns, and asked if the theory fitted better in the southern hemisphere where there was little interference from land masses. Mr. Sumner, in reply, said that the motion of each trough which had an up-wind counterpart could and should be considered; for periods up to 24 hr. the motion of a trough was largely determined by the initial characteristics of the patterns, but for longer periods what was happening to the up-wind member also had to be considered. He had no experience of southern-hemisphere patterns, but agreed that the effect of topography was very important, possibly more so than the land-sea contrast.

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3. SUMNER, E. J.; A test of the Rossby formula as applied to the movement of long atmospheric waves at the 500-mb. level. *Met. Res. Pap., London,* No. 605, 1951.
4. CHARNEY, J. G.; On a physical basis for numerical prediction of large-scale motions in the atmosphere. *J. Met., Lancaster Pa,* **6,** 1949, p. 371.
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6. SMITH, C. V. and FORSDYKE, A. G.; Some down-stream features associated with large amplitude troughs in upper air circulation patterns. *Met. Res. Pap., London,* No. 752, 1953.
7. CRESSMAN, G. P.; Some effects of wave-length variations of the long waves in the upper westerlies. *J. Met., Lancaster Pa,* **6,** 1949, p. 56.

METEOROLOGICAL RESEARCH COMMITTEE

At the meeting on January 22nd the Synoptic and Dynamical Sub-Committee considered two papers on upper winds, one by Mr. D. G. Harley[1] giving an analysis of the equivalent headwinds on the great circle Shannon–Gander, and a second by Mr. C. S. Durst[2] showing the relation between the wind flow over the British Isles and the Mediterranean. Two papers of synoptic interest were also discussed, one by Messrs. C. V. Smith and A. G. Forsdyke[3] on some down-stream features associated with large amplitude troughs in upper air circulation patterns, and a second by Mr. D. H. Johnson[4] on the wind field of middle latitudes. A paper by Mr. Hurst[5] on the profile of a jet stream which was observed on September 1, 1952, aroused considerable interest. The relative merits of isotachs and contours for forecasting winds at high levels were also discussed.

ABSTRACTS

1. HARLEY, D. G.; Analysis of equivalent headwinds on the great circle Shannon–Gander, and of errors in forecasts of the same, at London Airport. *Met. Res. Pap., London,* No. 749 S.C. II/117, 1952.

Equivalent headwinds are measured from forecast 700- and 500-mb. contours; the procedure and sources of error are discussed. The monthly distributions and extremes of actual equivalent headwinds and percentage frequency distribution of errors, are tabulated and discussed. The mean errors were very small, but standard deviations ranged from 6·5–12·7 kt. Large errors were mainly due to timing of developments.

2. DURST, C. S.; The relation between wind flow over the British Isles and the Mediterranean. *Met. Res. Pap., London,* No. 776, S.C. II/133, 1952.

Winds at 200 mb. over Larkhill were correlated with those over Rome and Malta. Vector coefficients (−0·15 to −0·30) were significant at all seasons, possibly indicating a partial compensation in zonal flow.

3. SMITH, C. V. and FORSDYKE, A. G.; Some down-stream features associated with large amplitude troughs in upper air circulation patterns. *Met. Res. Pap., London,* No. 752, S.C. II/118, 1952.

Circumpolar 500-mb. polar charts were examined for simple troughs over America on 4 following days. Changes in amplitude or new formations of down-stream troughs are tabulated, but little relation was found except when the "primary" trough persists for 2–3 days. The same procedure was applied to 1000–500-mb. thickness troughs. The results do not suggest that oscillations are regularly transferred down stream, but rather the development of each trough by local energy. The modes of formation of down-stream troughs are classified as (*a*) simple growth, (*b*) amalgamation or "phasing in", (*c*) blocking patterns. Examples illustrated are: (*a*) Feb. 13–15; (*b*) Apr. 21–23; (*c*) Jan. 24–28, May 17–19, Nov. 25–27.

4. JOHNSON, D. H.; Further notes on the wind field of middle latitudes. *Met. Res. Pap., London,* No. 761, S.C. II/123, 1952.

Structure of upper westerlies in January 1950 is studied by daily cross-sections (1000–150 mb.) from Greenland to Mediterranean and Azores to Baltic, with contours of 1000- and 300-mb. surfaces over the whole area. All showed a central maximum of jet-stream type near the tropopause. The summary for the month includes histograms of height (peak 300–325 mb.), mean velocity profiles and shear profile referred to centre of jet, mean cross-section Angmagsalik–Tunis, etc.

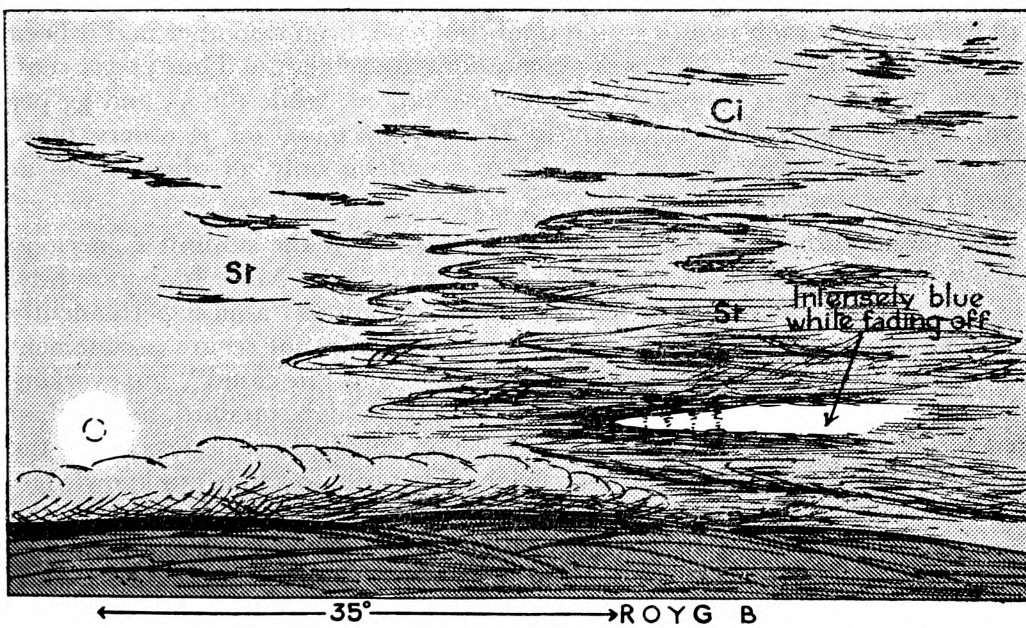
5. HURST, G. W.; The profile of a jet stream observed September 1, 1952. *Met. Res. Pap. London,* No. 772, S.C. II/131, 1952.

Wind profile of a flight from Bedford to north Scotland at 300 mb. on September 1, 1952, is discussed. Between 55° and 56°N. jet stream (110 kt.) blowing from 245° was crossed. For comparison a vertical section is constructed from radio-sonde ascents.

LETTER TO THE EDITOR

Rare mock sun seen from Gresford, Denbighshire

I first noticed a very brilliant patch of light at 1510 on December 12, 1952, and was immediately impressed by its brilliance and colouring, the latter being most vivid and noticeable. The patch appeared, as indicated in the sketch, rather like a comet with a brilliant tail. The "nose" ranged rainbow fashion from deep red to green then followed an intensely blue-white tail which faded off into the background of cloud.



I took a sight on the distance of the nose from the sun, using the only means at my disposal, a protractor and two pins. The mean angle I obtained from four sights was 35° with a variation of $\pm 1\frac{1}{2}°$. The patch of light was in line with the sun horizontally, and appeared to be in a large cirrus sheet behind a lot of stratus which subsequently blotted out the phenomenon.

R. SCUTT

85 Box Lane, Wrexham, North Wales, January 19, 1953

[This phenomenon appears to have been the mock sun associated with the rare halo of 32° produced by refraction through pyramidal ice crystals as described by Humphreys*.—Ed., *M.M.*]

NOTES AND NEWS

Frequency of cloud at mountain summits

In a note on the radio-telephone station at Great Dun Fell, Cumberland, in this Magazine for October 1951, it was stated that this station at the summit, 2,780 ft. above sea level, is almost permanently in cloud in winter. A more precise statement can now be given as a result of observations made by the radio-mechanics on duty there. They recorded whether the station was in or out of cloud, initially at 0900, 1500 and 1800, and later at 0900, 1200, 1500, 1800, 2100 and 2400. There was a break in the records but the observations cover three Januaries, three Februaries and two each of the other months within the period December 1948 to June 1952. The results are summarized in Table I.

TABLE I—FREQUENCY OF REPORTS OF STATION IN CLOUD AT GREAT DUN FELL

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						percentage frequency							
0900	55	59	53	52	24	41	34	55	45	48	63	55	49
1200	71	59	65	43	16	32	24	35	50	30	59	...	45
1500	53	51	61	33	16	15	23	19	33	33	63	53	37
1800	58	51	54	33	27	19	20	27	32	37	65	58	40
2100	74	69	62	47	47	30	24	47	73	59	82	...	57
2400	68	69	62	47	50	52	36	63	71	64	89	...	62

The values for each month would doubtless have been smoother had it been possible to use the same number of observations at each hour. Thus 71 per cent. at 1200 in January is based on only 62 observations, while the 55 and 53 per cent. at 0900 and 1500 respectively in January are based on 93 observations. The percentages given for December are based on only 38 observations at 0900, 1500 and at 1800.

The observations show, as would be expected, that the summit is in cloud on the fewest occasions at 1500 and in the months of May, June and July. Clearly also the observers did not regard the station as "almost permanently in cloud in winter". The writer of this article could not secure a statement from the observers of the criterion used for entering "in cloud", but working under such conditions they may well have adopted a high standard, higher than that of the normal office worker who would be appalled at the severity of the weather experienced in winter at such heights. In order to add to our knowledge, the observers are being asked to record, in future, additional information as to the furthest observation post which can be seen, the posts being set up at distances of 10, 22, 44 and 110 yd.

During the period when observations were made six times a day, the station was in cloud continuously at these times for over seven days from 0900 on January 4 until 1800 on January 11, 1952. The longest period when the station was out of cloud was four days, in May 1952.

Similar observations were made at the radio station on Lowther Hill, 2,377 ft., near Wanlockhead, to the north of Dumfries, but they were restricted to 0900, 1200, 1500 and 1800. The percentage frequencies of station in cloud

* HUMPHREYS, W. J.; Physics of the air. 3rd edn, London and New York, 1940, p. 534.

are set out in Table II. The observations at Lowther Hill given for December are based on only 38 observations, at 0900, 1200, 1500, and 1800, by far the fewest for any month. Too much weight should not be given therefore to the smaller percentages in December than in January and November.

TABLE II—FREQUENCY OF REPORTS OF STATION IN CLOUD AT LOWTHER HILL

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						percentage frequency							
0900	60	60	47	55	32	34	31	56	37	65	63	43	48
1200	59	52	41	46	26	23	20	43	40	40	59	46	40
1500	64	52	38	40	35	21	20	34	30	50	55	43	39
1800	62	54	40	52	39	22	22	37	48	59	69	55	44

It is interesting to note that, taking all the values, the percentages at 0900, 1200, 1500 and 1800 are very similar at Great Dun Fell and Lowther Hill. It might be expected that Great Dun Fell would be more often in cloud because the summit is slightly higher, 2,780 ft. compared with 2,377 ft. at Lowther Hill, but on the other hand Great Dun Fell is further south and therefore likely to be in cloud less often. So far, therefore, it appears that both places are about as often in cloud. We get the same answer when considering rainfall (a measure of cloud frequency) in that both summits appear to be about equally wet with an annual average of 75 in.

It is interesting to compare these values with those given for hill tops round Glen Nevis*. The values are given as percentage frequency of mist or fog but this is also referred to as the frequency with which the mountains were in cloud.

TABLE III—FREQUENCY OF MIST OR FOG OVER SOME HILL TOPS ROUND GLEN NEVIS
Period: October 25, 1901—February 28, 1902

	Height	0900	1000	1400	2100	Mean
	ft.		*percentage frequency*			
Ben Nevis	4,406	73	70	66	64	67
Sgor-a-Mhaim ...	3,601	54	55	51	42	51
Cairn Dearg	3,348	52	54	50	38	49
Mullach nan Coirean	3,077	46	48	46	36	43
Meall Cumhann ...	2,306	26	27	16	11	20
Mean ...	3,346	50	51	46	38	46

These figures show an increase of cloud with height and that the smallest values occur at 2100, unlike the records from Great Dun Fell and Lowther Hill where the least cloud occurred at 1500. The values for Great Dun Fell and Lowther Hill are more similar to those for the altitudes of 3,077 and 3,348 ft. than for the station at the lower level of 2,306 ft.

The annual number of hours of bright sunshine recorded at Ben Nevis Observatory for the period 1884–1903 was only 736 hr., or 16 per cent. of the total duration of daylight. The percentage varied from 10 in November, December and January, to 22 and 23 in May and June. It would be interesting to record the duration of bright sunshine at Great Dun Fell or Lowther Hill, since in the absence of records we can only give a rough estimate, based on the Ben Nevis records, of about 1,000 hr./yr.

J. GLASSPOOLE

*MOSSMAN, R. C.; The meteorology of Glen Nevis, Appendix to the Meteorology of the Ben Nevis Observatories. Part V. *Trans. roy. Soc. Edinburgh*, **44**, 1910, p. 644.

Thick fog, December 7, 1952

The photograph facing p. 145 was taken at 1800 G.M.T. on Sunday, December 7, 1952, during the thick fog experienced in London. The lamp was 16 yd. away from the camera and the tree 8 yd. One hour later the lamp was invisible but the tree could just be seen against the glow, whilst at 2100 visibility had improved so that the lamp was again visible.

In the photograph it is interesting to note that light scatter from fog particles has rendered the tree trunk less dark than the hedge near the camera.

Rime, December 7, 1952

The photographs in the centre of this magazine were taken in the Royal Botanic Gardens, Kew, in the early afternoon of Sunday, December 7, 1952—that is in the very foggy spell.

The weather was foggy and the sky mostly obscured although the outline of the sun was very occasionally identifiable. The visibility was very variable, between 30 and 100 yd., within the ¼ square mile covered. At Kew Observatory the temperature was 29·3°F. at 1330 G.M.T. rising steadily to 31·5°F. by 1400. The ice crystals, however, showed signs of melting at the time of the exposures, and water was dripping from the trees by 1400.

OFFICIAL ANNOUNCEMENT

The Secretary of State for Air has approved the appointment of Professor O. G. Sutton, C.B.E., D.Sc., F.R.S., J.P., at present Dean and Bashforth Professor of Mathematical Physics in the Royal Military College of Science, Shrivenham, to succeed Sir Nelson K. Johnson, K.C.B., D.Sc., A.R.C.S., as Director of the Meteorological Office on the latter's retirement in the autumn of this year.

BOOKS RECEIVED

Onweders, optische verschijnselen enz. in Nederland. Koninklijk Nederlands Meteorologisch Instituut. No. 81, 9½ in. × 6½ in., pp. 56, *Illus.*, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1951. Price: *fl.*2·00.

Upper air data, 1949. Koninklijk Nederlands Meteorologisch Instituut. No. 106A, 12½ in. × 8¾ in., pp. 90, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1951, Price: *fl.*12.00.

ERRATA

FEBRUARY 1953, PAGE 51, bottom line; *for* "Senior Nautical Assistant," *read* "Senior Nautical Officer,".

MARCH 1953, PAGE 87, line 13; *for* "*A century of London weather*," *read* "*A century of London weather.* By W. A. L. Marshall."

WEATHER OF MARCH 1953

Mean pressure was exceptionally high over Europe, the 1020-mb. isobar enclosing almost the whole of this region. The excess of pressure above normal was 10 mb. or more, and reached 18 mb. over the United Kingdom where mean pressure was 1030 mb. The lowest mean pressure, 1001 mb., occurred to the south and east of Greenland, and the mean pressure at the Azores, 1011 mb., was 11 mb. below normal.

Mean temperature was 35° to 40°F. in Scandinavia, 40° to 50°F. in west Europe and 50° to 55°F. in the Mediterranean region, and at most places there was an excess of 2° to 4°F. above normal.

In the British Isles the weather was dry with frequent fog. Mean pressure was exceptionally high and except in the north of Scotland the month was unusually quiet. Sunshine exceeded the average on the whole, and mean temperature was above the average in the north but somewhat below in the south.

Anticyclonic conditions prevailed until the 25th with little or no rain. Fog was widespread in England, Wales and Ireland during the first six days both inland and at some coastal stations, fog or low stratus cloud persisting occasionally all day in some places. This made both sunshine amounts and day temperature very variable. At places with persistent fog very low maxima were registered, for example 32°F. at Watnall on the 1st, 34°F. at Pershore and 35°F. at West Raynham and Cranfield on the 2nd, 33°F. at Mildenhall and 35°F. at Ross-on-Wye on the 3rd and 34°F. at Aberporth on the 4th. On the 7th drier air arrived behind a cold front moving south over the country, and subsequently there was not much persistent fog though it often occurred at night and in the morning. Early morning frost was registered frequently throughout the anticyclonic period, with occasional screen minima of 25°F. or below up to the 16th even in the south. There were many sunny days and maximum temperatures were often above the average, particularly in the west and north. Towards the end of the anticyclonic spell it was notably warm, temperature rising to 70°F. locally on the 24th and 25th. By the 25th absolute drought had lasted for 36 days in many parts of East Anglia and Yorkshire and for 34 days in many areas including London. It was probably the longest drought at this time of year since 1893. On the 25th the anticyclone retreated southward and became less intense and on the 26th a cold front moved south-east across the country ending the drought almost everywhere, though no measurable rain fell locally in north-east England. A changeable westerly type of weather prevailed for the rest of the month. On the 28th a small secondary disturbance moved east across northern England giving heavy rain in Wales and north-west England (4·22 in. at Llangurig, Montgomeryshire, 3·00 in. at Aberangell, Merionethshire, 2·97 in. at Lake Vyrnwy and 2·25 in. at Darwen). On the 29th and 30th another small depression, which formed on an almost stationary front, moved north-east from a position off the south of Ireland; further heavy rain fell in parts of Wales and the Midlands (2·68 in. at Rhondda Water Works, Glamorganshire, 2·40 in. at Treherbert and 2·11 in. at Swansea Water Works, Brecknockshire on the 29th). In other areas rainfall was not heavy; at Tynemouth no rain occurred until the 30th and even then it was only 0·02 in.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	71	16	−0·4	40	−10	117
Scotland	69	16	+1·9	38	−12	130
Northern Ireland ...	65	23	−0·9	19	−14	108

RAINFALL OF MARCH 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·43	24	*Glam.*	Cardiff, Penylan ...	1·66	53
Kent	Dover	0·27	13	*Pemb.*	Tenby, The Priory ...	2·45	79
,,	Edenbridge, Falconhurst	0·31	13	*Radnor*	Tyrmynydd	4·88	91
Sussex	Compton, Compton Ho.	0·55	20	*Mont.*	Lake Vyrnwy	5·19	115
,,	Worthing, Beach Ho. Pk.	0·22	11	*Mer.*	Blaenau Festiniog ...	5·31	62
Hants.	Ventnor Cemetery ...	0·37	18	,,	Aberdovey	2·04	61
,,	Southampton, East Pk.	0·54	24	*Carn.*	Llandudno	1·17	58
,,	S. Farnborough ...	0·42	21	*Angl.*	Llanerchymedd ...	0·99	33
Herts.	Royston, Therfield Rec.	0·58	32	*I. Man*	Douglas, Borough Cem.	0·62	21
Bucks.	Slough, Upton	0·37	21	*Wigtown*	Newton Stewart ...	0·53	15
Oxford	Oxford, Radcliffe ...	0·67	41	*Dumf.*	Dumfries, Crichton R.I.	0·48	16
N'hants.	Wellingboro' Swanspool	0·83	46	,,	Eskdalemuir Obsy. ...	0·91	19
Essex	Shoeburyness	0·25	19	*Roxb.*	Crailing	0·27	13
,,	Dovercourt	0·23	15	*Peebles*	Stobo Castle	0·83	29
Suffolk	Lowestoft Sec. School ...	0·30	19	*Berwick*	Marchmont House ...	0·37	14
,,	Bury St. Ed., Westley H.	0·59	31	*E. Loth.*	North Berwick Res. ...	0·26	14
Norfolk	Sandringham Ho. Gdns.	1·05	55	*Midl'n.*	Edinburgh, Blackf'd. H.	0·42	21
Wilts.	Aldbourne	0·77	35	*Lanark*	Hamilton W. W., T'nhill	0·92	33
Dorset	Creech Grange	0·59	21	*Ayr*	Colmonell, Knockdolian	0·29	9
,,	Beaminster, East St. ...	0·67	23	,,	Glen Afton, Ayr San. ...	1·10	26
Devon	Teignmouth, Den Gdns.	0·37	14	*Renfrew*	Greenock, Prospect Hill	2·38	51
,,	Cullompton	1·05	38	*Bute*	Rothesay, Ardencraig ...	1·32	37
,,	Ilfracombe	1·56	54	*Argyll*	Morven (Drimnin) ...	2·34	48
,,	Okehampton	1·74	42	,,	Poltalloch	2·03	53
Cornwall	Bude, School House ...	1·01	41	,,	Inveraray Castle ...	3·74	59
,,	Penzance, Morrab Gdns.	1·26	39	,,	Islay, Eallabus	1·95	51
,,	St. Austell	1·10	32	,,	Tiree	1·33	40
,,	Scilly, Tresco Abbey ...	0·94	36	*Kinross*	Loch Leven Sluice ...	1·19	40
Glos.	Cirencester	1·41	61	*Fife*	Leuchars Airfield ...	0·45	23
Salop	Church Stretton ...	1·26	52	*Perth*	Loch Dhu	2·62	40
,,	Shrewsbury, Monksmore	1·17	70	,,	Crieff, Strathearn Hyd.	1·01	32
Worcs.	Malvern, Free Library ...	1·12	58	,,	Pitlochry, Fincastle ...	1·03	37
Warwick	Birmingham, Edgbaston	1·66	87	*Angus*	Montrose, Sunnyside ...	0·39	19
Leics.	Thornton Reservoir ...	1·56	85	*Aberd.*	Braemar	0·65	22
Lincs.	Boston, Skirbeck ...	0·79	51	,,	Dyce, Craibstone ...	0·30	11
,,	Skegness, Marine Gdns.	0·81	49	,,	New Deer School House	0·28	11
Notts.	Mansfield, Carr Bank ...	1·39	67	*Moray*	Gordon Castle	0·50	22
Derby	Buxton, Terrace Slopes	3·01	73	*Nairn*	Nairn, Achareidh ...	0·91	49
Ches.	Bidston Observatory ...	0·89	47	*Inverness*	Loch Ness, Garthbeg ...	2·08	62
,,	Manchester, Ringway ...	2·00	89	,,	Glenquoich	5·01	52
Lancs.	Stonyhurst College ...	1·68	46	,,	Fort William, Teviot ...	3·04	45
,,	Squires Gate	0·44	19	,,	Skye, Duntuilm ...	2·37	54
Yorks.	Wakefield, Clarence Pk.	0·75	42	,,	Skye, Broadford ...	3·58	59
,,	Hull, Pearson Park ...	0·54	30	*R. & C.*	Tain (Mayfield) ...	1·30	58
,,	Felixkirk, Mt. St. John ...	0·09	5	,,	Inverbroom, Glackour ...	3·18	64
,,	York Museum	0·23	14	,,	Achnashellach	3·63	53
,,	Scarborough	0·24	13	*Suth.*	Lochinver, Bank Ho. ...	2·04	54
,,	Middlesbrough	0·13	8	*Caith.*	Wick Airfield	1·26	56
,,	Baldersdale, Hury Res.	0·70	24	*Shetland*	Lerwick Observatory ...	1·82	58
Norl'd.	Newcastle, Leazes Pk. ...	0·09	4	*Ferm.*	Crom Castle	0·48	15
,,	Bellingham, High Green	0·75	26	*Armagh*	Armagh Observatory ...	0·35	15
,,	Lilburn Tower Gdns. ...	0·19	7	*Down*	Seaforde	0·44	15
Cumb.	Geltsdale	0·60	21	*Antrim*	Aldergrove Airfield ...	0·35	14
,,	Keswick, High Hill ...	0·79	18	,,	Ballymena, Harryville ...	0·54	17
,,	Ravenglass, The Grove	0·39	13	*L'derry*	Garvagh, Moneydig ...	0·57	18
Mon.	Abergavenny, Larchfield	1·55	51	,,	Londonderry, Creggan	1·01	32
Glam.	Ystalyfera, Wern House	4·71	88	*Tyrone*	Omagh, Edenfel ...	0·91	29

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

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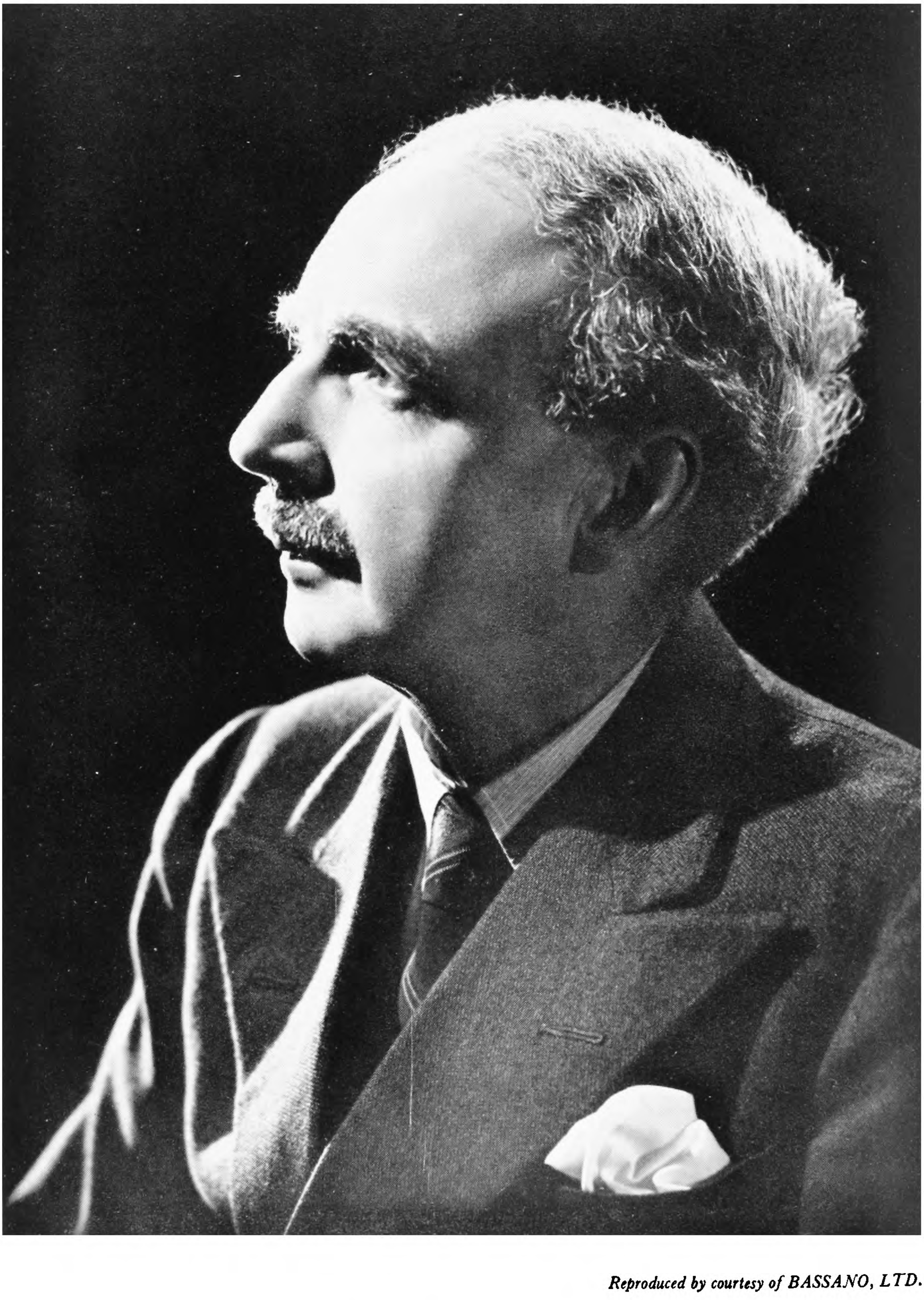

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DR. A. H. R. GOLDIE, C.B.E., F.R.S.E.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 972, JUNE 1953

DR. A. H. R. GOLDIE, C.B.E., F.R.S.E.

Dr. A. H. R. Goldie retired on May 4, 1953, after nearly 40 years' service in the Meteorological Office. Dr. Goldie's early years were spent at Glenisla, Angus. He was a student at the University of St. Andrews and St. John's College, Cambridge, from which he graduated as a Wrangler in the Mathematical Tripos of 1913.

On joining the Meteorological Office in August 1913 he served successively in the Forecast Division, at Falmouth Observatory and as Senior Assistant at Eskdalemuir Observatory until June 1915. He was then commissioned in the newly-formed Meteorological Section, Royal Engineers and served overseas for the remainder of the First World War. He was Meteorological Officer to General Rawlinson at H.Q. Fourth Army for a considerable time. After setting up the meteorological organization for the British Forces in Italy late in 1917 and the first half of 1918, he returned to France and subsequently assumed command of the Meteorological Section with headquarters in Cologne. He attained the rank of Major and was twice mentioned in dispatches.

On demobilization in 1919 Dr. Goldie returned to the Meteorological Office as Superintendent of the Local Centres Division. He held this post until October 1924 when he was appointed Superintendent, Meteorological Office, Edinburgh.

During his period as Head of the Local Centres Division the results of his researches, then especially devoted to changes of upper air temperature in depressions and anticyclones, began to appear in papers in the *Quarterly Journal of the Royal Meteorological Society* and in letters to *Nature*. He was the first to notice, in 1923, the occurrence of multiple tropopauses. During the years at Edinburgh his abilities in research were revealed in an impressive series of papers in *Geophysical Memoirs*, the *Proceedings of the Royal Society of Edinburgh*, the *Transactions of the Royal Society of Edinburgh* and the *Quarterly Journal of the Royal Meteorological Society*. The subjects comprised the electrical systems in the high atmosphere producing magnetic storms, the physics of the development of the large-scale wind structure of depressions and the degree of its approximation to standard hydrodynamic vortices, diurnal variations in both frontal and air-mass rainfall, small-scale waves on surfaces of discontinuity and the associated pressure and wind variations, and the gustiness of wind in relation to type of air mass and wind speed. The approach to these diverse problems was characteristically realistic. In 1935 he revised and brought up-to-date Abercromby's celebrated book "Weather". He proceeded to the degree of D.Sc. at St. Andrews in 1936 and has been a Fellow of the Royal Society of Edinburgh since 1925. His standing in terrestrial magnetism and atmospheric electricity was recognized internationally by his appointment in 1936 as Secretary of the International Association for these subjects; he held this post until 1947. Apart from his research activities Dr. Goldie carried a heavy load of official duties in Edinburgh, both in the climatological work, in which difficult legal questions often arose, and in the control of the three Scottish Observatories. He was also largely responsible for setting up the anemometer at Bell Rock lighthouse in 1929.

In 1938 when the Director began to plan a Research Organization in the Meteorological Office, one of his first steps was to transfer Dr. Goldie to Headquarters as Assistant Director with special responsibility for research. The outbreak of the Second World War interrupted the fulfilment of these plans, and in November 1939, Dr. Goldie moved to Stonehouse, Gloucestershire, as Assistant Director (Climatology and Instruments) in charge of the Marine, Climatological and Instruments Branches which had been evacuated from South Kensington. The research plans were only temporarily interrupted, and when the Meteorological Research Committee was set up in 1941 Dr. Goldie became responsible for the official administration of its work. He possesses to an exceptional degree a capacity for sound administration which he was able to exercise simultaneously with the carrying out personally of research of a high order.

On the reorganization of the Office early in 1948 Dr. Goldie became a Deputy Chief Scientific Officer and was appointed Deputy Director for Research. Since then he has been responsible for the general co-ordination of research and for more immediate direction of research into meteorological physics such as cloud structure, problems of turbulence and radiation, instruments, terrestrial magnetism and electricity, and has controlled the Observatories, the Meteorological Research Flight, and the Headquarters Branches concerned. Early in 1950 the Climatology Division and Marine Branch again came under his charge. Dr. Goldie has exercised a predominant influence in the development of the research facilities within the office. His encouragement and personal example will long be gratefully remembered by all those associated with him.

Early in the Second World War Dr. Goldie studied the physics of the formation of condensation trails by aircraft, then a serious military problem, and he produced a theory which permitted the height of trail formation to be forecast. The theory led to the printing of a new curve, the "Mintra line", on the Meteorological Office tephigram and to the formulation of rules for advising pilots on how to avoid trail formation. Dr. Goldie was also much concerned with research into atmospheric turbulence affecting aircraft, but his most recent personal researches have dealt mainly with the large-scale circulation of the upper atmosphere. He has, to mention only one aspect of this work, used the observations of humidity made in the stratosphere by the Meteorological Research Flight to deduce in broad outline the circulation of air from the high equatorial troposphere into the stratosphere over temperate latitudes.

In 1951, Dr. Goldie was appointed C.B.E. in recognition of his services.

Dr. Goldie first married, in 1928, Miss Marion Wilson of the staff of the Meteorological Office, Edinburgh. At Stonehouse Mrs. Goldie's personal work for the staff greatly mitigated the difficulties of evacuation and there was deep sorrow at the news of her death in 1948.

In 1952, to the pleasure of all their friends, Dr. Goldie married Miss Helen Carruthers of the scientific staff of the Climatology Division. Now with Dr. Goldie's retirement we have also to regret the resignation of Mrs. Goldie whose great ability in the application of statistics to meteorology has, in collaboration with Dr. C. E. P. Brooks, been shown in such important works as "Upper winds over the world" and the newly published "Handbook of statistical methods in meteorology".

We extend our best wishes to Dr. and Mrs. Goldie and look forward to many more contributions from them to meteorological knowledge.

The Director on behalf of the staff of the Office presented Dr. Goldie, at a small ceremony held in Victory House on May 1, with a cheque with which to buy a greenhouse. In making the presentation and expressing the good wishes of the staff, the Director referred particularly to the large number of subjects to which Dr. Goldie had contributed, from the structure of depressions to terrestrial magnetism, and to Dr. Goldie's ability to combine first-class research with administration. Dr. Goldie, thanking the staff, recounted some memories of life in the Office before 1914 and of those with whom he had worked in the Office.

Mr. R. G. Veryard, Assistant Director for Climatology, presented Mrs. Goldie on April 30 with a 20-in. slide-rule and a set of grape-fruit glasses from her friends at Harrow. Mr. Veryard referred to the work, in the application of statistical methods to meteorology, in which Mrs. Goldie had played an important part during her ten years' service and particularly to *Geophysical Memoirs* No. 85, "Upper winds over the world", and the newly published "Handbook of statistical methods in meteorology". Mrs. Goldie in reply spoke of the friendliness she had always found in the Meteorological Office and how she would always feel she belonged to the Office.

THE FORMATION OF NEW ANTICYCLONES

By R. C. SUTCLIFFE, Ph.D.

Summary.—Defining a new anticyclone simply as a new centre of high pressure on the surface synoptic chart, 42 cases over the Atlantic–west European region in 1950–51 were examined according to the associated 500-mb. patterns. Only 4 cases occurred with a simple sinusoidal oscillation in the upper westerlies north of a pre-existing subtropical anticyclone (classical general-circulation model), but 21 cases with such an oscillation when the surface pressure was already low to the south of the upper westerlies. Nine cases occurred with anticyclonic disruption of the upper westerlies and 8 were complex. The two processes, oscillation and disruption in the baroclinic zone, are common and regularly produce anticyclonic development, but the distinct new high centre is exceptional.

Introduction.—Depressions and anticyclones are for the most part the manifestation of eddies in an atmosphere which is perpetually turbulent on the synoptic scale. The new depression or new anticyclone on the surface chart may then be expected to emerge from small beginnings, as it were from nowhere, in association with some self-developing distortion in the three-dimensional flow patterns, and such evolutions will naturally present deep-seated difficulties in practical prediction, difficulties which theoretical understanding will not necessarily overcome. At present the forecaster is assisted by a knowledge of the types of situation liable to give rise to new developments and by a knowledge of the typical patterns of behaviour; this investigation adds a little to this knowledge. Cases are examined where new anticyclones have appeared (on the surface synoptic charts) and are classified according to the associated behaviour patterns of the 500-mb. contours and the 1000–500-mb. thickness.

Data and classification.—The object is to obtain a representative sample of "new anticyclone formations" without making any assumptions as to their three-dimensional structure or to theory, to obtain the sample tolerably objectively and to exclude the weak, small-scale or ephemeral centres which have little dynamical significance. The area selected for study is shown in Fig. 1, and a "new anticyclone" is defined as a closed high-pressure centre on the synoptic charts published in the *Daily Weather Report* of the Meteorological Office (isobars at 4-mb. intervals); further, the centre must persist for at least 24 hr. and must not be continuous with a previous centre either inside or outside the area.

It will not be supposed that such a definition will catch all or even the majority of cases of essentially new "anticyclonic development", for typically, over the area concerned, the result of a new development is merely a ridge of high pressure or the movement of a pre-existing high, not a new centre. In this respect anticyclonic development differs from the cyclonic which normally gives rise to a new centre. This difference is partly a feature of the synoptic climate of the region and is not true everywhere.

Over the two years 1950–51, 42 cases were selected; they are listed in Table I.

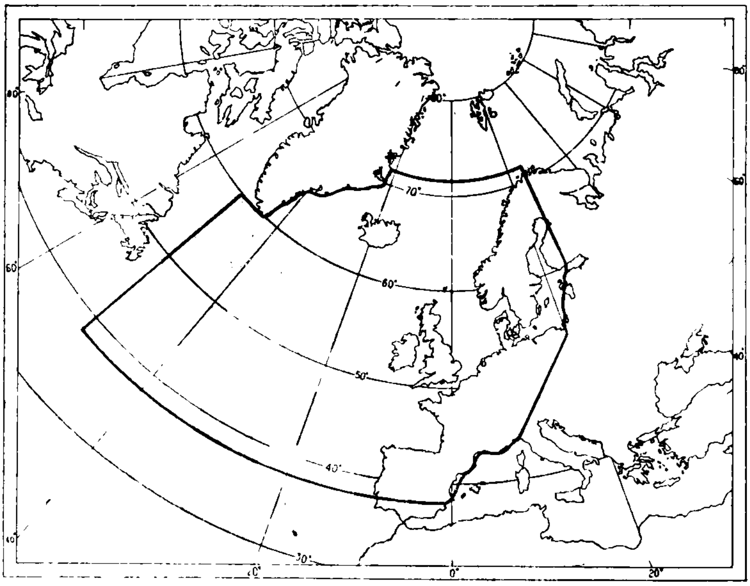


FIG. 1—AREA STUDIED FOR NEW ANTICYCLONIC CELLS

TABLE I—NEW ANTICYCLONIC CENTRES 1950–51

Total No. of Cases = 42

Type	Date	Location	Remarks
I—Simple upper oscillation in baroclinic zone with pre-existing anticyclone to south. No. of cases = 4	Oct. 20, 1950	East Atlantic	Illustrated in Fig. 2
	Nov. 4, 1950	North of British Isles	But initially lower pressure to south; almost type II
	Aug. 11, 1951	Central Atlantic	Tendency towards a double frontal system
	Oct. 26, 1951	Scandinavia	Soon absorbed high to south
II—Simple upper oscillation in baroclinic zone but without pre-existing high to south of anticyclogenetic region. No. of cases = 21	June 10, 1950	British Isles	Pre-existing cold depression Portugal, see Fig. 3
	July 2, 1950	British Isles	Low Spain to north Africa
	July 8, 1950	France	Low north-west Africa. Azores high (July 8, 12, 18)
	July 12, 1950	France	
	July 18, 1950	France	
	July 25, 1950	France to Germany	Low north-west Africa. Weak oscillation
	Aug. 19, 1950	France to Germany	Low north-west Africa. Azores high. Weak oscillation (Aug. 19, 29)
	Aug. 29, 1950	North Spain to France	
	Nov. 21, 1950	South of Greenland	Cut-off cold low to south
	Nov. 26, 1950	British Isles to Germany	Cut-off cold low Azores
	Dec. 1, 1950	South of Greenland	Cut-off cold low Azores. Large oscillation. See Fig. 4
	Feb. 28, 1951	France	Low Mediterranean. Large oscillation
	Apr. 16, 1951	East Atlantic	Cut-off cold low Azores
	Apr. 19, 1951	North Sea	Cut-off cold low Biscay (Apr. 19, May 29)
	May 29, 1951	North of British Isles	
	Aug. 17, 1951	South-west of British Isles	Low north-west Africa (Aug. 17, Sept. 14)
	Sept. 14, 1951	North Spain to France	
	Sept. 16, 1951	South-east of Greenland	Cut-off cold low north-west of Azores
	Nov. 4, 1951	Scandinavia	Large cold low British Isles
	Nov. 15, 1951	North Scandinavia	Large cold low east Atlantic
	Dec. 12, 1951	East Atlantic	Low Azores
III—Anticyclonic disruption of upper wave pattern. No. of cases = 9	Mar. 8, 1950	East Atlantic	Cold low formed to west of Portugal
	Mar. 26, 1950	East Atlantic	Cold low moved to west of Portugal. See Fig. 6
	Apr. 20, 1950	Baltic	Cold low cut-off Mediterranean
	June 12, 1950	South-west of Iceland	Cold low cut-off north of Azores
	Aug. 30, 1950	Iceland	Cold low cut-off British Isles
	Feb. 12, 1951	North of British Isles	Cold low cut-off Biscay
	Mar. 23, 1951	Central Atlantic	Cold low cut-off south of Azores
	Apr. 25, 1951	Central Atlantic to south-west Iceland	Cold low cut-off Azores
	Apr. 9, 1951	France to Germany	Cold low cut-off Italy
IV—Complex No. of Cases = 8	Feb. 20, 1950	Central Atlantic	Double structure. See Fig. 7
	July 29, 1950	Jan Mayen	Low formed east of Greenland
	Nov. 4, 1950	North of British Isles	Double structure, lows to north and south
	Dec. 26, 1950	South Scandinavia	
	Mar. 20, 1951	British Isles	Almost type II
	June 6, 1951	Central Atlantic	Double structure, almost Type III
	July 11, 1951	South of Iceland	Small-scale feature
	Oct. 28, 1951	Central Atlantic	Small scale. Double structure

Each case, having been selected from the surface charts alone, was considered in the light of the upper air charts, mainly the 500-mb. contour charts and the 1000–500-mb. thickness charts. Leaving aside some 20 per cent. of cases which arose in complex synoptic situations, two distinct models became apparent: the sinusoidal oscillation of the upper westerlies and the disruption of the upper westerlies into two parts, both models being of course familiar enough to synoptic meteorologists. The types are discussed in separate paragraphs below and are illustrated with examples.

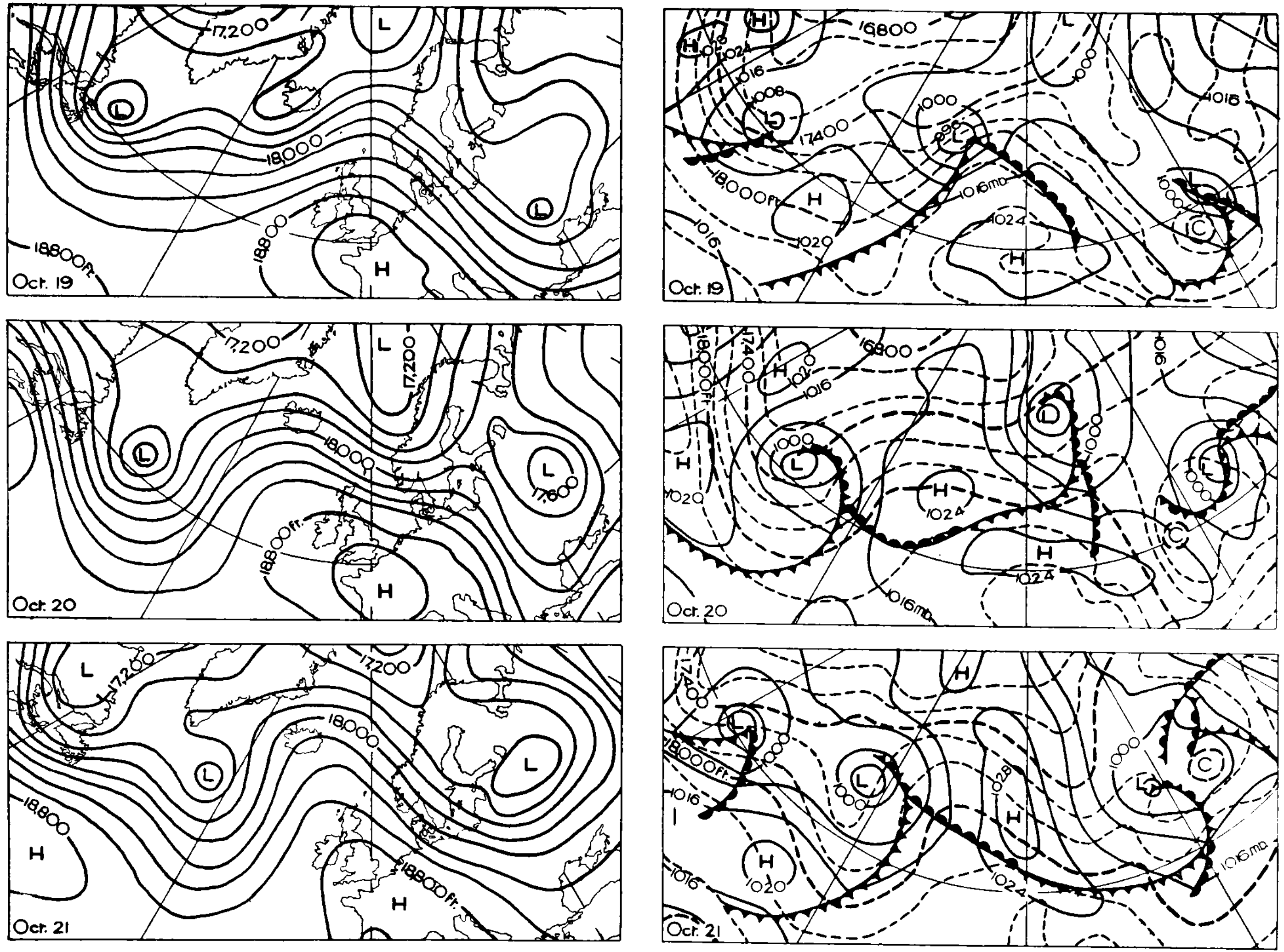
Simple sinusoidal oscillation.—The growing (unstable) wave model of the depression in a baroclinic zone is generally familiar, theoretically well founded and synoptically common. The corresponding anticyclone model is perhaps less well known, but the mechanism has been discussed briefly by Sutcliffe and Forsdyke[1]. There is still some doubt as to the exact criteria of "instability" if account is taken of all the controls, but certainly something of the kind is present somewhere at all times, and perhaps every steady baroclinic current is unstable for some such development of appropriate synoptic scale.

Classical general circulation model.—In the classical model of the general circulation of the atmosphere, with the unsettled westerlies lying on the poleward side of the subtropical anticyclonic belts, the typical sequence is one of developing, occluding and ultimately filling depressions separated not by closed anticyclones but by more or less intense wedges or ridges extending from the semi-permanent highs. Although this model is accepted and does not lack dynamical explanation the rarity with which a new high centre was in fact formed when the broad weather type in the region fitted this general circulation model, came as something of a surprise. The broad weather type is of course common over the Atlantic sector with the Azores anticyclone setting the pattern, and the degree of development of the baroclinic ridge is a regular and important problem for forecasting. But, excluding the cases where there was a temporary and weak closed centre, usually behind the cold front, but where otherwise the ridge construction was satisfactory, it was difficult to find a clear case of new anticyclone formation associated with the simple upper oscillation. Typically the ridge would relax within a day or two, and even in the cases where the development was strong and led to a large change in the broad weather pattern it was manifest by the old warm anticyclone being displaced to higher latitudes rather than by a definitely new surface formation. Fig. 2 illustrates a good example of pronounced anticyclonic building of this type. A few comments on the case follow.

October 19–21, 1950 (Fig. 2)

On the 19th there are two developing depressions in the Atlantic in the heart of the baroclinic zone shown by the thickness lines; the 500-mb. chart shows a rather weak sinusoidal pattern. The lower latitudes are dominated by the subtropical anticyclone lying south-west of the British Isles and outside the main upper stream of westerlies. The two depressions are separated by a baroclinic ridge from a detached high cell to the south. Over the next two days the depressions move east and the amplitude of the upper wave pattern grows considerably, the surface ridge develops at the same time, and by the 21st has effectively absorbed and displaced the old warm anticyclone into the baroclinic zone. There is, strictly speaking, no new anticyclone formation; rather the case illustrates the merging of two high centres into one. But there is very obviously a pronounced process of anticyclogenesis of the simple oscillation type.

In the two years only four cases of this type were picked out showing a distinct new surface centre, and none was very clear-cut or without some complicating factor. The conclusion is that anticyclogenesis associated with a simple oscillation in the upper westerlies north of a high-pressure belt may



500-mb. contour charts, 0300

Surface isobars, 0000, full lines
1000–500-mb. thickness, 0300, broken lines

FIG. 2—ANTICYCLONIC DEVELOPMENT WITH SIMPLE OSCILLATION IN THE UPPER WESTERLIES, OCTOBER 19–21, 1950

lead to a ridge (perhaps containing a weak separate cell) which is absorbed by the old subtropical high, or to one which itself absorbs the old high, but rarely to a distinct and detached new centre. Although the ridge model is well known to be typical, the rarity of the new detached high centre is rather remarkable when one recalls that a new cyclone centre regularly appears in the quite early stages of almost any cyclonic oscillation.

Non-classical broad-scale situation.—The position is very different when the broad weather situation is not roughly that of the classical general circulation model, when the region of upper baroclinic westerlies in which ridges and cyclones develop does not lie poleward of an established high but has generally low surface pressure at lower latitudes. This pattern can arise in many ways but there are certain rather common cases in our region. Two examples are illustrated in Figs. 3 and 4.

June 9–11, 1950 (Fig. 3)

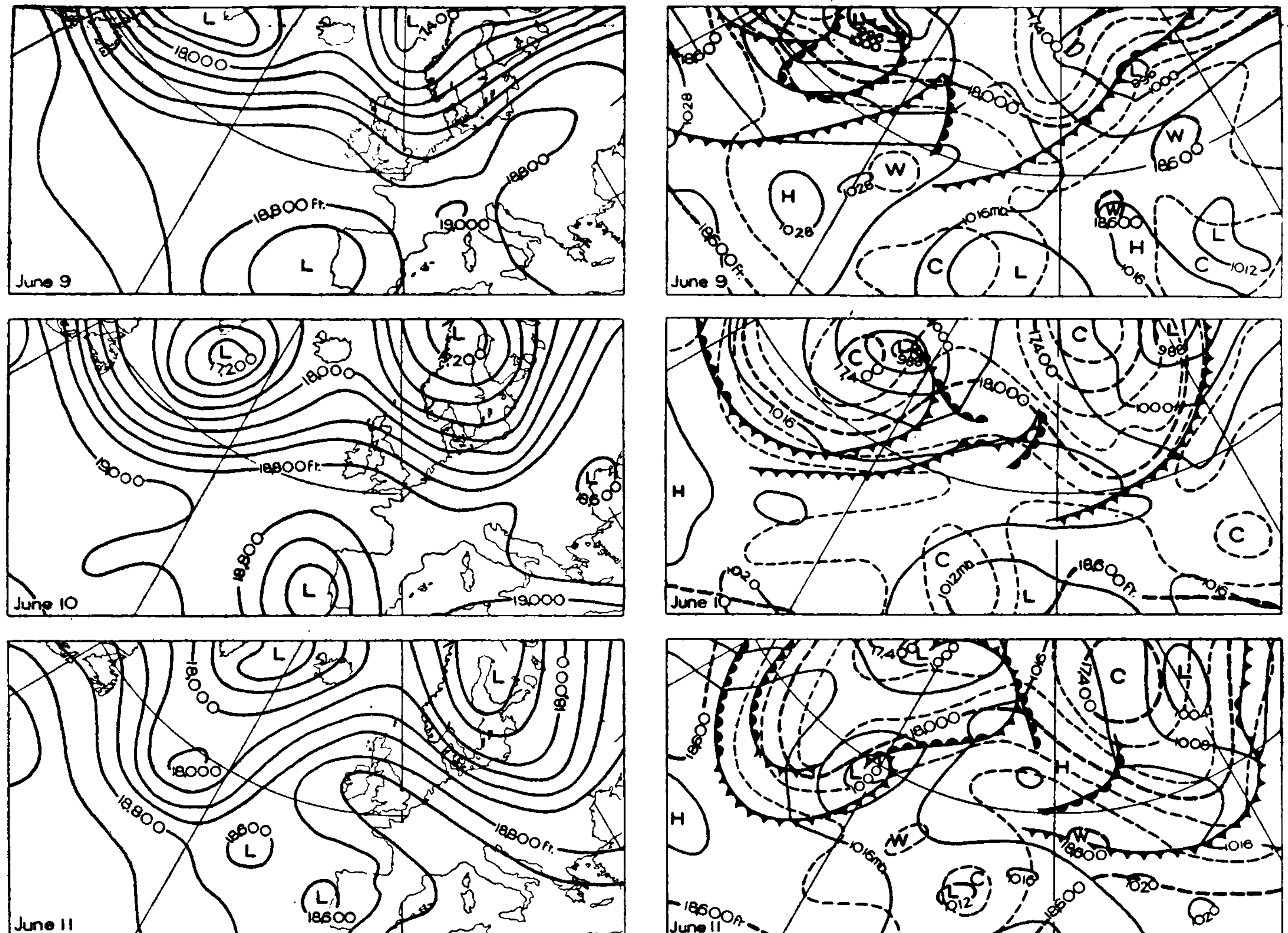
In this case the zone of upper westerlies shown on the 500-mb. charts is north of its mean position, and, as in the period October 19–21 there are two baroclinic depressions separated by a ridge extending, in this case, from the large high away to the south-west. There is, however, on the 9th generally low pressure over south-west Europe associated with a cut-off cold upper air vortex. As the sinusoidal wave pattern in the westerlies moves east and grows in amplitude the ridge breaks off from the high to the west thus giving a clear case of a new anticyclone. The example shows how a simple oscillation in the westerlies may readily give rise to a new high cell when there is no pre-existing anticyclone to the south of the anticyclogenetic region of the wave pattern, and a ridge construction is then hardly possible on geometry alone.

November 30–December 2, 1950 (Fig. 4)

There is clearly much similarity, in a broad sense, between this and the previous case. The main westerlies and the main baroclinic zone are again well north and there is already a large-amplitude oscillation. The low-latitude surface depression in mid Atlantic is completely cut off from the upper westerlies and is also thermally cut off as a cold pool. With further growth in the amplitude of the eastward-moving upper wave pattern a new high centre is formed on the 1st, this time appearing to detach itself from the high-latitude anticyclone. One can well imagine that if a similar oscillation were to arise in the absence of the low-latitude depression (that is if the Azores high were present as in the classical general circulation model) there might well be only a ridge development with no new high cell. Incidentally, the Atlantic situation on the 30th may be regarded as a "block" (higher-latitude high and lower-latitude low with separation of the upper westerlies into two branches), and a tendency for the block to be resolved can be seen on the 2nd by the cut-off, low-latitude, cyclonic vortex at 500 mb. being swept up, as it were, into the trough extension from the north-east.

The last two examples show clear cases when the new high, associated with a large oscillation of the westerlies, became a major feature near the British Isles, but, quite generally, whenever the upper westerlies run north of a low-pressure region high cells are readily formed even with quite small-scale oscillations. Thus it is common to have a more or less normal subtropical Atlantic anticyclone with a col extension across south-west Europe north of low pressure in the Mediterranean (common in winter) or over north Africa (typical of summer). Then, associated with ridges between travelling higher-latitude depressions, new high cells appear to detach themselves from the Azores high and move eastwards across Europe. These cells may be quite important for detailed, short-period forecasting. There were several cases in July 1950.

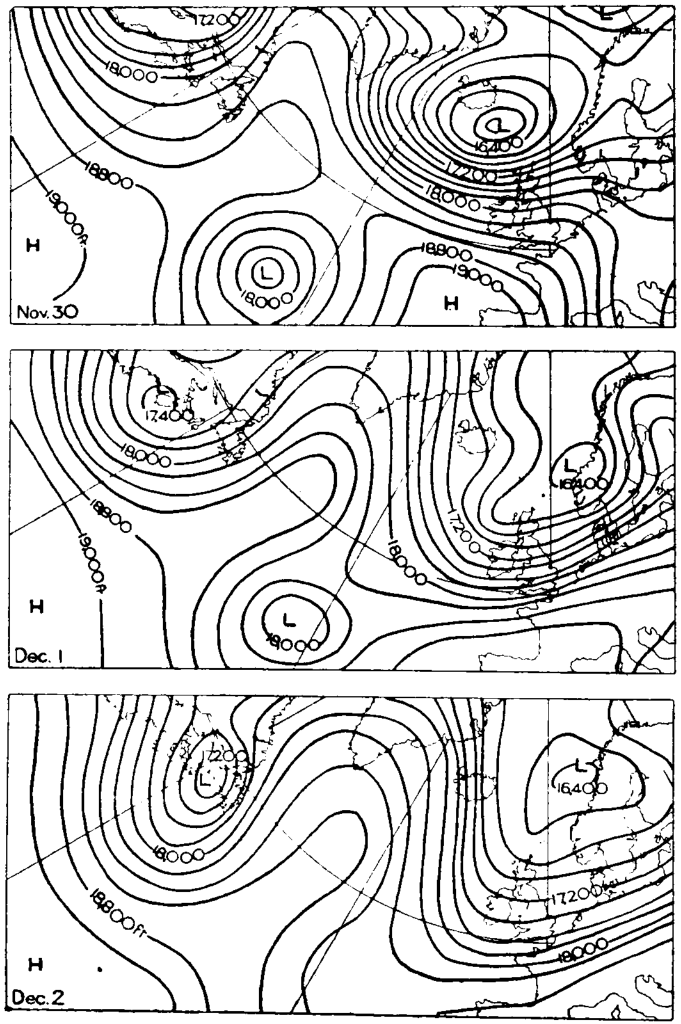
Something rather similar occurs when there is an occluded cold depression, say over the British Isles, with high-level westerlies continuing in a baroclinic zone at rather high latitudes (analysed as containing the arctic front). Then new high cells may appear to detach themselves from a semi-permanent high in the polar seas and move east or south-east into Scandinavia. These occur usually with quite conventional oscillations in the upper westerlies of these latitudes. There were two cases in November 1951.



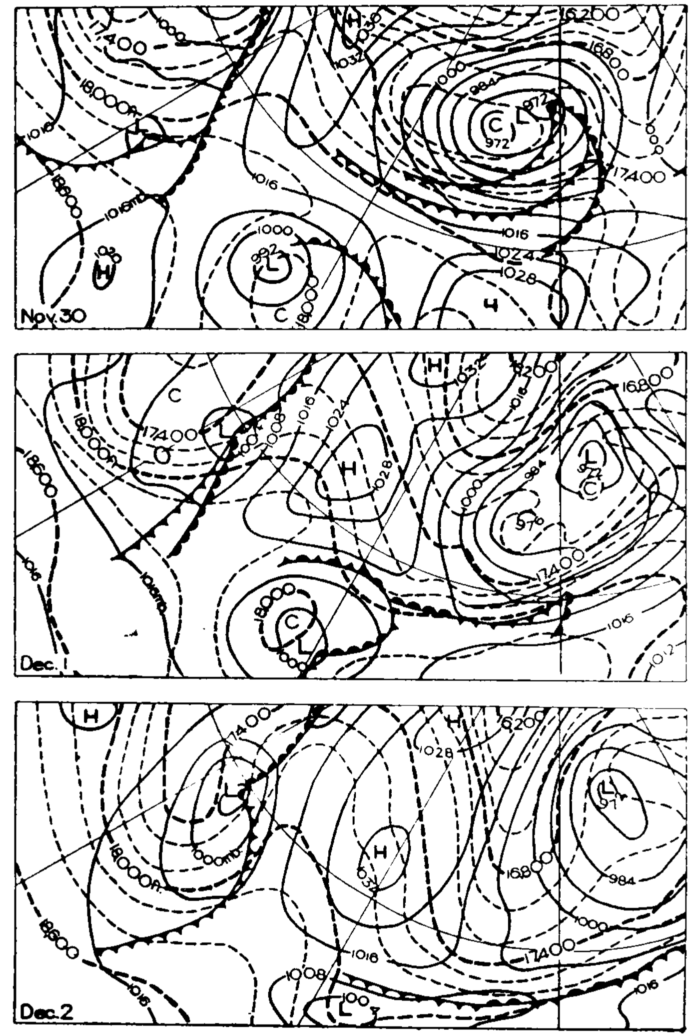
500-mb. contour charts, 0300

Surface isobars, 0000, full lines
1000–500-mb. thickness, 0300, broken lines

FIG. 3—NEW ANTICYCLONE WITH OSCILLATION IN UPPER WESTERLIES NORTH OF PRE-EXISTING DEPRESSION, JUNE 9-11, 1950



500-mb. contour charts, 0300



Surface isobars, 0000, full lines
1000–500-mb. thickness, 0300, broken lines

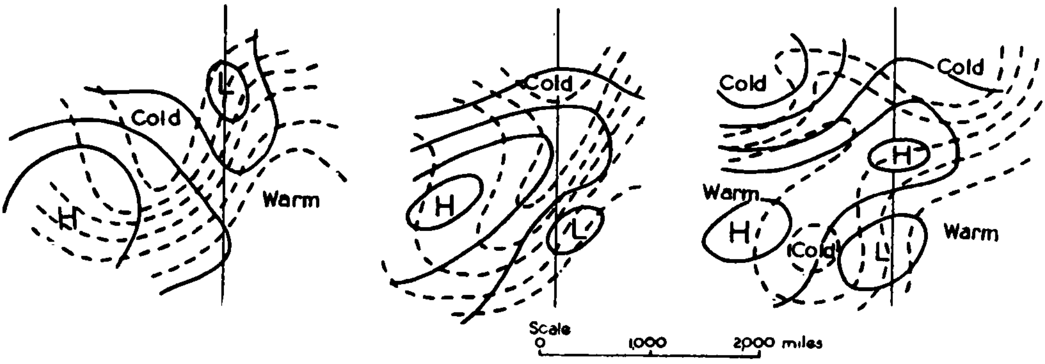
FIG. 4—NEW ANTICYCLONE WITH OSCILLATION IN UPPER WESTERLIES NORTH OF PRE-EXISTING DEPRESSION, NOVEMBER 30–DECEMBER 2, 1950

Disrupting Oscillation.—For the most part (but rarely over the whole hemisphere at the same time) the picture given by a study of the upper westerlies of middle latitudes and the associated surface pressure features is of one baroclinic zone with a number of wave-like distortions passing between cold troughs and warm ridges which are linked with the surface features according to various models which it is not necessary to describe here. New cyclonic centres are regularly, and new anticyclonic centres in our region are sometimes, associated with new sinusoidal oscillations in the upper current but the main upper stream remains concentrated around one maximum. From time to time, however, especially when the oscillation reaches a large amplitude, the current and the wave pattern disrupt, the stream divides and two distinct wave-like distortions move at different speeds rapidly becoming out-of-phase. This process of disruption has been described in connexion with "blocking" (e.g. by Rex[2,3]) and "cutting-off" (e.g. by Palmén[4]) although no satisfactory explanation of the dynamics or criterion for the occurrence is yet available.

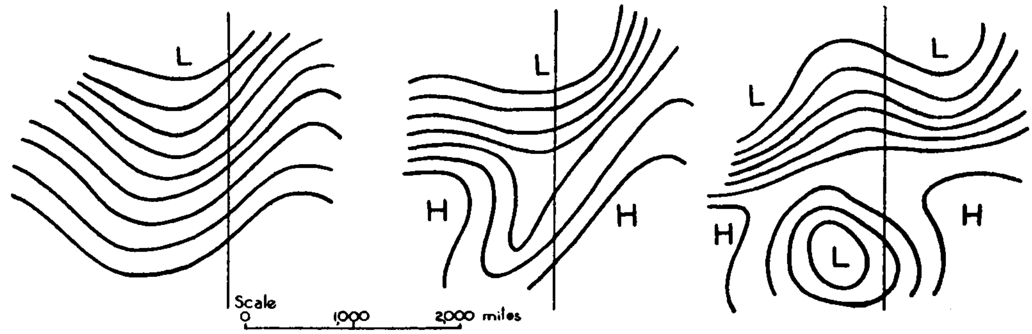
The problem of disruption is likely to be difficult until at least there is an acceptable quantitative explanation of the spatial coherence of the upper wave pattern and the associated depressions and anticyclones which do persist as features in spite of the very large variations in wind speed both horizontally and vertically. It is more remarkable that any large-scale wave-like form can hold together than that it should disrupt from time to time. It is however relevant to note that a wave form in the westerlies, if moving with uniform speed over the earth's surface, will tilt forward at high latitudes merely owing to the shape of the earth while the Rossby retrogressive effect on the phase velocity $\beta L^2/4\pi^2$ (where β is proportional to the cosine of latitude and L is the wave-length) has a direct bearing on the relative stagnation of the lower-latitude wave form once disruption has occurred, and may be an important factor in the dynamics of disruption.

While, geometrically, the wave form is to be imagined as disrupting by relative progression either at the higher or the lower latitude the former would on the above considerations seem the more likely, and in fact does occur much more definitely and frequently. A schematic representation of the sequence of charts is shown in Fig. 5. It is characterized by the lagging behind of the low-latitude upper trough followed by complete disruption and the cutting off of a low-latitude upper low generally with a cold pool and also, in our region, a low-latitude surface depression; at the same time high pressure builds across the neck of the cut-off.

As the relative shear between the two parts of the trough is anticyclonic in sense, with the surface ridge across the neck appearing rather like a roller, the process will be called "anticyclonic disruption". Some nine of our new anticyclone centres appeared in this way, one of which is illustrated in Fig. 6 and discussed below. It must however be noted that the process does not normally produce a new high cell, according to our definition, but more commonly gives only a ridge development or a displacement across the neck of a pre-existing high from the west. Thus in the two years there were some 50 cases of anticyclonic disruption over the region; all gave a ridge building across the neck and all gave a cut-off low-latitude depression, but only nine clearly satisfied our criterion of formation of a new high centre; as in the case of simple oscillation the anticyclogenetic process is much more common than the emergence of a new, detached, high centre.



Surface isobars = full lines. 1000–500-mb. thickness = broken lines



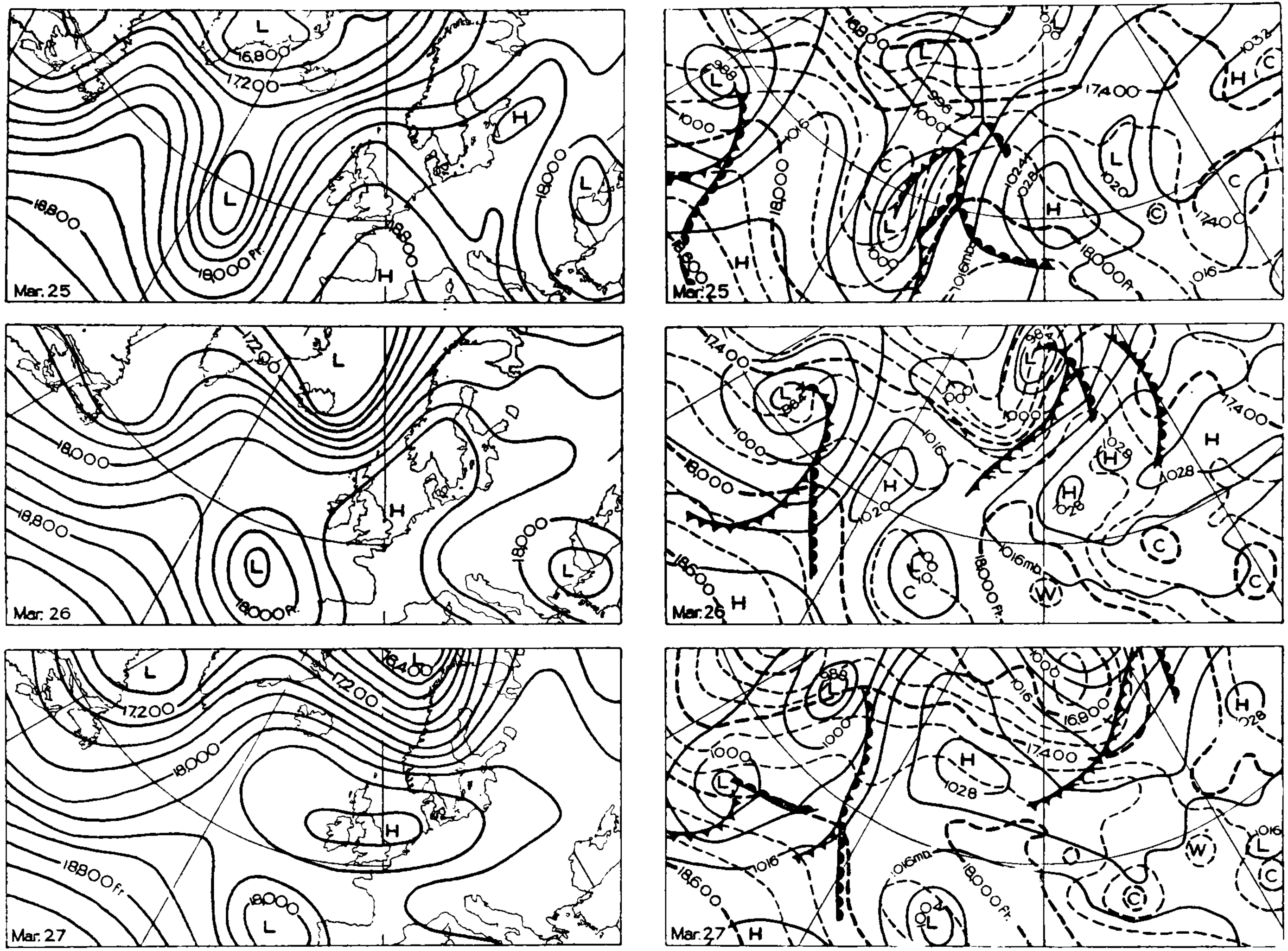
500-mb. contours = full lines

FIG. 5—SCHEMATIC MODEL OF ANTICYCLONIC WAVE DISRUPTION: PROGRESSION TO NORTH, STAGNATION AND CUTTING OFF TO SOUTH WITH SURFACE RIDGE BUILDING ACROSS THE NECK

March 25–27, 1950 (Fig. 6)

On the 25th the 500-mb. westerlies show one broad current across the Atlantic although the large-amplitude trough is already broken across the neck. At the surface there are two depressions associated with this upper trough, one to the east of the southern limit of the trough, the other further north. By the 26th the upper disruption is complete, the high-latitude part of the trough has moved to the north of Scotland lagging in phase behind the associated surface low in the normal way. The low-latitude part of the upper trough has moved more slowly and become a well separated vortex almost in phase with the cold pool and the surface depression. A new anticyclone now detaches itself from the ridge to the west and builds across the neck. By the 27th higher-latitude progression has continued, the new anticyclone is phased into the development region between the two depressions and is due north of the low-latitude cut-off low (so constituting a block in the westerlies).

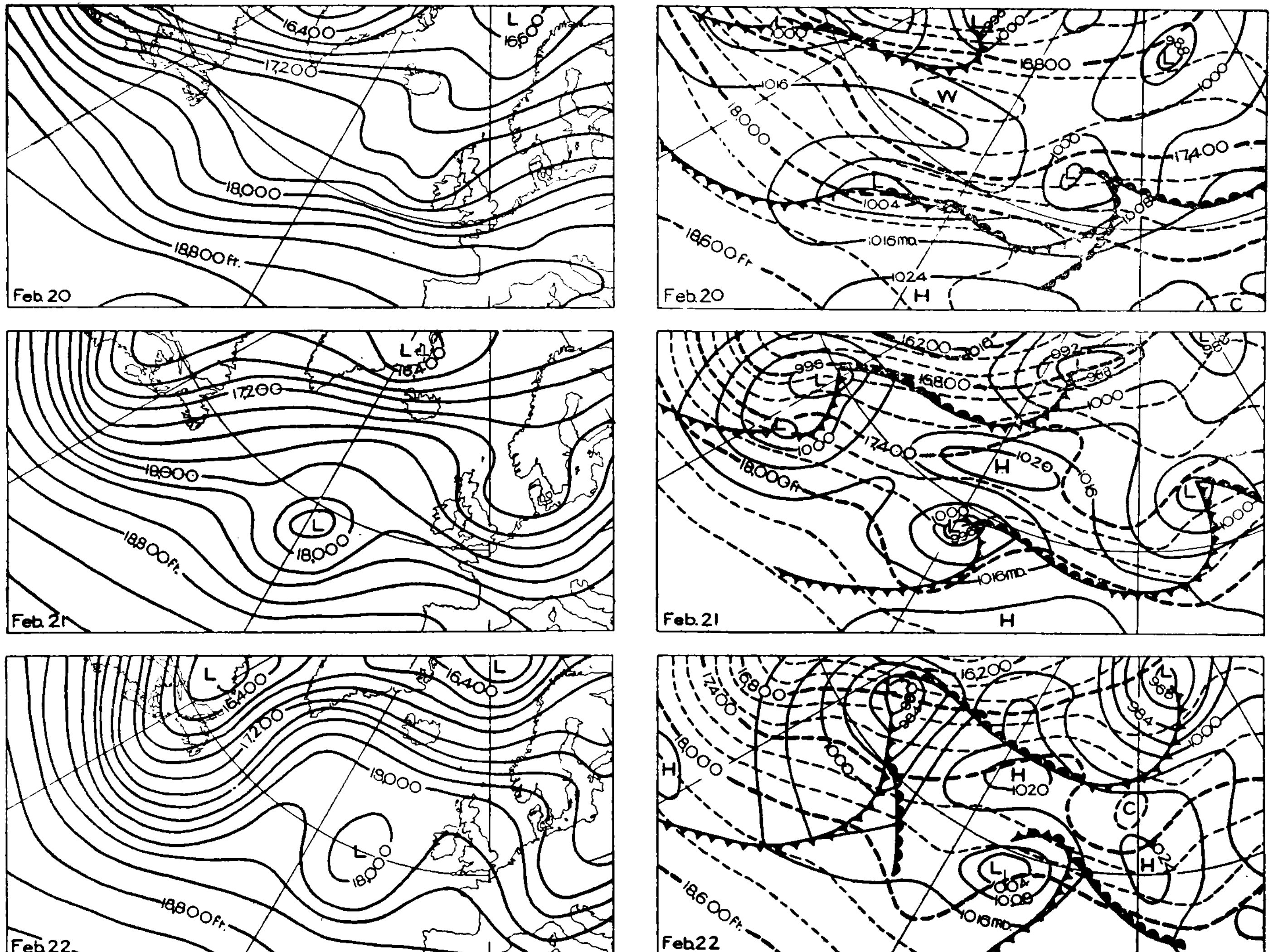
Although anticyclonic disruption is the common way in which a simple upper wave pattern may disrupt and the stream divide, an inspection of the upper charts alone will reveal cases where the southern part of an upper trough breaks forward and undercuts a higher-latitude ridge; a cold cut-off lower-latitude depression is the normal outcome. The process is found to westward of a blocked situation and is well illustrated by Berggren, Bolin and Rossby[5]. The immediate controlling system is a baroclinic cyclogenesis in the westerlies as they approach a strong diffluence and may be called a "cyclonic disruption". Although it is associated with a blocking high, even with its development or retrogression, there is no clear case of a new anticyclone appearing in the process over the two years considered, and, in spite of the importance of the situation in the general problem of anticyclones, it calls for no further attention here.



500-mb. contour charts, 0300

Surface isobars, 0000, full lines
1000–500-mb. thickness, 0300, broken lines

FIG. 6—ANTICYCLONIC DISRUPTION, MARCH 25–27, 1950



500-mb. contour charts, 0300

Surface isobars, 0000, full lines
1000–500-mb. thickness, 0300, broken lines

FIG. 7—NEW ANTICYCLONE IN COMPLEX SITUATION WITH TWO SERIES OF BAROCLINIC (FRONTAL) DEPRESSIONS FEBRUARY 20–22, 1950

Complex situations.—Although it proved possible to classify some 80 per cent. of the cases into the two types of simple oscillation and wave disruption there remain a number of cases which can only be called complex, where more than one region of dynamical development, more than one system of depressions although to some extent independent, interact giving rise to a new high cell as an element in the complex. This sort of process is to be expected, and it is perhaps surprising only in that the number of cases is so small. The only approach likely to lead to useful comment is by quantitative dynamical analysis of each occurrence, and in the present state of quantitative methods one would not choose the unusually complicated as an exercise. One example is however illustrated.

February 20–22, 1950 (Fig. 7)

This is a clear case of two baroclinic zones over the Atlantic with two sets of frontal depressions. Between the two a new high cell is detached on the 21st in mid Atlantic and this later divides, one part phasing in between the pair of depressions in the north, the other dropping into place appropriately in the southern system over Europe. The northern high may be regarded as developing with the growing 500-mb. oscillation, as a simple case of the class studied on p. 168. But between the 20th and 21st there is deepening of four neighbouring baroclinic depressions simultaneously, a situation which is rare and may well be unprecedented in recorded meteorology.

Conclusions.—There are apparently only two modes of break-down of the zonal westerlies which give rise to new anticyclonic centres: the growing sinusoidal oscillation (unstable wave) and the anticyclonic disruption.

These modes of break-down are invariably associated with anticyclonic building at the surface but most commonly only a ridge or wedge development occurs. The new high centre is exceptional in the Atlantic–western European region, especially so when the broad synoptic situation is of the classical general circulation type (subtropical high pressure south of the baroclinic westerlies).

Although one or other form of dynamical break-down is essential for initiating an anticyclone it is evidently not sufficient to ensure the formation of a new centre or the development of an important system.

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2. REX, D. F.; Blocking action in the middle troposphere and its effect upon regional climate. *Tellus, Stockholm,* **2,** 1950, p. 196 and p. 275.
3. REX, D. F.; The effect of Atlantic blocking action upon European climate. *Tellus, Stockholm,* **3,** 1951, p. 100.
4. PALMÉN, E.; Origin and structure of high-level cyclones south of the maximum westerlies. *Tellus, Stockholm,* **1,** 1949, p. 22.
5. BERGGREN, R., BOLIN, B. and ROSSBY, C.-G.; An aerological study of zonal motion, its perturbations and break-down. *Tellus, Stockholm,* **1,** 1949, p. 14.

CLEAR-AIR TURBULENCE AT 20,000 ft. IN A FRONTAL ZONE

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

At 1500 G.M.T. October 22, 1952, a Hastings aircraft of the Meteorological Research Flight was flying westward at 20,000 ft. over Southampton Water when turbulence was encountered for two minutes. The turbulence was classed as moderate to severe, and caused pronounced pitching and rolling which made positive control of the aircraft difficult. The true airspeed of the Hastings was 165 kt.; an aircraft flying at a much higher speed would probably have reported severe turbulence because of the greater accelerations.

The same course was maintained for a further three minutes in smooth air before turning on to a reciprocal heading. Three minutes later turbulence was again encountered for about the same period as before. Unfortunately a fuller investigation of this turbulent region could not be made as the aircraft developed engine trouble and had to return to base.

The normal character of the turbulence met with near the surface, or in stratocumulus and in some layers of medium cloud, is similar to the bumpiness felt in driving over a cobbled road. On this occasion a longer-period component of the turbulence gave the impression that there were irregular dips and humps in the road.

Upper air information.—The cross-section in Fig. 1 shows the position of the front and the jet stream between Camborne and Hemsby. The frontal zone was associated with an active warm front reaching the surface about 300 miles to the south-west of Scilly.

A comparison of the temperatures taken from the aircraft on the ascent with those of the simultaneous radio-sonde ascent from Larkhill shows similar features, see Fig. 2. The apparent overall increase of the temperature as measured from the aircraft is probably due to instrumental lag as measurements

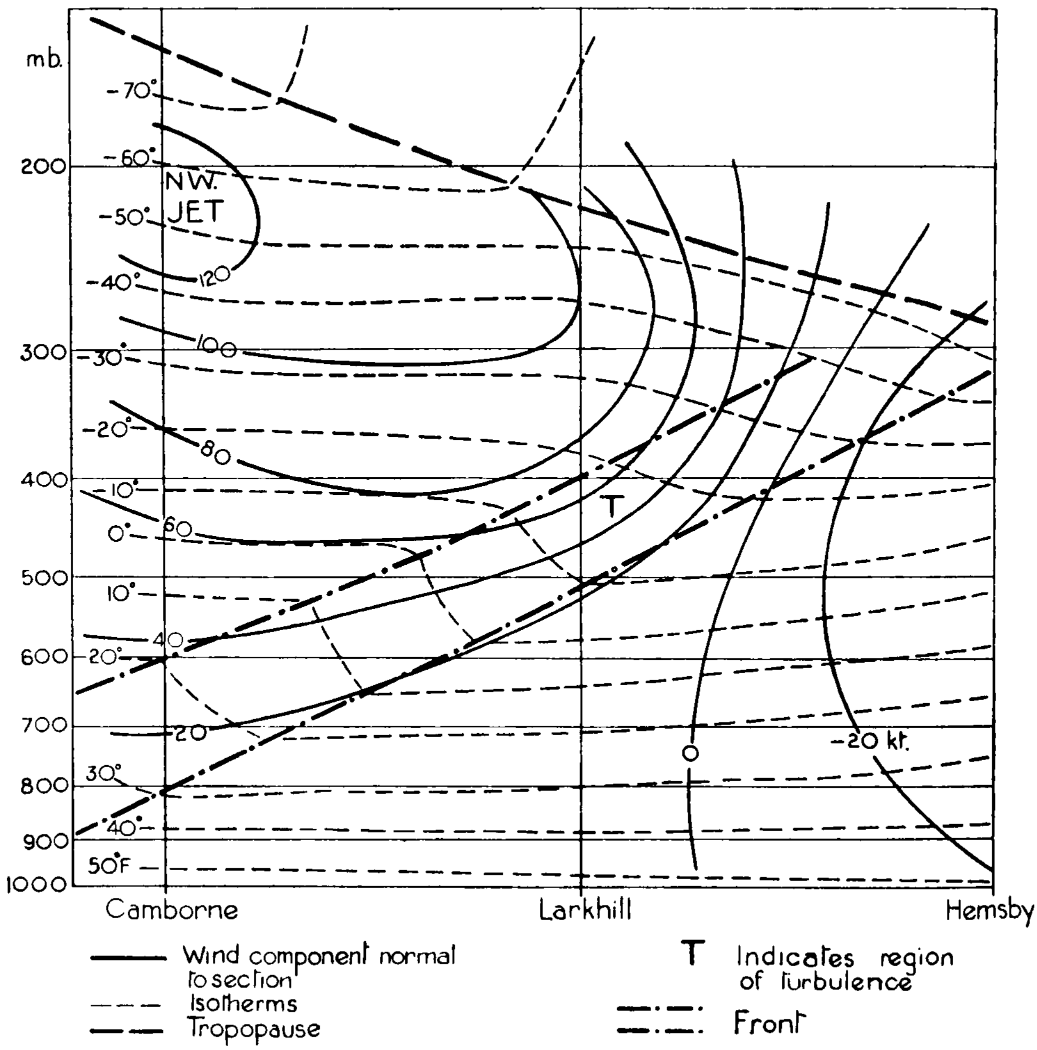

FIG. 1—CROSS-SECTION FROM NORTH-EAST TO SOUTH-WEST, 1500 G.M.T., OCTOBER 22, 1952

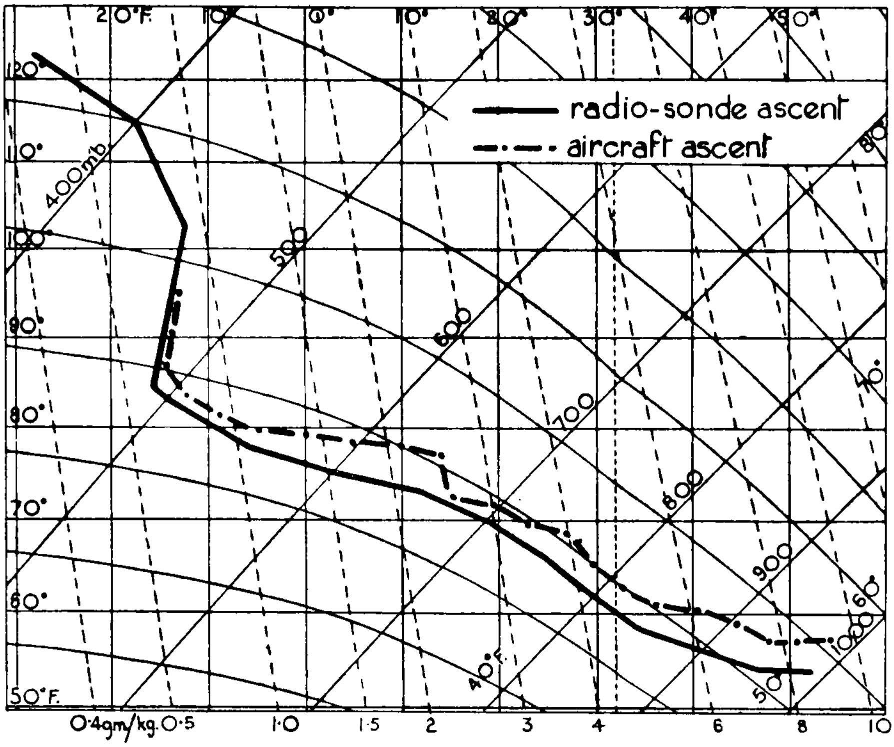

FIG. 2—COMPARISON OF AIRCRAFT TEMPERATURE ASCENT WITH RADIO-SONDE ASCENT FROM LARKHILL, 1500 G.M.T., OCTOBER 22, 1952

were made while the aircraft was climbing rapidly. The similarity of the ascents is thought to justify the use of the cross-section as a description of the conditions over Southampton Water which is about 30 miles south-east of the plane of the cross-section. Differences due to the distance are minimized by the fact that the jet stream is north-westerly and the front lies in the same direction.

An important feature of the temperature curve is the inversion of 3°F. through the frontal zone between 18,500 and 21,000 ft. The turbulence occurred within this region. The component part of the wind shown in Fig. 1 is the major part of the resultant wind in the turbulent region (T) so that a representative value of the wind shear can be obtained directly from the information given.

Vertical shear.—The vertical shear through the turbulent region is large, averaging 10 kt./1,000 ft. over 5,000 ft. It is probably stronger over a smaller height interval. Because of this large shear it is likely that the turbulence on this occasion was primarily due to vertical shear although horizontal shear was sufficiently large to indicate the possibility of turbulence from this cause alone.

Horizontal shear.—The horizontal shear along the north-east to south-west line of maximum shear through the turbulent region is 0·40/hr. In a previous analysis[1] of a report of severe clear-air turbulence at 30,000 ft. the associated horizontal shear was of the same order as in the present case.

Richardson's number and vertical shear.—L. F. Richardson[2] related static stability and wind shear to give a dimensionless number (R_i) which is related to the nature of flow in the atmosphere. As a criterion for the increase or decrease of turbulence Richardson used R_i less than or greater than unity. On this occasion, considering the vertical shear alone, the value of R_i was 1·59.

Bannon[3] used R_i as a parameter in an investigation of turbulence in the upper troposphere and lower stratosphere, and found a definite relation between turbulence and small values of R_i at these levels (i.e. values of R_i less than 10).

Conclusion.—The existence of moderate to severe turbulence in a region of strong wind shears, with a small value of the Richardson number ($R_i = 1 \cdot 59$), is in agreement with the evidence that small values of R_i are associated with marked turbulence in the atmosphere.

The only known criteria for forecasting clear-air turbulence at present are strong wind shears and low values of the Richardson number. These criteria are usually applied to the upper troposphere and lower stratosphere, particularly in the vicinity of jet streams.

The analysis of this occasion of clear-air turbulence is interesting, in that it shows that if the requisite conditions exist at lower levels such as in a dry frontal zone, then the same criteria are of equal importance in assessing the likelihood of clear-air turbulence being found.

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2. RICHARDSON, L. F.; The supply of energy from and to atmospheric eddies. *Proc. roy. Soc., London*, A, **97**, 1920, p. 354.
3. BANNON, J. K.; Meteorological aspects of turbulence affecting aircraft at high altitude. *Prof. Notes met. Off., London*, **7**, No. 104, 1951.

JET STREAM OF OCTOBER 28, 1952

By D. H. JOHNSON, M.Sc.

The jet stream which affected the British Isles on October 28, 1952, attracted an unusual degree of interest at the Central Forecasting Office, Dunstable. Very strong winds were reported at comparatively low levels within the current, and one ascent made at 0900 G.M.T. into the core of the jet stream showed the strongest wind to be located near the 500-mb. level. Since, in the autumn season near the British Isles, jet-stream centres normally occur between 300 mb. and 200 mb., it was thought that the phenomenon merited brief investigation, a short account of which is given below.

Synoptic situation.—At 0300 G.M.T. a jet stream flowed from the south-west towards the British Isles (Fig. 1). At the surface, a very deep depression was centred to the north-west of Ireland and was moving steadily north-east as an associated frontal system crossed the country. Fig. 2 contains a vertical cross-section, taken through the exit of the jet stream, normal to the direction of flow at the jet centre, the isokinetics giving the component of wind speed perpendicular to the line of section. Beneath the jet stream there was unusually strong flow down to the 900-mb. level and the greatest baroclinity occurred below 550 mb.; only weak thermal gradients existed between 550 mb. and the top of the troposphere. The exact level at which the wind maximum occurred is a little in doubt; as drawn its position agrees with the Aldergrove upper winds but the decrease of wind above 400 mb. depends on an observation made when reception of the reflected radar signals was poor. From the temperature field alone, one might expect to find the highest wind between 350 and 300 mb. The section lies almost parallel to an occluded surface front which was not clearly marked in the thermal field. The warm-air tropopause was ill

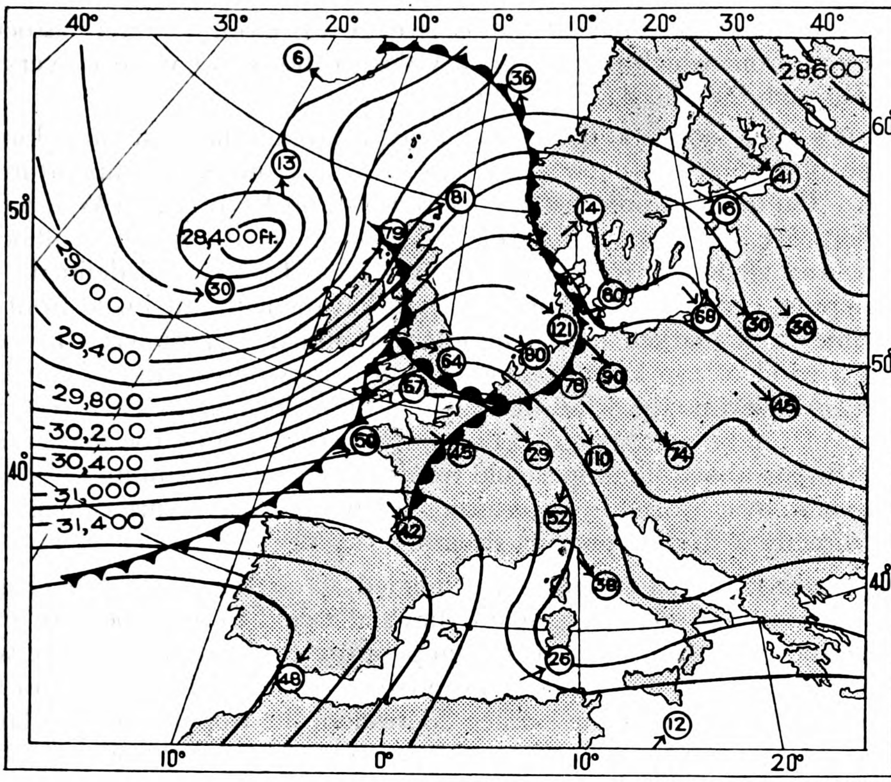

FIG. 1—300-MB. CONTOUR CHART, 0300 G.M.T., OCTOBER 28, 1952
Erratum: *for* "30,400 ft." *read* "30,600 ft."

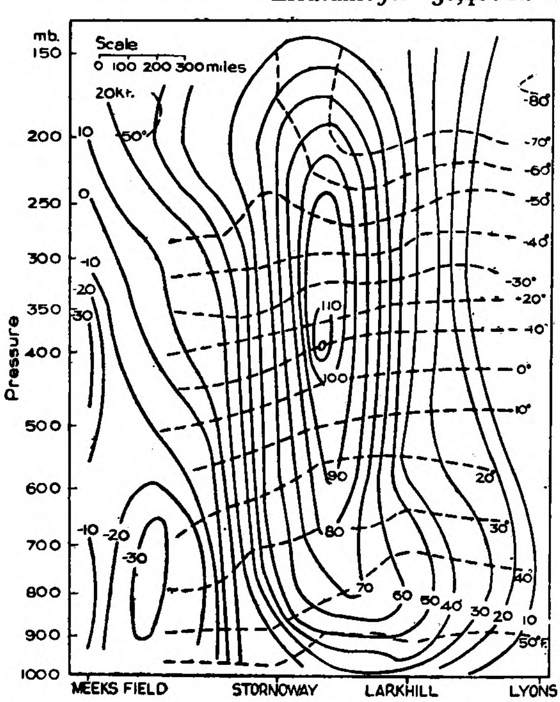

FIG. 2—CROSS-SECTION THROUGH LIVERPOOL NORMAL TO THE UPPER FLOW, 0300 G.M.T., OCTOBER 28, 1952

- - - - - Isotherms

——— Isokinetics, positive for WSW. wind components

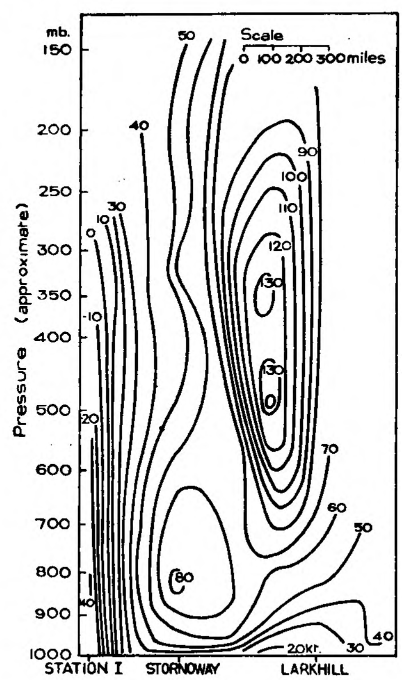

FIG. 3—CROSS-SECTION THROUGH LIVERPOOL NORMAL TO THE UPPER FLOW, 0900 G.M.T., OCTOBER 28, 1952

——— Isokinetics, positive for WSW. wind components defined. Upstream from its exit the jet stream was more definitely associated with the cold front which the ascent at Valentia shows to have been very well marked through the middle troposphere.

Fig. 3 is a cross-section at 0900 G.M.T. drawn through the jet stream along the same line of section (at 0900 G.M.T. upper winds but not temperature are observed). On this occasion the ascents from station I (59°N., 19°W.), Stornoway, Aldergrove, Liverpool and Larkhill reached 30,000 ft., 53,000 ft., 48,000 ft., 39,000 ft. and 28,000 ft. respectively, so the wind field is well defined. The strong, sloping, cyclonic shear zone suggests that the associated cold front was, at this time, well marked in the middle and upper troposphere. Liverpool reported a wind of 110 kt. at 14,000 ft. and a maximum wind of 147 kt. at 19,000 ft. Above this the wind decreased a little, but there was a secondary maximum of 129 kt. at 27,000 ft. Evidently there was little thermal gradient in the warm air above the upper cold front. The wind maximum of 80 kt. at about 5,000 ft. over Stornoway was associated with the deep surface depression and not directly with the upper jet stream.

By 1500 G.M.T. the jet stream had extended across the North Sea (Fig. 4), and the cross-section of Fig. 5 again shows the cold front to be very strong thermally and to contain most of the temperature contrast between the warm and cold air masses in the upper troposphere. To the north of the cold front and south of the centre of the surface depression, the troposphere was largely barotropic so that the wind field showed little change from the surface almost to the top of the troposphere. However, to the north of the centre of the depression the atmosphere was sufficiently baroclinic for the easterly flow to become negligible at the 300-mb. level.

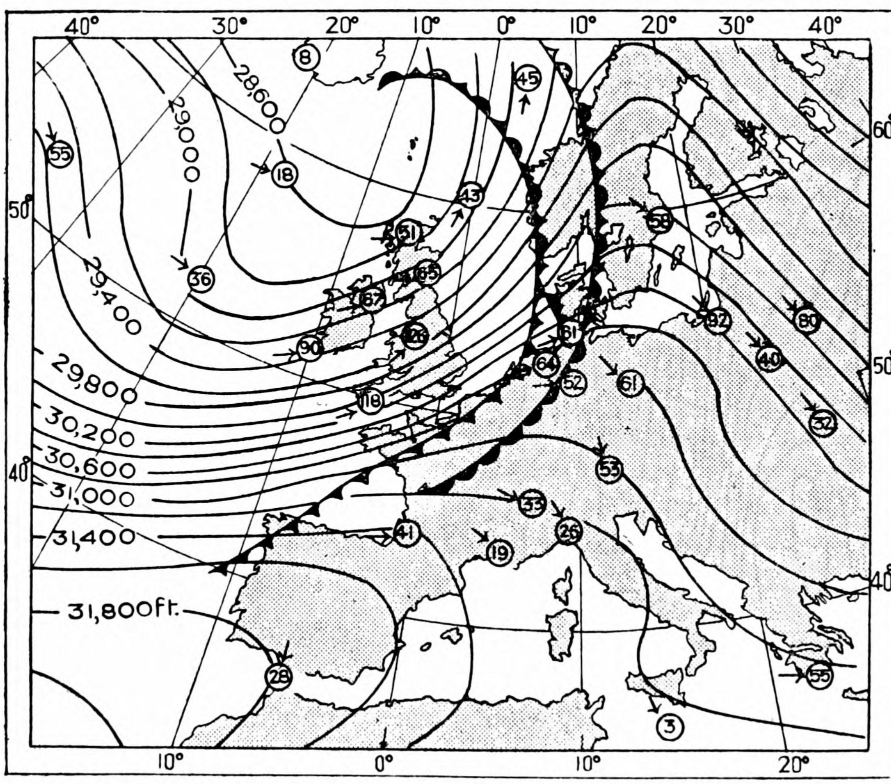

FIG. 4—300-MB. CONTOUR CHART, 1500 G.M.T., OCTOBER 28, 1952

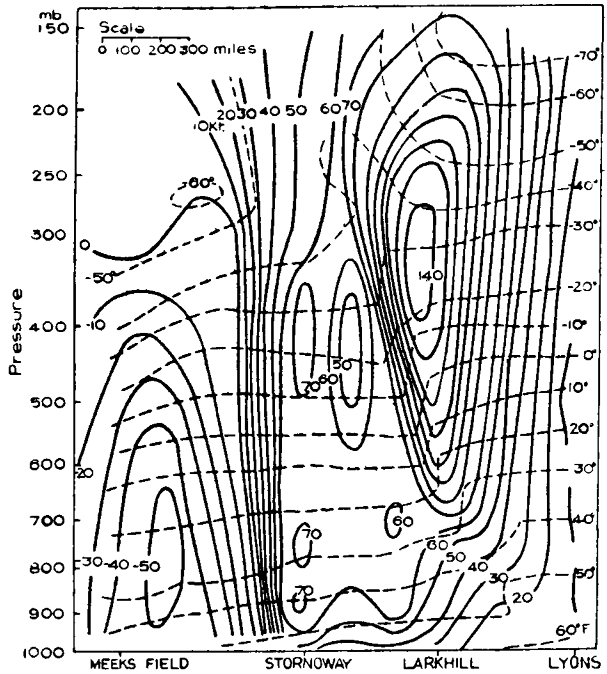

FIG. 5—CROSS-SECTION THROUGH LIVERPOOL NORMAL TO THE UPPER FLOW, 1500 G.M.T., OCTOBER 28, 1952

- - - - - - Isotherms
——— Isokinetics, positive for WSW. wind components

Comment.—The feature which led to the construction of these sections was the occurrence of the wind maximum at 0900 G.M.T. above Liverpool at 19,000 ft., apparently well beneath the region of the tropopause. It is clear that away from the delta region, where there are always complexities, the jet stream was characterized by the unusually intense sloping frontal zone and the quasi-baroclinic nature of the warm air above the front. These features appear to have been particularly well developed at 0900 G.M.T. when the vertical wind profile through the core of the current had an exceptionally flat maximum with minor peaks at 19,000 ft. and 27,000 ft. In view of this the occurrence of the highest wind speed at 19,000 ft. is a little less surprising since an additional, possibly ageostrophic, wind component at that level of only some 20 kt. has to be accounted for. Examination of the graph of rate of ascent plotted against time for the ascent at Liverpool at 0900 G.M.T. indicates that the 147-kt. wind occurred over a minute interval when the apparent rate of ascent of the balloon was about 500 ft./min. greater than average. A possible explanation of the phenomenon, which could account for additional components of both vertical and horizontal speed of the required order of magnitude, is that the effect was due to a standing wave set up in the solid south-westerly flow over the Welsh Mountains. However, since the exceptional horizontal and vertical displacements of the balloon took place over the same minute interval the possibility of an error having been made in the measurement of the slant range of the balloon cannot be discounted.

Summarizing briefly: at one stage in the history of this jet stream its thermal structure appears to have approximated to the simple model of a sloping frontal layer separating two barotropic air masses. Experience shows such a structure to be unusual. When it does occur, it is to be expected that the exact position of the jet-stream axis in the horizontal depends to a greater extent than is usual on the surface wind field, and in the vertical depends largely on minor irregularities of the flow; it may not be situated very close to the tropopause.

METEOROLOGICAL RESEARCH COMMITTEE

At their meeting on January 29, 1953, the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee considered a paper by Mr. Sawyer[1] in which the author demonstrated that atmospheric inhomogeneities in temperature having no synoptic significance may lead to "kinks" on an upper air temperature sounding similar to those caused by frontal surfaces. Two papers by Mr. R. F. M. Hay[2,3] giving a statistical analysis of upper winds over Singapore and Hongkong respectively were considered, and Mr. Sumner[4] presented a paper containing a statistical and synoptic study of cold pools. The Committee also considered the revision of the synoptic and dynamical part of the Meteorological Research Committee's research programme.

At the Instruments Sub-Committee meeting on February 5 the Committee considered the accuracy of the British radio-sonde 300-mb. contour observations, and also a paper by Dr. Palmer[5] describing an improved automatic frost-point hygrometer, an instrument which promises to be of great value. Recommendations for revision of the instruments part of the Meteorological Research Committee's research programme were also agreed.

At the Physical Sub-Committee meetings on February 10 and 23, the technical reports considered included a paper by Mr. R. Frost[6] summarizing the meteorological aspects of the "Singapore cloud detection trials" in which an aircraft fitted with radar investigated the characteristics of clouds from which a radar echo was obtained. Dr. Scrase[7] presented a paper in which he had used the detailed measurements made on an upper air sounding to obtain a picture of the turbulence in the upper air. The variation of wind in short periods of time between 30,000 and 35,000 ft. was also discussed in a paper presented by Mr. Durst[8]. Dr. Goldie[9] gave an account of the global circulation of stratosphere air and the mechanism of change of tropopause level.

The Sub-Committee also considered the revision of Part III of the research programme and the Annual Report.

The main Committee met on March 20. At this meeting the Annual Reports from the Sub-Committees were received and the revision of the research programme for the coming year approved. The Chairman's Annual Report to the Secretary of State for Air was also agreed.

ABSTRACTS

1. SAWYER, J. S.; The effect of atmospheric inhomogeneity on the interpretation of vertical temperature soundings. *Met. Res. Pap., London*, No. 775, S.C. II/132, 1952.

Small-scale temperature fluctuations (radius 50 Km. or so) limit interpretation of vertical soundings. Flight grids in a homogeneous air mass gave standard deviation of about 0·5°F. in normal layers and 0·75°F. in stable layers. Vertical correlation between fluctuations varies from 0·85 for small separation to zero for 2,000 ft. From these facts it is found that any departure of less than 1·5°F. from a smooth curve must be treated with caution.

2. HAY, R. F. M.; Wind at high levels over Singapore (1950–52). *Met. Res. Pap., London*, No. 770, S.C. II/130, 1952.

Summary of 149 radar observations, of which 101 exceeded 55,000 ft. and 18, 70,000 ft. Easterlies are found above 25,000 ft., very strong (some over 90 kt.) in 48,000–54,000 ft. There is a strong shear at about 60,000 ft. to SW., sometimes exceeding 10 kt./1,000 ft. Tables show vector resultants at each month and height, scalar speeds, highest speeds and corresponding heights, shear values and frequencies integrated through layers.

3. HAY, R. F. M.; Wind at high levels over Hongkong. *Met. Res. Pap., London*, No. 778, S.C. II/135, 1952.

Radar and radio-sonde winds 1950–51 are tabulated and graphed for 850–60 mb. Daily observations show almost abrupt change from mostly westerlies to easterlies at 100 mb. in late May and back in early or mid October; at 150 and 200 mb. duration of easterlies is shorter. Extremes were 123 kt. from 268° and 78 kt. from 40°.

4. SUMNER, E. J.; Cold pools: a statistical and synoptic study. *Met. Res. Pap., London*, No. 764, S.C. II/125, 1952.

Thickness (1000–500 mb.), intensity and movement of cold-pool centres in 60°W.–30°E. south of 80°N. are plotted and tabulated; mainly late spring and early summer. Mean duration 3 days. Origin (mostly by cutting off a cold trough) examined. Associated pressure systems are classified into 6 types and distribution discussed. Tables and graphs show surface pressure at centres of pool and of associated high or low, cloud frequencies, type of precipitation and central thickness. Forecasting applications are considered.

5. PALMER, H. P.; An improved automatic frost-point hygrometer. *Met. Res. Pap., London*, No. 774, S.C. I/72, 1952.

An improved and simplified ex-Elliott automatic hygrometer with a germanium thimble, for use in aircraft, is described with diagrams of construction.

6. FROST, R.; Meteorological report on the Singapore cloud-detection trials. *Met. Res. Pap., London*, No. 757, S.C. III/141, 1952.

Runs were made towards and through cumulus and cumulonimbus by aircraft with 3-cm. radar. Heights of cumulus giving radar echo 13,000–33,000 ft., many below freezing level; cumulonimbus 29,000–55,000 ft. At transition level temperature is −30° to −35°C. Mean diameter, visual, 6 miles, radar 4½ miles. Occasions of hail and of snow tabulated; risk of severe icing small. Lightning occurred only with cloud top above 35,000 ft. up- and down-draughts tabulated; maximum up-draughts 53 ft./sec. Gust accelerations summarized in relation to position in cloud. Practically all turbulence can be avoided by avoiding radar-response areas by a mile.

7. SCRASE, F. J.; Turbulence in the upper air, as shown by radar wind and radio-sonde measurements. *Met. Res. Pap., London*, No. 771, S.C. III/144, 1952.

After allowing for random errors, eddy velocities were obtained from minute by minute radar winds on a radio-sonde up to 30 Km. over Downham Market. Mean wind 25 kt., fluctuations 5–10 kt. in periods of 3–4 min. Temperature fluctuations were 0·85°F. in troposphere and 0·64°F. in lower stratosphere. Results are used to estimate momentum and heat fluxes and coefficients of eddy diffusion and their bearing on the theory of heat diffusion is discussed.

8. DURST, C. S.; The variation of wind in short periods of time between 30,000 and 35,000 ft., January 1950 to January 1952. *Met. Res. Pap., London*, No. 745, S.C. III/140, 1952.

Observations of 86 pairs of smoke puffs emitted by aircraft at Orfordness, England, at intervals of 10 min. are used to calculate vector change of wind (kt./10 min.). Values ranged from 0·7 to 21·0; the larger ones tended to occur with greatest wind speeds and near tropopause or in stratosphere.

9. GOLDIE, A. H. R.; The global circulation of stratosphere air and the mechanism of change of tropopause level. *Met. Res. Pap., London*, No. 734, S.C. III/134, 1952.

January and July temperature and potential temperature, 500–90 mb. at Larkhill are plotted in relation to tropopause pressure and to tropopause at equator. The marked discontinuity at tropopause is attributed to slow air flow towards equator below and from equator above it. Steepness of the fall of potential temperature in latter current while descending 11,000 ft. points to a continual loss of heat, 67 per cent. of adiabatic gain in January and 52 per cent. in July being lost by radiation. This requires 3–4 weeks. Polar minima require loss of all or more of adiabatic gain. More rapid displacements of tropopause require convergence and vertical motion; the mechanism is discussed with examples.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on January 21, 1953, a discussion was held with the British Gliding Association on the subject of "Fair-weather cumulus".

Dr. A. A. Yates described his experiences of convection elements. He said that "bubbles" of warm air broke away from the heated ground at an average rate of one in ten minutes though there was much variation, and that an average "bubble" had a diameter of some 1,000 ft., was about 1°C. warmer than the surrounding air, and rose at about 15 ft./sec. He gave a rough theory of the rate of rise of a "bubble", considered as a sphere of buoyancy balancing drag, which tended to show that the rate of rise was proportional to the square root of the excess temperature inside the "bubble". He thought "bubbles" had a wake in which the warm inner air mixed with the surrounding air so that the shape became more and more elongated as the "bubble" rose. He stressed the need for more detailed observations, especially of temperature excess.

Dr. D. G. James of the Meteorological Research Flight described observations made with highly sensitive thermometers and hot-wire anemometers during a flight in a Hastings aircraft below fair-weather cumulus with base 3,200 ft. over Hampshire on August 28, 1952. The observations showed that below 1,000 ft. there were many convection "bubbles" having diameters of 200–4,000 ft. with a temperature excess in the interior of about 1·0°F. Above 1,000 ft. and below 3,000 ft. the records showed a marked decrease in the number of "bubbles". At these levels their diameters were almost entirely within the 200–1,000-ft. range (although one "bubble" appeared to have a diameter of 8,000 ft.) and they had a temperature excess of 0·3°–0·4°F. Above 3,000 ft. and below cloud base there existed a third region, the sub-cloud layer, which showed slow large temperature variations over distances of about 2 miles in addition to a sharp rise of temperature produced by a "bubble" of about 1,000-ft. diameter. The slower change was attributed to the descent of air from the sides of the developing cloud, whilst the increased bumpiness there was tentatively associated with the mixing of air of several different origins at this level.

Mr. Welch said "bubbles" stayed at much the same size as they rose, and described the diurnal variation of the strength and rate of formation of "bubbles". In the morning they were small but strong, and in the evening as strong as in the afternoon but formed less frequently. Fair-weather clouds were hollow at the base with an indentation which might be 250 ft. deep in a large cumulus. He added that marked contrasts of temperature, such as were found near large rivers, stimulated "bubble" formation.

Mr. F. H. Ludlam described temperatures measured with an Imperial College glider which showed an almost isothermal layer of air just below the base of cumulus clouds. He showed cine-films of air bubbles rising through water and speeded-up films of cumulus development.

Mr. F. G. Irving described temperature observations made at Cranfield which showed much smaller temperature excess than the values given by Dr. Yates.

Mr. Poulter suggested the low lapse-rate zone just below the cumulus clouds was above the condensation level and was the zone in which the droplets grew to visible size.

Professor P. A. Sheppard referred to the need for theoretical meteorologists to tackle the convection problem.

Dr. R. S. Scorer, in summing up the discussion, supported Dr. Yates's demand for glider pilots to make more scientific observations, and congratulated the Meteorological Research Flight on its successful observations of convective movements.

ROYAL ORNITHOLOGICAL CLUB

Bird migration through Great Britain in different synoptic situations

On December 17, 1952, a meeting of the Royal Ornithological Club was held at which K. Williamson read a paper on "The nature of spring and autumn passage migration through Britain". Mr. Williamson based his paper on observation of bird movements at Fair Isle throughtout 1951, a year which he said proved suitable for this purpose as the quality of spring and autumn migration was excellent. Migration at Fair Isle was found to be most marked in both spring and autumn with E. and SE. winds; this was true for both north and south bound birds. There was often a pronounced double peak in the passage of a given species at either season, the first peak coming with easterly weather, the second following a few days later in quiet anticyclonic weather. A significant fact which led to the theory put forward later in the paper was that migrant birds reaching Fair Isle were found to have lost 20–30 per cent. of their normal body weight during their overseas flight. Since birds cannot lose weight at this rate for very long before exhaustion and death follow, it is concluded that birds do not undertake such long sea crossings if an alternative overland or coastal route exists.

Previous to this work other meteorological factors, variations in temperature and pressure, passage of warm and cold fronts were considered to be the main factors influencing migration. In 1951 the migration data obtained at Fair Isle were compared directly with the *Daily Weather Report*, which led to the conclusion that migration is stimulated by lack of wind, i.e. during anticyclonic conditions and in other conditions where pressure gradients over the area are slight. It is also probable that migration is stimulated by clear weather which allows of sun orientation.

Mr. Williamson showed a most comprehensive series of slides of various synoptic situations during 1951, and described the species of migrants recorded at Fair Isle on each occasion. These slides confirmed the ideas described, and strikingly showed that a drift-migrant's best way to ensure survival was to fly with the wind and cease attempts to fly in a "preferred direction". Thus, during outbreaks of arctic air masses, species from Iceland and even Spitsbergen arrive at Fair Isle; sometimes in autumn species from central Asia are found on the Frisian coasts and at Fair Isle when easterly currents from these regions persist for a few days. In the discussion which followed speakers stressed the interesting possibilities which were opened up as a result of the pioneer work of Mr. Williamson and the novel use of the *Daily Weather Report*. Cmdr. Frankcom referred to work of this nature carried out by ornithologists on British ocean weather ships, and Mr. Hay, in discussing the synoptic aspects of the paper, suggested that on occasions reports of rare migrants from such remote places could be a useful means of identifying air masses.

R. F. M. HAY

LETTER TO THE EDITOR

Remarkable changes in the screen temperature at Waddington

During the evening of December 5, and the morning of December 6, 1952, several abrupt changes of temperature were recorded in the screen at Waddington, the most remarkable occurring on the 6th when the temperature rose 13°F. in 2 hr. These changes are a good illustration of the temperature changes associated with valley stratification in light winds, and also afford a striking example of the effect of turbulence over the Lincoln Edge.

It is generally understood that when nocturnal cooling takes place on the slope of a hill or the side of a valley the cold air at the top of the slope drains into the valley below under the influence of gravity. Geiger has pointed out that the cold air does not flow straight downhill as does water, but that little circulations are set up on the slope as warmer air flows in to the slope to take the place of that moving downhill. A cold "lake" is formed at the bottom of the slope, but as a result of the circulations a much warmer layer is found near the top of the slope. The resulting temperature distribution (according to Geiger) is shown in Fig. 1 together with a cross-section west to east through Waddington airfield. It will be seen from the cross-section that Waddington airfield (235 ft. above mean sea level) is near the crest of the Lincoln Edge, the eastern side of which slopes gently down to the Witham Valley, whilst to the west there is a sharp escarpment with a drop of about 200 ft. in 500 yd. The Lincoln Edge itself runs almost exactly north–south.

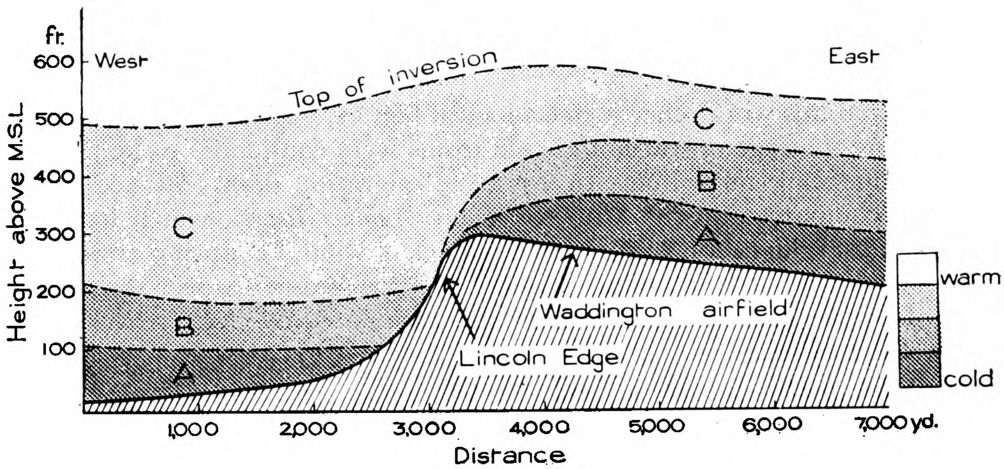

FIG. 1—TEMPERATURE DISTRIBUTION OVER LINCOLN EDGE, DECEMBER 5–6, 1952

The synoptic situation on the night of December 5–6, showed a ridge of high pressure from Poland extending westwards over the Low Countries and East Anglia with a light S.–SSW. gradient wind over Lincolnshire.

The Hemsby ascent was the most representative of air over Lincolnshire, and at 0200 on the 6th it showed a marked surface inversion with surface pressure and temperature, 1035 mb. and 30°F. respectively. The top of the inversion was at 1019 mb., where the temperature was 39°F. Allowing 28 ft./mb. the top of the inversion was 448 ft. above Hemsby and thus approximately 500 ft. above sea level.

The temperature at Waddington fell steadily during the late afternoon and early evening of the 5th. Applying the Hemsby ascent to Waddington it appears that a marked, but vertically very shallow, inversion developed at Waddington, and the top of this inversion may have been only 250–350 ft. above the airfield. Fig. 2 gives the temperature curve for Waddington from 1200 on the 5th to 2300 on the 6th, and hourly surface winds have been inserted. From Fig. 2 it can be seen that commencing at 1500 on the 5th temperature fell steadily, and by 1900 was down to 29·4°F., and that during this period the surface wind direction was 190° or further to the south-east. Between 1900 and 2000 the wind veered to 210° for a short period, and at 2000 the temperature had risen to 34·8°F., though by this time the wind had backed again to 170°. At 2100 the temperature had fallen again to 28·9°F. The wind veered to 210° at 2100 and continued at 200° or further west until 0600 on the 6th. The temperature rose to 33·4°F. at 2200 and to 35·2°F. at 2300, but by 0600 had been reduced to 33·2°F. by slight nocturnal cooling. By 0700 the wind had backed again to 180° and the temperature had fallen to 28·5°F. The wind continued at 170–180° and by 0900 temperature had fallen to 26·2°F. Fog formed at 0745 when the temperature had fallen to 28·0°F.

During the next 2 hr. a remarkable rise of temperature occurred. The wind which had been from 170° at 0900 veered to 210° for a period around 1000. The temperature rose from 26·2°F. at 0900 to 29·0°F. at 1000, and by 1100 had reached 39·1°F. Thus a rise of 10°F had occurred in 1 hr., but as the fog had cleared at 1030 it is possible that the change had occurred in less than 1 hr. and perhaps in as short a period as 40 min.

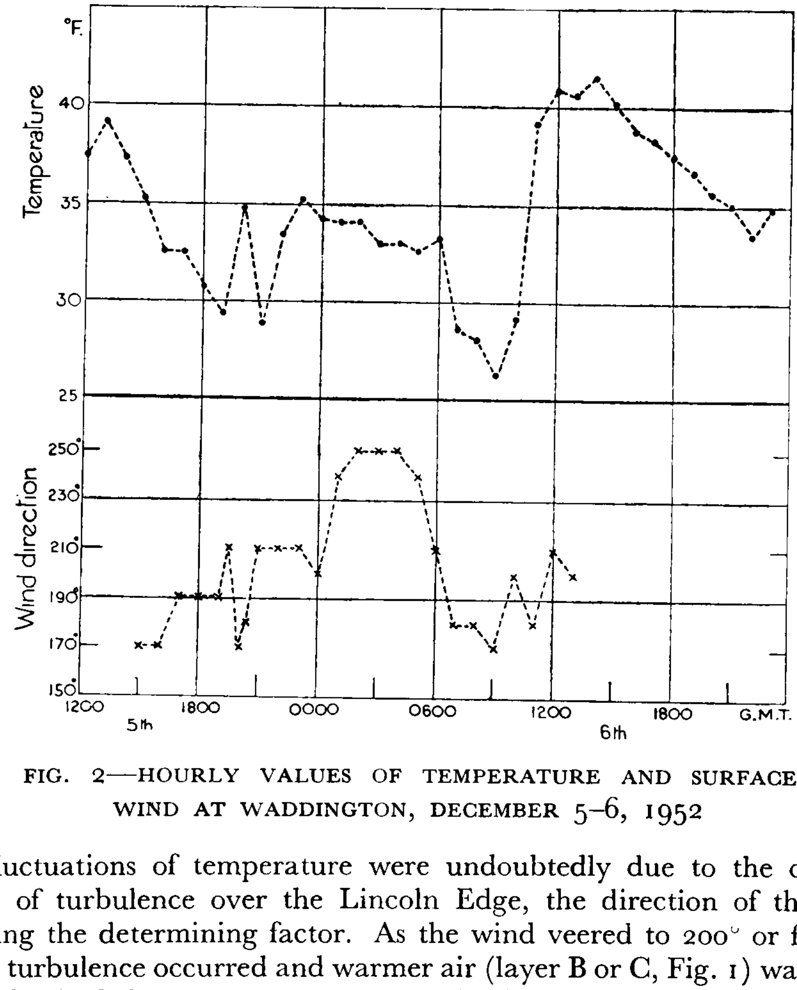

FIG. 2—HOURLY VALUES OF TEMPERATURE AND SURFACE WIND AT WADDINGTON, DECEMBER 5–6, 1952

The fluctuations of temperature were undoubtedly due to the onset and cessation of turbulence over the Lincoln Edge, the direction of the surface wind being the determining factor. As the wind veered to 200° or further to the west, turbulence occurred and warmer air (layer B or C, Fig. 1) was brought down and raised the screen temperature. As the wind backed from 200° cold air (layer A, Fig. 1) was brought back across the airfield again.

In the case of the 10°F. rise of temperature it is most probable that the turbulence associated with the veer of wind to 210° at 1000, together with the effect of the rising sun, was strong enough to break down the inversion completely, and in the resulting mixing the screen temperature was quickly raised to that of the air at the top of the inversion.

The turbulence on this occasion had an effect on the weather. Fog had been forecast to re-form early in the evening of the 5th; visibility however remained at 2,500 yd. or more until 0745 on the 6th when the temperature fell and fog formed at the forecast fog point of 28°F. The fog cleared again during the period of the large temperature rise.

The orientation of the Lincoln Edge as stated earlier is 360–180° and the examples given above point to 200° as being a critical direction for turbulence over the Edge particularly in the vicinity of Waddington.

W. B. PAINTING

Waddington, December 27, 1952

NOTES AND NEWS

Exposure of instruments on an ocean weather ship

The photograph at the end of this issue of the O.W.S. *Weather Watcher* was taken by a *Scottish Daily Mail* photographer aboard an R.A.F. aircraft during a "Methop" (air-sea rescue) exercise on December 30, 1952. On this occasion the aircraft dropped New Year mail and newspapers to the ship in Lindholme containers, and some of the crew can be seen on the foredeck triumphantly holding their mails overhead. The figure in white is the ship's cook who performed a very important function on board on Christmas day and New Year's day. It will be seen from the photograph that the wind on the port beam is approximately force 4, and the ship although stopped is lying quietly and comfortably. The two temperature screens for wet- and dry-bulb readings can be very clearly seen on each side of the bridge, and on top of the balloon shelter aft can be seen the screen for the distant-reading thermograph which records humidity and temperature in the ship's meteorological office which is situated beneath the balloon shelter. The radar antenna on the platform between the bridge and the foremast is obviously following the aircraft as she encircles the ship. This is a radar which is used for upper wind observations. The smaller Decca radar used for navigational purposes will be noticed on the fore end of the wheel house.

C. E. N. FRANKCOM

Large pressure variations

Mr. M. H. O. Hoddinott, 19 Dickson Drive, Chester, writes that he and Mr. S. E. Ashmore propose to investigate the large pressure variations of July 6, 1952*, and asks for the loan of barograms for that day. Only clear barograms of which the error in time, if any, is known so that points in the trace can be timed to 5 minutes will be of use. Barograms lent will be returned as soon as a record has been made of the trace.

Mammatus cloud, Rickinghall, Suffolk, October 24, 1952

An unusually good display of mammatus and turbulence cloud occurred at Rickinghall, Suffolk (5 miles from Diss, Norfolk) at sunset on October 24, 1952. The photographs facing p. 192 were taken at 1640 and 1645 G.M.T. looking east to east-north-east at a receding line of cumulonimbus cloud. The sun had just set behind a neighbouring ridge and the low angle of illumination gave the cloud a brilliant orange hue against the background of greyish-purple cumulonimbus. Estimation of the height of the mammatus-cloud elements was difficult, but about 5,000 to 6,000 ft. was thought to be a near approximation.

* *Weather, London*, 7, 1952, p. 291 and p. 320.

The following notes on the weather may be of interest. Rickinghall had had a moderate thunderstorm in the preceding 30 min. and hail up to 0·5 cm. diameter was lying 5–10 cm. deep in sheltered hollows. Examination of synoptic charts showed that at 1800 G.M.T. a deep depression centred at about 58°N. 15°W. was moving east slowly and was maintaining a south-westerly stream of unstable maritime polar air over England with general shower activity. Observations from neighbouring stations and "sferic" reports suggested that the storm and cloud formation was associated with a minor instability trough, although no marked squall was noticed.

Conditions representative of the air mass concerned are believed to be shown by the 1400 G.M.T. radio-sonde ascent from Hemsby. A fairly solid current of about 230–240°, 40–50 kt. existed up to 500 mb. Above that level there was very marked vertical shear associated with a jet stream with the wind reaching 250° 129 kt. at 300 mb. Temperature showed a dry adiabatic lapse rate up to the condensation level at about 850 mb. and a super wet adiabatic lapse rate 850 to 440 mb., apart from shallow stable layers at 775 to 750 mb. and 600 to 560 mb. Moisture content showed about 75 per cent. saturation below 700 mb. and somewhat drier conditions above. The freezing level was about 6,500 ft. These conditions would favour the development of marked instability phenomena up to about 500 mb. as was observed.

OBITUARY

Dr. James Esmond Belasco.—It is with great regret that we record the death on April 16, 1953, in his 59th year, of Dr. J. E. Belasco, Senior Scientific Officer, after a long service in the Meteorological Office dating back to January 1916.

Dr. Belasco had a wide experience, having served in the Marine Branch, the Instruments Branch, the Office in Edinburgh, in synoptic meteorology, and finally in the British Climatological Branch.

He wrote a number of important papers, amongst which may be mentioned:

The temperature characteristics of different classes of air over the British Isles in winter. *Quart. J.R. met. Soc., London*, **71,** 1945, p. 351.

Rainless days of London. *Quart J.R. met. Soc., London*, **74,** 1948, p. 339.

Characteristics of air masses over the British Isles. *Geophys. Mem., London*, **11,** No. 87, 1952.

Dr. Belasco set a fine example by his determination and courage to carry on although handicapped by heart trouble, which developed in later life, and which he expected would sooner or later overcome him. He leaves behind a widow to whom we offer our deepest sympathy.

Walter John Davies.—We regret to record the death of Mr. W. J. Davies, Experimental Officer, on March 22, 1953.

Mr. Davies joined the staff of the Office in February 1935, and served at Royal Air Force stations at home and overseas. His last six years of service were in Flying Training Command; in May 1946 he went to re-open and take charge of the meteorological office at Feltwell, and remained there until his sudden death. He developed an ideal technique in teaching elementary meteorology to new pupil pilots and had been complimented by the R.A.F. Central Examination Board and the Central Flying School Examiners.

Both Mr. Davies and his family took an active part in the social life at Feltwell. He was well liked and esteemed by his colleagues in the Office and in the R.A.F. Mr. Davies leaves a widow and a son and daughter to whom we offer our deepest sympathy in their loss.

ERRATUM

APRIL 1953, PAGE 105, TABLE I; All values of α in column 9 should be positive not negative.

BOOKS RECEIVED

8° Annuario 1951. Osservatorio di Fisica Terrestre del Seminario Arcivescovile di Milano. $13\frac{1}{2}$ in. × $9\frac{3}{4}$ in., pp. 36, *Illus.*, Societa' Arti Graphiche S. Abondio, Como, 1952.

Report on the administration of the Meteorological Department of the Government of India in 1950–51. $13\frac{1}{2}$ in. × $8\frac{1}{2}$ in., pp. ii + 46. India Meteorological Department, Delhi, 1952.

METEOROLOGICAL OFFICE NEWS

Sport and Athletics.—*Football.*—The Meteorological Office beat Finance by 3 goals to 1 in the final of the Air Ministry competition for the Football Cup at Northolt on May 5. Goals were scored by Martin, Mayes and Farr. This is the eleventh occasion on which the Meteorological Office have won the Cup and the sixth consecutive year. The win was somewhat unexpected since several of the previous year's team were unavailable owing to injury and new players had to fill their places.

Chess.—Mr. P. M. Shaw won the Air Ministry Chess Championship on behalf of the Meteorological Office.

Bishop Shield.—With points gained from swimming, cross country running, lawn tennis, football, chess and bridge, the Office are in a strong position to retain the Bishop Shield for the year which ends with the Air Ministry Sports on July 1, 1953.

WEATHER OF APRIL 1953

Mean pressure was below normal over most of North America and west Europe and above normal over the North Atlantic (north of latitude 45°N.) and east and south-east Europe. Mean pressure exceeded 1020 mb. over Greenland and was as much as 12 mb. above normal over the extreme south of this region; the mean pressure of 1015 mb. at the Azores, however, was 8 mb. below normal. Mean pressure was also low off the west coast of Norway where it fell to 1006 mb., about 6 mb. below normal.

Mean temperature was about 4°F. above normal over Europe and 4°F. below normal over the United States, except in the extreme east. In Europe the values of mean temperature were between 45° and 55°F.

In the British Isles the weather was sunny and rather cool; it was wet in most districts except south-west Scotland and Northern Ireland. A fine, sunny spell occurred from the 18th to the 25th apart from some rain in the north and west on the 23rd to 25th.

In the opening days pressure was low to the north of Scotland and associated troughs of low pressure moved north-east across the British Isles; cool weather prevailed, with rain or showers, wintry in places. On the 4th a depression off west Ireland moved south-east and subsequently turned north-east across England and Wales to Denmark giving rain in most districts, except the north of Scotland, and local thunderstorms. On the 7th a wedge moved north-east across England and Wales, while a small secondary depression moved east over the north of Scotland; fair, sunny weather prevailed over England, Wales and most of Ireland but heavy showers fell at times in north-west Scotland. On the 8th a depression over the Bay of Biscay moved slowly north-east and a cold north to north-east stream of air spread over much of Scotland; rain occurred in the extreme south-west of England and in the Channel Islands and showers locally in Scotland. Early morning frost occurred rather widely in the west and north on the 7th, in the southern half of the country on the 8th and in northern districts on the 9th (temperature in the screen fell to 22°F. at Eskdalemuir on the 7th, 24°F. at Midleton, near Cork, on the 8th and 23°F. at Wick on the 9th). On the 10th a wedge moved south-east across the British Isles giving fair weather in England, Wales and the extreme south of Scotland. On the 11th a depression off the Hebrides moved north-east causing a severe gale and heavy rain locally in the north-west. Subsequently a cold front moved south-east across England giving a wet day in the south-east and east on the 12th. Thereafter pressure was high over the Atlantic and cold north-westerlies prevailed with some sleet or snow in Scotland. On the 15th a small depression moving south-east from north-east Scotland gave further snow in Scotland and this was followed by a deeper depression which gave rain in all areas. Subsequently a ridge of high pressure extended from the Atlantic across the British Isles to Germany and anticyclonic conditions persisted until the 23rd, with good records of bright sunshine from the 19th to the 23rd. The highest temperature of the month was registered at most places on one of the days from the 22nd to the 24th (70°F. at Valentia and 71°F. at Poole and Hurn on the 22nd). On the 24th and 25th rather cold northerly winds spread south, with snow showers in the north of Scotland but in most districts it remained fine over the 25th. On the 26th a depression moved south-east from westward of Ireland to the mouth of the English Channel, and during the following day it moved north-east to combine with another centre which moved north from the Strait of Dover; rain fell in all districts and was heavy locally. On the 29th another depression moved north-east across England to the North Sea giving general rain, heavy in some parts, particularly in Wales (2·51 in. at Llangurig, Montgomeryshire, 2·42 in. at Rhondda Water Works, Glamorganshire and 2·40 in. at Llyn-y-fan Fach, Carmarthenshire).

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	71	16	−1·4	138	0	114
Scotland	72	16	−1·8	118	+1	115
Northern Ireland ...	67	28	−2·2	84	−1	109

RAINFALL OF APRIL 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·50	162	*Glam.*	Cardiff, Penylan ...	3·89	156
Kent	Dover	1·55	96	*Pemb.*	Tenby	2·32	101
,,	Edenbridge, Falconhurst	2·67	143	*Radnor*	Tyrmynydd	4·99	135
Sussex	Compton, Compton Ho.	2·41	121	*Mont.*	Lake Vyrnwy	5·00	158
,,	Worthing, Beach Ho. Pk.	2·53	162	*Mer.*	Blaenau Festiniog ...	7·07	114
Hants.	Ventnor Park	1·16	68	,,	Aberdovey	3·57	137
,,	Southampton (East Pk.)	1·80	97	*Carn.*	Llandudno	2·51	149
,,	S. Farnborough ...	2·06	135	*Angl.*	Llanerchymedd ...	3·28	148
Herts.	Royston, Therfield Rec.	1·92	122	*I. Man*	Douglas, Borough Cem.	3·33	136
Bucks.	Slough, Upton... ...	2·30	161	*Wigtown*	Newton Stewart ...	1·82	71
Oxford	Oxford, Radcliffe ...	2·08	130	*Dumf.*	Dumfries, Crichton R.I.	2·67	113
N'hants.	Wellingboro' Swanspool	1·99	133	,,	Eskdalemuir Obsy. ...	4·40	129
Essex	Shoeburyness	1·61	133	*Roxb.*	Crailing...	2·90	181
,,	Dovercourt	2·08	166	*Peebles*	Stobo Castle	2·93	140
Suffolk	Lowestoft Sec. School...	1·74	117	*Berwick*	Marchmont House ...	2·82	140
,,	Bury St. Ed., Westley H.	2·50	163	*E. Loth.*	North Berwick Res. ...	1·94	139
Norfolk	Sandringham Ho. Gdns.	2·77	182	*Midl'n.*	Edinburgh, Blackf'd. H.	2·02	137
Wilts.	Aldbourne	2·64	143	*Lanark*	Hamilton W. W., T'nhill	1·76	94
Dorset	Creech Grange... ...	2·56	119	*Ayr*	Colmonell, Knockdolian	1·58	62
,,	Beaminster, East St. ...	3·84	162	,,	Glen Afton, Ayr San. ...	3·78	126
Devon	Teignmouth, Den Gdns.	2·67	133	*Renfrew.*	Greenock, Prospect Hill	2·58	75
,,	Cullompton	3·10	137	*Bute*	Rothesay, Ardencraig...	2·74	92
,,	Ilfracombe	2·45	117	*Argyll*	Morven (Drimnin) ...	3·87	106
,,	Okehampton	4·24	133	,,	Poltalloch	4·41	146
Cornwall	Bude, School House ...	2·34	124	,,	Inveraray Castle ...	4·75	103
,,	Penzance, Morrab Gdns.	2·72	112	,,	Islay, Eallabus... ...	2·04	71
,,	St. Austell	3·04	108	,,	Tiree	2·84	115
,,	Scilly, Tresco Abbey ...	2·86	146	*Kinross*	Loch Leven Sluice ...	2·41	126
Glos.	Cirencester	2·69	144	*Fife*	Leuchars Airfield ...	2·47	155
Salop	Church Stretton ...	3·27	150	*Perth*	Loch Dhu	4·11	87
,,	Shrewsbury, Monkmore	2·80	189	,,	Crieff, Strathearn Hyd.	2·15	98
Worcs.	Malvern, Free Library...	2·53	141	,,	Pitlochry, Fincastle ...	1·48	66
Warwick	Birmingham, Edgbaston	2·77	159	*Angus*	Montrose, Sunnyside ...	3·56	196
Leics.	Thornton Reservoir ...	2·37	139	*Aberd.*	Braemar	2·49	105
Lincs.	Boston, Skirbeck ...	2·13	158	,,	Dyce, Craibstone ...	2·52	122
,,	Skegness, Marine Gdns.	2·53	189	,,	New Deer School House	2·62	132
Notts.	Mansfield, Carr Bank...	2·64	153	*Moray*	Gordon Castle	2·26	129
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Ches.	Bidston Observatory ...	1·82	112	*Inverness*	Loch Ness, Garthbeg ...	4·02	123
,,	Manchester, Ringway...	2·33	130	,,	Glenquoich	7·90	122
Lancs.	Stonyhurst College ...	3·40	125	,,	Fort William, Teviot ...	4·64	103
,,	Squires Gate	2·36	133	,,	Skye, Duntuilm ...	4·88	150
Yorks.	Wakefield, Clarence Pk.	1·97	117	,,	Skye, Broadford ...	5·97	132
,,	Hull, Pearson Park ...	2·12	136	*R. & C.*	Tain, Mayfield... ...	1·82	99
,,	Felixkirk, Mt. St. John...	2·51	150	,,	Inverbroom, Glackour...	5·56	149
,,	York Museum	2·16	135	,,	Achnashellach	5·79	108
,,	Scarborough	2·43	156	*Suth.*	Lochinver, Bank Ho. ...	3·38	119
,,	Middlesbrough... ...	1·40	102	*Caith.*	Wick Airfield	2·14	108
,,	Baldersdale, Hury Res.	3·08	141	*Shetland*	Lerwick Observatory ...	2·89	126
Norl'd.	Newcastle, Leazes Pk....	2·45	154	*Ferm.*	Crom Castle	1·25	49
,,	Bellingham, High Green	3·76	174	*Armagh*	Armagh Observatory ...	2·17	103
,,	Lilburn Tower Gdns. ...	3·05	154	*Down*	Seaforde	2·08	79
Cumb.	Geltsdale	2·97	139	*Antrim*	Aldergrove Airfield ...	1·05	50
,,	Keswick, High Hill ...	3·82	124	,,	Ballymena, Harryville...	2·32	88
,,	Ravenglass, The Grove	2·52	102	*L'derry*	Garvagh, Moneydig ...	2·30	94
Mon.	Abergavenny, Larchfield	3·79	150	,,	Londonderry, Creggan	3·10	121
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[*To face p. 192*

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MAMMATUS CLOUD, RICKINGHALL, SUFFOLK, OCTOBER 24, 1952
(see p. 188)

Reproduced by courtesy of the Scottish ***Daily Mail***

O.W.S. WEATHER WATCHER, STATION I, DECEMBER 30, 1952
(see p. 188)

E. G. BILHAM, B.Sc., D.I.C.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 973, JULY 1953

MR. E. G. BILHAM, B.Sc., D.I.C.

Mr. E. G. Bilham, Deputy Director (Forecasting) retired from the Meteorological Office on May 30, 1953, after 38 years' service.

Mr. Bilham graduated with honours in Physics from Imperial College, London, in 1913, and joined the staff of the Meteorological Office in April 1915 as resident observer at Kew Observatory. While at Kew Observatory he analysed the observations of the level of water in a well for tidal and meteorological effects, and later published the results in a series of papers in the *Proceedings of the Royal Society* and the *Quarterly Journal of the Royal Meteorological Society.* He was transferred to the Benson aerological observatory in 1916, and from Benson to the Forecast Division at Headquarters, South Kensington, in 1917. He remained a forecaster for seven years, and in that period wrote papers on isallobaric analysis and on the synoptic meteorology of summer fog at Scilly.

In 1924 Mr. Bilham was promoted Superintendent and given charge of the Instruments Division. He was posted in 1930 to be Superintendent of the British Climatology Division which included the British Rainfall Organization, and held that post until the end of 1938. During his fourteen years in the Instruments and British Climatology Divisions he invented a height computer for aerological work and a humidity slide-rule; he also wrote many papers on a large number of subjects including methods of testing instruments, climatology, and the fall of hailstones. His study of the frequency of intense falls of rain, published in *British Rainfall 1935*, is a very important contribution to the application of rainfall data in engineering. At this time, too, he wrote the book which immediately became the standard work on its subject, "The climate of the British Isles", published by Macmillan in 1938.

Mr. Bilham returned to synoptic meteorology in January 1939 as Superintendent of the Headquarters Forecast and Civil Aviation Division. Soon afterwards he had to solve the complex problems associated with the evacuation of the Headquarters forecast organization to Birmingham in August 1939 and its transfer to Dunstable in February 1940. The war greatly increased the work and size of the Forecast Division and brought the introduction of new techniques such as "sferics" and upper air analysis. Mr. Bilham was promoted Assistant Director (Forecasting) in 1942, and on the re-organization in 1947 was promoted Deputy Chief Scientific Officer and appointed Deputy Director for Forecasting.

Mr. Bilham described the methods and organization of weather forecasting in "Here is the weather forecast", a book for the general reader published in 1947.

He has been a member of the Commission for Aeronautical Meteorology of the International Meteorological Organization and of the Commission for Synoptic Weather Information of the International Meteorological Organization and its successor, the World Meteorological Organization; in these capacities he has represented the Meteorological Office at several important international conferences.

Mr. Bilham's work has been characterized by ingenuity and practical skill in the improvement of meteorological instruments and techniques generally, and his ability for clear exposition has been of great value in the writing of such official publications as the "Observer's handbook" and "Your weather service". He may well claim to have left his imprint on all the major divisions, Instruments, Climatology and Forecasting, of which he has been in charge.

Mr. Bilham is an accomplished pianist and has always been ready to place his talent at the disposal of the staff at official parties. His retirement will be a considerable loss to the Meteorological Office which he leaves with the good wishes of all those with whom he has been associated.

The Director expressed the good wishes of the staff to Mr. Bilham at a meeting in Victory House on May 30 and presented him on their behalf with a camera and a cheque towards a motor lawn mower. Mr. Bilham in giving his thanks told interesting and amusing anecdotes of his early years at Kew and Benson and of some of those under whom he had served.

THE VARIATION OF WIND NEAR THE TROPOPAUSE

By E. GOLD, F.R.S.

The interesting result found by Austin and Bannon[1], that on occasions of strong upper winds, 70 kt. or more, the maximum wind occurs 30 to 40 mb. (3,000 to 4,000 ft.) below the level of the tropopause, means that the thermal wind is reversed before the tropopause is reached. In general the isotherms in the upper troposphere are approximately parallel to the isobars (or the contour lines) and temperature and pressure increase together in a horizontal direction. The rate of increase of temperature is of the order of 1°C./100 Km., though it may be sometimes much more, or much less, rapid. So long as this normal thermal structure is maintained the wind will increase with height. If there were no horizontal gradient of temperature the geostrophic wind would decrease slowly with height in the troposphere. From equation (1) below, the horizontal gradient of temperature necessary to counterbalance this decrease is

$$M = 2\omega V \sin\phi \frac{L}{g}$$

where the letters have the meanings given below. For a geostrophic wind of 90 kt. and a lapse rate of 8°C./Km. the value of M is 2×10^{-8} °C./cm. or 1°C./500 Km.

The change of wind as the tropopause is approached, or passed, is dependent on the thermal structure, and may give useful information confirming or correcting the recorded temperatures and the deductions based on them.

The major factor producing the change of wind (or *vice versa*) is the slope of the tropopause. As a rule, if there is no slope, i.e. if the tropopause is practically horizontal, there will be no marked variation in the character of the change of wind with height as the tropopause is approached or passed. This is not a common case and is unlikely to occur where the upper wind is of the order of 70 kt.; it is much more likely to be found in a region of light upper winds.

If the tropopause, as it generally does, slopes upwards towards the higher pressure and higher temperature (and therefore intersects horizontal planes along isobars or contour lines) the wind will decrease in passing through the tropopause. If there is an inversion, there will be a corresponding sudden decrease of wind, followed by a gradual decrease with height. If there is no inversion the decrease of wind will be gradual throughout. Unless there is a decrease in the lapse rate in the troposphere before the inversion is reached the decrease of wind will begin only at the inversion and not below it.

If the slope of the tropopause is upwards from the high pressure towards the low, the wind will increase up to and through the tropopause unless the horizontal gradient of temperature in the troposphere is reversed and is opposite to the gradient of pressure. In that case the wind would decrease up to the tropopause but would begin to increase at the tropopause or soon after.

If the lapse rate in the troposphere, after being constant or increasing, begins to decrease at a distance h below the tropopause and continues to decrease up to the tropopause, the wind will also begin to decrease before the tropopause is reached, and the maximum wind will, in this case and only in this case, occur below the level of the tropopause. It is emphasized that h is measured from the tropopause so that the height at which the decrease of lapse rate begins increases as the tropopause rises. The wind would not begin to decrease in the troposphere if the decrease of lapse rate began at a fixed height above sea level.

The amount of the change in the geostrophic wind for these different conditions can be expressed in terms of the lapse rates, the magnitude of inversion of temperature, the horizontal gradient of temperature, the distance h and the geostrophic wind itself.

Four general cases can be taken:—

(i) Lapse rate L up to the tropopause. Inversion of t°C. at the tropopause, i.e. in a relatively small distance. Lapse rate zero above the inversion.

(ii) Lapse rate L up to tropopause, l above tropopause. Discontinuity of lapse rate at tropopause.

(iii) Lapse rate L up to level at distance h below tropopause. Uniform decrease of lapse rate to zero at tropopause. Lapse rate l above tropopause.

(iv) Lapse rate in the troposphere increasing (or decreasing) towards the higher pressure.

In all cases the tropopause slopes at an angle A and the tropopause contours are parallel to the isobars or to the contours of the isobaric surface at tropopause level.

The following symbols are used; the values quoted are used in the examples:

- g gravity acceleration. $9{\cdot}8 \times 10^2$ cm./sec.^{2}
- R constant in equation $p = R\rho T$. $2{\cdot}87 \times 10^6$ cm.^{2}/sec.^{2}°C.
- ω angular velocity of earth. $7{\cdot}3 \times 10^{-5}$ radians/sec.
- ϕ latitude. For latitude 50°, cosec ϕ is $1{\cdot}3$
- λ $2\omega \sin \phi$. For latitude 50°, λ is $11{\cdot}2 \times 10^{-5}$
- T temperature in degrees Absolute. Tropopause temperature 220°A.
- p pressure

L lapse rate. 8×10^{-5} °C./cm. (4·4°F./1,000 ft.)
l lapse rate. 2×10^{-5} °C./cm. and -2×10^{-5} °C./cm.
M horizontal gradient of temperature in the troposphere. 10^{-7} °C./cm. (1°F./30 miles approximately)
A angle of slope of tropopause. $\tan A = 1/100$
V geostrophic wind
v change in geostrophic wind
z vertical co-ordinate, positive upwards
x horizontal co-ordinate at right angles to isobars and positive towards increasing pressure.

The rate of change of geostrophic speed with height, under the conditions specified, is readily derived from the fundamental relations between pressure, temperature, density and geostrophic wind.

From the relations $$\frac{dp}{dx} = \lambda\rho V, \quad \frac{dp}{dz} = -g\rho$$

it follows, by differentiating the first with regard to z and the second with regard to x that

$$\lambda\rho\frac{dV}{dz} = -\lambda V\frac{d\rho}{dz} - g\frac{d\rho}{dx}.$$

By using the result $d\rho/\rho = dp/p - dT/T$ derived from $p = R\rho T$, the equation becomes

$$\lambda T\frac{dV}{dz} = \lambda V\frac{dT}{dz} + g\frac{dT}{dx} \quad \ldots\ldots (1)$$

$$= \lambda VL + gM,$$

and the total change of speed in a height z is, approximately,

$$v = -\frac{V_m Lz}{T_m} + g\frac{Mz}{\lambda T_m} \quad \ldots\ldots (2)$$

where T_m is the mean temperature and V_m the mean speed in the atmosphere from 0 to z.

At an inversion, sloping at an angle a, Lz is $-t$ and M is $\pm t/z \cot a$ the plus or the minus sign being taken according as the slope is upwards towards the high or the low pressure. Also $V_m = V$ and $T_m = T$, z = thickness of inversion layer and $t°$ the increase of temperature.

Thus at an inversion $$v = \frac{Vt}{T} \pm gt\frac{\tan a}{\lambda T}. \quad \ldots\ldots (3)$$

These equations will now be applied to evaluate the changes in the cases mentioned; the first term of equation (2) is usually small, only 1 or 2 kt. for a change of height of 1,000 m., and the first term of equation (3) is usually smaller still.

Inversion $t°$ at tropopause.—From (3) with $a = A$, i.e. a slope of 1/100, the value of the second term in latitude 50° is $4t$ m./sec. or $8t$ kt. Slopes even steeper than 1/100 may occur, e.g. on January 5, 1950 there was a slope of 1/50 south of Ireland, but these very steep slopes extend for only 100 miles or so. When the slope is nearly uniform for 500 or 600 miles it is more likely to be 1/200, as for example on January 11, 1952, when the tropopause was about 20,000 ft. higher over the Mediterranean than over England with contour lines nearly equally spaced running approximately from west to east across France and Spain. But clearly, sudden decreases of 20 kt. or more may occur when there is a marked inversion at the tropopause. The value of the term Vt/T is only $\frac{1}{2}$ kt. if V is 110 kt. and t is 1°C. and may therefore be disregarded.

If the slope were reversed, i.e. upwards towards the low pressure, the wind would increase $8t$ kt. at the tropopause with a 1/100 slope.

In the stratosphere the horizontal gradient of temperature is $M - L \tan A$ and as $L \tan A$ is 8×10^{-7} while M is only 10^{-7}, the geostrophic wind decreases very rapidly in the stratosphere above a steeply sloping tropopause. At a height z the decrease is $gz\,(L \tan A - M)/T$. With the values quoted above this gives a decrease of 28 m./sec. or 55 kt. at a height of 1,000 m. above the tropopause.

If the slope were 1/200 the decrease at the tropopause would be halved, $4t$ kt., but the decrease in the stratosphere would be only 3/7 as great, i.e. 12 m./sec. or 24 kt. at 1,000 m.

Lapse rate changing at the tropopause from L to l.—There is no sudden change in V at the tropopause in this case. The decrease above the tropopause would be very slow except for the horizontal gradient of temperature which is $M - (L - l) \tan A$. Thus the total change in a height z is by equation (2)

$$v = -\frac{V_m l z}{T_m} + \frac{gz(M - (L - l)\tan A)}{\lambda T_m}.$$

For the values quoted and $z = 1{,}000$ m. the decrease, disregarding the small first term, is 20 m./sec. or 39 kt. If l is negative, i.e. increasing temperature in the stratosphere, the decrease is 36 m./sec. or 71 kt.

If the slope were 1/200 the decreases would be 16 and 31 kt. instead of 39 and 71 kt.

If M were large and the slope small $(L - l) \tan A$ could be less than M and the wind would increase in the stratosphere.

Lapse rate decreasing to zero at the tropopause from the value L at and below a level distant h beneath the tropopause.—If z is measured from the level h below the tropopause, the horizontal gradient of temperature, in this layer of decreasing lapse rate, is $M - L \tan A . z/h$ and the lapse rate is $L\,(1 - z/h)$. Thus in this layer the integration of equation (1) leads to the following equation for the change of geostrophic speed,

$$v = \frac{V_m L z}{T_m}\left(1 - \frac{z}{2h}\right) + \frac{gz}{\lambda T_m}\left(M - L \tan A \frac{z}{2h}\right).$$

The first term is, in general, small compared with the second. The wind begins to decrease near the level

$$z = \frac{2Mh}{L \tan A}$$

$$= \frac{h}{4}$$

if L is 8×10^{-5} and M is 10^{-7}.

If h is 1,000 m. the decrease up to the tropopause is 12 m./sec. or 24 kt. Above the tropopause the horizontal gradient of temperature is $M - (L - l) \tan A$ and the further decrease of wind is:

$$v = \frac{V_m l z}{T_m} + \frac{g z}{\lambda T_m} (M - (L - l) \tan A).$$

At a height of 1,000 m. in the stratosphere, this additional decrease is 39, 55 or 71 kt. according as l is 2×10^{-5}, zero, or -2×10^{-5}.

Lapse rate in the troposphere increasing (or decreasing) towards the higher pressure.—The variation of lapse rate may be represented by $L \pm Bx$ and the horizontal gradient of temperature is then $M \mp Bz$. Therefore the change of wind is

$$v = -\frac{V_m z}{T_m} (L \pm Bx) + \frac{g z}{\lambda T_m} (M \mp \tfrac{1}{2} B z).$$

For a change in lapse rate of 1°C./Km. in a horizontal distance of 100 Km., which would be a rather rapid change, the value of B is 10^{-12} and $\frac{1}{2}Bz$ is only equal to M when z is 2,000 m. ($M = 10^{-7}$). If M were zero the change in speed would be 4 kt. in 1,000 m. and 16 kt. in 2,000 m. It appears likely therefore that a horizontal variation of lapse rate is only a subsidiary cause of decrease of wind before the tropopause is reached and that the main cause is a decrease of lapse rate commencing about 1 Km. below the tropopause. There will, however, be many occasions when the lapse rate is changing both horizontally and vertically in a sense tending to decrease the wind, but the magnitude of the changes is not sufficient to outweigh the increase due to M but only to reduce the rate of this increase, in the layers just below the tropopause.

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GLOBAL CIRCULATION OF AIR AT HIGH LEVELS AND MECHANISM OF CHANGE OF TROPOPAUSE LEVEL

By A. H. R. GOLDIE, D.Sc.

In earlier papers the writer has referred to the effects on tropopause level and stratospheric temperature of the vertical component of circulation, both as between high and low pressure systems in specific cases[1] and as between tropical and temperate latitudes in the longer-period average global circulation[2].

It is many years since W. H. Dines[3] pointed out that the mean temperature of the atmosphere at the equator differs much less from the mean in England than it would do if temperature were solely a matter of radiative equilibrium, and that the factor making for equalization is, of course, circulation.

The chief purpose of this paper is to discuss the hypothesis that the air which constitutes the lower stratosphere of middle and high latitudes comes continually from the upper troposphere of the tropics and returns eventually to the troposphere of the polar regions in winter. This is one side of the global circulation. The other side in which air of the lower troposphere of middle and high latitudes drifts equatorwards, is heated and rises, is not discussed in this paper.

The recent classification by Bannon[4] of temperatures in the upper troposphere and lower stratosphere in England according to tropopause pressure provides a starting point, and also prompts some further discussion of the local patterns of air flow above and below the tropopause which might lead to the variety of temperature distributions found in temperate latitudes.

Typical distributions of temperature.—The data of Fig. I of Bannon's paper[4] have been used to plot the right-hand side of the upper part of Fig. I of the present paper. The figures used for column A are mean temperatures at the various pressure levels when tropopause pressure lies between 159 and 140 mb., those in column B relate to tropopause pressure between 179 and 160 mb. and so on. Isopleths of temperature have been drawn in, and also the position of the tropopause. The result may be taken as giving a typical average cross-section from high tropopause to low tropopause in temperate latitudes. On the extreme left of the picture are given mean values for the equator. The two sets of isopleths are connected by dotted lines.

The lower part of Fig. 1 is a picture of the same data transformed into potential temperatures for a pressure of 400 mb. The conditions from A to K in these two diagrams are all to be found typically at one time or another in the month of January (or indeed generally in winter) in the southern part of the British Isles. Fig. 2 represents similarly the typical distributions for July. By what processes of movement and/or radiation can such variety of temperature distributions be brought about in a given month of the year?

Evidence for an average global meridional circulation.—It is obvious from all these figures that the tropopause is an important discontinuity or boundary in the pattern of temperature. From the characteristic wind distribution across the tropopause it is known similarly that there is in general a discontinuity in air movement. Typically the wind increases with height up to a maximum a short distance below the tropopause. There is then a very steep drop in wind speed on passing into the (relatively) slow-moving air of the stratosphere.

There is another feature which establishes not only a discontinuity of conditions between troposphere and stratosphere but a discontinuity of recent past history of the air and which points to an almost complete lack of mixing across the boundary. This feature is the customarily very low frost point in the lower stratosphere, a frost point for which there is no obvious explanation other than that the stratospheric air of temperate latitudes has in its recent past history come through a temperature equivalent to that in the upper troposphere of the tropics. Brewer[5] has discussed certain aspects of this subject. The coincidence of the range of frost points found in the lower stratosphere over England[6] with the range of temperatures found in the upper troposphere over the equator is too remarkable to be acceptably explained on any other ground at present conceived. Table I shows the percentage frequency of the frost points in the tropopause and in the stratosphere respectively for levels of observations from 350 mb. to 187 mb. Not only are the frost points, level for level, much lower in the stratosphere than in the troposphere, but they are grouped more closely. It is found also that in the troposphere the higher the temperature, the higher, on the average, the frost point. In the stratosphere the frost point is either quite independent of temperature or possibly on the whole falls as temperature rises. If values at the extremes are excluded as being possibly unreliable, it is found that about 90 per cent. of the stratospheric frost points lie within −79° to −111°F. (or 211° to 193°A.). The higher and lower values here correspond to the average temperatures in the tropics at 13 Km. and at 17 Km. (the tropopause) respectively. The low frost points found are thus consistent with drift of air from the upper 4 Km. of the tropical troposphere into the lower stratosphere over England.

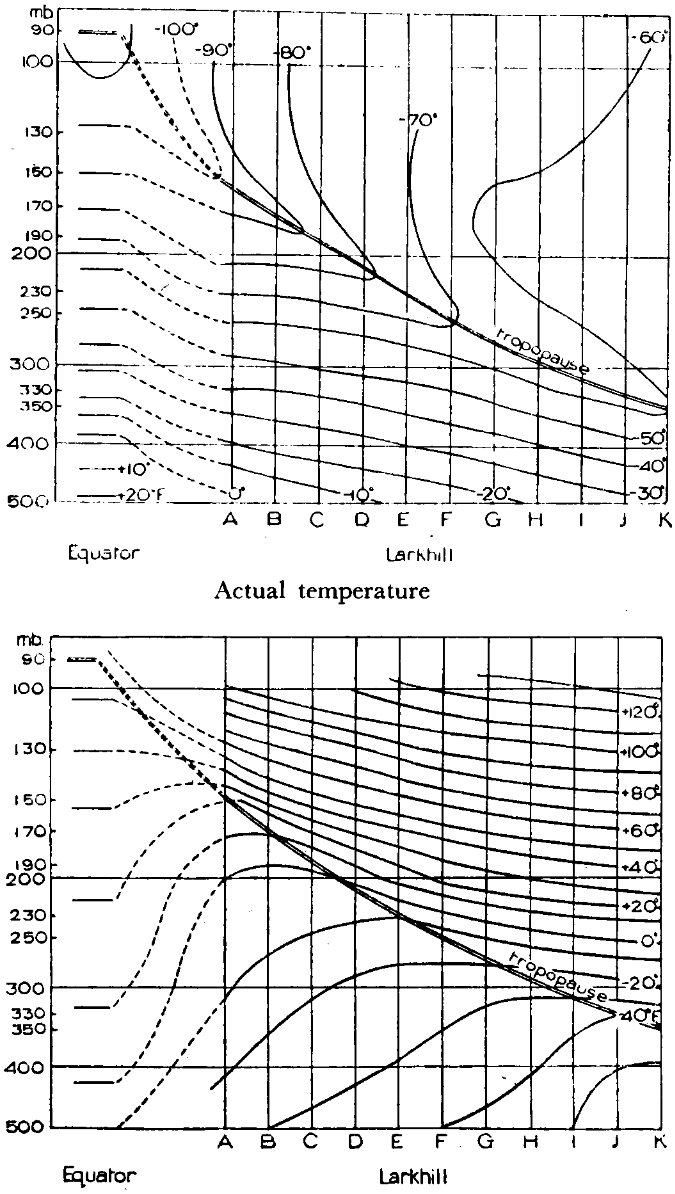
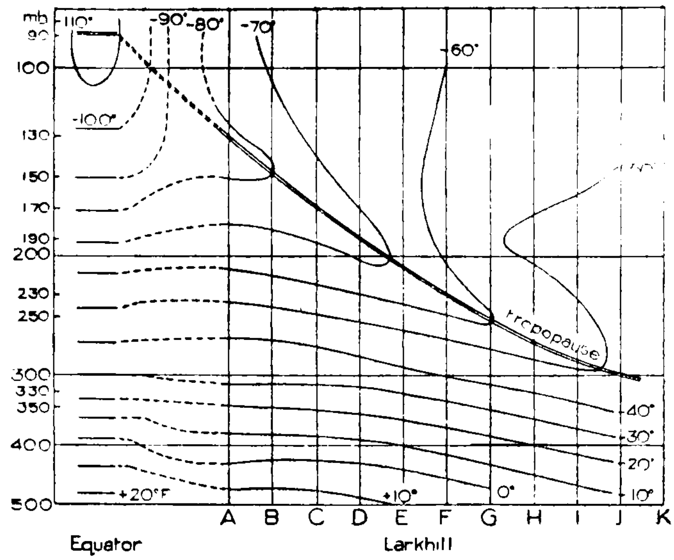
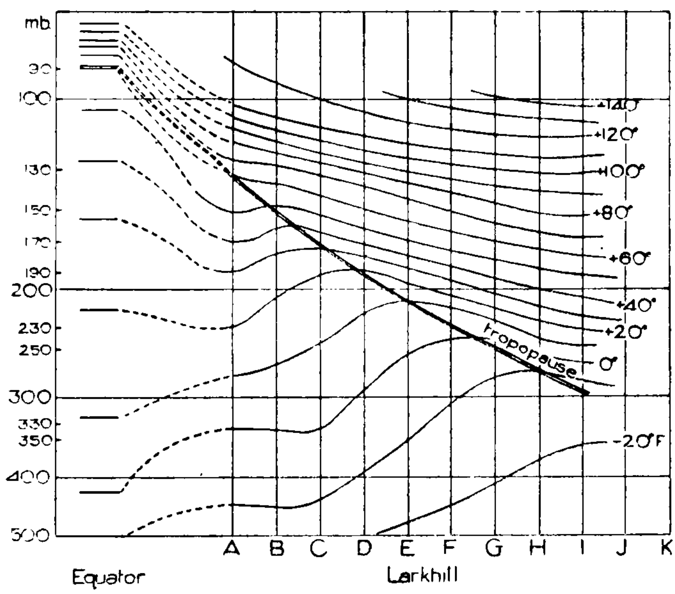


FIG. 1—JANUARY TEMPERATURE AT LARKHILL IN RELATION TO TROPOPAUSE LEVEL AND AVERAGE JANUARY TEMPERATURE AT EQUATOR

There is, however, other (and much earlier) evidence, namely from the phenomena following the Krakatoa eruption[7] of August 27–28, 1883, for the actual existence of a drift of this sort. According to the discussion by E. Douglas Archibald, the evidence as to the spread of the optical phenomena, and in particular the evening glows, showed "that while in the equatorial zone the manner in which the first appearances succeeded one another, demands a due westerly current of considerable velocity, that in which they afterwards spread into higher latitudes in the northern hemisphere, shows a north easterly trend . . . the approach of the glow phenomena, both towards Europe and towards America, seems to have been from the south west".



Actual temperature



Potential temperature (400 mb.)

FIG. 2—JULY TEMPERATURE AT LARKHILL IN RELATION TO TROPOPAUSE LEVEL AND AVERAGE JULY TEMPERATURE AT EQUATOR

The tropical upper "westerly current" (i.e. E. wind) referred to was found to have a speed of about 76 m.p.h. It is known now from upper wind measurements that this at once identifies the region of fast travel with the upper troposphere within the tropics, say within some 13 to 17 or 18 Km. height, and possibly in some longitudes the lower stratosphere.

The average height of the principal part of the stratum producing the twilight glows was determined at various places in Europe and America as being about or slightly over 17 Km. It ranged from about 30 Km. in the tropics at first to about 13 Km. in high latitudes several months later. The twilight glows were most in evidence in middle latitudes from November 1883

TABLE I—PERCENTAGE FREQUENCY DISTRIBUTION OF FROST POINTS

Frost Point	Troposphere 350–187 mb. (609 cases)	Troposphere 250–187 mb. (163 cases)	Stratosphere 350–187 mb. (323 cases)
°F.		*per cent.*	
−33 or higher	1	0	0
−34 to −36	1	0	0
−37 to −39	1	0	0
−40 to −42	2	0	0
−43 to −45	4	0	0
−46 to −48	3	0	0
−49 to −51	3	1	0
−52 to −54	5	0	0
−55 to −57	7	1	0
−58 to −60	6	1	0
−61 to −63	7	4	1
−64 to −66	9	5	0
−67 to −69	9	6	1
−70 to −72	7	8	2
−73 to −75	7	7	3
−76 to −78	6	11	2
−79 to −81	6	13	7
−82 to −84	4	10	6
−85 to −87	4	10	7
−88 to −90	3	7	9
−91 to −93	1	4	10
−94 to −96	2	5	10
−97 to −99	1	4	10
−100 to −102	1	2	9
−103 to −105	0	1	8
−106 to −108	0	0	5
−109 to −111	0	0	6
−112 to −114	0	0	2
−115 to −117	0	0	1
−118 to −120	0	0	1

to February 1884, and had certainly reached latitude 60°N. by the end of November. This indicates a total time for the spread in latitude from Krakatoa (about 6°S.) as some 60 to 90 days to cover some 50° to 66° of latitude, the rate of the northward movement being slower as the latitude increased. This provides not only evidence that a drift of the sort postulated above does exist but also a measure of the time scale for air to get from the tropical upper troposphere and lower stratosphere to the stratosphere of temperate latitudes. The drift may not be steady, it may vary with longitude and season, but in some measure it must always go on.

The further discussion below will therefore be based on the feature that the air of the lower stratosphere of temperate latitudes has in fact in its recent life history got into the stratosphere via the upper troposphere of the tropics, and that the temperatures found over England in the stratosphere are the combined result of high-level tropical conditions, plus circulation including vertical motion, plus gain or loss of heat by radiation in the interval of time since leaving the tropics. Further comment on the causes of the lowering of the tropopause in middle and high latitudes is given on p. 206.

Dynamical effects accompanying the drift of air.—There are several points now to be noted about Figs. 1 and 2. The first is the relatively small gradient of potential temperature with height in the tropical troposphere, a condition consistent with global thermal circulation in which the heat is applied to the air principally in the tropics at the ground. Below the level shown on these diagrams the potential temperature in the tropics actually rises as the ground is approached.

The second point about Figs. 1 and 2 is that, level for level, both the actual and potential temperatures increase in the troposphere from temperate to low latitudes and in the stratosphere from low to temperate latitudes. The former is understandable enough in terms of the insolation, whether with or without a horizontal movement of air towards the equator. The latter (like the frost points found) can only continue to exist if northward drift with mass subsidence of air of higher potential temperature is continually in progress.

It is further to be noted, however, that the isopleths of potential temperature are not parallel to the tropopause but have only about half the slope of the tropopause. If there were no loss of heat on the journey from tropics to temperate latitudes and in the process of subsidence, the isopleths of potential temperature would be very widely spaced and would be parallel to the tropopause surface.

Without knowing the actual trajectories of the air masses (which may be devious) certain consequences can be seen. Compare air just above the tropopause in column A of Fig. 1 with air just above the tropopause in column H. If the stratospheric air all came into the temperate-latitude tropopause from the tropics, at or above the tropopause of column A, then the air just above the tropopause at H has subsided roughly 13,000 ft. more than that at A since leaving the tropics. With an actual temperature of −98°F. at 150 mb. at A, it ought in the course of such subsidence to have risen in temperature to −22°F. at 290 mb. Actually the temperature is only about −66°F., i.e. subsidence should have gained for it 76°F. and the actual gain is 32°F. The loss by radiation at H as compared with A is thus some 58 per cent. of the gross adiabatic gain in getting from A to H.

The amount of heat lost by air in getting from the tropics to temperate latitudes with a tropopause at, say, 150 mb. can be deduced, but in this case an estimate is first required as to the level at which the air—found eventually near the tropopause in temperate latitudes—leaves the tropics. This estimate can be got through the frost points. Table II, based on data from *Geophysical Memoirs* No. 88[6] shows the mean actual frost points in each season as measured by the Meteorological Research Flight over southern England at the tropopause and at levels 25, 50 and 75 mb. above the tropopause, and the mean actual pressure at these levels. Between these columns has been inserted the pressure at which, on the average, is found at the equator an air temperature equal to the mean actual frost point obtained by the Meteorological Research Flight. It is believed that in the upper troposphere of most of the tropical regions of the globe the air is normally saturated, i.e. the air temperature in the tropics may be taken as being also very approximately the frost point. Thus, if the stratospheric air as observed over southern England came originally from the tropical upper troposphere and has continually subsided, its frost point can be taken as a pointer to the level at which it left the tropics. The difference between the mean actual pressure and the corresponding equatorial pressure giving the amount of subsidence is included in Table II as well as the mean actual air temperature observed by the Meteorological Research Flight and the temperature

TABLE II—SEASONAL EFFECTS OF SUBSIDENCE AND RADIATION DURING MERIDIONAL MOTION ON TEMPERATURE OVER SOUTHERN ENGLAND

P_c = pressure at tropopause

Pressure level	Mean frost point	Corresponding equatorial pressure	Mean actual pressure	Amount of subsidence	Mean actual temperature	Temperature with adiabatic subsidence from equator	Gain or loss by radiation
	°F.	mb.	mb.	mb.	°F.	°F.	°F.
			WINTER (Jan. to Mar.)				
$P_c - 75$	−102	110	176	66	−58	−48	−10
$P_c - 50$	−98	120	201	81	−62	−41	−19
$P_c - 25$	−98	120	226	106	−68	−28	−40
P_c	−89	160	251	91	−72	−37	−35
			SPRING (Apr. to June)				
$P_c - 75$	−105·7	98	174	76	−53	−41	−12
$P_c - 50$	−101·4	112	199	87	−57	−37	−20
$P_c - 25$	−93	130	224	94	−64	−31	−33
P_c	−81·5	155	249	94	−67	−28	−39
			SUMMER (July to Sept.)				
$P_c - 75$	−104	105	164	59	−49	−53	+ 4
$P_c - 50$	−99	117	189	72	−52	−45	− 7
$P_c - 25$	−90·4	147	214	67	−57	−47	−10
P_c	−76·8	167	239	72	−63	−35	−28
			AUTUMN (Oct. to Dec.)				
$P_c - 75$	−105	100	215	115	−51	−17	−34
$P_c - 50$	−98	120	240	120	−52	−21	−31
$P_c - 25$	−90·6	147	265	118	−61	−23	−38
P_c	−79	164	290	126	−63	−11	−52

which the air observed by the Meteorological Research Flight would have had if the subsidence had been under adiabatic conditions. The difference between these last two columns gives the apparent gain (+) or loss (−) of temperature by radiation.

It will be seen that the four seasons have certain features in common. There is a considerable loss of heat by radiation at and just above the tropopause. At the tropopause indeed the average loss of temperature amounts to 72 per cent. of the gross adiabatic gain. At somewhat higher levels in the stratosphere, however, there is less loss and in summer there is even a small gain of heat by radiation. It must be pointed out, however, that whilst these calculations start from average conditions at the equator, the observations by the Meteorological Research Flight are somewhat selective. The temperatures at the higher levels happen to be a good deal warmer than the long-period seasonal means for Larkhill.

Theoretical extension to higher levels.—In Table III are summarized the mean amounts of subsidence taken from Table II. In the main, the amount of subsidence decreases with height. Each layer that drifts from equator to temperate latitudes is passing into ever narrowing circles of latitude and in addition to subsiding might be expected to be converging and increasing in thickness. If the convergence were proportional to the narrowing of the circles of latitude (which it need not be, because the relative speeds are also involved), then a thickness of about 45 mb. at the equator, or alternatively a thickness of 49 mb. at latitude 23°, would give 75 mb. in southern England.

From the corresponding equatorial pressure given in Table II it will be seen that the initial "equatorial" thicknesses (corresponding to 75 mb. in England) are 50 mb. in winter, 57 mb. in spring, 62 mb. in summer and 64 mb. in autumn.

TABLE III—SUBSIDENCE OF AIR FROM EQUATORIAL UPPER TROPOSPHERE TO LOWER STRATOSPHERE OVER SOUTHERN ENGLAND

P_c = pressure at tropopause

	WINTER (Jan. to Mar.)	SPRING (Apr. to June)	SUMMER (July to Sept.)	AUTUMN (Oct. to Dec.)
		millibars		
$P_c - 75$	66	76	59	115
$P_c - 50$	81	87	72	120
$P_c - 25$	106	94	67	118
P_c	91	94	72	126

It is important to get an idea of what happens at higher levels. For these there are as yet no frost-point measurements. One way of examining the problem is to extrapolate the mean amounts of subsidence from Table III on the assumption that the subsidence tails off to zero at zero pressure. On this basis the initial equatorial pressure of air arriving in England at the following pressure levels can be estimated as follows:—

Pressure level over England	Initial equatorial pressure of air Winter	Summer
mb.	mb.	mb.
75	38	45
100	52	63
125	67	78
150	82	95

Most of these levels imply starting points in the lower stratosphere of the tropics which is in accord with Goldie[2].

Table IV can now be compiled in which, however, the average temperatures over Larkhill are used rather than the temperatures observed by the Meteorological Research Flight from P_c − 50 mb. upwards. The result, for about a 170-mb. thickness above the tropopause, is seen to be that there is large radiation loss in the lowest part (as before), much smaller loss, especially in summer, about the 125-mb. level and large loss again at very high levels, especially in winter.

If the resultant gain or loss for the stratosphere up to the 75-mb. (18-Km.) level is averaged in the layers, weighted according to density, to 150 mb., a mean loss of 40°F. is obtained in winter, which is some 62 per cent. of the gross adiabatic gain, and a mean loss of 17°F. or 36 per cent. in summer. Probably the explanation of the differences with level is simply that where convection is inoperative radiation exchange within the system works continually towards the production of an isothermal condition. Too much significance should not, however, be attached to individual levels, because the individual figures could be altered a good deal by different assumptions as to the way in which subsidence changes with height. At low pressure a small change of pressure has, of course, a large adiabatic effect. It is to be noted that in England[8] in summer, a short way above the highest level (18 Km.) included in Table IV the temperature begins to rise steeply, and that at 30 Km. (or a pressure of about 13 mb.) the mean temperature is about −35°F.

TABLE IV—RADIATION EFFECTS ON TEMPERATURES OVER LARKHILL

P_c = pressure at tropopause

Pressure level	Equatorial temperature	Equatorial pressure	Mean pressure (Larkhill)	Amount of subsidence	Mean temperature (Larkhill)	Temperature with adiabatic subsidence from equator	Gain or loss by radiation
	°F.	mb.	mb.	mb.	°F.	°F.	°F.
			WINTER (Jan. to Mar.)				
P_c − 175	−86	38	75	37	−72	+ 3	−75
P_c − 150	−90	52	100	48	−69	− 7	−62
P_c − 125	−100	67	125	58	−69	−26	−43
P_c − 100	−110	82	150	68	−68	−42	−26
P_c − 75	−102	110	176	66	−70	−48	−22
P_c − 50	−98	120	201	81	−72	−41	−31
P_c − 25	−98	120	226	106	−68	−28	−40
P_c	−89	160	251	91	−72	−37	−35
			SUMMER (July to Sept.)				
P_c − 175	−89	45	75	30	−61	−24	−37
P_c − 150	−97	63	100	37	−63	−40	−23
P_c − 125	−108	78	125	47	−63	−54	− 9
P_c − 100	−106	95	150	55	−63	−52	−11
P_c − 75	−104	105	164	59	−64	−53	−11
P_c − 50	−99	117	189	72	−62	−45	−17
P_c − 25	−90	147	214	67	−57	−47	−10
P_c	−77	167	239	72	−63	−35	−28

Going back now to the time scale deduced previously, the result is that air moving from the tropical upper troposphere and subsiding to constitute the lower stratosphere of temperate latitudes has to lose in, say, an average of about 75 days (possibly more or less according to season) some 40°F. in winter and some 17°F. in summer out of the gross gain which it would have made under completely adiabatic conditions. This seems reasonable—half a degree Fahrenheit a day in winter and a quarter of a degree in summer.

The low tropopause of high latitudes.—At the thermal equator the tropopause is always high, close indeed to the height (17·5 Km.) computed by the author on the principle of global thermal circulation[2]. Even in high latitudes, the tropopause can be high if the pressure distribution is favourable to it; and in middle latitudes it can on occasions be very low. It might be said that the whole or most of the variety of conditions in middle and high latitudes arises from advection, and the author was probably the first to give weight to this effect[9]; but the upper wind observations accumulated since that time show that, though average latitude stratospheric characteristics may tend to be advected, the troposphere cannot simply carry the same stratospheric air with it. This does not mean that pressure distribution and circulation of hemispherical dimensions may not earlier have produced the features that were advected. Experience suggests that the tropopause cannot become very low, or remain very low, unless in a region surrounded by a strong cyclonic circulation. If such a circulation diminishes in intensity, the tropopause rises. The evidence indicates that the primary control on tropopause level in middle and high latitudes is tropospheric circulation, rather than latitude or temperature. If the troposphere becomes very cold in any area, the barometric gradient increases rapidly with height and favours a circulation around that area increasing with height up to the tropopause, and this is precisely the sort of circulation which should tend dynamically to lower the tropopause (see V. Bjerknes[10]) and warm the stratospheric air by subsidence.

Continued loss of heat from the stratosphere in the arctic winter may in itself tend to obliterate the tropopause, i.e. the diagram of Fig. 2 continued farther to the right would tend to a condition in which the potential temperature at the tropopause is no more than at the ground. It is most probably in this way that, in the arctic and antarctic, air is returned from stratosphere to troposphere. It can be shown that subsidence with radiation losses of the same order would suffice. Consider some examples of air starting with the potential temperature of the upper troposphere of the tropics and travelling to the arctic or antarctic with subsidence to various levels. In each case the starting condition will be taken as −115°F. at 90 mb. This air if it subsided to the 9, 6, 4 and 3 Km. levels with no heat lost in the process would rise to temperatures of +31°, +97°, +140° and +163°F. respectively. Actually the average temperatures found in midwinter at some of the coldest stations in high latitudes at these levels are about −61°, −49°, −25° and −20°F. From this it is seen that to arrive at the appropriate temperature the radiation losses accompanying the subsidence require to be 63, 69, 65, and 66 per cent. respectively. Conversely, radiation losses of slightly higher order would appear to render inevitable the exchange of stratospheric air near the poles of cold with tropospheric air of surrounding regions. Considered along its trajectory, the air may be gaining in actual temperature but it is continually losing potential temperature. The extreme temperatures in the upper air imply greater percentage losses and presumably involve loss of heat by radiation over longer periods in the polar winter. For example, the lowest found at Maudheim is given as −130°F. (−90°C.) at about 11 Km. In such a case the radiation loss would exceed the adiabatic gain by 30 per cent.

The more rapid changes of tropopause level.—What has been said previously related to the more gradual processes of tropopause change taking place as air from high levels in the tropics finds its way to positions in temperate latitudes. The changes in stratospheric and tropospheric temperature which might take place as superposed effects within an air mass in the shorter-period changes, such as the deepening or filling up of depressions, may now be considered. Since the scale of time is now in hours or days as against some 75 days, the extent to which radiation reduces the adiabatic gains or losses of temperature is presumably correspondingly less. It would thus be reduced to the order of one twentieth of the values estimated previously, i.e. the radiation loss would be of the order of 3 per cent. of the gross adiabatic temperature change. Where the loss is of this order, 3 per cent. (or even up to 10 per cent.) the difference in percentage loss at different levels should not seriously affect the conclusions reached below. Probably, in view of the actual temperature distribution, the maximum loss or gain of heat by radiation is close to the tropopause on either side.

Consider first curves D and F of Fig. 1: that is the mean temperature-pressure curves for Larkhill for January for tropopause pressures in the ranges 219–200 mb. (D) and 259–240 mb. (F) respectively.

Regarding these temperature distributions as derivable dynamically from one another, the amount of ascent or subsidence of air required at each level can be calculated to convert curve D, with mean tropopause 210 mb., to curve F, mean tropopause 250 mb. For this purpose, and as averages are being considered, the stratosphere has been taken for purposes of computation as being initially approximately isothermal and the troposphere as having the average lapse rate of 3·5°F./1,000 ft. Thus subsidence or ascent of 1,000 ft. implies in the stratosphere a gain or loss of temperature of 5·4°F. (the adiabatic rate), but in the upper troposphere of only 1·9°F. (the difference between the adiabatic and the average lapse rate). The result is shown in Fig. 3. Each

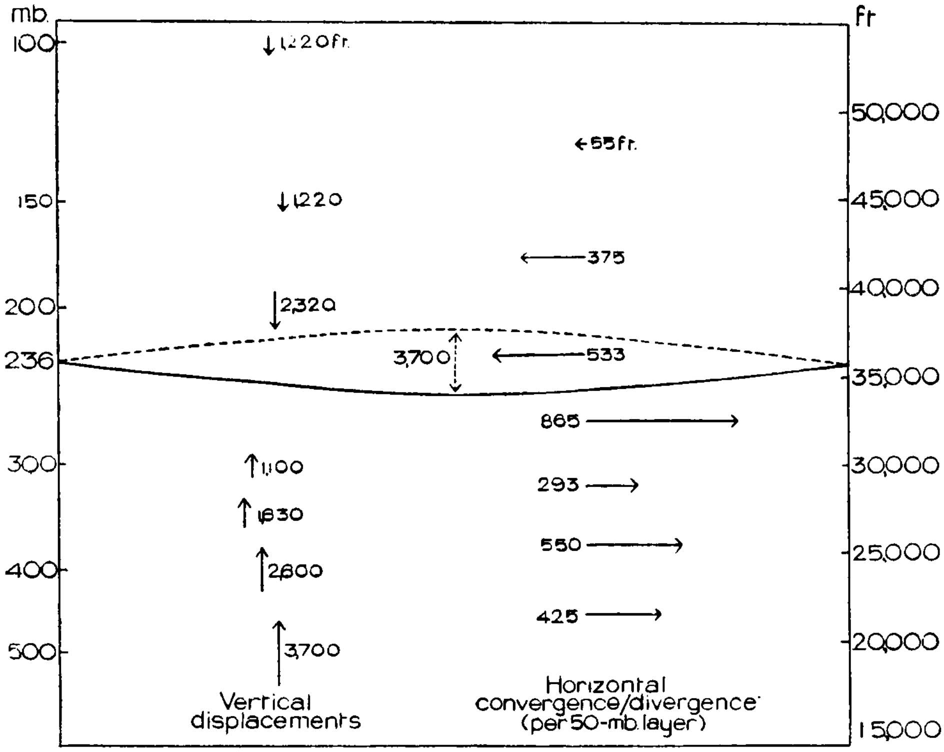


FIG. 3—CHANGE OF TROPOPAUSE FROM 210 MB. TO 250 MB. DURING JANUARY

vertical arrow indicates the required amount and sense of vertical displacement in feet, at the level at the centre of the arrow. The dotted arrow indicates the vertical movement of the tropopause. From the vertical displacements thus indicated it is possible to calculate the relative convergence or divergence required at different levels in the form of aggregate inward or outward displacement of 50-mb. slices of the atmosphere around the area within which the tropopause change is supposed to take place. These convergences and divergences and their sense are similarly indicated by horizontal arrows on a scale of their own.

Fig. 4 represents the results of a similar calculation applied to a rather extreme example taken from October. It has to be remembered that to include the effect of radiation, all the displacements shown in this figure would have to be increased by possibly 3 to 10 per cent.

The points of interest attaching to the mechanism thus shown are as follows:—

(i) Each case has maximum vertical displacement downwards in the stratosphere just above the tropopause. In the troposphere from the 500-mb. level up to near the tropopause there is considerable upward motion.

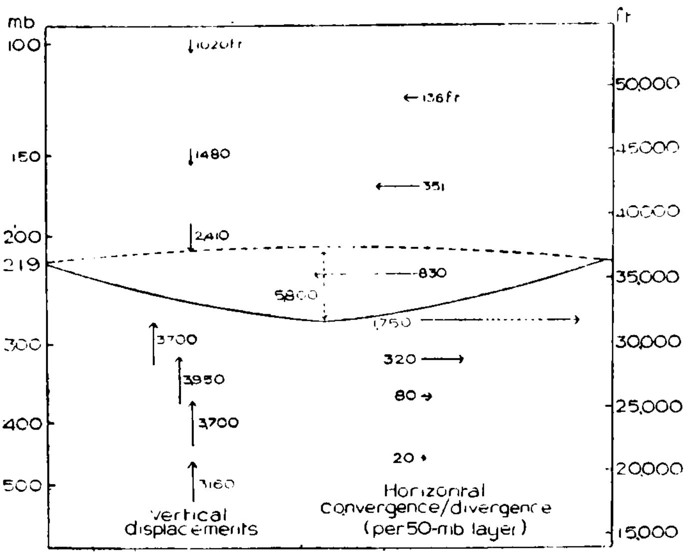


FIG. 4—CHANGE OF TROPOPAUSE FROM 210 MB. TO 270 MB. DURING OCTOBER

(ii) The horizontal divergence in the troposphere and the convergence in the stratosphere each tend to a maximum as the tropopause is approached. Even allowing that the components of convergence and divergence may be small in relation to wind speed, this probably means that appreciable shear of wind exists at the tropopause when tropopause level is changing.

(iii) In a downward change of the tropopause, the stratospheric air near the tropopause is rising in temperature by subsidence, but losing some heat by radiation. In the tropospheric air just below the effects are reversed. It is here probably therefore that the exchange of heat by radiation reaches its maximum.

Summary.—On the hypothesis—for the adoption of which reasons are given—that the air in the lower stratosphere of middle and high latitudes is air which has drifted, with subsidence, from the upper troposphere of the tropics, computations are made of the percentage losses by radiation of the increase of temperature which should have been gained if the subsidence had been under adiabatic conditions. It is found that the gross adiabatic gain of temperature would require to have been offset by radiation losses of 62 per cent. in winter or 36 per cent. in summer to produce the average distributions of temperature found in temperate latitudes in the stratosphere up to the 18-Km. level. The rate of loss by radiation requires to be about half a degree Fahrenheit a day in winter and a quarter of a degree in summer.

Radiation losses equalling or exceeding the adiabatic gains would be required to account for winter polar extremes of temperature. Losses exceeding around 70 per cent. would make inevitable the return of stratospheric air to the troposphere in the polar winter. Assuming corresponding time rates of radiation losses for the shorter-period time-scale of the depressions of middle latitudes, estimates are made of the air displacements associated with rapidly changing tropopause level.

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NIGHT COOLING UNDER CLOUDY SKIES

By W. D. SUMMERSBY, B.Sc.

Saunders[1], recently investigated night cooling under clear skies at Northolt, and on the basis of his results devised a practical routine for forecasting the night minimum temperature. The following is an attempt to arrive at a method for extending his work so that cloudy, or partly cloudy, nights also may be dealt with.

Method.—It was decided to select a number of cases at Northolt, ascertain the night minimum temperature as predicted in each case by Saunders's method on the assumption of no cloud, and then to determine the correction to be applied to this night minimum to bring it into agreement with the actual night minimum for each cloudy night. It was hoped by this means to discover a relation between the correction to the night minimum and the average cloud conditions during the night which could be used in practical forecasting.

In selecting suitable cases for this treatment, the following were excluded for obvious reasons:—

(i) Nights with no cloud or only cirrus.

(ii) Nights with any precipitation.

(iii) Nights during which any front, however weak, crossed the London area, or on which any advective change of dew point was noted. In this latter connexion, the normal tendency is for the dew point to rise slightly until the time of T_r (Saunders's notation for the screen temperature at the evening discontinuity in cooling rate) and then to fall slowly by some 3–4°F.[2] Nights on which this general tendency was shown were regarded as acceptable.

The cloud-amount parameter adopted was merely the arithmetic mean, A, of the number of oktas of cloud reported in the hourly observations, irrespective of cloud type or height. Here, following Saunders, fog with sky obscured was regarded as 8 oktas cloud, whilst in cases of fog with sky discernible, the cloud amount reported was used as with no fog. The minimum temperature as predicted for no cloud was subtracted from the observed minimum in each case yielding the correction (ΔT) which would be required. Simultaneous pairs of values of ΔT and A were plotted in the form of a dot diagram and the

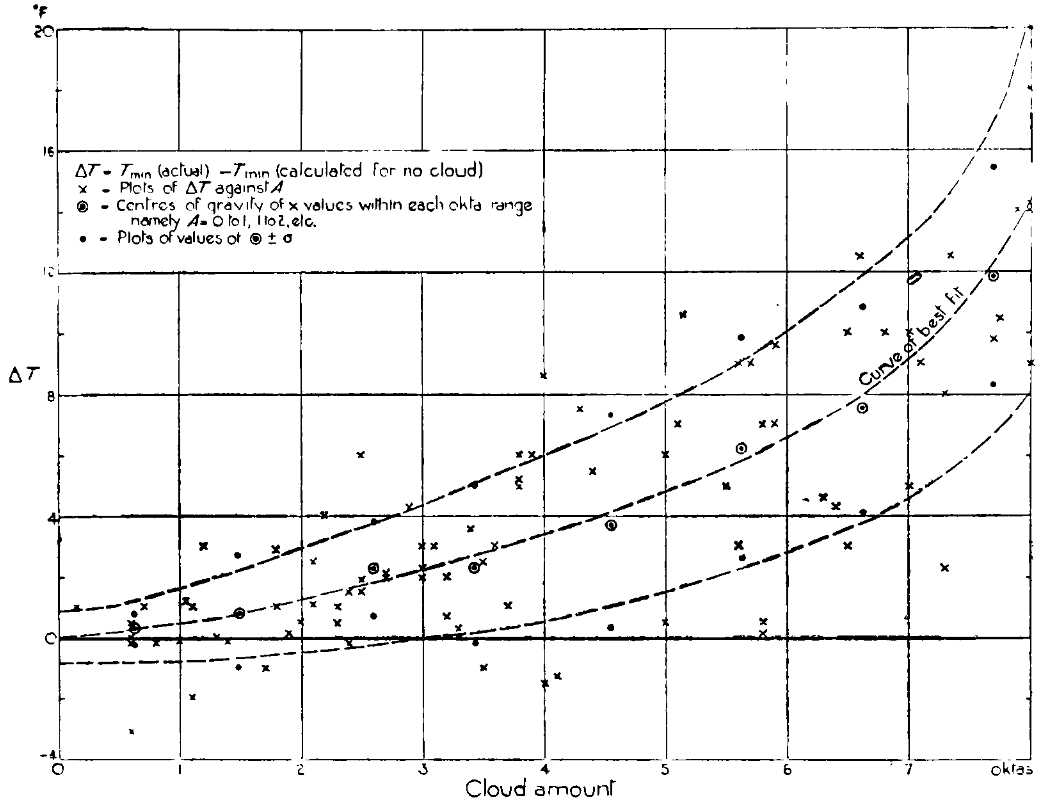

FIG. 1—RELATION BETWEEN AVERAGE CLOUD AMOUNT AND DECREASE IN COOLING

curve of best fit drawn; 90 cases were used for this diagram which is given at Fig. 1.

Discussion.—The curve of best fit was drawn simply through the centres of gravity of each group of points within the cloud-amount ranges: >7 oktas up to 8 oktas; >6 oktas up to 7 oktas, etc. As a check, the deviation, χ, of each point from the curve was evaluated, and an histogram drawn of the frequencies of deviations within given ranges, Fig. 2. The histogram shows central distribution, thus confirming the accuracy of the curve of best fit.

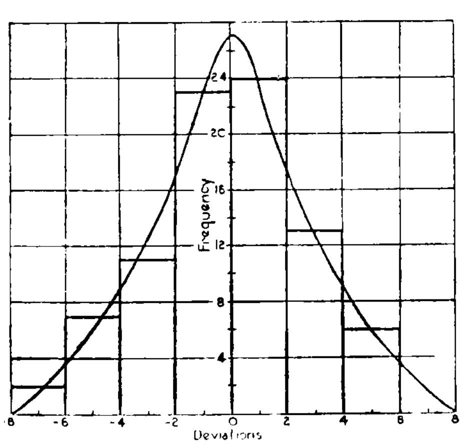

FIG. 2—FREQUENCY DISTRIBUTIONS OF DEVIATIONS AT ΔT FROM CURVE OF BEST FIT IN FIG. 1

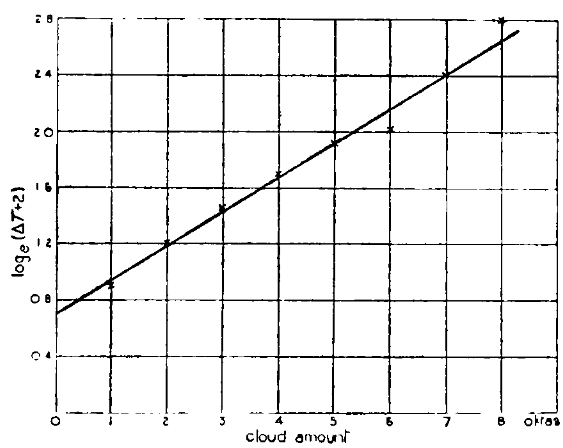

FIG. 3—GRAPH OF LOG$_e$ $(\Delta T + 2)$ PLOTTED AGAINST CLOUD AMOUNT

Having noted χ within each okta range of A, the root mean square deviation for each range was calculated, namely $\sigma = \sqrt{(\Sigma\chi^2/n)}$. The results are given in Table I.

TABLE I

Cloud amount range Greater than	Up to	σ	Cloud amount range Greater than	Up to	σ
oktas	oktas	°F.	oktas	oktas	°F.
7	8	3·59	3	4	2·60
6	7	3·23	2	3	1·52
5	6	3·59	1	2	1·84
4	5	3·46	0	1	0·56

The values of σ were used to draw the two curves shown above and below the curve of best fit in Fig. 1. As about 70 per cent. of the points have less deviation from the mode than the probable error, the curves enclose the area within which it is reasonable to expect about 70 per cent. of points to lie, and therefore give an indication of the accuracy which would be expected from using the curve of best fit in practice.

Relations of an exponential form are commonly encountered in dealing with cooling problems, and the shape of the curve obtained suggests a relation of the type:—

$$\Delta T = C_1\{\exp(C_2A) - 1\}$$

where C_1 and C_2 are constants

or $\log_e(\Delta T + C_1) = C_2A + \log_e C_1$.

If such a relation be assumed to apply, calculation from the data yields a value for C_1 of about 2°F. The result of plotting the values of $\log_e(\Delta T + 2)$ for the intercepts of the curve of best fit with the ordinates at $A = 1, 2, 3$, etc. against those values of A is shown in Fig. 3; the conspicuously linear nature of the curve will be noted. The slope of the line is found to be 0·246, so that to a close degree of approximation

$$\Delta T = 2(e^{A/4} - 1).$$

Table II, shows the agreement between the values of ΔT at $A = 1, 2, 3$, etc. taken from the curve of best fit and those calculated from the above formula.

TABLE II

A	ΔT curve	$\Delta T = 2(e^{A/4} - 1)$	A	ΔT curve	$\Delta T = 2(e^{A/4} - 1)$
0	0·0	0·00	5	4·8	5·00
1	0·5	0·58	6	6·5	6·96
2	1·3	1·29	7	9·1	9·53
3	2·2	2·25	8	14·3	12·78
4	3·4	3·44			

A further idea of the accuracy of the relation found was obtained by evaluating $2(e^{A/4} - 1)$ for each of the 90 cases, and finding the deviation, d, of each from the observed value of ΔT. The standard deviation for the whole okta range ($= \sqrt{(\Sigma d^2/90)}$) was found to be 2·74°F. This may be regarded as encouraging, especially as only cloud amount was taken into account.

It will be remembered that the standard deviations given in Table I vary from 0·56°F. for cloud amount 0 to 1 okta up to 3·59°F. for 7 to 8 oktas. This increase is clearly due to the greater effect of cloud type, height and thickness for large average cloud amounts than for small amounts. It was appreciated that these factors would be significant, but attempts to obtain separate curves corresponding to different cloud types and height ranges proved fruitless owing to the complications involved. There was a suggestion, however, that cloud thickness would be a more useful parameter to introduce as a refinement, and it is proposed to examine this question separately. In using these results in practice, a forecaster would of course depart from the curve of best fit for large cloud amounts, moving towards the upper curve in conditions of thick low cloud and to the lower curve with thin high cloud. In practice, therefore, greater accuracy might be obtainable with large cloud amounts than the figure 3·59°F. would appear to indicate.

Conclusion.—The results described provide the forecaster with a practicable method of forecasting the night minimum temperature on cloudy or partly cloudy nights, by applying a correction to the minimum as predicted by Saunders's method for clear skies[1]. Either the curve in Fig. 1 or tables based on the exponential relation may be used to find the correction. It is presupposed for this purpose that the average cloud amount for the night can be forecast successfully. The curve and relation obtained for ΔT are, strictly, applicable to Northolt alone but would probably be satisfactory at stations with similar subsoil and topography. At other stations a trial on similar lines would be desirable.

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METEOROLOGICAL OFFICE DISCUSSION

Fog investigations

The discussion on March 16, 1953, held at the Royal Society of Arts was opened by Dr. K. H. Stewart who described three groups of fog investigations undertaken by the Meteorological Office. He dealt first with the measurement of visibility at airfields; in the past there had been many complaints from pilots that meteorological reports of visibility did not give a true picture of the conditions they experienced on landing, and a good deal of work had been done to clear up the discrepancies. There were three obvious reasons for differences between pilots and ground observers:—

(i) Difference of place; the runway in use might be a mile or more from the place where routine meteorological observations were made.

(ii) Difference in object looked at; the meteorological quantity "visibility" was intended to be a measure of the properties of the atmosphere only, and was therefore defined and measured as the range at which ideal black objects disappeared against a sky background, whereas pilots, of course, were interested in the range at which the runway, or its lights, disappeared.

(iii) Difference in height; meteorological observations were normally made about 5 ft. above ground level, but a pilot might be looking down from a height of a few hundred feet.

The Runway Visual Range Scheme, in which observers close to the runway measured the range of the actual markers of lights used as guidance by pilots, had been introduced eighteen months ago and seemed to be very successful in overcoming the difficulties mentioned in (i) and (ii). Meanwhile experiments in the measurement of "slant visibility" to avoid the difference (iii) had been pursued. Dr. Stewart described the four methods of measuring slant visibility—by balloon-borne light, by pyrotechnic flares, by balloon-borne photo-electric fog-density indicator, and by inclined searchlight beams—that had been developed, and the attempts to test them by comparison with direct observations from aircraft. He said, however, that there was now some doubt as to whether slant-visibility measurements would really provide any extra useful information. Runway visual range provided a very good approximation to what pilots wanted to know, and it might well be that the inevitable errors due to the inherent patchiness of fog were more serious than those due to neglect of the vertical variation of fog density. The main aim of the work in the past winter had been to collect information about the time and space variation of fog density (by recording photo-electric visibility meters and by balloon-borne apparatus at Cardington) to help in deciding whether routine slant-visibility measurements were necessary at airfields.

The second set of investigations was that being made at Cardington. On occasions when radiation fog was expected, observations of temperature, humidity and wind speed up to 4,000 ft. were made, using apparatus hung from a large barrage balloon, in addition to normal surface observations. These observations should, in due course, lead to improved methods of fog forecasting, though it might well be several years before sufficient data are accumulated to give any significant improvement over methods such as that due to Saunders[1]. The Cardington observations could also provide a basis for more detailed experiments on particular physical processes. The first aim of these experiments was to find how and why the water content of the air near the ground decreased on a radiation night. The most obvious explanation was that it appeared as dew, and methods of measuring dewfall were being developed. More complicated measurements, such as those of radiation and convection, might be necessary later on. Problems involving the size and number of drops were also being considered, and measurements of drop-size distribution were planned.

Finally, Dr. Stewart showed slides illustrating the extent and intensity of fog in the London area in early December 1952. These had been prepared from reports collected from many sources in addition to ordinary synoptic stations. While the dirt and deadliness of the fog had been due to man-made pollution, he thought that the direct effect of solid polluting particles on visibility had been relatively small. Pollution might well have had important indirect effects on visibility, however, by providing many nuclei for condensation. The fog had therefore probably contained a larger number of very small droplets than most fogs, and the chances of partially clearing it by means of a brine spray would have been greater than usual.

Mr. Rustom, of Pan American Airways, said he thought that runway visual range measurements would be improved if brighter lights were used in the estimation of range; on some occasions of patchy fog the runway lights could be seen through the fog while the goose-neck flares used in range estimation could not. He felt that slant-visibility information would save many abortive approaches.

Mr. Wallington also thought there was a need for pilots to know the slant visibility before they started to approach. Visibility on an approach was often only half that on the ground, particularly in smoky conditions. In forecasting fog, he thought it was necessary to allow some time for the fog particles to grow sufficiently to affect visibility, after the theoretical fog point was reached.

Mr. Harley quoted a recent case at London Airport where the visual range on the approach was far less than that on the ground because of the dazzling effect of the sun on a haze layer.

Mr. Mercer, of the Ministry of Supply Blind-Landing Experimental Unit, said that experience in fog trials had shown that pilots found advance information as to when they should pick up lights very helpful. This information could be given quite reliably from simple measurements with a balloon-borne light. In many cases conditions at 200 ft. had been very significantly worse than those at ground level. He did not think that the patchiness of fog was a good reason for limiting the accuracy of measurements; it would be better to measure the patchiness. He ended by expressing great appreciation of the co-operation of the staff of the Meteorological Office at Wattisham in providing forecasts for his trials.

Mr. Russell said that slant-visibility measurements would be useful in the development of FIDO.

Mr. Harley said that if, as had been suggested, it was safe for a pilot to descend to a critical height of about 200 ft. from which he could estimate the slant visibility, it seemed unnecessary to measure this quantity from the ground.

Mr. Stallibrass said that some estimate of slant visibility was essential for civil aviation purposes. He agreed that it might turn out that it was better to deduce the slant visibility indirectly from surface observations than to measure it directly.

Mr. Durward emphasized that slant visibility, like surface visibility, was a variable quantity.

Mr. Saunders suggested that it would be better to collect slant-visibility statistics near London than at Cardington; he thought that smoke had important effects on slant visibility. Referring to the question of loss of water on a radiation night, he thought that it was important to establish the normal mode of variation of dew point at various heights in the absence of advection.

Mr. Poulter said that he had investigated the fall of temperature close to the ground. The discontinuity reported by Saunders seemed to occur at a fixed time after sunset.

Mr. Jacobs (partly communicated) reported on some tests of Saunders's method of predicting fog point. At Defford, of the 47 fogs in the last 6 months only 11 could be classified as true water fogs. The calculated and actual fog points were the same, within 1°F., on 8 of these 11 occasions. In two of the remaining three cases the temperature fell 4–5°F. below the estimated fog point before a fog formed, but there was difficulty in finding representative radio-sonde ascents (a difficulty which occurs on other occasions at Defford) particularly as rain occurred before the sky cleared. On the last occasion the fog point was reached only for a short time. At Filton, fog formed on 24 of the 59 radiation nights during the last year and water fog always occurred. In 17 of these 24 cases the calculated fog point was within 2°F of the actual fog point (12 within 1°F.); in 4 of the remaining 7 cases the estimated fog point was below freezing point and air and ground frost, which did occur, complicated the issue. Of the 35 radiation nights when no fog formed, the calculated fog point was not reached on 21, and of the remaining 14 no less than 10 had a calculated fog point of below or near freezing point, frost actually occurring on all these occasions. Further tests are being made at stations in the Gloucester group of meteorological offices.

Cmdr Frankcom asked if it had been foreseen that the early December fog would be so persistent in the lower reaches of the Thames; he felt that forecasts for this area were important. In some cases, e.g. in the Tees–Tyne area, he thought that smoke alone could have a big effect on visibility. He suggested that counts of nuclei in the very pure air at an ocean weather station might be useful.

Mr. Illsley pointed out that visibility indoors during the London fog of early December, for example in Covent Garden Opera House, had been very low at times, and suggested this was presumably due to pollution alone, without water drops.

Dr. Scrase said he thought that measurements by Wright[2] at Kew had shown that the removal of smoke would produce a great improvement in visibility.

Mr. Clark said that the idea of using a salt spray to clear fog was well known, but had various disadvantages. Other methods, using electrical deposition or dispersal by heat were also available; during the war, the FIDO method appeared to be the cheapest.

Dr. Stewart, in reply, agreed with Mr. Rustom that brighter lights would be an advantage in the measurement of runway visual range. He believed that smoke pollution alone could reduce visibility to 200 or even 100 yd., but that pollution in the amounts actually measured during the December fog could not reduce it to lower values. The indirect effects of pollution, in providing nuclei, might be important and might explain the indoor observations if the relative humidity had been much above 70 per cent.

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2. WRIGHT, H. L.; Atmospheric opacity: a study of visibility observations in the British Isles. *Quart. J. R. met. Soc., London*, **65**, 1939, p. 411.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on February 18, 1953, the President Sir Charles Normand in the chair, the following papers were read:—

*Best, A. C.—Condensation nuclei and the development of radiation fog**

Mr. Best said his paper was mainly an attempt to see if the size distribution of condensation nuclei, supposed to be sea salt, had any effect on the formation of fog as relative humidity increased from 80 to 100 per cent. It was assumed that as the humidity increased the size of the drops increased in equilibrium with the humidity of the surrounding air. This assumption was justified, except for large nuclei in nearly saturated air, by showing that the time taken for the drop size to respond to a sudden increase of 5 per cent. in relative humidity was less than 1 sec. Arbitrary size distributions of nuclei were assumed and the following quantities computed as relative humidity increased:

* *Quart. J.R. met. Soc., London*, **79**, 1953, p. 112.

(*a*) total water content

(*b*) visibility (from Koschmieder's and Houghton's formulae)

(*c*) drop-size distribution at saturation. It was found that the total water content and the atmospheric opacity in a developing fog were proportional to the salt content, but that the shape of the nucleus-distribution curve had little effect on them. The calculated visibility and drop-size distribution in air just become saturated agreed well with observation; as relative humidity increases to slightly over 100 per cent. the drops can grow indefinitely in size.

In the discussion some criticism was expressed by Mr. Ludlam and Mr. Gold of the validity of the assumption of equilibrium between drop size and humidity in nearly saturated air. Dr. Lessing discussed the effect of pollution of urban fogs by sulphur compounds which he believed made the fog more stable. Mr. Mason said little was known of the actual distribution of nuclei in the air and that observations at Los Angeles showed that relative humidity could vary rapidly in fog by several per cent. Mr. Sawyer said he had noticed that if the air was clear then, as relative humidity increased, any fog that formed did so suddenly, whereas in polluted air there was a gradual decrease in visibility.

*Saunders, W. E.—Some further aspects of night cooling under clear skies**

Mr. Saunders described a method of forecasting the temperature during a radiation night for purposes of fog prediction. He had noticed some years ago the existence of a sudden reduction after dusk in the rate of fall of temperature over grass in England. A similar effect was, he pointed out, noticeable in readings of temperature near the ground made in Texas, which showed that the discontinuity was very pronounced near the ground and was less pronounced in the screen. It had been suggested to him that the discontinuity might mark the onset of dew which provided a source of heat. A regression equation method of calculating the temperature of the discontinuity from the day maximum temperature and dew point was described, and curves were set out from which the rate of fall of temperature after the discontinuity could be determined. The method gives a prediction of the minimum temperature as well as the rate of cooling. For full details reference must be made to the paper*.

The discussion turned mainly on the reason for the discontinuity in the rate of fall. Dr. Penman believed it to be real and associated with the cessation at nightfall of transpiration from plants. Dr. Robinson could find no discontinuities in Kew thermograms but a very marked one in the record of net inward radiation flux at the ground. Dr. Sutcliffe said the paper was a very serious practical contribution to fog forecasting whatever the cause of the discontinuity. Mr. Gold said dew sometimes formed even before sunset. Mr. Pilsbury commented that the time of discontinuity changes rapidly after the first radiation night in October which suggested lowered soil temperature was of basic importance. Mr. Saunders in reply agreed with Mr. Gold that some dew might form before sunset, but he had observed copious dew formation at the time of the discontinuity, and that the discontinuities occurred in Texas at the same times relative to sunset as they did in England. In reply to a query by Mr. Bonacina he thought the reason for the increase in difference between screen and grass minima with decreasing temperature was a decrease in the amount of atmospheric moisture.

* *Quart. J.R. met. Soc., London,* **78**, 1952, p. 603.

LETTER TO THE EDITOR

Rainbow phenomenon

The rare phenomenon mentioned in Mr. Pilsbury's letter published in the *Meteorological Magazine* for February 1953 was observed at Benbecula on December 16, 1952. The arcs observed were travelling slowly through the straits separating Benbecula from North Uist.

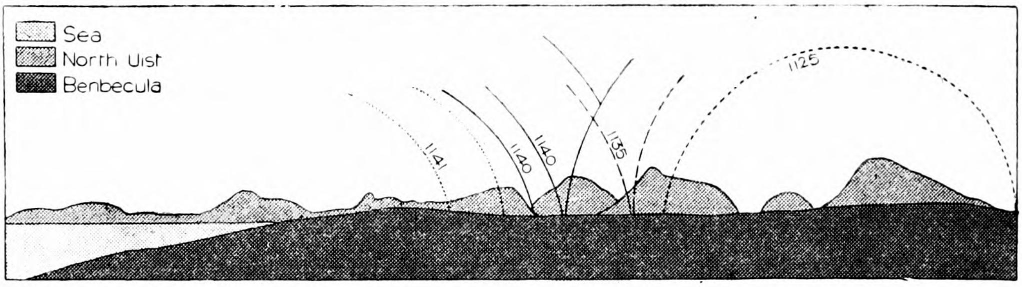

FIG. 1—LOOKING NORTH FROM CONTROL TOWER, BENBECULA AIRPORT

The weather had been cloudy with continuous moderate rain from 8 oktas of nimbostratus at 1,500 ft. with patches of fractostratus at 1,000 ft., the wind at the time being 180° 15 kt. At 1055 G.M.T. a break in the cloud became visible in the south-west, and at 1115 the wind veered to 280° 12–15 kt. indicating the passage of a trough. After this, the wind dropped slightly and the rain became intermittent, and during this period a faint but complete rainbow was observed at 1125 between Benbecula and North Uist. At 1135 an arc formed in the opposite direction to the original bow which had faded and now had only an arc composed of the western half of the bow, red being uppermost in both arcs. Subsequent developments are shown in Fig. 1, red being uppermost in all the arcs shown. In this diagram the lengths of the arcs and the angles between the bows are only approximations.

L. E. WATSON

Benbecula Airport, Outer Hebrides, March 2, 1953

NOTES AND NEWS

Hurricane force winds at ocean weather station "India"

During Voyage 42 of O.W.S. *Weather Watcher*, while on duty at station INDIA (59°N., 19°W.) on December 22, 1952, the vessel experienced winds of hurricane force. A heavy sea struck the ship and completely smashed her two starboard boats. The ship returned to Londonderry forthwith, and, having landed her two smashed boats, borrowed two similar boats from *Weather Observer* who was at that time homeward bound from station JULIETT. It is unusual for one of these ships to take any heavy water on board. In fact, this is the first occasion that any of the weather ships has sustained sea damage worth mentioning in the 4½ years they have been in operation.

The following extracts from the Master's report upon this occurrence show the way in which this exceptionally heavy sea built up:—

"The weather from midnight 21st to midnight 22nd December, 1952, was as follows:

Midnight 21st		Wind ESE., having just freshened to force 8–9, sea 12 ft.
0100	22nd	Wind ESE., force 11–12, sea 15 ft.
0200		Wind ESE., force 10–11, sea 18 ft.
0300		Wind SE., force 10, sea 20 ft.
0400		Wind S'ly, force 10, sea 18 ft.
0800		Wind S'W., force 9, sea 20 ft.
1200		Wind SSW., force 11–12, sea 25–30 ft.
1300		Wind SSW., force 12, sea 28–30 ft. Very confused.
1600		Wind SW., force 12, sea 28 ft. Becoming less confused.
2000		Wind SW., force 12, sea 30–35 ft., with occasional 40-ft. seas but now true in direction.
Midnight 22nd		Wind SW., force 10–11, sea 28 ft.

Wind continued SW'ly, moderating steadily to force 8 by 0800 23/12/52.

"At midnight December 21, 1952, the ship had been stopped for a number of hours, wind at the time being ESE. force 8–9 and increasing, seas 12 ft. By 0100 the wind had increased to force 11–12, and the seas were 15 ft. Ship was now rolling very heavily so we commenced steaming into wind and sea at 60 revolutions, minimum speed to give steerage way. As the seas became higher speed had to be steadily increased and by 0800 we were doing 70 revolutions, and at 1130 we further increased speed to 75 revolutions. Our courses were, at 0530 185 degrees, at 0700 190 degrees, and at 1130 195 degrees.

"Ship was riding the seas well and we had not shipped any really heavy water, nor did I consider we would under the present conditions.

"At 1230 when we were comfortably having dinner the ship suddenly gave a violent lurch to port and there was a loud report of a sea striking the ship. I immediately went up on deck to find that we had shipped what must have been an exceptionally heavy sea and that our starboard lifeboat and dinghy had been smashed beyond repair, as well as other damage."

C. E. N. FRANKCOM

REVIEW

Micrometeorology. By O. G. Sutton. 9 in. × 6 in., pp. xii + 333, *Illus.*, McGraw-Hill Publishing Co. Ltd, London. Price 61*s*. net.

To many meteorologists the subject of turbulence in the lowest layers of the atmosphere has some of the characteristics of a "closed shop". The complaint has been heard that the subject has its own jargon, and has sometimes been accompanied by the implication that the devotees are only related to the family of meteorologists and are not part of it. To some extent this attitude probably arises from the lack of a comprehensive and connected account of the subject (in English). This lack has now been remedied.

Professor Sutton's declared intention has been "to meet the needs of meteorologists, and of workers in other fields, who require detailed information about physical processes in the regions of the atmosphere where life is most abundant". To meet these needs the author has written a book of which roughly the first half provides the basic physics and mathematics and the second half gives a detailed discussion of the extent to which experiment supports, or refutes, theory. Throughout the early pages the development of the basic mathematics and physics is carried out with a view to application to the lower atmosphere. The result is a connected and self-contained textbook, suitable alike for the student about to start work in this field and for the research worker who requires "an integrated account of the major developments in the field". Inevitably the subject is mathematical, but in only a few places will the reader of modest mathematical ability find any real difficulty, and then only if he is not prepared to accept the stated solution to a differential equation.

After a preliminary short first chapter dealing with the usual relations governing temperature and humidity in a static atmosphere the second chapter treats laminar flow in the atmosphere. The equations of motion of an inviscid fluid are developed and applied to irrotational air flow over an undulating surface and over a cliff and to winds on a rotating earth. The Navier-Stokes equations for motion of an incompressible viscous fluid are obtained and applied to flow over a plane surface. Finally, the idea of a boundary layer in laminar flow and the appropriate equations are developed and applied to flow over a plane surface.

Chapter 3 deals with turbulent flow. The Reynolds' stresses are introduced, and the idea of exchange coefficients developed by analogy with molecular processes and applied to the problem of the approach to the geostrophic wind. The author then introduces the idea of a turbulent boundary layer over smooth and rough surfaces, and follows with a consideration of velocity profiles in this layer in relation to the mixing length hypothesis. The chapter finishes with a discussion of statistical theories of turbulence and a brief section devoted to the similarity theory.

Chapter 4 discusses heat transfer and problems of diffusion. The mathematics of the diffusion of heat in a fluid and the idea of a thermal boundary layer are followed by a section which discusses free convection as a result of buoyancy. A long section then treats the solution of the Fickian diffusion equation, with a constant transfer coefficient, for various different boundary conditions corresponding to different meteorological applications. The mathematics of turbulent heat transfer, both by forced and free convection and in relation to the mixing length concept, are discussed, and the chapter closes with a discussion of the Richardson number as a criterion of the effect of density gradient on the growth of turbulence.

Chapter 5 deals with radiation. Following a brief description of the fundamental relations there are factual descriptions of the passage of short-wave radiation to the earth and of the transfer of heat by long-wave radiation. The last part of the chapter discusses the factors governing the night-minimum temperature and various formulae which have been suggested for prediction of this temperature.

Chapter 6 is entitled "Temperature field of the lowest layers of the atmosphere". It starts with a description of surface conditions, including temperature variations in the ground, the effect of soil characteristics and of soil cover and the variation of surface temperature. Then the published measurements of temperature profiles in the lowest layers are discussed and analysed. There follows a theoretical treatment of heat transfer in the lowest layers of the atmosphere leading to the variation of temperature and to the propagation of the diurnal temperature wave in the vertical. This is done for both constant diffusivity and for a diffusivity which varies as a power of the height, and is accompanied by a comparison with observations of the variation with height of the phase and amplitude of the diurnal wave. The chapter finishes with a short discussion of the effects of buoyancy and of radiative transfer of heat.

Chapter 7 discusses problems of wind structure near the surface. The available data for the first few metres are described in terms of the logarithmic profile for neutral stability and on the basis of Deacon's formula for other stabilities. The author then discusses the approach to the geostrophic wind, following Köhler, with an eddy coefficient represented by a power of the height. A detailed discussion of wind near the surface deals with eddy velocities, gustiness, the drag of the earth's surface and the Reynolds' stresses and relates the measurements to wind-velocity profiles. After a brief section on the effect of stabilizing density gradients the chapter closes with a comparison of the theory of winds on slopes with observations.

The final chapter discusses diffusion and evaporation. Following a description of the characteristics of clouds from artificial sources the theoretical solutions of the diffusion equation for various kinds of source and for constant and variable eddy coefficients are given. The solutions obtainable using the statistical theory of turbulence are examined. This is followed by a brief discussion of diffusion from an elevated source and a discussion of the free convective jet in the atmosphere. Evaporation from a saturated surface is treated primarily as a problem in diffusion for both limited and unlimited areas and a comparison made with experimental results. Finally there are brief sections on a comparison of the exchange coefficients for heat, momentum and matter and on the similarity theory of turbulence.

Each chapter is accompanied by a bibliography.

Inevitably the present book invites comparison, or contrast, with the monograph on "Atmospheric turbulence" by the same author. Although there is much similarity in the subject matter the latest book is not simply an expanded version of the monograph. "Micrometeorology" is a course of reading, planned as a continuous treatment and designed to carry the student from the hydrodynamics of a frictionless fluid to our present knowledge of the structure of the lower atmosphere. This has involved some repetition but this is not a disadvantage. Throughout the book theory and experiment are related, but an essential feature is the change in emphasis in about the middle from the basic work of the first four chapters to observed facts and their relation to theory in the last three chapters.

There is no doubt that the author's reputation will be greatly enhanced by his latest contribution to meteorology. It very adequately fills an obvious gap in the literature, and is one of the most important meteorological textbooks produced in English during the past twenty years. The production is excellent and the reviewer noticed very few misprints.

A. C. BEST

OBITUARY

Clarence Vivian Davies Bolton.—It is with great regret that we record the death, on April 14, 1953, at the age of 46, of Mr. C. V. D. Bolton, Experimental Officer, Llandow.

Mr. Bolton joined the Office in March 1937, and served as assistant and, later, forecaster mainly at Royal Air Force stations in the United Kingdom. From 1950 until his last illness he was in charge of the meteorological office at St. Athan, later transferred to Llandow. He was a loyal, cheerful and efficient officer whose first interest was his work. Mr. Bolton left a widow, a son and daughter, to whom we offer our sincerest sympathy in their great loss.

HONOURS

The following awards were announced in the Coronation Honours List, 1953:

C.M.G.

Mr. J. Durward, Deputy Director (Services), Meteorological Office

O.B.E.

Mr. A. C. Best, Principal Scientific Officer, Meteorological Office

OFFICIAL ANNOUNCEMENT

Appointment of Deputy Directors of the Meteorological Office.—Mr. S. P. Peters has been appointed Deputy Director for Forecasting in succession to Mr. E. G. Bilham, and Dr. R. C. Sutcliffe, O.B.E., Deputy Director for Research in succession to Dr. A. H. R. Goldie, C.B.E.

The appointments took effect on June 1, 1953.

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—The following is an extract from the report of the Master, *Weather Observer*, Voyage 47: "This has been the best voyage I have experienced, the weather for almost all the period on station (April 5–25, 1953) has been perfect with the crew sunbathing and swimming almost daily. During the last week on station (52°30′N. 20°00′W.) a number of swallows and martins flew around the ship in an exhausted state; some were caught and the Second Officer tried valiantly to feed the birds with a fountain-pen filler but unfortunately they died."

Sport and Athletics.—*Bishop Shield.*—On May 29, at Chiswick, for the fifth year in succession, the Meteorological Office Harrow Ladies' netball team won the Air Ministry Bishop Shield competition.

Walking.—Mr. G. M. Band is evidently maintaining his form: he won the Iraq Command Walking Championship held earlier in the year at Habbaniya, covering the seven-mile course in 59 minutes.

WEATHER OF MAY 1953

Mean pressure was above normal in the region extending south-eastward from Greenland to Iceland and most of Europe except the south; it was below normal over the North Atlantic south of latitude 60°N. and over most of North America. The greatest excess of pressure, 6 mb., occurred in the region of north-east Greenland, where mean pressure was 1019 mb. while the greatest deficit of pressure, also 6 mb., was at approximately 50°N. 30°W. where mean pressure fell to 1008 mb. At the Azores the mean pressure was 4 mb. below normal.

Mean temperature was above normal in Europe, generally between 2° and 5°F., and below normal over most of the United States except the east. The mean temperature varied from 45° to 50°F. in Scandinavia, 55° to 65°F. in west and central Europe and 65° to 70°F. in the Mediterranean region.

In the British Isles the weather was rather warm generally and sunny in most districts; it was dry until the 13th. A very warm spell occurred in England and Wales during the Whitsun holiday on the 24th and 25th. Severe thunderstorms in northern and central districts of Great Britain on the 25th caused floods and considerable damage in places, with some loss of life by lightning.

An occlusion over the southern North Sea gave rain in the south-east on the 1st. Meanwhile an anticyclone built up off the south-west coasts and moved north-east over the country, becoming more intense. This system maintained fine weather almost everywhere until the 13th. There were fairly widespread early morning ground frosts up to the morning of the 4th and day temperatures reached or somewhat exceeded 70°F. in places from the 3rd to the 6th. On the 5th and 6th the anticyclone moved north to the Norwegian Sea but pressure continued high in a wedge across the British Isles, and fine weather persisted although it was generally cooler. Ground frost was again rather widespread in the early morning from the 9th to the 13th. A spell of unsettled weather ensued. On the 13th and 14th a deep Atlantic depression approached west Ireland and an associated trough of low pressure moved north-east over the British Isles, giving rain in southern districts on the 13th and throughout the country on the 14th. Subsequently the main depression moved north-east, and further secondary disturbances crossed the country giving rain or showers and local thunderstorms. On the 18th and 19th a small depression moved northward from south-west France to east Scotland giving general rain and thunderstorms at some places on or near the south-east coast of England. Thereafter pressure was relatively high over France, while Atlantic depressions moved north-north-east along the western seaboard and associated troughs gave rain in most areas (2·20 in. at Maesteg, Glamorganshire on the 22nd) but it was only slight in the south-east. By the 23rd a warm moist air stream of tropical origin covered most of the country with some fog on the south and west coasts. An anticyclone built up over France and moved north-east; south-easterly winds set in over most of the British Isles and very warm weather prevailed over England and Wales, with temperatures up to 80°F. at some places in the south-east on the 24th and over much of England on the 25th, when London Airport registered a maximum of 89°F. On the 24th a cold front, associated with a small depression which developed off north-west Scotland, approached west Ireland and subsequently moved east giving widespread, severe thunderstorms in many northern and central districts; the storms were accompanied by heavy rain and floods (2·52 in. at Fort William during the 24 hours ended at 0900 on the 25th, 2·12 in. at Barnard Castle, Durham, on the 25th) and several people were killed or injured by lightning. There were thunderstorms in east and south-east England on the 27th. The rest of the month was mainly dominated by a large anticyclone centred to the south-west of Ireland and rather cool, changeable weather prevailed, though rainfall amounts were mainly small.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	89	26	+2·6	109	−3	113
Scotland	79	24	+2·6	108	−2	98
Northern Ireland ...	75	31	+3·3	90	−3	107

RAINFALL OF MAY 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·41	80	*Glam.*	Cardiff, Penylan ...	3·47	142
Kent	Dover	1·73	104	*Pemb.*	Tenby, The Priory ...	2·84	123
,,	Edenbridge, Falconhurst	1·52	82	*Radnor*	Tyrmynydd	3·19	93
Sussex	Compton, Compton Ho.	3·24	146	*Mont.*	Lake Vyrnwy	3·23	100
,,	Worthing, Beach Ho. Pk.	2·09	127	*Mer.*	Blaenau Festiniog ...	5·55	98
Hants.	Ventnor Cemetery ...	2·51	144	,,	Aberdovey	1·78	71
,,	Southampton, East Pk.	2·65	133	*Carn.*	Llandudno	1·77	99
,,	South Farnborough ...	1·83	105	*Angl.*	Llanerchymedd ...	3·21	137
Herts.	Royston, Therfield Rec.	1·48	76	*I. Man*	Douglas, Borough Cem.	2·63	105
Bucks.	Slough, Upton	1·29	77	*Wigtown*	Newton Stewart ...	2·52	95
Oxford	Oxford, Radcliffe ...	1·68	90	*Dumf.*	Dumfries, Crichton R.I.	2·37	86
N'hants.	Wellingboro' Swanspool	1·42	73	,,	Eskdalemuir Obsy. ...	2·90	88
Essex	Shoeburyness	1·49	115	*Roxb.*	Crailing	1·58	79
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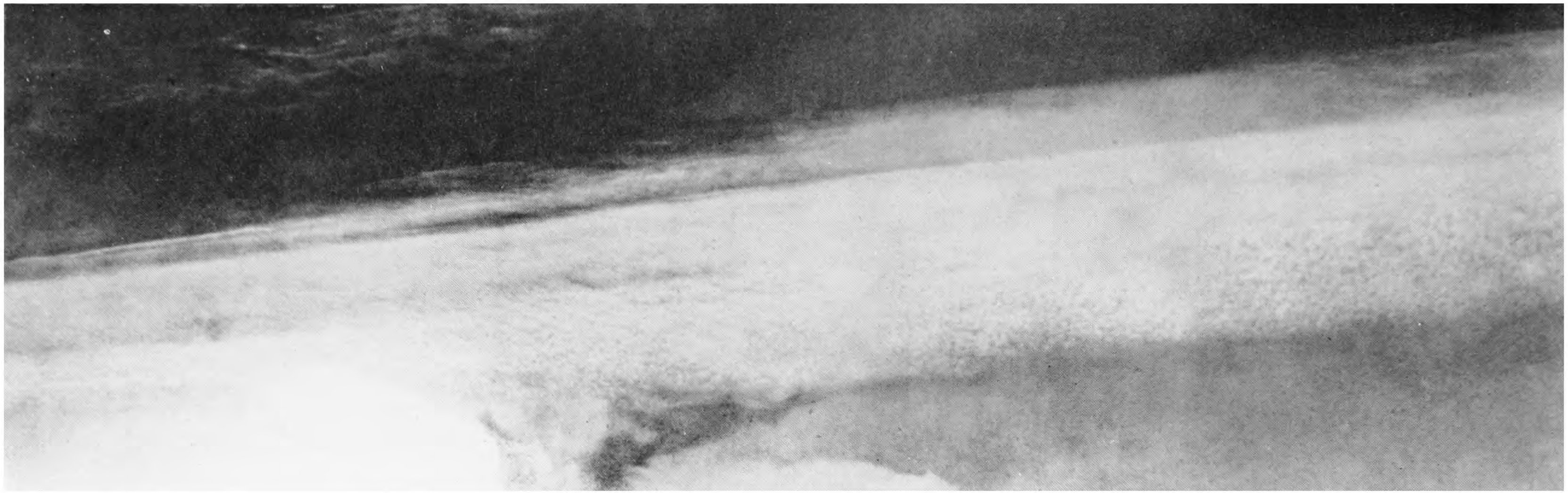
Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-34. K16.



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CIRRUS CLOUDS, HARLINGTON, MIDDLESEX, MAY 14, 1953, 1400 G.M.T.

The line of cirrus photographed was one of a number which formed and dissipated throughout the day in the northerly air stream which covered the British Isles. The clouds formed at approximately 20,000 ft., and extended north–south for about 43 miles. These clouds are of the type considered by Mr. F. H. Ludlam to be of orographic origin (see p. 52).

Photo by the Royal Aircraft Establishment, South Farnborough

CREPUSCULAR RAYS

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 974, AUGUST 1953

REVIEW OF METHODS OF LONG-RANGE FORECASTING WITH PARTICULAR REFERENCE TO THE BRITISH ISLES

By J. M. STAGG, D.Sc.

This paper is a critical summary of the principal processes that have been explored or proposed for forecasting for periods longer than can be dealt with by extending the normal synoptic methods used in short-period forecasting.

It is an abridgement of a *Meteorological Research Paper*. The only important change from the original paper consists in the omission of suggestions for future research prepared for the consideration of the Meteorological Research Committee; all the essential technical information has been retained.

Each principal process suggested for long-range forecasting will be considered in turn.

Regression equations.—Statistical relations in the form of multiple correlations or regression equations between present- or past-weather elements and later events in the same or other regions have been used in various parts of the world, particularly where large-scale processes dominate the weather over a wide area. In India regression procedures have proved of value in assessing whether temperature and rainfall are likely to be substantially above or below normal during the monsoon season.

Because few of the relationships among meteorological events are simple or direct, especially when separated in time as they have to be for application to forecasting, the correlations are liable to be unstable, and therefore the regression equations require to be modified from time to time so that new or improved correlations may replace those whose validity has deteriorated. And even though the physical processes behind the regression equation may be broadly understood the relationships are purely statistical, so that the forecaster can exercise only such judgement as the transformation of the arithmetic of his result into the words of his forecast allows him.

The search for correlations among meteorological elements in different parts of the world can improve understanding of the functioning of the atmosphere, and the use of regression equations may be helpful in conjunction with other methods. But forecasting by this means alone cannot lead far, especially in a meteorologically complex area like the British Isles, even if the correlations were elaborated and extended to take account of the more recently available upper air information.

Pressure waves.—Analysis of selected barograms of surface pressure from selected stations in middle and high latitudes has shown that apparently regular wavelike oscillations are set up in the atmosphere from time to time: the principal periods are approximately 72 and 48 days and their submultiples. If one or more of these oscillations can be diagnosed early enough, they may be used to estimate the future pressure pattern over a network of stations. A similar procedure has been applied to pressure-height contours at 500 mb. and higher levels. Pressure waves have been extensively investigated and applied to long-range forecasting in Germany where other important properties have been attributed to particular waves. For example the 72- and 36-day waves are believed to extend into the stratosphere and exercise control over the direction of travel of the 6-day wave and the movements of the centres of the 24-hr. isallobaric pattern; the amplitude of the 24-day wave on the other hand decreases rapidly with height and is conspicuous only in high latitudes. Pressure waves have also been investigated in the Meteorological Office.

It has been shown that a single- or double-layered model atmosphere, having prescribed kinds of temperature structure, can oscillate in a number of periods ranging from 6 to 72 days, and also that the oscillations are propagated from west to east in middle and high latitudes. But there is no unanimity about their origin; they have been variously attributed to unstable gravitational waves between troposphere and stratosphere induced by extension upwards of instability waves on the polar front, to roughly periodic outbreaks of cold air from the polar calotte or the breaking away of cold pools, to waves dependent upon the temperature differences between the main land and sea masses around zones of the earth, and even to precession movements in the wind circulation zones around the earth set up by unsymmetrical pressure fields tilting the wind belts out of their appropriate latitude. No one of these explanations is physically satisfactory or complete.

But even without a satisfactory physical basis the existence of regular trains of periodic oscillations might be of value in forecasting if they were sufficiently regular, of big enough amplitude and sustained over long enough intervals. Unfortunately these requirements are seldom, if ever, all met. The wavelengths of the dominant waves vary over a considerable range and a sequence of oscillations seldom continues for more than three or four cycles; the use of the word wave (in the sense of a sustained and regular recurrence pattern) in connexion with the tendency of the atmosphere to oscillate is misleading.

It has to be concluded that wavelike oscillations of the atmosphere probably do exist, and that further study may well be valuable in giving further information about the structure and behaviour of the atmosphere; but pressure waves are too transient and irregular, and perhaps too localized and variable from season to season and year to year to be of real assistance in forecasting.

Symmetry patterns.—From time to time the sinusoidal pattern formed by the larger surges of pressure in particular areas over an interval of a month or more from a particular date is roughly a direct, or less frequently an inverted, mirror image of the pattern before that date; and the pattern as a whole appears to be translated into other areas as if it were embedded in the circulation. Only a very few patterns are recognizable without detailed analysis, and they are found only a few times a year, mainly in winter. But if a pattern of this kind can be recognized before, or by the time of, the central date as likely to be a symmetry pattern, harmonic or other analysis can be employed to extend it into the future over a grid of stations, and so allow it to be applied to forecasting the surface pressure distribution.

The chief components in a symmetry pattern are found to be the same as in pressure waves, namely 72 days and its submultiples, and its formation is therefore explained by the simultaneous existence of pressure waves phased so that the extreme minimum or maximum values coincide at the point of symmetry. If this is the only physical explanation of symmetry patterns—and it fits the facts—then the value of their application to forecasting is as precarious as is the use of pressure waves. There are however some further aspects. The 24-day wave is one of the most prominent constituents of every symmetry pattern, and this has been attributed to major outbursts of polar air from the arctic basin; if there is a tendency for these outbursts to occur at about 24-day intervals, the occurrence of a roughly symmetrical pattern a few times each year may express little more than the tendency for one prolonged weather type (e.g. south-westerly, with its series of depressions each having its particular family characteristics) to be interrupted by a polar-air outburst. This leaves open the questions whether the polar-air surges do have a 24-day rhythm, even if only for two or three cycles, and whether, if there is an approximate rhythm, it is inherent in the build-up and break-down of pressure over the polar cap, or whether it is started by a smaller and less spectacular tendency for the atmosphere to oscillate naturally at about 24-day intervals. There is so much doubt about the answers to these questions, and indeed about any system which depends on the analysis of an element like pressure having intrinsic coherence in its day-to-day variation, that some authorities have concluded that symmetry patterns are the result of fortuitous circumstances in the pressure field.

To be of value in forecasting the existence of a pattern and the symmetry date must be known as soon as possible after the central point of symmetry has been reached, and its main features must be reproducible by a few of the harmonic components. But there is no known method of forecasting the symmetry date, and even if there were, the lack of persistence in the pattern and uncertainty about its form and amplitude after the central date would make the information of very doubtful value. Methods have been devised and applied both in Germany and in Great Britain by which the pressure field over a whole region can be analysed in means of one to three or more days, but such statistical devices do not compensate for the inherent weaknesses of the method both in physical interpretation and practical application.

Climatic singularities.—In probably every region of the world there is a tendency for particular types of weather, or abrupt changes in its annual course, to recur round about the same calendar dates each year. These singularities (as the German meteorologists who have studied them most have called them) include large-scale phenomena like the beginning of the Indian monsoon, or, at the other extreme, discontinuities in trend of mean temperature through the year such as were first discussed by Mossman and Buchan for south-east Scotland. Lamb has recently shown that many of the singularities listed by German meteorologists appear also in the weather of the British Isles.

When the singularities are restricted to a few well marked events each with a genuine physical basis there can be little doubt of their value in forecasting;

the reality and value of many singularities become more questionable when their number is increased so that six or eight are expected each month. It is admittedly dangerous to discount a phenomenon because it has no obvious explanation, and until more is known of the mechanism which leads to the major changes in the zonal tropospheric circulation in middle latitudes the explanation of the high incidence of particular pressure distributions over an area on days linked with the calendar must be lacking. But the reality of individual singularities can be accepted and used as an auxiliary factor in forecasting only when their frequency of occurrence over a long series of years is substantially higher than random, and when some explanation, at least proximate, can be offered when they fail to occur or are much displaced from their position in the calendar.

Up to now the only explanation of singularities is in terms of pressure waves, particularly the 72-day wave and its submultiples. According to this, the wave processes determine the pattern of surface pressure distribution and through it the major changes from zonal to meridional circulation; on this theory the absence or displacement of singularities is to be taken as a warning that another system of waves has been established or the phase altered, and this in itself is a tool in the experienced forecaster's hand.

In current synoptic language many of the more important singularities are probably associated with greater or lesser degrees of "blocking" of the zonal westerlies, and an intensive study of this phenomenon might therefore throw light on the cause of authentic singularities. Alternatively the study of real singularities, critically segregated from the merely fortuitous, might well be extended to the middle and higher troposphere and lower stratosphere; even though it might not lead to conclusions directly applicable to long-range forecasting, a study of this kind would be one method of obtaining further experience of the three-dimensional behaviour of the atmosphere which could hardly fail to have applications to forecasting practice.

Pressure trends and other trend phenomena.—As the amount of detailed information in synoptic charts is apt to conceal the slow, though widespread, changes that may be in progress, charts representing the deviation of the mean surface-pressure distribution over a number of days from the long-term normal distribution have been used to bring these slower trends into prominence. In this way centres of abnormally high or low pressure are identified, and their movements studied with the object of extrapolating their trajectories. But the results of at least one experiment on these lines conducted by C. E. P. Brooks using 6-, 12- and 24-day mean charts were not encouraging.

A similar kind of procedure forms part of other systems of forecasting. For example trends of index figures representing the strength of the zonal circulation have been applied to help in assessing the future circulation pattern; surface-pressure profiles at a network of stations are similarly used as a clue to the general trend of pressure over an area.

In these and other applications trend procedures are quite empirical, and for want of knowledge of the causes of the trend the bias in extrapolation must always be toward normal. It is therefore not surprising that the contribution of trend methods to long-range forecasting has not been found helpful; at best they can be only auxiliary aids.

Long waves in the zonal westerly circulation of middle latitudes.—The working hypotheses which allow long-wave ideas to be applied to forecasting are, first, that the waves are more slowly variable and their immediate behaviour is a little more amenable to forecasting than the surface-pressure field, and secondly, that the main features of, and changes in, the surface field are related to the pattern of the upper tropospheric circulation. Unfortunately these hypotheses are not conspicuously reliable beyond the second or third day. The only approximately realistic theory of long waves so far developed rests on assumptions, both as regards the physical characteristics of the medium and the nature of the undulations, which seldom hold in the actual atmosphere, so that substantial empirical and subjective factors have to be superposed when the theory is applied in practice. Even then inferences can be made about speed and wave-length only of waves that already exist; little help can be given about the time and place of formation of new waves or about the intensification or decay and disappearance of old ones. For these aspects of the long-wave pattern the forecaster must use the second hypothesis in reverse, and assess the changes in the pattern of tropospheric circulation that are likely to be brought about by the development and movement of surface features. And reliance on this interaction is impaired in that its extent depends among other things on the scale and intensity of the surface developments. Small and shallow depressions and high-pressure cells are steered by the circulation pattern without altering it substantially, but the larger and more vigorous features of the pressure field impress their effects on the circulation.

Notwithstanding these weaknesses, techniques based on circulation theory and experience have contributed to the preparation of 5- and 30-day forecasts in the United States of America, and of 10-day forecasts in Germany. In the United States 5- and 30-day mean configurations of the surface and upper air circulation patterns are dealt with as units, using step-by-step daily practice for the first 2 or 3 days as a check in the preparation of the 5-day forecast. In Germany the technique adopted is understood to be a grafting of an extension of daily synoptic practice for the first five days on to a forecast derived from a combination of other methods for the second half of each 10-day period.

Apart from the uncertainties inherent in the use of circulation ideas, application of the wave theory to 5-or-more-day mean patterns introduces further doubts. It may be contended that mean circulation charts for even as many as 5 days can have little physical significance and that the equations of circulation theory cannot be satisfied by mean values of meteorological elements which do not correspond with any actual state. On the other hand those who use them claim that 5- and even 30-day mean circulation charts and their surface field counterparts have real physical individuality, and that only mean charts can disclose the centres of action which regulate the longer-period trends in weather; they claim that the results of long-wave theory can be applied to mean charts with only a little more empirical modification than is already necessary for daily charts, and, further, that the broad features of weather, e.g. departure of temperature and rainfall from normal, can be inferred from the mean surface charts deduced from the mean charts of circulation.

But whatever value these methods may have for large continental regions, they are unlikely to give much useful guidance for areas of the size and meteorological situation of the British Isles, where quite small displacements of the main features of the circulation have such important effects on the weather.

Kinematics of air flow and trajectories of pressure cells.—With their weather dominated for much of the year by anticyclones and their vast plains providing a natural laboratory for the study of air-mass and pressure-cell movements, it is not surprising that Russian meteorologists should have been led to base their system of forecasting on trajectories of high-pressure cells. Though analogues and rhythms and dynamical reasoning also play an important part in the system begun by Multanovski and elaborated by Pagava, the movements of anticyclonic cells and the pressure fields associated with them form the "natural" basis of their "natural" processes within "natural" regions.

According to the Multanovski-Pagava school the anticyclonic nuclei that invade Russian territory come predominantly either from the Azores, from Greenland, or from the arctic basin by way of the Taimyr peninsula. They have preferred axes along which they move, and the frequency of invasion from each of the main centres and the orientation of their trajectories depend on the time of year and on the kind of season. In some years, for example those characterized by unusually mild autumns, the frequency and the orientation of the tracks followed are consistently abnormal. Once a high-pressure cell has started to migrate its future track is approximately known, and by reference to charts which have been constructed to show the positions of the other high- and low-pressure cells relative to similar tracks followed about the same time in other years, the general form of the surface pressure distribution linked with a particular anticyclonic axis can be forecast. As the likely orientation of the trajectory of a high-pressure cell can be determined within 2 or 3 days after the nucleus of the cell has appeared and as the average life of a cell is 10–12 days, it is possible by the Multanovski-Pagava system to forecast 7 or 8 days ahead.

This period of 7–8 days can be extended by other considerations. At a time varying from 30 to 35 days before the start of a high-pressure cell process, there are recognizable premonitory symptoms in the surface field, and in the interval between the appearance of these warnings and the start of the process there are several recognizable phases of 6 to 15 days each characteristic of a stage leading to the formation of the anticyclone. In addition the Russian long-range forecasting school has discovered that there is a tendency to rhythms with still longer periods in the behaviour of the atmosphere. The principal rhythms are of 3 and 5 months' duration and are related to major outbreaks of air south or south-westwards from the Taimyr area.

It is difficult to form an appreciation of the Multanovski-Pagava system of forecasting, and even if it were proved to be successful in Russia it does not follow that it could be successfully applied to any other area, because Russia's extent (east–west and into the arctic basin) and surface topography relative to the general circulation are unique. But the Russian emphasis on dynamic climatology, on natural periods and natural regions, and on the genesis, development, migration and decay of high-pressure cells are aspects of the system which might well repay further study in other countries.

Analogues.—In forecasting for short periods, frequent observations, good communications and simple extrapolation go a long way to fill blanks in the forecaster's knowledge of the physical processes, and so the use of mechanical means of aiding his memory is unnecessary and is even to be deprecated. Physical reasoning should replace memory. But if it be accepted that a preliminary to starting any system of forecasting for periods more than 2 or 3 days ahead must be an intensive study (with a broader perspective than short-period forecasting requires) of the modes of evolution of particular types of weather and of the corresponding thermal and flow pattern in the middle and higher troposphere and lower stratosphere then the information derived from the study must be systematized. The best way to systematize it is to devise a theory which takes account of the dynamics and thermodynamics of the whole field of interaction. But it is unlikely that that will be available for many years. So, unless each member of the forecasting team makes his own study so as to build up his own background of case histories, an adequate analogue system for comparing and grouping situations of like evolution may be useful so long as it is kept in mind that any analogue system is only an auxiliary and interim measure, to be discarded as fast as physical knowledge of the underlying processes replaces empiricism. But there are at least as strong reasons for avoiding the use of any analogue system, even though the development of an equally successful, but scientifically sounder, procedure for forecasting may take longer.

Solar phenomena.—As regular seasonal changes in solar radiation so obviously affect the general temperature in each hemisphere and the tempo and intensity of weather changes, it is contended that the irregular changes in the sun's output of radiation which are assumed to vary in parallel with particular indices of its surface activity should also affect weather. Much work has been done in many countries to discover relationships; mean annual, monthly and daily values of sunspot numbers, and of measures of the solar constant, numbers of faculae and other indices have been correlated with a great range of climatic and weather parameters. The results, though of interest for the light they shed here and there (or fail to shed) on indirect relationships between solar activity and terrestrial weather, are of no value for forecasting; the only reliable and persistent correlation so far found is between sunspots and temperature in the more cloudy regions of the tropics, and this (negative) correlation shows up only in the mean annual values. More must be known about the relationships between measures of solar activity and the output of radiation from the sun in various spectral regions, particularly in the ultra-violet, and about the possible effects of corpuscular radiation, before solar phenomena can be of use in forecasting; and even then it is not clear that it will be any easier to forecast behaviour on the sun than the behaviour of our own atmosphere, except perhaps in a general way for the 11- (or 22-) year cycle.

Ozone.—Although much is now known about the life history of atmospheric ozone, its distribution over the globe, its seasonal changes and its relation to the pattern of the surface pressure field especially in moderate and high latitudes, measurements of ozone are so far of value to the forecaster only as pointers to the nature of the upper air processes that accompany the birth, growth and decay of low- and high-pressure cells in the lower troposphere. Even if the redistribution of ozone by some extra-terrestrial influence preceded rather than accompanied the changes in the higher circulation pattern and surface field it would still be necessary to forecast the behaviour of the mechanism which effects the irregular changes in the amount and distribution of the ozone.

Conclusion.—There is no ready-made procedure or combination of procedures suitable for long-range forecasting in the British Isles. The objections to the methods that have been tried or proposed are that most of them are primarily applicable to large continental areas, that they rely too much on empirical and impermanent relations, that they are too dependent on personal judgement, and that too few of them are founded on lines which will allow organic development into sound physical methods as knowledge of the atmosphere grows. A worth-while system of long-range forecasting, like any modern system of day-to-day synoptic forecasting, requires the gradual building up of an elaborate procedure and the accumulation of experience in its use. To avoid waste of effort it is therefore necessary to see that any new system should start on sound physical lines, and should be sufficiently elastic to permit modification for absorbing new ideas without wholesale abandonment of technique and experience.

Much research has still to be done on the maintenance of the zonal westerly circulation, its role in the interchanges of heat and momentum with adjacent zones and its interactions with the great land and ocean surfaces below and with events in the stratosphere above; and it may be that deeper insight into these processes will shift the emphasis to some more fundamental mechanism. But the circulation is likely to continue to be regarded as the main link between the still imperfectly understood primary causes and the changes in the field of flow near the earth's surface which have weather as their end product. While the basic research proceeds, it is therefore inevitable that the study of the modes of behaviour of the westerly zonal circulation corresponding with the main weather types and spells, and of the modes of transition from one weather type to another must be the starting point for any modern system of longer-range forecasting.

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All the important papers which have been consulted in the preparation of this review are given in the comprehensive "Selective annotated bibliography on general and extended forecasting" compiled by C. E. P. Brooks in *Meteorological abstracts and bibliography, American Meteorological Society, Boston Mass.*, **2,** 1951, p. 42 and p. 124. The only important omissions are the unpublished reports by Dr. C. E. P. Brooks and his colleagues and by Mr. J. Wadsworth on British experiments in forecasting by pressure waves.

FORECASTING MOUNTAIN AND LEE WAVES

By R. S. SCORER, Ph.D.

It is a complicated matter to calculate wave amplitudes and lengths even in a simple hypothetical case, but some indication as to whether waves will be good or not can be fairly simply given. The best lee waves are produced by hills with smooth, fairly steep lee slopes if they lie across the wind, but the air current must also be of the right kind. Waves are more likely if the wind direction does not vary much with height and is across a mountain ridge. It has also been shown[1] that waves over the mountains and to their lee only become noticeable when the quantity l^2 decreases with height and the purpose of this note is to indicate how this quantity can be fairly quickly estimated. By definition:

$$l^2 = g\beta/U^2 - U''/U$$

where g is gravity, β is the static stability and equal to θ'/θ, θ being the potential temperature, U is the wind across the mountain and a prime denotes a differentiation with respect to height. Because it is only important in shallow layers and cannot be computed with much accuracy the second term is best ignored in the present state of the subject in forecasting problems. It is actually more convenient to calculate l^{-1} and the following procedure has been adopted:

(i) Obtain an estimate of the wind and temperature profiles of the air current, and plot them on a tephigram up to 400 mb. at least.

(ii) For each 100-mb. layer obtain the thickness Δz in feet and the difference in potential temperature between the top and the bottom of the layer in degrees Fahrenheit. These can be read directly from the tephigram.

(iii) From Fig. 1 read off the value of $(Ul)^{-1}$; multiply this by U, the average wind speed in the layer in knots, and obtain l^{-1} in miles.

If l^{-1} increases substantially with height waves are more likely than if it does not. The best conditions are when there is a layer at least 200 mb. thick near the ground in which l^{-1} is considerably less than in a layer higher up at least 300 mb. thick. Sharp inversions and changes of wind with height are best smoothed out in these calculations. The formula is not accurate in these regions if the inversion is a fairly thin layer or if the velocity profile is very curved, but it is adequate over most of the heights dealt with here.

If l^{-1} is very large near the ground a thicker layer above in which it is small (with another layer in which it is large above that) is required for waves.

If l^{-1} does not change much in the lowest 500 mb. it may be necessary to continue the calculation up to 300 or 200 mb.

Very roughly the lee waves have a maximum amplitude at the top of the layer in which l^{-1} is small, i.e. at the level where l^{-1} begins to increase substantially with height.

The wave-length of lee waves will be less than $2\pi l^{-1}$ as measured in the upper layers and more than $2\pi l^{-1}$ as measured in the lower layers; and it will be in miles if l^{-1} is calculated as just described. If the ridge is well defined and fairly narrow the first lee wave is only three-quarters of a wave-length from the ridge crest. If during the day, because of a decrease in lapse rate in the lower layers, l^{-1} increases, the wave-length also increases; but as it cannot exceed $2\pi l^{-1}$ as measured in the upper layers waves may become impossible, only to return again in the evening with a slowly shortening wave-length.

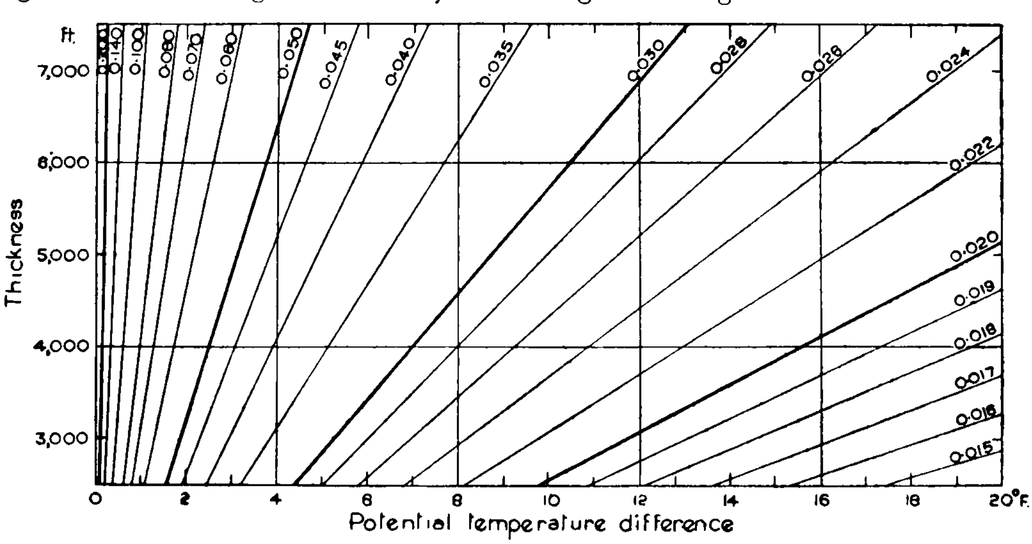

FIG. 1—ISOPLETHS OF $1/Ul$ TO GIVE $1/l$ IN MILES WHEN U IS IN KNOTS

Generally, when conditions are favourable for lee waves they also favour large-amplitude disturbances over the hills themselves. If mountains have great extent in the direction of the wind the disturbance may not be proportional to the height. In such cases there may not be much observable vertical motion unless the mountains have a fairly steep lee slope.

It is impossible to be more precise than this without also becoming much more involved. It seems best that this simple calculation should be tested for its adequacy first.

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HELM-WIND EFFECT AT RONALDSWAY, ISLE OF MAN

By F. W. WARD

With straight isobars from a direction between 340° and 360°, the surface wind at Ronaldsway has been noticed to be subject to unexpected deviation from that which had been forecast. Sometimes the wind was considerably stronger than expected whilst the direction has been observed to change by as much as 180° in a few seconds. On July 28, 1952, the wind which had been blowing steadily NW. with a strength of about 10 kt. suddenly became SSW. 13 kt.

Frequent observations of the wind velocity were made in an attempt to trace the origin of this strange behaviour. Eventually a marked difference between the wind at the Control Tower and that at a wind-sock some 800 yd. due east of the Control Tower was noticed. A selection of the observations is given in Table I.

TABLE I—WIND OBSERVATIONS AT CONTROL TOWER AND AT WIND-SOCK

G.M.T.	Tower Direction	Tower Speed	Wind-sock Direction	Wind-sock Speed
		kt.		kt.
0700	S.	15	..	..
0716	calm	..	..	..
0728	360° cycle	8	..	..
0731	SE.	14	N.	14
0736	N.	10	SW.	9
0741	SW.	6	N.	14
0748	ENE.	14	N.	5
0752	calm	..	N.	14
0754	W.	10	N.	9
0802	SW.	10	N.	14
0808	E.	6	NW.	9
0824	calm	..	NW.	9

From 0830 G.M.T. onwards the wind both at the Control Tower and at the wind-sock behaved normally averaging NNW. 10–15 kt.

Other Observations.—Cloud conditions varied between 2 and 4 oktas stratocumulus or cumulus with the base at 1,700 ft. (estimated) and tops at 3,000 ft. (estimated). The cloud was in four cylindrically shaped bands, each aligned approximately south-west to north-east. The northernmost band was about six to eight miles long, and lay just above the crest of the mountain range to the north and west. The second was about 4 miles south of the first and about half a mile north of the Control Tower. The third was situated about 2½ miles south of the second and was much shorter. The fourth band, about 2½ miles further south, was thinner, less well defined and shorter than any of the others. Cloud motion round the second and third bands was noticed to be in the form of a circular whirl, moving from a northerly direction at the base of the cloud and then ascending almost vertically round the southern boundary of the roll. There was no cloud between the first and second, and between the second and third rolls (see Fig. 1). No upper lenticular cloud was observed.

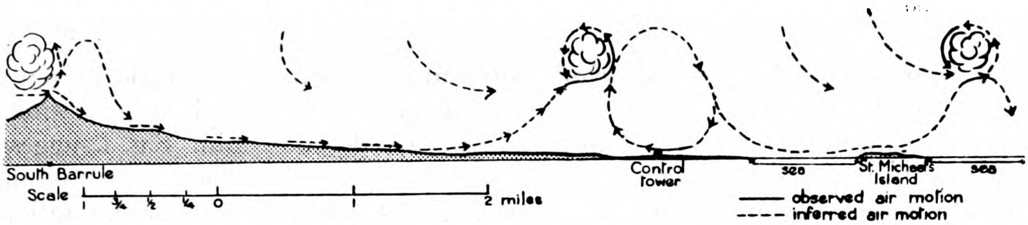

FIG. 1—VERTICAL CROSS-SECTION SHOWING OBSERVED AND INFERRED AIR MOTION

After 0826 G.M.T. when the wind variations were no longer apparent, the cloud formation ceased to be of the band form described above, and became the more normal detached cumulus or broken stratocumulus type.

The dry-bulb temperature rose from 54°F. at 0700 to 55°F. at 0800 and to 56·5°F. at 0900 G.M.T.

The routine tailless pilot balloon ascent made at 0800 G.M.T. at Ronaldsway gave the results shown in Table II.

TABLE II—0800 G.M.T. PILOT BALLOON ASCENT AT RONALDSWAY

Height	Wind Direction	Wind Speed	Height	Wind Direction	Wind Speed
ft.	°true	kt.	ft.	°true	kt.
4,000	330	16	1,000	360	6
3,000	360	5	Surface	calm	..
2,000	330	21			

People resident on the airport about 1,000 yd. north-north-east of the Control Tower remarked on the strong wind during the night and early morning. The wind strength at the Control Tower during the same period did not exceed 13 kt.

Topography.—A range of hills aligned approximately south-west to north-east forms the rocky backbone of the Isle of Man, and runs practically throughout the whole length of the island. The hills reach a height of over 1,400 ft. in several places, the highest point in the southern portion of the range being South Barrule (1,585 ft.) 4½ miles north by west of the airport at Ronaldsway. Between the summit of South Barrule and the sea at Derby Haven the ground falls 1,000 ft. in the first mile and then the slope becomes more gentle (see Fig. 2).

Synoptic situation.—At 0600 G.M.T. on July 28 an anticyclone was centred about 50°N.25°W. and a depression was situated over Denmark. The British Isles lay under the influence of a cold northerly air stream. The 0300 G.M.T. ascent from Aldergrove showed a marked inversion at about 3,000 ft. with dry air aloft. The winds at Aldergrove at 0900 G.M.T. are given in Table III. The gradient wind measured over the Isle of Man on the 0600 G.M.T. chart was 350° 20–25 kt.

TABLE III—0900 G.M.T. ASCENT FROM ALDERGROVE

Height	Wind Direction	Wind Speed	Height	Wind Direction	Wind Speed
ft.	°true	kt.	ft.	°true	kt.
24,000	10	36	5,000	350	28
14,000	10	33	4,000	350	28
10,000	355	25	3,000	350	27
8,000	350	25	2,000	350	25
6,000	350	26	1,000	350	18

Explanation of observed wind and cloud motions.—The wind strengths found by the Ronaldsway tailless pilot balloon ascent are based on the assumption that the balloon was rising at a uniform rate of 500 ft./min. Fig. 1 suggests that vertical upward currents would be present from the surface to at least the height of the cloud base giving a higher value of h, the height above the station, than was used in the computation. This would result in too low a value of the horizontal wind speed. The speed found at the assumed height of 2,000 ft. would similarly be high if the balloon were affected by down-currents. The low value of the wind at the assumed height of 3,000 ft. is more difficult to explain, but it is possible that the balloon was near the third of the cloud rolls and was under the influence of another upward current, or it may have been

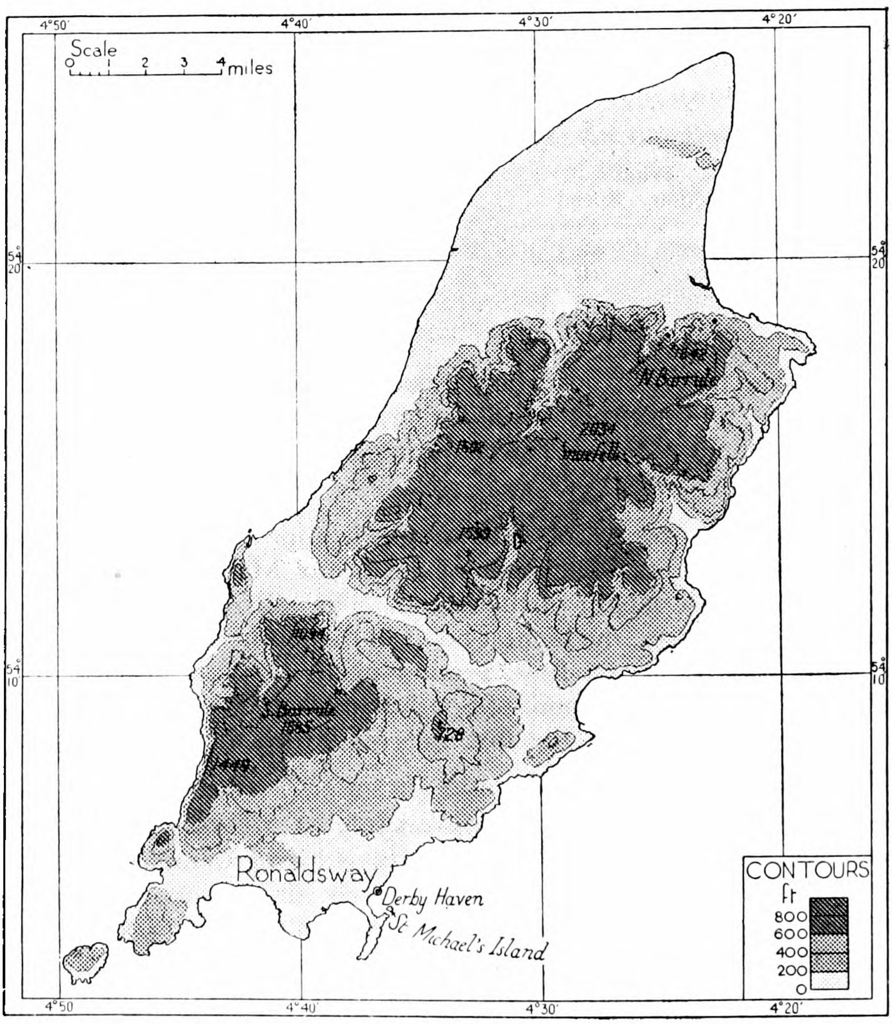

FIG. 2—ISLE OF MAN

caught in the southerly drift near the upper edge of the third roll resulting in a small northerly component averaged over the whole minute. The higher value of the wind at 4,000 ft. (assumed) could be explained by similar reasoning to that at 2,000 ft.

The irregularities in the wind speeds found by the ascent from Ronaldsway and the cloud motions observed point strongly to the existence of eddy currents caused by the mountainous ridge of South Barrule. This is also supported by the peculiar roll-form cloud indicating at least four standing waves in the lee of the mountainous ridge.

There seems little doubt that the effect is very similar to that investigated by Manley* in the Crossfell district of the northern Pennines, and that the whole phenomenon is of the three-bar type described in Manley's paper. The wind at the wind-sock was obviously much less affected than that at the Tower, but some rapid fluctuations did take place.

Break-down of the helm wind and bars.—The 1400 G.M.T. ascent from Aldergrove shows only a small increase (about 10 mb.) in the depth of cold air since 0200, and the decrease in the wind strength over the period of the helm wind was imperceptible. The only element to show any significant change was the dry-bulb temperature which rose from 54·0°F. at 0700 to 56·5°F. at 0900 G.M.T. From the ascent from Aldergrove for 0200 G.M.T. the formation of small cumulus, base 2,000 ft. tops 3,000 ft., would be expected when the surface temperature reached 54·5°F. The detached type of cumulus did not, in fact, form until the surface temperature reached 56°F., and it is in this that a possible explanation of the break-down of the helm wind and bars can be found.

The four roll-shaped bands of cloud were undoubtedly caused by the ascent of the air over the mountainous ridge which initiated a train of standing waves in its lee. When the surface temperature reached 54·5°F., weak vertical convection currents would be produced in the cloud-free spaces between the rolls. The air flow of the standing-wave system in the cloud-free spaces would oppose the convection currents, and cloud would not form. When however the dry-bulb temperature reached 56°F., the convection currents must have been stronger than the descending currents in the standing-wave system. The whole wave system would be disturbed with the subsequent break-down of the roll-form cloud and the development of the usual detached cumulus type of cloud.

Manley* also has noticed that the helm wind of Crossfell is checked by increased convectional activity.

Comparison with the helm wind of Crossfell.—The main point of interest in the "helm" wind produced by South Barrule is that the effect can be initiated by a range of hills as low as 1,500 ft. The long narrow backbone shape of the southern range of hills in the Isle of Man is similar to that of Crossfell, and the slope from the summit is unbroken by obstacles.

The variability of the surface wind at Ronaldsway would appear to be greater than that found near Crossfell. It is possible that the slightly greater steepness of slope (1 : 5 compared with 1 : 6) may be the reason for this.

It is interesting to note that the ratio of the depth of cold air to the height of ridge is similar to the critical conditions found near Crossfell (3,000 : 1,585 compared with 6,000 : 2,930 near Crossfell) and is approximately 2 in both cases.

* MANLEY, G.; The helm wind of Crossfell, 1937–1939. *Quart. J.R. met. Soc., London,* **71**, 1945, p. 197.

INFLUENCE OF THE ETESIAN WINDS ON THE SUMMER TEMPERATURE IN ATHENS

By L. N. CARAPIPERIS

During the summer, along the shores and the coastal plains of the eastern Mediterranean and especially over the Aegean Sea, calm conditions seldom prevail, because either the etesian winds or sea breezes constantly blow. These winds control the climate of the above places and they are of great importance to human comfort.

This paper is concerned with the influence of the etesian winds on the summer temperature in the Athens area, where they blow from a direction between NE. and NW.

Athens is situated at a distance of about 5 Km. from the Gulf of Saronikos and 55 Km. from the east coast of Euboea. The etesian winds, as previously shown[1,2], appear, though with little strength and stability, in the above area from the beginning of May and maintain this character till the end of June. From the beginning of July their frequency increases, and from the middle of this month until the middle of September they have their greatest strength and stability. After this their frequency decreases and they become infrequent by about the middle of October.

Etesian winds and the fluctuations of summer temperature.—A comparison between the mean summer temperature for each year of the period 1901–50 and the corresponding number of etesian days* makes the influence of these winds upon the summer temperature in the Athens area obvious. The deviations of the summer temperature from the average, have the same sign as the corresponding deviations of the number of etesian days from their average for 42 of the 50 years of the above period. Specifically from the 26 years which present a summer temperature higher than the average, 22 of them have deviations of the same sign as the corresponding deviations of etesian days. From the remaining 24 years which represent a summer temperature lower than the average, 20 of them have deviations which are also of the same sign as the deviations of the etesian days.

The highest mean summer temperature during the period 1901–50, 28·04°C., occurred in the year 1946 in which there was also observed the greatest number of etesian days, and the lowest summer temperature, 24·33°C., occurred in the year 1913 in which was noted the least number of etesian days. But the correlation between the above winds and the summer temperature in Athens, is more clearly seen in Fig. 1, in which the continuous line shows the mean temperature of the summer for each year of the period 1901–50 and the dotted one the number of etesian days, both curves having been smoothed by using the formula $\frac{1}{4}(a+2b+c)$. The principal maxima and minima of summer temperature coincide with the maxima and minima of the number of etesian days, in almost all cases. If the small irregularities which appear in the first ten years are excepted, in the remaining part of the period both lines are nearly parallel.

The coefficient of correlation between the frequency of etesian days and the summer temperature amounts to 0·68 for the period 1901–50 and to 0·82 for the period 1910–50.

* Only those days throughout which a wind having the special characteristics of the etesian wind are considered as etesian days. This was made possible by the use of charts from a Meteorological Office pressure-tube anemograph and a Richard's "anémo-cinémograph" and from the general meteorological records.

From all the above it is concluded that stronger etesian winds and higher summer temperature occur together in the Athens area.

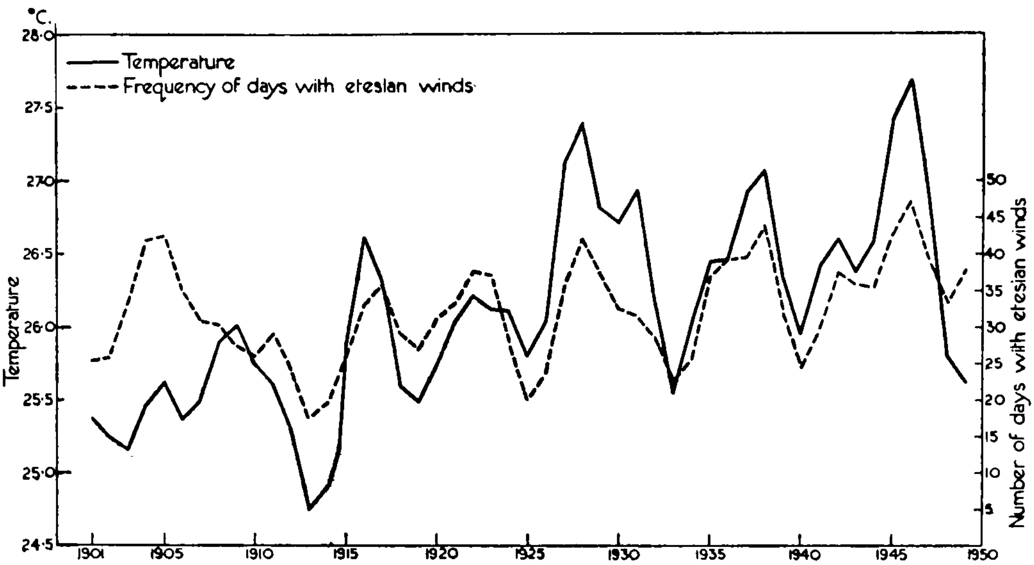

FIG. 1—MEAN SUMMER TEMPERATURE AND THE FREQUENCY OF ETESIAN DAYS IN ATHENS, 1901–50

However, since the sea breeze increases the relative and absolute humidity of the air, especially in the afternoon[3], and the evaporation during the days of sea breeze is less than during the etesian days, the cooling power is greater in the latter. That is why, especially in the afternoon[4-6], the etesian winds in the Athens area often seem fresher than the sea breeze.

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STATISTICAL ANALYSIS OF GEOPHYSICAL TIME SERIES

By R. P. WALDO LEWIS, M.Sc. and D. H. McINTOSH, M.A., B.Sc.

This note concerns some methods which have been found useful in the statistical analysis of geophysical data.

Reduction of standard deviation by removal of linear trend.—Geophysical series frequently have a secular trend arising from a definite (and usually known) physical agency. Failure to allow for such trends leads to an over-estimation of the variability resulting from random influences and may thus lead to a failure to recognize a significant result. The effect of the trend on the standard deviation is here obtained as an approximate correction to be applied to the standard deviation of the original series; tedious removal of the trend from the original observations may be avoided in suitable cases by applying this correction.

In a series x_i of n terms let $x_i = x_i' + (i - 1)\,\delta$ where x_i' is random and δ the trend per unit interval (assumed regular).

Then $$\bar{x}_i = \bar{x}_i' + \frac{\Delta}{2}$$

where Δ is the total trend and is $(n - 1)\,\delta$. If x_i has standard deviation σ and x_i' standard deviation σ'

$$\sigma^2 = \Sigma\frac{x_i^2}{n} - \bar{x}_i^2$$
$$= \Sigma\frac{x_i'^2}{n} - \bar{x}_i'^2 + \left(\frac{2\delta}{n}\right)\Sigma\,(i - 1)\,x_i' + \left(\frac{\delta^2}{n}\right)\Sigma\,(i - 1)^2 - 2\bar{x}_i'\frac{\Delta}{2} - \frac{\Delta^2}{4}.$$

Since $$\Sigma\,(i - 1)\,x_i' \simeq \bar{x}_i'\,\Sigma\,(i - 1)$$
$$= \bar{x}_i\frac{n}{2}(n - 1)\,,$$

and $$\Sigma\,(i - 1)^2 = \frac{n}{6}(n - 1)\,(2n - 1)\,,$$

then $$\sigma^2 = \sigma'^2 + \frac{\delta^2}{12}(n^2 - 1)\,.$$

Thus $$\sigma'^2 = \sigma^2 - \frac{\Delta^2\,(n + 1)}{12\,(n - 1)}$$
$$\simeq \sigma^2 - \frac{\Delta^2}{12}$$

for large n.

The correction to σ obtained above may be applied only in those cases where the data are spaced at fairly regular time intervals and where the trend is approximately linear, as, for example, in the analysis of geomagnetic data subject to secular change and of ionospheric data subject to solar-cycle variation. Analogous trends to these are not evident in meteorological data which in general show only periodic variations of period length, a day or a year. The application of the correction to meteorological data is justified only in the analysis of a small sample not covering times of maximum or minimum, e.g. a series of daily values for months near an equinox.

Effect of linear trends on a correlation coefficient.—In the correlation of two time series, each with a secular trend and with fluctuations about the trend, it may be necessary to know the contributions to the correlation coefficient made by the two trends on the one hand and by the two sets of fluctuations on the other. A method for easy calculation of these separate influences is given below.

Let the two series be given by x_i and y_i, with standard deviations σ_x and σ_y,

$$x_i = x_i' + (i - 1)\,\delta$$
$$y_i = y_i' + (i - 1)\,\varepsilon$$

where x_i' and y_i' are random with zero mean and standard deviations σ_x', σ_y' and δ and ε are the trends per unit interval (assumed regular)

$$\Sigma x_i y_i = \Sigma\{x_i'y_i' + \delta\,(i - 1)\,y_i' + \varepsilon\,(i - 1)\,x_i' + (i - 1)^2\,\delta\varepsilon\}$$

[To face p. 240

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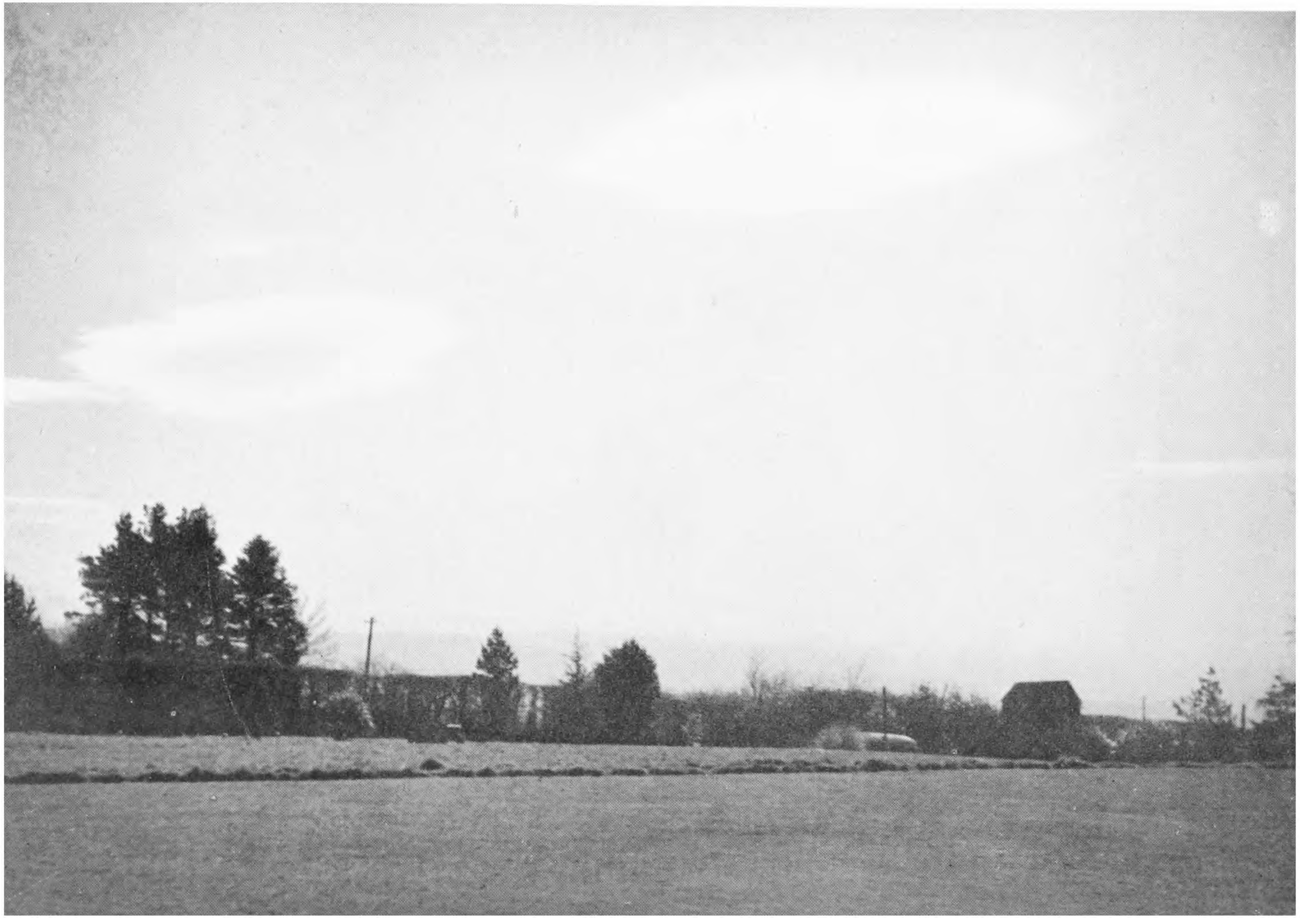
LENTICULAR CLOUDS BETWEEN PENRITH AND KESWICK, JULY 16, 1937



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LENTICULAR ALTOCUMULUS

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LENTICULAR ALTOCUMULUS

Reproduced by courtesy of J. W. Wilkins

WAVELIKE IRIDESCENT CLOUDS, DUNKELD, SCOTLAND, MAY 25, 1953
(see p. 249)

$$\Sigma (i - 1) y_i' \doteq \Sigma (i - 1) x_i'$$
$$\doteq 0.$$

Therefore $$\Sigma x_i y_i = \Sigma x_i' y_i' + \frac{\delta \varepsilon n}{6} (n - 1)(2n - 1)$$

and $$\Sigma \frac{x_i y_i}{n} - \bar{x}_i \bar{y}_i = \Sigma \frac{x_i' y_i'}{n} + \frac{\delta \varepsilon}{6}(n - 1)(2n - 1) - \frac{\delta \varepsilon}{4}(n - 1)^2$$
$$= \Sigma \frac{x_i' y_i'}{n} + \Delta E \frac{(n + 1)}{12 (n - 1)}$$

in terms of the total trends Δ and E.

If the correlation coefficient between x_i and y_i is r, and between x_i' and y_i' is r',

$$r = \frac{\Sigma \frac{x_i y_i}{n} - \bar{x}_i \bar{y}_i}{\sigma_x \sigma_y}$$
$$= \frac{\Sigma \frac{x_i' y_i'}{n} + \frac{\Delta E (n + 1)}{12 (n - 1)}}{\sigma_x \sigma_y}$$
$$= \left(\frac{\sigma_x' \sigma_y'}{\sigma_x \sigma_y}\right) r' + \frac{\Delta E}{12 \sigma_x \sigma_y}\left(\frac{n + 1}{n - 1}\right),$$

and $$r' = \left(\frac{\sigma_x \sigma_y}{\sigma_x' \sigma_y'}\right) r - \frac{\Delta E}{12 \sigma_x' \sigma_y'}\left(\frac{n + 1}{n - 1}\right),$$

where σ_x', σ_y' can be calculated by the method of the preceding section. If Δ and E are small and n is large, the formula may be written approximately as

$$r' = r - \frac{\Delta E}{12 \sigma_x \sigma_y}.$$

Effect of periodic trends on σ and r.—The influence on σ and r of such systematic periodic trends as are common in meteorological elements was given by W. H. Dines in the "Computer's handbook". Putting these results in the form obtained for the effects of linear trends

$$\sigma'^2 = \sigma^2 - \frac{\Delta^2}{8}$$

$$r' = \left(\frac{\sigma_x \sigma_y}{\sigma_x' \sigma_y'}\right) r - \frac{\Delta E}{8 \sigma_x' \sigma_y'} \cos (\phi - \chi),$$

where Δ and E are the respective total trends (i.e. twice amplitude of oscillation) of the two series and ϕ and χ the respective phase angles.

Comparison shows that the effects of periodic and linear trends of equal magnitude are in the ratio 12 : 8. This results from the fact that the average departure from mean is greater for the periodic than for the linear trend values because of the flattening of the periodic trend curve near times of maximum and minimum.

Significant tests in coherent series.—A common test for significance in statistical investigations is the consideration of the difference of two sample means of an element in terms of the general variability of the element. Thus the standard error of the difference between two means of n terms of standard deviation σ is usually taken as $\sqrt{2}\sigma/\sqrt{n}$, and significance is not attached to such a difference unless it exceeds $\sqrt{2}\sigma/\sqrt{n}$ by more than about three times. This value for the standard error of a difference is obtained on the assumption of complete independence between the two sample means. The case where each of the means is calculated from n values which are not independent has received a good deal of attention. The effect in such a case is, briefly, that the standard error of the means themselves and of their difference is increased so that a difference between the means greater than $3\sqrt{2}\sigma/\sqrt{n}$ is required for significance. Here the case is considered where, although each mean is calculated from n independent values, the means are yet not independent because they are adjacent, or near-adjacent, terms in a coherent time series. It is apparent that two such means have a greater-than-random probability of being identical, and thus a difference between them smaller than $3\sqrt{2}\sigma/\sqrt{n}$ must suffice for significance.

Let the means to be considered be $\bar{x}_i$ and $\bar{x}_{i+j}$. These are produced by summing vertically over n examples of a coherent series, each example being of course written horizontally; the two means are separated by an interval j. If the standard deviations of the individual x_i's and x_{i+j}'s are both σ the standard errors of the means are $\sigma/\sqrt{n}$, assuming vertical independence. While, in practice, it is easy to achieve vertical independence by choice of appropriate data, horizontal coherence, the effects of which are being considered here, must remain.

The standard deviation of the difference $(x_i - x_{i+j})$ (s, say) is given by:—

$$\begin{aligned} s^2 &= \frac{1}{n}\Sigma(x_i - x_{i+j})^2 - (\bar{x}_i - \bar{x}_{i+j})^2 \\ &= \frac{1}{n}\Sigma x_i^2 + \frac{1}{n}\Sigma x_{i+j}^2 - \bar{x}_i^2 - \bar{x}_{i+j}^2 \\ &\qquad - \frac{2}{n}\Sigma x_i x_{i+j} + 2\bar{x}_i\bar{x}_{i+j} \\ &= 2\sigma^2 - 2\sigma^2 r_j \end{aligned}$$

where r_j is the correlation coefficient between terms separated by j intervals; r_j calculated from the means is the average of the values of r_j calculated from the individual rows.

Thus, since the differences are independent vertically, the standard error of the mean difference $\bar{x}_i - \bar{x}_{i+j}$ is given by

$$\frac{\sqrt{2}\sigma}{\sqrt{n}}\sqrt{(1 - r_j)}$$

The case $r_j = 0$ is that of independence between the two means; this is approximately true in most geophysical series of successive daily values for $j > 5$.

Two cases may be quoted in which it would be necessary to take account of a positive value of r_j: (i) in a test of the significance of apparent discontinuities in a mean variation, e.g. two closely separated maxima in an otherwise smooth curve; (ii) in an assessment of the accuracy of apparent time of maximum in a mean curve by comparison of the differences between the maximum value and those on either side with the standard deviation $\sqrt{2}\sigma\sqrt{(1 - r_j)}/\sqrt{n}$. These examples of the way in which the coherence of time series can lead to some relaxation in the stringency of the tests to be applied for significance contrast with the more familiar case of lack of independence requiring increased stringency of tests.

OFFICIAL PUBLICATION

The following publication has recently been issued:

Condensation trails. Notes for the use of pilots.

Simple physical explanations are given in this pamphlet of the two main types of condensation trails which may be formed by the passage of aircraft through the air. These types are exhaust trails which are formed by condensation of water vapour from the engine exhaust, and trails of aerodynamic origin, sometimes called adiabatic trails. The former type is by far the more common and important of the two and can only occur at low temperatures. Immunity temperatures, i.e. temperatures above which exhaust trails are very unlikely to form, are given for various heights for the Spitfire and Canberra aircraft as typifying propeller and jet-engined aircraft respectively. A complete discussion of the physical theory of condensation trails is given in "Condensation trails from aircraft".*

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Royal Meteorological Society held on March 18, 1953, the President, Sir Charles Normand in the chair, the following papers were read:—

Mason, B. J.—The growth of ice crystals in a supercooled water cloud†

Mr. Mason described the production of the crystals in a chamber 10 ft. high containing a supercooled cloud of water drops and their growth as they fell through the cloud. The experiments were carried out at different temperatures, and he found that in the ranges of temperature shown below the following crystals formed:—

0 to − 5°C. Hexagonal plates.
− 5 to −10°C. Hexagonal prisms.
−10 to −25°C. Plates and star-shaped crystals.
below −25°C. Hexagonal prisms.

There was a marked change from plates to prisms at about −5°C., but in the ranges of temperature below that indicated above, the corresponding types of crystals were predominant but were sometimes mixed with crystals of the other types.

Wexler, R.—Theory of the radar upper band‡

Dr. Wexler's paper, which was read for him, dealt with the theory of the upper bright radar band above the main bright band of the radar echo produced by melting snow at the freezing level. The upper band was first reported by Bowen in Australia though it has also been noticed in Great Britain and North America. The band is observed to form and then move downwards to coalesce with the main bright band. At intervals a new upper band will form and move down. Wexler's theory is briefly that the upper band is caused by reflection from graupel particles (ice crystals with frozen water droplets attached). The graupel particles are believed by Wexler to form at the level at which more liquid water is condensed in the up-draught than can be used up in the growth of ice

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* London, Meteorological Office. Condensation trails from aircraft. 2nd edn, London, 1952.
† *Quart. J.R. met. Soc., London,* **79**, 1953, p. 104.
‡ *Quart. J.R. met. Soc., London,* **78**, 1952, p. 372.

crystals by diffusion from the water droplets. The rate of growth of graupel increases rapidly with their size and fall. In falling they remove much of the liquid water above the freezing layer. The theory is given mathematically in the published paper.

*Browne, I. C.—Precipitation streaks as a cause of radar upper bands**

Mr. Browne gave a different explanation of the radar upper band. In his view it is produced by reflection from precipitation streaks which form in small volumes in the upper part of the cloud, and in which owing to the increase of wind with height the drops trail up wind as they fall. As a precipitation streak moves across the beam of a radar set directed vertically upwards the particles in the streak enter the beam at continually lower heights and so produce the falling echo. A mathematical theory gave values of the rate of fall of the echo calculated from the terminal velocity of the particles, wind speed and wind shear, which agreed well with those observed.

The principal contributor to the discussion on these two last papers was Mr. Jones of the Meteorological Office radar station at East Hill. Mr. Jones showed photographs of upper bands produced by falling streaks seen as such in a height-range presentation and also of horizontal bands. Mr. B. J. Mason said falling streak echoes had also been observed in Canada and the United States.

At the meeting of the Society held on April 29, 1953, the President, Sir Charles Normand in the Chair, the Symons Memorial Lecture was delivered by Dr. T. W. Wormell, Lecturer in Meteorological Physics in the University of Cambridge, on the subject of "Lightning".

The first part of Dr. Wormell's lecture was a historical survey of the development of the investigation of the structure of lightning, from Franklin's demonstration that lightning was an electric spark to C. T. R. Wilson's measurements, with earthed spheres and plates, of the sudden changes in the vertical electric field near the ground associated with lightning and the discovery of the stepped leader and return stroke mechanism by B. F. J. Schonland with the Boys rotating lens camera. These investigations gave much information also on the approximate distribution and magnitude of the electric charges in the cloud, showing that the positive and negative charges were of magnitude 20 to 30 coulomb with voltage difference of 10^8 to 10^9 volts between the main charge centres.

The second part of the lecture was devoted to recent work by Dr. Wormell and his colleagues at the Cavendish Laboratory on the detailed structure of the electric disturbance produced both by close and by distant lightning discharges. The intensities of the electromagnetic radiation in atmospherics from distant sources are being recorded on an oscillograph and their variation with time from the initial impulse examined. It is found that the atmospherics received at night from sources to the south and east at distances up to 2,000 Km. produce a sharply peaked oscillation with peaks decreasing in amplitude with time. The peaks of the oscillation are produced by waves reflected an increasing number of times from the ionosphere. With this type of atmospheric it is possible for a single station to determine both azimuth and distance of the source. Measurements of distance obtained in this way agree with those found by the

* *Quart. J.R. met. Soc., London*, **78**, 1952, p. 590.

Meteorological Office "sferic" method. This situation, however, does not hold for sources at over 1,500 Km. over the Atlantic, which produce a smooth quasi-sinusoidal variation which does not fit the reflection theory and which cannot be used for finding the distance of the lightning flash. By day almost all atmospherics produce smooth oscillations.

The publication of Dr. Wormell's lecture in the *Quarterly Journal of the Royal Meteorological Society* will be awaited with much interest.

ROYAL SOCIETY

At a meeting of the Royal Society on Thursday, April 23, 1953, Dr. T. V. Davies read a paper of meteorological interest.

The paper, entitled "Forced flow of a rotating viscous liquid which is heated from below", described experimental and theoretical work similar to the now familiar Chicago dish-pan experiment of Dr. Fultz. Using a cylindrical vessel, with a heating element attached to its base near its outer edge, containing water and rotating about its axis of symmetry, Dr. Davies produced two distinct régimes of fluid flow. Below a critical angular velocity he obtained a low rotation régime in which lines of flow spiralled inwards towards the centre; above the critical angular velocity a high rotation régime, with a long-wave pattern similar to that found in the atmosphere was obtained. The wave pattern progressed relatively to the cylinder, and with different angular velocities the number of waves and their amplitude varied.

When the Rossby numbers (inertia terms/coriolis terms) for the experiment and for mean conditions in the atmosphere were calculated, they were found to be in good agreement. From similarity arguments, Dr. Davies suggested that the experiment may be expected to produce effects which occur in the atmosphere.

Dr. Davies then described the results of his theoretical work. He solved the equations of motion, including the viscous terms, for the low rotation régime of the experiment and obtained the horizontal and vertical velocity fields. For simplicity he initially ignored the non-linear terms in the equations, and found for the meridional flow that the fluid should rise at the outer edge, move inwards along the upper surface, descend at the centre and move outwards along the bottom of the cylinder. The effect of the non-linear terms would be to cause the fluid to descend at an intermediate radius as well as at the centre. For zonal motion he found that there should be a region of maximum velocity in the direction of rotation on the upper surface and elsewhere a varying velocity field in the direction of rotation. When he included the non-linear terms he found that a region of velocity should exist in the opposite direction in the lower levels at the outer edge of the cylinder.

Apart from finding a region of maximum velocity on the surface at an intermediate radius, Dr. Davies found no further experimental evidence to support the theoretical results—the technical difficulties have proved, to date, to be unsurmountable.

In conclusion Dr. Davies pointed out the striking resemblance between his theoretical results for the low-rotation régime and the actual conditions found in the atmosphere, e.g. he identified the region of counter-rotation velocities with the low-level equatorial easterlies.

LETTERS TO THE EDITOR

Unusual temperatures recorded during fog

When I read the thermometers in the screen this morning, March 3, 1953, I could hardly believe my eyes. There was dense fog, visibility about 20 yd.; there was dew on the lawn; the bare ground was not frozen; there was no hoar-frost or rime; and the dry bulb read 28½°F., the wet bulb 29¾°F.

I felt so incredulous that I examined the lawn and confirmed that it was dew and the bare ground where it was damp to confirm that it was not frozen. It was quite soft; the dry knobs were powdery. I began to doubt the thermometer so I put an inspector's thermometer in the screen, at 8.45 a.m. About 20 min. later this thermometer was a degree below its lowest graduation, 30°F. My dry bulb was vindicated.

I then, seeking for ice, found clear transparent frozen droplets on the twigs of a *Cornus Mas* shrub on the edge of the lawn; and a little further away, similar frozen dewdrops on the horizontal wires of a framework supporting young cordon apple trees. I emphasize the transparency and globular form of the drops because in so dense a fog at a temperature so much below freezing point I should have expected rime, and not glazed frost.

I can think of no convincing explanation of this or of the temperature at screen level in nearly calm, radiation conditions with no frost on the ground; a superadiabatic lapse between the ground and 4 ft. in a dense fog seems unusual. The phenomenon was not an isolated occurrence. The following morning, March 4, with a fog not quite so thick (visibility about 50 yd.) the temperatures in the screen were both 31°F. at 9.15 a.m. and the lawn was again covered with dew. The temperature just afterwards on the short grass was 35·7°F., but 1½ in. above it was only 33·1°F. By this time, 9.20 a.m., the sun was just visible through the fog. On bare soil immediately afterwards the temperature was 36°F. On March 10, at 7.30 a.m., with visibility about 60 yd. the temperatures in the screen were both 29°F. and again the lawn was covered with dew and the ground was not frozen. The temperature on the grass just afterwards was 30·7°F. and on bare soil 30·4°F. On both days there were clear ice globules on the *Cornus Mas*, many on March 4, but only one or two on March 10.

On the other hand, on March 5, between 7.10 and 7.20 a.m. with clear sky and no fog there was hoar-frost on the lawn, the temperature in the screen was 31°F., on the grass 29°F. and 2 in. above the grass 31½°F.

On all these days I verified that the temperature at about screen level in the open air was nearly the same as in the screen, i.e. the lag in the screen temperature was small.

E. GOLD

8 Hurst Close, London, N.W. 11, March 14, 1953.

[London Airport had a screen minimum of 26° and a grass minimum of 28°F. for the period ending 0900 on March 3. The dry- and wet-bulb temperatures were identical from 0400 to 1000: 29·4° at 0400, 28·0° at 0600, 26·4° at 0800, 26·8° at 0900 and 27·8°F. at 1000. There was thick wet fog with visibility 40 to 110 yd. The observer realized the unusual relation of the minima and an independent check was made.

At Kew Observatory, Northolt, Hampstead, Camden Square, Kensington Palace, and Regents Park, on March 3, the screen minimum was higher than the grass minimum. The grass minimum at Northolt was 15° and at Kew 23°F.

Mr. A. G. Howard reports that at Woodcock Hill, Kenton, Middlesex, early on March 3 there was frost on hedge tops but the ground was not frozen, and Mr. Pilsbury that at Rayners Lane, Pinner, Middlesex, there was ice on tall trees but dry ground. Mr. W. E. Saunders writes that at Chivenor, near Barnstaple Devon, the screen and grass minima were 30° and 31°F. respectively on the 4th and 26° and 30°F. on the 5th. There was fog at Chivenor throughout both nights and rime was observed on hedges and dew on the grass.

The *Daily Weather Report* shows grass minima higher than screen minima at Bristol on the 3rd (22–23°), 4th (25–27°) and 5th (29–30°) at Manchester (31–33°) on the 3rd, and Lympne (27–28°), Mildenhall (27–28°) and Ross-on-Wye (25–28°) on the 4th. All these stations had fog. At Prestwick on the 4th the same applied (34–35°) but there was stratus, 8 oktas, at 700 ft. without fog.

Sunrise was at 0743 in London on March 3.

These observations show that a surface temperature some 3° above screen temperature is quite possible during fog.

The development of a lapse of temperature in fog is described in papers on the temperature-gradient observations at Leafield[1] and Ismailia[2], and explained on the basis of excess upward radiation in the upper part of the fog[3], but temperatures below screen level were not observed.

Mr. A. C. Best suggests the phenomenon is not unusual. There may be an adjustment between cooling by radiation at the top of the fog and the upward flow of heat through the soil such that ground temperature remains above 32°F. while air temperature falls below 32°F. Such a state can only occur when there is shallow dense fog and a ground temperature slightly above freezing. With regard to the lapse rate between ground and screen Mr. Best asks if there is any evidence that the superadiabatic lapse rate extended up to 4 ft. or if it was confined to the lowest one or two inches.

Dr. G. D. Robinson states it is not safe to infer a ground temperature above freezing point from the presence of dew as he has several times seen copious water and no detectable ice on grass whose surface temperature was undoubtedly below 32°F. On one such occasion the surface temperature measured by thermometer and radiometer was as low as 24·5°F.

The 0300 Larkhill radio-sonde observations on March 3 were:—

Height	Dry bulb	Dew point
ft.	°F.	°F.
5,350	43	−60
3,810	48	−60
2,300	52	20
950	37	29
Surface 440	24	24

Mr. Corby suggests that if, as seems certain, the fog was several hundred feet thick, then radiation from the top of the fog is unlikely to have affected the lapse rate in the lowest few feet of the atmosphere.—Ed., *M.M.*]

REFERENCES

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2. FLOWER, W. D.; An investigation into the variation of the lapse rate of temperature in the atmosphere near the ground at Ismailia, Egypt. *Geophys., Mem., London,* **8,** No. 71, 1937.
3. HEYWOOD, G. S. P.; Some observations on fogs and the accompanying temperature gradients. *Quart. J. R. met. Soc., London,* **57,** 1931, p. 97.

Iridescent wavelike clouds

On Thursday, February 19, 1953, between 1630 and 1700 G.M.T. the following interesting cloud formation was observed from the meteorological office at London Airport. To the westward a series of short parallel bands of alto-cumulus cloud orientated east–west attracted attention through their unusually marked iridescent colouring. Closer observation revealed that the bands were in fact forming at the crests of successive waves, the first one forming on a bearing of 250°. The crests were most clearly marked by cloud at the southern end of the series and gradually faded away northwards; at one time sixteen such crests were counted.

IRIDESCENT WAVELIKE CLOUDS, HARROW, FEBRUARY 19, 1953

The wave motion was very clearly marked on the first two crests with streamers of cloud even being carried down into the trough between them. An elevation of 15° was measured with the searchlight alidade, and, assuming a height of 3½ miles (18,000 ft. approximately), the clouds were forming at a point 13 miles away. From measurements taken, the width across a crest was of the order of 700 yd. and the depth from crest to trough approximately 1,500 ft.

Readings taken with the nephoscope indicated a wind of 165° 27 kt. at the height of the cloud. The 500-mb. chart for 1500 drawn at London Airport showed a small low centred over the Welsh border area, and such a wind seems probable. Radar winds reported at Larkhill were 16,000 ft., 222° 38 kt.; 18,000 ft., 228° 44 kt.; 20,000 ft., 224° 67 kt.; and at Liverpool 16,000 ft., 69° 11 kt.; 18,000 ft., 50° 15 kt.; and 20,000 ft., 29° 13 kt.

It is wondered whether the feature responsible for producing this series of waves could possibly be either the Hog's Back (height 505 ft.) or Leith Hill, just south-east of Guildford (height 965 ft.).

Other clouds to the west at the time of observation were a sheet of strato-cumulus low in the sky cutting off the sun from direct view and also a band of cirrus at about 80° elevation stretching north–south and marking the rear edge of the cloud associated with a surface trough which went through London Airport just before 1500.

C. R. BARRINGTON

London Airport, February 21, 1953

While on holiday in Scotland recently I was fortunate enough to observe a similar phenomenon to that reported by Mr. C. R. Barrington and observed by Mr. J. L. Monteith and myself.*

*This account of the February clouds is to be published in a future issue of *Weather*.

The wavelike clouds were seen from Dunkeld, at 2030 G.M.T. on Monday, May 25, 1953, after the passage of a vigorous cold front. On this occasion there were two parallel sets of clouds—one to the westward, the other to the eastward, both with the same characteristics. The westward series shown in the photograph facing p.240 were better illuminated by the setting sun, and several of the clouds exhibited iridescence. Unfortunately the uneven nature of the countryside in the area did not permit the clouds to maintain their wavelike structure for long and the leading members were breaking up quite rapidly.

Their estimated height was 18,000 ft., and using that assumption they were calculated to be 10 miles distant, with a distance of ½ mile between the crests. Both sets of clouds were moving down wind but their actual velocity was difficult to gauge.

Topography may be suggested as the cause, but as the present-day theory does not take into account the subsequent movement of topographic clouds, caution is certainly needed when nominating their source of origin. Under the circumstances it appears that they are most likely to occur within a post-frontal subsiding air mass and possibly in the lee of hills. Further reports of the occurrence and circumstances of such clouds are required for analysis before any definite theory as to their origin may be forthcoming.

J. W. WILKINS

21 Sheen Park, Richmond, Surrey, June 20, 1953

Medium-level instability

I should like to point out an interesting development of instability at medium levels which occurred here recently. This was shown by the sequence of cloud forms noted during Thursday, February 26, 1953.

At approximately 1100 G.M.T., patches of fine altocumulus lenticularis, resembling cirrocumulus, rapidly developed on the spot until about 6 oktas coverage of altocumulus densus was produced, which, by 1200, locally showed signs of vertical development. After 1300, altocumulus floccus appeared, first on the edges of the sheet, but later within the sheet itself, as shown by obvious tufts of virga below the cloud base, and the percentage of this type steadily increased throughout the afternoon and evening, being locally of considerable vertical extent (estimated at 5,000 ft.) by 1900. Two other interesting points were:—

(i) At about 1330 an aircraft, having flown horizontally through the cloud sheet, left a contrail in the form of a thickening of the cloud into a dark roll, which, within half an hour, had developed a prominent fringe of virga, extending for probably at least five miles across the sky. This contrail was continuous with a distrail formed only at the edge of the cloud sheet, the whole extending over about 140° azimuth.

(ii) At sunset, a mammatus structure was illuminated beneath many of the denser floccus patches.

By means of a balloon, the height of this cloud was observed at 1400 to be 15,000 ft., which agrees well with discontinuity levels marked on the 0200 and 1400 radio-sonde ascents by a sharp increase of humidity with height, and by a wind shear of about 120°. Although no temperature inversions were noted at this height, the wet-bulb potential temperature shows the discontinuity to be a diffuse frontal surface, separating a tropical air mass with about 50 per cent.

humidity from a much drier, subsided polar air mass, the two showing some degree of intermixing.

Convergence and turbulence are unlikely to be involved in the cloud formation. The former because the synoptic situation was definitely anticyclonic, and the latter because the resulting mixing with the dry polar air would tend to dissipate rather than form cloud. Frontal uplift is possible, especially when its wide extent, as shown by the numerous reports from southern England, is considered, but the transformation of a water-droplet cloud (altocumulus densus) to an ice-crystal cloud (altocumulus floccus) remains unexplained, since the air above 15,000 ft. was shown by the ascents to be not even latently unstable, assuming the 40-mb. uplift required for saturation (at 0200) to be possible.

Incidentally, two interesting points on the observation of clouds were well indicated on this day:—

(i) Thin altocumulus lenticularis may be easily confused with cirrocumulus even to the characteristic fine structure and rippling.

(ii) Altocumulus may be so dense and coarsely globular as to resemble stratocumulus with a base about 6,000 ft., even though the true base is 15,000 ft. This is borne out by the reported cloud heights from some stations in southern England at 1200 and 1800.

D. E. PEDGLEY

Larkhill, Wilts. March 11, 1953

NOTES AND NEWS

Exceptionally high mean pressure over the British Isles

In March 1953 mean pressure over the British Isles was exceptionally high. An examination of the values for all stations throughout the country for which the information is available since 1901 shows that the mean pressure in 1953 was

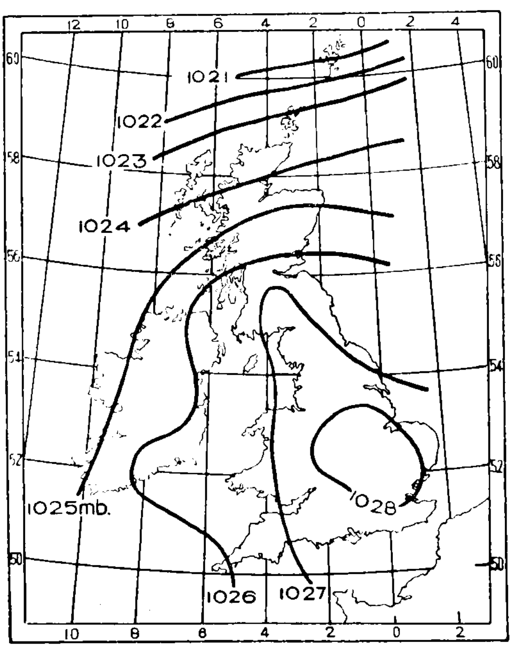

FIG. 1—MEAN PRESSURE, MARCH 1929, 0700 G.M.T.

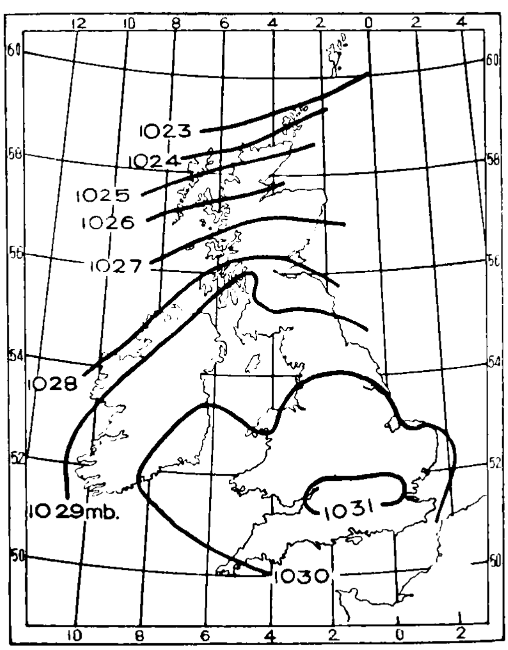

FIG. 2—MEAN PRESSURE, MARCH 1953, 0900 G.M.T.

everywhere the highest for March during this period. The March in which mean pressure most closely resembled that for 1953 over the country as a whole was that of 1929; in that month mean pressure ranged from more than 1028 mb. in the English Midlands to slightly less than 1021 mb. in the Shetland Islands compared with slightly more than 1031 mb. in an inland area in the south of England and somewhat less than 1023 mb. in the Shetlands in March 1953. The charts show the mean pressure at 0700 in March 1929 and at 0900 in March 1953. Observations have been taken at some stations for a much longer period, and from these records it appears that the pressure in March this year was the highest for a very much longer period than the present century. At Edinburgh in a record going back to 1769 the mean pressure for March 1953 has only once been exceeded, namely in 1840. At Southport, where local records have been kept since 1871, the value was higher than in any previous March, while at Oxford the pressure was the highest for March in a record going back to 1881 and has only once been exceeded in any month, that is in February 1891.

On March 10, 1953, pressure was exceptionally high in England and Wales; at Filton, Bristol and Abingdon the reading at 0900 was 1045·0 mb., the previous record for the month being 1044·5 mb. at Gorleston on March 13, 1929.

L. F. LEWIS

REVIEWS

Climate and growing of malting-barley in the Netherlands. By C. Kramer, J. J. Post and W. Wilton. *Meded. ned. met. Inst., De Bilt*, A, No. 57, 1952, pp. 152, *Illus.*, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1952. Price: *fl.*2.25.

In this contribution to the ecology of spring barley the authors have examined the influence of climate on the yield and quality of the crops grown in three provinces of Holland where soil conditions and methods of husbandry are fairly similar. They have examined the available literature on the growth of barley, and point out that the ideal weather conditions for maximum yield or vegetative yield differ from those required for best malting quality.

Regression equations were computed for forecasting yield, but the correlation coefficients between weather data and yield or quality data seldom exceeded a value of 0·6. Nevertheless the results showed that cool dry weather in late spring favoured a high yield, and that dry sunny weather was needed in July for good quality.

Experimental work in the field showed that the rate of growth of the leaves was governed mainly by temperature; reduction of light by artificial shading decreased the rate. A close relation was shown to exist between average yield and the area below a curve of average total length of leaves plotted against time. During this work the importance of the relative incidence of diseases such as mildew and rust and the effect on yield and quality became evident; such incalculable factors often militate against a successful analysis of crop-yield data.

L. P. SMITH

Climate of the Canadian Arctic Archipelago. By R. W. Rae. 10·9 in × 8·2 in. pp. vi + 90, *Illus.*, *Canada Department of Transport, Toronto*, 1951. Price: $0.35.

This work is based on the observations of 20 stations between 60° and 80°N., 60° and 120°W.; the periods of observation are short but half of them cover

10 years. The stations are mainly coastal and not representative of the climate of the interior. With these limitations, a clear picture is given of general conditions by first discussing the climatic controls of latitude, distribution of land, water and ice, and the seasonal changes of pressure distribution, followed by a seasonal analysis of the observations of temperature, precipitation, winds, cloud, visibility and relative humidity. Tables give average monthly values of these elements and there are bi-monthly charts of the mean pressure distribution.

Special interest attaches to winter temperature conditions which may vary greatly from year to year, on account of the varying intensity of cyclonic activity in the area of the Davis Strait. Mean winter temperature is generally below 0°F. for six months and a minimum as low as −50°F. may be expected every year. Summer temperatures are more uniform because of the stabilizing influence of the ice-filled waters of the polar channels.

Snow may fall in any month but rain is limited to the short summer period—from the point of view of total annual precipitation, the Archipelago is a dry region, only 5–10 in. a year being recorded for stations between 75°N. and the Arctic Circle. The impossibility of accurate measurement of snowfall is emphasized.

In the extreme north, least cloud occurs in winter and most in summer, but generally the amount of winter cloud depends on the amount of open water near the station. An interesting analysis is given (for Resolute) of occasions when "fog" visibility is produced either by drifting snow, falling snow or radiation and sea fog.

Winds are discussed in relation to the pressure distribution; wind speeds are low in winter because of the stable stratification of the cold air.

J. PEPPER

Essentials of fluid dynamics with applications to hydraulics, aeronautics, meteorology and other subjects. By L. Prandtl. $8\frac{3}{4}$ in. × $6\frac{1}{4}$ in., pp. x + 452, *Illus.*, Blackie and Sons Ltd., London, 1952. Price: 35*s.* 0*d.*

This book is a translation of the 1949 edition of "Fuhrer durch die Stromungslehre". It covers a wide field, as may be seen from the five chapter headings which are as follows:—

I—Equilibrium of liquids and gases

II—Kinematics: dynamics of frictionless fluids

III—Motion of viscous fluids: turbulence: fluid resistance: practical applications

IV—Flow with appreciable volume changes (dynamics of gases)

V—Miscellaneous topics:—

(*a*) Combined effects of more than one state of matter

(*b*) Rotating body and rotating system of reference

(*c*) Flow in heavy stratified fluids

(*d*) Heat transfer in moving fluids.

Chapter V includes a discussion of a few special meteorological and oceanographical problems. There is an excellent bibliography, including references to post-war English and American work.

The author states in his Preface that the book is intended "to be a guide to the reader, to the beginner and the advanced student, as well as to the expert in an adjoining field of research", and he certainly should achieve his purpose. The condensation necessary to realize this completeness will make some sections difficult for the beginner (e.g. the paragraph on the stress tensor on p. 5 and the introduction to the use of conformal representation, p. 67), but it may be rightly said that such parts are unimportant at a first reading. For the most part, the book is delightfully easy to read, and if some item is not pursued far enough for a particular purpose the reader is told how or where to obtain more information.

The author also says that ". . . complex mathematics has been avoided as far as possible . . . the principal object being the awakening of clear, intuitive appreciation". Certainly the text is not overburdened with mathematics, but it is doubtful whether intuition is the ideal faculty with which to tackle such a complex subject as fluid dynamics. Mathematical formulation is but a shorthand method of writing down physical principles, and, so long as tedious manipulation of symbols to achieve limited ends is avoided, it is surely best to retain the mathematics rather than risk confusion and error by basing arguments on what seems intuitively reasonable. Needless to say, no false premises or arguments were discovered in Professor Prandtl's book, but intuition may be dangerous in others.

Though this reviewer would have sometimes preferred a more mathematical treatment he found the, to him, unusual approaches stimulating.

This book will be most valuable to meteorologists not for its description of a few particular problems, such as the general circulation on a rotating globe which may be found in more detail elsewhere, but as a general introduction or book of reference to other problems of fluid dynamics with which he may not be familiar, but which may concern him indirectly. Aerofoil theory, supersonic flow, shock waves, resistance of projectiles and many others are subjects on which the meteorologist may require guidance and they are all described.

The book is pleasantly printed on good paper, and is recommended as a general textbook and also as a first book of reference.

J. K. BANNON

ERRATUM

MAY 1953, PAGE 158, lines 4 and 5 from bottom of page; for "mean pressure at the Azores, 1011 mb., was 11 mb. below normal." read "mean pressure at the Azores, 1021 mb., was 1 mb. below normal."

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—Ocean weather ship *Weather Explorer*, on being relieved from station Juliett on June 6, proceeded to Plymouth where she refuelled and was painted before taking up anchorage off Ryde Pier (Isle of Wight) on the morning of June 14 to take her place in the Review of the Fleet at Spithead by Her Majesty the Queen. Some senior officers with their wives witnessed the Review aboard the ship where they also spent the night of the 15th–16th.

Staff suggestions.—Meteorological Office staff in common with all other Air Ministry staff are encouraged to submit suggestions "for improving efficiency and effecting economy" and cash prizes are offered for suggestions which are adopted or which are considered to have special merits.

Mr. A. Blackham, Senior Scientific Assistant, at the meteorological office, Cranwell, is believed to be the first member of the Office staff to receive an award under this scheme. He has prepared two tables which can be used to eliminate most of the labour of frequent divisions by 24 and 31 in the compilation of climatological tables. After a successful trial, copies of these tables have been sent to all offices responsible for climatological returns.

Sports and athletics.—The annual sports of the Air Ministry and Ministry of Civil Aviation were held at the White City on July 1 and marked the end of the year for the Bishop Shield competition. The Office won the Shield for the fifth successive year with a score of 123 points. Runners-up were the Ministry of Civil Aviation with 64 points. Successes in football, netball, swimming, lawn tennis, athletics, chess and bridge were the main contributions to the achievement, and these were due to the wholehearted co-operation of the staff.

The Jones Memorial Cup awarded for the highest number of points gained at the annual sports was won by the Office for the fourth consecutive year. The Office again won the Ladies' and Men's Relays and Miss C. Newman and Mr. R. Cohen ran well in the sprint events. A new cup, presented for the cross-country team race, has now been added to those held by the Office.

Lady Johnson presented the prizes at the termination of the sports meeting.

This year the sports meeting organized by the Harrow Meteorological Office Social and Sports Club was extended to include entrants from all meteorological offices in the London area and a very enjoyable evening was spent on the track at Headstone Manor Recreation Ground on Monday, June 22, 1953. Most events were well supported and an excellent innovation this year was an archery demonstration given by Dr. and Mrs. Frith. The evening ended with the presentation of medals and prizes by Mrs. Frankcom.

WEATHER OF JUNE 1953

Mean pressure was above normal over Scandinavia (as much as 9 mb. in the extreme north) and over the Atlantic between latitudes 40°N. and 50°N.; it was also above normal over much of the United States. Mean pressure was below normal over west and south Europe, generally between 2 and 4 mb. The mean pressure was highest over the Azores, 1027 mb. (2 mb. above normal), and it decreased northwards to 1006 mb. off south-east Greenland, where it was 4 mb. below normal. Another centre of high mean pressure, about 1021 mb., occurred to the north of Scandinavia.

Mean temperature was very high in Scandinavia, reaching 63°F. in many places, about 10°F. above normal. Over the rest of Europe, mean temperature was generally normal varying from 60°F. in the north to 70°F. in the south. The mean temperature in the east and south of the United States exceeded 70°F. and reached 85°F. in places and was generally 3°F. above normal.

In the British Isles the weather was dull, notably so in eastern and midland districts. Rainfall was variable owing to heavy local falls of thundery rain. The month was also unusually quiet, particularly in northern districts.

Early in the month pressure was high over the Atlantic and low over southern Scandinavia and the Low Countries giving cold, northerly winds and showery weather in the British isles, with widespread thunderstorms on the 1st and heavy rain locally in north-east England on the 2nd (2·69 in. at Uswayford, Northumberland). The 3rd was an exceptionally cold day; at Oxford, apart from June 4, 1909, it was the coldest June day on record. From the 5th to the 8th a belt of high pressure moved slowly east over the country maintaining dry weather, with varying amounts of bright sunshine; temperature rose in the west on the 6th but not until the 9th in the east and even then it was cool over much of East Anglia. On the 9th and 10th a trough of low pressure moved slowly east across the country giving rain in most parts. On the 11th a depression moved south-west from a position near Heligoland to the coast of East Anglia bringing rain to much of east England and the Midlands. This depression became stationary and filled slowly. On the 14th a depression moved into the British Isles from the Atlantic and was centred over Great Britain from the 15th to the 17th, maintaining a cool, unsettled type, with varying amounts of rain and local thunderstorms (3·50 in. in a thunderstorm at Brigflats, near Sedbergh, Yorkshire on the 16th). On the 18th and 19th a trough of low pressure moved east over the country giving further rain. Another depression moved east-south-east from south-west Ireland on the 21st–22nd causing heavy rain in the south-west (2·25 in. at Princetown, Dartmoor) and thunderstorms on the east coast from Kent to Norfolk during the following night. On the 23rd an anticyclone built up over Scandinavia and pressure became relatively low over France and central Europe. Low pressure persisted over France and central Europe for the remainder of the month, and winds over the British Isles were mainly from north or north-east; the weather became warm and close and low stratus cloud and fog were prevalent in the mornings in eastern and midland districts but it mostly cleared during the day except locally on the coast. Severe thunderstorms occurred at times from the 25th onwards, particularly in western and central districts from the 25th to 27th, when they were accompanied by heavy rain and hail causing floods and considerable damage. Among heavy falls in 24 hr. or less were 2·10 in. at Langham Waterworks, Essex, and 1·54 in. in 79 min. at Ruscombe, Gloucestershire on the 25th and 3·15 in. in 30 min. at Eskdalemuir, 2·09 in. in 39 min. at Langley, Cheshire, 1·72 in. in 15 min. at Nelson (all three very rare falls) and 2·15 in. in 90 min. at Ambleside on the 26th. Heavy rain fell locally in the south of England during thunderstorms on the 30th; at Ryde, Isle of Wight, 0·85 in. fell in 30 min. Temperature reached 80°F. locally on most days from the 23rd to the 30th and touched 83°F. at Prestwick on the 24th and at Poole and Weymouth on the 29th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	83	30	−0·4	98	+2	74
Scotland	83	29	+1·4	87	−3	86
Northern Ireland ...	78	35	+0·3	77	0	103

RAINFALL OF JUNE 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·63	81	*Glam.*	Cardiff, Penylan ...	2·46	98
Kent	Dover	2·23	116	*Pemb.*	Tenby	1·92	80
,,	Edenbridge, Falconhurst	1·69	77	*Radnor*	Tyrmynydd	2·14	65
Sussex	Compton, Compton Ho.	2·30	92	*Mont.*	Lake Vyrnwy	2·09	65
,,	Worthing, Beach Ho. Pk.	1·86	106	*Mer.*	Blaenau Festiniog ...	4·46	69
Hants.	Ventnor Park	1·89	100	,,	Aberdovey	2·56	94
,,	Southampton (East Pk.)	2·70	134	*Carn.*	Llandudno	1·26	66
,,	South Farnborough ...	1·35	70	*Angl.*	Llanerchymedd ...	1·80	76
Herts.	Royston, Therfield Rec.	1·70	76	*I. Man*	Douglas, Borough Cem.	1·63	67
Bucks.	Slough, Upton... ...	1·45	70	*Wigtown*	Newton Stewart ...	1·34	51
Oxford	Oxford, Radcliffe ...	1·59	71	*Dumf.*	Dumfries, Crichton R.I.	1·70	67
N'hants.	Wellingboro' Swanspool	1·81	86	,,	Eskdalemuir Obsy. ...	5·50	175
Essex	Shoeburyness	2·06	117	*Roxb.*	Crailing...	1·47	67
,,	Dovercourt	1·75	99	*Peebles*	Stobo Castle	3·62	155
Suffolk	Lowestoft Sec. School...	1·83	101	*Berwick*	Marchmont House ...	2·57	111
,,	Bury St. Ed., Westley H.	3·48	166	*E. Loth.*	North Berwick Res. ...	1·27	77
Norfolk	Sandringham Ho. Gdns.	4·24	195	*Midl'n.*	Edinburgh, Blackf'd. H.	1·50	75
Wilts.	Aldbourne	2·26	97	*Lanark*	Hamilton W. W., T'nhill	1·10	50
Dorset	Creech Grange... ...	1·97	86	*Ayr*	Colmonell, Knockdolian	0·84	33
,,	Beaminster, East St. ...	3·46	153	,,	Glen Afton, Ayr San. ...	...	...
Devon	Teignmouth, Den Gdns.	1·77	92	*Renfrew.*	Greenock, Prospect Hill	1·24	40
,,	Cullompton	2·68	126	*Bute*	Rothesay, Ardencraig...	1·51	49
,,	Ilfracombe	1·72	79	*Argyll*	Morven (Drimnin) ...	2·41	78
,,	Okehampton	1·68	61	,,	Poltalloch	1·40	46
Cornwall	Bude, School House ...	1·13	56	,,	Inveraray Castle ...	1·58	40
,,	Penzance, Morrab Gdns.	1·93	87	,,	Islay, Eallabus... ...	2·53	97
,,	St. Austell	2·55	97	,,	Tiree	1·46	57
,,	Scilly, Tresco Abbey ...	1·85	107	*Kinross*	Loch Leven Sluice ...	2·13	97
Glos.	Cirencester	1·51	63	*Fife*	Leuchars Airfield ...	0·76	46
Salop	Church Stretton ...	1·97	78	*Perth*	Loch Dhu	2·59	62
,,	Shrewsbury, Monkmore	2·30	111	,,	Crieff, Strathearn Hyd.	3·47	131
Worcs.	Malvern, Free Library...	1·97	85	,,	Pitlochry, Fincastle ...	2·91	139
Warwick	Birmingham, Edgbaston	1·93	83	*Angus*	Montrose, Sunnyside ...	1·66	100
Leics.	Thornton Reservoir ...	3·02	140	*Aberd.*	Braemar	3·19	163
Lincs.	Boston, Skirbeck ...	3·14	173	,,	Dyce, Craibstone ...	2·52	135
,,	Skegness, Marine Gdns.	3·38	188	,,	New Deer School House	2·78	140
Notts.	Mansfield, Carr Bank...	2·01	89	*Moray*	Gordon Castle	3·05	150
Derby	Buxton, Terrace Slopes	3·52	109	*Nairn*	Nairn, Achareidh ...	2·55	144
Ches.	Bidston Observatory ...	1·56	71	*Inverness*	Loch Ness, Garthbeg ...	4·27	187
,,	Manchester, Ringway...	2·37	98	,,	Glenquoich	1·68	34
Lancs.	Stonyhurst College ...	1·70	55	,,	Fort William, Teviot ...	1·09	31
,,	Squires Gate	1·45	70	,,	Skye, Duntuilm ...	2·10	81
Yorks.	Wakefield, Clarence Pk.	1·82	85	,,	Skye, Broadford ...	1·65	42
,,	Hull, Pearson Park ...	3·52	171	*R. & C.*	Tain, Mayfield... ...	2·50	135
,,	Felixkirk, Mt. St. John...	4·13	189	,,	Inverbroom, Glackour...	2·28	81
,,	York Museum	1·24	60	,,	Achnashellach	1·43	38
,,	Scarborough	3·13	170	*Suth.*	Lochinver, Bank Ho. ...	1·69	79
,,	Middlesbrough... ...	2·35	124	*Caith.*	Wick Airfield	1·64	91
,,	Baldersdale, Hury Res.	2·31	105	*Shetland*	Lerwick Observatory ...	0·71	40
Norl'd.	Newcastle, Leazes Pk....	2·05	97	*Ferm.*	Crom Castle	0·79	29
,,	Bellingham, High Green	1·58	69	*Armagh*	Armagh Observatory ...	2·33	93
,,	Lilburn Tower Gdns. ...	2·97	143	*Down*	Seaforde	1·65	60
Cumb.	Geltsdale	2·25	83	*Antrim*	Aldergrove Airfield ...	2·21	92
,,	Keswick, High Hill ...	1·57	54	,,	Ballymena, Harryville...	2·93	101
,,	Ravenglass, The Grove	1·10	42	*L'derry*	Garvagh, Moneydig ...	2·82	111
Mon.	A'gavenny, Plâs Derwen	2·28	85	,,	Londonderry, Creggan	2·52	89
Glam.	Ystalyfera, Wern House	4·80	127	*Tyrone*	Omagh, Edenfel ...	1·23	44

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

Wt-34. K16.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 975, SEPTEMBER 1953

EFFECT OF ATMOSPHERIC INHOMOGENEITY ON THE INTERPRETATION OF VERTICAL TEMPERATURE SOUNDINGS

By J. S. SAWYER, M.A.

The atmosphere is subject to oscillations and fluctuations ranging in period from a fraction of a second to several days and in scale from a few centimetres to a thousand kilometres or more. For the purpose of synoptic weather analysis and forecasting, attention is concentrated on weather systems with a minimum horizontal extent of 200 to 300 Km.; smaller-scale irregularities affect only one reporting station at a time and therefore cannot be incorporated in the analysis. Frith[1] has demonstrated the existence of temperature fluctuations of up to 2°F. over horizontal distances of 50 Km. These disturbances are too small to be incorporated in synoptic weather analysis, but nevertheless the temperature differences which arise in them are sufficient to be of interest to the synoptic analyst. The departures of the temperature from the true mean value for an area of the order of 100 Km. square must be regarded by the analyst as an error due to the unrepresentative nature of his sounding.

Relatively small-scale temperature fluctuations become of particular significance in the analysis of vertical soundings of temperature. The small-scale temperature variations may introduce changes in lapse rate, which are quite unrepresentative of the area around the sounding station but which may simulate frontal lapse-rate discontinuities or lead to false deductions regarding air-mass stability. It is the purpose of the present note to investigate the limitations imposed on the interpretation of vertical soundings by the existence of such temperature fluctuations.

A direct method of carrying out such an investigation would be to compare individual temperature soundings with the mean temperature sounding representative of an area of radius 50 Km. or so around the sounding station. Unfortunately there is no method of obtaining mean temperatures for a horizontal area of this extent in the free atmosphere at a large number of levels simultaneously without the use of a prohibitively large number of radio-sondes or aircraft. The problem must therefore be approached from a different point of view, and in the following paragraphs an estimate is made of the effect of the small-scale temperature fluctuations in modifying some tephigrams based on simple air-mass and frontal conditions. An examination of these reveals the magnitude of the spurious irregularities in lapse rate. For this purpose information is needed regarding the magnitude of the temperature fluctuations and the vertical scale of the disturbances. This has been taken from the original records of the Meteorological Research Flight which carried out a large number of flights during 1948 and 1949 for the purpose of studying these fluctuations. On each occasion the aircraft flew to and fro along a set of parallel horizontal tracks making temperature observations at points about $2\frac{1}{2}$ Km. apart. A rectangular area with sides about 50 Km. long was thus covered by an observational grid.

Standard deviation of temperature.—From the records of the Meteorological Research Flight 34 cases were found in which a horizontal grid had been flown within an air mass (i.e. not within a frontal zone). In some cases more than one grid was flown on a particular occasion, usually at different levels. From each grid flight the standard deviation of temperature from the mean for the flight was calculated. Three of the flights were conducted in an inversion or markedly stable layer. These gave standard deviations of temperature of 0·79°, 0·77° and 0·78°F., values larger than obtained on the remaining flights. The average standard deviation for the remaining flights was 0·51° and the standard deviation of the individual standard deviations about this mean was 0·16°.

A reasonably representative value of the standard deviation of temperature over an area of some 50-Km. radius therefore seems to be about 0·5° in normal air masses and about 0·75° in inversion or other very stable layers.

Vertical correlation of the temperature fluctuations.—In order to discuss the effect of small-scale temperature fluctuations on the appearance of a temperature sounding curve, it is necessary to know not only the magnitude of the temperature fluctuations but also the vertical scale of the temperature variations. This is best examined by means of the correlation coefficients between the temperatures at pairs of levels with various vertical separations.

Flights have been made by Meteorological Research Flight aircraft to examine the vertical scale of the temperature fluctuations. In some of these two aircraft were used flying simultaneously along parallel tracks with vertical separation from zero to 2,000 ft. On other occasions one aircraft only was employed, and this returned along a track as nearly as possible vertically above the air through which it flew on the outward flight. Data are available from some 14 pairs of levels, and the correlation coefficients between the temperatures at each pair of levels have been calculated. The correlation coefficients are plotted against the vertical separation between the levels in Fig. 1.

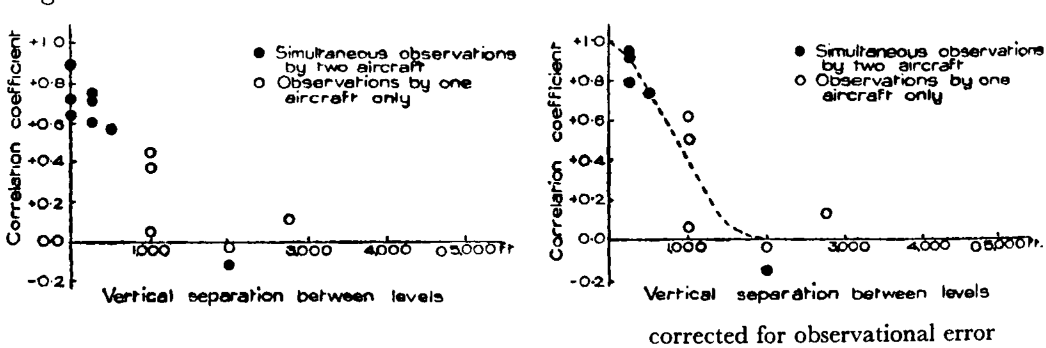

FIG. 1—CORRELATION COEFFICIENT BETWEEN TEMPERATURE AT TWO LEVELS OVER DISTANCES OF 100 TO 200 KM.

As would be expected the correlation coefficient decreases with increasing separation between the levels and becomes zero when the separation reaches about 2,000 ft. When two aircraft are employed flying as close together as possible the correlation coefficient does not reach unity. This may be attributed to errors of observation and to temperature variations on a still smaller scale. If this difference from unity is assumed to be due to random errors of observation the remaining correlation coefficients may be corrected, and this has been done in the right-hand half of Fig. 1 to give a better representation of the true correlation between the temperature fluctuations at two levels. Although, as would be expected, there is a good deal of scatter, nevertheless it seems that the variation of the correlation coefficient with separation between the levels can be adequately represented by the curve superimposed on the diagram, and such a variation has been assumed in assessing the effect of the temperature fluctuations on vertical soundings.

Simulated temperature fluctuations.—During the flight of a radiosonde, observations of temperature, pressure and humidity are made in sequence so that a set of discrete observations of temperature is obtained referring to a set of levels separated by about 400 ft. The observed temperatures will differ from the true mean temperature representative of the area by an amount, ε, due to the small-scale temperature fluctuations. The values of ε at consecutive observations are correlated, and the correlation will decrease with increasing separation and become zero between observations separated by 2,000 ft., i.e. five observations apart.

The next step in the investigation was to construct sets of numbers which could represent possible sets of values of ε, i.e. sets of departures of observed temperature from representative mean temperature at a sequence of levels 400 ft. apart. The conditions which had to be satisfied were—

(i) The numbers should have a Gaussian distribution

(ii) Their standard deviation should be appropriate to the small-scale temperature fluctuations

(iii) The autocorrelation of the series should be appropriate to the curve corrected for observational error.

Such series were constructed by first preparing random sets of numbers with a Gaussian distribution. The standard deviation was then adjusted to be 0·5° or 0·75°F., appropriate to normal lapse or inversion condition respectively. From these sets a coherent series of numbers was prepared by forming running means of the form

$$\frac{2a_{n-2} + 3a_{n-1} + 5a_n + 3a_{n+1} + 2a_{n+2}}{\sqrt{51}}.$$

These coherent series should have autocorrelation coefficients, $r_1 = +0{\cdot}82$, $r_2 = +0{\cdot}57$, $r_3 = +0{\cdot}24$, $r_4 = +0{\cdot}08$, $r_5 = 0$, appropriate to levels separated by 400, 800, 1,200, 1,600, and 2,000 ft. respectively.

In order to study the effect of such temperature fluctuations on the appearance of the tephigram, various idealized tephigrams were drawn appropriate to frontal and non-frontal situations. The temperature was read off at 400-ft. intervals and a set of values of ε taken from one of the coherent series and added term by term. The resulting temperatures were replotted on a tephigram and examined. The curves so obtained were more irregular than the usual temperature sounding used in upper air analysis. This difference is primarily a result of the smoothing introduced during the computation of the radio-sonde results and their transmission to a central office. It was desirable therefore to simulate these processes also, before considering the effect of small-scale temperature fluctuations on aerological analysis.

It is unnecessary to describe the procedure of radio-sonde computation in detail. It is sufficient to note that the radio-sonde observations are first plotted against time and the curve is simplified by joining selected plots by straight lines, subject to the requirement that no intervening omitted point should differ by more than 0·5°F. from the straight lines so drawn. The pressure and temperature are computed for the corner points, and these are transferred to a temperature-log pressure diagram and again joined by straight lines. Interpolation on this diagram gives values for the levels which are reported to the central office and plotted on the final tephigram. These levels are at 50-mb. intervals, but additional significant points are reported wherever the error of reporting would otherwise exceed 0·5°F. This procedure has been closely simulated in the present experiment using the ideal lapse rates to which the simulated temperature fluctuations have been added. The tephigrams produced in this way will be referred to as the soundings "as reported", and the results will be described in the following paragraphs.

Simulated air mass soundings.—Fig. 2 shows four idealized tephigrams representing smooth lapse rates in homogeneous air masses. Fig. 3 shows the result of modifying these soundings by the addition of a coherent series representing the effect of the small-scale temperature fluctuations. The standard deviations of the series used are indicated. Fig. 4 shows the same soundings as they would have been reported.

It is interesting to note that the curves in Fig. 4 are very similar in general form and in the nature of their irregularities to the curves actually plotted from radio-sonde reports. In three out of the four soundings spurious stable layers have been introduced. The standard deviation of the series used in forming curves B and D (namely 0·75°F.) is perhaps rather large for a homogeneous air mass, but a stable layer also appears in curve A for which the standard deviation of the simulated temperature fluctuation was only 0·5°F.

The irregularities of curves in Fig. 4 are not large, but they are sufficient to be misinterpreted by an analyst as minor air-mass boundaries if he were to regard them as real, or to lead him to erroneous conclusions on the development of convective cloud.

Simulated frontal soundings.—To illustrate the effect of small-scale temperature fluctuations on frontal soundings, an idealized frontal transition of moderate intensity has been studied. The same total air-mass temperature change has been considered, first as being linear over an interval of 100 mb. (Fig. 5, curve I), secondly as being somewhat smoother over about the same pressure range (curve II), and thirdly as spread smoothly over a range of about 250 mb. Temperature fluctuations have been added to these idealized curves, and the soundings replotted as they would have been reported. The results are presented in Fig. 6. The standard deviation of the series used is indicated beneath the sounding. The following points are of interest:—

(i) The sharp frontal transition of curve I has been little affected by the added fluctuation, but between 612 and 565 mb. another stable layer has been introduced which has an almost equally good claim to be treated as a frontal layer.

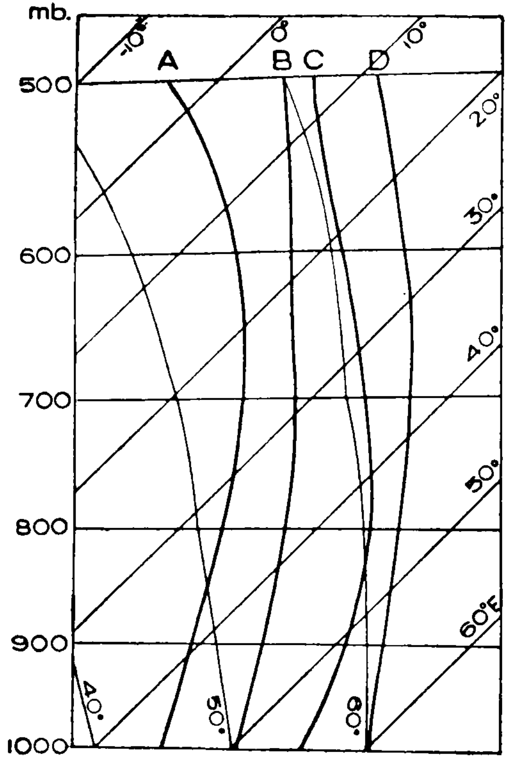

FIG. 2—IDEALIZED TEPHIGRAMS FOR HOMOGENEOUS AIR MASSES

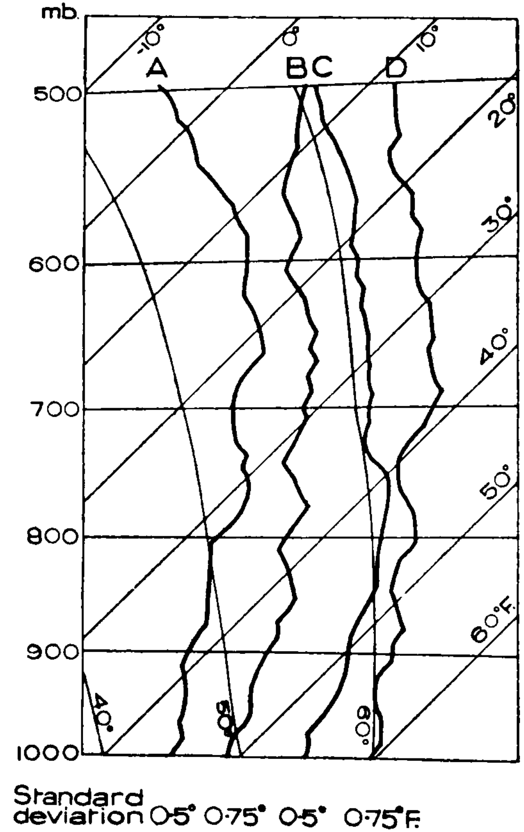

FIG. 3—IDEALIZED LAPSE RATES MODIFIED BY ADDITION OF COHERENT TEMPERATURE FLUCTUATIONS

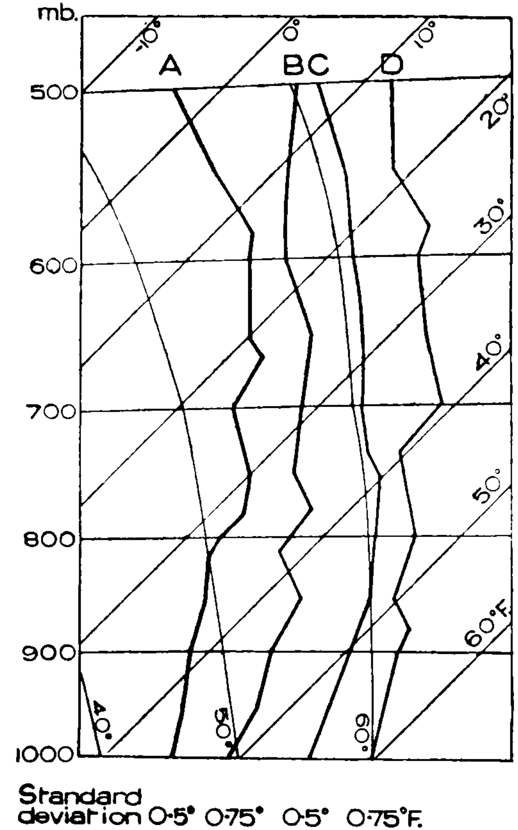

FIG. 4—SOUNDINGS OF FIG. 3 "AS REPORTED"

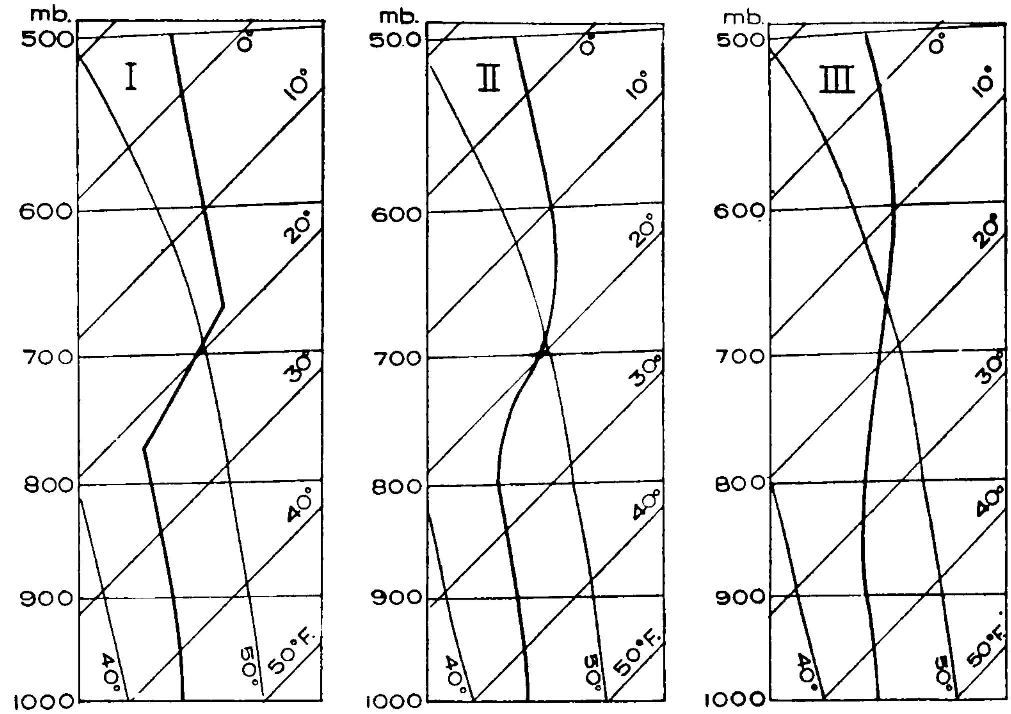

FIG. 5—IDEALIZED SOUNDINGS THROUGH FRONTS

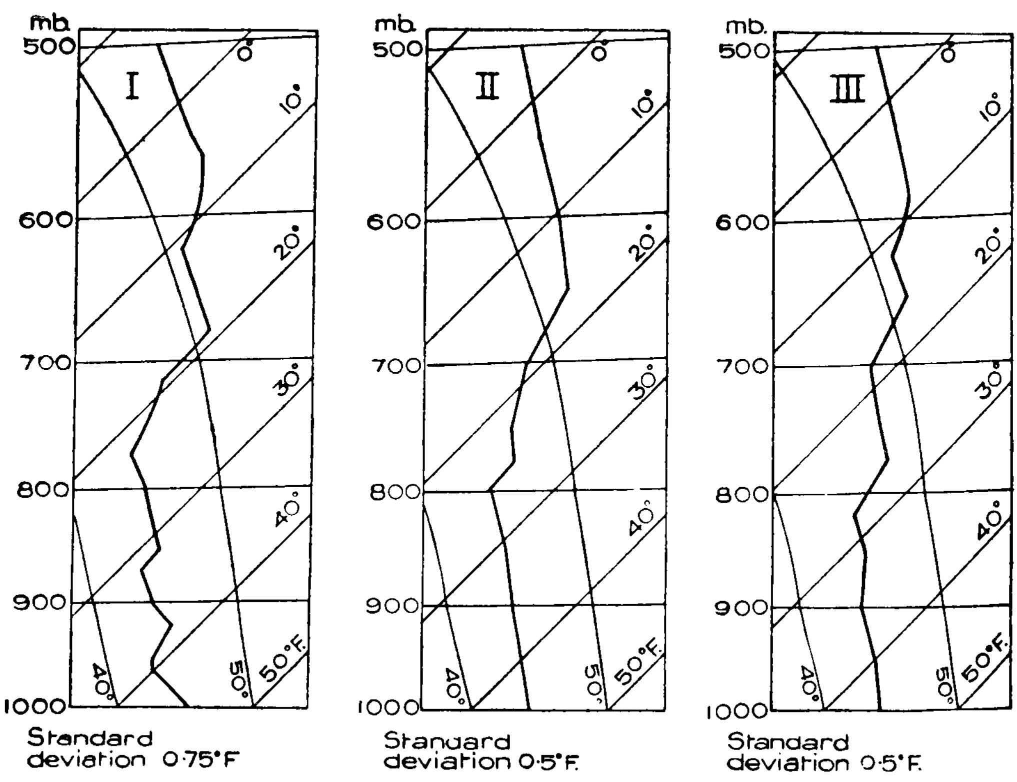

FIG. 6—SOUNDINGS THROUGH FRONTS "AS REPORTED"

(ii) The frontal transition is quite well defined in curve II "as reported". However, although in Fig. 5 the boundaries of the frontal zone were deliberately smoothed off, in Fig. 6 they appear to be quite sharp.

(iii) The very smooth transition of curve III Fig. 5 has been broken down into three distinct and rather sudden temperature changes. Similar transitions are not uncommon on observed soundings and there has been some uncertainty as to whether the individual steps should be regarded as real frontal subzones.

Discussion of Results.—So far no mention has been made of the errors of the radio-sonde itself. Sheppard[2] has estimated the probable error of reading as about 0·2°F. and the casual error of the temperature element itself as 0·6°F. (corresponding to standard deviations of 0·3° and 0·9°F.). A considerable part of the error of the element is probably systematic so far as a single sounding is concerned, and it seems probable that the effect of instrumental error on the sounding curves will be to add a random error with standard deviation about 0·4°F. to the individual readings. This will make the irregularity of the sounding curve somewhat greater than indicated in Figs. 4 and 6. It is evident that for synoptic purposes no advantage would be gained by further reducing the purely random errors of the individual radio-sonde readings, because the irregularities due to real local temperature irregularities in the atmosphere limit the accuracy of the values which can be obtained.

In the preceding sections it has been demonstrated that minor irregularities in temperature soundings may easily arise from the known small-scale temperature irregularities in the free atmosphere. These irregularities are large enough to be misinterpreted as real phenomena of importance in frontal analysis or in restricting convection. It is difficult to lay down any specific rules for the large-scale significance of irregularities on a sounding curve, but it is clear that one must treat with caution any irregularity which does not depart by more than 1·5°F. from a smoothed curve following the sounding.

It is also apparent that it is quite impossible to decide whether a frontal zone is best represented by a linear transition with discontinuities of lapse rate at the boundaries, or by a gradually changing lapse rate; also that division of a broad frontal zone into two or more subzones is of doubtful validity unless the subzones themselves are very well marked on the sounding (departing by 2°F. or more from the smooth curve).

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2. SHEPPARD, P. A.; The application of upper air observations. Part VII, On the accuracy of Meteorological Office radio-sonde temperature, height and wind observations. Unpublished; copy in Meteorological Office Library, London, 1944.

RADIATION MINIMUM TEMPERATURE OVER A GRASS SURFACE AND OVER A BARE-SOIL SURFACE

By R. W. GLOYNE, B.Sc.

Introduction.—The minimum temperature recorded during a 24-hr. period by an unscreened radiation minimum ("grass" minimum) thermometer when placed with the bulb just touching the tips of short grass is a routine observation at most climatological stations. These data are frequently quoted and utilized by writers on scientific horticulture (e.g. Gardner, Bradford and Hooker[1]) and it is the purpose of the present note to examine the relationship between the minima over short turf and that just above bare soil as revealed by nearly two years' observations (namely from January 1, 1949–December 14, 1950) at the National Agricultural Advisory Service's Subcentre at Starcross, Devon.

There is a considerable amount of evidence, as given in papers by Cornford[2], Seeley[3], Cox[4], Young[5,6] and Rogers[7], that the night minimum over grass is lower than over bare soil, and lower over long grass than over short grass—results largely explicable in terms of the insulating property of the turf surface. An early paper by Glaisher[8] deserves special mention as a pioneer investigation to establish the effect of the characteristics of a surface on the minimum temperature recorded on or just above it. Of the many materials he used, a pad of raw wool placed on the ground gave rise to the lowest radiation minima. On one cold night in October 1843, for example, the air minimum was 28½°F., that on wool 16°F., over long grass 17°F., short grass 20½°F., on gravel 26½°F. and on loam 24½°F.

Clearly if the published figures of "grass minima" are used as estimates of the night minima over any surface other than short grass misleading conclusions will follow. In particular, if they are assumed to be close estimates of the minimum temperature just above a soil surface carrying seedlings, minimum temperature may be seriously under-estimated and the frequency of "ground frosts" seriously over-estimated.

Site and technique.—The investigation was carried out at the climatological station at Starcross which lies at 29 ft. above M.S.L. and is situated a few hundred yards from the west bank of the Exe estuary, some 4 miles north of Dawlish. The soil is a sandy loam of the Permian series with a good deal of alluvial silt. The water table is high and the drainage rather impeded during a wet period, but in summer the surface layers dry out quickly and the soil cracks and sets in hard lumps. The climatological station is well exposed in all directions.

On the soil plot the thermometer was set with its bulb between ¼ and ½ in. above the surface. Previous tests over five months had established that the point-to-point variation of two such instruments placed at random 2–3 ft. apart rarely exceeded ½°F., and only one instrument was in consequence used for this investigation. Every observation was carefully examined with reference to other observations at this and at neighbouring stations, and as a result it was found necessary to reject 21 observations and 6 observations respectively from the 1949 and 1950 records.

Observations and analysis of results.—It was clearly desirable to link the difference between "soil" and "grass" minima to the difference "screen minimum — grass minimum", and special note was taken of the former differences on "radiation" nights, i.e. nights on which the depression of the grass minimum reading was 7°F. or more below the screen minimum. This limit was found by Hogg[9] and Foley[10] to be a useful criterion for specifying those reasonably clear still nights when there is a rapid loss of heat from the surface. It has been consistently used by the Meteorological Office (Agricultural Branch) with satisfactory results.

Means and extremes.—The monthly means and monthly maxima are set out in Table I. Throughout this paper the value next to the absolute extreme will be given in brackets to indicate roughly the degree of dispersion.

In both tables the agreement between years is good for the months April–October (inclusive). In the winter months the thin, poor grass and frozen, flooded or snow-covered surfaces introduce complicating factors liable to differ widely

TABLE I—MONTHLY MEANS OF SCREEN MINIMUM — GRASS MINIMUM AND BARE-SOIL MINIMUM — GRASS MINIMUM AT STARCROSS, DEVON

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees Fahrenheit						
					Screen minimum — grass minimum							
1949	5·0	6·0	5·0	6·2	6·0	5·5	4·7	5·3	5·2	5·7	4·5	4·7
1950	3·4	5·0	4·8	6·6	5·5	5·9	5·8	7·0	5·8	6·3	8·3	8·2*
					Bare-soil minimum — grass minimum							
1949	1·7	2·6	2·5	3·3	3·2	3·6	2·3	2·2	2·5	2·8	1·1	0·8
1950	0·6	0·9	1·3	2·7	2·7	3·6	2·7	3·7	2·3	3·0	3·1	3·2*

*Dec. 1–14 inclusive

TABLE II—MONTHLY MAXIMA AND NEXT HIGHEST VALUE (IN BRACKETS) OF SCREEN MINIMUM — GRASS MINIMUM AND BARE-SOIL MINIMUM — GRASS MINIMUM AT STARCROSS, DEVON

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						degrees Fahrenheit						
					Screen minimum — grass minimum							
1949	9·9	10·5	10·0	12·5	10·5	9·1	8·4	10·5	9·4	10·4	9·4	9·7
	(9·1)	(10·1)	(9·1)	(10·2)	(9·3)	(8·9)	(7·7)	(10·1)	(9·0)	(10·0)	(9·2)	(7·9)
1950	6·8	10·4	9·6	11·6	11·1	10·9	8·3	10·5	10·8	10·9	12·6	12·9*
	(6·7)	(9·5)	(9·5)	(10·9)	(9·4)	(10·7)	(8·2)	(10·1)	(9·8)	(10·9)	(11·9)	(11·5)*
					Bare-soil minimum — grass minimum							
1949	4·1	6·4	6·0	9·8	5·6	7·1	6·9	5·0	7·6	5·0	3·5	2·9
	(3·7)	(6·4)	(5·7)	(6·2)	(5·2)	(5·6)	(4·8)	(4·3)	(4·5)	(4·6	(3·3)	(2·5)
1950	2·5	2·7	4·3	5·9	5·5	7·5	5·3	7·2	6·0	6·2	5·6	12·0*
	(2·2)	(2·4)	(2·7)	(4·8)	(5·5)	(6·7)	(4·9)	(5·4)	(5·2)	(5·5)	(5·4)	(5·1)*

*Dec. 1–14 inclusive

in their incidence from year to year and to override the effect of insulation which is our main concern.

On the average the contribution of the component "bare-soil minimum — grass minimum" to the total depression of "grass" below screen minimum is substantial, and in the warmer months of the year amounts to 50 per cent. or more.

Turning to monthly extremes, the approximate equality of the extreme value (about 10°F.) of "screen minimum — grass minimum" is worthy of note. The same result is implicit in the paper by Hogg and is explicitly mentioned by Glaisher. Foley's tables also show an extreme monthly depression of "grass" below "screen" minimum of about 10°F. independent of the actual month. In most months therefore, it appears that there will be at least one occasion when the night minimum over the bare soil will be 5°F. or more above that over neighbouring short turf.

Daily variation.—For each month dot diagrams were prepared, and the linear regression of "bare soil — grass minimum" upon "screen — grass minimum" computed; Fig. 1 relates to the observations for April 1949 and April 1950. In most months the regression line crossed the vertical axis within ± 1°F., and hence the regression and correlation coefficients quoted in Table III fairly adequately represent the general results.

The standard errors of the parameters are not given owing to doubts as to how many statistically independent observations correspond to the thirty or so individual daily values per month.

TABLE III—SLOPE OF THE LINES OF LINEAR REGRESSION OF "BARE SOIL MINIMUM — GRASS MINIMUM" ON "SCREEN MINIMUM — GRASS MINIMUM" TOGETHER WITH CORRELATION COEFFICIENTS BETWEEN THE TWO VARIABLES

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					Slope of the lines of linear regression							
1949	0·37	0·50	0·54	0·61	0·44	0·49	0·58	0·49	0·47	0·44	0·31	0·25
1950	0·21	0·24	0·09	0·51	0·41	0·39	0·66	0·42	0·41	0·50	0·33	0·46*
					Correlation coefficient							
1949	0·64	0·64	0·88	0·86	0·74	0·66	0·82	0·87	0·77	0·81	0·67	0·66
1950	0·48	0·63	0·19	0·86	0·75	0·70	0·81	0·64	0·76	0·84	0·68	0·50*

*Dec. 1–14 inclusive, value much influenced by one extreme observation.

As with the previous tables, Table III reveals an encouraging consistency between the values at least for the April–October period. The only serious anomalies occur in the winter months and in March 1950. On the vast majority of nights, screen minimum > bare-soil minimum > grass minimum. The "bare soil" minimum exceeded the screen minimum on 14 occasions in 1949 and 16 in 1950; and the grass minimum exceeded the bare-soil minimum on 14 and 12 occasions respectively, and of these 9 occurred in each year distributed between the four months January, February, November and December. Only in 3 of these 56 anomalous cases were any of the differences more than 2°F., and were generally much less.

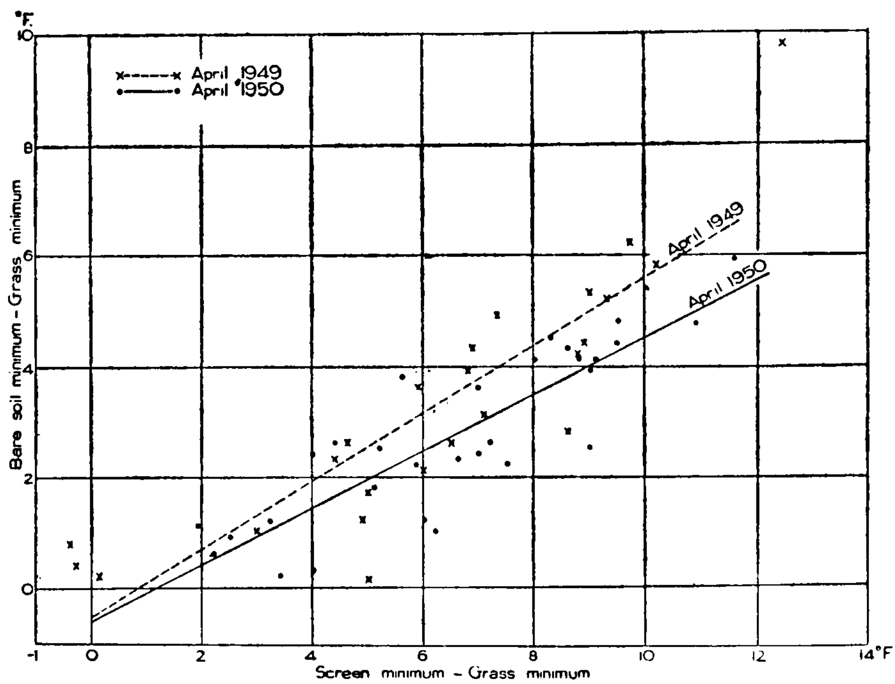

FIG. 1—LINEAR REGRESSION OF "BARE SOIL — GRASS MINIMUM" ON "SCREEN MINIMUM — GRASS MINIMUM" APRIL 1949 AND APRIL 1950

Behaviour on "radiation" nights.—Such nights are of particular interest in view of their close association with frost in certain months of the year.

In the period April to October on such nights, the temperature over short grass was on average some 4°F. or more above that over ~~short turf~~ bare soil and on individual nights the excess was rarely less than 2°F.

TABLE IV—VALUES ON "RADIATION" NIGHTS OF MEANS OF SCREEN MINIMUM — GRASS MINIMUM; MEANS OF BARE-SOIL MINIMUM — GRASS MINIMUM; AND LOWEST, AND NEXT LOWEST (IN BRACKETS), INDIVIDUAL VALUE OF "BARE-SOIL MINIMUM — GRASS MINIMUM" WHICH ACTUALLY OCCURRED

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	degrees Fahrenheit											
	Means of screen minimum — grass minimum											
1949	8·2	8·3	8·3	9·1	8·3	7·8	7·6	8·2	8·5	8·5	8·4	8·1
1950	..	8·7	8·4	8·7	8·7	9·1	7·8	8·6	8·5	9·2	9·7	9·5
	Means of bare-soil minimum — grass minimum											
1949	2·6	3·7	4·4	5·2	4·1	4·9	4·4	3·5	3·9	4·1	2·3	2·0
1950	..	1·5	2·4	3·9	4·1	4·9	3·9	4·5	3·7	4·6	3·6	3·8
	Lowest, and next lowest (in brackets), individual value of "bare-soil minimum — grass minimum" which actually occurred											
1949	0·9	1·4	2·3	2·8	2·6	2·1	3·0	2·2	2·2	3·5	1·6	1·5
	(1·8)	(1·9)	(3·1)	(3·1)	(3·3)	(4·3)	(3·2)	(2·6)	(2·7)	(3·8)	(1·7)	(1·8)
1950	..	0·9	0·7	2·2	−0·3	3·2	0·7	0·8	1·9	2·8	0·9	1·0
	..	(1·2)	(2·1)	(2·4)	(2·8)	(4·3)	(3·2)	(3·5)	(2·3)	(3·5)	(2·5)	(1·5)

Ground frosts.—When the minimum over grass is 30·4°F. or less a "ground frost" is said to have occurred. Accepting this convention as applying to the bare-soil surface also, the following monthly frequencies resulted:—

TABLE V—FREQUENCY OF "GROUND FROSTS" OVER A SURFACE OF SHORT TURF AND OVER BARE SOIL AT STARCROSS, DEVON

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Over grass ...	1949	12	13	16	7	4	0	0	0	0	2	7	10
	1950	11	10	7	8	0	0	0	0	0	5	18	11*
Over bare soil	1949	8	10	9	1	0	0	0	0	0	1	5	9
	1950	10	8	2	3	0	0	0	0	0	1	8	10*

*Dec. 1–14 inclusive.

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METHODS OF SYNCHRONIZING THE OBSERVATIONS OF A "SFERICS" NETWORK

By A. L. MAIDENS, B.Sc.

In the location of thunderstorms by the cathode-ray direction-finding method, three or more stations of a network each observe, or record, the direction of approach (the compass bearing) of the atmospheric generated by a single lightning flash. To complete the process of location these observations must then be made available to a control station, where the bearings can be transcribed on to a chart of suitable projection, and the source of the atmospheric thus determined.

Rapid communication between the controlling and observing stations is essential, not only for the purpose of transmitting the bearings but also for synchronizing the observations made at the individual stations, in order that the bearings relating to the same lightning flash can be identified.

As atmospherics often may occur in quick succession, and each persists for an extremely short period of time, the method of synchronization must be of a high order of accuracy and must be capable of distinguishing between successive discharges occurring within a fraction of a second of one another. The British "sferics" network is fortunate in that the network is connected by a private telephone system which permits a wide variation of method, and ensures a high degree of reliability and simplicity in operation. The system can be used for the transmission of two general categories of synchronizing signals—continuous or selective. In general, continuous synchronization is most suitable when automatic recording is adopted, and selective methods when visual observing is employed, but no hard and fast rule can be laid down, and the choice of method must depend upon the use to be made of the observations. The telephone system also provides a rapid means of passing the results to the controlling station.

The normal routine method for the operation of the network is designed primarily to meet synoptic requirements, necessitating rapid identification of storm centres. Suitable arrangements when the observations are required for statistical, research or climatological purposes are described later. Routine observational "runs" are made for ten minutes each hour, and for each run one station is made responsible for selecting the atmospherics to be located. Selection is made automatically by a device* which can be incorporated in a certain circuit of the cathode-ray direction-finding apparatus, and which generates a short audio-frequency pulse on the arrival of an atmospheric of signal strength of more than a pre-determined value. This pulse is then fed into the telephone network so that it is heard by all stations simultaneously, as far as the observers can detect, with the visual indication of the flash on the cathode-ray tube. Bearings are at once taken, aided by the afterglow which persists on the face of the cathode-ray tube and are called out by the operators over the telephone network for recording and plotting at the control station at Dunstable. To avoid the confusion which could arise from over-rapid selection, it is arranged that the device, having once operated, will not function again for a predetermined period of time. The time delay normally used for observing and transmitting the bearing is 7 sec., but this can be varied at will, and observational runs with selection at 4-sec. intervals have been made by experienced observers quite satisfactorily during periods of intense "sferic" activity.

Any one of the four observing stations or the control station itself can undertake the task of selection, the choice being made by the control station prior to each observational period in accordance with the synoptic situation. The employment of the selecting device does not interfere in any way with the

*Described briefly in the *Meteorological Magazine* for October 1951.

normal operation of the cathode-ray direction-finding apparatus, and flashes can be observed even during the quiescent period of the device. If, during this period, the observer at the selecting station observes a flash of particular interest, for example, from a source not previously explored, he may inject an oral call for bearings to be taken. The use of the device ensures a random sampling of the thunderstorms in progress at the time. This ability to combine random selection with a degree of discretion together with the speed with which location is determined, are the great merits of the system for synoptic purposes.

The provision and maintenance of a special telephone system adds greatly to the cost of a "sferics" network, and, in fact, could not be achieved in many parts of the world, particularly where long base lines exist between the individual observing stations. Very successful experiments have been made with a variation of the system, which retains all the advantages of the telephone apart from a somewhat greater delay in obtaining the results, in which one W/T transmitter is employed for short intervals in lieu of the telephone system. Although not in regular use such a method has given excellent results, both within the British Isles and to stations overseas. In this case the selecting device is connected, *via* a telephone link if necessary, to a convenient high-power radio transmitter. A simple additional piece of apparatus is incorporated in the system which automatically secures the transmission from the radio station of a signal equivalent to a morse "dot" virtually simultaneously with the selected lightning flash. It also provides for the lengthening of every fifth signal to a morse "dash" and of every twenty-fifth to the length of two "dashes". Thus, in the event of non-reception of an individual signal, there is no ambiguity in regard to subsequent bearings, and, although a group of five atmospherics may be lost, the run may be continued thereafter.

In these experiments no special W/T transmitter has been set up, the otherwise unused "break periods" in a broadcast normally used for meteorological messages being employed. Nor are the normal "sferics" observers specially trained in W/T operation, a few hours of practice being sufficient to instruct them in sending and receiving the simple call signs which are transmitted at the start and end of observational periods. When a "run" is concluded, the results are transmitted to the control station over normal meteorological channels in a code which gives the bearings in the order that they have been selected, with reference to the specially indicated fifth and twenty-fifth signals.

For research and climatological purposes the British "sferics" network can be adapted to a continuously recording system. Cameras are clamped over the face of the cathode-ray tubes and the "flashes" photographed on a slow-moving film. Each camera is provided with a small neon lamp which, when illuminated, projects a narrow pencil of light on to the margin of the film. By this means signals are recorded beside the record of the atmospheric. The neon lamp can be actuated, through suitable apparatus, quite conveniently by independent W/T receivers at the individual observing stations, each receiver being tuned to a certain radio transmission which, providing it is continuous for the period of observation, need be in no way under the control of the "sferic" organization. The recordings may be compared with reference to the morse symbols appearing on the margin of the film, when an analysis of the atmospherics is undertaken after the films have been developed and dispatched to a central laboratory.

This method is not so convenient when the individual observing stations themselves require to measure the bearings from the film, and in this case a simple form of synchronizing signal is transmitted from the control station by employing either the existing telephone network or a special W/T broadcast. In practice the synchronizing signal is produced by the aid of a teleprinter auto-transmitter actuated by a suitably perforated tape, which results in the transmission and recording on the film of a sequence of "dots" identified by morse symbols for the figures 0 to 99. By reference to these symbols and a suitable method of subdivision between "dots", the control station can obtain the bearings of every recorded flash which it is desired to examine.

A further modification of the system has been developed as a result of co-operation between the Meteorological Office and research workers engaged in the examination of the wave form of the atmospheric. To locate the source of the particular atmospheric which has actuated the wave-form recording apparatus the marking of the film can be actuated by the research authority. In such cases the marking can be achieved automatically by a signal operated by the wave-form recorder, or by simple hand keying.

The purpose of this paper is to indicate the great flexibility in the methods of communication on which a cathode-ray direction-finding "sferics" network may be based, and how the system most suited to the facilities available and the task in hand may be chosen.

OBSERVATIONS ON LOCAL CLIMATIC CONDITIONS IN THE ABERYSTWYTH AREA

By G. MELVYN HOWE

The closer study of individual areas has shown that weather conditions vary, often quite surprisingly, within relatively small distances. Using average figures for the period 1929–48 for three climatological stations at different heights within a $7\frac{1}{2}$ mile radius of Aberystwyth, Smith[1,2] has presented the differences in values of the monthly means of the various elements. The differences are appreciable, but mean figures and mean differences convey a quite inadequate picture of local climatic conditions.

Temperature conditions probably best lend themselves to detailed observation, and the significance of low-temperature contrasts which lead to frost pockets in low-lying ground has long been recognized. Hawke[3,4], Heywood[5], Manley[6] and Balchin and Pye[7] give details of English examples of these peculiar conditions taking place in association with valley bottoms and sheltered hollows during calm, clear-sky conditions.

Howe[8] has presented details of a minor Welsh example of a frost hollow within three miles of the sea at Aberystwyth, but apart from this little or no quantitative work has been done on these lines in the Principality. With a view to correcting this unfortunate omission, at least for the district around Aberystwyth, arrangements are in hand to conduct occasional investigations into local temperature conditions by means of group projects of an intensive, short-period character. One such investigation took place on the night of November 28–29, 1952, when, equipped with whirling psychrometers certified by the National Physical Laboratory, 22 student observers made $\frac{1}{4}$-hourly observations of temperature from 11 p.m. on November 28 to 5 a.m. November

29, 1952. A ridge of high pressure covered Scotland, Wales and the northern half of England. There was no cloud and little or no wind in the Aberystwyth district, and the meteorological station at Aberporth confirmed that conditions were favourable for radiation, and forecast a slight ground inversion.

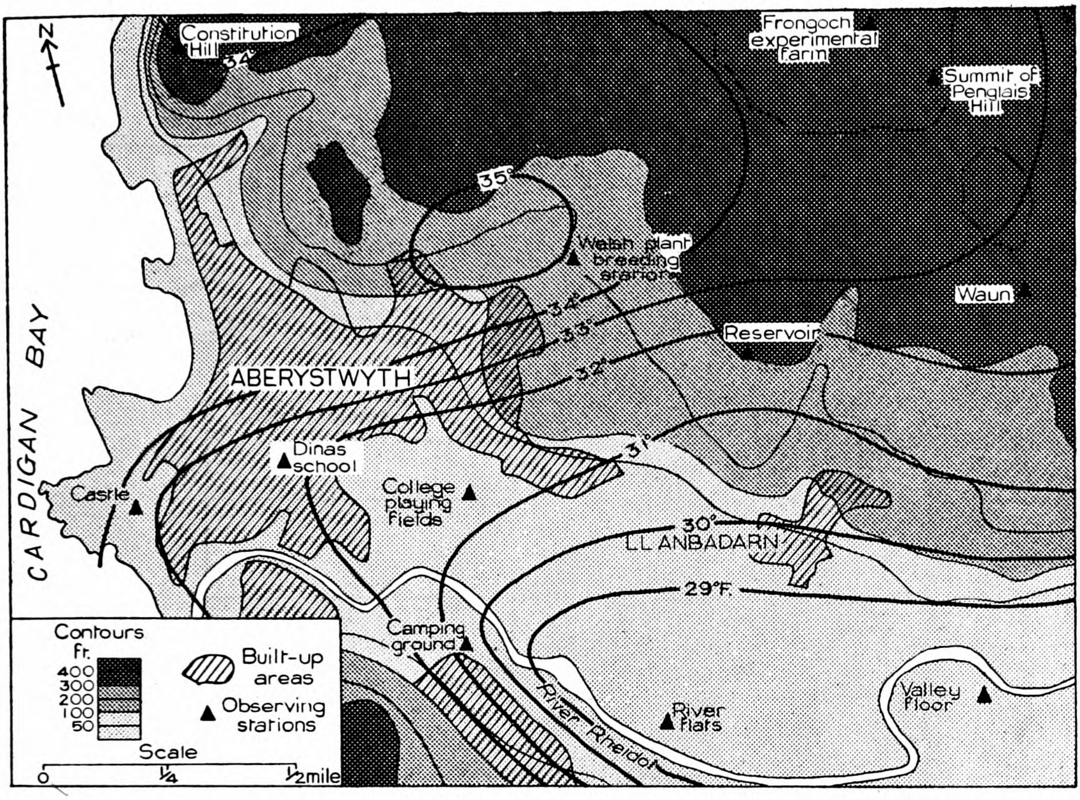

FIG. I—LOCAL TEMPERATURE CONDITIONS IN THE ABERYSTWYTH AREA, 11 P.M. NOVEMBER 28, 1952

Fig. 1 shows the local temperature conditions at the beginning of the investigation. Cold air had drained to and accumulated in the floor of the Rheidol Valley and temperatures there were 6°F. or more lower than at a point about half way up the weather slope of Penglais Hill at a height of 200 ft. above mean sea level. Here 35°F. was recorded. On the other hand, near the summit of Penglais Hill temperatures were more than 2°F. lower than on the hill side. A tongue of warm air appeared to extend up the weather slope of the hill from the sea to the hill summit while the floor of the valley was occupied by a "lake" of cold air. It is assumed that this "lake" extended well inland along the floor of the Rheidol Valley. Seaward and toward the town of Aberystwyth there was a notable rise in temperature, due probably to proximity to the sea and a minor heat island associated with the built-up area.

Fig. 2 shows in graphical form the temperature at two-hourly intervals at selected observing stations. To show relative heights, relief profiles have been drawn along lines connecting the stations concerned. The altitude scale is given on the right side of each graph; the horizontal scale is also shown. Temperatures for the particular times of observation have been plotted immediately above their respective stations according to the temperature scale on the

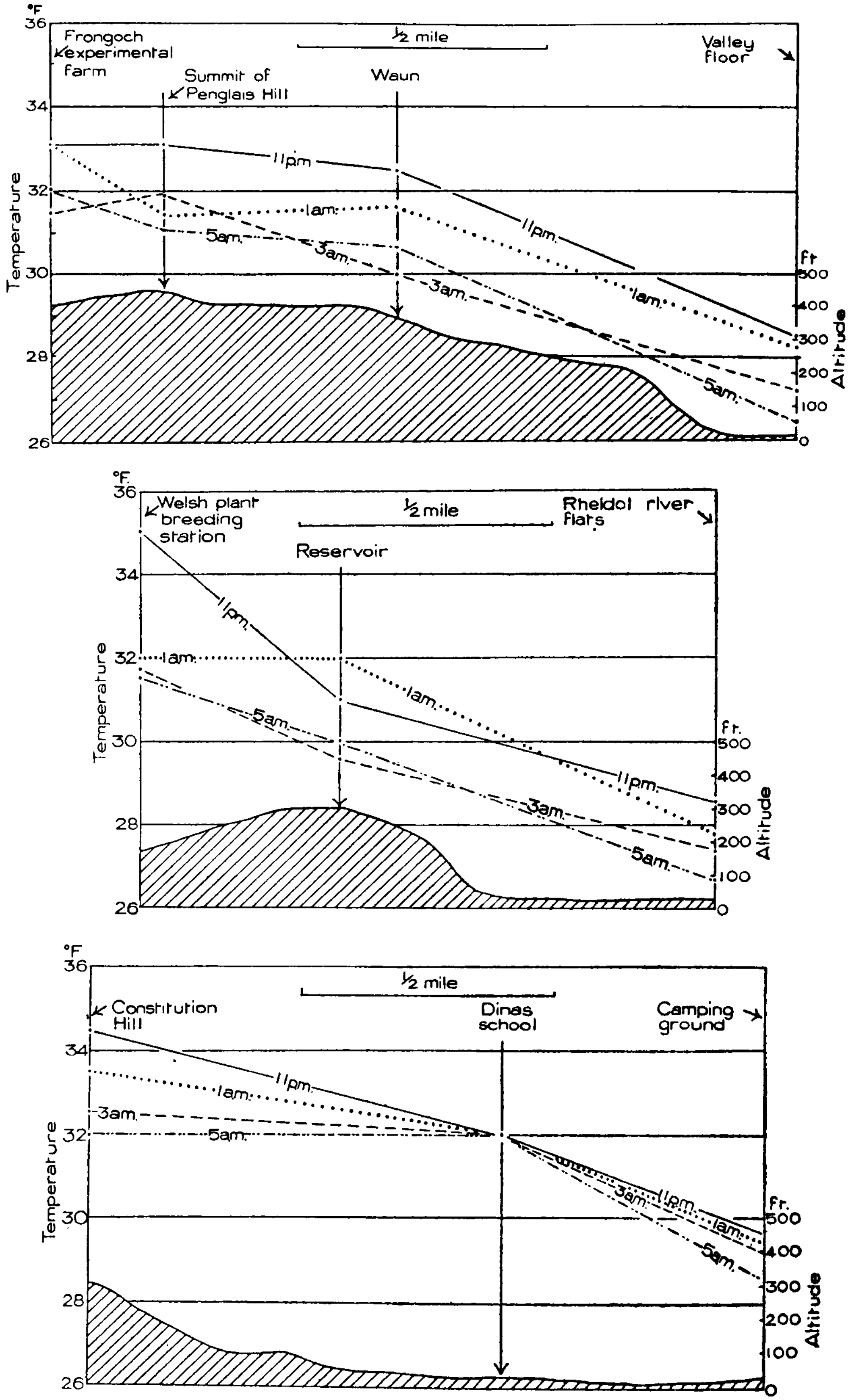

FIG. 2—LOCAL TEMPERATURE CONDITIONS AT SELECTED OBSERVING STATIONS

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WIND EFFECT ON TREES AT CAMBORNE

The photograph was taken facing south and shows the deformation of a hawthorn tree by the westerly winds. The smooth curve outlined by the branch ends against the sky will be noted.

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WIND EFFECT ON TREES AT CAMBORNE

This photograph was taken facing north. The Cornish elms on the west side of the road are unable to grow upright and symmetrically, whilst those on the east side are sheltered and grow normally. Note the deformation of the trees opposite the gap in the left foreground.

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WIND EFFECT ON TREES AT CAMBORNE

This photograph is also taken facing north and shows the suppression of growth by the wind on the west side of hawthorn, oak and ash.

To face p. 273]

Reproduced by courtesy of R. McGill

O.W.S. *Weather Explorer* AT THE ROYAL REVIEW OF THE FLEET

(see p. 279)

left side of each graph. A gradual fall of temperature, both in the valley floor and on the hill side and summit, is illustrated by the graphs. The valley floor, however, is constantly colder than either the hill side or summit. The katabatic inversion of temperature appears to have failed to influence the readings at Dinas school which remained fairly constant at 32°F. throughout the period of investigation. Yet a mobile observer within the town noted temperatures in places which would suggest that occasionally the fairly constant temperature of the minor heat island was being lowered by the inflowing of cold air. It was also observed that temperatures on the promenade were constantly above freezing level while those behind the houses which back the promenade were generally below freezing and surfaces were covered with hoar-frost.

Local temperature conditions at 5 a.m. November 29 at the termination of the investigation are shown in Fig. 3. The pattern is very like that for 11 p.m. the previous evening except that the pocket of warm air on the hill slope has disappeared and the temperatures are everywhere lower by more than 2°F. A slight valley mist had also formed.

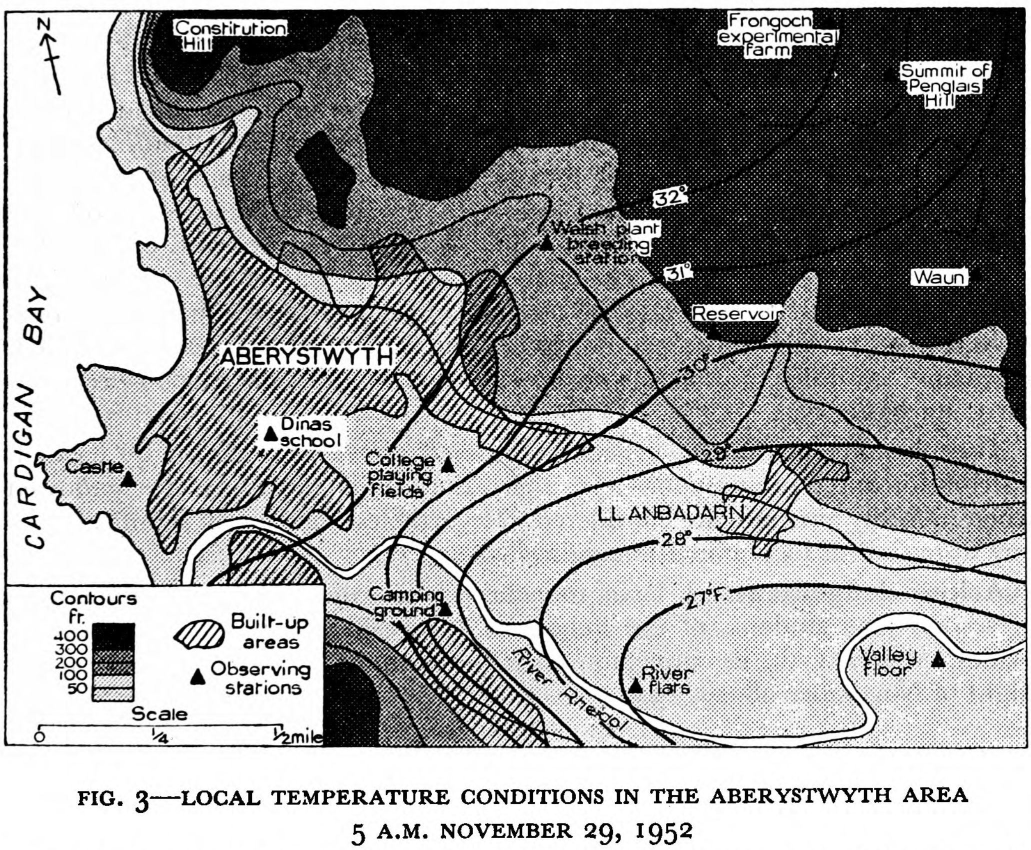

FIG. 3—LOCAL TEMPERATURE CONDITIONS IN THE ABERYSTWYTH AREA
5 A.M. NOVEMBER 29, 1952

Local temperature variations of another kind lead to mist and fog from the sea. Not infrequently during warm spells in the summer a line of fog develops and completely obscures the immediate coastline leaving places less than 100 yd. from the sea still bathed in sunshine. The fog usually forms about midday after a hot, calm morning during which vigorous evaporation has apparently taken place. A light cool wind from off the sea is then sufficient to cause the fog and mist. Such occurrences were noted on May 18, 1952, and again on

August 2, 1952, but quantitative observations were not made. Ruck[9] has drawn attention to a similar mist or fog forming over St. David's, Pembrokeshire. Such mist along the coast can also form in winter as the following example shows.

On February 27, 1953, Aberystwyth was bathed in brilliant sunshine until 11.15 a.m. There was no wind or cloud. Temperatures read at 9 a.m. in the Health Resort screen in the Castle were: dry bulb 40·2°F., wet bulb 39·3°F., relative humidity 92 per cent. Air temperatures taken with a whirling psychrometer at 11 a.m. were dry bulb 50·1°F., wet bulb 46·8°F., relative humidity 79 per cent. (Marvin's tables for relative humidity).

At 11.15 a.m. a thin layer of sea mist began to develop at about 200 ft. on the seaward side of Constitution Hill immediately to the north of Aberystwyth (see Fig. 1). By 11.30 a.m. the whole of the immediate coastline was obscured by the mist which then extended to sea level. Visibility was 120 yd. The mist advanced very slowly eastward over Aberystwyth. Air temperatures at 11.30 a.m. were dry bulb 39·9°F., wet bulb 39·9°F., relative humidity 100 per cent. Thus there was a drop of 10·2°F. in $\frac{1}{4}$ hr. The sea temperature was also taken at 11.30 a.m. and was 43·1°F.

For comparative purposes, temperatures were read at 11.30 a.m. at Frongoch experimental farm, which is situated at about 400 ft. above M.S.L. and less than 1 mile inland from Aberystwyth. The ceiling of the mist was about 350 ft., and so this station continued to enjoy brilliant sunshine. Readings were dry bulb 51·0°F., wet bulb 47·5°F., relative humidity 76 per cent. at 11.30 a.m. At 2 p.m. temperatures were dry bulb 54·5°F., wet bulb 50·0°F., relative humidity 71 per cent. at this farm, while Aberystwyth was still enshrouded in the mist and continued to show temperatures of 40°F. and relative humidity 100 per cent. Cars were obliged to use lights in Aberystwyth during the afternoon, while $\frac{1}{2}$–1 mile eastward the clear sky and brilliant sunshine still prevailed. It was not until 8 p.m. that this extremely local sea mist dispersed to reveal a clear, starlight sky.

The phenomena that have been considered above are admittedly local in distribution and represent short-term aberrations which tend to be overshadowed when monthly averages are considered. Nevertheless they are of significance in any appraisal of local climatic conditions.

Acknowledgement.—I have to acknowledge the generous co-operation of second-year students of the School of Geography, University College of Wales, Aberystwyth, in connexion with the temperature observations on the night of November 28–29, 1952.

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ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on May 20, 1953, the President, Sir Charles Normand in the chair, the following papers were read:—

McIntosh, D. H.—Annual recurrences in Edinburgh temperature*

Mean daily temperatures at Edinburgh were examined for different groups of years: for 1901–1950 at Blackford Hill, for previous periods of 50 and 100 yr. published by Mossman, and for the whole period of 150 yr. The magnitudes of the departures, in the various periods, of the daily temperatures from the corresponding seasonal values were compared with theoretical values based on no tendency for annual recurrences, the seasonal values being calculated from the monthly mean temperatures, using the first two harmonics. The following general conclusions were reached from this statistical analysis:—

(i) the non-seasonal temperature fluctuations are very largely random

(ii) there is strong evidence that any real anomalies are mainly negative in character

(iii) recurrences on the days of the cold and warm spells detailed by Buchan do not depart to a significant degree from chance expectations

(iv) it is unlikely that there are significant short-lived anomalies which are masked in long-period mean departures by changes of phase.

In the subsequent discussion it was appreciated that the paper represented a useful piece of statistical work. Dr. Weickmann was quoted as saying that some people believe in "singularities" and others do not. Dr. Sutcliffe thought "singularities" ought to be defined, i.e. can they be dated or are they only typical of some period? Prof. Manley regarded "singularities" as an event linked with the calendar, but emphasized that Buchan referred to cold and warm spells as irregular and subject to variation from year to year. Mr. Gold thought that the figures of the paper justified a stronger statement of the case for the existence of non-random temperatures and referred to the recent cold spell about May 11–13, the days of the "Ice saints". Other points made were that harmonic analysis might not be the best method of determining the seasonal values, since it involved too long a wave-length, and that minimum temperature rather than the mean temperature might have been used with advantage.

Brown, P. R.—Climatic fluctuation in the Greenland and Norwegian Seas†

Ship observations of air and sea temperature, as recorded on Hollerith cards, were summarized for the sea areas between 60°N. and 70°N., extending from Greenland to Norway with Iceland in the centre of the area, to give decadal means, from 1900–09 to 1940–49, for the year, for July, and for the period December to March. Over the 10 Marsden 5-degree squares involved there was a general increase of air temperature from 1900–09 to 1930–39. The rise was less marked in the neighbourhood of the Irminger current around Iceland. There was a marked decrease in the decadal annual means of sea temperature from 1930–39 to 1940–49 to the east of Iceland but an increase to the south of Iceland.

Cmdr Frankcom considered that the paper brought out the close relationship between meteorology and oceanography, and suggested further lines of research; the correlation of sea temperature observations of the previous year in the Gulf Stream area with air temperature up the Norwegian coast, and the relation

*Quart. J. R. met. Soc., London, **79**, 1953, p. 262.
†Quart. J. R. met. Soc., London, **79**, 1953, p. 272.

of ice cover on the Grand Banks with temperature trends. Mr. Schove showed a slide to bring out the association between cold winters in Norway and warm winters in Greenland and *vice versa*, together with associated mean pressure and wind-flow maps.

Manley, G.—The mean temperature of central England, 1698–1952*

Serial values of the monthly mean temperature of central England are given for the period 1698–1952. The values are based on the mean of the Oxford and Lancashire record† back to 1815. For earlier years a number of records distributed over central England though extending as far as Edinburgh, London and Plymouth were used, but for 1707–22 the values had to be estimated from those at Utrecht. The extraction of these records from various libraries and their interpretation has involved a great deal of work. In the discussion Dr. Glasspoole emphasized some of the uncertainties involved in this method of piecing together records in different parts of the country. While temperature changes are broadly similar over a wide area there are distinct local variations, since the changes of temperature, year by year or decade by decade, over the country can be mapped. Moreover there is a greater variability in the annual values in the east than in the west of the country and a marked difference over the country in the seasonal variability.

INSTITUTION OF ELECTRICAL ENGINEERS

Utilization of solar energy

At the Institution of Electrical Engineers on May 20, 1953, Dr. E. C. Bullard, Director of the National Physical Laboratory delivered a lecture on the utilization of solar energy summarizing the work of a National Physical Laboratory Committee.

He opened by stating that the energy of solar radiation at the outside of the atmosphere was about 1·3 Kw./m.^{2}, and that under a clear sky an area at the earth's surface normal to the sun's rays could receive, at most, energy of about 1 Kw./m.^{2} Averaged over the year the amount on a horizontal surface was 0·1 to 0·2 Kw./m.^{2} Immediate difficulties were the intermittency of the supply and the fact that the energy received is least in winter when for many purposes it is most needed. It was better to use solar energy for direct warming of buildings or producing hot water than in the production of mechanical or electrical energy, because of the inevitable low efficiency of such production associated with the second law of thermodynamics.

Warming of houses or production of domestic hot water by heating water in tubes under glass by the sun was feasible, but not economical, because the cost of the heater and a large insulated storage tank was very high, and in any case normal heating apparatus could not be dispensed with. Cooking with a mirror of about 0·3 m.^{2} area to concentrate the energy was possible in the tropics, but the cost might be too high for peasants to pay. The driving of a refrigerator for the cooling of buildings in the tropics was also possible using a collector covering about half the roof area. Orthodox steam or hot air engines for pumping water or generating electricity were very inefficient; a collector

* *Quart. J. R. met. Soc., London*, **79**, 1953, p. 242.

† MANLEY, G.; Temperature trend in Lancashire, 1753–1945. *Quart. J. R. met. Soc., London*, **72**, 1946, p. 1.

about 18 m.^{2} in area would be needed to produce on the average 1 Kw. of useful power. Direct production of electric currents by the thermo-electric or photovoltaic effects was also very inefficient.

Growth of trees or plants to produce fuel for burning in a boiler has the advantage of overcoming the intermittency associated with direct use of insolation, but the disadvantage of requiring areas of ground so large as to affect food supply.

Continuous growth of algae in tanks so arranged that the plants could be filtered off, dried, and burnt to produce useful heat had been suggested. The proposal involved recovery of the mineral constituents of the plants and of the carbon dioxide which would be returned as carbonate to supply carbon for the next crop. To produce 10,000 Kw. an area of over 3 Km.^{2} of algae tanks would be needed.

His general conclusion was that no way in which solar radiation can be made to supply a large amount of power can at present be envisaged, but that there were distinct possibilities in applications, such as air conditioning in the tropics, calling for a relatively small amount of energy.

Reference should be made to *Research, London,* **5,** 1952, p. 522 for the Committee's full report on the utilization of solar energy.

LETTERS TO THE EDITOR

Four simultaneous concentric halos

On April 10, 1953, the following observations were made at Alston, Cumberland:

0830–0930 G.M.T.

A 22° halo with both parhelia and a faint parhelic circle.

1040–1105 G.M.T.

A 46° halo almost complete and coloured and an upper arc of contact to a very bright 22° halo.

1105–1150 G.M.T.

An exceptionally bright 22° halo with a brilliant upper arc of contact.

A 9–11° halo clearly visible without smoked glasses and slightly red on the inner limb.

An 18–20° halo which was incomplete and in two parts, it affected about 240° of the circle altogether, the inner red limb was clear and a suggestion of green could be discerned on the outer.

The 46° halo recorded earlier, very faint and intermittent, but for most of the time, when present, almost complete.

Parhelia and parhelic circle, but only faintly visible dnring this period.

1150–1230 G.M.T.

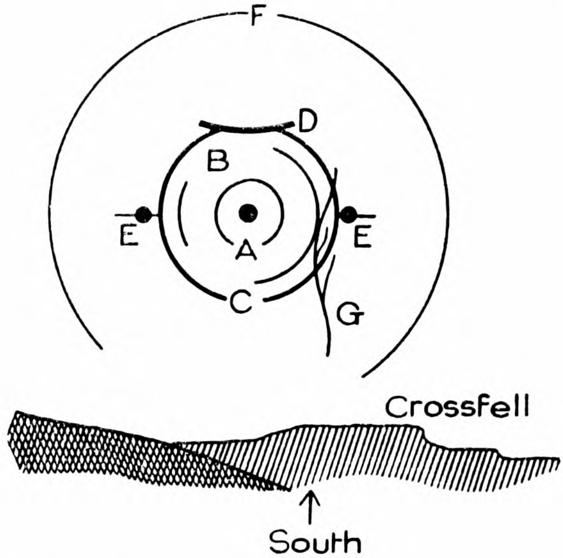
The 22° halo only with upper arc of contact.

1500–1830 G.M.T.

The 22° halo with distinct parhelia and upper arc of contact.

The phenomena seen between 1105 and 1150 is shown in Fig. 1.

At 1600 the 22° halo was measured along its vertical axis with a theodolite, and the figures 9–11° and 18–20° have been adopted as a result of deductions made by non-instrumental methods. Unfortunately the display with the four halos was seen whilst I was a long way from suitable equipment, but as a substitute rough measurements were made by extending the arm and using the knuckles to give a scale which could be converted into degress at a later time. The 22° halo having been established accurately the measurements 9–11° and 18–20° were adopted from the proportions suggested from the crude field work.



A = 9–11° halo
B = 18–20° halo in two parts
C = 22° halo
D = Upper arc of contact
E = Parhelia
F = 46° halo
G = Position of cirrus structure in cirrostratus veil

FIG. 1—HALO AT ALSTON, APRIL 10, 1953

The altitude of the sun was about 40° when the 9–11° and 18–20° halos were visible. The sky was well veiled with cirrostratus cloud which, in only a few places, produced a structure which could be called cirrus. One such patch was very near to the main part of the 18–20° halo.

W. E. RICHARDSON

The Grove, Alston, Cumberland, April 10, 1953

[The halos of radii between 9 and 11° and between 18 and 20° are very occasionally seen, but it is extremely rare for both to be seen together and with the 46° as well as the 22° halo. Mr. Richardson was fortunate to see such a spectacle.

The nearest approaches to it are, the observation by C. W. Hissink[1] at Zutphen, Holland, on May 19, 1899, of halos of radii 7·5°, 17·5°, 19·5° and 22°, and the observation by C. G. Andrus[2] at Sand Key, Florida, United States, on May 11, 1915, of halos of radii 8–9°, 17–18°, 18–19°, 22°, and 28°. Captain C. J. P. Cave[3] wrote that his observation of a halo of 18°30′ radius with the 22° one on May 16, 1926, was the most remarkable meteorological phenomenon he had ever seen. W. F. Watson and G. A. Clarke[4] observed a halo of radius 10–11° on May 1, 1938.

More instrumental measurements of the halos of radii less than 22° are needed.—Ed., *M.M.*]

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3. CAVE, C. J. P.; A very rare halo. *Nature, London,* **117,** 1926, p. 791.
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Condensation trails

On p. 125 of the *Meteorological Magazine* for April 1953, dynamic instability in large horizontal shear is tentatively suggested as a possible explanation of the shearing of the condensation trail shown in the photographs in the centre of that magazine. In the region of Stroud, where the trail was seen, there are many large hills, and with much smaller ones permanent distortions of marked lines of air have been shown to occur*. Such kinks as that shown in Mr. Tuke's photograph would, I think, be expected as the air passed over a hill whose size was about that of the kink. This is a very rough estimate, but the theory leaves no doubt about the order of magnitude of their size, and so this explanation seems possible.

R. S. SCORER

Imperial College, London, S.W.7, May 12, 1953

NOTES AND NEWS

Weather ship at Royal Review of the Fleet

The British O.W.S. *Weather Explorer* had the honour of being present at the Review of the Fleet by Her Majesty the Queen at Spithead on June 15, 1953. *Weather Explorer* was relieved at ocean station "Juliett" by the Netherlands vessel *Cirrus* on June 6, and instead of returning forthwith to Greenock as is customary she proceeded to Plymouth in order to refuel, give shore leave to her ship's company and to complete the painting of her hull for this royal occasion. The ship arrived at her appointed anchorage in line K of the Review area, situated about three-quarters of a mile to the east-north-east of Ryde Pier, early on Sunday, June 14, 1953.

The early morning of June 15, the day of the Review, provided a heavily overcast sky and gusty westerly winds of Beaufort force 5 to 6. One of the guests from the Meteorological Office Headquarters who, accompanied by their wives, travelled from London to be aboard the ship during the Review, telephoned Victory House at 0730 for a forecast and was informed that there would be fresh to strong W. to NW. winds during the day with overcast skies and perhaps quite a lot of rain but some sunshine. In the event, though the sky was generally overcast, some welcome sunshine did occur in the afternoon and there was no rain though "precipitation in sight" was recorded in the ship's deck log at 1600. The wind was fresh and squally during most of the day.

Those of us who were privileged to be aboard the ship, as guests of the Master and officers for this memorable occasion, witnessed a truly magnificent spectacle; every detail of which had been worked out with that meticulous attention to

*SCORER, R. S.; Theory of airflow over mountains, II—The flow over a ridge. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 70.

detail which one expects of the Navy and which went, so far as can be judged, exactly according to plan. The long lines of warships, not only of the Royal Navy but of visiting Navies as well, stretching as far as the eye could see, were bedecked on this royal occasion with bunting. It was noticed that no less than 12 of the Merchant ships present, similarly gaily festooned for the occasion, were "selected ships", whose officers voluntarily make observations at sea on behalf of the Meteorological Office. The surface visibility was at least seven miles, so that one could see the whole extent of the line of ships, and it was noteworthy how even in broad daylight the prominent "eternal flame" which burns at the Fawley Oil Refinery showed like a golden flag against the skyline. The fresh breeze was an advantage for it enhanced the effect of the flags with which every ship was dressed overall.

Those aboard *Weather Explorer* had a good view of the progress of the procession of vessels which accompanied Her Majesty aboard H.M.S. *Surprise* as she steamed down the lines of warships, and *Weather Explorer's* cheer joined those emanating from the Naval ships as Her Majesty passed.

The fly-past of about 300 Naval aircraft of various types reminded us of the amphibious nature of a modern Naval officer's job. By this time the cloud level had dropped to about 1,000 ft., but this did not interfere with the aircraft as they passed over the Fleet at a height of about 300 ft.

During the early evening the ship's motor boat did two short tours, for the benefit of the guests and the ship's company, around some of the assembled warships. The illumination of the warships and the firework display which followed were incredibly well synchronized and most efficiently executed and presented a fitting and colourful climax to this memorable occasion. The weather remained fine and clear throughout the evening and one B.B.C. announcer, during the course of the day, said he hoped that the presence of the weather ship at the Review was to some extent contributing to the fine weather which was experienced. *Weather Explorer* with her black hull and bright yellow upperworks—dressed overall with flags—looked very immaculate, and the 16 guests who were aboard her were impressed with her cleanliness, the admirable meals provided and the hospitality and kindness showed them by Captain Wilkinson and all the ship's company. The following morning *Weather Explorer*, having landed her guests at 0500, weighed anchor and returned to Greenock whence she sailed again for station "Juliett" on June 24, 1953.

C. E. N. FRANKCOM

"Navigation to-day"

The exhibition "Navigation to-day", which opened at the Science Museum on April 22 and remains open until mid September, includes exhibits showing the application of meteorological information in both marine and aerial navigation.

The exhibit of the Meteorological Office in the marine section includes examples of the published charts of mean winds and currents and some synoptic charts drawn on merchant vessels at sea with notes on the use made in reducing passage time. The aerial section includes two beautifully constructed layer models showing wind roses at 10,000, 20,000, 30,000, 40,000, and 50,000 ft. over the British Isles and mean vector winds at the same levels over North America, the North Atlantic and much of Europe. Two composite upper air forecast charts for flight across the North Atlantic are shown with the tracks flown on them, which though longer in distance than the great circle track took less time because of the wind distribution. Some synoptic 500-mb. contour maps are also exhibited. Meteorologists will also be very interested in many other exhibits from the ship's bridge complete with the latest instruments for navigating and steering to the maps and spoken description of the control of civil aircraft.

Smoke haze observed from an aircraft

The opportunity recently arose to undertake a flight over the central and southern Midlands to study the effect of smoke on visibility. One or two of the points observed were particularly striking, and it is for this reason that this note is written.

The flight was made on January 8, 1953, and the synoptic situation at 1500 G.M.T. showed a feeble ridge extending from the Scilly Islands towards Lincolnshire; this was moving south-eastwards, whilst a warm front west of Ireland was advancing slowly. Winds at 2,000 ft. were northerly at 0900 G.M.T. and west-north-westerly at 1500 G.M.T. over the Midlands as a whole, and about 10 kt. throughout; the back of the wind across the ridge was marked. There was no low cloud over the central Midlands, but stratocumulus was reported from the extreme south. The flight took place during the period 1420–1600 G.M.T.

It has frequently been noticed that the visibility at Benson in a north-westerly air stream is appreciably worse than that at Abingdon; the only apparent explanation is that smoke produced in the Oxford area affects Benson, 12 miles to the south-east, and not Abingdon, 5 miles to the south-west. However, Oxford is not primarily an industrial city, and one might not have expected pollution at such a distance. On the day concerned, the reported visibilities at Abingdon and Benson, at 1400 for example, were 5 miles and 3,000 yd. respectively. The flight to Abingdon and thence to Oxford confirmed the above explanation; appreciable smoke was being emitted both from the few (approximately six) major chimneys in Cowley and from Oxford itself (breweries, etc.), and visibility to the south-west of the city was many miles greater than to the south-east.

From Oxford north, the flight was made at heights up to 4,500 ft. The main, and perhaps surprising, impression was of the smoke generated by industrial sources being many times greater in pollution effect than that emitted by domestic sources. This was very striking over the Birmingham area, where the surface wind was almost due westerly. The western half of the city (the residential area) was relatively clear with visibility 5–10 miles, but at the edge of the industrial area to the east the visibility dropped very rapidly and dense fog could be seen in the streets, with roofs standing clear. The weather had been cold, and although domestic fires must have been in widespread use their lack of effect on the visibility was very apparent. Away from Birmingham, in the open country, it was noticed that isolated chimneys (e.g. cement works) produced spreading plumes of smoke several miles long, and that even roadmen's hedging fires constituted an appreciable source of pollution.

A point of real interest was that the smoke haze had a very clearly defined top at just over 2,000 ft., and the smoke from an individual chimney ascended in a gentle curve, finally drifting down wind at that level. Above 2,000 ft.

visibility everywhere was at least 30 miles, but below and to the east of Birmingham it was only about one mile. Neither the Larkhill nor Liverpool ascents showed any variation in, nor gave any indication of, this lapse rate at 2,000 ft.; there was no discontinuity below 4,000 ft. at either 0900 or 1500 G.M.T. Presumably the 2,000-ft. level marked the limit of convective turbulence. It was observed that the stratocumulus cloud in the vicinity of Reading also had a fairly flat upper surface at the same height.

A rather noteworthy feature was the manner in which high ground tended to stand clear of the haze although it did not by any means reach to the haze top. Travelling northwards from Oxford to Birmingham, it was observed that the ridges Edge Hill and Clent Hills, neither of them higher at any point than 1,100 ft. above sea level, stood out clearly from many miles away, whilst the lower ground disappeared beyond a distance of about 8 miles.

We are indebted to Sqd.-Ldr W. J. Kenyon, Commanding Officer of 540 Squadron, for arranging the flight, and to Flt-Lt J. P. Walker for piloting us on this flight.

G. W. HURST
P. G. F. CATON

REVIEWS

Weather inference for beginners made clear in a series of actual examples. By D. J. Holland. 10 in. × $7\frac{3}{4}$ in., pp. xiii + 196, *illus.*, Cambridge University Press, Cambridge, 1953. Price: 30*s.* net.

This book is the outcome of a youthful enthusiasm for observing the weather. When the writer was a schoolboy he developed the habit of keeping a day-to-day record of weather, cloud, visibility, wind and often temperature. The observations were made whenever he could conveniently do so, sometimes two or three times a day, occasionally almost hourly. The book he has now written is built around a series of observations made in the London area during the last five months of 1936. Using these observations in chronological order, he introduces the reader to meteorological theory by relating what he saw to the probable synoptic situation and—in the later part of the book—to the analyses published in the *Daily Weather Report.* Whereas most books progress from theory to example, in general Mr. Holland takes the bold step of reversing this order.

A certain meteorological equipment is needed before anything at all can be learnt from a set of observations, so the first half-dozen pages are devoted to a very brief introduction to the ideas of air masses, fronts and circulations. Then Chapter II introduces the codes and gives a fairly detailed description of the standard cloud types (without illustrations) and the notation for present weather The reader is now regarded as ready to open the weather diary, and the next six chapters provide a reasoned interpretation of its contents. Every few days the writer finds a situation enabling him to introduce some new branch of the theory, and by the time he is midway through the book the reader has an acquaintance with the main weather types, the use of the tephigram, instability, radiation, pressure and wind, and even the circulation theorem.

The second half of the book follows the pattern of the first, but the approach is now synoptic. A good selection of *Daily Weather Reports* is reproduced, and the reader is shown how to associate the local observations with what is happening on charts. The "armchair talks" are now a thing of the past and it is as if the reader were invited into a forecast room. By Chapter X, if he is a conscientious reader, he will even find himself under the obligation to "grid" an upper air chart. Indeed, in the last few pages he receives such peremptory instructions on the art of forecasting for aviation as to be almost persuaded that he is on the staff of the Meteorological Office.

In a book written for specialists an author has considerable latitude in th matter of structure and tempo; he should present his subject scientifically, but has the right to expect a fair degree of industry on the part of his reader. On the other hand, a book written primarily for the general reader, as this is, calls for an accurate appreciation of his needs. It must be persuasive and inviting, and not so difficult as to discourage him, yet not so easy that the reader loses the sense of achievement. Scientific accuracy is something it cannot always attain, yet the half-truth must not be disguised.

The opening pages show that Mr. Holland set out to retain the interest of his reader. He adopts a friendly, conversational tone and is always ready with a simple analogy. His style, however, is somewhat staccato, and in places the flow is broken by the use of ugly abbreviations which hardly help the reader. Nevertheless something more than *bonhomie* is required to save the reader from mental indigestion after the fare that Mr. Holland provides. For example, within the space of a single page he is confronted with the low-level variation of wind with height, thermal winds, variation of wind with height as indicating temperature advection, and convergence through the drift of air across the isobars of a changing pressure system. There is not a single explanatory diagram, and in this respect the whole book is markedly deficient. The offence, in the opinion of the present writer, lies not only in the concentration of so much material into what are little more than lecture notes, but in missing such excellent opportunities to teach the reader to reason meteorologically. It is a peculiarity of forecasting that so many problems entail a close investigation of basic data and cannot be solved by a set of rules unless the reasoning behind those rules is ingrained in the mind of the forecaster. No better example of this can be found than the art of drawing thickness lines on an upper air chart, which involves much more than fitting lines to the observations. Nor is there any need for the general reader to avoid the theory, for such things as thermal winds and convergence can be presented in a simple, detailed and interesting way, and the understanding gained is invaluable in the study of charts.

Criticism of a book which can be applied equally to other books is perhaps no more than an expression of the idiosyncracies of a reviewer. However, the present writer holds the view that any introductory book should progress strictly from cause to effect, from solar radiation to air masses and later to fronts and circulations. If the reader cannot wait a few chapters to find out why it rains he is too impatient to profit from his studies. The desire to reach frontal examples as soon as possible results in the development of a parochial view of the structure of the atmosphere. A front should not be merely something that bobs up as bad weather in the vicinity of a weather ship, but should be expected because it is a boundary to a fully-charted air mass. Part of an organism such as the atmosphere cannot be studied without some knowledge of the whole of which it is part.

Mr. Holland touches on most of the subjects one expects to find in a book of this kind and his treatment is orthodox. Nevertheless, the emphasis is surprisingly uneven. The conception of potential instability, so difficult for a beginner, is described (albeit in three sentences) yet the reader is given no indication of what an ascent through a frontal surface looks like. In a practical book it is strange, too, to find no reference to ice accretion, or to the physics of rain. Again, despite the number of pages allotted to the actual work of the forecaster, we are not shown an aviation forecast or told what items are included. We may have hoped, too, that this would be the first book to explain in elementary fashion exactly why the wind blows (not simply how it fits the isobars). Further, the study of trajectories is, in the opinion of the reviewer, a major omission on the part of both Mr. Holland and earlier authors. The flow of air, so different in pattern from the isobars of moving systems, is the main cause of variations within an air mass, and so is the major factor in determining most of the weather we experience. The analogy between circulation round a depression and what happens near the bath plug is one that does more harm than good, and the presentation of isobars as though they were tram-lines rather than stream-lines does little to help to visualize the movements of the atmosphere. As Mr. Holland says, "there is indeed more in the beautiful patterns of air-flow than meets the eye," and it is a pity he went no further.

C. J. BOYDEN

Flying saucers. By D. H. Menzel. 8 in. × 5½ in. pp. xii + 319, *Illus.*, Putnam and Co. Ltd., London. Price: 21*s*. net.

The author of this book is Professor of Astrophysics at Harvard University and his purpose in writing it was to answer the question "What are the flying saucers?" He describes a large number of alleged observations of these apparitions and easily provides in nearly all cases a simple natural explanation. Besides the recent "flying saucers" accounts of a number of apparently peculiar objects seen in past years, such as Maunder's "torpedo beam", are included and there is a chapter on false radar echoes. The book contains excellent elementary accounts of meteorological optics with some very good photographs, and of the aurora, radar and parts of astronomy. It is light in manner but very serious in purpose, for belief in "flying saucers" has caused much agitation and a number of deaths.

G. A. BULL

Report of the Hampstead Scientific Society, 1947–8—1951–2. 8 in. × 6½ in., pp. 32. Typescript, London. Price: 1*s*. 6*d*. net.

This report covers the activities of the Society over the five years October 1947 to September 1952 and includes accounts of the work of its meteorological, astronomical and natural history sections. The main meteorological contribution is a comprehensive note by E. L. Hawke, M.A., on the "Climate of Hampstead Heath". Mr. Hawke has superintended the climatological station since it was established on the extreme summit of the heath (450 ft. above sea level) late in 1909. His note includes tables showing monthly and annual average and extreme values of temperature, of rainfall amount and duration and of sunshine, linked by an interesting commentary comparing the climate of the heath with that of other parts of the London area. The differences of snowfall and snow lying and of sunshine are specially worthy of note. Hampstead Heath receives on the average 167 hr. more sunshine a year than Regent's Park and 12 hr. more than Kew Observatory.

H. C. SHELLARD

SPECIAL PROMOTION ON MERIT

One of the proposals of the Barlow Committee of 1945 on Government Scientific Staff (Cmd. 6679) was that provision should be made for the special promotion on merit of individual research workers of exceptional ability to posts outside normal departmental administrative complements.

It has now been announced that, on the recommendation of the Inter-departmental Scientific Panel, Dr. G. D. Robinson, Superintendent of Kew Observatory, has with effect from July 1, 1953, been awarded a special promotion on merit to the rank of Senior Principal Scientific Officer. Dr. Robinson is the first member of the staff of the Meteorological Office to be awarded such a promotion.

Dr. Robinson graduated at the University of Leeds with first class honours in Physics in 1933 and proceeded to the degree of Ph.D. in 1935. He joined the staff of the Meteorological Office at Kew Observatory in 1936, and became associated with the exploration of the electric field in thunderstorms by means of alti-electrographs carried by free balloons. He was joint author with Sir G. C. Simpson of a Royal Society paper on this subject.

During part of the 1939–45 war he was concerned, at H.Q., R.A.F. Balloon Command, with the meteorological-electrical problems of the kite-balloon barrage.

On returning to Kew Observatory in 1946 Dr. Robinson embarked on detailed studies in atmospheric radiation and the related subject of the transfer of heat and moisture between the ground and the air. The studies are basic to problems of energy exchange in the atmosphere—a subject which is receiving increasing attention. Dr. Robinson has applied his carefully controlled measurements of atmospheric radiation to an examination of the validity of the radiation chart devised by Elsasser about ten years ago for the purpose of computing the vertical flux of radiation from data on the vertical distribution of temperature and humidity, and has suggested a modified chart. Another outcome of the field work at Kew Observatory is the demonstration that, at least in the surface layers of the atmosphere, the radiational transfer of heat can be comparable in magnitude with convective tranfers. In these intricate investigations Dr. Robinson has shown marked experimental and observational acumen and a highly developed faculty of critical discussion and interpretation. His published papers on this work are widely recognized as important contributions. The investigations continue and have recently been extended to include the study (by specially designed equipment) of fine-scale fluctuations in air motion and temperature near the earth's surface.

Dr. Robinson, assisted by junior colleagues, has also been engaged in a critical examination of the technique used in continuous measurement of the solar radiation and daylight illumination received at the earth's surface. The results are to be incorporated in analyses and discussions, now in preparation, of five years' simultaneous recordings of components of solar radiation and daylight illumination at Kew Observatory.

Dr. Robinson was awarded the Buchan Prize of the Royal Meteorological Society for 1947 to 1951 in recognition of his contributions to atmospheric radiation and turbulent transfer published in papers in the *Quarterly Journal of the Royal Meteorological Society* during that period.

It is proposed that Dr. Robinson shall continue research on the basic problems of energy exchange in the atmosphere, extending the investigations to the flux of radiation at different heights above the ground, and secondarily that he shall carry further the investigations on solar radiation and daylight illumination.

METEOROLOGICAL OFFICE NEWS

Domestic help?—The July 1953 number of *Air Clues* contains an excellent article on "Jet Streams" by Sqd.-Ldr L. G. Press, A.F.C. It describes, by way of illustration, the jet streams encountered by the Canberras of No. 12 Squadron R.A.F. (which Sqd.-Ldr Press commands) on their recent tour of South and Central America, and, though written mainly for pilots, contains much first-hand information about flying in jet streams which should be of interest to all who forecast for jet aircraft.

Sqd.-Ldr Press would have ready access to advice on meteorological problems, for Mrs. Press (formerly Miss Catherine Fielding) was for some years a forecaster. She joined the W.A.A.F. (Meteorological Section) in 1942, was later commissioned and promoted Section Officer in 1944. After demobilization she became successively an Assistant Experimental Officer and Experimental Officer. She resigned in 1952.

Sport.—Mrs. J. M. Sugden gained second place in the Civil Service Ladies' high jump championship at Chiswick on Saturday, July 18, 1953.

WEATHER OF JULY 1953

Mean pressure was below normal (2 to 6 mb.) over Scandinavia and westwards to Iceland and Greenland. It was a little above normal (1 to 3 mb.) over south and west Europe and westwards to the Azores and over much of the United States. The lowest mean pressure, about 1006 mb., extended over the region between Scandinavia and Iceland; the highest mean pressure was 1028 mb. over the Azores.

Mean temperature was generally above normal over most of Europe, about 2°F. on the average. It varied from 60°F. in Scandinavia to 65–70°F. in central Europe and 75–80°F. in the Mediterranean region.

In the British Isles the weather after the first few days was unsettled and rather cool. Thunderstorms occurred on no fewer than 16 days and were widespread on the 9th, 16th–18th and 27th. There were some heavy falls of rain and rainfall was considerably above the average for the month in all areas except north-east England. Eskdalemuir with 9·60 in. had its highest July total since records began in 1910. More than the average sunshine was recorded in the west and south-west but most of Scotland and eastern England had a deficit.

During the opening days a ridge of high pressure moved very slowly south-eastwards across the country. Apart from considerable cloud in eastern districts and some local rain or drizzle in south-east England and northern Scotland up to the 4th, it was mainly fine and sunny. Temperature reached 80°F. locally in England on the 1st, 2nd and 5th and daily sunshine totals exceeding 14 hr. were recorded at places in the western half of the country. There was fog locally inland at night and early morning, and it occurred also in coastal areas, persisting after noon in places on the north-east coast on the 2nd. By the 5th the ridge had moved to England where it maintained warm sunny weather, but troughs of low pressure brought cloud and rain from the Atlantic to Scotland and Northern Ireland. These conditions reached Wales in the evening and spread over England during the night, rain being heavy locally in the west (2·05 in. at Blaenau Festiniog, Merionethshire on the 5th). A period of cloudy weather with occasional rain ensued with fog banks in the English Channel and on the south-west coasts on the 6th and 7th. From the 8th to the 10th a cool unstable west to north-west air stream gave showers and bright periods in most districts with widespread thunderstorms in east and south-east England on the 9th. The showers became more scattered on the 10th as a weakening ridge of high pressure moved across the country. For the remainder of the month the weather was dominated by four large slow-moving depressions whose centres passed north-eastwards over or near Ireland and Scotland, giving an unsettled south-west to westerly type of weather and frequent rain or showers. On the 11th rainfall was considerable in the west and south (2·02 in. at Compton, Sussex and 3·16 in. at Maesteg, Glamorgan on the 11th, and 2·20 in. at Shanklin in 24 hr. on the 11th and 12th). There were also heavy falls on the 12th to 14th in the Midlands and north of England and in Scotland, and flood damage was reported at a number of places (2·45 in. at Naseby Reservoir, Northamptonshire and 2·52 in. at Warrington, Lancashire on the 12th and 2·45 in. at Ballindalloch, Banffshire on the 13th). Widespread thunderstorms occurred on the 16th to 18th and were reported to have seriously affected crops in the west Midlands and central Scotland while there was local damage due both to lightning and flooding and some loss of life. In a severe storm in London on the 18th 0·63 in. of rain fell in 15 min. at Kensington Palace. During this period temperature in most areas was somewhat below the average and the sunniest places were in the south. During the 19th and 20th temperature rose appreciably, and although the unsettled weather continued with heavy rain at times in the west and north (2·76 in. at Blaenau Festiniog, Glamorgan, on the 20th and 2·33 in. at Thirlmere, Cumberland, on the 24th), there were some warm sunny days in the south-east on the 20th and 21st and on the 24th and 25th, temperature reaching 80°F. locally on the 25th. From the 26th to the 28th an unstable south-west to westerly air stream gave a renewal of cool showery weather, and on the 27th widespread thunderstorms occurred causing damage in many areas, particularly to crops in the eastern half of England and the Midlands. On the 29th a weak trough moved over the central districts of England giving duller weather and some rain, and on the 31st a shallow depression moved across southern England causing periods of continuous rain. Elsewhere the cool showery weather with bright intervals continued to the end of the month.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	84	37	−1·1	135	+5	104
Scotland	84	36	−0·6	147	+7	76
Northern Ireland ...	75	45	−0·9	146	+5	97

RAINFALL OF JULY 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	4·09	172	*Glam.*	Cardiff, Penylan ...	4·76	155
Kent	Dover	2·73	129	*Pemb.*	Tenby	5·40	183
„	Edenbridge, Falconhurst	3·41	148	*Radnor*	Tyrmynydd	5·56	135
Sussex	Compton, Compton Ho.	5·25	186	*Mont.*	Lake Vyrnwy	8·09	227
„	Worthing, Beach Ho. Pk.	2·47	121	*Mer.*	Blaenau Festiniog ...	15·32	180
Hants.	Ventnor Park	2·56	124	„	Aberdovey	3·86	110
„	Southampton (East Pk.)	4·38	192	*Carn.*	Llandudno	1·39	62
„	South Farnborough ...	2·81	138	*Angl.*	Llanerchymedd ...	2·99	105
Herts.	Royston, Therfield Rec.	3·10	123	*I. Man*	Douglas, Borough Cem.	5·03	164
Bucks.	Slough, Upton	3·14	164	*Wigtown*	Newton Stewart ...	5·44	173
Oxford	Oxford, Radcliffe ...	3·23	136	*Dumf.*	Dumfries, Crichton R.I.	5·94	182
N'hants.	Wellingboro' Swanspool	2·72	119	„	Eskdalemuir Obsy. ...	9·56	233
Essex	Shoeburyness	2·53	138	*Roxb.*	Crailing...	3·30	114
„	Dovercourt	2·92	146	*Peebles*	Stobo Castle	4·66	161
Suffolk	Lowestoft Sec. School ...	2·51	111	*Berwick*	Marchmont House ...	3·40	111
„	Bury St. Ed., Westley H.	3·72	149	*E. Loth.*	North Berwick Res. ...	4·12	160
Norfolk	Sandringham Ho. Gdns.	2·50	100	*Midl'n.*	Edinburgh, Blackf'd. H.	4·60	163
Wilts.	Aldbourne	2·96	124	*Lanark*	Hamilton W. W., T'nhill	3·79	132
Dorset	Creech Grange... ...	3·94	161	*Ayr*	Colmonell, Knockdolian	4·91	156
„	Beaminster, East St. ...	4·02	155	„	Glen Afton, Ayr San. ...	5·51	131
Devon	Teignmouth, Den Gdns.	2·12	91	*Renfrew.*	Greenock, Prospect Hill	6·70	181
„	Cullompton	..	..	*Bute*	Rothesay, Ardencraig ...	5·90	149
„	Ilfracombe	5·99	236	*Argyll*	Morven (Drimnin) ...	6·67	151
„	Okehampton	3·90	120	„	Poltalloch	5·58	135
Cornwall	Bude, School House ...	4·47	182	„	Inveraray Castle ...	8·33	177
„	Penzance, Morrab Gdns.	5·23	192	„	Islay, Eallabus	5·45	160
„	St. Austell	4·28	128	„	Tiree	4·52	125
„	Scilly, Tresco Abbey ...	4·57	206	*Kinross*	Loch Leven Sluice ...	4·45	155
Glos.	Cirencester	3·24	126	*Fife*	Leuchars Airfield ...	2·58	99
Salop	Church Stretton ...	2·95	112	*Perth*	Loch Dhu	7·13	148
„	Shrewsbury, Monkmore	2·58	123	„	Crieff, Strathearn Hyd.	3·81	128
Worcs.	Malvern, Free Library...	3·31	145	„	Pitlochry, Fincastle ...	2·93	109
Warwick	Birmingham, Edgbaston	3·57	154	*Angus*	Montrose, Sunnyside ...	3·25	124
Leics.	Thornton Reservoir ...	2·38	96	*Aberd.*	Braemar	3·35	130
Lincs.	Boston, Skirbeck ...	1·40	64	„	Dyce, Craibstone ...	4·53	150
„	Skegness, Marine Gdns.	1·92	88	„	New Deer School House	3·76	123
Notts.	Mansfield, Carr Bank ...	..	..	*Moray*	Gordon Castle	3·97	124
Derby	Buxton, Terrace Slopes	5·51	140	*Nairn*	Nairn, Achareidh ...	4·05	159
Ches.	Bidston Observatory ...	2·42	93	*Inverness*	Loch Ness, Garthbeg ...	4·47	141
„	Manchester, Ringway...	4·24	153	„	Glenquoich	8·88	138
Lancs.	Stonyhurst College ...	7·61	197	„	Fort William, Teviot ...	6·89	141
„	Squires Gate	3·53	127	„	Skye, Broadford ...	6·71	121
Yorks.	Wakefield, Clarence Pk.	2·73	108	„	Skye, Duntuilm ...	5·27	141
„	Hull, Pearson Park ...	2·20	94	*R. & C.*	Tain, Mayfield... ...	3·07	102
„	Felixkirk, Mt. St. John...	3·47	127	„	Inverbroom, Glackour...	5·12	138
„	York Museum	1·74	69	„	Achnashellach	7·97	164
„	Scarborough	1·82	75	*Suth.*	Lochinver, Bank Ho. ...	5·48	181
„	Middlesbrough... ...	2·73	107	*Caith.*	Wick Airfield	4·12	157
„	Baldersdale, Hury Res.	3·16	108	*Shetland*	Lerwick Observatory ...	5·00	218
Norl'd.	Newcastle, Leazes Pk....	3·13	122	*Ferm.*	Crom Castle	4·09	118
„	Bellingham, High Green	4·09	124	*Armagh*	Armagh Observatory ...	4·14	143
„	Lilburn Tower Gdns. ...	2·72	110	*Down*	Seaforde	4·18	131
Cumb.	Geltsdale	5·34	165	*Antrim*	Aldergrove Airfield ...	4·68	167
„	Keswick, High Hill ...	6·49	169	„	Ballymena, Harryville...	4·18	122
„	Ravenglass, The Grove	5·23	139	*L'derry*	Garvagh, Moneydig ...	5·15	159
Mon.	A'gavenny, Plâs Derwen	4·31	158	„	Londonderry, Creggan	5·47	149
Glam.	Ystalyfera, Wern House	8·55	186	*Tyrone*	Omagh, Edenfel ...	6·07	179

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

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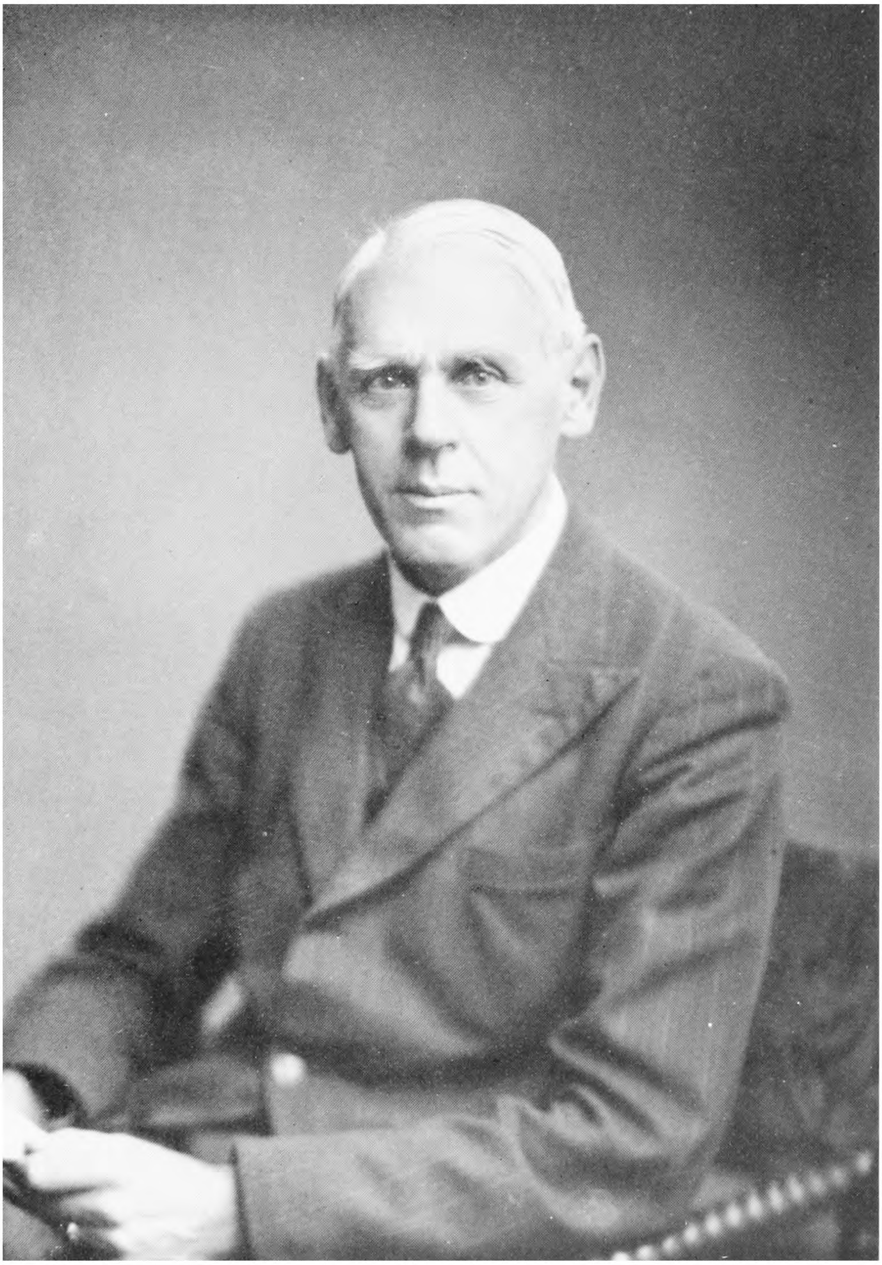

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SIR NELSON K. JOHNSON, K.C.B., D.Sc., A.R.C.S.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 976, OCTOBER 1953

DIRECTOR OF THE METEOROLOGICAL OFFICE

The retirement of Sir Nelson Johnson on September 1, 1953, closed another chapter in the history of the Meteorological Office.

Sir Nelson will always be known nationally as the Director who guided the work of the Office through the Second World War and the period of reconstruction which followed, and as the prime mover in the foundation of the Meteorological Research Committee. Internationally, he will always be remembered as the last President of the International Meteorological Organization and the first President of the World Meteorological Organization.

Sir Nelson graduated with honours in physics from the Royal College of Science in 1913. He was subsequently engaged in astrophysical work at the College and at the Norman Lockyer Observatory, Sidmouth. During the First World War, 1914–18, he served as a pilot in the Royal Flying Corps.

He joined the Meteorological Office in 1919, and after serving at Shoeburyness was given, in 1921, the task of forming the new meteorological section at the War Office Chemical Defence Research Establishment at Porton. The investigation then instituted at Porton of the meteorology of the lower layers of the atmosphere gave full scope to his ability in experimental research and led to important advances in the knowledge of atmospheric diffusion. Sir Nelson devoted himself especially to the study of the vertical gradient of temperature; new methods using electrical resistance thermometers were devised for measuring the gradient and his work in this field, published in *Geophysical Memoirs* Nos. 46 and 77, has become classic. Other papers by him, or in which he collaborated, during this period dealt with the measurement of the lapse rate of temperature by an optical method, measurements of temperature near the surface in various kinds of soils, the vertical gradient of wind velocity in the lowest layers of the atmosphere, and atmospheric oscillations shown by the microbarograph. He left the Meteorological Office in 1928 for service under the War Office, first as Director of Experiments at Porton and later as the Chief Superintendent of the Chemical Research Department.

In September 1938 he returned to the Meteorological Office as Director in succession to Sir George Simpson. Almost immediately he was confronted by the precautionary measures necessitated by the Munich crisis.

The Second World War, 1939–45, brought many new problems and requirements, which increased as the scope and character of military operations changed, with a corresponding increase in the Director's responsibilities. The staff of the Office, including the R.A.F.V.R. Meteorological Branch, increased during the war from about 800 to over 6,000. New methods of observation and analysis were developed. Networks of stations were established for making upper air soundings and "sferics" observations and meteorological reconnaissance flights were introduced. Close contact was maintained with, and much assistance given to, Allied Meteorological Services. All these activities made great demands on the Director, who was rarely away from his office in London except for brief intervals, in those unquiet years. Visits were paid early in the war to the British Expeditionary Force in France, and in 1944 to Allied Commands in the Middle East, India and Ceylon.

Sir Nelson has been greatly concerned to secure provision for research within the Office. Preliminary plans made in 1938–39 were inevitably delayed by the events of the next few years, but in 1941 the Air Ministry Meteorological Research Committee was set up by the Secretary of State for Air. In the major re-organization of the Office in 1947–48 Divisions and Branches were established to carry out a comprehensive programme of research. Since then provision has also been made for dealing with the meteorological aspects of agricultural and hydrological problems. In the post-war years Sir Nelson maintained developments in the methods and use of upper air observations and he encouraged and assisted the expansion of these observations in Commonwealth countries. He reviewed and developed the practice, initiated by Sir Napier Shaw, of monthly gatherings of the staff for the purpose of discussing research carried out in this and other countries. He was intimately associated with the introduction of the ocean-weather-ship scheme in 1947.

In 1946 at the first post-war International Conference he was elected President of the International Meteorological Committee. In that capacity he presided over the Washington Conference in 1947, which established the Convention of the World Meteorological Organization. In 1951 he became, for the period of its opening Congress, President of the new Organization.

Great progress in the organization of British and international meteorology has been made under Sir Nelson's guidance and his services were recognized by his appointment as K.C.B. in 1943.

All who have served under him will wish him good health for many years in which to pursue his varied interests, in which carpentry and the collection and renovation of antique clocks, play, we believe, a large part.

At a crowded ceremony in Victory House on August 28, Mr. J. Durward presented Sir Nelson, on behalf of the staff of the Office, with a cheque for a television set. In conveying to Sir Nelson the good wishes of the staff, Mr. Durward referred to the highlights of Sir Nelson's career and mentioned in particular the skill with which Sir Nelson had conducted meteorological affairs in the international, national and domestic field, his achievement in putting meteorological research within the Office on a sound basis and his consideration for the staff.

The remarks of Mr. Durward were supplemented by Mr. E. Gold who, before his retirement in 1947, had been Sir Nelson's deputy. Mr. Gold gave some touching recollections of his service with Sir Nelson, and mentioned the happy combination of scientific comprehension and administrative ability which Sir Nelson had displayed, and he quoted instances of Sir Nelson's flair for taking the right course with clear reasons for so doing. Both Mr. Gold and Mr. Durward voiced the wishes of the staff of the Office in expressing the hope that Sir Nelson would be able to catch up with the leisure which had been denied him for so many years.

After valedictory messages from staff overseas had been read out, Sir Nelson expressed his gratitude to those who had joined in the presentation and paid tribute to the loyal support which he had received from the staff. He referred especially to the cordial relations between the Meteorological Office and other Government Departments and stressed his appreciation of the friendly co-operation which he had received from colleagues both in the academic world and in other meteorological services.

COLD POOLS: A STATISTICAL AND SYNOPTIC STUDY

By E. J. SUMNER, B.A.

The cold pool is one of the more common synoptic models which have come to be recognized since the introduction of upper air charts into forecasting practice. There is already a considerable amount of literature on the subject, most of it however being concerned with studies of the life history and detailed structure of individual pools. Little work of a statistical and synoptic nature appears to have been done, at least in recent years (before which the observational coverage was scarcely adequate), and the present study was undertaken in order to fill in some of the gaps.

A cold pool may be defined as a mass of cold air in depth entirely surrounded by relatively warm air, and appears as one or more closed lines in the thickness isopleths for any fairly deep atmospheric layer. The area within the outermost of these closed lines may for present convenience be identified with the cold pool. A similar definition to the above was given by Douglas[1]. Various related terms are in use in the literature; these include cold domes, cold poles, cold drops (Kaltluftropfen), cold lows, cold highs and cold "cut-offs". A cold pool, in the sense used here, may occur with any of these phenomena.

Data and measurements.—The charts used in this study were the 0300 and 1500 G.M.T. circumpolar 1000–500-mb. thickness maps, prepared daily in the Forecasting Research Division of the Meteorological Office. The data are for the 5-yr. period from September 1946 to August 1951, and for the area between longitude 60°W. to 30°E. and south of latitude 80°N. These limits were chosen so as to exclude the semi-permanent winter cold pools over the Asian and American continents, and to confine the investigation to those features which might be of direct concern to the British Isles and its environs.

Thickness lines on the circumpolar charts are drawn at intervals of 200 ft. (the even hundreds). Only well defined and fairly persistent pools were considered, the minimum requirements being that there should be two or more closed thickness lines surrounding the pool which should appear on at least two successive 0300 G.M.T. charts, the closed lines lying entirely within the area delineated above. However, within a particular spell one-day interruptions during which the pool was represented by a single closed line at 0300 were included (5 cases in all), thus allowing for a period of temporary waning.

The central position of each pool was recorded to the nearest degree of latitude and longitude, and also the interpolated value of the 1000–500-mb.

thickness at the centre to the nearest 50 ft. The "centre" was taken as the approximate centre of gravity of the area of the pool (no matter how irregular in shape) and was estimated by eye. The intensity of the pool was also recorded on the scale: one closed thickness line, intensity one; two closed lines, intensity two; . . . and so on.

Some general statistics.—Within the 5-yr. period under consideration the total number of spells was 75, ranging from 2 to 10 days' duration, the average being almost exactly 3 days*. The total number of individual pools involved (i.e. occurrences on 0300 charts) was 224. There were 171 pools of intensity two, 41 of intensity three, 5 of intensity four and 2 of intensity five; all those of intensity greater than three were north of 65°N. There was no relationship between the initial intensity and the subsequent duration of a spell, although there was a small positive correlation between the duration and the average intensity within a spell.

With respect to the geographical and seasonal distribution of cold pools the greatest concentration was over Europe in all seasons, but in spring and summer there were several other clusters, more notably over the Atlantic and in the area between north-east Greenland and north Scandinavia. There was an almost complete absence of pools of intensity two or more just west of the British Isles, around and to the east of Iceland, and over the western Atlantic south of 50°N. (summer and autumn only); though actually a very small number of pools of intensity two did occur in these areas but did not last beyond a day.

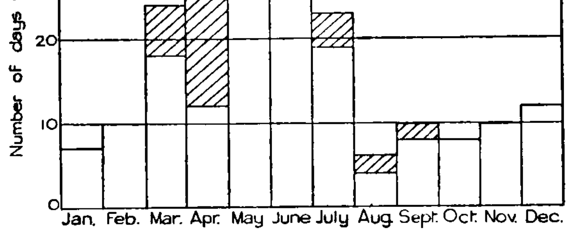

FIG. 1—FREQUENCY DISTRIBUTION OF INTENSE COLD POOLS
5-yr. period September 1946–August 1951

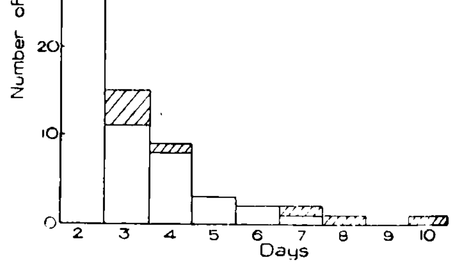

FIG. 2—FREQUENCY DISTRIBUTION OF SPELLS

These gaps possibly arise in part from the shelter provided by the (warm) American continent in summer and the Greenland ice-cap at all seasons. However, the preference of blocking (usually warm) highs for the north-eastern Atlantic in May and June, when the pools are most frequent (see Fig. 1), is also associated with the general paucity of pools in the Iceland region.

* A spell is said to be of *n* days' duration if the same cold pool, beginning and ending with intensity two or more but possibly with one-day interruptions of intensity one, appeared on *n* successive 0300 charts.

Most of the pools were fairly slow moving (usually less than 500 miles a day), and any rapid displacements were seldom continued beyond a day. In particular the pools in high latitudes showed no tendency to come southwards beyond 65°N.; these latter are presumably the cold "poles" of the northern hemisphere, and in what follows they were conveniently separated from the others and later left out of account.

Fig. 1 shows the frequency distribution of pools by months (5 Januaries, 5 Februaries, etc.), pools north and south of 65°N. being distinguished. Table I gives the number of spells by months. It is evident that, within the area considered, these intense cold pools are largely spring and early summer phenomena, an outstanding maximum occurring in May and June.

TABLE I—NUMBER OF SPELLS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
South of 65°N.	3	2	7	5	12	14	6	2	3	3	2	3	62
North of 65°N.	0	0	2	2	4	1	2	1	1	0	0	0	13

The frequency of spells in days is given in Fig. 2. A persistence of two days, the minimum required by our definition, is very much more likely than any longer spell. This applies to all seasons. The average spells north and south of 65°N. were 3·9 days and 2·8 days respectively. North of 65°N. there were 51 pools (13 spells) in all, the corresponding figures south of this parallel being 173 pools (62 spells).

Pools south of 65°N.—In the following pages only those pools south of 65°N. will be considered, partly for the reason given previously and also because the more detailed study of weather, cloud, etc., attempted here is not possible in higher latitudes owing to insufficiency of observations.

Mode of formation and disappearance.—The greatest number of pools starting a spell—49 out of 62—were formed as a result of a partial or complete cutting-off of the cold air near the southernmost extremity of a cold trough. The cold trough was usually fairly slow moving and of large amplitude at the time of cutting-off or was increasing in amplitude, the low-latitude part slowing down still further or stagnating while the high-latitude part moved on. A good example of this cut-off process is given in Figs. 3, 4 and 5. In this example there was marked anticyclonic building across the middle of the trough (blocking) with a cyclone maintained to the south in association with the developing pool. A certain amount of warm advection from the west round the top of the anticyclone completed the cutting-off*. There are, however, many variants of this basic model mainly depending on the degree of development of these surface features. In 8 of the 49 cases the depression predominated, and warm advection from the east round the northern flank of the low seemed to be responsible for cutting off the pool; on 19 occasions the low was vestigial and marked anticyclonic building and presumably subsidence across the neck of the trough appeared to be the main agency; in a further 8 cases both these effects seemed to be important. In 2 cases the cold pool actually formed "over" the surface high

* In connexion with blocking and the seasonal distribution of cold pools, the indirect agreement with the results of Brezowsky, Flohn and Hess[2] is striking. These authors found a pronounced maximum of blocking highs, with axes in the sector 20°W.–10°E., to occur in May and June (70 years' data).

but was then quickly transferred—almost "jumped"—south to come more in association with the low. The remaining 14 cases were due to a more subtle combination of advectional and dynamical thermal processes (including local cooling at the centre of the pool and warm-air advection from the west round a depression in high latitudes) operating in different parts of the field. It is not suggested that the above remarks adequately represent what goes on, or that such thermodynamical processes are primarily responsible for this type of development.

Of the remaining 13 pools, 6 moved into the area from outside, 5 of them into the western Atlantic from the north-west, one from the east into the Baltic, and 7 were formed in association with a surface low in rather higher latitudes than usual (55–60°N.), partly by a vague sort of cutting-off but with a certain amount of cooling *in situ* as an important contribution. However, these cold lows were not associated with a "blocking" of the westerlies, whereas the "cut-off" pools almost invariably were.

The greatest number of pools (33 out of the 62) disappeared, or were reduced in intensity and therefore no longer considered, by warming more or less *in situ*. In 9 further cases the pool moved so as to be absorbed into the colder air of higher latitudes, 2 were re-absorbed into the original cold trough by renewed advection from the north, and another 2 seemed to be re-absorbed in this way

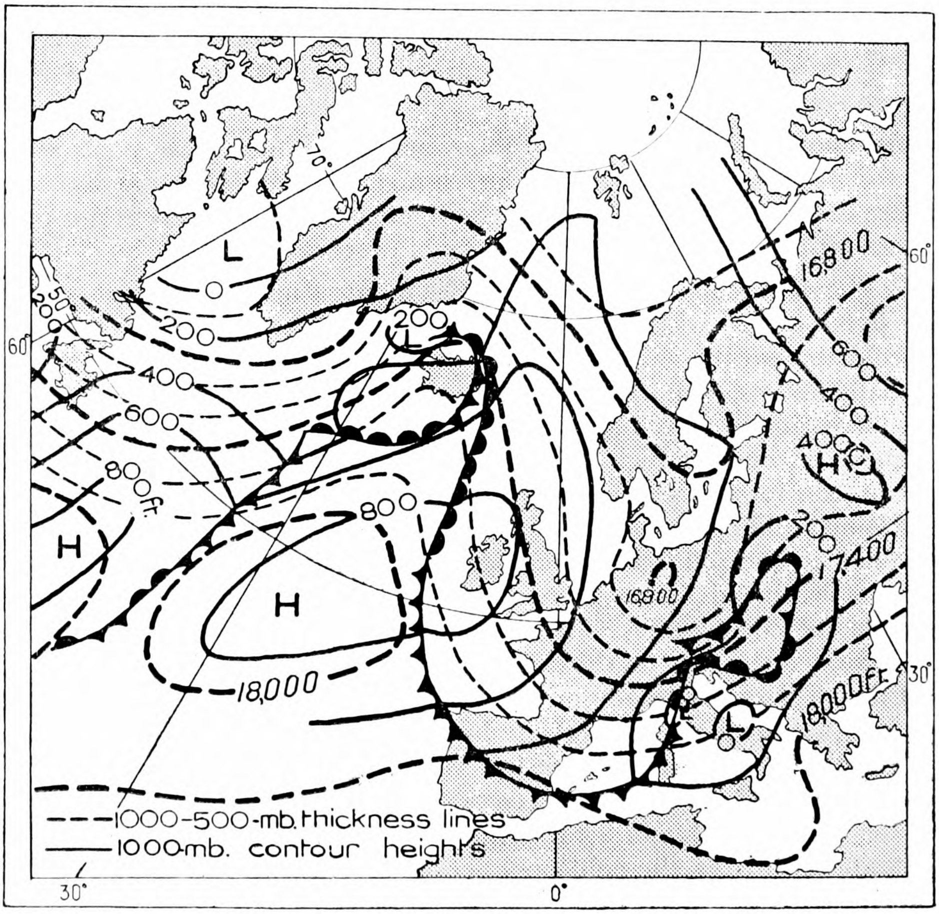

FIG. 3—1000-MB. CONTOUR PATTERN AND 1000–500-MB. THICKNESS LINES, 0300 G.M.T., MARCH 19, 1949

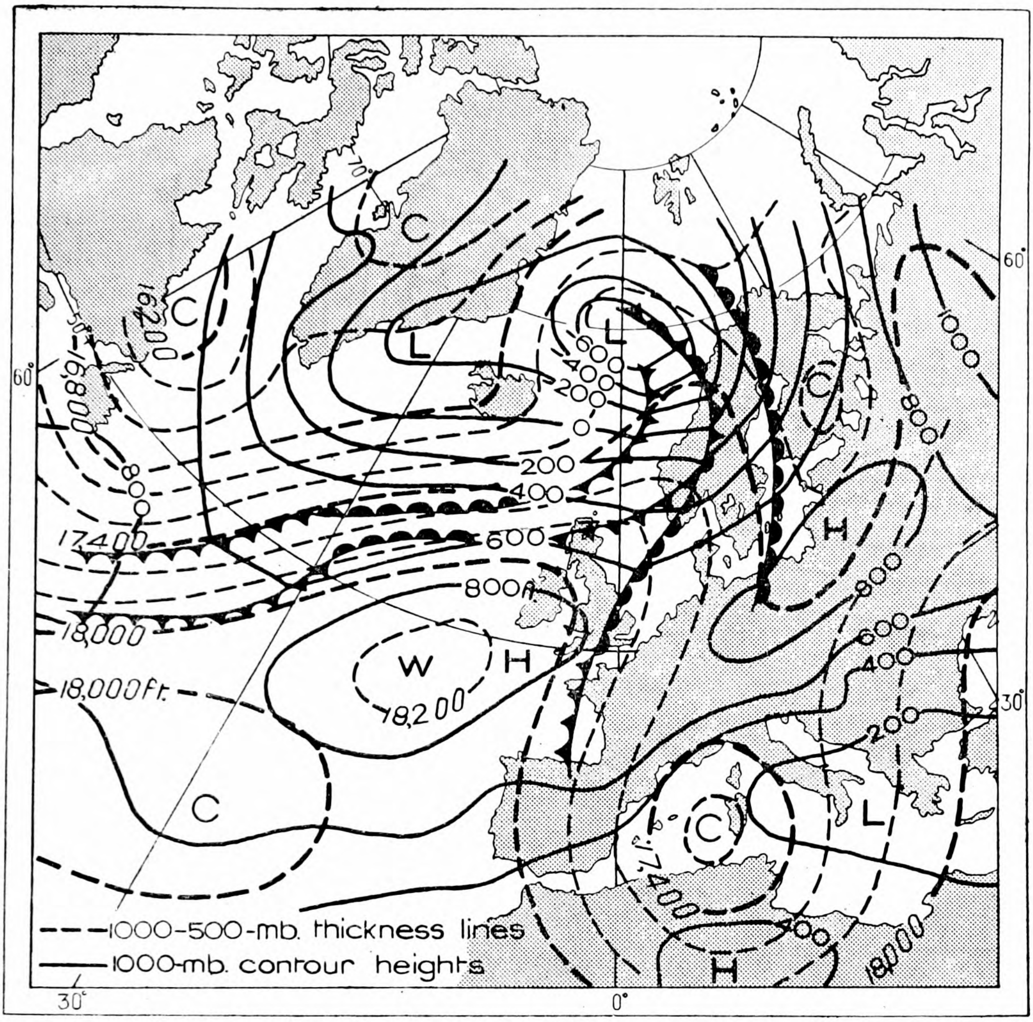

FIG. 4—1000-MB. CONTOUR PATTERN AND 1000–500-MB. THICKNESS LINES, 1500 G.M.T., MARCH 20, 1949

by local cooling to the north of the pool. The remaining 16 disappeared as a result of a combination of these factors, warming of the central core being one important agency in most of them. In all these classes about half the pools remained at intensity one for a further day or more before finally disappearing from the charts.

Surface-pressure systems associated with cold pools.—It is evident from experience that cold pools may be associated with practically any synoptically possible surface-pressure field. It is however convenient to classify associated surface patterns in terms of a few well known types as follows: a low (L), a trough (T), a high (H), a ridge (R), a slack area or col (C)*, and a fairly straight run of isobars more or less midway between a large high and a large low (S). Three of these types are usually called the cold low (L type), the cold high (H type) and the cold drop (S type) respectively, but the terms cold trough or cold ridge are not used in this context. The results of this classification on a seasonal and "land-sea" basis are shown in Table II.

* Actually only one instance of a col was recorded, the rest were cases of a very weak and irregular pressure field.

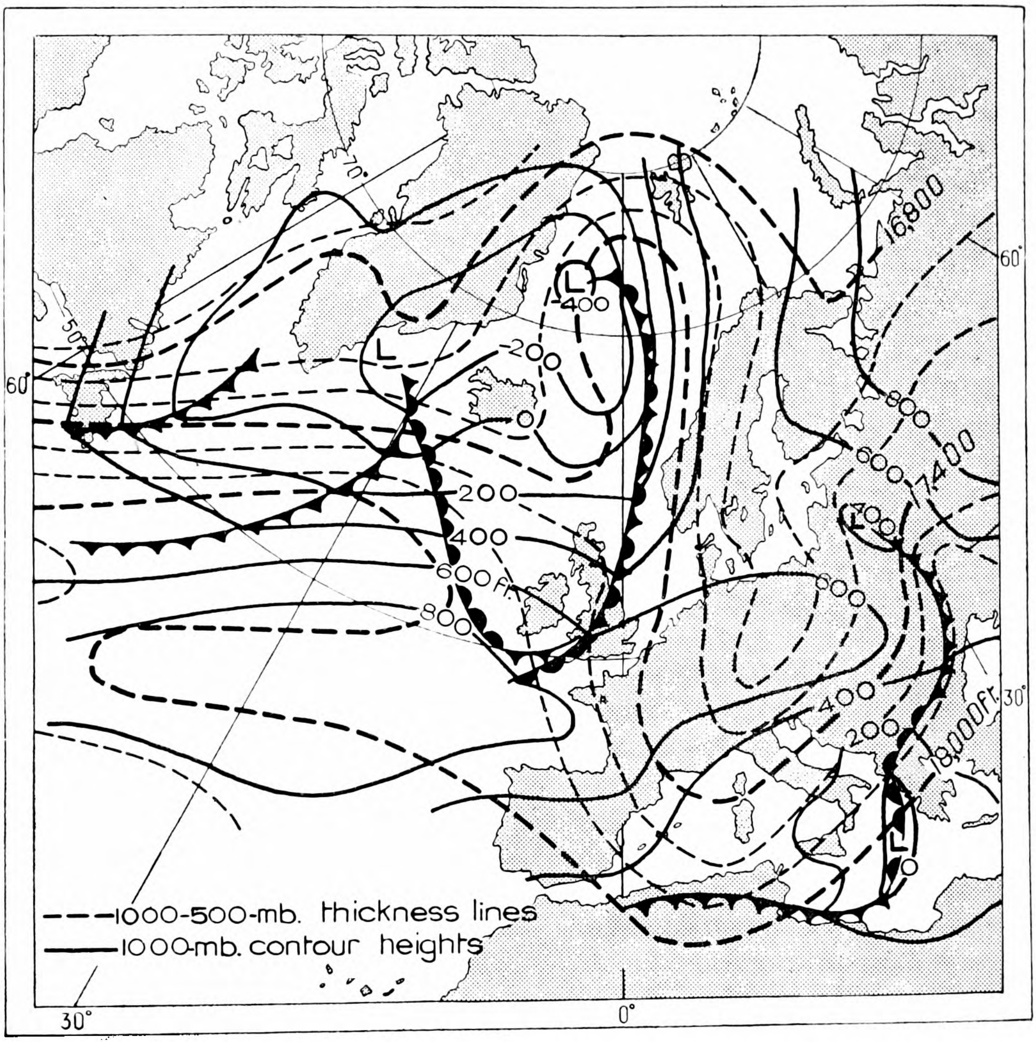

FIG. 5—1000-MB. CONTOUR PATTERN AND 1000–500-MB. THICKNESS LINES, 0300 G.M.T., MARCH 22, 1949

TABLE II—CLASSIFICATION OF SURFACE-PRESSURE PATTERNS ASSOCIATED WITH COLD POOLS

Associated surface-pressure system	Winter Dec.–Feb. Land	Sea	Spring Mar.–May Land	Sea	Summer June–Aug. Land	Sea	Winter Sept.–Nov. Land	Sea	Year Land	Sea	Both
L	9	2	7	23	4	18	7	1	27	44	71
T	0	2	3	4	7	6	1	1	11	13	24
H	1	1	0	0	1	0	3	2	5	3	8
R	3	0	1	0	5	0	3	1	12	1	13
C	4	2	3	2	5	4	2	1	14	10	24
S	5	2	11	4	3	6	2	0	21	12	33
Total	22	9	25	33	25	34	18	6	90	83	173

By far the greatest number of cold pools were associated with surface lows at all seasons, the second greatest being cold drops. Associated troughs and slack areas were next in almost equal proportions, ridges and anticyclones being in a minority. Lows and troughs were relatively more frequent over the sea, and all other types (highs and ridges especially) over land. Except in the case of highs and ridges, the seasonal distribution for each class was in keeping with Fig. 1, i.e. with a maximum in spring and summer. In winter and autumn cold pools are more frequent over the land than over the sea, and *vice versa* in spring and summer.

Within about half the spells, there was no great change of surface type from beginning to end. The remaining half showed day-to-day type changes, usually within the combinations L-T-S and R-H-C, respectively. Extreme changes from an associated high or ridge to a low or trough, or *vice versa*, were very infrequent. When they did occur pressure gradients were usually slack (borderline C type) with a high general level of pressure; in such circumstances comparatively small pressure changes would suffice to produce definite ridges and troughs (or even weak lows) on alternate days.

There was a definite tendency for the straight isobars of the S type to become more cyclonically curved with time, with a change to a T or even an L type; in fact, over the sea, there were no pure S types—all changed, mostly to L or T types.

Most of the associated lows were 300 miles or less from the cold pools, although few of them (especially over the land) were quite concentric with the pool. The average distance between the centre of the pool and that of the surface low was about 300 miles over the land and 220 miles over the sea. All lows more than 300 miles away were situated in the sector between south-east and north-east from the associated pools; the remainder were randomly distributed in direction with respect of the centre of the pool. The corresponding averages for the few cold anticyclones were 340 miles over the land and 700 miles over the sea.

The surface pressure was read off, to the nearest millibar, at the centre of each pool and at the centre of an associated high or low, if any. Corresponding pressure anomalies (departures from a 40-yr. normal) were also computed. The average pressure and pressure anomaly at the centre of the pool were 1013·3 mb. and −1·8 mb. respectively. The corresponding averages for the individual types (anomalies in brackets) were:—

L	1007·0 mb. (−8·0)	S	1017·5 mb. (+2·0)
T	1013·5 mb. (+0·5)	R	1021·0 mb. (+2·5)
C	1017·5 mb. (+1·5)	H	1028·5 mb. (+12·0)

For the cold lows the average pressure was 6·5 mb. less over the sea than over the land; in the remaining types there was little significant difference. The average pressure and pressure anomaly at the centre of the associated low were 1001·5 mb. and −13·0 mb. respectively; the average pressure was 5·0 mb. less on the sea than over the land. The corresponding figures for cold highs were 1034·5 mb. and +19·5 mb., average pressures being 3·0 mb. higher over the sea than the land.

It is evident from the above that cyclonic circulations tend to be more intense and (from Table II) relatively more frequent over the sea. A few cases are on record where a cold pool associated with more or less straight surface isobars or with a weak surface low, moved from the land to the relatively warm sea in winter. In each case there was a noticeable increase in the associated cyclonic circulation at the surface (with the formation of a low if one were not present originally), although with a pressure drop of only a few millibars in the general level of pressure.

For pools over the sea, the mean surface pressure at the centre of the pool was about 8 mb. less in spring and summer than in autumn and winter, and the pressure anomalies changed from positive in the latter to negative in the former seasons. Over the land there was no corresponding variation in the mean pressure anomalies. There was practically no latitudinal variation of mean surface-pressure anomaly at the centres of the pools, either over the land or over the sea. This was also the case for the mean surface-pressure anomaly at the centres of the associated lows; there were not enough data on cold highs to decide one way or the other.

The lowest central pressure of an associated low was 976 mb. and the highest 1022 mb., but nearly 90 per cent. of the cases were within 10 mb. of the average, namely 1001·5 mb. The corresponding extremes for associated highs were 1025 and 1040 mb. respectively (average 1034·5 mb.). A comparison with the 40-yr. statistics of the frequency of occurrence of all lows and highs in particular localities, revealed that the cold lows were usually shallow for the area in question whereas the cold highs were well up to their usual intensity.

Surface-pressure changes at the centres of the pools were usually small; the overwhelming majority were less than 10 mb. (rise or fall) a day, the average, irrespective of sign, being 4·5 mb./day (5·5 mb./day over the sea and 3·5 mb./day over the land). The greatest pressure rise found was 16 mb. in 24 hr. (with an associated surface low) and the greatest fall was 23 mb. (cold-drop type); both were over the sea. There was a definite tendency at all seasons, no matter what the associated pressure system, for the pressure at the centre of the pool to return to normal; this was however less marked for pools over the sea.

The pressure changes at the centre of an associated low or high were even smaller, most of them being less than or equal to 5 mb./day. The greatest 24-hr. rise was 11 mb. (over the land) and the greatest fall, 9 mb. (over the sea); both were in a low. The average changes irrespective of sign were 4·5 mb./day, whether over land or sea. There was no noticeable tendency for these central pressures to return to normal. However for depressions, whatever the initial anomaly, the chances were slightly in favour of a rise rather than a fall of central pressure, although day-to-day changes were very erratic both in sign and magnitude.

Weather associated with cold pools.—The amount of cloud and the type of precipitation within the area of the cold pool (not that associated with the surface-pressure system) were recorded for 0300 and 1500 G.M.T.* The cloud amount was classified as b if the weather were predominantly fine ($<\frac{1}{4}$ cover of cloud) over the entire area, bc if it were partly cloudy (between $\frac{1}{4}$ and $\frac{3}{4}$ cover), c if it were mainly cloudy ($>\frac{3}{4}$ cover) and o for completely overcast. A note was also made of the type of precipitation (rain, hail, snow or sleet), if any, and whether it was reported predominantly as showers, intermittent or continuous precipitation, and its intensity (light, moderate or heavy). The occurrence of thunderstorms was also noted.

More than half the pools were classified as cloudy, about a quarter as partly cloudy, while there were relatively few cases of overcast or fine (each just under

* Since the coverage of "surface" observations is usually better at the main synoptic hours, the weather at 0300 was based on a general impression of the 0000, 0300 and 0600 G.M.T. charts; and that at 1500 on the 1200, 1500 and 1800 G.M.T. charts.

10 per cent. of the total). Pools of the L type usually had the largest cloud amounts, and the S and C types the smallest. There was a definite diurnal variation of cloudiness in pools situated over the land, the proportion of occasions classified as o and c increasing from 55 per cent. at 0300 to 70 per cent. at 1500 G.M.T. However, within this general trend from lower to higher cloudiness there was an appreciable counter-drift, since about 15 per cent. (of the total) changed from o or c at 0300 to bc or b by 1500 G.M.T. This diurnal rhythm was present irrespective of the type of associated surface-pressure system. There was, on the other hand, no discernible diurnal variation in the cloud over the sea, but this is more uncertain owing to the scantier observation coverage.

On the whole there were slightly more cases with than without precipitation of some sort. Within the above cloud groupings the proportion with precipitation increased from nil with fine conditions to 100 per cent. with completely overcast, the figures for partly cloudy and cloudy being about 45 and 55 per cent. respectively. The L type had the highest proportion with precipitation (nearly 70 per cent.), the S and C types the lowest (about 40 per cent.). The H and R types showed a surprisingly high proportion with precipitation. This was however invariably slight snow or sleet in the case of highs; but with ridges in association all forms and intensities of precipitation occurred, including one case of widespread moderate rain and another with thunderstorms. General precipitation over the entire area of the pool was recorded on about 20 per cent. of the total occasions, 30 per cent. had only local precipitation and the remainder none at all.

Of the 62 spells, 6 were predominantly dry throughout with variable cloud (average duration 2·1 days), 13 were predominantly cloudy or overcast with fairly general precipitation most days (average duration 3·2 days; this figure is heavily weighted however by 1 eight-day spell), the remainder (average duration 3·0 days) being mainly fair to cloudy with intermittent and/or local precipitation, often infrequent.

Only 6 cases of thunderstorms were noted; on the other hand there were very many more occasions of "sferics" reported within the area of the pool, mostly occurring in the warmer months over Europe. These showed a definite diurnal variation with the greater frequency in the afternoon. The positioning error in "sferic" observations is, however, such that they might often have referred to thunderstorms in the peripheral regions of the pools. Although it is possible that some storms escaped observation, their reported infrequency within cold pools is probably real. The paucity of thunderstorms in the central regions of cold lows has been remarked on by E. A. Amman[3].

There was a fairly clear-cut division in the value of the central thickness of the pool as between rain and snow. For showery precipitation, all cases of snow had a central thickness of 17,150 ft. or below, and all cases of rain had a value above 16,900 ft. For precipitation other than showers (including intermittent as well as continuous precipitation) there was a fairly distinct separation at 17,200 ft.; there were no instances of rain below this value and only 3 cases of snow (out of 47) with a higher value, none of them occurring with a thickness above 17,350 ft. There were only 6 cases of sleet (2 showers, 4 otherwise) and these had a central thickness between 16,950 and 17,200 ft. The intensity of the precipitation did not affect these criteria perceptibly.

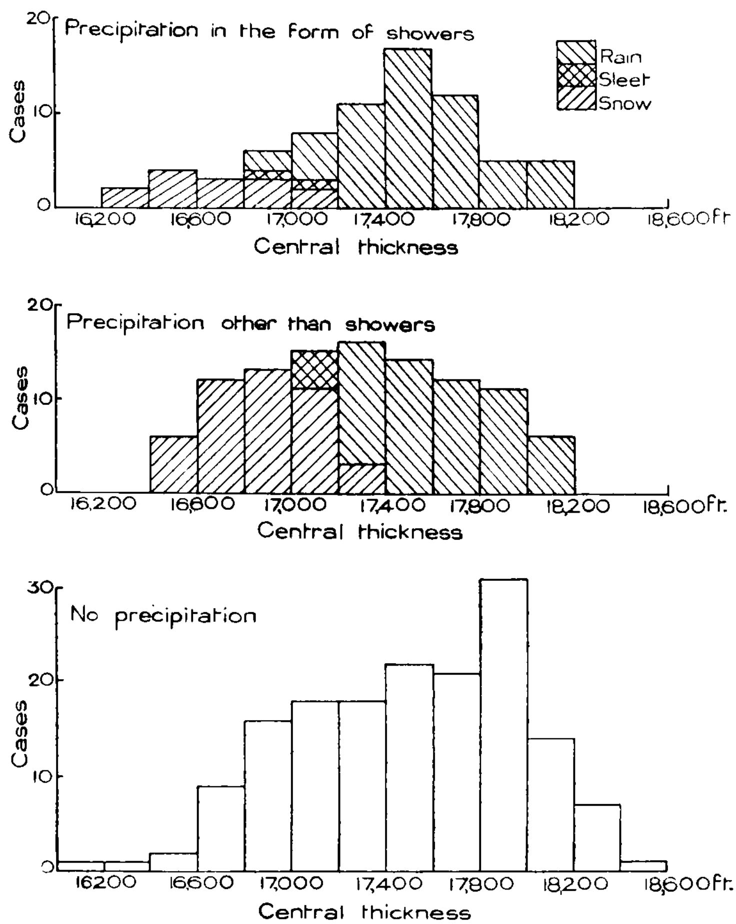

FIG. 6—FREQUENCY DISTRIBUTION OF 1000–500-MB. THICKNESS AT THE CENTRES OF COLD POOLS

Fig. 6 shows the frequency distribution of central thickness, rain, snow and sleet being distinguished. Both the 0300 and 1500 G.M.T. observations are taken into account in these diagrams, and in the values given in the above paragraph; the implication is that if the thickness changed across any of the above limits between these times, the nature of the precipitation would also change.

1000–500-mb. thickness values at the centres of cold pools.—The average central thickness showed a marked seasonal variation with a maximum in summer, and, except for summer, was significantly less over the land than the sea; all these differences are in the sense one would expect. The land-sea difference also showed up in most of the different types of cold pool.

The average thickness anomaly (departure from the 5-yr. mean) for all cases was −540 ft., −480 ft. for pools over the sea and −590 ft. for those over the land; the numerical value of the anomaly was on the whole smallest in the summer. The greatest and least anomalies for all the data were −1,150 ft. and −150 ft. respectively, but such extreme values were very infrequent; every pool had a central thickness below the 5-yr. mean for the time and place, and for as long as it maintained the requisite intensity. There was no relationship between the initial anomaly and the subsequent duration of a spell. Nor was there any between 24-hr. thickness and surface-pressure changes at the centres of the pools.

There was a marked and smooth latitudinal variation of mean thickness anomaly. The data were segregated in 5° latitude bands from 30° to 65°N., and the greatest departure from normal (−660 ft.) occurred in middle latitudes (46–50°N.) falling fairly uniformly to minima on either side (anomaly about −375 ft. in both cases). This sort of distribution was in evidence both over land and sea.

In general, anomalies less than about −450 ft. were followed by rising central thickness and the (numerically) smaller anomalies by falling thickness. Since the changes which occur at the centre of the pool are being followed, thermal advection may be neglected, and the implication is that warming from below and dynamical and radiational processes (presumably a net cooling) tend to balance out about this value of the thickness anomaly. This rough "point of balance" seemed to be independent of the presence of cloud or precipitation, or whether the pools were situated over the land or the sea.

There was a definite diurnal variation of central thickness with the higher values in the afternoon, both over land and sea, the average amplitude being about +75 ft. and +60 ft. a day respectively. These values were based on the average difference of 1000–500-mb. thickness between the 1500 and 0300 values, with the mean "trend" (amounting to about +40 ft./day over the land, and +35 ft./day over the sea) eliminated. The diurnal variation in the winter months was only 50 ft. over land, but 100 ft. over the sea; however there were only 9 cases of the latter, and the increase as compared with the corresponding figure for all the data is scarcely significant. A selection of pools with broken cloud (b or bc) at one or both of the 0300 and 1500 observations and with no precipitation at either, showed very similar values for the diurnal variation as for all the data. From an inspection of the data there was no reason to suppose that any other selection would give very different results.

It may be assumed that the diurnal variation is mainly due to the interaction between the two factors: (*a*) the net long-wave radiational heat loss from the cloud and the air itself, going on night and day without much change; and (*b*) eddy fluxes of heat into the column and the absorption of short-wave radiation by water vapour and clouds, both associated with insolation and therefore have a diurnal variation with a maximum in the afternoon (this would be most marked in the warmer months when most of the cases occurred). With this oversimplified picture, then on the assumption that (*b*) operates for half the day (or more) and that the above values represent the total range, the radiational loss from the 1000–500-mb. layer, factor (*a*), works out as roughly 2°C./day (or less) over land, and somewhat lower over the sea. This is in keeping with other estimates currently accepted.

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RECURRENCE TENDENCIES IN KEW SURFACE PRESSURE

By R. P. WALDO LEWIS, M.Sc. and D. H. McINTOSH, M.A., B.Sc.

Introduction.—It has been variously suggested that the time interval separating peaks (or troughs) in a series of daily pressure values for European locations is not entirely random, but that specified intervals appear more frequently than can be accounted for by chance. Thus, for instance, pressure "waves" of period 72 days and its submultiples have been recognized and associated with the "singularities" studied mainly by German meteorologists. Recently Essenwanger[1] has found, in winter months only, a significant "wave" of period about 30 days, with maximum amplitude in the North Sea. These pressure "waves" have generally been found by the methods of harmonic analysis and autocorrelation. Here the problem is examined, in so far as it affects Kew, in another way.

Method.—The method is an adaptation of that used by Chree and Stagg[2] to demonstrate the occurrence of what may, by analogy, be termed geomagnetic disturbance "waves" of period length 27 days, corresponding to the period of rotation of the sun. Two days of clearly defined midday pressure maximum at Kew were selected in each month in the period 1926–50. Independence was secured by ensuring that no two maxima in the whole pressure series were nearer than 7 days. The mean values of midday pressure were then determined on a large number of days round the 600 selected pressure-peak days. Mean midday pressure values were also determined round 600 pressure-trough days selected in a similar way. These mean values were calculated at intervals of 3 days, from days −6 to +6 (referred to the selected "0" day) then at day intervals to day +38; also at day intervals from +46 to +50, and from +70 to +74. Those intervals to which "wave" significance had mainly been attributed were thus included.

Results.—The variations of average pressure, referred to the two types of selected day, are shown in the accompanying graph in which the standard

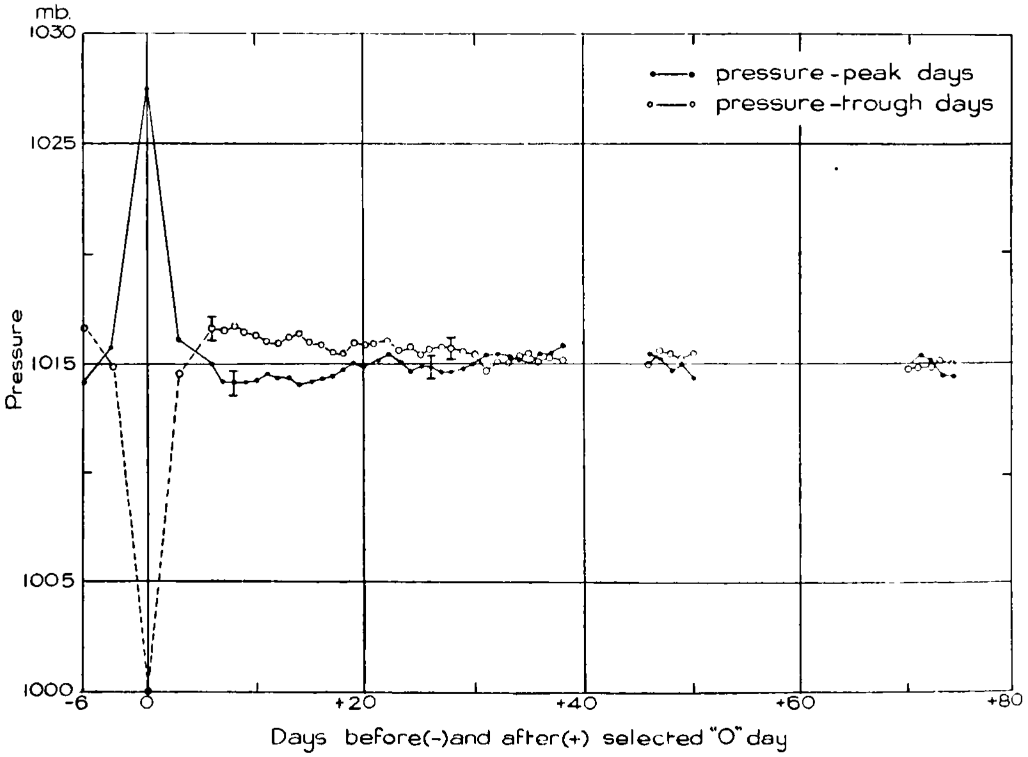

FIG. I—MEAN VARIATION OF KEW MIDDAY SURFACE PRESSURE AROUND 600 PRESSURE-PEAK DAYS AND 600 PRESSURE-TROUGH DAYS, 1926–50 errors of the means are indicated by vertical lines at intervals. The method of investigation implies that the levels of pressure following the chosen maximum and minimum days are, for a period after the "coherent" interval of about 5 days, respectively below and above the long-period average. Inspection of the graph indicates that this "compensation" effect is complete by about day +30. In the assessment of the results in terms of possible pressure "waves" allowance must be made for this effect of a slow recovery to the long-period mean. This allowance is made in Table I by expressing the means on those days up to +30 as departures from appropriate running mean values; for days +31 and upwards the departures from a value approximating closely to the long-period mean are considered.

Table I shows, in numerical form, the results subdivided according to the occurrence of the selected days in "winter" (October–March) and "summer" (April–September). The pressure means are here expressed (i) on days +12 to +30, as departures from the corresponding running mean value of 11 consecutive days, e.g. the value for day +12 is the departure from the mean value of the 11 days +7 to +17; and (ii) on day +31 and upwards, as departures from the seasonal mean value of all such days. The standard error of the means forming the departures is given for ready consideration of the significance of the results. The figures are given only for alternate days.

TABLE I—DEPARTURES FROM APPROPRIATE MEANS OF AVERAGE KEW PRESSURE, FOLLOWING SELECTED DAYS OF HIGH AND LOW PRESSURE

Type of "o" day	Season	Approximate standard error of mean	Days following "o" day									
			12	14	16	18	20	22	24	26	28	30
			millibars									
High	Winter	0·7	+0·2	−0·4	−0·1	+0·4	0	+0·6	−0·9	−0·3	+0·2	+0·6
	Summer	0·5	0	−0·1	−0·4	−0·4	+0·2	+0·4	+0·3	+0·2	−0·9	−0·7
	Year	0·4	+0·1	−0·3	−0·2	0	+0·1	+0·5	−0·2	−0·1	−0·3	0
Low	Winter	0·7	−0·7	+0·4	−0·1	−0·7	−0·4	+0·5	+0·3	0	+0·1	0
	Summer	0·5	−0·1	+0·1	−0·3	−0·3	+0·5	+0·1	−0·3	0	+0·3	0
	Year	0·4	−0·3	+0·4	−0·1	−0·4	+0·1	+0·3	0	+0·1	+0·7	0

Type of "o" day	Season	Approximate standard error of mean	Days following "o" day									
			32	34	36	38	46	48	50	70	72	74
			millibars									
High	Winter	0·7	−0·2	−0·5	+0·1	+0·7	+0·1	+0·1	−0·4	+0·3	+0·5	−0·2
	Summer	0·5	+0·5	+0·9	+0·5	+0·6	+0·4	−0·9	−1·2	−0·6	−0·4	−0·9
	Year	0·4	+0·2	+0·2	+0·4	+0·7	+0·3	−0·4	−0·7	−0·1	+0·1	−0·5
Low	Winter	0·7	0	+0·4	−0·2	−0·2	−0·2	+0·2	+0·5	−0·4	−0·5	+0·3
	Summer	0·5	−0·1	0	+0·1	0	0	+0·7	+0·2	−0·2	−0·1	−0·7
	Year	0·4	0	+0·2	0	0	−0·1	+0·5	+0·4	−0·3	−0·2	−0·3

Conclusion.—The method of investigation adopted here is one that should reveal any intermittent pressure influence of changing phase—an influence, in fact, of such a nature as has usually been attributed to pressure "waves". A tendency for pressure recurrences after *n* days would, for instance, be revealed by a peak centred at this point on the curve on which the "o" day is a maximum; or by a trough centred at day +*n* on the minimum "o" day curve. No such effects appear on the graph, and inspection of the numerical results shows that the pressure departures from appropriate means are no larger than can readily be accounted for by the range of day-to-day pressure variation. This result is interpreted as showing that there is no reason to believe that there is, at Kew, anything of the nature of pressure "waves" of any specified length within the limits which have been considered here. This conclusion applies to "winter" and "summer" separately; a further subdivision of the data for varying sun-spot epochs also gave a negative result.

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ON THE DISTRIBUTION OF RAINFALL RATES AT SOME COASTAL STATIONS IN THE BRITISH ISLES

By D. J. McCONALOGUE

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This note describes the results of an investigation to find the proportion of the total time during which the rate of rainfall exceeds a specified value.

The stations chosen were: Lerwick (Shetlands), Ronaldsway (Isle of Man), St. Eval (Cornwall) and Valentia (Co. Kerry). The rainfall for the year 1951 was considered in detail. The information was abstracted from the day-by-day records of a Meteorological Office tilting-siphon rain recorder, which gives the rate of rainfall R as the gradient of an automatically traced curve, by the relationship $R = 1 \cdot 14 \tan \alpha$, where α is the angle of the gradient. The lower rainfall rates are therefore more accurately measurable than the higher. Histograms of percentage time against rainfall rate were computed, and from these, cumulative curves were constructed for months in which rain fell for more than 2 per cent. of the time. These curves give the time during which rain fell at a rate exceeding R mm./hr. as a percentage of the total time. This percentage is designated by P_R. The percentage time during which rain of any intensity was falling is thus P_o.

Examination of these cumulative curves showed a remarkable similarity of form, especially for months in which the percentage time of rainfall was high, and the curve correspondingly smooth. On fitting exponential curves, $P_R = P_o \times 10^{-\lambda R}$, very close agreement was got. λ was obtained by making the curve pass through a convenient point on the graph. The following are typical:—

	R = 0	½	1	2	3	4	5	7	10
	LERWICK, September, $P_o = 5 \cdot 3$, $\lambda = 0 \cdot 2937$								
P_R empirical	5·3	3·6	2·5	1·4	0·7	0·4	0·3	1	0·03
P_R exponential	5·3	3·8	2·7	1·4	0·7	0·4	0·2	0·05	0·01
	RONALDSWAY, December $P_o = 11 \cdot 3$, $\lambda = 0 \cdot 3073$								
P_R empirical	11·3	8·5	6·1	2·7	1·3	0·8	0·4	0·2	0·1
P_R exponential	11·3	7·9	5·6	2·7	1·3	0·7	0·3	0·1	0·01
	ST. EVAL, February, $P_o = 5 \cdot 2$, $\lambda = 0 \cdot 2007$								
P_R empirical	5·2	3·8	2·6	2·0	1·3	0·7	0·5	0·2	0·05
P_R exponential	5·2	4·1	3·3	2·1	1·3	0·8	0·5	0·2	0·05
	VALENTIA, October, $P_o = 10 \cdot 9$, $\lambda = 0 \cdot 2075$								
P_R empirical	10·9	8·1	6·8	4·2	2·6	1·9	1·2	0·6	0·2
P_R exponential	10·9	8·6	6·8	4·2	2·6	1·6	1·0	0·4	0·1

Equally close agreement was obtained for longer periods. The cumulative curve for Valentia for the entire year is shown in Fig. 1.

If the cumulative curve is given by $P_R = P_o e^{-\mu R}$, then the distribution function $f(R)$ must be $P_o \mu e^{-\mu R}$

$$\text{since } P_R = \int_R^\infty f(R)\, dR.$$

This relationship is found to give good agreement with the observed data; the histogram for Ronaldsway, January–March, is shown in Fig. 2, together with the exponential distribution function as calculated from the cumulative curve.

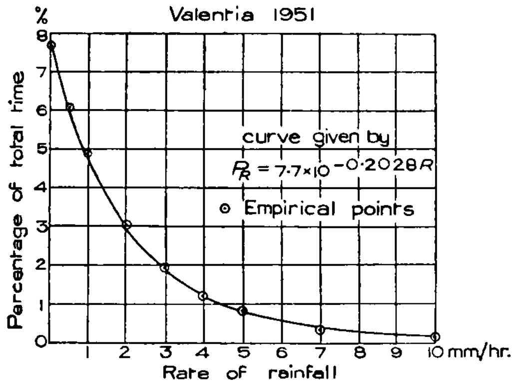

FIG. 1—CUMULATIVE CURVE, VALENTIA

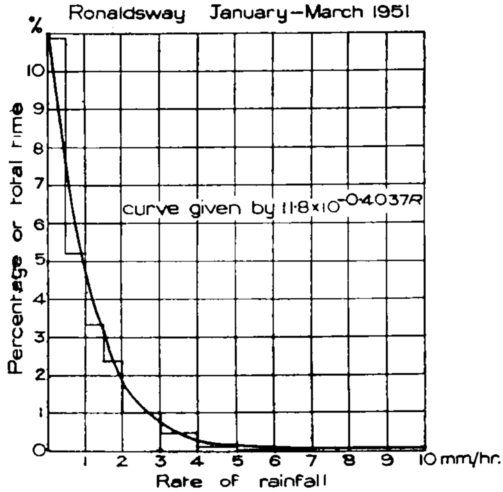

FIG. 2—HISTOGRAM, RONALDSWAY

The total precipitation p mm. is given by

$$p = k\int_0^\infty R\, f(R)\, dR$$

$$= k\ P_o \mu \int_0^\infty Re^{-\mu}\, dR$$

where k is the number of hours in 1 per cent. of the period.

This gives $$p = \frac{kP_o}{\mu}$$

$$\text{or } \mu = \frac{kP_o}{p}$$

$$= \frac{1}{R_o}$$

where R_o is the average rate of rainfall in millimetres per hour.

Thus the original formula becomes

$$\frac{P_R}{P_o} = e^{-R/R_0}$$

and the distribution function $f(R) = \dfrac{P_o}{R_o} e^{-R/R_0}$.

These relationships, if generally true, would allow a prediction to be made of the distribution in any period, if the total duration of rainfall in the period kP_o and the total precipitation were known. While exponential distributions are not additive, nevertheless a reasonable approximation to the distribution in any period can be made by an exponential curve, which has the advantage of being analytically simple.

Acknowledgements.—Thanks are due to the Director of the Meteorological Office, London, and the Director of the Meteorological Service, Dublin, who supplied the charts from which the information was obtained. This note is published by permission of the Admiralty.

THE RATE OF RISE OF PILOT BALLOONS

By F. H. LUDLAM

In many places it is the practice to deduce the height of a pilot balloon from an assumed constant rate of rise. However, observers who have measured balloon heights (e.g. by the tail method or by using two theodolites) will agree that the upward speed is usually rather irregular, and that its mean is not always close to that which would be assumed from the standard formula. The following questions arise: do the balloons rise steadily relatively to the air, and are the observed irregularities reliable indications of vertical motions in the atmosphere?

The authorities at the Royal Albert Hall very kindly allowed members of the Imperial College staff to experiment with balloons in their building; our results do not answer the questions conclusively but are interesting and probably worth recording.

Experiments.—The balloons (which were supplied by the Meteorological Office) were released from the floor and rose 120 ft. to a skylight in the circular roof. Observers stationed on the galleries timed the intervals between the release of each balloon, its passage at their level, and its arrival at the skylight. The balloons reached the roof in about 15 sec., and the deduced speeds are liable to an observational error of about $\pm$ 2 per cent.

First, four 20-gm. balloons (Nos. 1–4) were inflated to have free lifts of 62, 72, 82, and 91 gm., their diameters increasing from 50 to 55 cm. (Their mean diameters at right angles to the diameters through the necks were found from the measured circumferences.) These all reached their terminal speeds within 20 ft. of the floor, and thereafter their speeds were the same, within the observational error, amounting to 2·5 m./sec. or about 490 ft./min. The balloons wavered from side to side and rolled a good deal.

Next, three balloons (Nos. 5–7) were loaded with suspended weights of 8, 35 and 60 gm. and given the same free lift of 62 gm. These held a rather steadier attitude and their rising speeds were indistinguishable from those of the first balloons.

On another day, four balloons (Nos. 8–11) were each brought to a dead weight of exactly 61 gm. by a suspended load of about 40 gm. and given a free lift of 62 gm. In flight they were not particularly steady; their ascent speeds were 2·3, 2·5, 2·2 and 2·6 m./sec.

Finally, ten balloons were inflated to a constant circumference (measured horizontally, with the neck beneath) such that the mean diameter was 50 cm.; the balloons became ellipsoidal with the longer diameter through the neck varying from 51 to 54 cm. Their free lift was then about 65 gm. Three hit lamps before reaching the skylight, and one hit the metal roof; excluding these the remaining six rose at a speed (measured this time from 23 ft. above the floor to the roof) which was constant within the observational error: 2·5 m./sec. The mean drag coefficient was 0·8.

Discussion.—When a balloon of cross-section A rises at a constant speed v, its buoyancy or free lift is equal to the drag:

$$H - W = \tfrac{1}{2} C_D A \rho v^2$$

where H is the total lift and W the total weight (including any load), ρ is the air density and C_D is the drag coefficient, a function of the Reynolds number ($R_e = vd/\nu$, d being the balloon diameter and ν the kinematic viscosity of the air).

After some manipulation the equation can be written

$$v^2 = \frac{4dB}{3C_D}$$

$$\text{where} \quad B = 1 - \frac{W}{H},$$

and from this C_D can be calculated from the data and plotted against R_e as shown by the full lines in Fig. 1. The pecked line shows that, over this range of R_e, values of C_D found for a sphere held fixed in an air stream are practically constant.

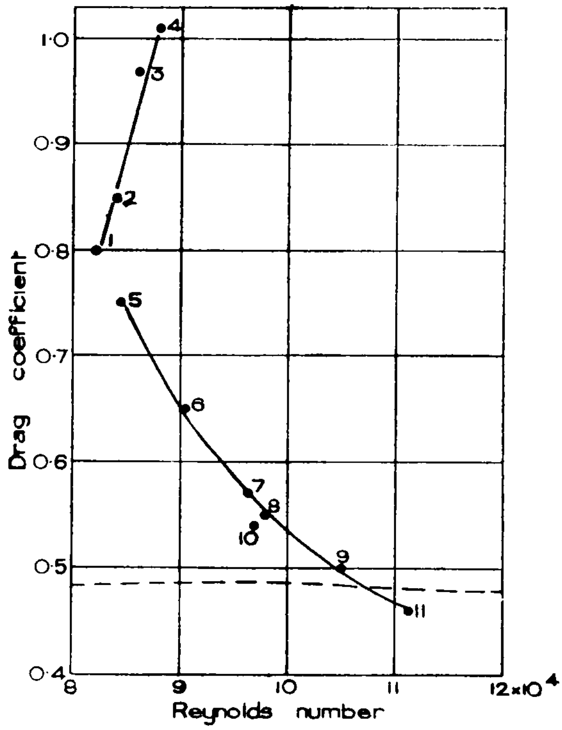

FIG. 1—DRAG COEFFICIENT AGAINST REYNOLDS NUMBER FOR 20-GM. BALLOONS:
Balloons 1– 4: free lift 62, 72, 82 and 91 gm. respectively; no added load.
Balloons 5– 7: free lift 62 gm.; loads of 8, 35 and 60 gm. respectively.
Balloons 8–11: dead weight brought to exactly 61 gm. by loads of about 40 gm.; free lift 62 gm.
The point 1 also represents the mean values for six balloons inflated to a mean diameter of 50 cm. and released without loads.
The pecked line shows accepted values for a sphere held in an air stream.

The drag coefficient of the balloons is considerably higher, apparently on account of their unsteady motion (wavering or rolling) for as they are steadied by an increasing load C_D falls towards the value for a sphere (balloons Nos. 5–7). The decrease of C_D as R_e increases under these conditions is confirmed by balloons Nos. 8–11, and is in striking contrast to the opposite trend shown by the unloaded balloons Nos. 1–4. This latter is the desirable trend, for a change in the buoyancy (as might be produced in the atmosphere by strong sunshine or a slow leak) is accompanied by a change in the drag coefficient which tends to leave the rising speed unaffected. This effect was discovered by J. S. Dines[1] in his original work on the rate of ascent of pilot balloons.

It must be admitted that these results are not in agreement with those which Cave and Dines[2] found, also in the Albert Hall.

They tested a formula

$$V = \frac{qL^{\frac{1}{2}}}{(W + L)^{\frac{1}{3}}}$$

L and W being respectively the free lift and the total weight of the balloon, in grams; they found that q was almost constant, varying by only a few per cent. about a mean value of 84 (when V is expressed in metres per minute). In our experiments q varied between 73 and 109; even with balloons Nos. 8–11, for which the value of $L^{\frac{1}{2}}/(W + L)^{\frac{1}{3}}$ was in each exactly the same, the speeds of ascent varied from 2·2 to 2·6 m./sec. and q from 96 to 109. In general the value of q rose with an increase in the load of the balloon, but more sharply than Cave and Dines found using smaller loads; our value of q for those balloons liberated without a load and given a free lift of about the customary amount agrees fairly well with the mean value of Cave and Dines, being about 82.

It is interesting in our results to find that the rate of ascent of the ten unweighted 20-gm. balloons was constant within the observational error (±2 per cent.), although the free lift varied from about 62 to 91 gm. and the mean diameter from 50 to 55 cm. This suggests that in field work such balloons may most conveniently be inflated to a particular circumference rather than to gain a certain free lift, without any loss in uniformity in the rate of ascent. Moreover, it seems that variations in the rate of rise of a single balloon, or of a succession of balloons, may be ascribed to vertical motions in the air if they considerably exceed some 5 cm./sec., or about 10 ft./min. It also appears that there is no advantage in loading balloons if they are intended to rise at about the usual rates, although our field experience leads us to think that a load has a valuable steadying influence on a balloon intended to rise very slowly, at less than 50·8 cm./sec. (100 ft./min.).

More accurate observations of the rate of rise of balloons might well show that their ascent speeds are, or could be made to be, even more reproducible, so that the pilot balloon might regain some of its former prestige, this time as a rather sensitive indicator of vertical movements in the atmosphere.

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1. DINES, J. S.; Rate of ascent of pilot balloons. *Quart. J.R. met. Soc., London*, **39**, 1913, p. 101.
2. CAVE, C. J. P. and DINES, J. S.; Further measurement of the rate of ascent of pilot balloons. *Quart. J.R. met. Soc., London*, **45**, 1919, p. 276.

BOOK RECEIVED

Jaarboek, A. Meteorologie 1950. Koninklijk Nederlandsch Meteorologisch Instituut. No. 97. 13¼ in. × 9½ in., pp. xiv + 94. Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1951. Price *fl.* 7.50.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

METEOROLOGICAL REPORTS

No. 13.—1000–500-mb. thickness, North America to Europe, 1946–51. Monthly means and extremes.

The enormous increase, since the early 1940s, of aerological data for the northern hemisphere has added considerably to the statistical information about the atmosphere available to a wide class of users, particularly those concerned with aviation. The professional meteorologist, however, has his own peculiar requirements, and in the British Meteorological Service the "thickness" of the atmospheric layer between the 1000-mb. and 500-mb. surfaces has been given particular prominence both in dynamical theories and synoptic practice; circumpolar thickness charts are now a commonplace tool of research workers and forecasters alike.

This publication includes maps of the distribution of mean thickness for each month of the year (based on one observation a day from the main upper air stations) for the 5-yr. period October 1946 to September 1951, and for the area from the Rockies eastwards to the Urals. The individual thickness isopleths are drawn at intervals of 200 ft. Separate monthly maps are also given of the envelopes of the extreme northward and southward penetrations of selected thickness lines, namely for the 18,000-ft. thickness and for intervals of 600 ft. above and below this value. These maximum and minimum positions are usually reached in, respectively, the thermal ridges and troughs associated with the largest-amplitude long waves of tropospheric flow patterns. Little attempt has been made to interpret and to explain the uses of these charts, although references are given to two papers concerned with their use in forecasting.

PROFESSIONAL NOTES

No. 107.—Upper air circulation in low latitudes in relation to certain climatological discontinuities. By R. Frost, B.A.

The most striking features of the upper air circulation over Arabia are the westerly jet stream of over 100 kt. at a pressure level of about 200 mb. in latitudes 25–30°N. during the winter months and an easterly jet stream of over 70 kt. at a pressure level of 100 mb. in about latitude 15°N. during July. The westerly jet stream reaches its maximum intensity in midwinter, moves slowly northwards and decreases slightly during the spring, and then moves to a position about 40°N. and weakens rapidly during midsummer. The easterly jet stream weakens rapidly during the autumn and is non-existent during the spring and winter. As the westerly jet stream moves north over Iraq there is an abrupt change in the level of the tropopause, and it is suggested that the break-down in this tropopause barrier helps to explain the surface discontinuities of temperature and wind which occur during these months and the spectacular onset of the monsoon over India.

METEOROLOGICAL RESEARCH COMMITTEE

The 26th meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held at Dunstable on May 21, 1953.

The Sub-Committee considered three papers by Mr. F. H. Bushby and Miss M. K. Hinds on numerical methods of assessing cyclonic development using an electronic computer. The first[1] discussed the computation of the field of atmospheric development, the second[2] discussed the computation of the 500-mb. height tendency in a baroclinic atmosphere and the third[3] discussed the computation of the 1000–500-mb. thickness tendency, the 1000-mb. height tendency and the horizontal field of vertical motion. Other papers discussed at this meeting included one by Mr. Crossley[4] dealing with measures of success in forecasting, and a study by Dr. A. G. Forsdyke[5] of depressions crossing the region of Labrador and the St. Lawrence Basin.

The Sub-Committee also reviewed the progress made in research.

ABSTRACTS

1. BUSHBY, F. H. and HINDS, M. K.; Computation of the field of atmospheric development by an electronic computer. *Met. Res. Pap., London*, No. 765, S.C. II/126, 1953.
A method of evaluating the Sutcliffe development formula for relative divergence between two pressure levels, using a grid (length 160 miles) and a reiterative process on an electronic computor, is described. It was applied to 12 synoptic charts for the North Atlantic and west Europe (surface isobars and 1000–500-mb. thickness), total time 1 hr. each. The computed developments are analysed. The method is a promising forecasting aid.

2. BUSHBY, F. H. and HINDS, M. K.; Computation of the 500-mb. height tendency in a baroclinic atmosphere, using an electronic computer. *Met. Res. Pap., London*, No. 790, S.C. II/139, 1953.

3. BUSHBY, F. H. and HINDS, M. K.; Computation of the 1000–500-mb. thickness tendency, the 1000-mb., height tendency, and the horizontal field of vertical motion, using an electronic computer. *Met. Res. Pap., London*, No. 794, S.C. II/140, 1953.
Referring to baroclinic model of J. S. Sawyer and F. H. Bushby, the authors reduce equations to a form suitable for use with an electronic computer. These were used first (*Met. Res. Pap.*, No. 790) to compute height tendency of the 500-mb. field over a grid centred on the British Isles for three synoptic situations, and later (*Met. Res. Pap.*, No. 794) to compute base-height and thickness changes in feet per hour, and vertical motion fields. Computing times were 12 and 15 min., and results were satisfactory—the chief difficulty being boundary conditions.

4. CROSSLEY, A. F.; Measures of success in forecasting. *Met. Res. Pap., London*, No. 788, S.C. II/138, 1953.
The paper deals first with forecasts of one or two alternative events ("black or white"), both with some persistence. If c, c' are forecast accuracies of these events, $I = \frac{1}{2}(c + c')$ and I_0 is the value of I obtained by forecasting persistence, criterion of success is $(I - I_0)/(1 - I_0)$. Examples of meteorological forecasts are assessed on this basis. C. H. B. Priestley's index (1945) of success in forecasting continuously varying elements is also applied to forecasts of upper winds and equivalent headwinds.

5. FORSDYKE, A. G.; A study of depressions crossing the region of Labrador and the St. Lawrence Basin. *Met. Res. Pap., London*, No. 777, S.C. II/134, 1952.
Relations between tracks of depressions near the American coast and the associated thickness and upper air patterns are studied. Depressions were classified according to track into and out of the area and the broad features of their behaviour are listed. Spells of the order of 10 days of similar types are described synoptically in Part 1. In Part 2 the deepening and movement of depressions are studied statistically in relation to thickness patterns. The large-scale upper-flow patterns give no consistent indications useful for medium-range forecasting, as the thermal and surface patterns evolve together.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on June 17, 1953, the main event was the delivery of Sir Charles Normand's presidential address.

Presidential Address—Monsoon seasonal forecasting

Sir Charles Normand opened his address by pointing out that the rainfall of the summer monsoon is the vital feature of the Indian climate on which the great mass of the population depends for its daily bread. Sir Charles traced the history of monsoonal forecasting beginning with the early work of Blanford in the 1870's and 1880's. Blanford noticed droughts were often preceded by heavy snow in the Himalayas, and based his forecasts on that and, later, on his inference that droughts were preceded by high pressure over parts of Asia and Australia. Sir John Eliot, Blanford's successor, continued the forecasting. He worked with "parallel curves" and "analogues" and believed, in opposition to his predecessor and successor, that high pressure at Mauritius was favourable to heavy monsoon rain. Sir Gilbert Walker, taking charge in 1903, extensively developed the correlation-coefficient technique, though fully conscious of its limitations and empirical nature. He began with the results of Hildebrandsson and Lockyer on relations between pressure variations at distant points, found a correlation between Indian rainfall and pressure variations in the Indian and Pacific Oceans, and went on to make a world-wide survey of tele-correlations. One of the difficulties for forecasting which emerged was that the monsoon rainfall was found to be better correlated with later events than with earlier events. Sir Gilbert examined the possibility of forecasting the rainfall of individual months but got much better results for the whole monsoon season. One important feature of his work was the introduction of statistical verification of the validity of the forecast. In 1930 Sir Charles Normand who succeeded Sir Gilbert in 1927 introduced numerical forecasts of the minimum rainfall expected, expressed as a percentage of normal and qualified by a statement of the odds against error. These were issued until 1948. In the course of his Address Sir Charles showed diagrams of the monsoon rainfalls of India from 1875 to 1948, and concluded with a broad appreciation of the value of the forecasts. The general result was that the overall accuracy of forecasting the total monsoon rainfall was much better than would have been obtained by chance, but the accuracy of forecasting of poor monsoons was decidedly lower than the overall accuracy, and the bad seasons were of course the most important.

As regards future work he considered that attempts to forecast the total monsoon rainfall should continue, but that the results need be made available only to scientific workers. He believed the oscillation of pressure between the Indian and Pacific Oceans merited re-examination, and if it still holds, a strong effort should be made to understand its physical basis, especially of the control of the southern summer on the succeeding winter.

The address will be published in the *Quarterly Journal of the Royal Meteorological Society.*

The summer meeting of the Royal Meteorological Society was held on July 15, at the Building Research Station, Watford. The Society was welcomed to the station by Mr. Pickles who spoke of the need for meteorological information in the design of buildings because buildings were a means of defence against the weather, producing an internal climate in which man could live. Information was needed on temperature, radiation, wind and rainfall.

Sections of particular interest to meteorologists seen by the visitors were the investigations of the thermal transmission of walls and roofs and of the weathering of materials used in external building. Thermal transmission of walls and ceilings is measured by the heat loss from small rooms maintained at constant temperature having their only external wall facing north. Weathering of materials is examined by exposing them to the atmosphere under varying degrees of protection. Bricks, for example, are exposed in shallow trays where they stand for long periods in rain-water as well as on a platform from which rain could drain away. A point of meteorological interest was that the damage to stonework by frost depended on the manner of the fall of temperature as well as on the minimum temperature reached.

The thanks of the Society to the station were expressed by Mr. R. G. Veryard at the close of an excellent tea in the canteen.

ROYAL SOCIETY OF ARTS

The scientist's place in the Services

The Pope Memorial lecture on the subject "The scientist's place in the Services" was given by Dr. O. H. Wansbrough-Jones, Chief Scientist, Ministry of Supply, to the Royal Society of Arts on April 29, 1953.

He traced the rise of scientists in the Services. Traditionally, the scientist was merely called in to solve some specific problem placed before him by the military authority; and his services were purely occasional. This was the state of affairs from the time of Archimedes almost to the beginning of the twentieth century. A number of very interesting examples of the work of scientists in this era were quoted; among the later ones, it was stated that Michael Faraday "advised very sensibly, on meteorological grounds, against the use of sulphur dioxide in the Crimean War." The scientific department giving full-time employment to scientists is largely a product of the twentieth century. Until the Second World War, its function was still "to give the Services what they wanted, which is not necessarily the same thing as giving the Services what they needed". Today, however, the scientist is an accepted and valued member of the planning team. The scientist must not expect special deference to his opinion outside his own particular field of knowledge; but he has certain qualities of mind which help him to contribute to the solution of service problems. Primarily he has a knowledge of certain special techniques, and is qualified to lead a team, or establishment, engaged in scientific work. He should also have a habit of formlating his problems precisely, and of using simplified models to represent them; he has a desire to test all results and opinions by every quantitative method available; and he will never commit himself to an answer until he is, at least, nearly sure he is right. Not all these qualities have, or should have, a place in the service mentality; and the great step forward made in the last war was the integration at high level of the two disciplines, service and scientific. The new position was generously and readily accepted by the Services, largely because the standard of scientific understanding in the Services themselves was, and is, much higher than is generally admitted. The Services have indeed made impressive contributions to science. The work of the Navy in hydrography and navigation has been outstanding for centuries, and Whittle's great work was carried out while he was a serving R.A.F. officer. Since the war, the Services have made further advances in their technical education, notably by the re-establishment and expansion of the Royal Military College of Science at Shrivenham. Some of the outstanding problems which await research are very difficult, and we cannot afford to work on all of them. The cost of research is very high, but the public has come to accept it as necessary, and press comment on the allocation to research in the recent estimates was favourable. Not all the questions of liaison between the Services and science have been answered, but there is good reason to hope that the present harmonious relationship will continue.

A meteorologist listening to this lecture could hardly help feeling a little isolated, because underlying much of it was the assumption that all scientific work is research. A comparison of the weather forecaster's approach to his work with the qualities of the scientific mind as stated by Dr. Wansbrough-Jones will reveal some wide differences. The forecaster may formulate his problems precisely, in the sense that he knows exactly what he wants to find out, but there is no precision about the rules by which the problem is to be attacked. If one could analyse a forecaster's mental processes, one would find that possibly half consists of fairly rigid scientific reasoning. The rest consists of a vague feeling that one solution looks right, while another does not; a memory of what happened last week, plus a somewhat inaccurate memory of something that happened about this time last year; and a determination so to word the forecast that, if it does go wrong, the result will be as little embarrassing as possible. But above all, it is the statement that the scientist "will never commit himself to an answer until he is at least nearly sure that he is right" which sets the meteorologist apart. He is in a special category and, perhaps, needs his own philosophy, distinct from the general philosophy of science. His nearest neighbour is probably the doctor, who also has a routine job to do, and who also has to adopt "working hypotheses" based on inadequate data.

B. C. V. ODDIE

LETTER TO THE EDITOR

Gale of December 17, 1952

In discussing the squall at Cranwell which was accompanied by the record gust for inland stations in Great Britain, 111 m.p.h. (96 kt.), Mr. C. K. M. Douglas states* that he has no knowledge of anything closely similar having been recorded in this country. I notice that before and after this gust, and a few smaller ones accompanying it, the mean wind speed lay mainly below 40 m.p.h. (34 kt.).

For many years the record gust in Great Britain was that at Quilty, Co. Clare, Ireland, on January 27, 1920, but its value, exceeding 111 m.p.h. (96 kt.), was quoted as open to doubt, as, unlike the recent Cranwell gust, nobody was watching the anemometer pens at the time, and this doubt was strengthened by the fact that the mean speed, apart from the big gust, was no more than 52 m.p.h. (45 kt.). This gust continued to be quoted until 1941, but after December 6, 1929, the highest gust in Great Britain was generally stated to be equal to (and not exceeding) 111 m.p.h. (96 kt.), as that value was touched at Scilly on that date. The question as to where the honour should go was finally resolved when a gust of 113 m.p.h. (98 kt.) was recorded at St. Ann's Head on January 18, 1945. However, the ratio of the maximum gust to that of the mean wind speed at Cranwell is of the same order as that at Quilty in 1920, and it would appear therefore that there may have been no justification for doubting the latter record; in fact it had probably genuinely exceeded that at Scilly in December 1929 and even that at St. Ann's Head in January 1945. Fortunately all these gusts have been exceeded in 1952 and 1953, and there is now no doubt that it is in one of these latter years that the record gust has occurred. However, it is regrettable that we have no instrument in general use capable of recording the very highest wind speeds that occur.

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*See *Met. Mag., London*, **82**, 1953, p. 73

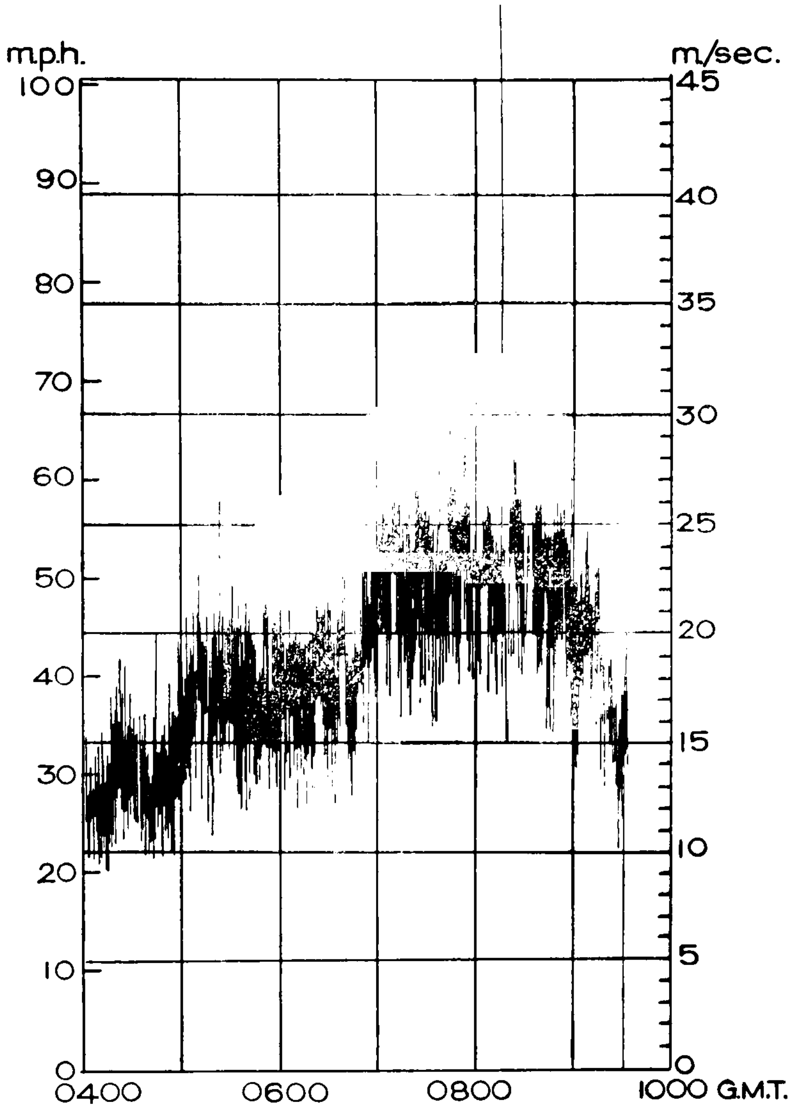

FIG. 1—ANEMOGRAM FROM QUILTY, JANUARY 26, 1920

Unfortunately at Wrexham the anemometer went out of order in the early stages of the gale of December 17, 1952; but the day was notable for virtually continuous hail from 9.15 a.m. to 6 p.m.; it was heavy enough to whiten the ground at times, but borne on the gale much of it failed to be registered by the rain-gauges.

S. E. ASHMORE

11 Percy Road, Wrexham, North Wales, May 11, 1953

[A tracing of the relevant part of the Quilty record is reproduced in Fig. 1 for comparison with the record from Cranwell for December 17, 1952, published in the *Meteorological Magazine* for March 1953, p. 73. The following paragraph is taken from the *Meteorological Magazine* for February 1920, p. 7:—

"There were several gusts of 31 m./sec. and over between 7h. and 8h. and one of 36 m./sec. at 7.45. After this the pen did not rise above 31 m./sec. until 8.20 when it rushed up to the very edge of the chart. It seems to have caught on the edge of the sheet and spluttered as it came down. The indicated speed of the wind was at least 50 m./sec. (over 110 m.p.h.). The duration of the squall cannot have been much more than a minute and the average strength of the wind afterwards was about the same as before, 22 m./sec."

Later, doubts were felt about the validity of the record and in the *Meteorological Magazine* for May 1922, p. 102, it was said that "the excursion of the pen was isolated and there is room for doubt as to its interpretation" and in the *Monthly Weather Report*, 1929, p. 195, "This gust (> 50 m./sec.) occurred as an isolated gust at a time when the mean wind speed was 23 m./sec. It appeared very exceptional and apparently artificial. The custodian affirmed in reply to an inquiry that the record had not been tampered with; unfortunately the circumstances at the time prevented personal investigation on the spot by a meteorological expert. Accordingly the record has been published in the absence of any positive external evidence of its apparently artificial nature".

Mr. Douglas has examined the working charts of January 27, 1920, and writes that an occlusion passed Quilty about the time of the squall and that the geostrophic wind on both sides of the occlusion was fully 130 m.p.h. and so much higher than the geostrophic wind at Cranwell at the time of the gust of December 17, 1953. He considers there is no good reason for doubting the Quilty record.

With reference to Mr. Ashmore's comment on anemometers for reading very high gusts, trials of a suitable recorder are in hand in the Meteorological Office.—Ed., *M.M.*]

NOTES AND NEWS

Wind damage to trees

In March, members of the Agricultural Branch of the Meteorological Office visited a Forestry Commission plantation at Bryncynfil (Dovey Forest), some five miles south-east of Machynlleth. The plantation lies along a narrow valley running south-south-west to north-north-east and sealed by a very steep scree at the southern end. Trees well exposed high up on the sides of the valley suffered little wind damage, but susceptible species, such as Douglas Fir and Norway Spruce, planted on the floor of the valley, suffered considerable "blasting", due apparently to consistent vicious down-draughts in the lee of the steep valley head. The photographs at the back of this issue of the magazine show the wind effect on the natural vegetation and the young conifers.

L. P. SMITH

REVIEWS

Effects of weather on the determination of heights by aneroid barometer in Great Britain. By B. W. Sparks. *Geogr. J., London,* **119,** 1953, p. 73.

Mr. Sparks's interesting article is based on practical experience of height measurement to an error of ±5 ft. checked against the final errors found on reaching a known height shown on the 6-in. ordnance maps after an hour's traverse. Winds exceeding force 3 make aneroid work impossible owing to the erratic pressure variations in the gusts. Sufficiently accurate surveying is possible in anticyclones and during large falls or rises of pressure provided no front actually crosses the area. Of course, when pressure is changing rapidly there will usually be too much wind. Intermediate errors are estimated by distributing the closing error over the readings proportionate to the time.

When there are fronts over the area or during showery and especially thundery weather pressure variations are so erratic that it is impossible to use an aneroid to obtain readings accurate to ± 5 ft. Mr. Sparks estimates that in south-east England 59 per cent. of days are suitable in summer and 48 per cent. in winter, but in north-west Scotland these figures fall to 33 per cent. and 19 per cent. Mr. Sparks regrets the ending of AIRMET but finds the early morning B.B.C. forecast of assistance.

He does not mention that for a small fee a special forecast of suitable weather can be obtained from the Meteorological Office; such forecasts would be of great value to surveyors waiting for an opportunity to make an aneroid traverse.

G. A. BULL

Present-day forecasting practice, by F. H. Ludlam, and *Watching the sky*, by R. S. Scorer. *Sci. Progr., London*, **41**, 1953, p. 84 and p. 54. Edward Arnold & Co., London.

Several reviews of the history of weather forecasting during the present century and of its present problems and possibilities have been published in the last few years. The major ones were those by C. K. M. Douglas and R. C. Sutcliffe in the 1952 numbers of the *Quarterly Journal of the Royal Meteorological Society* and by H. C. Willett in the "Compendium of meteorology". Now in the January number of *Science Progress* F. H. Ludlam gives a useful summary of these and some other papers on the subject. In the same number R. S. Scorer contributes a short article, illustrated with some admirable photographs, on the value and delight of watching the sky. He looks forward to the use of more informative cloud classifications which will provide reports of clouds of greater value in revealing to the meteorologist the three-dimensional air movements.

G. A. BULL

Geographical Journal. Vol. CXIX. Part 2, June 1953

The June 1953 number of the *Geographical Journal* includes much of meteorological and geophysical interest.

Mr. G. de Q. Robin's lecture to the Society on the International Expedition to Antarctica 1949–52 includes a preliminary report on the meteorological and glaciological observations of the expedition. Interesting points are that on clear calm winter days the temperature inversion between the bottom and top of a 10-m. mast was as large as 15°C. and the confirmation of the phenomenon, originally observed by the U.S.A. expedition in 1947, of the absence of a tropopause at times in winter over the Antarctic.

The review by Jean Fortt of the H.M. Stationery Office publication *Land and Population in East Africa* includes a discussion of the rainfall of the marginal areas of that territory. Mr. F. Kingdon-Ward gives a vivid description of his experiences in camp near the epicentre of the great Assam earthquake of August 15, 1950 and of the topographical changes it produced.

G. A. BULL

OBITUARIES

Walter Charles Reynolds.—Mr. Reynolds was killed instantly on August 1, 1953, while travelling home on his motor-cycle; he was 32. The news of his untimely death came as a great shock and leaves those of us who knew him with a profound sense of loss. We offer our deepest sympathy to his bereaved parents.

Charles Reynolds joined the Meteorological Office as an Assistant III in March 1939 at Bircham Newton. He served at the Training School and at White Waltham and in July 1942 received his forecasting training course. For the next 2½ yr. Reynolds served as an Assistant II at Bomber Command stations in Yorkshire and was commissioned in the R.A.F.V.R. in April 1943. The period July 1945 to March 1948 was spent in India; he was promoted to Flight-Lieutenant and to Assistant I early in 1946. Release from the R.A.F.V.R. in April 1948 did not break the continuity of his service for he returned to duty immediately and was promoted to Experimental Officer in July 1948.

It was here that the final period began; the period during which we had countless opportunities to appreciate his sterling honesty and determination to succeed. For 2 yr. he fulfilled the exacting duties of a forecaster in constant touch with the daily press; in 1950 these changed to the no less onerous duties of a forecasting instructor at the Training School. During these four years, Reynolds attended evening lectures at Birkbeck College, studying for the B.Sc.(Special) degree in mathematics. It was in connexion with this course that we had occasion to admire his tenacity and determination; success crowned his efforts in 1952 and in October he was moved to the Special Investigations Branch where full use was made of his mathematical ability. Such was Reynolds' deep interest in theoretical meteorology, however, that he was well aware that its problems require more advanced mathematics than he had learnt and he continued his studies of the mechanics of continuous media with a view to obtaining the Ph.D. degree.

His untimely death cheated him of this success. His loss has made the office poorer and deprived his colleagues of a stimulating companion and a worthy friend.

R. C. SIVILL

Dr. Wladyslaw Gorczyński.—It is with great regret that we learn of the death on June 25, 1953, in his 74th year, of Dr. Gorczyński, professor of meteorology and climatology at Copernicus University in Toruń, Poland.

After the First World War Dr. Gorczyński organized the State Meteorological Service in Poland and became the first director of the Meteorological Institute in Warsaw. In 1923 he undertook an actinometric expedition to Siam and Java, during which he discovered a diminution of intensity in the red part of the solar spectrum. In 1926–36 he carried out investigations of the solar climate of the Riviera, visited the Sahara and Tunis, where he observed the infra-red part of the solar spectrum, and twice went to Mexico. The outbreak of the Second World War found him in Washington and he had to stay in the United States of America throughout the whole war. In 1947 he returned to Poland where he was appointed professor of meteorology and climatology at the Copernicus University in Toruń.

During his lifetime Dr. Gorczyński published over 260 papers in different languages both in Poland and abroad, the main field of his scientific work being solar radiation and climatology. He also devised some instruments, of which his solarimeter became widely known.

Professor Gorczyński was a member of many societies and organizations including the Polish Academy of Science, the Academy of Science in Mexico and the International Solar Radiation Commission as a charter member from its constitution in 1912 until its dissolution in 1946.

METEOROLOGICAL OFFICE NEWS

Academic successes.—Information has reached us that the following members of the staff have been successful in examinations this summer; we offer them our congratulations.

London B.Sc. (*Special*): 2nd class honours in mathematics, C. H. Hinkel, H. D. Hoyle; 2nd class honours in physics, J. E. Burns; Pass in mathematics, R. C. Sivill.

Intermediate B.Sc.: pure and applied mathematics, physics, C. H. Chubb, A. W. R. Hewat, T. D. D. Jennings, Miss A. Leeves; pure and applied mathematics, geography, D. T. Tribble.

General Certificate of Education (*Advanced level*)*:* pure and applied mathematics, physics, R. A. Cashmore, C. H. Chubb, A. A. Diver, M. Grimmer, J. H. Grundy, B. W. Hamilton; applied mathematics, physics, D. C. Davis, J. W. Rayner, J. Scot; physics, mathematics and distinction in chemistry, H. G. Griggs; pure mathematics, physics, R. C. Friend, P. J. S. Greenaway, F. B. Webster; applied mathematics, W. M. Mills; pure mathematics, R. F. Scarsbrook; physics, Miss U. M. Bannister, E. G. Butler, J. Gregson, O. M. Hull, A. Lambley, J. M. Ward; geography, M. Curme, A. G. Rogers.

Library Association Entrance Examination: Miss P. Gorringe.

M. Grimmer has been accepted for a studentship at the Royal Military College of Science, Shrivenham.

Higher National Certificate: mechanical engineering, A. L. Alexander.

Sport.—Messrs. A. F. and S. W. Lewis have been selected to play for the Civil Service representative water polo team, against the Navy on September 10 and the Army on September 14.

The brothers Lewis now have regular places in the Civil Service team.

WEATHER OF AUGUST 1953

Mean pressure was above normal over west and south Europe and the Bay of Biscay, and also over the east of the United States. Mean pressure was below normal over the Atlantic north of 45°N., excluding the Bay of Biscay, by as much as 5 mb. over Iceland and the sea area off south-east Greenland. The mean pressure was highest just south-west of the Azores, 1024 mb., and lowest, 1004 mb., off south-east Greenland.

Mean temperature differed little from normal. In Europe it varied from 55°F. in north Scotland and Norway to 75°–80°F. in the south of Spain, Italy and Greece. Mean temperature in the east of North America varied from 57°F. in southern Quebec to over 80°F. in Florida.

In the British Isles the weather was mainly fair and warm until the 12th, when it became less settled with local thunderstorms. The latter half of the month was rather cool with frequent rain, heavy at times in some areas. Rainfall was variable, exceeding the average in western Scotland, northern England, west Wales and over an area stretching across the Bristol Channel to Huntingdonshire. Sunshine exceeded the average on the whole.

In the first three days a wedge of high pressure moved slowly south-east across the British Isles maintaining fair sunny weather apart from some showers chiefly on or near the east coast. On the 4th and 5th a depression moved east across Iceland and a westerly type of weather prevailed with appreciable rainfall locally in the north of Scotland in the early hours of the 4th, and some scattered light rain or showers and a good deal of cloud in most parts of the country on the 5th and 6th; there was also fog on the south-west coasts at times during the period 4th–7th. Subsequently an anticyclone off our south-west coasts moved north-east and dry weather prevailed until the 12th, apart from some slight rain at times mainly in the extreme west and north-west. By the 12th pressure was highest over southern Scandinavia, while a trough of low pressure moved over the British Isles from the west giving thunderstorms on the 12th and 13th; the storms were heavy locally in north-east England on the 13th. A warm south-south-easterly air stream in front of the trough was accompanied by notably high temperatures, 90°F. or a little above being reached at a number of places in the eastern half of England. Temperature fell rapidly behind the trough; for example, at Dishforth the maximum on the 13th was 64°F. as compared with 92°F. on the 12th. From the 14th to 17th a depression south of Iceland moved very slowly north; on the 14th an associated trough gave rain in western districts and on the following day it moved slowly east giving thundery rain and local thunderstorms. On the 17th a secondary depression off west Scotland moved slowly north-east and troughs moved eastward across the British Isles giving general rain, heavy locally in the north and west (2·13 in. at Patterdale, Westmorland). From this time onward a westerly type of weather persisted, with frequent rain. On the 19th troughs associated with a depression off the Hebrides crossed England and Wales bringing heavy rain (2·87 in. at Maesteg, Glamorganshire) and on the 20th and 21st the main depression moved slowly over Scotland giving varying amounts of rain and rather widespread thunderstorms on the 21st and scattered showers on the 22nd. Further rain, heavy locally in the south, occurred on the 23rd and showers and scattered thunderstorms on the 24th. Thereafter a wedge of high pressure moving east was associated with a short spell of fair weather over most of the country on the 25th and 26th and over much of England also on the 27th, but troughs of low pressure brought renewed rain to the north on the 27th and to most parts on the 28th and 29th; the rainfall was heavy at times, particularly on the 29th (2·78 in. at Maesteg and 2·25 in. at Walton-in-Gordano, near Clevedon). Mainly fair weather prevailed over much of southern England on the last two days but showers and local thunderstorms occurred in Scotland and Northern Ireland on the 30th and widespread heavy rain in northern districts of England and Wales, southern Scotland and the Isle of Man on the 31st (2·63 in. at Ulverston, Lancashire, 2·51 in. at Oughtershaw, Yorkshire, and 2·31 in. at Kendal, Westmorland).

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	93	36	+0·6	99	−3	115
Scotland	83	32	+0·4	91	+1	102
Northern Ireland ...	74	43	+0·3	93	−1	97

RAINFALL OF AUGUST 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·08	94	*Glam.*	Cardiff, Penylan ...	5·55	131
Kent	Dover	2·12	92	*Pemb.*	Tenby, The Priory ...	3·40	89
,,	Edenbridge, Falconhurst	1·98	76	*Radnor*	Tyrmynydd	4·49	83
Sussex	Compton, Compton Ho.	2·47	80	*Mont.*	Lake Vyrnwy	5·01	94
,,	Worthing, Beach Ho. Pk.	1·81	80	*Mer.*	Blaenau Festiniog ...	11·31	101
Hants.	Ventnor Cemetery ...	1·62	79	,,	Aberdovey	6·00	135
,,	Southampton, East Pk.	1·86	71	*Carn.*	Llandudno	2·90	103
,,	South Farnborough ...	2·02	91	*Angl.*	Llanerchymedd ...	2·89	80
Herts.	Royston, Therfield Rec.	2·54	99	*I. Man*	Douglas, Borough Cem.	5·23	137
Bucks.	Slough, Upton	1·58	73	*Wigtown*	Newton Stewart ...	3·20	77
Oxford	Oxford, Radcliffe ...	2·92	128	*Dumf.*	Dumfries, Crichton R.I.	2·85	71
N'hants.	Wellingboro' Swanspool	2·60	109	,,	Eskdalemuir Obsy. ...	4·90	95
Essex	Shoeburyness	1·92	108	*Roxb.*	Crailing	2·29	78
,,	Dovercourt	1·22	68	*Peebles*	Stobo Castle	2·66	75
Suffolk	Lowestoft Sec. School ...	2·30	105	*Berwick*	Marchmont House ...	2·27	69
,,	Bury St. Ed., Westley H.	1·84	71	*E. Loth.*	North Berwick Res. ...	1·89	60
Norfolk	Sandringham Ho. Gdns.	2·42	90	*Midl'n.*	Edinburgh, Blackf'd. H.	2·03	63
Wilts.	Aldbourne	3·14	119	*Lanark*	Hamilton W. W., T'nhill	2·95	86
Dorset	Creech Grange... ...	2·49	87	*Ayr*	Colmonell, Knockdolian	2·18	55
,,	Beaminster, East St. ...	2·41	77	,,	Glen Afton, Ayr San. ...	3·37	62
Devon	Teignmouth, Den Gdns.	1·31	58	*Renfrew*	Greenock, Prospect Hill	5·00	97
,,	Cullompton	..	..	*Bute*	Rothesay, Ardencraig ...	5·35	110
,,	Ilfracombe	4·90	136	*Argyll*	Morven (Drimnin) ...	6·01	114
,,	Okehampton	3·20	75	,,	Poltalloch	..	..
Cornwall	Bude, School House ...	2·75	98	,,	Inveraray Castle ...	7·81	119
,,	Penzance, Morrab Gdns.	2·40	76	,,	Islay, Eallabus	4·71	108
,,	St. Austell	2·06	57	,,	Tiree	4·63	110
,,	Scilly, Tresco Abbey ...	2·25	82	*Kinross*	Loch Leven Sluice ...	2·03	53
Glos.	Cirencester	4·03	134	*Fife*	Leuchars Airfield ...	1·74	56
Salop	Church Stretton ...	2·97	89	*Perth*	Loch Dhu	6·07	90
,,	Shrewsbury, Monksmore	1·75	63	,,	Crieff, Strathearn Hyd.	2·11	50
Worcs.	Malvern, Free Library...	4·20	145	,,	Pitlochry, Fincastle ...	2·35	66
Warwick	Birmingham, Edgbaston	2·45	90	*Angus*	Montrose, Sunnyside ...	2·32	83
Leics.	Thornton Reservoir ...	2·14	76	*Aberd.*	Braemar	2·03	60
Lincs.	Boston, Skirbeck ...	3·02	126	,,	Dyce, Craibstone ...	2·51	83
,,	Skegness, Marine Gdns.	2·20	90	,,	New Deer School House	2·65	90
Notts.	Mansfield, Carr Bank ...	1·35	48	*Moray*	Gordon Castle	2·12	67
Derby	Buxton, Terrace Slopes	5·14	117	*Nairn*	Nairn, Achareidh ...	2·73	112
Ches.	Bidston Observatory ...	2·99	97	*Inverness*	Loch Ness, Garthbeg ...	3·73	115
,,	Manchester, Ringway...	3·65	111	,,	Glenquoich	10·17	124
Lancs.	Stonyhurst College ...	6·47	128	,,	Fort William, Teviot ...	8·07	130
,,	Squires Gate	3·76	110	,,	Skye, Duntuilm ...	5·79	130
Yorks.	Wakefield, Clarence Pk.	2·48	95	,,	Skye, Broadford ...	..	..
,,	Hull, Pearson Park ...	2·52	87	*R. & C.*	Tain (Mayfield) ...	2·18	81
,,	Felixkirk, Mt. St. John...	3·64	128	,,	Inverbroom, Glackour...	4·32	103
,,	York Museum	2·88	114	,,	Achnashellach	6·67	106
,,	Scarborough	3·26	117	*Suth.*	Lochinver, Bank Ho. ...	3·52	105
,,	Middlesbrough... ...	3·54	129	*Caith.*	Wick Airfield	2·88	105
,,	Baldersdale, Hury Res.	5·21	157	*Shetland*	Lerwick Observatory ...	4·60	153
Norl'd.	Newcastle, Leazes Pk....	4·20	149	*Ferm.*	Crom Castle	3·80	92
,,	Bellingham, High Green	4·36	124	*Armagh*	Armagh Observatory ...	3·68	102
,,	Lilburn Tower Gdns. ...	2·08	74	*Down*	Seaforde	3·55	95
Cumb.	Geltsdale	5·38	131	*Antrim*	Aldergrove Airfield ...	2·52	70
,,	Keswick, High Hill ...	5·93	114	,,	Ballymena, Harryville...	4·30	101
,,	Ravenglass, The Grove	4·56	100	*L'derry*	Garvagh, Moneydig ...	3·90	99
Mon.	A'gavenny, Plâs Derwen	3·44	104	,,	Londonderry, Creggan	5·00	108
Glam.	Ystalyfera, Wern House	5·47	89	*Tyrone*	Omagh, Edenfel ...	3·43	80

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WIND DAMAGE TO PLANTATIONS
(see p. 315)

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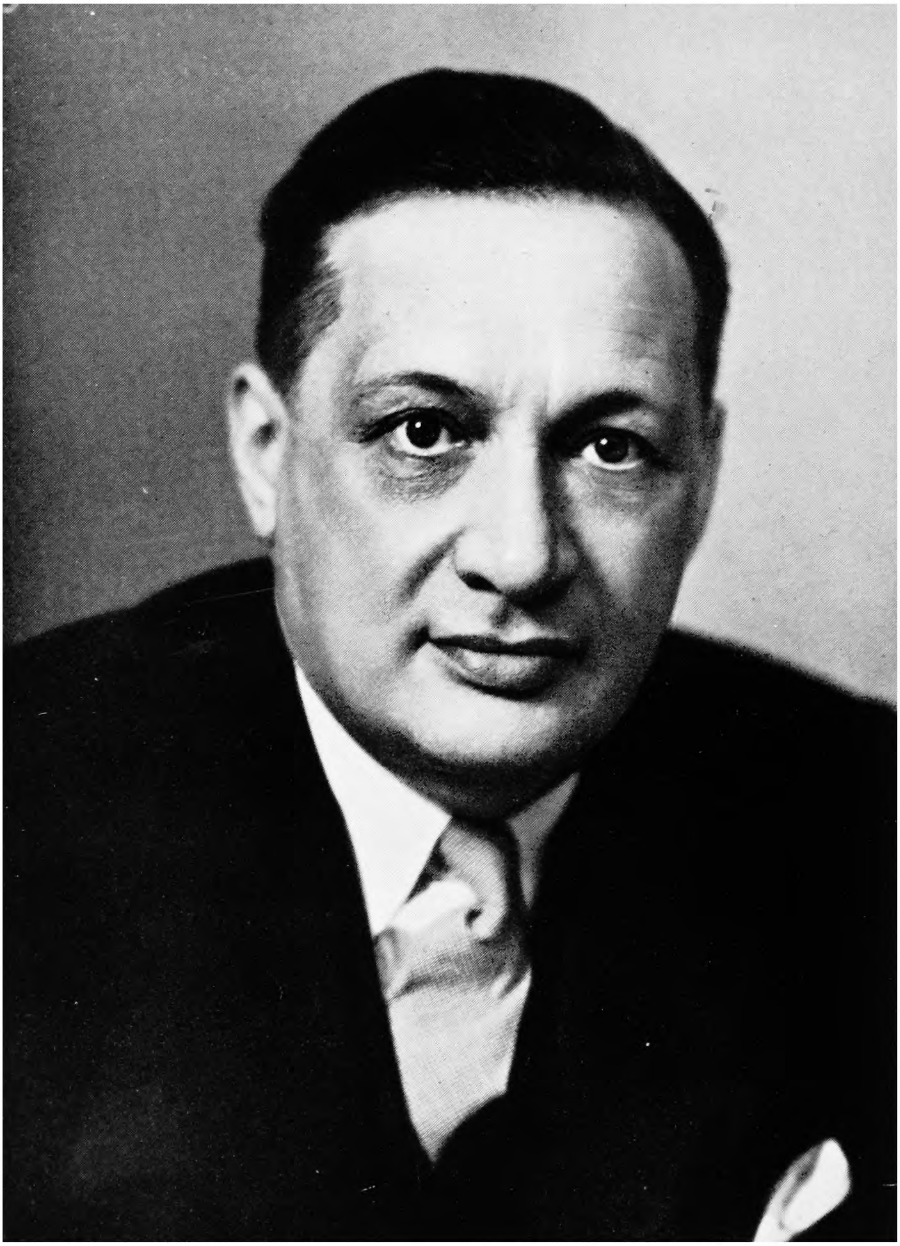
WIND EFFECT ON NATURAL VEGETATION
(see p. 315)

To face p. 321]



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DR. O. G. SUTTON, C.B.E., F.R.S.

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 977, NOVEMBER 1953

Dr. O. G. SUTTON

Dr. O. G. Sutton, C.B.E., D.Sc.(Wales), B.Sc.(Oxon), F.R.S., took up his duties as Director of the Meteorological Office on September 1, 1953, in succession to Sir Nelson Johnson.

Dr. Sutton is well known as an expert of world-wide fame in the dynamics of the lower atmosphere. He graduated with honours in mathematics at the University College of Wales, Aberystwyth, and later took the degree of B.Sc. Oxford as a scholar of Jesus College. He was a mathematical lecturer at Aberystwyth from 1926 to 1928, and then joined the Meteorological Office as a Junior Professional Assistant. After service at Shoeburyness he was seconded in 1929 to the War Office for service at the meteorological office attached to the Chemical Defence Experimental Establishment, Porton.

This position gave full scope for Dr. Sutton's mathematical ability in the development of the theory of turbulence and its application to practical problems. Theoretical work at Porton before his arrival had been based solely on the concept of the coefficient of eddy diffusivity, the so-called "K" theory. Dr. Sutton's early work at Porton was the application of Prandtl's mixing length theory and Taylor's theory of diffusion by continuous movements to atmospheric diffusion. His paper on these matters, published in the *Proceedings of the Royal Society* as early as 1932, has become classical. During the years up to the outbreak of war he worked continuously on turbulence, and published numerous important papers on atmospheric diffusion, evaporation and the vertical variation of wind speed. In 1942 he was appointed Superintendent of Research in Chemical Defence at Porton, and from 1943 to 1945 was Superintendent of Tank Armament Research. He went to the Radar Research and Development Establishment in 1945 as Chief Superintendent, and in 1947 was appointed Bashforth Professor of Mathematical Physics in the Royal Military College of Science, Shrivenham, latterly becoming Dean of the College.

While occupying these posts outside the Meteorological Office Dr. Sutton continued his meteorological researches, published a number of important theoretical papers such as "Application to micrometeorology of the theory of turbulent flow over rough surfaces"* and "Stability of a fluid heated from below"†, and applied the theory of eddy diffusion to practical problems such as the dispersion of smoke from factory chimneys, in "The theoretical distribution of airborne pollution from factory chimneys"‡ and "Dispersion of hot gases

* *Quart. J.R. met. Soc., London*, **75**, 1949, p. 335.
† *Proc. roy. Soc., London*, A, **204**, 1950, p. 297.
‡ *Quart. J.R. met. Soc., London*, **73**, 1947, p. 426.

in the atmosphere"*. He has also written important general accounts of the meteorology of the "regions where life is most abundant" in his book "Atmospheric turbulence"†, in his article on "Atmospheric turbulence and diffusion" in the "Compendium of meteorology"‡, and, finally and most important, in the comprehensive textbook "Micrometeorology" §. His "The science of flight" || is a useful semi-popular book on aerodynamics.

Dr. Sutton, was elected a Fellow of the Royal Society in 1949 and appointed C.B.E. in 1950. He was Scientific Adviser to the Army Council in 1951, is Chairman of the Atmospheric Pollution Research Committee, and has recently been elected President of the Royal Meteorological Society for the period beginning October 1953. Before becoming Director he represented the Royal Society on the Meteorological Committee and was a personal member of the Meteorological Research Committee.

Dr. Sutton has a long experience and a very high reputation in scientific research and the administration of scientific departments. All readers of the Magazine will join in wishing him every success as Director of the Meteorological Office.

WIND DIRECTION AT NORTH FRONT, GIBRALTAR

By A. WARD

Introduction.—The nature of the air flow through the Straits of Gibraltar and the problems of forecasting surface winds at Gibraltar have received close attention from a number of investigators, notably R. S. Scorer and A. H. Gordon, and there is a considerable amount of published and unpublished information on the subject. This paper amends and brings up to date some of the earlier statistical data[1], and is based on the records of the pressure-tube anemograph at the Meteorological Office at North Front.

The site of the anemograph and the topography of the Rock and of the surrounding country are shown in Figs. 1 and 2. The northern face of the Rock rises precipitously to a maximum height of 1,400 ft. about 1,100 yd. distant from the anemograph in the direction 145°, and falls steadily to sea level about 900 yd. away in the direction 210°. As a result, there are often marked local variations in wind speed and direction over the airfield, and, on such occasions, the anemograph winds may be completely unrepresentative of the wind conditions along the greater part of the runway. These local variations are to be investigated in detail in the near future.

Apart from the general effect of the Rock, the exposure of the anemometer head is influenced by the building on which it is sited and by groups of buildings to the south-west and west. Prior to July 1951, the anemometer head was 29 ft. above ground level and 13 ft. above the buildings in the immediate vicinity, and it appears that for all wind directions, but in particular for those between 180° and 270°, the recorded wind speeds were too low; "effective heights" of 10 ft. for the quadrant between 180° and 270° and 16 ft. for the remaining sector were adopted . In July 1951, the anemometer head was raised to a height of 39 ft. above ground level and 23 ft. above the buildings in the immediate vicinity, and new "effective heights" of 22 ft. for the quadrant

* *J. Met., Lancaster, Pa.*, **7**, 1950, p. 307.
† Atmospheric turbulence. London, 1949.
‡ Compendium of meteorology. Boston, Mass., 1951, p. 492.
§ Micrometeorology. London, 1953.
|| The science of flight. London, 1949.

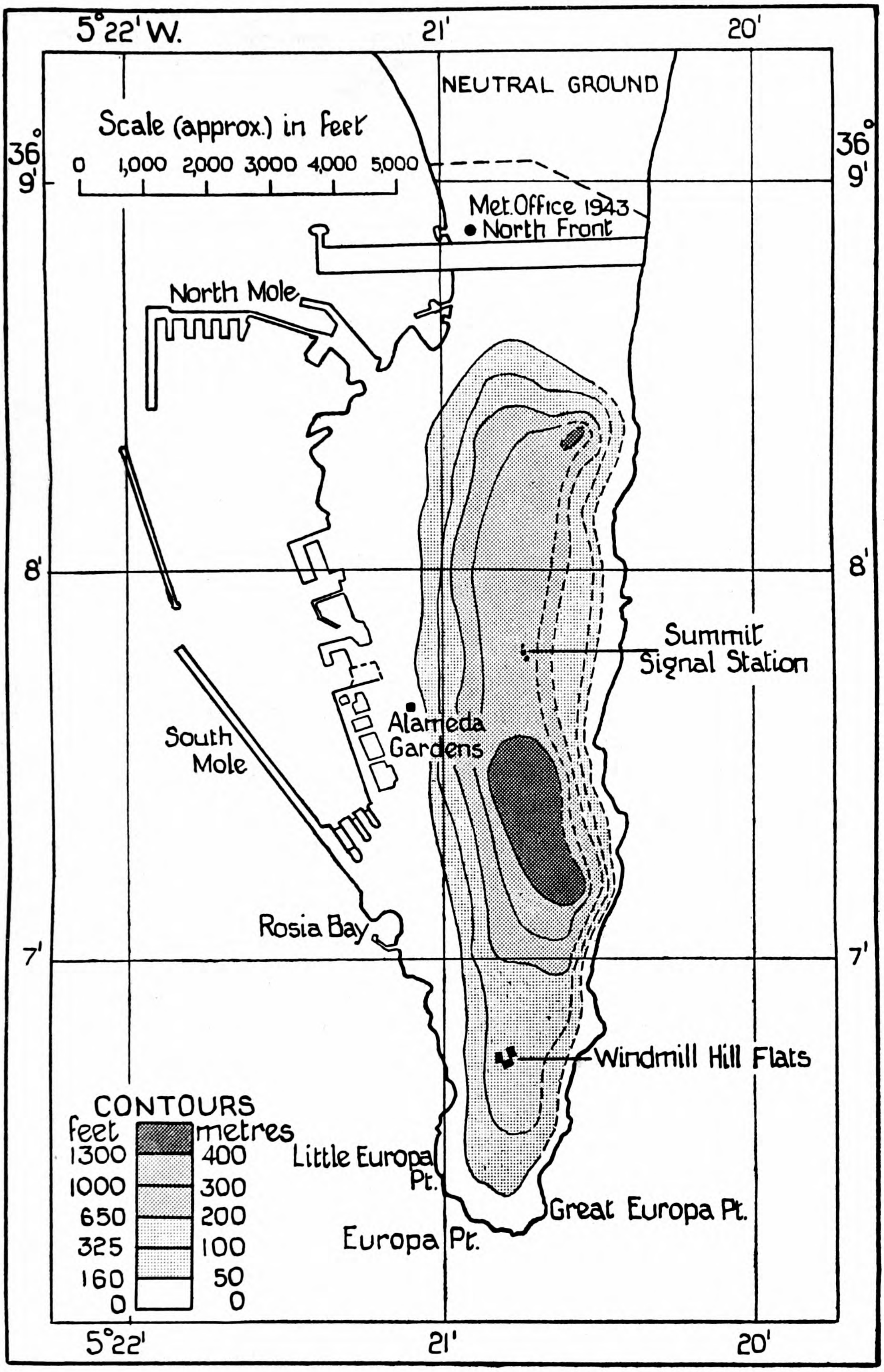

FIG. 1—PLAN OF THE ROCK OF GIBRALTAR SHOWING THE SITE OF THE METEOROLOGICAL STATION AT NORTH FRONT

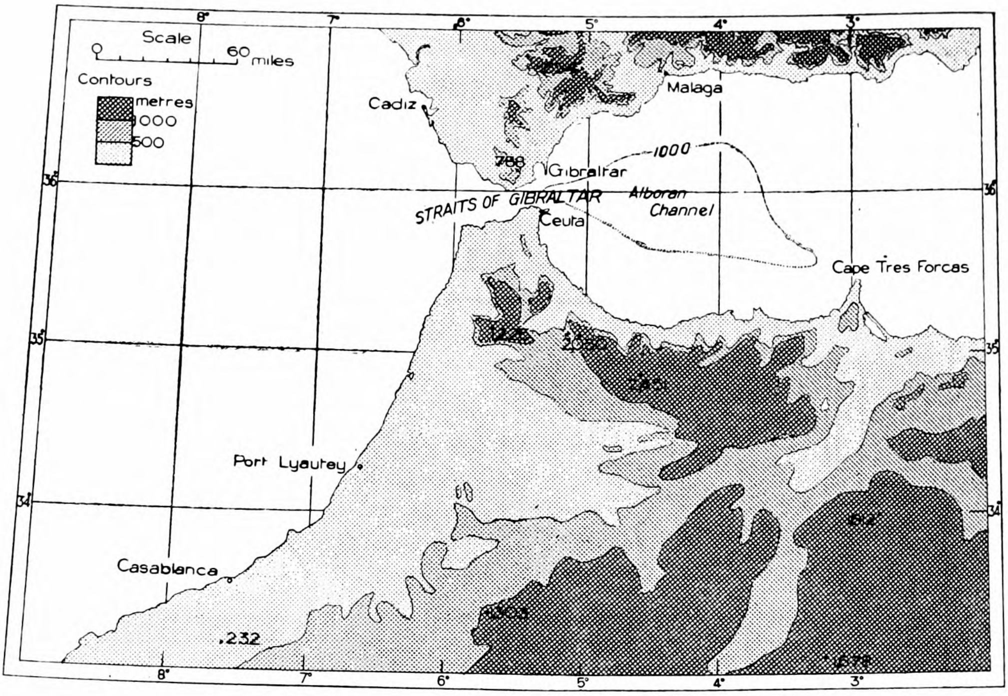

FIG. 2—TOPOGRAPHY OF THE REGION AROUND GIBRALTAR

between 180° and 270° and 33 ft. for the remaining sector were then adopted. In view of the uncertainty regarding these "effective heights", the uncorrected tabulated values of wind speed and direction were used in this investigation. On the basis of visual observations over a long period it is considered unlikely that the recorded wind directions are significantly affected by these buildings.

General nature of the air flow through the Straits of Gibraltar.—It is a well established fact that, as a direct result of the topography, the surface winds at Gibraltar are usually E. or W., and blow towards the end of the Straits where pressure is lower. The "steering" effect of the Straits is very well marked up to about 2,000 ft., and is even discernible at 5,000 ft., as illustrated in Tables I and II. It should be noted that the various columns in the tables do not all include an equal number of degrees.

TABLE I*—PERCENTAGE FREQUENCY OF SURFACE WIND DIRECTION AT NORTH FRONT

	60–120°	130–160°	170–190°	200–210°	220–230°	240–300°	310–50°
				per cent.			
January	26·1	0·5	1·2	3·7	10·5	49·3	8·9
February	28·3	0·7	2·4	7·4	12·1	45·2	3·9
March	44·6	0·7	1·3	4·2	10·4	32·5	6·2
April ...	47·9	0·8	2·3	3·9	7·0	32·3	5·6
May ...	26·2	0·8	2·1	5·0	12·4	47·8	5·5
June ...	45·2	0·6	1·7	6·1	10·9	28·6	7·0
July ...	46·7	0·4	3·6	8·2	11·5	19·7	9·9
August ...	37·3	0·3	4·2	9·9	15·8	20·7	11·9
September	44·9	0·4	3·5	6·3	12·0	23·8	9·0
October...	41·6	0·2	2·8	4·5	8·6	32·1	10·3
November	35·4	0·4	1·5	3·8	9·1	40·8	9·0
December	34·3	0·4	0·7	1·6	6·7	47·2	9·4
Year ...	37·3	0·6	2·2	5·4	10·7	36·0	7·8

*Table I is an extract from a paper by O. M. Ashford[2] and is based on tabulated records for the period 1947–51 inclusive.

TABLE II—PERCENTAGE FREQUENCY OF UPPER WIND DIRECTION AT NORTH FRONT

	360–50°	60–100°	110–120°	130–180°	190–230°	240–250°	260–300°	310–350°
				per cent.				
				At 5,000 ft. or 850 mb.				
January	13·4	19·0	7·8	4·9	7·1	7·5	22·0	18·3
April ...	9·9	17·9	15·7	8·0	6·5	7·6	18·7	15·6
July ...	2·9	13·4	13·7	18·4	19·1	10·1	17·0	5·4
October...	8·1	18·6	13·5	12·2	7·5	5·4	17·3	17·3
				At 2,000 ft. or 950 mb.				
January	2·9	30·0	9·2	3·7	6·6	5·9	29·6	12·3
April ...	3·7	39·2	6·3	2·2	3·3	3·7	31·3	10·1
July ...	2·8	42·5	6·4	2·8	2·5	1·8	30·6	10·7
October...	3·5	35·9	9·5	5·7	4·1	2·8	24·6	13·9

Table II is based on radar-wind data for three times daily at 0200, 0800 and 1400 G.M.T. over the period 1949–51 inclusive. The markedly increased frequency of winds from between 130° and 230° at 5,000 ft. in July reflects the change in the thermal pattern from winter to summer. During the winter months the frequent bursts of cold air southwards over France into the western Mediterranean result in a thermal gradient from west to east, a gradient which is reversed in summer by the intense heating over north Africa and Spain.

The theoretical and practical aspects of the air flow through the Straits have been discussed by Scorer[3,4] and Gordon[5], and the reader is referred to the original papers for a complete account . It will be sufficient to say here that a distinction must be made between occasions when convection is active up to or over mountain-top level and occasions of great stability. In the first case the interchange of momentum between the surface and upper layers results in a surface wind which closely follows the wind at about 2,000 ft., whereas in the second case the surface wind may differ appreciably from the wind at 2,000 ft. and is very noticeably directed towards the low-pressure end of the Straits.

Table I shows that, apart from E. and W. winds, the most frequent wind direction at North Front is between S. and SW. During the winter months strong south-westerly winds occur ahead of active cold fronts approaching Gibraltar from the west; the increased frequency of winds from this direction during the summer months reflects the influence of the southerly sea-breeze.

Changes of wind from west to east and from east to west.—On a large number of occasions the weather at Gibraltar is determined almost entirely by the direction of the surface wind. During the summer months a light easterly wind may advect low stratus and fog patches over the airfield[6], whereas a westerly wind is normally associated with fine clear weather, but with the attendant risk of a strong, southerly sea-breeze developing during the afternoon[7]. A correct forecast of a wind change, therefore, is often vital to the success of the whole forecast.

Table III shows, as a percentage frequency, the time of change of wind from W. to E. and from E. to W. and the average number of wind changes each season during the period 1947–51 inclusive. Occasions of calms have been classed as a continuation of the earlier régime.

The table illustrates the pronounced tendency for a wind change to E. to occur between sunrise and noon, and a change to W. to occur a few hours

TABLE III—TIME OF CHANGE OF SURFACE WIND AT NORTH FRONT

	0000 –0300	0300 –0600	0600 –0900	0900 –1200	1200 –1500	1500 –1800	1800 –2100	2100 –2400
				per cent. W. to E.				
Winter	6·8	3·9	13·6	38·0	13·6	8·7	8·7	6·8
Spring	8·6	3·8	21·0	23·8	12·4	7·6	10·5	12·4
Summer	12·5	7·0	25·0	18·8	14·1	7·8	7·0	7·8
Autumn	12·7	7·3	20·0	31·8	8·2	9·1	8·2	2·7
				E. to W.				
Winter	12·6	12·6	3·9	7·8	11·6	13·6	22·3	15·5
Spring	14·4	14·4	6·7	1·9	12·5	13·5	13·5	23·0
Summer	23·0	19·0	4·0	4·8	8·7	10·3	12·7	17·5
Autumn	12·6	12·6	19·9	8·1	5·4	14·4	15·3	11·7
				Average number of wind changes				
Winter	4·0	3·4	3·6	9·4	5·2	4·6	6·4	4·6
Spring	4·8	3·8	5·8	5·4	5·2	4·4	5·0	7·4
Summer	9·0	6·6	7·4	6·0	5·8	4·6	5·0	6·4
Autumn	5·6	4·4	8·8	8·8	3·0	5·2	5·2	3·2

after sunset. This distribution is commonly attributed to the effect of a very shallow, westerly katabatic wind which, on quiet nights, replaces any light easterly wind blowing at dusk, and reverts to a light easterly wind after dawn. It is unlikely, however, that the large number of wind changes to E. during the forenoon are entirely due to the reversal of a night katabatic wind, and it seems probable that external influences favour a wind change to E. at this time of day.

Another noteworthy feature of Table III is the marked increase in the number of wind changes to E. between midnight and 0300 in summer and autumn, an increase which is at complete variance with the idea of a dominant, westerly katabatic wind during the night. During the summer an unexpectedly large number of wind changes occur in this period, possibly the result of two effects of similar magnitude in opposition, i.e. the katabatic effect and some external effect favouring an easterly wind.

The problem is closely allied to that of the diurnal variation of wind speed during spells of easterly winds, discussed in the next section.

Diurnal variation of surface winds.—Table IV shows the percentage frequency of E. and W. winds and calms at stated hours during the period 1947–51 inclusive. In the table, winds from due N. have been included with E. winds and winds from due S. with W. winds.

The maximum frequency of westerly winds and minimum frequency of easterly winds during the night in all months reflects the influence of the westerly katabatic wind.

Westerly winds.—A distinction must be made between occasions when convection is active up to or over mountain-top level and occasions of great stability. In the former case, the solar heating during the day results in a transfer of momentum downwards, and the surface wind follows the wind at 2,000 ft., i.e. with the normal distribution of wind at 2,000 ft. the surface wind freshens and veers to westerly. Exceptions occur with light upper winds, i.e. winds of less than 15 kt., during the summer months when the sea-breeze effect is important and results in a southerly surface wind[7].

In the latter case, even with winds of 20 kt. at mountain-top level, the surface wind may remain light SW. to W. throughout the day, and frequently,

TABLE IV—SURFACE WIND DIRECTION AT NORTH FRONT AT STATED HOURS

	0000	0300	0600	0900	1200	1500	1800	2100
				per cent.				
January								
calm	5·8	7·8	8·4	6·4	2·6	..	4·5	6·4
E. wind	26·4	27·0	25·8	27·8	37·5	40·0	35·5	28·4
W. wind	67·8	65·0	65·7	65·7	60·0	60·0	60·0	65·0
April								
calm	4·7	6·7	5·3	2·0	..	0·7	..	1·3
E. wind	48·6	43·3	45·3	50·0	56·7	54·0	52·7	54·7
W. wind	46·6	50·0	49·3	48·0	43·3	45·3	47·3	44·0
July								
calm	7·1	10·3	1·9	1·9	..	..	0·7	4·5
E. wind	52·3	44·5	47·1	54·9	58·0	58·7	58·0	54·9
W. wind	40·6	45·1	51·0	43·3	42·0	41·3	41·3	40·6
October								
calm	9·0	8·4	6·4	3·2	..	..	2·6	6·4
E. wind	42·5	41·3	42·5	48·4	54·1	54·1	51·6	47·1
W. wind	48·4	50·3	51·0	48·4	45·8	45·8	45·8	46·5

in particular during the summer months, a strong southerly sea-breeze sets in during the forenoon and continues until early evening[7].

Easterly winds.—A light easterly wind by day shows a very marked tendency to become a calm or light westerly at night because of the effect of the westerly katabatic wind. However, Table III and the discussion in the preceding section show that, during summer and autumn, there is a slight tendency towards a change back to easterly between midnight and 0300 although this tendency is not apparent in Table IV.

The diurnal variation of wind speed during spells of easterly winds is unusual, and, as shown in Table V, during most of the year the maximum is reached during the forenoon with a pronounced minimum during the evening. The delayed maximum in July is attributed to a sea-breeze effect resulting in a freshening easterly wind during the afternoon. This effect has been discussed in an earlier paper[7], where it was also shown that the southerly sea breeze does not normally occur with an easterly gradient wind.

TABLE V*—DIURNAL VARIATION OF EASTERLY SURFACE WINDS AT NORTH FRONT EXPRESSED AS THE DIFFERENCE FROM THE MONTHLY MEAN

	Mean	Hour centred at 0030	0330	0630	0930	1230	1530	1830	2130
					knots				
January	20·3	−0·4	−0·1	+0·6	+1·6	+1·0	−0·3	−1·0	−1·2
April	18·8	−0·8	+0·1	+0·5	+2·6	+2·2	−0·2	−2·3	−2·4
July	13·2	−0·8	−0·5	−0·3	+1·8	+2·1	+1·1	−1·0	−2·5
October	14·3	+0·6	+0·3	−0·3	+1·3	+1·1	−0·1	−1·5	−1·6

*Table V is based on tabulated hourly values for days when the wind was easterly throughout the 24 hr. during the period 1947–51 inclusive.

Forecasters at Gibraltar have long been aware of the tendency for an easterly surface wind to freshen during the night, and this tendency is clearly illustrated in Table V. An explanation has been suggested by Scorer[4]. He argues that if the easterly wind decreases with height in the mixing layer—a common occurrence at Gibraltar—the transfer of momentum upwards from the surface layer will be decreased at night owing to increased stability, and the surface wind should therefore increase. This theory has been investigated statistically for the period 1947–51 inclusive, and the results are presented in Table VI.

TABLE VI—CHANGES IN STRENGTH OF EASTERLY WINDS WITH HEIGHT

	Easterly wind decreasing with height at 0200	Easterly wind increasing with height at 0200
	No. of occasions	
Surface easterly wind increased at night	33	55
Surface easterly wind decreased at night	5	38

The investigation was not entirely objective, since there were no ready means of ascertaining whether or not an increase or decrease of surface wind at night was due to external causes. In practice, it was assumed that the general situation had remained unchanged throughout the night if the radar winds, as given by the preceding 1400 observation, the 0200 observation in question, and the succeeding 0800 observation, varied by less than 5 kt. The depth of the mixing layer was assumed to be the level of marked wind change shown by the 0200 observation; this was usually about 3,000 ft.

The results confirm that an easterly wind decreasing with height normally results in a freshening easterly surface wind at night, but also indicate that on a large number of occasions a freshening surface wind is associated with an increasing wind with height. In view of this, and the results of an earlier investigation by Skelton[8]—of which an extract is given in Table VII—based on the records from the anemometer at 1,310 ft. above sea level, at the summit of the Rock, it seems that the increase in wind speed may be general throughout the mixing layer.

TABLE VII—DIURNAL VARIATION OF EASTERLY WINDS AT THE SUMMIT OF THE ROCK

	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
	knots											
Difference from mean value	+0·9	+0·9	+1·0	+1·1	+1·2	+1·1	+1·0	+1·0	+0·9	+0·9	+0·5	+0·2

	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
	knots											
Difference from mean value	−0·1	−0·4	−0·9	−1·3	−1·6	−1·5	−1·2	−1·1	−0·9	−0·7	−0·3	−0·1

It will be noticed that, at the summit of the Rock, the maximum and minimum values are reached some 4–6 hr. earlier than on the surface; no satisfactory explanation of this effect can be suggested.

Although the explanation for a freshening easterly wind at night suggested by Scorer must apply to a certain extent, it cannot now be accepted as complete. A further contributory factor may be the diurnal pressure changes in the vicinity of Gibraltar, and these will be discussed in the next section.

Diurnal pressure variations in the vicinity of Gibraltar.—In the experience of forecasters at Gibraltar, a wind change at North Front often occurs soon after the reversal in sign of the pressure difference between Malaga and Casablanca, i.e. easterly winds being associated with a positive difference and westerly winds with a negative difference. A knowledge of the diurnal pressure variations at these stations is therefore important for forecasting surface-wind changes at North Front, and the results of an investigation based on data extracted from the working charts at Gibraltar are presented in Table VIII. The period covered is 1950–52 inclusive, except for January where it is 1951–53 inclusive. A number of observations were missing from the Gibraltar charts, and the investigation was eventually restricted to days for which observations were available at all of the eight synoptic hours; the minimum number of such days was 47. The diurnal pressure variations at Gibraltar, based on observations during 1950–52 inclusive, are included for comparison.

TABLE VIII—DIURNAL VARIATION OF PRESSURE AT MALAGA, GIBRALTAR AND CASABLANCA EXPRESSED AS THE DIFFERENCE FROM THE MONTHLY MEAN

	Station	Mean	0000	0300	0600	0900	1200	1500	1800	2100
			millibars							
January	Malaga	1021·48	+0·45	+0·22	−0·27	+0·57	+0·49	−0·86	−0·58	−0·02
	Gibraltar	1020·27	+0·19	−0·12	−0·38	+0·67	+0·57	−0·84	−0·36	+0·27
	Casablanca	1021·17	+0·17	−0·17	−0·51	+0·73	+0·69	−0·83	−0·35	+0·28
	Malaga — Casablanca		+0·28	+0·39	+0·24	−0·16	−0·20	−0·03	−0·23	−0·30
April	Malaga	1017·14	+0·38	+0·02	−0·20	+0·58	+0·33	−0·58	−0·81	+0·26
	Gibraltar	1016·23	+0·40	−0·47	−0·34	+0·44	+0·52	−0·43	−0·63	+0·48
	Casablanca	1016·92	+0·41	−0·53	−0·40	+0·48	+0·44	−0·49	−0·47	+0·59
	Malaga — Casablanca		−0·03	+0·55	+0·20	+0·10	−0·11	−0·09	−0·34	−0·33
July	Malaga	1017·19	+0·69	−0·06	−0·03	+0·53	+0·65	−0·14	−1·30	−0·36
	Gibraltar	1015·91	+0·39	−0·30	0·00	+0·64	+0·66	−0·28	−1·03	−0·06
	Casablanca	1016·77	+0·62	−0·34	−0·22	+0·40	+0·34	−0·50	−0·71	+0·38
	Malaga — Casablanca		+0·07	+0·28	+0·19	+0·13	+0·31	+0·36	−0·59	−0·74
October	Malaga	1018·63	+0·19	−0·36	−0·31	+0·74	+0·49	−0·61	−0·50	+0·37
	Gibraltar	1017·41	+0·20	−0·49	−0·43	+0·73	+0·53	−0·66	−0·39	+0·49
	Casablanca	1017·66	+0·36	−0·42	−0·39	+0·71	+0·43	−0·82	−0·54	+0·47
	Malaga — Casablanca		−0·17	+0·06	+0·08	+0·03	+0·06	+0·21	+0·04	−0·10

Some interesting features of the diurnal changes emerge. In January and April, the evening pressure rise takes place earlier at Casablanca than at Malaga; one would expect the westward-moving pressure wave to produce rising pressure earlier at Malaga. In all seasons, the pressure rise at 2100 is noticeably greater at Casablanca than at Malaga.

The difference, Malaga — Casablanca, shows a minimum between 1800 and midnight and a maximum around 0300 in January and April and around 1500 in July and October. The diurnal variation of the difference has a pattern similar to that of the diurnal variation of the speed of easterly winds shown in Table V, and the minima appear to be very closely related. The complete break-down of the geostrophic relationship in the Straits, where the low-level flow is dominated by the accelerational terms in the equations of motion[4], makes it difficult to assess the effect of the pressure differences on the wind velocity at Gibraltar; but it is clear that the net pressure rise at Malaga between 2100 and 0300, a rise which is particularly well marked in July, will result in an addition to any existing wind of an isallobaric wind component from the north-east.

Conclusions.—Marked changes of wind may occur at North Front without any apparent change in the general pressure distribution. A wind change to E. occurs preferentially during the forenoon and a change to W. preferentially after dusk, and, in the main, this distribution may be attributed to the effect of a westerly katabatic wind frequently replacing a light easterly wind blowing at dusk and reverting to a light easterly after dawn.

The marked increase in the number of wind changes to E. between midnight and 0300 in summer and autumn, and the tendency for a freshening easterly wind after 2100, require some further explanation. It now seems probable that these effects are due to the diurnal pressure variations in the vicinity of Gibraltar, which favour a maximum westerly wind between 1800 and midnight and a maximum easterly wind at about 0300 in January and April and at about 1500 in July and October. The tendency for a maximum easterly wind at about 0300 in January and April is not reflected in the frequency tables of wind direction at North Front, and is probably over-compensated by a stronger katabatic flow during these months.

It is not at all clear why such marked differences in the diurnal pressure variation between Malaga and Casablanca should arise, but it is possible that the pressure variation at Malaga is greatly influenced by a pronounced anabatic and katabatic flow in the mountainous coastal regions bordering the Alboran Channel.

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ELECTRONIC COMPUTATION OF THE FIELD OF ATMOSPHERIC DEVELOPMENT

By F. H. BUSHBY, B.Sc. and M. K. HINDS, B.Sc.

Introduction.—For some years upper air charts have been used increasingly in forecasting, and it is important to know as much as possible about the relationship of upper air patterns to surface developments. Sutcliffe[1], in his formula expressing cyclonic and anticyclonic development in terms of rates of change of vorticity and the vertical shear of the horizontal wind, made an important contribution to this subject. In recent years forecasters have been using ideas based qualitatively on this theory (Sutcliffe and Forsdyke[2]), but until now all methods applying the formula quantitatively have proved too lengthy to be of practical use. However, with the advent of modern electronic computing machinery the calculations necessary to produce a chart of Sutcliffe's expression for development can be carried out within a few minutes, and it was considered desirable to study the practical value of such charts.

In the present article an outline is given of a method of evaluating the field of development using an electronic computing machine. One development chart is described in relation to the relevant synoptic situation, and some general observations are made on the results of twelve such computations which have been described in detail by Bushby and Hinds[3].

Method of Computation.—Sutcliffe[1] has shown that, subject to various approximations, the relative divergence between two pressure levels p_0 and p_1 is given by

$$l\,(\mathrm{div}_p\,\mathbf{V}_1 - \mathrm{div}_p\,\mathbf{V}_0) = -\mathbf{V}'.\,\mathrm{grad}_p\,(l + \zeta_0 + \zeta_1) \quad \ldots\ldots (1)$$

where l is the Coriolis parameter, $\mathbf{V}_0$, $\mathbf{V}_1$, ζ_0 and ζ_1 are the horizontal wind velocities and the vertical components of vorticity at the pressure levels p_0 and p_1, $\mathbf{V}'$ is the vertical wind shear $\mathbf{V}_1 - \mathbf{V}_0$, and the suffix p represents differentiation in an isobaric surface with respect to orthogonal curvilinear distance co-ordinates on the sphere.

It has been shown by Sutcliffe[4] that the left-hand side of equation (1) can be interpreted in terms of vertical motion, and hence in terms of cyclonic and anticyclonic development. If $p_0 > p_1$ then the left-hand side of equation (1) is positive for ascending motion and negative for descending motion.

The equation is particularly valuable because the horizontal divergence which appears on the left-hand side cannot be estimated from geostrophic winds, and even when the most dense network of actual wind observations is available, the values of divergence which can be obtained are inadequate to give a satisfactory estimate of the difference of divergence between two levels. It is, however, permissible to substitute geostrophic values in the right-hand side of equation (1), and it is then practicable, using finite difference methods, to calculate its value over a network of points.

The values of p_0 and p_1 used in the computation were 1000 mb. and 500 mb., and the development term was evaluated at a network of 12×8 points covering most of the north-east Atlantic and western Europe (see Fig. 1). When an electronic computing machine is used for this computation it is necessary to feed into the machine the values of the 500-mb. height and 1000–500-mb. thickness at the points of a 16×12 grid, these being read directly from the working charts. It is also necessary to feed into the machine a programme of orders instructing it how to do the computation, together with the value of $\sin \phi$ (where ϕ is the latitude) for each grid point. The programme and the $\sin \phi$'s are of course the same for each computation, and only need to be prepared once. Both data and programme are fed into the machine on punched tape similar to that used by teleprinters. The answers are printed on a teleprinter attached to the machine.

For each computation the machine took 3 min. to read in the programme and data, 1 min. to perform the calculations and $1\frac{1}{2}$ min. to print the results, making a total of $5\frac{1}{2}$ min. machine time. It is necessary to allow a certain time for reading data off charts, punching data tapes and plotting the answer, but it is estimated that a development chart could be produced in about 1 hr. from the time the initial charts were ready. This compares very favourably with the 4–5 hr. that would be needed if a Sawyer-Matthewman[5] scale were used, the most efficient method of hand computation.

Results.—The development chart computed for 1500 G.M.T. March 14, 1949 is shown in Fig. 1, and Figs. 2, 3 and 4 give a series of three synoptic charts at 12-hr. intervals. Anticyclonic development areas are shown as positive and cyclonic development areas as negative. These may be directly associated with vertical motion but only indirectly with surface pressure changes.

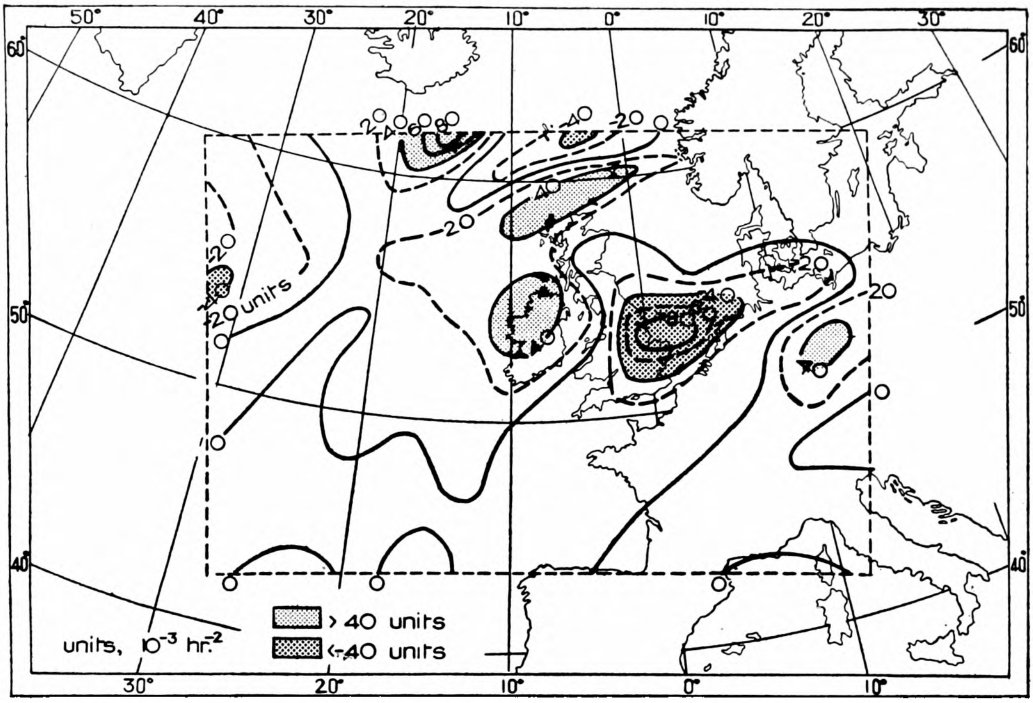

FIG. 1—DEVELOPMENT CHART, 1500 G.M.T., MARCH 14, 1949

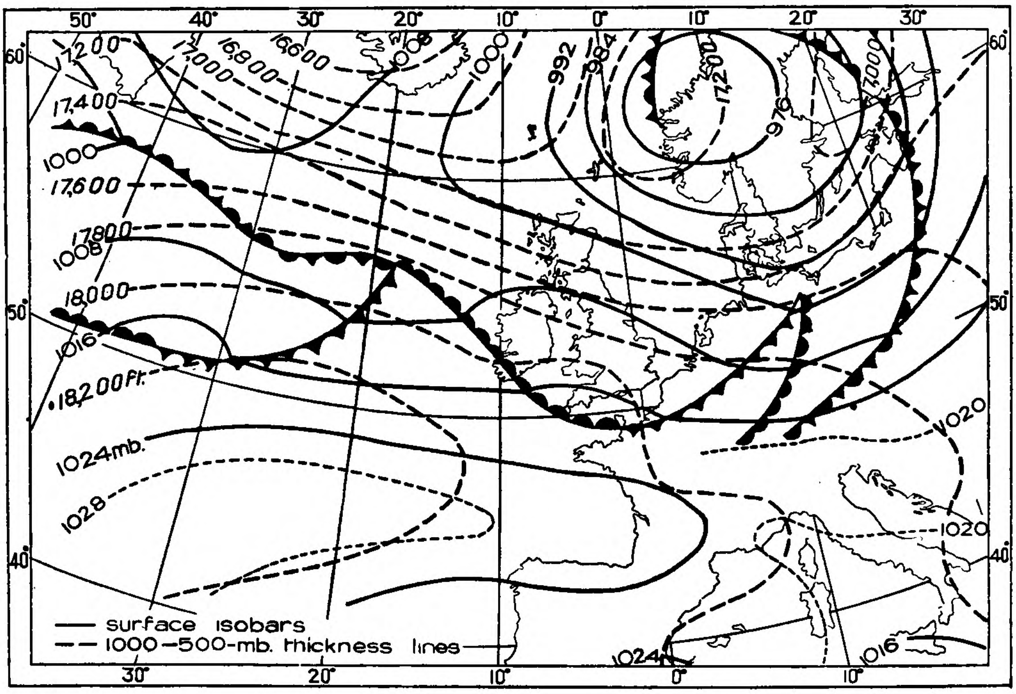

FIG. 2—SYNOPTIC CHART, 0300 G.M.T., MARCH 14, 1949

Fig. 1 in conjunction with Fig. 3 indicates the eastward motion of the main troughs and ridges in the latitude of the British Isles as maximum anticyclonic development areas occur to the east of the main ridges and cyclonic development areas occur to the east of the main troughs. Corresponding movements did in fact occur. A negative area between the Faeroes and Lerwick and a marked

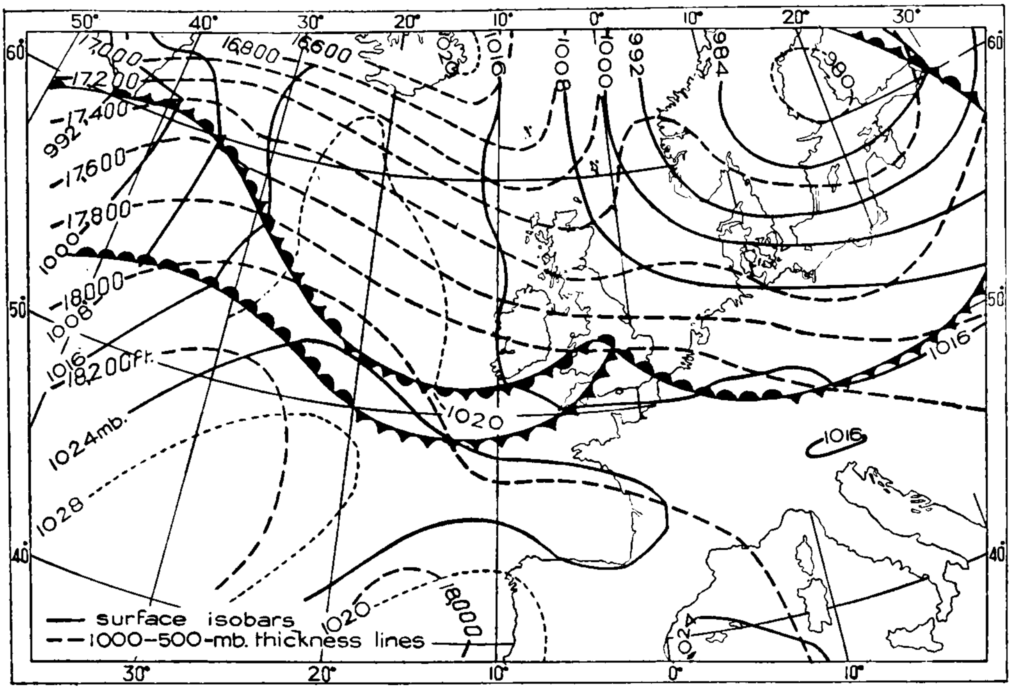

FIG. 3—SYNOPTIC CHART, 1500 G.M.T., MARCH 14, 1949

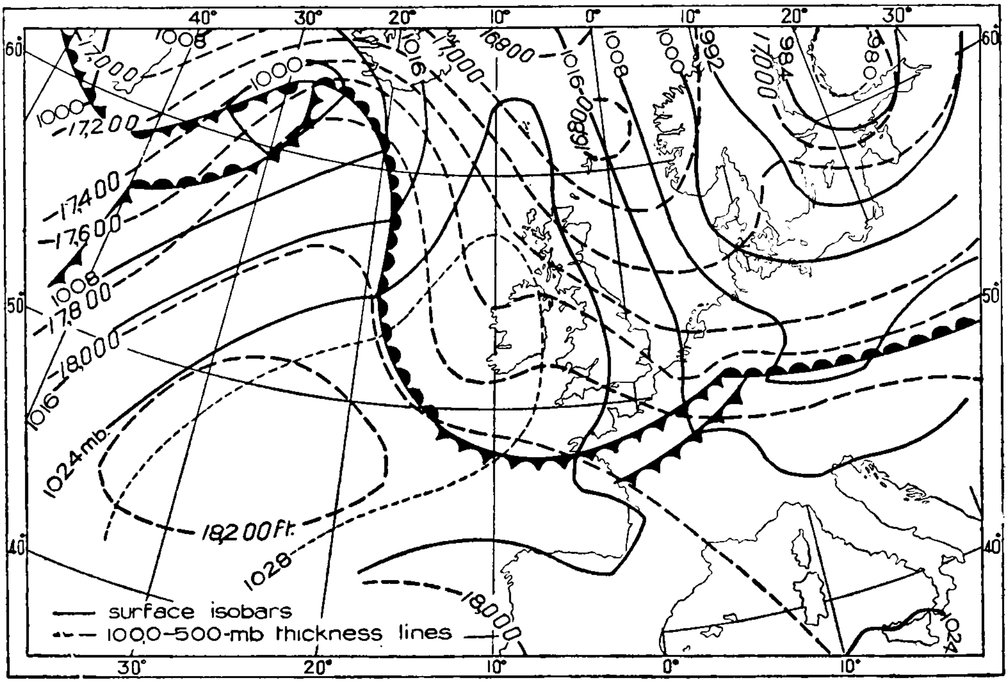

FIG. 4—SYNOPTIC CHART, 0300 G.M.T., MARCH 15, 1949

positive area slightly further west are in agreement with the formation of a cut-off cold pool to the north of Lerwick and the strengthening of the surface-pressure ridge at 10°W. Another feature of note is the negative area about 55–60°N. 30°W. A quite well marked surface trough had appeared in this region by 0300 G.M.T. March 15, with a break-away depression at 63°N. 30°W. just outside the area for which the computation was made.

Development charts were also produced for eleven other occasions so that their usefulness in various synoptic situations could be judged.

All development areas numerically greater than 40 units (10^{-3} hr.$^{-2}$) have been classified as follows, according to their value to the forecaster:—

A ≡ useful guidance.
B ≡ not particularly useful, but not misleading.
C ≡ misleading.

The B classification has been used mainly for those development areas which were greater than 40 units but which were overshadowed by other development areas. Although this is a very subjective classification it gives some idea of the usefulness of development charts, and a summary of the results is shown in Table I.

TABLE I—NUMBER OF CASES IN EACH CLASS

A	B	C
41	36	13

There were many more development areas in class A than class C, whilst most of those in class B might have been disregarded by forecasters with experience in the use of development charts.

The more intense features on the development charts were nearly always, though not invariably, connected with an appropriate change in the synoptic situation. There also appeared to be some connexion between rainfall and maximum cyclonic development areas, but there were occasions when rainfall forecasts based on the development charts would probably have been wrong.

Features of lesser intensity are difficult to assess. They may be irrelevant, having been arbitrarily brought into the computations, either as a result of difficulties of interpolation in reading data from the charts, or from slight inconsistencies in the analysis. Alternatively, these features may be real, and if development charts were used as an aid to forecasting one would have to decide whether they were significant as individual features or whether they were likely to be swamped by adjacent, more intense, developments.

Conclusions.—Given the necessary computing facilities it is now possible to have development charts computed in about an hour from the time the initial charts are ready. It seems probable that such charts would be useful to the forecaster, although it is difficult to assess their practical value without a test under working conditions. However, if electronic facilities are available, more elaborate calculations become possible with little increase in the time involved; better estimates of vertical motion are likely to be possible than those obtained simply from development charts and therefore the introduction of electronic computing machinery for the routine calculation of development charts seems somewhat premature.

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FOG INVESTIGATION AT WELLESBOURNE MOUNTFORD

By W. W. CLEAVER and R. A. S. RATCLIFFE, B.A.

An investigation has been made into the frequency of fog at Wellesbourne Mountford based on observations for the period September 1941 to January 1946. Wellesbourne Mountford is situated in the Avon Valley some 150 ft. above M.S.L.; it is almost surrounded by low hills of the order of 300 ft. high. It is 5 miles east of Stratford-on-Avon and 10 miles south-south-west of Leamington Spa. The area within about 20 miles radius is mainly rural, the greater Birmingham area lying some 20 miles to the north-north-west. The soil is clay.

Fig. 1 shows the diurnal variation of fog frequency. The basis of the diagram is a statistical analysis of all occasions when visibility was reported as less than 1,100 yd. (excluding those cases adjudged due to heavy precipitation). Observations were divided into 5-day periods. To smooth out irregularities, means over a 15-day period were taken. Throughout Fig. 1 the percentage frequency ascribed to each 5-day period is the mean over a 15-day period and is usually based on 75 observations in the 5-yr. period.

Of the several factors affecting the formation and persistence of fog at Wellesbourne Mountford, the following two appear to be important:—

(i) Slow drainage of cooled air into the Avon Valley from the low hills surrounding the station, this may be the most important single factor.

(ii) Clay soil which easily becomes waterlogged and is usually permanently wet from late September until March.

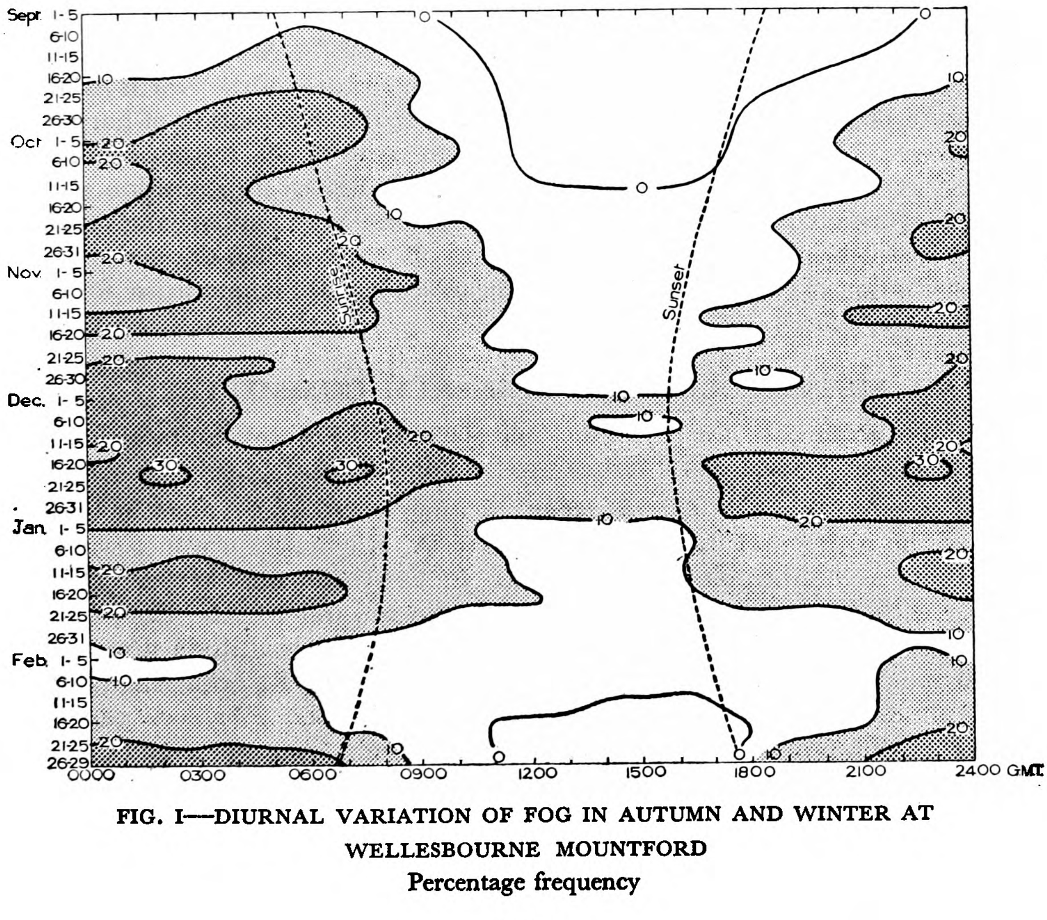

FIG. 1—DIURNAL VARIATION OF FOG IN AUTUMN AND WINTER AT WELLESBOURNE MOUNTFORD

Percentage frequency

The most interesting points in Fig. 1 are the differences between this diagram and a similar one prepared for London Airport[1]. The chief differences are:—

(i) Maximum frequency of fog at Wellesbourne Mountford always occurs immediately before sunrise, whereas London Airport has a maximum 2–3 hr. after sunrise in the winter months.

(ii) There is no minimum before sunrise in winter at Wellesbourne Mountford such as occurs at London Airport.

(iii) Higher general fog frequency at Wellesbourne Mountford.

Factors (i) and (ii) of the foregoing paragraph would appear to indicate that there is in general little smoke pollution at Wellesbourne Mountford. Fig. 1 is very akin to a similar type of diagram showing the frequency of mist at Mildenhall[2], another rural situation. Fig. 1 may well be typical of a country station uncomplicated by smoke pollution.

The high general fog frequency is therefore probably due to the valley situation and the saturated clay soil in the winter half of the year.

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OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 90.—*Seasonal change of surface temperature of the North Atlantic Ocean.* By T. H. Kirk, B.Sc.

The facts of the seasonal change of surface temperature of the North Atlantic Ocean are presented by means of charts showing the distribution of harmonic parameters. This method makes it possible to write down, by inspection, an analytic expression for the process of seasonal change at any position within the area of the charts. The influence of the various factors underlying seasonal change is also briefly discussed. A new series of charts is then derived to show the distribution of the rate of change of mean sea-surface temperature for each month of the year.

METEOROLOGICAL RESEARCH COMMITTEE

The 27th meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on July 9, 1953.

The meeting was devoted to papers dealing with upper winds in various parts of the world and included one by Mr. A. Gilchrist[1] on upper winds in the tropics and subtropics, one by Miss E. E. Austin and Mr. D. Dewar[2] dealing with upper winds over the Mediterranean and Middle East, one by Mr. J. K. Bannon[3] dealing with the structure of the high-altitude strong wind belt in the Middle East in winter and one by Lieut. R. R. Fotheringham[4] on high-altitude winds over the ocean weather ship *Polar Front*. A paper by Mr. D. H. Johnson[5] on the accuracy of the 100-mb. contour height was also considered.

ABSTRACTS

1. GILCHRIST, A.; Upper winds in the tropics and subtropics. *Met. Res. Pap., London*, No. 795. S.C. II/141, 1953.

With a view to revision of "Upper winds over the world" charts showing mean winds (40°N.–40°S.) for January, April, July and October at 300, 200, 150 and 100 mb. are given, based on rawind observations and geostrophic winds mostly for 1951. Cross-sections of mean zonal winds and potential temperature are given for 80°W., 45°E., 140°E. and 165°E. All charts show a subtropical westerly jet, about 30°N. in winter, further north in summer; structure is shown for individual days. Nearer equator is a system of easterlies.

2. AUSTIN, E. E. and DEWAR, D.; Upper winds over the Mediterranean and Middle East. *Met. Res. Pap., London,* No. 811, S.C. II/148, 1953.
Monthly vector resultant winds, standard vector deviations and scalar mean velocities 1948–50 for 8 British stations between Gibraltar, Habbaniya and Nairobi, 850–100 mb., are shown in tables and plotted. A number of points are brought out, including a subtropical jet in winter.

3. BANNON, J. K.; Note on the structure of the high-altitude strong wind belt in the Middle East in winter. *Met. Res. Pap., London,* No. 821, S.C. II/155, 1953.
Upper winds and temperatures at Habbaniya and Bahrein 400–60 mb. were plotted twice daily for January 1951 (example shown January 12–14) and a mean cross-section drawn for 45°E. Position of belt of strongest winds (between lower and upper tropopauses) was estimated. The 100-kt. isokinetic is about 700 miles wide; level of maximum wind falls southwards.

4. FOTHERINGHAM, R. R.; High-altitude winds at O.W.S. *Polar Front. Met. Res. Pap., London,* No. 812, S.C. II/149, 1953.
Upper wind velocities in 66°N. 2°E., June 1948–April 1952, are plotted to show seasonal frequencies at 19,600–64,000 ft. above various speeds (80–160 kt.). There is a marked maximum at 25,000–30,000 ft. and a decrease in summer compared with other seasons. Directions are mainly westerly. Results are compared with Larkhill and Lerwick.

5. JOHNSON, D. H.; The accuracy of 100-mb. contour heights. *Met. Res. Pap., London,* No. 800, S.C. II/144, 1953.
Observed winds at 100 mb. over British Isles are reasonably accurate, and discrepancies with slope of 100-mb. levels are due to errors in the latter. Comparisons give standard error in height measurement of 100-mb. surface as 145 ft.

The 25th meeting of the Physical Sub-Committee of the Meteorological Research Committee was held on July 10.

At this meeting Dr. G. D. Robinson[1] presented a report dealing with some examples of the energy spectrum of turbulence in the atmosphere near the ground and Mr. N. E. Rider[2] described some work in which he continued an earlier investigation into the eddy diffusion of momentum, water vapour and heat in the lowest two metres of the atmosphere. A laboratory investigation into the temperature decay law of a naturally convected air stream with distance from its source of heat was described by Dr. W. Railston[3]. An experiment in the measurement of wind shear in the free atmosphere by taking a sequence of photographs of a vertical smoke trail laid by an aircraft was reported by Mr. I. J. W. Pothecary and Mr. R. J. Murgatroyd[4]. Recently the Meteorological Research Flight, in collaboration with the Clarendon Laboratory at Oxford, have made measurements of the vertical distribution of atmospheric ozone at heights up to 12 Km. A report of the preliminary measurements was presented by Dr. R. H. Kay[5] of the Clarendon Laboratory.

ABSTRACTS

1. ROBINSON, G. D.; Some examples of the energy spectrum of turbulence in the atmosphere near the ground. *Met. Res. Pap., London,* No. 808, S.C. III/151, 1953.
A number of hot-wire records of air speed, 150 cm. above ground at Kew Observatory, including large positive and negative temperature gradients were analysed by autocorrelation of readings at intervals of $\frac{1}{8}$ or $\frac{1}{4}$ sec. The three components of turbulent motion were equal (isotropic turbulence) at frequencies of 3 c./sec. to limit of observation at 8 c./sec., and energy varied as inverse square of frequency, in accord with Kolmogoroff. Horizontal components were equal above 1·5 c./sec. The local rate of viscous dissipation appeared to balance the local rate of working of Reynolds stress.

2. RIDER, N.E.; The eddy diffusion of momentum, water vapour and heat near the ground. *Met. Res. Pap., London,* No. 809, S.C. III/152, 1953.

Vertical profiles of wind, temperature and humidity 15–200 cm. above short grass at Cardington, with rate of evaporation, aerodynamic surface drag and components of heat balance, are tabulated. Eddy diffusivities of momentum, water vapour and heat are calculated. It is found that wind speed and temperature profiles always, and humidity generally, had the same form. In adiabatic conditions (R_i small) the established laboratory law for surface drag holds with $k = 0 \cdot 41$ and $Z_0 = 0 \cdot 3$ cm. In unstable conditions E. L. Deacon's generalized wind-profile law holds; in stable conditions the equations of C. G. Rossby and R. B. Montgomery, or of B. Holzman, hold. It is found that diffusivities for momentum and vapour are given by identical parameters and are equal in all conditions, but that of heat is sometimes larger.

3. RAILSTON, W.; The temperature decay law of a naturally convected air stream with distance from its source of heat. *Met. Res. Pap., London,* No. 818, S.C. III/155, 1953.

In air rising from an electrically heated 3½-cm. gauze square, temperatures were measured by thermistor at points 5–70 cm. above gauze. Rising air stream was observed by a very sensitive Schlieren system to exclude draughts. Mean temperature distribution across rising jet, corrected for radiation, was represented by

$$91 \cdot 3 \; Q^{0 \cdot 675} \; Z_0^{-1 \cdot 52}$$

where Q = heat output in watts and Z_0 = height above theoretical equivalent point source. An expression was also derived for width of rising jet. Both these agreed closely with theoretical formulae due to O. G. Sutton.

4. POTHECARY, I. J. W. and MURGATROYD, R. J.; The use of aircraft to measure wind shear by observation of vertical smoke trails. *Met. Res. Pap., London,* No. 810, S.C. III/153, 1953.

Describes trails of a smoke generator falling vertically from an aircraft, producing a trail 5,000 ft. long which is observed and photographed from a second aircraft. Examples are shown and analysed, and improvements suggested.

5. KAY, R. H. (Clarendon Laboratory, Oxford); An interim report on the measurement of the vertical distribution of atmospheric ozone by a chemical method to heights of 12 Km. from aircraft. *Met. Res. Pap., London,* No. 817, S.C. III/154, 1953.

Measurements of ozone by oxidation of potassium iodide (Ehmert's method) on 13 flights are described. Amounts below 12 Km. (0·001–0·002 cm./Km.) averaged 8 per cent. of total O_3. No regular discontinuity was found at tropopause. Results compare well with Umkehr method.

The 28th meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on July 22, 1953.

At this meeting the Committee discussed a paper by Mr. J. S. Sawyer and Mr. F. E. Dinsdale[1] on cloud in relation to active warm fronts, and a paper by Mr. D. H. Johnson and Miss Sylvia Daniels[2] on rainfall in relation to the jet stream. Two interesting papers analysing observations made by the Meteorological Research Flight were also considered. The first by Mr. J. S. Sawyer[3] discussed the free atmosphere in the vicinity of fronts and the second by Mr. R. Murray[4] discussed the upper troposphere and lower stratosphere near jet streams. The problem of standing waves and dangerous flying conditions near mountains was also considered.

ABSTRACTS

1. SAWYER, J. S. and DINSDALE, F. E.; Cloud in relation to active warm fronts near Bircham Newton during the period April 1942 to April 1946. *Met. Res. Pap., London,* No. 799, S.C. II/143, 1953.

Clouds observed by airplane were classified and analysed statistically. Results confirm that cloud increases towards front. There is some increase with increasing frontal slope and with decreasing pressure thickness of frontal zone. Cloud is mainly in warm air more than 200 miles from front, but extends down through frontal zone nearer the surface front. Positive relations were found with speed difference between surface and upper wind normal to surface front and with speed differences of warm air and surface front.

2. JOHNSON, D. H. and DANIELS, S.; Rainfall in relation to the jet stream. *Met. Res. Pap., London,* No. 803, S.C. II/145, 1953.

Rainfall in British Isles was tabulated against position in regard to axis, entrance, centre and exit of jet streams. Means per hour: entrance, left of axis 0·9 mm., right 1·8 mm.; centre, left 2·4, right 2·3; exit, left 4·6, right 2·3. Amounts within 50 miles of axis generally small. The preponderance of rainfall to right of confluence and left of diffluence implies mean cross-axis vertical circulations with ascent beneath the right entrance and left exit, and descent beneath left entrance and right exit, in accord with dynamical theory.

3. SAWYER, J. S.; The free atmosphere in the vicinity of fronts—analysis of observations by the Meteorological Research Flight, 1950–52. *Met. Res. Pap., London*, No. 807, S.C. II/147, 1953.
Analyses 23 flights to study structure of fronts, with temperature and frost-point profiles, synoptic situations and cross-sections. Discussion deals with thermal, humidity and cloud structure and turbulence (not especially great except in convective clouds), illustrated by frequency histograms. Results showed the great complexity of frontal regions. Fronts are associated with a sloping baroclinic zone; about half the temperature contrast lies within a width of 100–200 miles. Irregularities of temperature of 1–5°F. are associated with condensation, precipitation and evaporation. Main frontal cloud usually forms in warm air and extends into transition zone.

4. MURRAY, R.; The upper troposphere and lower stratosphere near jet streams: an examination of observations made by the Meteorological Research Flight, Farnborough. *Met. Res. Pap., London*, No. 813, S.C. II/150, 1953.
From 20 special flights near jet stream and synoptic studies it is found that: (i) mean temperature gradient was 3°F./100 n. miles, and structure agreed with that normally given by vertical sections; (ii) frost point was variable; average relative humidity at jet-stream level was 50 per cent. 300 miles to right of axis (looking down wind) and 10 per cent. 300 miles to left; (iii) layer cloud occurred to right of axis but not to left or above, consistent with ascent in troposphere on high-pressure side and descent on low-pressure side; (iv) tropopause on low-pressure side is sometimes disrupted. Occurrence of clear-air turbulence is also discussed.

INSTITUTE OF NAVIGATION

At the meeting of the Institute of Navigation held on June 26, 1953, papers were read by Mr. D. G. Harley on "Equivalent tailwinds Shannon–Gander on actual and forecast charts" and by Mr. C. S. Durst on "The accuracy of wind forecasts for aviation".

Mr. Harley described the results of a comparison between forecasts prepared at the meteorological office, London Airport, of tailwinds for west-bound flights across the Atlantic Ocean to Gander along the great circle route and subsequent estimates of the same winds from the isobaric contour charts drawn up for a time during the currency of the forecast. The forecast charts are composite charts so that the time of validity varies along the route. The time interval between the taking of the observations on which the forecast is based and the period of validity also varies along the route; it is about 20–24 hr. at the mid point. The work was done for the 700-mb. and 500-mb. levels for the period April 1949 to May 1953. The forecasts were made in the conventional manner by drawing predicted contour charts and measuring geostrophic winds on them. Seasonal means of the equivalent tailwinds were given for each year. These means showed a considerable variation from year to year, but on the whole the monthly means at 700 mb. were about −28 kt. (i.e. headwind) in winter, the season of strongest winds, and −12 kt. in spring, the season of lightest mean winds; corresponding values at 500 mb. were −40 kt. in winter and −17 kt. in spring. The standard deviations were about half the means except in spring when they approximated to the mean values. Extreme values were, at 700 mb. −68 kt. and +29 kt. and at 500 mb. −124 kt. and +35 kt. Comparison of these estimated actual winds with those forecast and of those forecast with the winds found by the aircraft is very difficult for several reasons. However, subject to some uncertainty, the mean seasonal differences between forecast tailwinds and values subsequently estimated are less than 2 kt. in absolute magnitude at both levels with standard deviations of from 6 to 13 kt. The differences satisfy the normal law of errors. A curve of the percentage frequencies of errors less than specified amounts showed that only 5 per cent. of the differences in winter, the worst season, exceeded 25 kt. at 500 mb. or 18 kt. at 700 mb., and it was pointed out that many large errors were associated with headwinds too strong for a direct crossing to be attempted. Appreciable errors are often associated with the timing of new developments. Finally, Mr. Harley compared the errors found with those to be expected from other methods. It appeared that the conventional forecasting methods over the North Atlantic route gave standard errors about 1 kt. less than those to be expected from a regression equation technique and nearly 2 kt. less than those to be expected from using "actuals" as forecasts.

The main theme of Mr. Durst's paper was the accuracy of forecasts of upper winds issued to pilots shortly before departure, with illustrations from the forecasts for flights of Comet aircraft at 40,000 ft. between London and Rome. Special attention was directed to the accuracy necessary in forecasting upper winds in relation to the accuracy of navigation in flying at great heights. Mr. Durst pointed out that the standard error of forecasts by conventional contour analysis of winds at 40,000 ft. was about 15 kt. at one point and rather less for a mean wind over a distance. In equatorial regions between about latitude 20°N. and 20°S. the contour technique could not be used, and measured winds provided the only reliable information. The high cost of upper air observing stations makes it essential for them to be situated where their observations will be most useful. A major factor is the variability of wind which, represented by the standard deviation of departures from the mean, has been charted in *Geophysical Memoirs* No. 85. The variation of wind in any given period and the errors of forecasting are proportional to the standard deviation. Mr. Durst then described the results of a check of the accuracy of the assessment of the tailwind at 40,000 ft. on the route from London to Rome, of the accuracy of forecasts, and the accuracy of winds found from aircraft navigation. The forecasts were based mainly on observations made about 12 hr. before the flight and were issued 2 hr. before the take-off. Comparison of assessments of the actual wind made independently from the same data gave a root-mean-square difference of 7·5 kt. between the two assessors. From this it is concluded that the error of a single assessment is between 5 and 6 kt. The root-mean-square difference between the forecast equivalent headwinds and the actual winds as subsequently assessed from the chart came to between 12 and 14 kt., which, allowing for assessment errors, gives a standard forecast error of 11 kt. The differences between forecast equivalent headwinds and those found by the aircraft however are as large as 20 kt., which suggests the standard error in "found" headwinds is of the order of 15–18 kt., a value somewhat larger than the standard error in the forecast winds. On the other hand another analysis by H. Keeling had given a standard error in headwinds calculated from flight data of only 8 kt. and of forecast winds of 15–18 kt.

In the final part of his paper Mr. Durst discussed the accuracy of wind forecasts over air routes in different parts of the world from known standard deviations of upper winds and gave advice on the location of upper air observing stations for maximum benefit in air-route forecasting. It emerged amongst other things, that if only one observing station can be provided it should be placed in the centre of the route, and would then be more useful than two stations, one at each end and none in between. The relation between the radius of action of homing aids and the accuracy of wind information was also described in detail. A major point raised in the paper is the accuracy of wind forecasts desirable in relation to the accuracy of navigation, for, if the latter is appreciably less than the former, expensive efforts to increase the accuracy of the wind forecasts are difficult to justify. Much of the discussion dealt with the accuracy of navigation. On the meteorological side Dr. Sutcliffe pointed out that, apart from immediate application in aerial navigation, upper air observations were essential for progress in dynamical understanding of the atmosphere. Publication of the full papers in the Institute's Journal for January 1954 will be awaited with much interest.

LETTERS TO THE EDITOR

Heavy Storm at Changi

A violent thunderstorm occurred at Changi during the afternoon of April 20, 1953, when 149 mm. of rain fell between 1350 and 1520 zone time (G.M.T. + 7). Of two hyetograms which are available, the one from the standard tilting-siphon recorder is undecipherable, but the other, from a standard recorder restricted to measure at 1/5 the normal rate, is well marked and easily analysed. The trace (Fig. 1) shows that the rate of fall was remarkably steady over a period of 40 min. at very nearly 150 mm./hr.

During the storm frequent lightning flashes were observed between cloud and earth, with heavy thunderclaps. The main fuse in the power supply to the cup generator anemometer was burnt out, and a soldered joint in the junction box at the cable terminal was broken down. It is not believed that the anemometer received a direct lightning stroke. The damage is thought to have been caused by induced currents produced by a very near discharge. A number of the staff were watching the anemometer when, simultaneously with a lightning flash and a deafening thunderclap, considerable sparking was seen at the rectifier and other electrical parts.

During the storm the surface wind was variable in direction and between 8 and 17 kt. in speed. The maximum gust observed was 27 kt. at 1506. Visibility was reduced to 100 yd. between 1430 and 1500.

The local nature of the storm is shown by the following total rainfall figures (0700–0700) for stations on Singapore Island for April 20.

	mm.
Changi	149
Kallang (12 miles west of Changi)	5
Seletar (10 miles west-north-west of Changi)	1
Tengah (25 miles west of Changi)	30

At 0700 on April 20 a line of convergence, at least up to 12,000 ft., was lying north-west to south-east across the Malayan Peninsula and extended to the east of Singapore Island, separating the westerly air stream over the Indian Ocean from the Pacific easterlies, the two streams gradually curving to become north-west and north-east, respectively. The eastern coastal stations of Malaya were reporting easterly winds. No significant change had taken place by 1300, but by 1900 the convergence line at the surface had moved south-westwards to be lying along the western seaboard of Malaya and Singapore Island. Easterly winds up to 2,000 ft. had spread in over south Malaya, although at 3,000 ft. and above the stream was still west to north-west. Both air streams

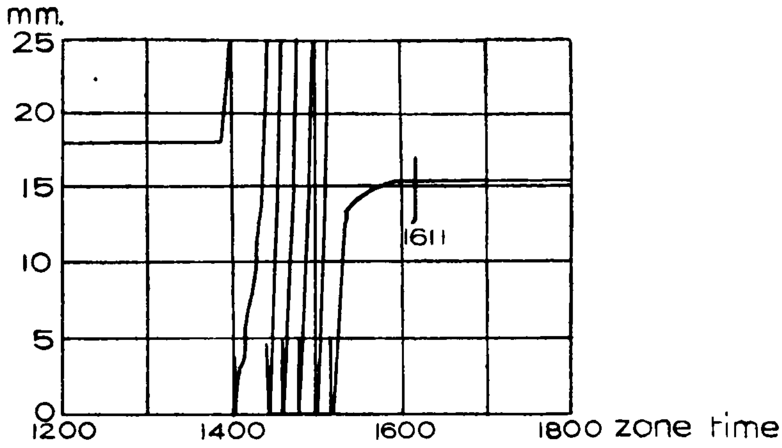

FIG. 1—HYETOGRAM FROM CHANGI, APRIL 20, 1953

being conditionally unstable, the immediate cause of the occurrence seems to be found in the impulse provided by the onset of the easterly sea-breeze over the extreme south-east of Malaya. By 1600 the surface wind at Changi had become light and variable.

This local occurrence is not considered to be a rare one for this region by any means. The main interest attached to it lies in that, being so severely local in its effect, it should have taken place exactly over a location equipped with recording instruments.

Changi, Singapore, April 20, 1953 W. G. PALMER

Unusually vigorous cumulonimbus cloud over southern England

Between 1645 and 1655 G.M.T. on July 1, 1953, reports were received by the meteorological office at Farnborough from pilots of four experimental aircraft of a cumulonimbus cloud top reaching to at least 40,000 ft. in a position about 20 miles east of Farnborough. All these pilots indicated that the speed of development of the cloud had been exceptional in their experience, which was in all cases considerable. The report of Sqd.-Ldr A. W. Bedford, an observer of considerable reliability, is of particular interest.

Sqd.-Ldr Bedford approached the cloud at 29,000 ft. trimmed for level flight, and during his traverse of the cloud was thrown up to 38,500 ft. in a time estimated to be between half-a-minute and a minute. During the traverse conditions were turbulent and visibility "comparatively good". There was no airframe icing though there were indications that the pitot head had iced up inside despite use of the pitot-head heater. On leaving the area the top had reached 42,000 ft.

After his traverse Sqd.-Ldr Bedford descended to cloud base in the Leatherhead area, and observed heavy rain and lightning beneath the cloud. He reports that there were dark, ragged fragments of cloud beneath the main mass being lifted into the cloud in a powerful vortex motion.

The meteorological office at Croydon reported at this time that a funnel-shaped cloud extended from the base of this cloud, 5,000 ft., to within 800 ft. of the ground, and that forked lightning discharges were frequent from the sides of the funnel cloud. This condition persisted for about 5–10 min.

Farnborough approach radar had the cloud under observation between about 1630 and 1720, and reported that the top of the echo was generally about 40,000 ft., and that the original single cumulonimbus was developing into a large, L-shaped complex having a general westerly motion of 15–18 kt.

The meteorological radar station at East Hill, Dunstable, reported that the tops of the echo were at 43,000 ft. and that the echo tops grew at a rate of 2,000 ft./min.

On this day the afternoon radio-sonde ascent from Crawley, West Sussex, showed a general tropopause level of 37,000 ft., so that it appears that this cloud penetrated into the stratosphere. However, recent work by Dr. James[1] of the Meteorological Research Flight and earlier work by Mr. D. R. Grant[2] have indicated pools of cold air lying over the tops of convective cloud, the temperature differential having a maximum value of 5–6°F. at low levels. In the case in question a pool 15–20°F. colder than the surrounding air would be necessary to raise the tropopause locally to 43,000 ft. Since the vigour of development was so great it is possible, however, that there may have been the usual pool 5–6°F. colder than the surrounding air raising the local tropopause to about 39,000 ft., and that the cloud did in fact overshoot into the stratosphere.

Other points worthy of note arise from Sqd.-Ldr Bedford's observations. First, if his assessment of the time of traverse is correct he encountered a mean up-draught of about 150 ft./sec. It is, of course, extremely difficult to estimate time intervals in such circumstances, so that if a reasonable lateral dimension is assumed of 10 miles for the cloud at the mean height of traverse, a time of traverse is reached of about 2 min. from his known indicated airspeed. Thus a probable value of about 80 ft./sec. is obtained for the mean up-draught. Even this value is very high since Byers and Braham[3] quote a maximum up-draught speed of 84 ft./sec. for the Project Thunderstorm flights. Further, they report that only 2 per cent. of up-draughts encountered during this series of flights caused displacements greater than 3,000 ft., and on only two cases was the displacement greater than 5,000 ft. The values obtained above for the up-draughts encountered by Sqd.-Ldr Bedford are dependent, of course, on that assumed for the lateral dimension of the cloud, but it is considered that the latter was probably a maximum value since Farnborough approach radar reported the echo dimensions to be 5 by 4 miles at the height of traverse.

Secondly, if in fact the pitot head did ice up there must have been super-cooled cloud droplets present at least at 29,000 ft., i.e. at a temperature of about −30°F., an unusually low figure which must presumably be associated with the unusual vigour of the up-draught.

G. J. DAY

Farnborough, July 25, 1953.

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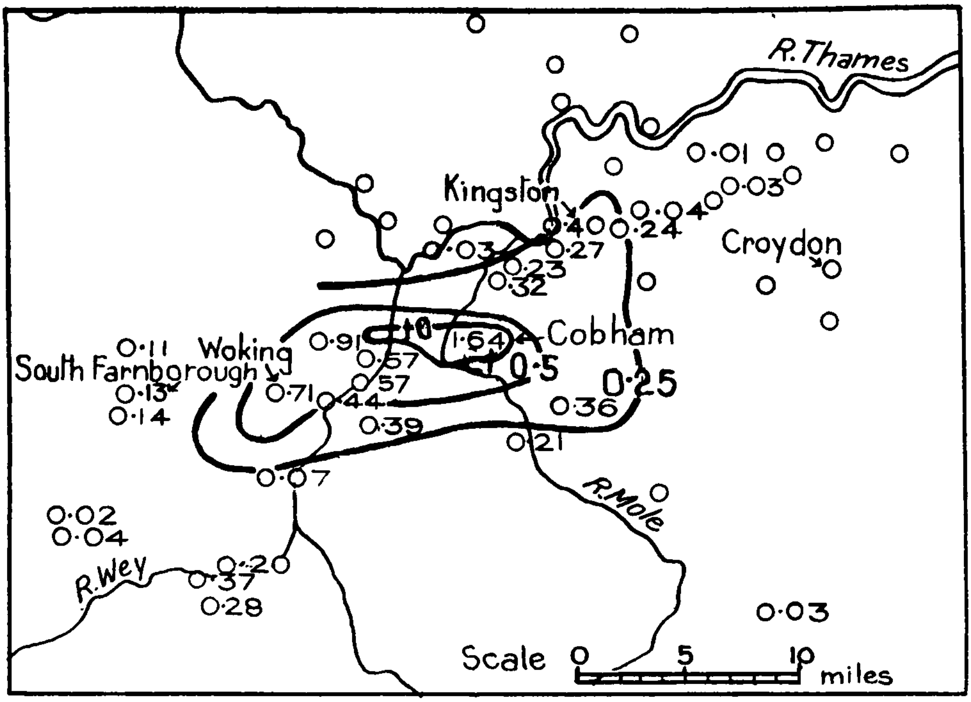
2. GRANT, D. R.; Fluctuations of temperature in clear air as recorded by an ultra-rapid thermometer. *Met. Res. Pap., London,* No. 658, 1951.
3. BYERS, H. R. and BRAHAM, R. R.; The thunderstorm, *Washington D.C.*, 1949.

[Thunderstorms with very heavy rain in places occurred over north Surrey on the afternoon of July 1. For most of the following information we are indebted to the Chief Engineer, Surrey County Council. The largest reported amounts of rain were 1·64 in. at Cobham Sewage Works and 0·71 in. at Goldsworth Road, Woking. Autographic rain-gauges maintained by the County Council showed that 0·24 in. fell at Raynes Park in 6 min. (1620–1626), 0·44 in. at Woking in 30 min. (1627–1703) and 0·40 in. at Kingston in 12 min.



Rainfall amounts given in inches

FIG. 1—RAINFALL DISTRIBUTION OVER NORTH SURREY, JULY 1, 1953

(1633–1645). The rainfall distribution is shown in Fig. 1. Mr. G. Nicholson of Stanley Road, Teddington, Middlesex, writes to the British Rainfall Organization that the first sign of a thunderstorm was a towering cumulus over Tolworth, Surrey, at 1445 G.M.T. Torrential rain fell in the Kingston area for about 12 min. at 1640, flooding roads. The edge of the rain area was very sharp: heavy rain fell at Atbara Road, Teddington, but 30 yd. north it was completely dry. At South Farnborough 0·13 in. (3·4 mm.) fell between 1815 and 1851 G.M.T.; the maximum rate of fall indicated by the Meteorological Office rate-of-rainfall recorder was 0·69 in./hr. (17·5 mm./hr.).—Ed., *M.M.*]

NOTES AND NEWS

Thunderstorms of June 26, 1953

Thunderstorms which gave very heavy rain and hail at many places broke out during the late morning and afternoon of June 26, 1953, over much of England, Wales and southern Scotland. The day will be remembered for the number of falls ranking as "very rare", "remarkable" or "noteworthy" which were reported from Renfrew to south Wales and Essex.

A weak ridge of high pressure extended north-east from the Azores to north-west of Scotland and a shallow complex area of low pressure covered the Continent. Surface winds over the British Isles were light to moderate from N.–NE. Over the western half of the British Isles the upper winds backed with height to between W. and S. and rose to about 18 kt. at a height varying at 1400 G.M.T. from 18,000 ft. over Liverpool to 8,000 ft. over Aldergrove. A weak quasi-stationary front extending south from Iceland moved slowly east across Ireland during the day. The lapse rate over Liverpool at 1400 equalled or exceeded the saturated adiabatic value between about 900 mb. (3,500 ft.)

and 500 mb. (18,900 ft.) and again from 400 mb. (24,300 ft.) to the tropopause at 250 mb. (34,600 ft.). The morning was sunny and surface temperatures exceeded 75°F. at most inland stations by midday. This temperature was high enough for it to be possible for convection currents to develop from the lower layers up to the tropopause. The ascent was doubtless helped by some convergence between the northerly and south-westerly air streams.

Floods occurred in many districts. The rain was particularly heavy in the Lake District and over south-west Scotland. At Eskdalemuir 3·15 in. of rain fell in 30 min. between 1333 and 1403 and 3·54 in. in the longer period of 55 min. These falls, which are well within the "very rare" category—unlikely to occur more than once in 160 yr. at the same place—have never been exceeded for amount amongst measurements for 55 min. or less as recorded in *British Rainfall* during the past 80 yr., but there have been instances of greater intensity of fall over shorter periods, such as 1·25 in. in 5 min. at Preston on August 10, 1893, and 1·88 in. at Ferriby Sluice, Lincolnshire, in 15 min. on September 14, 1943.

The account of the storm at Eskdalemuir has been extracted from information provided by Mr. Ian Grant of the Observatory staff to whom we are also indebted for the photographs at the end of this number of the Magazine.

The hills round the Observatory were quickly covered with an inch or so of water, and mountain streams were turned into raging torrents. Some stone walls were knocked down by the first rush of water and several bridges over the River Esk were broken. The Esk Valley was flooded under 6 ft. of water. Considering the intensity of the fall—equivalent to nearly a gallon of water per second on a patch 10 yd. square—there was surprisingly little damage though it should be pointed out that the moor is uncultivated and virtually uninhabited.

The total rainfall for the day was 4 in. at the Observatory, 3 in. at Eskdalemuir village (3 miles south of the Observatory), 2 in. at Ettrick (10 miles north of the Observatory) and 3·3 in. in the Daer Valley, south Lanarkshire (17 miles west-north-west of the Observatory).

At Eskdalemuir Observatory the early morning had been fine and exceptionally warm (69°F. at 0800), but subsequently altocumulus cloud increased to about half cover. Towards noon cumulus began developing rapidly—3 oktas of large cumulus at 1100 and 6 oktas of cumulonimbus at 1200. The actual timing of the rain can be given accurately as the recording rain-gauge was time marked both before and after the heaviest downpour. Distant thunder was heard about 1130 G.M.T., and the storm moved steadily nearer. Heavy rain began quite suddenly at 1222 and continued for 35 min.; then it died away and stopped altogether at 1302, by which time 0·29 in. had fallen; this was probably enough to saturate the ground, which tends to be rather boggy in all but the driest weather. Thunder and lightning continued, and after 27 min. heavy rain began again at 1329; by 1333 it had reached or surpassed tropical intensity, and this violent downpour continued for a further 30 min., in which time 3·15 in. was recorded. After 1403 the rain steadily decreased in intensity.

During the heaviest rain (which was accompanied by some hail) it was almost impossible to stand out-of-doors. The wind was gusty, 20–30 kt. (maximum gust 49 kt.), visibility was down to 200 yd. or less, and the air was filled with spray. If a door was opened even a few inches, this spray drifted in and saturated everything in a matter of seconds, while outside a raincoat was no protection. At about 1345 the observer, Mr. Hogg, ran out to the Stevenson screen to read the thermometers; he was out less than a minute, but in this time he was soaked to the skin, even though he was wearing a waterproof coat.

By 1340 the ground was covered with approximately an inch of water, and streams and rivulets were beginning to form; five minutes later three inches of water was running across the instrument enclosure (this was part of a "river" carrying water away from the higher ground 150 yd. to the north-north-west). Flooding in the Observatory grounds was at its worst by about 1400; the position then is shown in the accompanying diagram. The Observatory, which is at the top of a small hill 800 ft. above sea level and about 120 ft. above the Esk Valley, is surrounded by a stone wall enclosing approximately 12½ acres. It seems fair to assume that flooding in the grounds was caused entirely by rain which fell within this area; the "rivers" originated in the north-western half which is fairly flat, and ran towards the main gate which is in the south-east corner and some 30 ft. lower.

After 1403 the rain continued fairly heavy till 1412 (0·20 in. in 9 min.), but by 1430 it had decreased to moderate (rainfall 1412 to 1522, 0·25 in. in 70 min.); however water continued to run off the grounds till 1530 or later. But the worst was over by then, and by 1600 even the level of water in the valley was falling.

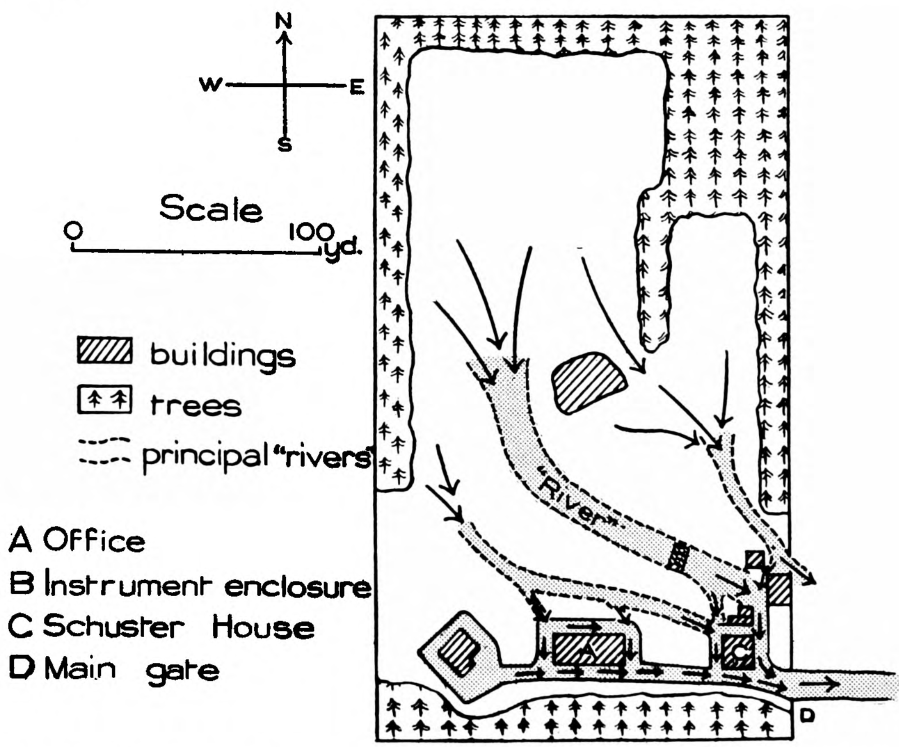


FIG. 1—FLOODING IN THE GROUNDS OF ESKDALEMUIR OBSERVATORY, 1400 G.M.T.

At 1400 there was 3–6 in. of water around the office and a "river", 6 in. deep, was flowing across the instrument enclosure. On the west side of Schuster House the water was 6 in. deep while on the east side the main "river" 6–12 in. in depth flowed rapidly. At the main gate the water reached 12 in. in depth. The grounds generally were under 2 in. of water.

Four other falls were reported for the 26th which rank as "very rare": 2·84 in. in 55 min. at Holehird in the Troutbeck Valley, Windermere; 1·72 in. in 15 min. at Nelson, Lancashire—a rate of 6·88 in./hr.; 2·09 in. in 39 min. at Langley, Trentbank Reservoir, Upper Mersey, Cheshire; 2·10 in. in 35 min. at Langham Waterworks, near Colchester.

At Troutbeck a wall of water 7 ft. high was reported to have come down the bed of a small stream and a man was drowned. Very intense rain was also observed at the north-west end of Lake Vyrnwy where bridges and roads were carried away. No direct rainfall observations are available for the storm period, but the Chief Engineer to the Liverpool Waterworks has estimated a fall of 3·00 in. in 90 min. near the centre of the storm, of which 2·00 in. probably fell in 30 min.

REVIEW

The theory of homogeneous turbulence. By G. K. Batchelor. $8\frac{3}{4}$ in. × $5\frac{3}{4}$ in., pp. xi + 197. *Illus.*, Cambridge University Press, Cambridge, 1953. Price: 25*s.* net.

Much of the recent work on turbulence is scattered in many different journals which are not always easy to assemble together, particularly for a meteorologist who is on an outstation. Dr. Batchelor has performed a real service in gathering the main results of recent research into a connected account in one volume.

The book is divided roughly into two parts: the first part, chapters II to V being mainly mathematical and the remaining chapters, VI to VIII, being much more physical in outlook. There is an introductory chapter defining homogeneous turbulence, and introducing the basic equations that are to be used. Homogeneous turbulence, as its name suggests, is turbulence in which the mean properties of the random motion are independent of position; this largely means that the experimentally measured properties of the random motion are independent of position, for an instrument usually measures a mean property. The basic equations of the flow, the equations of continuity and Navier-Stokes, are familiar to all meteorologists; the main difference is that most often the meteorologist is concerned with much larger-scale motions, so that his equations include the effect of the earth's rotation and neglect the viscosity effect. However, in much of the book the Navier-Stokes equations are in the background, acting mainly as a check on the size of the phenomena which are investigated.

In chapters II to V the author sets up a mathematical model and investigates the consequences. First he defines what he means by "average", a point which has sometimes not been stressed sufficiently in work on atmospheric turbulence and which is of importance in interpreting experimental results in the light of theory. The main tools used are Cartesian tensors and Fourier transforms; the main results concern correlations and the distribution of energy over the spectrum of eddy size. Chapter II deserves close study before proceeding to the kinematics of the motion in chapters III and IV. The conditions of homogeneity restrict and simplify the form of the tensors which arise in the theory; in particular axisymmetric and isotropic turbulence are defined, and isotropic turbulence considered in detail. The definition of isotropic turbulence is mathematical (a considerable restriction on the form of the tensors which arise) and leads to predictions; experimental evidence provides non-negative rather than positive proof of the existence of isotropic turbulence. The evidence is mainly drawn from wind-tunnel experiments, but it is clear that isotropic turbulence is not confined to such experiments. Chapter V deals with the decay of turbulence; it is not as formidable as it looks, and contains much of interest to the meteorologist in the flow of energy in turbulent motion and its final dissipation.

The remaining chapters contain much more physical argument. Bearing in mind the author's article in the *Quarterly Journal of the Royal Meteorological Society** meteorologists will want to study chapter VI, which is concerned with Kolmogoroff's theory of similarity. There are roughly two parts of the turbulent motion contained by the smaller eddies, one which dissipates the energy by viscous processes and one in which negligible dissipation occurs, so that the transfer of energy is largely caused by inertia forces. The latter will be the more important to the meteorologist who will want to examine the various hypotheses that are discussed. The author is very careful to differentiate between what follows from the theory which he has set up in the previous chapters and what is newly imported, and does not ride any particular hobby-horse. Chapter VII deals with the eddies which contain the principal part of the energy, and, being largely independent of the foregoing theory, provides a valuable survey of the experimental work which has led to a knowledge of the distribution of energy and its dependence upon initial conditions. Since it is found generally in wind-tunnel experiments that the turbulence settles down very quickly to a statistical state with about 80 per cent. of the total energy distributed approximately independently of the initial conditions, it seems that something of this sort may occur in atmospheric turbulence, so that the meteorologist will want to examine this chapter. The hypotheses advanced in explanation are examined carefully. The final chapter on the probability distributions continues the review of experimental work, and the results resemble those concerning the correlations of temperature and wind with much larger scales of distance and time in the atmosphere.

These few remarks can only give too brief an idea of the scope of the book and its appeal to meteorologists. It is not written with any chosen applications in view, but there is much of deep interest for us here and also much that is enlightening. Many of the problems concerning turbulence in the atmosphere are concerned with transfer or diffusion; the author excludes such problems in this book. We can only hope that he will provide another companion volume dealing with turbulent diffusion.

The book itself is intensively written so that it will require much study. It will not do to borrow a copy for a short time and it is not particularly expensive. The publisher's name is a guarantee of beautiful printing and display, and there are only a few trivial misprints, e.g. on pp. 37, 38 and 86, and surely a mis-statement concerning the exponential term in 5.4.4.

E. KNIGHTING

RETIREMENT

Mr. John Crichton retired from Eskdalemuir Observatory in July. It is natural to speak of him retiring from the Observatory because more than half of his 34 years in the service of the Meteorological Office have been spent at the two observatories Lerwick and Eskdalemuir, and for the past 14 years he had been continuously at Eskdalemuir. To visitors to Eskdalemuir and to large numbers of Office staff who, at some time, have been stationed there it

*BATCHELOR, G. K.; The application of the similarity theory of turbulence to atmospheric diffusion. *Quart. J. R. met. Soc., London*, **76**, 1950, p. 133.

must be difficult to think of the place without John Crichton as Superintendent. Civil servants are sometimes accused of being moulded into a standard pattern, but no one can be imagined further removed from the comic paper caricature of the civil servant than Crichton. In dress, in blunt speech and in rugged independent thought he conformed to no conventional type.

He joined the Meteorological Office after service during the 1914–18 war in the "Met" sections of the R.N.V.R. and the R.F.C., chiefly at airship stations. In 1921 he was selected to be the officer-in-charge of the new magnetic observatory in the Shetlands near Lerwick, and he worked literally like a navvy in establishing the work there. Observatory work was his absorbing interest, but he worked at times in the Forecast Division and at Edinburgh.

In 1939 while stationed in the Forecast Division he suffered the amputation of a foot, the result of his diabetic complaint. He refused to be crippled by this, and on the outbreak of war was posted again to Eskdalemuir where he led a very active physical and mental life until the amputation of his other foot early this year caused him to seek retirement. To this second cruel blow he is dauntlessly accommodating himself, driving a car and very actively engaged in setting up a new home in Kirkcudbright. All who have served with him will wish him and Mrs. Crichton much happiness in their new surroundings.

NEWS IN BRIEF

The L. G. Groves Memorial Prize for Meteorology has been awarded this year to Mr. R. F. Jones, B.A., Principal Scientific Officer, Meteorological Office, East Hill, who has made a special study of the employment of radar technique for examining the internal structure of cumulonimbus clouds. Simultaneous measurements of vertical acceleration by aircraft flying through the cloud have also provided a more detailed knowledge of the conditions to be expected by pilots than was previously available. Mr. Jones has also made a study of the turbulence which occurs in the upper atmosphere outside clouds, and he has been able to show that some at least of the occasions of occurrence of such turbulence can be explained in terms of the irregularity of temperature and humidity distributions. These results have a direct application to the safety and comfort of high-speed flying.

The L. G. Groves Memorial Award for Meteorological Air Observers has been awarded to Sergeant G. N. Franklin (3127399) Royal Air Force, for meritorious work and devotion to duty with No. 202 Squadron. He trained as a meteorological air observer in January 1951, and since then he has flown consistently at Gibraltar and Aldergrove, completing no less than 87 meteorological sorties involving 1,130 flying hours. He has also for some time carried out the duties of Squadron Meteorological Air Observer Leader remarkably well, gaining by his example of keen interest and enthusiasm the respect and admiration of the whole Squadron.

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—The ship's company of *Weather Observer* celebrated her 50th voyage as an ocean weather ship at a dinner and dance in Greenock on September 3, 1953. *Weather Observer* was formerly H.M. Flower Class Corvette *Marguerite*; she was launched in July 1940, and was engaged on convoy escort duties in the North Atlantic and other theatres during the last war. She was the first of the British ocean weather ships to put to sea and she sailed her first voyage to station JULIETT on August 1, 1947. At the dinner there was a good attendance of staff from all departments of the ship with their lady guests. At the head table, in addition to Captain Sobey and his wife, were seated four who had served continuously in the ship for the 50 voyages; Mr. Gascoyne, Chief Steward; Messrs. Dunning and Sharland, Radio Mechanics and Mr. Clifton, Bo'sun. The fifth veteran (Mr. Lambert, Radio Overseer) was unavoidably absent. Cmdr Frankcom, Marine Superintendent, was the guest of honour. Mr. Gaskin (Meteorological Assistant) was master of ceremonies and under his guidance the party was an enormous success.

Academic successes.—To the lists published in the October number should be added:—

Intermediate B.Sc.: pure and applied mathematics, physics, J. W. Simpson.

General Certificate of Education (Advanced Level): applied mathematics, physics, E. A. Southey.

Horticultural show.—Belated congratulations are offered to successful competitors at the Air Ministry Horticultural Society's Summer Show held at Adastral House on July 7 last: to Miss H. G. Chivers, who obtained the special prize for the fruit section, to Messrs. H. A. Scotney and L. S. Clarkson for flower and vegetable exhibits, and to Mr. Ben G. Brame for winning the Banksian Medal of the Royal Horticultural Society for the second time in three years.

Retirements.—Mr. W. J. Grassick, who has been Senior Meteorological Officer at Watnall since April 1945, retired on September 30 on the completion of 33 years' service. At an informal gathering at Watnall he was presented with a standard reading lamp and a travelling clock subscribed for by many of his colleagues. Mr. Grassick has accepted a temporary appointment in the Meteorological Office and is now at the Air Traffic Control Centre, Preston.

Mr. S. T. A. Mirrlees also retired on September 30: a note on his career in the Office will be published later.

Christmas party.—It is the intention of the Social and Sports Committee to hold a staff Christmas Party again this year. Tuesday, December 15, is the date fixed and the venue the same as last year—Air Ministry Refreshment Club, Adastral House.

WEATHER OF SEPTEMBER 1953

Mean pressure was below normal over a large area including most of the United States, Greenland, Iceland, the North Atlantic and north-west Europe; the deficit of pressure was generally 1–3 mb. but reached 5 mb. in the region between Greenland and Iceland, where the mean pressure was 1002 mb. Over south-east Europe and the Mediterranean, mean pressure was a little above normal, generally about 1 mb. The mean pressure in the Azores was 1021 mb.

Mean temperature over most of the United States and Europe was above normal to the extent of 2–3°F. The means varied from 45° to 55°F. in Scandinavia, 55° to 65°F. in west Europe, 70° to 75°F. in the Mediterranean region and 80° to 90°F. in north Africa.

In the British Isles the changeable weather of late August persisted during the first few days of September. A fair spell set in on the 5th and lasted until the 14th. The remainder of the month was mainly unsettled and there was a notable gale on the 21st. Mean temperature exceeded the average in northern districts and was about or slightly below the average in the south. Rainfall was mostly above average but there was a deficit over eastern England and locally in the north of Scotland. Sunshine considerably exceeded the average in southern and eastern England but was below the average in Scotland and Ireland.

In the opening days a depression off west Scotland moved north-east, while associated troughs of low pressure crossed the British Isles. Rain fell in the north and west on the 1st and throughout the country on the following night, and showery weather with sunny periods prevailed on the 2nd and 3rd. Subsequently a ridge moved slowly east over the British Isles and increased in intensity, the highest pressure being found over Germany by the 6th. Fine weather set in in the south-east on the 5th and soon became general; temperature reached 80°F. locally in England and Wales on the 6th and 8th and there were local maxima of 75°F. or somewhat higher in both Scotland and Ireland during this spell; 78°F. at Dyce near Aberdeen on the 7th and 8th was the highest temperature registered there in September since records began in 1941. On the 8th the anticyclone over the Continent declined and a north-westerly type became established as another anticyclone built up on the Atlantic. Temperature fell on the 9th but the fine weather persisted apart from slight rain chiefly in the west and north. On the 12th to 13th the anticyclone moved north-east to Scandinavia. The fine weather was brought to an end in the south-west on the 14th and elsewhere on the 15th as a trough moved slowly north-east across the country bringing rain to most districts. A spell of thundery weather ensued from the 16th to the 18th. On the 19th a depression to the north-west of Ireland moved east-north-east across Scotland giving general rain, heavy locally, and a gale in south-west Cornwall. On the 21st an exceptionally deep depression, which was formerly a tropical cyclone in the Bermuda area, approached north-west Ireland and moved across southern Scotland giving widespread gales, severe locally, and heavy rain or showers in places (3·09 in. at Patterdale, Westmorland, 2·90 in. at Watendlath Farm, Cumberland, 2·65 in. at Challacombe, Devon, and 2·18 in. at Lake Vyrnwy, Montgomeryshire). Pressure at Claremorris, north-west Ireland, fell to 957 mb. at 0700, the lowest pressure on record in the British Isles in September. This disturbance was followed by a secondary depression which moved east across southern England during the night of the 22nd and then turned north-east to the North Sea giving a gale in south-west England and more heavy rain. Subsequently the depression filled up and a weak ridge formed over southern England giving a spell of fair weather, with widespread morning fog in the south, though some rain occurred in northern districts. An unsettled westerly type of weather prevailed during the last few days with considerable rain at times in the west and north, particularly on the 30th (3·57 in. at Fort William (Teviot), 3·16 in. at Inveraray, Argyllshire, 2·73 in. at Llechwedd Quarries, Merionethshire, and 2·59 in. at Windermere Nurseries, Westmorland), but there were long sunny periods on the 28th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	81	32	+0·3	125	0	111
Scotland	79	31	+2·0	139	+1	92
Northern Ireland ...	76	41	+2·4	115	+3	81

RAINFALL OF SEPTEMBER 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·78	98	*Glam.*	Cardiff, Penylan ...	4·61	151
Kent	Dover	2·99	129	*Pemb.*	Tenby, The Priory ...	3·84	122
,,	Edenbridge, Falconhurst	4·02	177	*Radnor*	Tyrmynydd	6·23	161
Sussex	Compton, Compton Ho.	3·16	113	*Mont.*	Lake Vyrnwy	7·36	204
,,	Worthing, Beach Ho. Pk.	3·95	185	*Mer.*	Blaenau Festiniog ...	12·48	158
Hants.	Ventnor Cemetery ...	3·34	131	,,	Aberdovey	5·74	179
,,	Southampton, East Pk.	3·46	159	*Carn.*	Llandudno	4·07	191
,,	South Farnborough ...	1·97	103	*Angl.*	Llanerchymedd ...	4·62	157
Herts.	Royston, Therfield Rec.	2·25	120	*I. Man*	Douglas, Borough Cem.	5·71	175
Bucks.	Slough, Upton... ...	1·60	91	*Wigtown*	Newton Stewart ...	6·76	198
Oxford	Oxford, Radcliffe ...	1·85	108	*Dumf.*	Dumfries, Crichton R.I.	5·17	191
N'hants.	Wellingboro' Swanspool	1·12	62	,,	Eskdalemuir Obsy. ...	5·74	155
Essex	Shoeburyness	1·86	111	*Roxb.*	Crailing	3·17	155
,,	Dovercourt	1·28	72	*Peebles*	Stobo Castle	3·47	138
Suffolk	Lowestoft Sec. School...	1·61	82	*Berwick*	Marchmont House ...	2·46	102
,,	Bury St. Ed., Westley H.	1·38	69	*E. Loth.*	North Berwick Res. ...	2·21	106
Norfolk	Sandringham Ho. Gdns.	1·45	70	*Midl'n.*	Edinburgh, Blackf'd. H.	2·64	129
Wilts.	Aldbourne	3·31	165	*Lanark*	Hamilton W. W., T'nhill	2·79	104
Dorset	Creech Grange... ...	2·98	109	*Ayr*	Colmonell, Knockdolian	6·30	182
,,	Beaminster, East St. ...	3·14	123	,,	Glen Afton, Ayr San. ...	7·29	187
Devon	Teignmouth, Den Gdns.	3·02	154	*Renfrew*	Greenock, Prospect Hill	7·16	159
,,	Taunton (Vivary Park)	2·63	124	*Bute*	Rothesay, Ardencraig...	5·59	138
,,	Ilfracombe	5·54	206	*Argyll*	Morven (Drimnin) ...	6·69	118
,,	Okehampton	5·09	182	,,	Poltalloch	8·73	191
Cornwall	Bude, School House ...	3·49	141	,,	Inveraray Castle ...	11·07	172
,,	Penzance, Morrab Gdns.	4·10	140	,,	Islay, Eallabus... ...	6·94	166
,,	St. Austell	4·10	129	,,	Tiree	5·63	152
,,	Scilly, Tresco Abbey ...	2·59	101	*Kinross*	Loch Leven Sluice ...	4·52	176
Glos.	Cirencester	3·01	137	*Fife*	Leuchars Airfield ...	2·11	109
Salop	Church Stretton ...	2·77	131	*Perth*	Loch Dhu	9·03	158
,,	Shrewsbury, Monksmore	2·44	150	,,	Crieff, Strathearn Hyd.	4·10	143
Worcs.	Malvern, Free Library...	2·49	129	,,	Pitlochry, Fincastle ...	4·22	168
Warwick	Birmingham, Edgbaston	2·33	130	*Angus*	Montrose, Sunnyside ...	2·64	133
Leics.	Thornton Reservoir ...	1·53	85	*Aberd.*	Braemar	3·06	122
Lincs.	Boston, Skirbeck ...	1·13	64	,,	Dyce, Craibstone ...	4·23	175
,,	Skegness, Marine Gdns.	1·22	67	,,	New Deer School House	3·06	121
Notts.	Mansfield, Carr Bank...	1·23	67	*Moray*	Gordon Castle	2·92	117
Derby	Buxton, Terrace Slopes	3·37	104	*Nairn*	Nairn, Achareidh ...	2·07	98
Ches.	Bidston Observatory ...	3·01	125	*Inverness*	Loch Ness, Garthbeg ...	3·66	118
,,	Manchester, Ringway...	2·45	108	,,	Glenquoich	10·67	123
Lancs.	Stonyhurst College ...	5·83	153	,,	Fort William, Teviot ...	10·58	166
,,	Squires Gate	3·92	145	,,	Skye, Broadford ...	8·45	122
Yorks.	Wakefield, Clarence Pk.	1·29	81	,,	Skye, Duntuilm ...	3·88	84
,,	Hull, Pearson Park ...	0·68	39	*R. & C.*	Tain (Mayfield) ...	2·00	87
,,	Felixkirk, Mt. St. John...	1·85	102	,,	Inverbroom, Glackour...	5·70	129
,,	York Museum	1·19	73	,,	Achnashellach	8·05	117
,,	Scarborough	0·84	47	*Suth.*	Lochinver, Bank Ho. ...	4·91	141
,,	Middlesbrough... ...	1·27	77	*Caith.*	Wick Airfield	2·09	84
,,	Baldersdale, Hury Res.	2·72	106	*Shetland*	Lerwick Observatory ...	3·32	110
Norl'd.	Newcastle, Leazes Pk....	1·82	92	*Ferm.*	Crom Castle	3·72	133
,,	Bellingham, High Green	3·74	156	*Armagh*	Armagh Observatory ...	2·97	121
,,	Lilburn Tower Gdns. ...	2·66	113	*Down*	Seaforde	2·78	101
Cumb.	Geltsdale	4·11	147	*Antrim*	Aldergrove Airfield ...	2·40	97
,,	Keswick, High Hill ...	8·95	212	,,	Ballymena, Harryville...	3·60	116
,,	Ravenglass, The Grove	5·64	167	*L'derry*	Garvagh, Moneydig ...	3·47	117
Mon.	A'gavenny, Plâs Derwen	4·68	183	,,	Londonderry, Creggan	3·85	117
Glam.	Ystalyfera, Wern House	7·23	165	*Tyrone*	Omagh, Edenfel ...	3·65	120

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By Geo. Gibbons Ltd., Leicester

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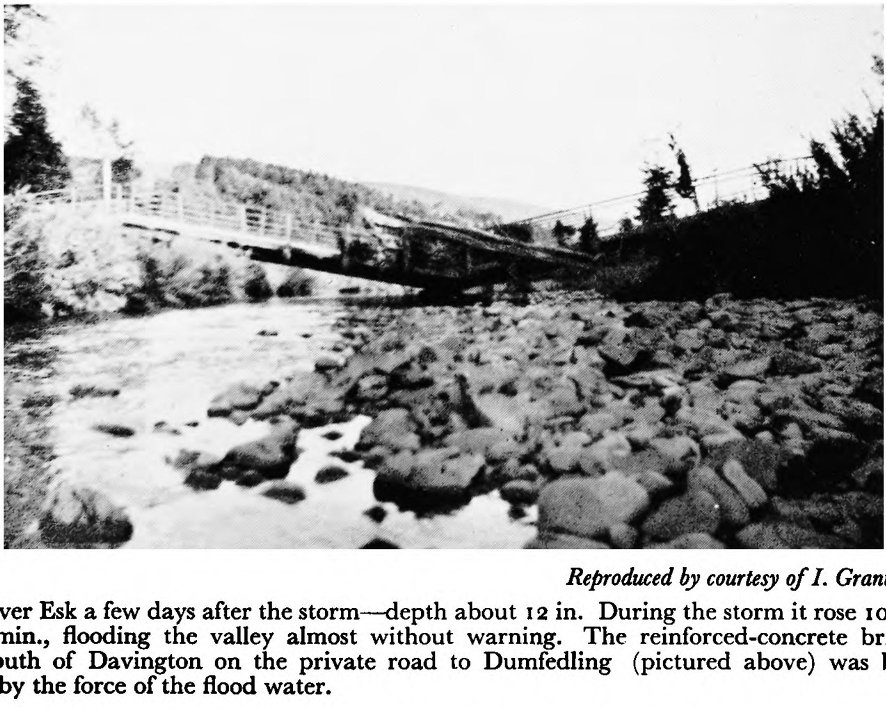
Flood water in the Observatory grounds. Water, pouring off higher ground less than 200 yd. away, turned some steps at the back of Schuster House into a miniature waterfall. At the foot of the steps the water was 4–6 in. deep. Fifteen minutes earlier the volume of water pouring over the steps was so great that the "waterfall" effect was lost.



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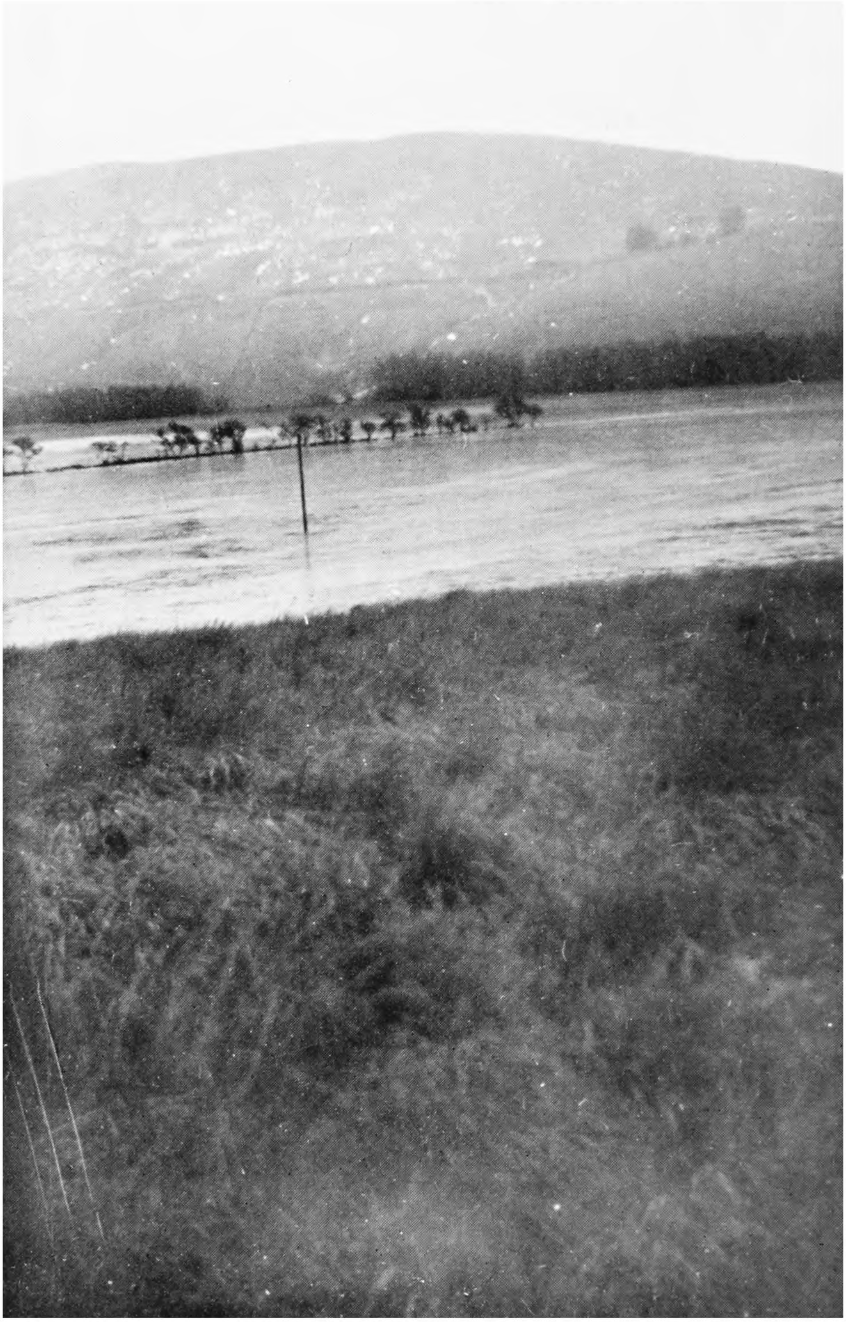
The River Esk a few days after the storm—depth about 12 in. During the storm it rose 10–15 ft. in 10 min., flooding the valley almost without warning. The reinforced-concrete bridge a mile south of Davington on the private road to Dumfedling (pictured above) was broken in two by the force of the flood water.

THE STORM OF JUNE 26, 1953, AT ESKDALEMUIR

(see p. 344)



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THE ESK VALLEY SEEN FROM THE OBSERVATORY HILL, 1615, JUNE 26, 1953

The whole valley was still flooded, but the water level was dropping. The white patches on Dumfedling Hill in the background are drifts of hailstones; 90 min. earlier the hillside presented a peculiar mottled-white appearance—hail and flood water combined. At 1400 the hail was 2 in. deep with drifts up to 12 in.; 24 hr. later some drifts still remained.

(see p. 344)

M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 978, DECEMBER 1953

RADAR-SONDE STATION AT CRAWLEY

By D. R. GRANT, B.Sc.

Introduction.—At a press conference on August 25, 1953, Mullard Ltd gave details of the radar-sonde* which they have developed in conjunction with the Radar Research Establishment, Ministry of Supply, and which they are at present installing at a specially built Meteorological Office station near Crawley in Sussex.

Limitations of current system.—The radio-sonde/radar wind system in current use fails in a number of respects to meet present-day forecasting requirements. The wind-finding equipment, using a radar reflector, is limited in range, and on days of strong upper winds the signal fades at relatively low heights. The failure of the wind-driven switch at low pressures sets a limit to the height at which the radio-sonde can operate, but even at much lower levels there is room for improvement in the accuracy of the pressure, temperature and humidity observations. Errors in pressure measurement are due mainly to the temperature coefficients of the various parts of the pressure-sensitive unit. Errors in temperature measurement caused by the lag of the temperature-sensitive element are appreciable, and errors due to solar radiation increase rapidly as the atmospheric pressure is reduced. Readings of relative humidity become valueless at temperatures below about −40°C. because of the lag of gold-beater's skin. If the errors in the meteorological units could be eliminated the accuracy of the sonde would depend on the accuracy of the telemetering system used. Although the radio-sonde telemetering is almost good enough to meet the accuracy specified for the radar-sonde, it cannot be used economically in conjunction with the radar-sonde wind-finding equipment. A different telemetering system is therefore required as well as improved pressure-, temperature- and humidity-sensitive elements.

Improvements expected from radar-sonde.—The radar-sonde has been designed to measure winds at greater ranges and to a higher accuracy than the present radar-wind system. The telemetering system incorporated in the sonde for measuring pressure, temperature and humidity is capable of an accuracy of 1 part in 1,000. The use of recorders and automatic computers eliminates any human errors, and reduces the staff required for each flight. The

* JONES, F. E., HOOPER, J. E. N. and ALDER, N. L.; The radar-sonde system for the measurement of upper wind and air data. *Proc. Instn elect. Engrs, London*, **98**, 1951, p. 461.

radar-sonde can operate at heights up to more than 80,000 ft., and can therefore be used with special high-altitude balloons for research purposes. Its maximum range of 100 nautical miles enables its transmission to be received from great heights even on days of exceptionally strong winds. The wind-driven switch in the present sonde is replaced by a motor-driven switch which will operate at the same speed at all heights. Errors in pressure caused by the temperature coefficient of the pressure-sensitive unit are reduced, and the errors in temperature due to lag and solar radiation are almost eliminated. At present no improvement in humidity measurement is expected, but development is in hand of suitable humidity-sensitive units which, it is hoped, will give a better performance than gold-beater's skin.

Radar-sonde wind-finding system.—The basic difference between the radar-sonde and the existing wind-finding system is the use of an airborne transponder in place of the radar reflector. The transponder is a small transmitter–receiver carried by the balloon. The ground station transmits 2 μsec. pulses on a frequency of 152·5 Mc./sec., with a peak power of 50 KW. and with a pulse recurrence frequency of about 400/sec. The transponder receives these pulses and re-transmits them on a frequency of 2,850 Mc./sec. with a peak power of 30 W. The difference in frequency between the ground and airborne transmitters is necessary on account of the difficulty in producing a light and inexpensive airborne receiver on centimetric wave-lengths. The centimetric transmitter in the transponder can be produced in quantity very cheaply, and is, in fact, the first ever designed for mass production. Power supplies for the airborne unit are obtained from three 2·3 v., 2·5 amp. batteries with a vibrator to supply high tension voltages. The complete airborne unit is enclosed in a container made of a very light, thermally insulating, material. During a flight the temperature change inside the unit is less than 10°C. The radio apparatus is thus kept at approximately room temperature.

At the ground station the equipment required for wind finding can be divided into three groups: radar units, computing and recording units, and power supplies. The radar units consist of the aerial unit, the 152·5 Mc./sec. transmitter, the 2,850 Mc./sec. receiver, the display unit and the control column. The aerial unit, shown in the photograph on the centre pages of this Magazine, includes the transmitting Yagi arrays and the receiving aerial which is a nutating dipole and paraboloid reflector. The nutating action is required to keep the dipole in a vertical plane while it is rotated about the focus of the paraboloid to produce a conical scan. A vertical receiving aerial is necessary to receive the vertically-polarized transmission from the balloon. The conical scan is used to obtain amplitude modulation of the incoming signal when the aerial is not directed towards the transponder. An error signal is thus produced, and is fed to a servo system which re-aligns the aerial on to the transponder. The transmitting aerials are mounted on the same pedestal as the reflector and are, therefore, also automatically directed at the transponder. The azimuth and elevation of the transponder at any time are obtained from the azimuth and elevation angles of the aerial unit, and the slant range from the transit time of the pulse to and from the transponder. These three variables are fed to the computer and also to the display unit, where slant range is displayed on a cathode-ray tube and azimuth and elevation on fine and coarse magslip indicators. The display unit is used only for observation of the performance of the complete system, and is not normally used for measuring winds.

The computer and recorder units calculate and record the wind speed and direction and the height of the transponder at a given time. The normal full scale reading of the wind speed chart is 100 kt., but when a gust exceeds this value the sensitivity is automatically reduced by a factor of two. The height record is given on a similar chart with a full scale reading of 10,000 ft. When this height is reached, the record is switched to read from 10,000 to 20,000 ft., and so on up to 100,000 ft. As the chart can be read to 1 per cent. of the full scale height can always be read to 100 ft., although its accuracy is limited by the computer to 0·5 per cent. The wind direction is displayed on a circular chart which is automatically rotated as the wind direction changes. A recording pen is driven radially inwards across the chart at a constant rate, thus providing a continuous record of wind direction against time. A total time of flight of 100 min. can be covered.

The transmitter, receiver, display unit and control column (which controls the power supplies remotely) are mounted in one radar console. The wind computer is built round the wind-direction recorder and the wind speed and height recorders are mounted as a separate unit (see photographs on centre pages of this Magazine).

Particular attention has been paid to the ease of servicing the ground station. All chassis are easily detachable and there is a comprehensive internal monitoring system for rapid fault finding.

Radar-sonde telemetering system.—A station containing the equipment so far described could be used as a wind-finding station. A complete radar-sonde station, measuring in addition to winds, pressure, temperature and humidity, contains two additional units, the telemetering unit and the sonde recorder. The airborne sonde unit contains, in addition to the transponder, the pressure-, temperature- and humidity-sensitive units, a motor-driven switch to connect the units to the circuit in sequence, and a high-precision pulse delay circuit. This circuit is used to generate a pulse at a time interval after the ranging pulse of anything from 200 to 1,200 μsec., depending on the value of the meteorological variable. For each pulse transmitted by the ground station there are two pulses transmitted by the airborne sonde. The time interval between the interrogating pulse transmitted by the ground station and the first pulse received back is a measure of the slant range of the sonde, and the time interval between the first and second pulses received is a measure of the meteorological variable. As about 400 pulses are transmitted from the ground every second, and as each meteorological unit is in circuit for about 3 sec., about 1,200 readings of each variable are transmitted before the next unit is connected. In the telemetering unit on the ground the first of the two pulses transmitted by the sonde is used to open an electronic "gate" and the second is used to close it. When this gate is open, pulses from a crystal controlled 1-Mc./sec. oscillator are allowed to pass through it. The number of pulses passing through is counted by electronic counters, and is equal to the time interval in microseconds between the first and second pulses. This interval is measured exactly 1,000 times (i.e. for 2½ sec. approximately), and the mean of these readings is a measure of the mean value of the meteorological variable during the 2½-sec. period. The reason for measuring the interval 1,000 times is to reduce random errors to negligible amounts. The answer, which is printed on a teleprinter in microseconds, is accurate to 1 part in 1,000. The system is therefore capable of telemetering and recording the meteorological information to an accuracy of 0·1 per cent. of the range of variation experienced in the atmosphere. For example, as the range of variation of pressure is 30 mb. to 1050 mb. pressure can be telemetered to an accuracy of 1 mb. The meteorological units to be used initially are not all capable of giving such high accuracy, but the radar-sonde may be used with improved units when they become available.

The design of the meteorological units for the radar-sonde is being undertaken by Mullard Ltd in conjunction with the Instrument Development Division of the Meteorological Office. In the first sondes the pressure- and humidity-sensitive units will be variable inductances operated by an aneroid capsule and gold-beater's skin respectively. As the pressure unit will be inside the container where temperature variations are small, it is expected that pressure measurement will be considerably more accurate than in the radio-sonde, especially at high levels. A variation in inductance is not, however, suitable for operation of the time-delay circuit in the sonde, and some additional components are required which may introduce small errors in measurement. It is hoped shortly to develop variable resistors controlled by pressure and humidity, which will make full use of the accurate telemetering circuit. A resistive temperature-sensitive unit has already been developed, and will be used in the first sondes. Coiled tungsten wire of very small diameter is used to obtain a room temperature resistance of about 6,000 ohms which is required to operate the telemetering circuit. The small diameter wire has a low lag coefficient and radiation error, and the almost linear variation of resistance against temperature makes calibration easy. It is expected that this temperature unit used in conjunction with the radar-sonde will give upper air temperature to an accuracy far exceeding that obtained with any existing radio-sonde system. A photograph of the pressure, humidity and temperature units is on the centre pages of this Magazine.

In order to keep a check on the performance of the sonde, a reference signal is transmitted for 3 sec. during every cycle in addition to the pressure, temperature, and humidity readings. This signal should give a constant reading, but if it changes slightly (indicating a change in performance of the sonde) it should be possible to make corrections to the readings of the meteorological variables to maintain the high degree of accuracy. Between each 3-sec. period a time of 1 sec. is required to transmit information necessary to ensure the correct operation of the counters. A complete cycle therefore takes about 16 sec. During this time four numbers are printed on the teleprinter indicating pressure, temperature, humidity, and "reference". The meteorological information is also plotted in graphical form to an accuracy of 1 per cent., in order to show up any significant points such as temperature inversions or the tropopause. All the readings recorded are in microseconds, and it is necessary to calibrate the sonde to obtain the relation between microseconds and the meteorological measurements.

Comparison of accuracy of radar-sonde, and radio-sonde/radar wind systems.—The following table has been prepared to give some idea of the expected accuracy of the radar-sonde. As no flights have yet been made, the figures are estimates based on tests of the component parts of the system. They may need therefore to be changed later. The standard errors quoted for the radio-sondes were obtained from a series of experiments carried out in 1947 at two radio-sonde stations. They include errors of observation and instrumental errors which are random as between one sounding and another.

	Present system	Radar-sonde	Radar-sonde with improved meteorological units
Standard error of pressure measurement at 200 mb. (mb.)	7	3	1
Standard error of temperature measurement at all levels (°C.)	0·6	0·2	0·2
Standard error of humidity measurement at low levels (%)	5	5	Not known
Error due to lag of temperature unit at 200 mb. in lapse rate of 6°C./Km. (°C.)	0·45	0	0
Error due to solar radiation (°C.) at 200 mb. ...	1·8	0·4	0·4
Error due to solar radiation (°C.) at 10 mb. ...	17·3	1·6	1·6
Standard vector error in wind at 200 mb. when mean wind from 1,000–200 mb. is 60 kt. (kt.)	5	1–2	1–2

Conclusions.—Although flight trials have not yet been carried out, it is clear that the radar-sonde will be capable of making upper air observations at greater heights than the radio-sonde. It is almost completely automatic in operation and easy to maintain and service. The accuracy of the measurements is much higher than in any existing system. The radar-sonde is undoubtedly an important development in upper air instruments, and might well provide a pattern for future stations in this country and in other parts of the world.

HUMIDITY OVER THE ATLANTIC OCEAN

By P. R. BROWN, M.Sc.

While much work has been carried out in obtaining temperature, wind, weather and cloud statistics over the oceans, the preparation of humidity statistics has received less attention. The main published sources of mean values of humidity over the oceans are the "Atlas of climatic charts of the oceans"[1], which includes seasonal charts of the depression of the wet bulb, and Száva-Kováts's charts of mean vapour pressure and mean relative humidity for January and July[2]. The values given in this Atlas of the mean wet-bulb depression, which were obtained directly from ships' observations, have only limited value as it is not possible to compute mean vapour pressure or relative humidity accurately from them, and Száva-Kováts's values are only computed indirectly from mean sea-surface temperature. The Marine Branch of the Meteorological Office have computed means of relative humidity for some sample areas on the main shipping routes. These have not been published, but they have been very useful in dealing with inquiries about problems such as the carriage of goods by sea. Owing to the immense amount of work involved it has not yet been practical to prepare charts of humidity over sufficient areas for inclusion in the meteorological atlases of the oceans. The need for accurate humidity statistics over the sea is increasing. World charts of vapour pressure for land areas are being prepared by the World Climatology Branch of the Meteorological Office, and the preparation of values over the oceans will doubtless be required in the foreseeable future. The purpose of this paper is to present the initial results of an attempt to prepare accurate monthly humidity statistics over the oceans and to bring forth any criticism of the methods used.

To obtain such statistics in the form of mean relative humidity or mean vapour pressure it is essential, first, to have a sufficient number of reliable psychrometer readings, and, secondly, to carry out a lot of computation. This computation is necessary as means of relative humidity and vapour pressure cannot be derived accurately from means of wet- and dry-bulb temperatures without the application of corrections which themselves entail considerable computation[3]. The Marine Branch have in their possession a great number of merchant ships' observations, which include readings of dry- and wet-bulb thermometers mounted in small portable screens. These screens are normally suspended on the navigation bridge, the level of which varies mostly between 30 and 70 ft. in British "selected" ships—the average height being about 45 ft. The observations of Black, mentioned in a paper by Sverdrup[4], indicate that the vertical variation of vapour pressure within this height range of 30–70ft. is not very great.

The reliability of the psychrometer readings and the accuracy of humidity statistics obtained therefrom is discussed later in this paper.

Method.—It was not possible to compute humidity statistics for the whole Atlantic Ocean, and it was therefore decided to select eleven 10° squares north of 10°S., seven of these being in the east and four in the west of the Ocean. The squares chosen and the Marsden system of notation are shown in Fig. 1. In squares where land exists, such as Marsden square 181, only ships' observations which are at least five miles from the coast were included. The observations used were those made since 1920, and they were on punched Hollerith cards. All cards for each 10° square for each month were sorted for dry-bulb temperature

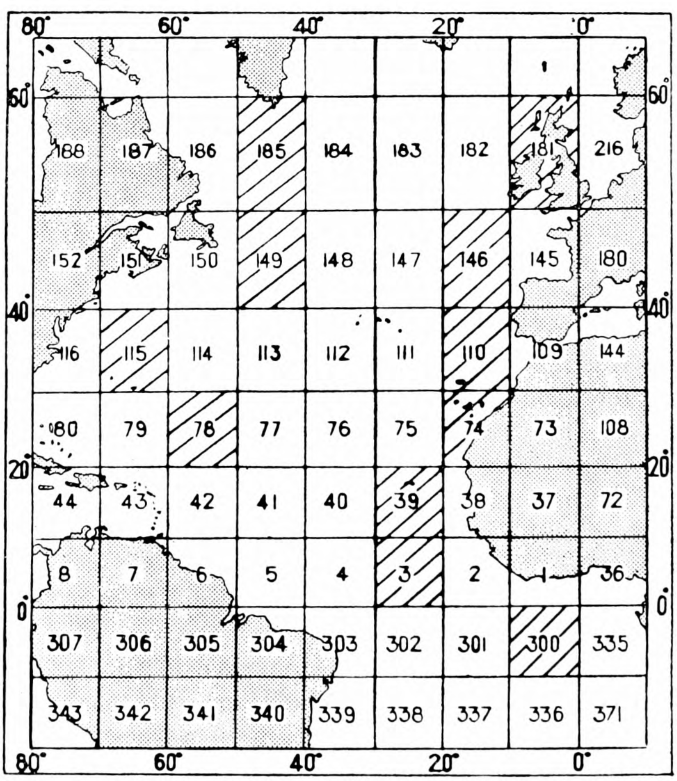

FIG. 1—MARSDEN SQUARE NOTATION SYSTEM

The squares with oblique lines crossing them are those for which humidity means were computed.

and the packs for each dry-bulb temperature sorted for wet-bulb temperature. Then the dry- and wet-bulb temperatures for each of the resultant packs of cards were tabulated, together with the number of cards in the pack. Thus one computation of humidity sufficed for the whole of one of the resultant packs. The mean vapour pressure, the standard deviation of the vapour pressures, the mean relative humidity and the 50-percentile value (median) of the relative humidity were calculated.

Vapour pressure and relative humidity.—The monthly values of mean vapour pressure, of the standard deviation of vapour pressures, of the mean and median of relative humidity are shown in Table I, together with the number of observations on which the values are based. The values of vapour pressure are given to the nearest 0·1 mb., and of relative humidity to the nearest one

TABLE I—HUMIDITY VALUES OBTAINED FROM BRITISH MERCHANT SHIP OBSERVATIONS

Marsden Square		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
181	Mean vapour pressure (mb.)	9·1	8·7	8·8	9·6	11·2	12·9	15·0	14·7	13·8	12·2	10·1	8·6
	Standard deviation of vapour pressure (mb.)	2·1	2·1	1·9	1·9	2·3	2·3	2·6	2·6	2·8	2·8	2·4	1·8
	Mean relative humidity (per cent.)... ...	84	83	83	83	83	85	86	85	85	85	83	81
	Median of relative humidity (per cent.)	85	85	85	85	86	87	87	88	87	87	85	83
	Number of observations	1396	1594	1877	2649	3273	3164	3157	3438	3752	3840	2390	1463
146	Mean vapour pressure (mb.)	11·1	11·1	11·4	11·3	12·5	14·9	16·7	17·1	16·7	15·2	13·3	11·7
	Standard deviation of vapour pressure (mb.)	2·5	2·3	2·2	2·9	2·3	2·4	2·8	3·1	3·3	3·2	3·1	2·5
	Mean relative humidity (per cent.)... ...	81	81	83	80	81	84	84	83	83	82	81	80
	Median of relative humidity (per cent.)	81	81	84	80	81	86	83	83	83	82	81	80
	Number of observations	3123	3411	3832	3565	3180	3148	3207	3175	3142	3265	3269	3376
110	Mean vapour pressure (mb.)	13·7	13·7	14·1	14·4	15·2	17·8	20·0	21·2	20·6	19·2	16·9	14·7
	Standard deviation of vapour pressure (mb.)	2·5	2·6	2·5	2·5	2·6	2·5	2·6	2·7	2·8	3·2	3·2	3·1
	Mean relative humidity (per cent.)... ...	76	77	78	77	77	80	81	80	79	78	77	76
	Median of relative humidity (per cent.)	76	76	77	77	77	79	80	80	79	78	77	75
	Number of observations	2360	2798	2717	2607	3136	3110	3089	3008	2805	3136	2758	3006
74	Mean vapour pressure (mb.)	15·5	15·9	17·1	17·1	17·9	19·4	21·5	23·3	23·1	22·2	19·6	17·1
	Standard deviation of vapour pressure (mb.)	3·2	2·3	2·6	2·4	2·3	2·3	2·3	2·4	2·5	2·6	2·8	2·8
	Mean relative humidity (per cent.) ...	74	77	79	78	78	81	84	84	82	81	78	75
	Median of relative humidity (per cent.)	73	77	78	77	78	79	84	85	81	81	79	75
	Number of observations	1842	2174	2255	2226	2426	2426	2433	2457	2467	2406	2286	2198
39	Mean vapour pressure (mb.)	20·7	20·0	21·0	21·4	21·9	24·3	26·0	28·4	28·9	28·1	25·7	23·1
	Standard deviation of vapour pressure (mb.)	3·2	2·8	2·8	2·9	2·6	2·7	3·1	2·7	2·6	2·9	3·2	3·6
	Mean relative humidity (per cent.)... ...	75	76	79	77	78	82	82	84	82	80	78	77
	Median of relative humidity (per cent.)	74	76	78	77	79	81	81	83	82	79	78	77
	Number of observations	702	995	994	1069	1053	1093	1205	1051	901	1134	1019	927
3	Mean vapour pressure (mb.)	27·4	26·3	26·9	27·4	27·8	28·4	27·4	27·6	28·0	28·4	28·8	28·3
	Standard deviation of vapour pressure (mb.)	2·6	2·9	3·0	3·1	2·6	2·2	2·5	2·6	2·7	2·3	2·1	2·4
	Mean relative humidity (per cent.)... ...	81	79	80	80	81	82	81	82	81	81	83	82
	Median of relative humidity (per cent.)	81	79	79	79	81	82	81	81	81	81	82	82
	Number of observations	690	801	955	983	1078	897	1150	959	978	983	899	808

TABLE I—HUMIDITY VALUES OBTAINED FROM BRITISH MERCHANT SHIP OBSERVATIONS—(*continued*)

Marsden Square		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
300	Mean vapour pressure (mb.)	26·4	27·3	28·5	28·1	26·5	24·5	22·5	22·0	22·2	22·6	23·8	25·0
	Standard deviation of vapour pressure (mb.)	2·9	2·9	3·0	2·9	3·1	3·0	2·2	2·5	2·6	2·9	2·9	3·1
	Mean relative humidity (per cent.)... ...	80	78	79	78	77	78	78	79	79	79	80	81
	Median of relative humidity (per cent.)	80	78	78	78	77	77	77	79	80	79	80	81
	Number of observations	1382	1432	1341	1280	1442	1435	1515	1542	1478	1473	1517	1382
185	Mean vapour pressure (mb.)	7·0	6·5	7·4	8·9	9·0	10·0	11·2	11·5	10·2	8·7	7·7	7·6
	Standard deviation of vapour pressure (mb.)	2·3	1·8	1·6	2·8	1·6	1·8	1·6	1·8	2·2	2·3	2·1	2·3
	Mean relative humidity (per cent.)... ...	84	87	81	81	85	88	91	89	85	84	84	83
	Median of relative humidity (per cent.)	85	89	82	81	85	91	92	92	85	83	83	83
	Number of observations	166	62	59	80	449	1035	1526	1841	1852	1870	1190	342
149	Mean vapour pressure (mb.)	8·1	8·3	9·2	11·0	10·9	13·2	17·3	19·4	16·0	12·6	10·5	8·8
	Standard deviation of vapour pressure (mb.)	3·6	3·7	3·6	4·2	4·2	5·0	5·7	5·5	5·5	4·3	4·1	3·8
	Mean relative humidity (per cent.)... ...	86	86	83	85	86	87	89	86	83	82	83	84
	Median of relative humidity (per cent.)	88	88	84	88	89	90	90	88	85	83	84	84
	Number of observations	2550	2305	2985	2939	3094	2549	2231	2099	1883	1928	2244	2676
115	Mean vapour pressure (mb.)	14·5	13·8	14·2	15·2	19·8	23·0	26·9	28·1	25·9	22·0	17·5	15·5
	Standard deviation of vapour pressure (mb.)	4·8	4·7	4·7	4·6	4·5	4·3	3·7	4·0	4·6	5·6	5·1	4·9
	Mean relative humidity (per cent.)... ...	78	77	77	78	81	81	81	81	80	77	74	76
	Median of relative humidity (per cent.)	79	77	78	80	83	83	83·	83	82	78	75	76
	Number of observations	1031	850	879	862	1134	884	1370	1460	1080	1106	1049	939
78	Mean vapour pressure (mb.)	20·3	19·9	19·3	20·6	23·4	25·8	27·2	28·3	28·1	26·5	23·9	21·5
	Standard deviation of vapour pressure (mb.)	3·2	3·3	3·7	3·5	3·1	2·8	2·7	2·5	2·8	3·1	3·6	3·7
	Mean relative humidity (per cent.)... ...	76	76	75	76	79	79	77	77	77	78	77	75
	Median of relative humidity (per cent.)	76	76	74	76	78	78	78	78	78	78	78	75
	Number of observations	1265	1627	1824	1855	1671	1624	1592	1753	1600	1826	1635	1783

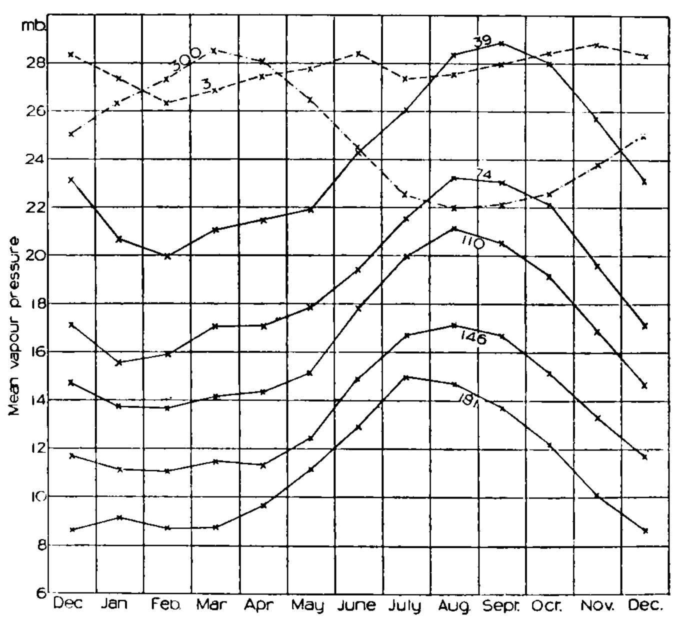

FIG. 2—MEAN VAPOUR PRESSURE IN EASTERN ATLANTIC

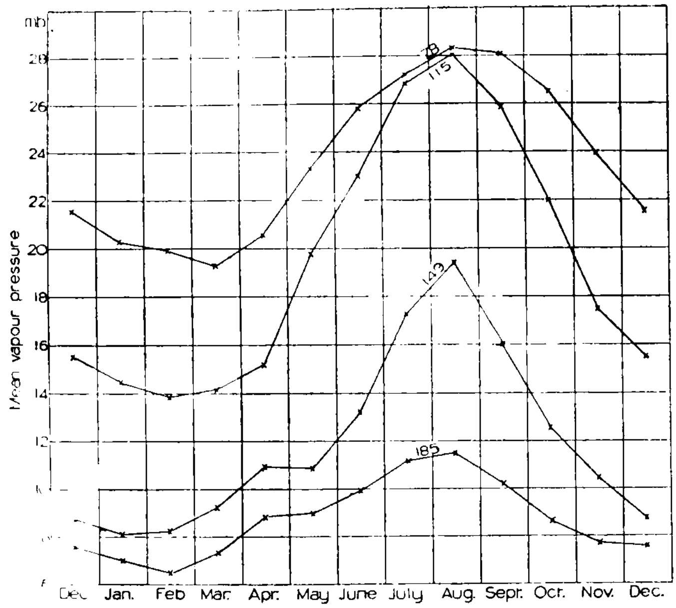

FIG. 3—MEAN VAPOUR PRESSURE IN WESTERN ATLANTIC

per cent. The values of mean vapour pressure for the eastern squares are shown graphically in Fig. 2 and those for the western in Fig. 3.

The values of mean vapour pressure were analysed harmonically, and the amplitudes and times of year of occurrence of the maximum of the twelve-monthly harmonic so obtained are shown in Fig. 4. The amplitudes of the six-monthly harmonic are small compared with those of the twelve-monthly in all the squares considered except Square 3, where they are 0·71 mb. and 0·61 mb. respectively. The amplitude of the annual variation is less for the squares in the eastern Atlantic than for those in the western part, except for Square 185.

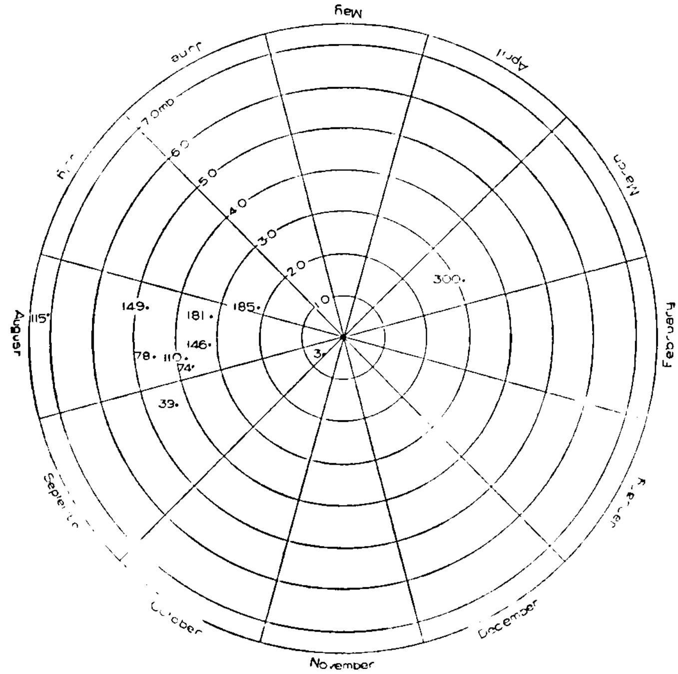

FIG. 4—AMPLITUDES OF ANNUAL VARIATION OF VAPOUR PRESSURE AND TIMES OF THE YEAR OF THE MAXIMA

Discussion of accuracy.—To obtain accurate humidity readings aboard ship using a screen it is necessary to ensure that the wet bulb and its fittings and the water employed are clean and free from spray; it is also important to hang the screen to windward to ensure that the flow of air passing the thermometers is unaffected by contact with the ship. The difficulties in carrying out these requirements are often considerable and have led many, including Kuhlbrodt and Wüst, to doubt the reliability of humidity readings made on merchant ships using thermometers in a screen, and the accuracy of statistics based thereon. Wüst[5] has expressed more confidence in the observations made by trained meteorologists on ocean weather ships. The author[6] has shown, however, that there is close agreement between humidity statistics computed from British merchant ship observations and those computed from British ocean weather ship observations, as long as the number of observations is sufficiently large, both sets of observations being made from thermometers in screens. It is doubtless true that many individual observations of humidity taken aboard merchant ships using a screen are liable to appreciable error, especially if the screen is not satisfactorily exposed to windward. The agreement found by the author between the two sets of statistics does suggest, however, that the errors in humidity observations made on merchant ships are of an approximately accidental character, and that errors in means are small when computed from a large enough number of observations.

During prolonged series of simultaneous readings made aboard British ocean weather ships using dry- and wet-bulb thermometers in a screen and an Assmann psychrometer, it has not been possible to show that the Assmann psychrometer gives more accurate humidity readings than those obtained from the screen.

Wüst[5] also points out that the presence of a ship distorts the water-vapour field over the ocean; while this is undoubtedly so, it is not obvious that errors so caused in attempting to observe the humidity in the undisturbed field would be other than approximately random, and so cause any appreciable error in a mean computed from a great number of observations.

Wüst[5] has also made a critical survey of the humidity values obtained by Száva-Kováts[7] by comparison with the observations of the German research ship *Meteor* during the years 1925–27. Száva-Kováts's means of vapour pressure for zones of 5 degrees of latitude for January and July, both for continental and oceanic regions, were obtained by interpolation from charts of isopleths of mean vapour pressure. Over land areas these charts were based on values from a network of land stations. Over the sea they were based on values calculated by computing the saturated vapour pressure at the sea-surface temperatures and applying corrections to allow for salinity, a height of 1·5 m. and wind strength. Száva-Kováts claims that these values for ocean regions were in good agreement with the direct observations from coastal and island stations. A comparison between the January and July means of vapour pressure obtained by the author and those of Száva-Kováts is given in Table II. The means of Száva-Kováts's values for the two relevant 5-degree zones are compared with the values for the corresponding months and squares obtained from British merchant ship observations.

It can be seen that the two sets of values for July are in fair agreement, but that for the region 30 — 60°N. Száva-Kováts's January means are lower than

TABLE II—COMPARISON WITH MEAN VAPOUR PRESSURE OBTAINED BY SZÁVA-KOVÁTS

Latitude	January			July		
	Száva-Kováts's mean	British ships Square	British ships mean	Száva-Kováts's mean	British ships Square	British ships mean
	mb.		mb.	mb.		mb.
60–50°N.	4·5	181	9·1	11·9	181	15·0
		185	7·0		185	11·2
50–40°N.	7·7	146	11·1	15·6	146	16·7
		149	8·1		149	17·3
40–30°N.	12·3	110	13·7	21·3	110	20·0
		115	14·5		115	26·9
30–20°N.	17·5	74	15·5	23·7	074	21·5
		78	20·3		078	27·2
20–10°N.	23·5	39	20·7	26·2	039	26·0
10– 0°N.	26·8	3	27·4	27·3	003	27·4
0–10°S.	27·3	300	26·4	26·3	300	22·5

TABLE III—COMPARISON OF MEANS FROM BRITISH MERCHANT SHIPS AND THE OBSERVATIONS OF THE *Meteor*

Date	*Meteor* observations: Position		No.	Mean relative humidity	Mean vapour pressure	British observations: Month	Square	Mean relative humidity	Mean vapour pressure	*Meteor* observations minus British observations: Relative humidity	Vapour pressure
	N.	W.		%	mb.			%	mb.	%	mb.
Apr. 23	41·6	12·3	3	86	12·5	Apr.	146	80	11·3	+6	+1·2
Apr. 24	39·1	14·9	6	73	11·5	Apr.	110	77	14·4	−4	−2·9
Apr. 25	36·1	17·6									
May 11	26·6	18·0	3	76	17·2	May	74	78	17·9	−2	−0·7
Feb. 14–17	10·2	26·6	19	79	20·5	Feb.	39	76	20·0	+3	+0·5
	12·8	21·8									
Feb. 21–23	16·5	20·5									
	16·9	25·1									
Mar. 2– 5	17·1	24·8	21	80	18·8	Mar.	39	79	21·0	+1	−2·2
	19·3	21·3									
Mar. 10–11	17·4	21·6									
	16·9	22·5									
Mar. 14	16·7	25·0									
Mar. 16	17·8	26·3									
Mar. 17	19·2	27·5									
May 6	14·6	25·8	19	79	21·5	May	39	78	21·9	+1	−0·4
May 7	11·5	27·1									
May 3– 7	15·1	28·7									
	19·3	25·0									
Feb. 12	8·2	29·6	6	75	22·7	Feb.	3	79	26·3	−4	−3·6
Feb. 13	9·4	27·9									
May 8–10	8·0	27·9	9	79	27·6	May	3	81	27·8	−2	−0·2
	1·3	29·1									
Oct. 19–26	0·6	29·3	24	82	28·1	Oct.	3	81	28·4	+1	−0·3
	7·2	21·3									
	S.	W.									
Sept. 9–12	9·0	1·5	12	73	19·2	Sept.	300	79	22·2	−6	−3·0
	9·1	8·4									
Dec. 26–29	2·3	1·8	12	85	27·3	Dec.	300	81	25·0	+4	+2·3
	1·2	9·1									

any obtained by direct computation for the squares considered. It can also be seen that some of Száva-Kováts's values for the regions of the trade winds are considerably higher than the values computed for comparable squares. Wüst also found that Száva-Kováts's values were too high in the region of the trade winds.

Although humidity over the oceans for any one time of the year varies little from year to year, it is not possible for two reasons to make an exact comparison between the humidity values obtained by the *Meteor* and those given in the paper. First, the few observations by the *Meteor* which were made in the areas considered in this paper are often near the boundaries of the squares, and, secondly, they are often either at the end or the beginning of the month. The observations cannot, therefore, be expected to approximate closely to the mean value of the square for the month. However, those relevant observations of relative humidity and vapour pressure made by the *Meteor* using an Assmann psychrometer during her observations of "profiles" across the Atlantic[8] during 1925–27 are compared in Table III with means obtained by the author. No large systematic difference appears to exist between the two sets of relative humidity values. The differences between the vapour-pressure values are also both positive and negative, but there does seem a slight tendency for the values of vapour pressure obtained by the *Meteor* to be lower.

As has been stated previously the Marine Branch will probably have, in the not too distant future, to consider the preparation of humidity statistics from ships' observations over the whole of the oceans. It is hoped that this paper will bring forth from potential users criticisms and suggestions as to the most convenient form such statistics should take.

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ERRORS OF TEMPERATURE MEASUREMENTS CAUSED BY THE EXHAUST OF JET AIRCRAFT

By B. C. V. ODDIE, B.Sc. and W. H. IRESON

At stations where jet aircraft operate, it may happen that the blast of hot air from the engines is directed towards the meteorological enclosure. When this occurs there is the immediate inconvenience that it is impossible to take reliable dry- and wet-bulb thermometer readings while the blast continues; and in addition it may cause entirely false readings of the maximum thermometer.

It was possible, with the co-operation of the Royal Air Force, Finningley, to carry out three experiments designed to discover the magnitude of the errors, and the distances at which they might be appreciable. The first experiment was exploratory, and details need not be given. The second was carried out on March 23, 1953. A Meteor aircraft (2 Rolls-Royce Derwent engines) was arranged with its tail pointing south-east, and the engines were run at the maximum taxi-ing speed of 7,000 r.p.m. The wind was 8·5 ft./sec. (5 kt.) from S., i.e. there was a component of some 6 ft./sec. against the jets; the air temperature was 54°F., and the weather fine and cloudless but hazy (visibility 2,200 yd.). At 100 yd. behind the aircraft no effect whatever could be perceived. At 50 yd., however, there was a considerable rise of temperature; the maximum reading of temperature was 86·5°F., giving an increase of 32·5°F. Finally, eleven maximum thermometers were set up, at a height of 4 ft. above the ground, along a line at right angles to the axis of the aircraft and 30 yd. behind the jets. Near the centre thermometer a portable cup anemometer was set up. The readings given by this installation are shown in Fig. 1.

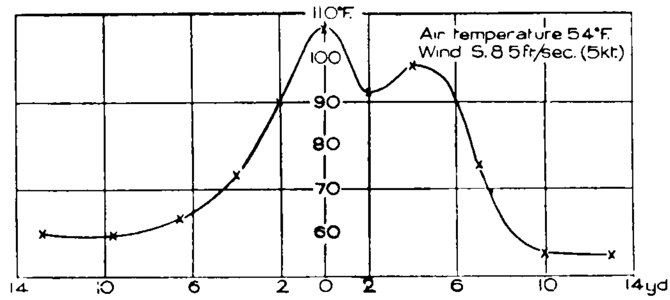

FIG. 1—TEMPERATURE ALONG A LINE 30 YD. FROM OUTLET OF JETS, MARCH 23, 1953, 1700–1727 G.M.T.

Jets pointing south-east. Wind speed at mid point of line 37 ft./sec.

In the second experiment, on May 27, 1953, the tail of the aircraft pointed down wind, and temperatures were taken every ten yd. from 60 to 200 yd., along what was judged to be the centre line of the exhaust stream. Conditions at the time were—wind NW. 25 ft./sec. (15 kt.), (20 ft./sec. at 4 ft.), weather fair, $\frac{3}{8}$ cumulus cloud at 3,000 ft., visibility $6\frac{1}{2}$ miles. The results are plotted in Fig. 2.

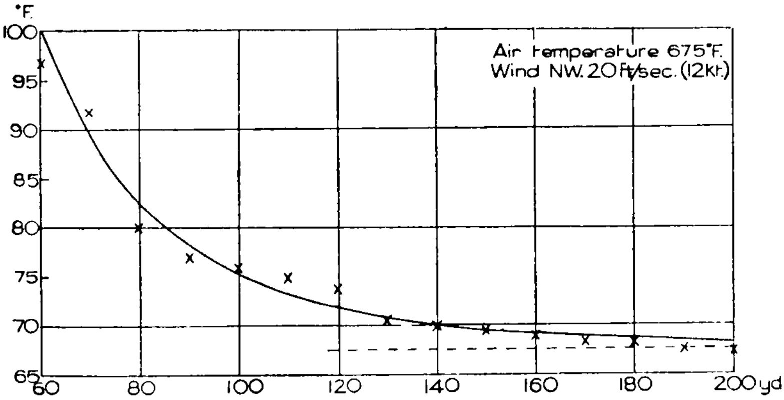

FIG. 2—TEMPERATURE ALONG CENTRE LINE OF EXHAUST STREAM, MAY 27, 1953, 1455–1520 G.M.T.

Discussion of results.—The curve plotted in Fig. 2 is

$$T = 2 \cdot 16 \times 10^9 (x + 30)^{-4} + 67 \cdot 5$$

where T is in degrees Fahrenheit and x in yards. It will be seen that this expression fits the points quite well, but it is not suggested that there is a general law of this form.

If it is assumed that the two experiments are comparable, the time taken by the exhaust gases to disperse and their range in still air at the surface can be determined from them. Let these two quantities be t sec. and d ft. In the second experiment, the gases were completely dispersed 570 ft. from their source, with a following wind of 20 ft./sec. Thus

$$d + 20t = 570.$$

Of the first experiment, it is only known that the gases reached a distance of between 150 and 300 ft. against a headwind of 6 ft./sec. There is no measure of t here, since the gases ceased to advance when their own speed was still 6 ft./sec., i.e. when it balanced the wind speed. Probably it would not be far wrong to assume that the time taken to reach this condition was about $\frac{2}{3}t$. From this experiment, then

$$d - 6 \times \tfrac{2}{3}t \simeq 225.$$

The solution of these two equations is approximately $t = 14 \cdot 4$ sec. and $d = 283$ ft. or about 94 yd.

The argument is loose; but if it is assumed that the two experiments are comparable, a few trials will show that no values greatly different from these will account for the facts.

The Derwent engine, at 7,000 r.p.m., ejects about 650 ft.^{3} of air per second, at a speed of 520 ft./sec. and a temperature of 716°F. (380°C.). It seems strange that this formidable blast cannot penetrate more than a hundred yards in still air, but such is apparently the case.

One may tentatively apply the result to find out what "safety distance" would be needed to render meteorological instruments entirely immune from the effects of Derwent engines. It may be assumed that, since the energy used in dispersing the gases comes largely from the engines, the time which is required is not very dependent on meteorological factors, i.e. the gases will always be fairly completely dispersed 14 sec. after emission, and that engines will rarely be run when wind speeds exceed 50 ft./sec., which is nearly gale force. These lead to a "safety distance" of about 330 yd.

At many airfields, of course, it would be impossible or intolerably inconvenient to place the meteorological enclosure so far from all areas on which engines are likely to be run. It is suggested that the following precautions would be sufficient, and are also necessary.

(i) Avoid any site which is down wind (with respect to the prevailing wind) of any area used for running engines, unless the distance is 300 yd. or more.

(ii) Avoid any site which is within 100 yd. of an area used for running engines. This will ensure freedom from gross errors, and also that no errors need be feared except when the wind is along the line from the aircraft area to the screen.

These distances would doubtless have to be increased somewhat for more powerful types of engine.

Convenient sites for screens are often close to taxi-tracks. It is evident that positions on the outside of a bend or corner in the track are to be avoided, since every aircraft negotiating the turn is liable to direct its exhaust straight at the screen. A position beside a straight section (or inside a bend) of the track, is probably satisfactory provided it is 40 yd. or so away, since the gases from a passing aircraft will affect the screen for a few seconds only, and are unlikely to cause appreciable errors.

This view may be worth examining further. If H is the heat capacity in calories of one cubic foot of air at "normal" temperature—say 59°F.—it will be found from the figures already given that the heat output of the Meteor with both engines at maximum taxi-ing speed is about 210,000 H/sec. If the aircraft were taxi-ing at 37 ft./sec., this quantity of heat would suffice to leave behind a trail of warm air of hemi-cylindrical form, 10°F. warmer than its surroundings and nearly 30 ft. in radius. While this is of course an impossible form, it gives an idea of the errors likely to occur. If there were a wind of 10 ft./sec. from runway to screen (120 ft. away) it would take over 12 sec. for the trail to reach the screen, and from the above there is reason to believe that it will be almost completely dispersed in that time. If the wind is stronger—say 20 ft./sec.—dispersal may not be complete when the trail reaches the screen. But even if its original form remained unaltered, it would pass, in these conditions, in 3 sec., and the thermometers would not respond noticeably. Unreal as the imagined conditions are, they strongly suggest that the merely passing aircraft is not a serious problem.

A somewhat different approach to the original experiments is instructive. The very great fall of temperature in the first few seconds after the gases leave the engine shows that they mix rapidly with a large quantity of the surrounding air; and it may be assumed therefore that they lose momentum mainly by the same process. There should therefore be a simple relationship between the fall in temperature and the fall in speed, at least near the centre of the jet.

Let T be the temperature and v the speed of the exhaust gases. Let T_1 be the temperature of the surrounding air, and v_1 its component speed parallel to the jet, and let T_2 be the temperature at some point P at or near the axis of the jet, and u the speed, assumed parallel to the axis. Suppose the atmosphere at P to consist of one part (by weight) of exhaust gas mixed with n parts of air. Since there is no appreciable difference in specific heats,

$$T - T_2 = n(T_2 - T_1).$$

Again by conservation of momentum

$$v + nv_1 = u(n + 1).$$

Eliminating n,

$$u = v_1 + \frac{(v - v_1)(T_2 - T_1)}{T - T_1}, \qquad \ldots\ldots (1)$$

or alternatively

$$T_2 = \frac{T(u - v_1) + T_1(v - u)}{v - v_1}. \qquad \ldots\ldots (2)$$

As already stated, for the Derwent engine at 7,000 r.p.m. $v = 520$ ft./sec. and $T = 716$°F. (or 380°C.). To this last—though it is scarcely significant—may be added 22°F. to allow for the kinetic energy of the gases.

In the first experiment, $v_1 = -6$ ft./sec., $T_2 = 106 \cdot 4$°F., and $T_1 = 54$°F. Substituting these values into equation (1), $u = 34$ ft./sec. The measured value of u was 37 ft./sec. Agreement so good must of course be partly accidental.

Prandtl* shows that the speed at points on the axis of a jet is inversely proportional to the distance from the point of origin. If this result is combined with equation (2), an expression for temperature at points on the axis of a jet is obtained which is quite unlike that plotted in Fig. 2. However, there is no real discrepancy, for the conditions are very different. The jet considered by Prandtl* is dispersed entirely by turbulent mixing, whereas the hot exhaust gases are lost from ground level mainly by convection.

Equation (2) might possibly be applied in some cases, where a jet has been directed up wind towards a screen, in order to determine whether the temperature readings have been affected. For, clearly, the exhaust jet cannot advance in this direction beyond the point where $u = 0$; and this gives

$$T_2 = \frac{-v_1 T + v T_1}{v - v_1},$$

$$\text{or } T_2 - T_1 = -\frac{v_1 (T - T_1)}{v - v_1}$$

$$\fallingdotseq -1 \cdot 2 v_1.$$

Thus, even if the wind speed is as low as 10 ft./sec., the thermometers should either be unaffected or in error by at least +12°F. However, the circumstances would have to be considered with some care, in applying the rule.

By the use of equation (1), it is easy to estimate, from the temperatures shown in Fig. 1, the total amount of heat per second passing through an area 1 ft. deep and coinciding with the line of thermometers. This turns out to be about one-twelfth of the heat output of the engine, which is certainly of the right order.

NIGHT COOLING UNDER CLEAR SKIES AT SHAWBURY

By T. H. PARRY

W. E. Saunders[1] has shown that the cooling curve on a radiation night is not smooth, but is characterized by a steep decline in the evening at the commencement of the cooling period, followed by a more gradual decline, with the two phases separated by a marked discontinuity in the rate of cooling. Two equations were given for forecasting the screen temperature at the change of cooling rate (T) in terms of T_{max} (maximum day temperature) and T_d (dew point at the time of T_{max}), at Northolt, according to whether there was or was not an afternoon inversion with base at or below 900 mb.

Saunders discusses the effect of recent rainfall etc. on T, and gives graphs of the following values for Northolt:—

(i) Time of the evening discontinuity throughout the year.

(ii) Subsequent cooling from T to T_{min} for inversion and non-inversion cases under carrying conditions of wind speed (where T_{min} is the final temperature of the subsequent cooling period).

An investigation along similar lines has been carried out for Shawbury. The results achieved are set out below, and some comparison is made with those found by Saunders for Northolt.

* PRANDTL, L.; Essentials of fluid dynamics. London, 1952.

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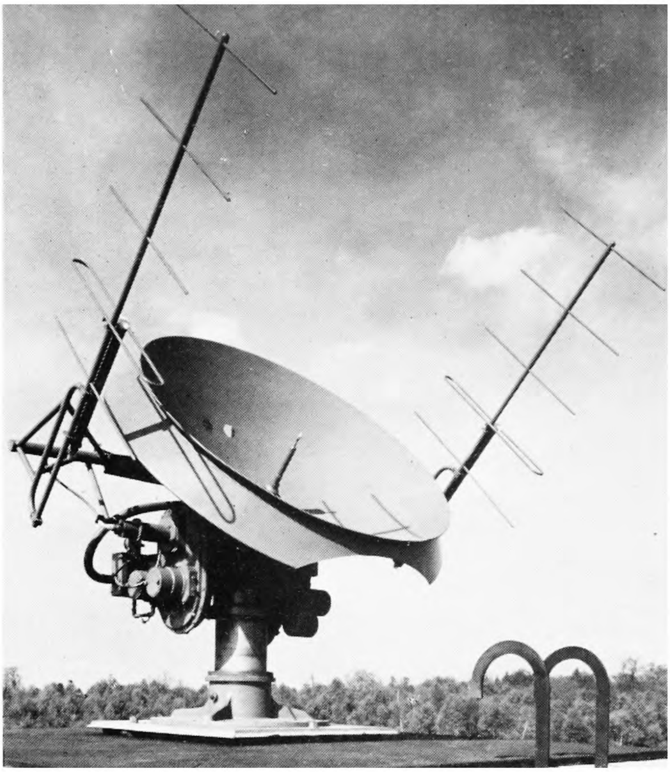
CLOUD FUNNEL OVER SOUTH SCOTLAND, JUNE 7, 1953

see p. 376.



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RADAR-SONDE AERIAL UNIT

This shows the Yagi transmitting arrays and the receiving dipole and reflector.

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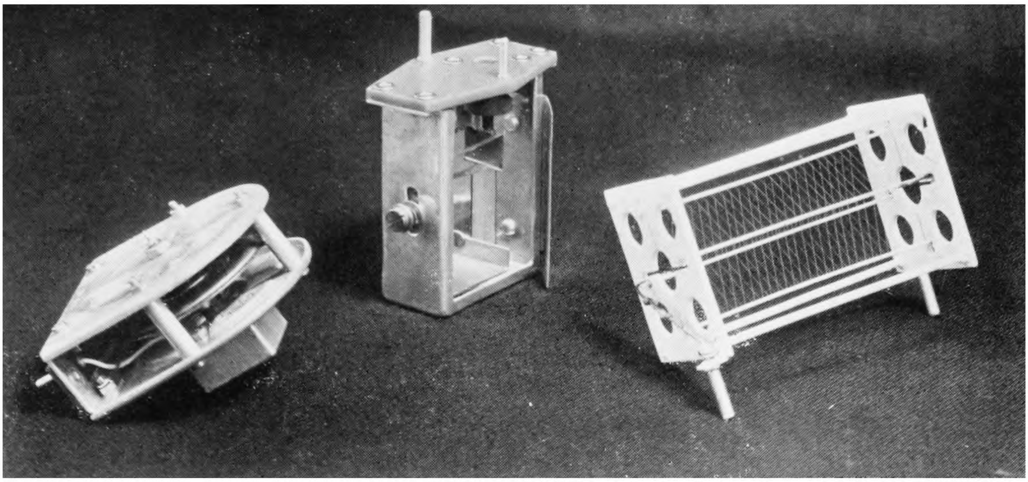
RADAR-SONDE WIND-DIRECTION RECORDER INCORPORATING THE WIND COMPUTER



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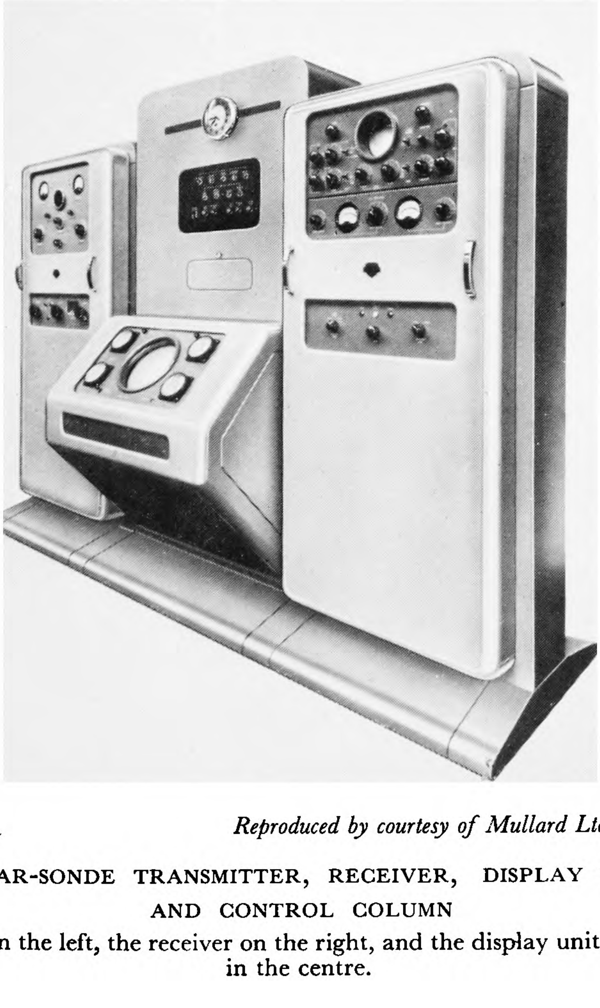
RADAR-SONDE PRESSURE-, HUMIDITY- AND TEMPERATURE-SENSITIVE UNITS



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RADAR-SONDE TRANSMITTER, RECEIVER, DISPLAY UNIT
AND CONTROL COLUMN

The transmitter is on the left, the receiver on the right, and the display unit and control column in the centre.

Reproduced by courtesy of R. M. Poulter

IRIDESCENT WAVELIKE CLOUDS, UXBRIDGE, 1630, FEBRUARY 19, 1953

see p. 376.

Method.—Initially, as likely radiation nights occurred, half-hourly temperature readings were taken, and a note made of the other parameters etc., to accumulate data for the investigation. It soon became clear, however, that this would prove too lengthy a procedure to yield results within a reasonable time. Accordingly, recourse was made to past records and all radiation nights from January 1949 to March 1953 were examined. Day maximum temperature, night minimum temperature, and state of ground at 1800 G.M.T. were extracted from the *Daily Register* for all occasions.

Those nights when radiation conditions existed for the beginning only of the cooling period were also utilized for the purpose of evaluating the value and time of occurrence of the evening temperature discontinuity.

An estimate of the value and time of occurrence of T was made from the thermograph records taken in conjunction with the hourly temperature records in the *Daily Register*. Difficulty was sometimes experienced and estimates were necessarily partly subjective, but care was taken to avoid excessive smoothing. The appropriate *Daily Weather Reports* were used for making estimates of the gradient wind speeds and also for separation of the data into "inversion" and "non-inversion" cases, i.e. according to the presence or absence of an air-mass inversion at or below 900 mb.

Results.—Suitable equations for the value of the evening temperature discontinuity T proved to be:—

With no inversion (131 occasions, standard deviation 0·23°F.)

$$T = \tfrac{1}{2}(T_{\max} + T_d) - 2{\cdot}5°\text{F.}$$

With inversion at or below 900 mb. (28 occasions, standard deviation 0·67°F.)

$$T = \tfrac{1}{2}(T_{\max} + T_d) - 3{\cdot}4°\text{F.}$$

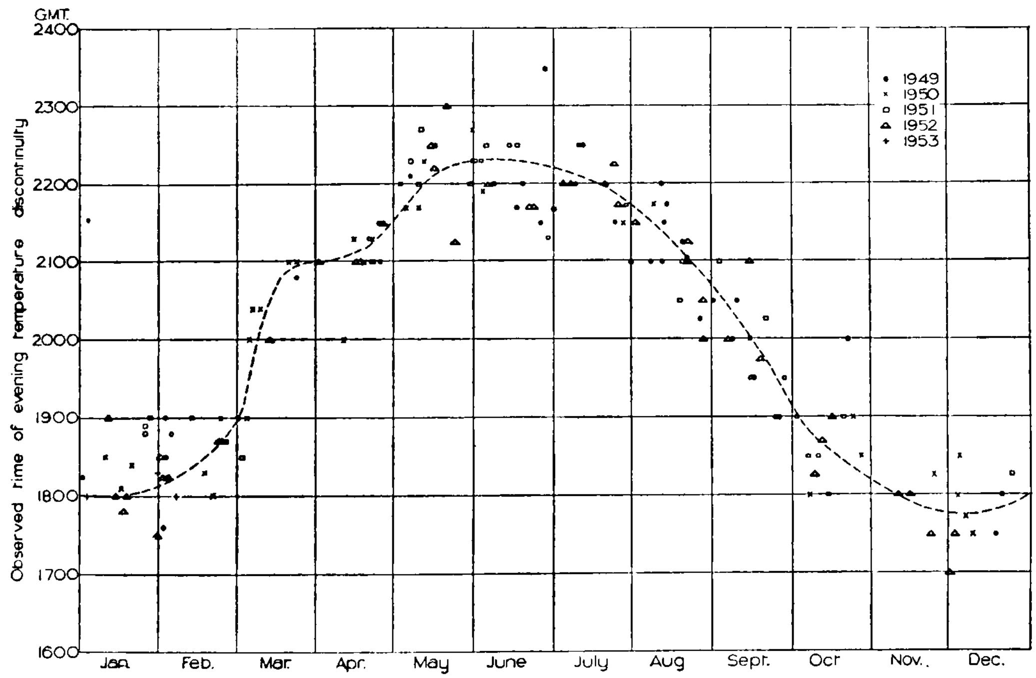


FIG. 1—VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY, SHAWBURY, 1949–53

The inversion cases give a result very close to that found by Saunders for Northolt, but in the absence of an inversion a rather lower value of T was found.

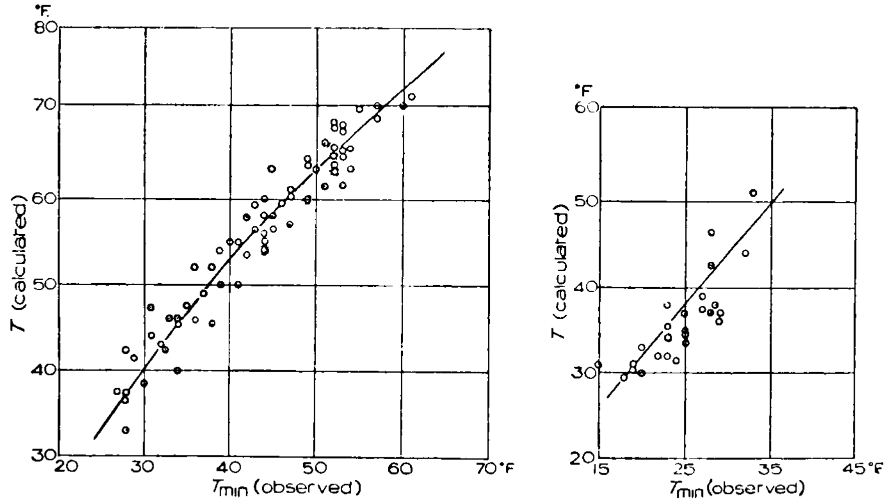
While Saunders[1] finds a difference of 3·4°F. between the inversion and non-inversion values for Northolt, it may be noted that Pedlow[2] finds a difference of only 0·6° between the two (for 8 and 13 cases respectively) at Rye, compared with the 0·9° difference for Shawbury.

Fig. 1 shows the variation of the time of the evening temperature discontinuity T throughout the year. In general, T would seem to occur nearly an hour later than at Northolt, of which only some 10 min. can be accounted for by variation in longitude, etc. Differences in soil and topography are probably the main reasons for this; the soil at Shawbury being of a rather light, loamy nature.

The curve shows a sharp rise during the first week in March with a second, less marked, rise at the end of April, as opposed to the slight fall in September at Northolt followed by the more pronounced fall at the beginning of October. Saunders[1] accounts for the irregularities by suggesting that they mark the transition to the winter period during which the topsoil remains premanently moist. If so, it may well be that the lighter, more easily drained soil at Shawbury dries out more rapidly in spring than the Northolt clay, and is also slower to revert to the moist winter conditions later in the year. It is not impossible of course that these irregularities may be merely chance, and that the curve for T is really symmetrical about a midsummer axis.

No definite indications were found to confirm the variation in the time of T found at Northolt with wet and dry top soil during the summer. This phenomenon may have been masked, however, by the coarser method of evaluation of T employed, although it is not improbable that the effect would be less marked on lighter soils.

Curves of subsequent cooling from T to T_{min} are shown in Fig. 2. Originally diagrams were prepared in the same manner as employed by Saunders, but as



Summer (Mar.–Oct.) Winter (Nov.–Feb.)

FIG. 2—RELATION BETWEEN INITIAL AND FINAL TEMPERATURES OF THE PERIOD OF SUBSEQUENT COOLING

Gradient wind speed $\leqslant$ 24 m.p.h.

it proved impossible to discriminate to the same extent, the simpler presentation of Fig. 2 was employed. All cases of gradient wind 0–24 m.p.h. were divided into the two periods as shown on the diagram. No advantage was gained by separating them into categories of "calm" and "light wind". This was not altogether surprising, as in view of its rather sheltered situation (except from the north-west) surface winds on cooling nights tend to be rather lighter at Shawbury than might be expected, even with quite moderate gradients.

No marked differences in the subsequent cooling of inversion and non-inversion cases were noted. Even at Northolt this would only be expected in winter but at Shawbury no tendency for greater cooling in more stable air masses could be found. This may possibly be linked to the closer similarity in the two equations for T.

After allowing for the different forms of presentation, the diagram gives results agreeing reasonably well with those for Northolt although slightly greater cooling is indicated during the winter at least.

Too few occasions with strong winds occurred to be of value. Fig. 3 is merely a reproduction of Saunders's curve for Northolt with the Shawbury values superimposed. The broken line is probably more nearly representative of Shawbury, especially as even with quite moderate gradients surface winds tend to be consistently lighter than elsewhere.

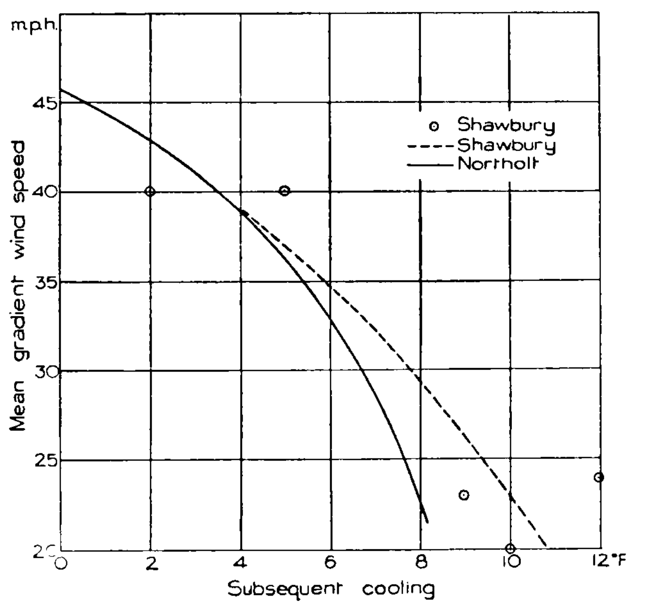


FIG. 3—RELATION BETWEEN THE MEAN GRADIENT WIND SPEED AND THE SUBSEQUENT COOLING FOR OCCASIONS OF STRONGER WIND

It also seems reasonable to postulate that a combination of radiation night with strong gradient normally occurs over the British Isles with NW.–N. wind direction. Under these circumstances, penetration of cloud from the Irish Sea gives partly cloudy conditions at Shawbury when most inland stations experience clear skies, accounting for the paucity of the occasions shown on Fig. 3.

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DIFFERENCES IN VISIBILITY BETWEEN A WEEK-DAY AND SUNDAY NEAR TO AN INDUSTRIAL AREA

By R. A. S. RATCLIFFE, B.A.

An investigation on this subject was carried out on the data available at the meteorological office at Finningley. Finningley is very liable to industrial smoke pollution; it is 5 miles east-south-east of Doncaster, approximately 20 miles north-east of Sheffield and Rotherham and 25–35 miles south-east of the main industrial belt of the West Riding of Yorkshire. In practice it is subject to industrial smoke for all surface wind directions between approximately SSW. and NNW.

The data analysed consisted of the Finningley records for Friday and Sunday from 1946–52 inclusive, for the winter six months from October 1 to March 31 only. Friday was chosen as a representative week-day. Observations for even hours from 0600–1800 G.M.T. (7 observations a day) were extracted.

Visibility observations were divided into 5 ranges as indicated in the table below. At a jet training station 3,000 yd. is the minimum visibility for a full flying programme. The other divisions in the table are those limits which define the necessity for issue of a special report under current Meteorological Office practice.

Range of visibility	Friday No. of observations	Friday Percentage frequency	Sunday No. of observations	Sunday Percentage frequency
below 880 yd.	106	8·3	83	6·5
880–2,000 yd.	164	12·9	143	11·2
2,000–3,000 yd.	157	12·3	132	10·4
3,000 yd.–3½ miles	300	23·5	240	18·9
above 3½ miles	547	43·0	674	53·0
Total	1,274	100	1,272	100

The results show that Sunday, on the average, has better visibility than Friday. For instance visibility is 3,000 yd. or less on 33·5 per cent. of occasions on Friday compared with 28·1 per cent. of occasions on Sunday. Also Sunday has 53·0 per cent. of occasions with visibility greater than 3½ miles while Friday only has 43·0 per cent. The investigation showed no significant difference between the results for October–December and those for January–March.

It is possible to obtain a rough verification of these results by inquiries to local industrial concerns. These reveal that whereas the British Electric Authority make no change in the working of their power stations at the week-end, the Area Coal Board and the English Steel Corporation at Sheffield state that such coal-burning plant as they have either shuts down completely or is considerably damped down on Saturday afternoons and Sundays. Doncaster Airport also states that of the 14 factory chimneys smoking in the vicinity of the airfield on week-days, all are smokeless on Sundays.

It is probable that there is more household smoke on Sundays, but this apparently is not enough to offset the smaller amount of industrial pollution.

It is interesting to note that it is possible to take advantage of this observed difference in average visibility between Sundays and week-days: the R.A.F. at Worksop (10 miles from Finningley) arranged to make Saturdays and Sundays full working days during the last winter, taking Tuesday afternoon and Wednesday off to compensate them. This affords a good practical example of adapting a task to gain as much advantage as possible from the weather.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Annual Report of the Director of the Meteorological Office, presented by the Meteorological Committee to the Secretary of State for Air, for the year April 1, 1952, to March 31, 1953.

The Meteorological Office, which forms part of the Air Ministry, provides meteorological services for a variety of needs. The greatest call on these services comes from the Royal Air Force and civil aviation, as well as the general public, but industrial undertakings and public corporations are among the numerous bodies which now obtain regular weather information for their special requirements. The report describes the organization needed to do this work and the lines along which advances are being made.

The increasing demand for forecasts of weather within the stratosphere has been taken a stage further by the introduction of jet aircraft in commercial flying, as well as through their wider use by the Royal Air Force. Much effort has been directed to improving upper air soundings and to extending our understanding of the mechanics of the upper atmosphere. A radar-sonde theodolite, the first instrument of its kind, is in course of erection at Crawley, in Sussex. The existing network of radio-sonde stations has maintained its programme of ascents, and systematic observations have been made by high-flying aircraft of significant weather features such as clear-air turbulence and high-cloud development. Experimental work on specific upper air problems has been carried out by a Mosquito aircraft of the Meteorological Research Flight at South Farnborough.

There was no major change in the network of overseas stations staffed by the Meteorological Office, which extends from the Far East to the West Indies and the Falkland Islands and includes the Western Zone of Germany. The political situation added to the difficulties and discomforts at Middle East stations, but services were maintained without interruption.

Research continued on short-range forecasting for general purposes, and a promising development was the investigation of mathematical methods requiring the use of an electronic computer. Further work was also done on medium-range forecasting, that is on the provision of forecasts in somewhat general terms for periods of four days ahead. No satisfactory method exists for forecasting for long periods, but a programme of research has been planned.

Such forecasts as those to the British Electricity Authority for the estimation of the hour-by-hour demand for electricity, or warnings to local authorities of the likelihood of snow, are now provided regularly. But again, as in previous years, there have been inquiries on widely differing problems, such as the effect of strong wind and extreme temperature on overhead cables, the feasibility of extracting water from certain rivers, the association of weather and bronchitis, and the protection of potatoes in storage and in transit.

GEOPHYSICAL MEMOIRS

No. 91—Vertical profiles of mean wind in the surface layers of the atmosphere. By E. L. Deacon, B.Sc.

A set of sensitive recording cup anemometers was installed in 1941 over an open grassland site at Porton, Wiltshire, adjacent to equipment for recording vertical temperature gradient. The wind-profile observations obtained there up to 1945, together with some data for other surfaces including the sea, have been analysed with particular attention to the effects of roughness of the surface and of thermal stratification.

The well known logarithmic relationship of Prandtl is shown to be a very adequate representation of the wind profiles under neutral conditions. For other conditions of stability the form of the wind profiles and the gustiness of the wind is found to be satisfactorily related to the Richardson number except under very stable conditions. The effect of thermal stratification on the wind profile is small near the surface but increases markedly with height, in keeping with the fact that the Richardson number is very close to zero at the surface and increases numerically almost linearly with height. A generalized wind-profile relationship is proposed which enables the eddy viscosity to be evaluated, and this is compared with some previous formulations. Observations bearing on the critical value of the Richardson number for the onset of turbulence are discussed in relation to the laboratory results of Reichardt.

LETTERS TO THE EDITOR

"Remarkable" rises in temperature

Mr. W. B. Painting's[1] letter in the June 1953 issue of the *Meteorological Magazine* was a most interesting contribution and presented valuable suggestions for further study. However, I was perplexed by the choice of "remarkable" as a word to be used in the title to his account. It must be assumed that a rise of 13°F. in 2 hr. is remarkable merely for Waddington in December.

At Alston, Cumberland, I have in my charge two bimetallic thermographs. Each is housed in a large Stevenson screen along with certified maximum and minimum thermometers which enable a weekly check on accuracy to be made. One station has been set up as near to the South Tyne River as is possible, whilst the other is about 170 ft. higher and ¾ mile away at Nether Park on the western side of the valley. The following table shows frequencies of temperature rises of 10°F.or more within 2 hr.

TABLE I—FREQUENCY OF VARIOUS TEMPERATURE RISES IN 2 HR.

January–June 1953

	Temperature rise (°F.)									Total
	10°	11°	12°	13°	14°	15°	16°	17°	18°	
Riverside, 900 ft. ...	7	4	6	2	5	2	3	2	1	32
Nether Park, 1,070 ft.	13	4	8	4	0	0	0	1	0	30

As may be expected, the valley bottom site experiences the greatest frequency of sharp rises. Two factors contribute:—

(i) After radiation nights the inversion is removed.

(ii) The aspect of the higher station, on an east-facing hill, accounts for lower maxima due to the acute angle of solar insolation from midday onwards.

In consequence the valley bottom has a greater range of temperature in anticyclonic weather, and since the times of maxima and minima usually coincide at the two stations the rise also must be greater at the riverside.

Frequencies for the months are shown in Table II, but few conclusions can be drawn. However the accompanying average cloud amounts give a correlation which may be of value. March 1953 was itself remarkable (Green[2]) and

TABLE II—FREQUENCY OF TEMPERATURE RISES OF 10°F. OR MORE IN 2 HR. AND OF CLOUD AMOUNT

January–June 1953

	Jan.	Feb.	Mar.	Apr.	May	June	Total
Riverside	0	0	16	5	3	8	32
Nether Park	0	0	16	5	2	7	30
			oktas				
Cloud amount ...	6·5	7·1	5·1	5·9	5·9	5·9	...

as a result the high number recorded against it must be something of a phenomenon. During this single month rises of 13° or more in 2 hr. were registered on 7 days at the lower station, and on 2 days at Nether Park.

The greatest rise was 18° in 2 hr. on March 25 when the temperature rose from 35° to 53° between 0600 and 0800 G.M.T. Using different time units other "remarkable" rises for Alston's riverside station have been 14° in 1¼ hr. on March 6; 23° in 3 hr. on April 23; and 8° in approximately ¼ hr. on July 16.

Compared with the frost hollow near Rickmansworth[3], however, I am sure that not even these figures can claim to be "remarkable".

W. E. RICHARDSON

Alston climatological station, The Grove, Alston, July 1953.

REFERENCES

1. PAINTING, W. B.; Remarkable changes in the screen temperature at Waddington. *Met. Mag., London,* **82,** 1953, p. 185.
2. GREEN, F. H. W.; A remarkable low humidity. *Weather, London,* **8,** 1953, p. 182.
3. HAWKE, E. L.; Thermal characteristics of a Hertfordshire frost-hollow. *Quart. J. R. met. Soc., London,* **70,** 1944, p. 23.

Evaporation of dew from funnel of rain-gauge

I noticed this morning that there was dew on the outside, the vertical face and on the narrow sloping rim of the newly installed 5-in. copper rain-gauge (Meteorological Office pattern) but no dew on the funnel inside. There was a moderate amount of dew on the grass, and I rather expected to find a trace in the gauge but it was quite dry.

I think the dryness is due to the base of the gauge being buried in the relatively warm ground, which results in the funnel being warmed by radiation and convection and thus preventing the deposition of dew. I mention the matter because it indicates a defect in the gauge as a collector of precipitation, especially in the autumn when the ground is very warm and the deposition of dew is often particularly heavy.

Possibly covering the under surface of the funnel with a non-conducting layer, or filling up the space with suitable packing would minimize or remove the defect. The splayed base of my gauge is only half buried at present. The warming effect would therefore be slightly less than if it had been fully buried. The order of magnitude of this result of the warming of the funnel by radiation from the warmer base beneath it, may be estimated as follows:

A conservative estimate of the difference of temperature between the base and the funnel on a night when dew is being deposited in appreciable amount is 5°F. The funnel would then receive from the base about 4 per cent. more radiation than it returned to the base. This excess would amount to about 1 gm.cal./cm.^{2}/hr. If this heat were used to evaporate dew it would, in 6 hr., evaporate approximately 0·1 mm. Thus the heat is enough to evaporate a relatively heavy dew. Convection would add to the excess heat received by the funnel.

Probably the funnel actually has its temperature raised enough to prevent the dew being deposited and the heat from the funnel is transferred to the air above it. It is to be noted that this is a one-way effect. At any time of year on a radiation night, the base of the gauge beneath the funnel will be warmer than the funnel. In winter the base may also be the warmer during cold rain, and cause a little evaporation from the funnel of the order of 0·1 mm. in 6 hr.

E. GOLD

8 Hurst Close, London N.W.11, September 24, 1953

NOTES AND NEWS

Cloud funnel over south Scotland

An unusually well marked cloud funnel was observed near Peebles by Mr. Rogerson of Edinburgh and his brother-in-law, Mr. Gib Arcus of New Zealand, who took a photograph of the funnel. Mr. Rogerson describes the phenomenon as follows:—"About 6.30 p.m. on June 7, 1953, while motoring from Peebles to West Linton, we ran into heavy rain from a thunder cloud. After passing through the rain, we noticed that one end of the cloud was becoming elongated and was moving south at considerable speed, almost like a tornado or whirlwind, but drawn out parallel to the earth's surface. There was great agitation in the part of the cloud funnel nearer to us, i.e. near the base of the cloud, the whirling movement apparently being clockwise looking up along the funnel. There was no thunder or lightning." It has been ascertained that the photograph was taken looking towards the south-east from a point approximately five miles south-west of Eddleston.

On the day in question, the weather was generally fair over the whole of the British Isles, and showers were very isolated occurrences. In fact the 1400 G.M.T. ascents at Leuchars and Stornoway show definite stability above about 12,000 ft., which, with freezing level at 8,000 ft., reduced the chance of heavy showers. No atmospherics were reported on the day in question. Winds from 1,000 to 4,000 ft. were very light; 280–290° $<$ 5 kt. at 2000 G.M.T. at Leuchars, 110–40° $<$ 8 kt. at Liverpool, and 200° 15 kt. at Stornoway. Thus the carrying of the cloud funnel to the south cannot be explained in terms of a general drift. Rather, the fact that the cloud funnel was parallel to the ground tends to bear out the theory of Wegener* who suggested that waterspouts originate in a horizontal vortex hidden inside the base of a cumulonimbus cloud.

P. E. PHILLIPS

Iridescent wavelike clouds

The photograph facing p. 369 was taken at Uxbridge at 1630 G.M.T. on February 19, 1953 and illustrates the description of the wavelike clouds† given by Mr. Barrington in the *Meteorological Magazine* for August 1953.

Mr. Poulter remarks that the iridescent colouring was very fine, and suggests that these are just the type of clouds which are not suited to nephoscope observations to obtain the wind velocity.

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*WEGENER, A.; Beiträge zur Mechanik der Tromben und Tornados. *Met. Z., Braunschweig*, **45**, 1928, p. 201.

† BARRINGTON, C. R.; Iridescent wavelike clouds. *Met. Mag., London*, **82**, 1953, p. 248.

REVIEW

Vision through the atmosphere. By W. E. Knowles Middleton. 10 in. × 7 in., pp. xiv + 250, *Illus.*, Toronto University Press. London: Geoffrey Cumberlege, 1952. Price: 68*s.*

By far the greater part of this book deals with matters with which the meteorologist is not directly concerned. The author discusses the scattering of light by spherical water particles; the properties of the eye; the "visual range"* of objects and lights in an idealized atmosphere with known optical properties (it being the responsibility of the meteorologist to measure these optical properties); vision through telescopes; the visibility of objects caught in searchlight beams; the visibility of flashing lights, and of coloured lights and objects; and so on. These chapters contain extensive, up-to-date, and critical reviews of published work on these topics together with a few illustrative examples. Middleton deduces, for instance, that if we had a range of "International Orange" mountains we should expect some to vanish in the distance while others still further off were again visible. (We are entirely with the author in describing this possibility as "mercifully hypothetical"!)

Fog lamps are mentioned but not very helpfully. The author writes: ". . . people can be found who deny that such lamps are of any use whatsoever, and others who insist that they are of great value." He concludes that the trouble is that fogs are not all the same. It is in this connexion that Middleton warns the reader that absorption (as distinct from scattering) is a complication which cannot yet be satisfactorily taken into account in practical applications of visual theory. He writes: "We hesitate to predict what further opinions on the extinction of light in fogs might accrue, if it were usual to make experiments in dust-storms! . . . In this book we shall use the word 'fog' to refer to aerosols containing a large number of water droplets of radius greater than, say, 2 microns". We shall return to this point later, but it is worth while mentioning that any theory of visibility in a fog, which is based on the assumption of no absorption will fail, not only in a duststorm, but also, for example, at London Airport.

These matters are discussed in Chapters I to VIII. The following two chapters, Chapters IX and X, are chapters avowedly written round a sermon; and the text of the sermon is this: that the meteorologist should "abandon the entire scheme of marks and estimates, make good instrumental measurements of the extinction coefficient and then *calculate something which will be of interest to the user of the datum.*"

Now it is sound practice never to use for routine measurements (and especially when the measurements are to be made by untrained, or semi-trained, observers) any instrument more complex than is necessary to obtain the accuracy required. And if the required accuracy can be obtained without the use of an instrument then it would be foolish to use one. The author does discuss the accuracy achieved by non-instrumental methods (albeit making the debatable assumption that the instrumental methods and the theory are both unquestionable)—but he does not discuss at all what accuracy is required by the user. Even the least critical reader is unlikely to be led astray by the author's rhetoric: "the datum which results from the observation [of visibility] has almost no relation to the optical state of the atmosphere at the time" and "It is now his [the

* The "visual range" of an object is the maximum distance from which that object can be seen.

author's] considered belief that there is only one way in which meteorological observations of this element [visibility] can be rescued from complete futility". These statements are too exaggerated to be taken seriously. Moreover on p. 221 we find this remarkable statement: "If it is objected that the estimates of *V* have been found adequate, he [the author] would answer that they have not been found nearly adequate for the purposes of the modern aviator who is trying to land a fast aircraft in marginal weather, and that efforts are actually being made to do something about this. One of the things that is actually being done with conspicuous success in the United Kingdom is to station an observer at the touchdown end of the runway to look at exactly what the pilot has to look at and tell him what he sees. Markers are furnished at intervals down the edges of the runway." In fact, the only circumstance in which it is suggested that our present technique might not be adequate concerns aviation; and there "conspicuous success" is being achieved with the use of markers and non-instrumental methods. Therefore any proposal to abandon this method in favour of instrumental measurements of the extinction coefficient would need strong support on other grounds. What are these other grounds? Middleton suggests none.

The one that occurs to us—it is one which is bound to occur to every scientist—is this: it is difficult to be certain that no benefit would accrue from more accurate measurements; it might be that if the measurements could be made more accurately some use could be found for them. Let us consider this.

There is no doubt that an instrument which measures the extinction coefficient would measure that quantity more accurately than it can be deduced from our present measurements of visibility; but it is far from being established that there would be, in fact, greater accuracy in the information supplied to the user. For consider:

(*a*) Users invariably require to know not what the visibility is, but what the visibility will be. Moreover there is no doubt that the inaccuracy of forecasting visibility (due largely to the enormous effect on the visibility of small changes of temperature or humidity or wind) far outweighs inaccuracy of measurements.

(*b*) Nor would improved basic observations of visibility enable better forecasts to be made. What matters to the forecaster are not the optical properties of the atmosphere, but the constitution of the atmospheric aerosol—the size, number and nature of the solid and liquid particles contained therein. If it had been possible to survey, as routine, the nature of the atmospheric aerosol at synoptic reporting stations then we should undoubtedly know a good deal more than we do about the formation of fog. Our present visibility estimates do give some information about the atmospheric aerosol—but very little; and improving the accuracy of measurement would not increase the information, since the connexion between the optical properties of the atmosphere and the atmospheric aerosol is most complex. For instance the same visibility, or the same extinction coefficient, can arise from quite different distributions of aerosol.

(*c*) Moreover, and this is perhaps the most important point of all, it is by no means established that an estimate of visual range computed from a measure of the extinction coefficient would, in fact, be any better than that obtained by present, more direct, methods. Even Middleton appears to be somewhat uneasy about this. On p. 78 we read: "there is now a general agreement that, *at least in conditions of fairly good seeing*, the atmosphere attenuates contrast in accordance with an exponential law." This is an assumption which is at the basis of the whole of the work in this book. The italics are ours. And, in another place, ". . . it should be noted [in an account of Middleton's own experiments] that no assumptions about the light or the atmosphere are made, the contrast itself being measured directly". We see then that unless there are "conditions of fairly good seeing" one cannot rely upon the contrast behaving as it is assumed to behave; and that, unless one actually measures the contrast (and the author is not suggesting that we do this) any further calculation may be marred by incorrect assumptions about the light or the atmosphere.

It is interesting to consider these assumptions in more detail. On p. 136 Middleton writes: "At this point it will be well to halt, and look back at the theoretical road we have travelled. We should indeed go back to Chapter IV, and consider the assumptions upon which our fundamental equations for the attenuation of contrast were derived (p. 61). Most of these are purely geometrical, but there are three which are often only approximately fulfilled, namely those regarding the curvature of the earth, the uniformity of the atmosphere in the horizontal, and the uniformity of the illumination. The first of these is of negligible importance unless the visual range is very great . . . But the non-fulfilment of the other two is responsible for much of the difficulty of attempts to verify the theory in any precise manner. Anyone who has conducted such experiments must have been exasperated by the rapid changes (in time and therefore presumably in space) in the extinction coefficient. These are especially notable in actual fog. The illumination of the air is also seldom spatially or temporally constant, except on a very clear cloudless day."

No indication is given of the order of magnitude of the errors which are likely to arise on these accounts. They are apparently large enough to prevent any precise verification of the theory.

There is a further point, to do with absorption. A measure of the extinction coefficient does not distinguish between scatter and absorption, and, except perhaps for a black object, the same extinction coefficient may be associated with different "visual ranges". Middleton writes (p. 107): "It appears that whenever $B_0 \neq 0$ [intrinsic brightness B_0 not zero], that is to say for any object but a black one, the simple exponential law expressed by equation (4.25) holds only if there is no true absorption. It is evident from equation (4.27) that a fairly dark object for which C_0 [the intrinsic contrast] approaches -1 will not be seriously affected, but white objects may have an intrinsic contrast of well over $+1$, and their behaviour in an absorbing atmosphere can only be predicted by applying equation (4.26) with the prior knowledge of how much absorption and how much scattering go to make up σ [the extinction coefficient]." (The argument is not easy to follow because equation (4.26) is obtained from equation (4.25) by differentiating. On the face of it if equation (4.25) does not hold, neither would equation (4.26).) Middleton deduces the odd result that, under certain conditions of lighting, a snow-covered mountain would have its apparent contrast raised by added absorption!

It is evident that if absorption is present it matters; and on p. 64 we find this statement: ". . . absorption is frequently of comparable magnitude to scattering".

Now it may be that none of these effects—absorption and non-uniformity of atmosphere or illumination—nor all of them together, will have any serious effect on the value of the visual range computed from a measure of the extinction coefficient. But we are certainly not sure of that. If in point of fact, the present state of the theory is such that the visual range can be obtained from a measure of the extinction coefficient no more accurately than we can now obtain it, then the last prop for the suggestion that we "abandon the whole scheme of marks and estimates" disappears. No one would be any better off—and instead of our present remarkably simple methods we should be using elaborate devices involving photo-electric cells, lamps, lenses, mirrors, galvanometers, constant voltage supplies and so on. Moreover, if this scheme were used for the benefit of the aviator who is trying to land a fast aircraft in marginal weather the consequences of an erroneous computation of the visual range, on account of either faulty instrumentation or faulty theory, might be disastrous.

Oddly enough in a book devoted very largely to "selling" instruments to meteorologists, the only good reason known to the reviewer for using instruments is not mentioned. This is that an instrument can be made to indicate (or record) at a distance. Although the relation between the readings of this instrument and the visual range of any particular object, or set of objects, is complex and may not be amenable to accurate calculation, nevertheless a change in the extinction coefficient will almost certainly mean a change in the visual range—and that is something it is useful for the forecaster at a busy airport to know.

If an apparently inordinate amount of space has been devoted to discussing but two chapters of this book, it is because these chapters are of direct concern to the meteorologist and because Middleton places very great stress upon them. In the conclusion to his book he writes: "It is thus up to the meteorologists to decide whether nor not they wish to use the modern techniques and information which have been made available to them by the devoted labours of so many physicists, psychologists, physiologists, and engineers—or to remain in the grip of an outmoded empiricism."

The meteorologists' answer to that challenge would be this. We realize that any deduction of the visual range of a specified object based upon our present observations of visibility may not be very accurate, unless we are ourselves observing the same object as we do on an airfield; but we have yet to see any evidence that, in practice, a better result would follow the use of a measure of the extinction coefficient.

The book is well produced and, on the whole, easy to read—although the reviewer had difficulty in one or two places in following the argument. For example on p. 90 it is not correct that a straight line on a log-log graph necessarily indicates that the product of the two quantities plotted is constant. There are remarkably few printing errors.

R. FRITH

RETIREMENT

Mr. S. T. A. Mirrlees (Head of R.A.F. (overseas) Branch) retired from the Meteorological Office on September 30 after 33 years' service.

Mr. Mirrlees graduated from Aberdeen University with honours in mathematics and natural philosophy in 1914, and, being already a member of the University Company of the 4th Gordons, he joined the battalion in September 1914, proceeded to France in March 1915, was wounded in an attack on the Menin Road and returned to England in June of that year. He then joined the

Meteorological Section of the Royal Engineers (under the leadership of Major E. Gold) and served at various observation stations near the front line. He was at a front-line station in the Fifth Army just before the great retreat of March 1918, and managed to bring all his staff, himself and most of his equipment back to Headquarters which itself was retreating. He was commissioned in August 1918, returned to the United Kingdom in January 1919 to complete his teaching course interrupted by the war, and finally joined the Meteorological Office in September 1920. Between 1920 and 1939 he served at outstations (Grain, Felixstowe, Holyhead, Kew Observatory, Leuchars) and at Headquarters (Aviation Services Division and General Climatology Division). In 1939 he took charge of the meteorological office at Gibraltar, and on his return to the United Kingdom in 1942 he was appointed Head of the R.A.F. (overseas) Branch—a position he occupied until his retirement.

Much of the work by which he is known was done in the General Climatology Division during the years 1927–33, and published in various *Geophysical Memoirs*—"Meteorological results of the British Arctic air-route expedition"*, (with C. E. P. Brooks) "Meteorological results of journeys in the southern Sahara made by Rennell Rodd"†, and, the most important of all (also with Brooks) "A study of atmospheric circulation over tropical Africa"‡. This last work has stood the test of time. Additional data gathered subsequently have done little but prove how accurate the original charts were. The work incidentally has proved of much importance in the war against the locust, the migratory habits of which are largely determined by the wind structure in the lower layers. It is thus fitting that Mr. Mirrlees should have been a member of the Advisory Committee on Anti-Locust Research.

Amongst other contributions to meteorological literature might be mentioned "Climatology and forecasting"§, "Notes on southern hemisphere circulation"||, "The weather on a Greenland air route"** and (with C. E. P. Brooks) "Irregularities in the annual variation of the temperature of London"††. The special Appendix on Gibraltar in the Mediterranean Naval handbook was written by him based on the first-hand knowledge he had acquired during his service there.

In the R.A.F. (overseas) Branch he did a great deal of the preliminary work, including costing, in connexion with the proposal for a unified Colonial Meteorological Service—a proposal which had ultimately to be abandoned. The work done, however, proved very valuable subsequently in assessing the United Kingdom subventions to the various Colonial meteorological authorities for services rendered outside what would be regarded as the normal scope of their meteorological service.

The work of Mr. Mirrlees was characterized throughout by thoroughness and meticulous attention to detail. His motto always has been "what is worth doing is worth doing well". His retirement will mean a considerable loss to the Meteorological Office, which he leaves with the good wishes of all those with whom he has been associated.

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* *Geophys. Mem., London,* **7,** No. 61, 1934.
† *Geophys. Mem., London,* **5,** No. 48, 1929.
‡ *Geophys. Mem., London,* **6,** No. 55, 1932.
§ *Met. Mag., London,* **74,** 1939, p. 40.
|| *Met. Mag., London,* **78,** 1949, p. 315.
** *Geogr. J., London,* **80,** 1932, p. 15.
†† *Quart. J.R. met. Soc., London,* **56,** 1930, p. 375.

Mr. J. Durward expressed the good wishes of the staff to Mr. Mirrlees at Victory House on September 30 and presented him on their behalf with a portable typewriter. He described Mr. Mirrlees as one who took every possible action to verify the accuracy of his statements.

Mr. Mirrlees thanked the staff in a witty reply which included an Aberdonian story appropriate to the occasion.

METEOROLOGICAL OFFICE NEWS

The R.A.F.V.R. in Portugal.—History was made when a small meteorological unit was sent to Portugal to brief a Coastal Command Squadron during Exercise "Mariner" from September 24 to October 4, 1953. The forecasters, Sqn-Ldr R. M. Poulter, O.B.E., R.A.F.V.R. and Fg-Off. M. J. Merrick, R.A.F.V.R. joined the Squadron of Shackleton aircraft at Ballykelly (Northern Ireland) and flew with them on September 22 to Montijo, near Lisbon. The Squadron was the first detachment from a foreign country to operate from Portugal and the meteorologists the first representatives of the R.A.F.V.R. to work in that country. The Portuguese Meteorological Service gave valuable help.

Retirement.—Mr. C. S. Durst retired on November 22, 1953, from the post of Assistant Director (Investigations). At a crowded meeting in the conference room of Victory House that afternoon he was given by Dr. R. C. Sutcliffe a present from his colleagues in the form of a cheque he intends to use for the purchase of one or two woodcuts. In expressing his thanks Mr. Durst recounted some interesting stories, grave and gay, of the people and events with which he had been connected.

Mr. Durst has accepted a temporary appointment in the Meteorological Office.

Courses for climatological observers.—Two courses, for climatological observers who forward returns to the Meteorological Office but are not on the staff, were held in October 1953; forty-one observers attended. In addition to formal instruction at the Training School, visits were arranged to the climatological and instrument branches of the Office at Harrow and to the forecast unit at Air Ministry.

Sports.—At the Air Ministry Swimming Gala held at Marshall Street Baths on November 3, Miss C. W. Fleming of the Meteorological Office won the Civil Service Ladies' breast-stroke championship. This is the first occasion on which a member of the Air Ministry staff has won a Civil Service swimming championship. Miss Fleming also won the Air Ministry Ladies' championship.

The Meteorological Office, represented by Messrs. Lewis, Martindale, Franklin and Wood, won the Air Ministry Men's inter-divisional championship for the fifth successive year. Mr. Martindale won the Men's handicap and Miss J. Baird was second in the Ladies' handicap. During the past season the Air Ministry Swimming Club have won the Harper Trophy, the Civil Service Swimming League, Division III, and were runners-up in the Civil Service Water Polo League and the London Business Houses League.

WEATHER OF OCTOBER 1953

Mean pressure was above normal over most of Europe but below normal over the Mediterranean, Spain and most of the North Atlantic except over the region just west of the Azores. The highest mean pressure was 1022 mb. over east Europe; the greatest excess above normal was 6 mb. over Scandinavia. The lowest mean pressure was 995 mb., which occurred between Iceland and Greenland, and was as much as 9 mb. below normal.

Mean temperature was above normal over the whole of Europe; the excess was 3° to 4°F. in most places but reached 7°F. in parts of Scandinavia. Mean temperature was also above normal over North America generally to the extent of 4° to 7°F.

In the British Isles the weather in most areas was drier and less sunny than the average, though rainfall exceeded the average over much of west Scotland and south-eastern England. Fog recurred fairly frequently and was sometimes slow to clear. In England and Wales the month was much less windy than is usual in October; at Oxford, for example, in a record going back to 1881, only one October, 1951, had a lower total run of wind.

At the beginning of the month pressure was high over the Continent and very low over Iceland and a warm south-west air stream covered most of the British Isles; temperature reached 70°F. at some places on the 1st and 2nd and touched 73°F. at Raunds, East Bergholt, Cromer and Ipswich on the 1st. A gale occurred in northern districts of Scotland on the 1st. A cold front moving south-east gave considerable rain locally, chiefly in north-western districts on the 1st to 3rd (0·93 in. at Inveraray Castle, Argyllshire on the 1st and 1·10 in. at Achnashellach, Ross and Cromarty, on the 2nd). On the 3rd to 4th an anticyclone moved in from the Atlantic and mainly dry, cooler weather prevailed over much of the country until the 11th, but some heavy rain occurred locally in north Scotland from the 9th to 11th (3·05 in. at Glenquoich, Inverness-shire on the 10th). A complex trough of low pressure came in from the west and south-west on the 12th and during that night and the next day there were some fairly heavy falls of rain. A ridge of high pressure followed, giving a short spell of mainly dry weather, but another trough moving east across the country gave more rain from the 15th to 17th. Subsequently a large anticyclone moved quickly north-east from south-westward of Ireland to reach southern Scandinavia by the 19th; dry weather prevailed over most of the country until the 19th and over much of England and Wales until the 21st. From the 22nd to the end of the month an unsettled southerly to south-westerly type of weather prevailed with frequent rain, which was sometimes heavy from the 23rd or 24th onward; thunder occurred locally on several days. Among the heavier daily falls were 2·05 in. at Llyn Fawr Reservoir, Glamorgan, on the 26th and 2·82 in. at Southampton, 2·26 in. at Patterdale, Westmorland and 2·22 in. at Winchester, Hampshire, on the 31st. Wind reached gale force locally in the Hebrides on the 24th and 29th, and on the 26th to 27th an intense trough moving eastward gave a widespread southerly gale, which was severe on west and north-east coasts.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	73	25	−0·3	72	−6	91
Scotland	69	24	+1·8	73	−4	92
Northern Ireland ...	66	32	+0·5	73	−5	91

RAINFALL OF OCTOBER 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.
London	Camden Square ...	2·79	106	*Glam.*	Cardiff, Penylan ...	3·56
Kent	Dover	3·12	80	*Pemb.*	Tenby	3·58
,,	Edenbridge, Falconhurst	4·08	113	*Radnor*	Tyrmynydd	3·71
Sussex	Compton, Compton Ho.	4·21	92	*Mont.*	Lake Vyrnwy	2·78
,,	Worthing, Beach Ho. Pk.	4·37	121	*Mer.*	Blaenau Festiniog ...	4·68
Hants.	Ventnor Park	3·08	77	,,	Aberdovey	2·68
,,	Southampton (East Pk.)	5·66	144	*Carn.*	Llandudno	1·73
,,	South Farnborough ...	3·14	98	*Angl.*	Llanerchymedd ...	2·85
Herts.	Royston, Therfield Rec.	2·95	108	*I. Man*	Douglas, Borough Cem.	5·00
Bucks.	Slough, Upton	2·66	95	*Wigtown*	Newton Stewart ...	4·58
Oxford	Oxford, Radcliffe ...	2·20	76	*Dumf.*	Dumfries, Crichton R.I.	3·76
N'hants.	Wellingboro' Swanspool	1·54	61	,,	Eskdalemuir Obsy. ...	3·55
Essex	Shoeburyness	1·57	67	*Roxb.*	Crailing...	1·57
,,	Dovercourt	1·68	70	*Peebles*	Stobo Castle	2·71
Suffolk	Lowestoft Sec. School...	1·67	60	*Berwick*	Marchmont House ...	1·46
,,	Bury St. Ed., Westley H.	2·62	97	*E. Loth.*	North Berwick Res. ...	0·94
Norfolk	Sandringham Ho. Gdns.	2·91	96	*Midl'n.*	Edinburgh, Blackf'd. H.	1·28
Wilts.	Aldbourne	3·94	117	*Lanark*	Hamilton W. W., T'nhill	1·90
Dorset	Creech Grange... ...	3·07	60	*Ayr*	Colmonell, Knockdolian	4·84
,,	Beaminster, East St. ...	4·16	93	,,	Glen Afton, Ayr San. ...	5·10
Devon	Teignmouth, Den Gdns.	2·78	72	*Renfrew.*	Greenock, Prospect Hill	4·89
,,	Ilfracombe	2·82	62	*Bute*	Rothesay, Ardencraig...	4·19
,,	Okehampton	4·84	80	*Argyll*	Morven (Drimnin) ...	6·83
Cornwall	Bude, School House ...	2·05	50	,,	Poltalloch	5·82
,,	Penzance, Morrab Gdns.	2·70	58	,,	Inveraray Castle ...	5·93
,,	St. Austell	2·78	53	,,	Islay, Eallabus... ...	4·40
,,	Scilly, Tresco Abbey ...	2·05	54	,,	Tiree	4·45
Somerset	Taunton	3·09	90	*Kinross*	Loch Leven Sluice ...	2·01
Glos.	Cirencester	2·45	74	*Fife*	Leuchars Airfield ...	1·47
Salop	Church Stretton ...	2·41	66	*Perth*	Loch Dhu	6·00
,,	Shrewsbury, Monkmore	1·95	70	,,	Crieff, Strathearn Hyd.	1·72
Worcs.	Malvern, Free Library...	2·24	75	,,	Pitlochry, Fincastle ...	2·87
Warwick	Birmingham, Edgbaston	2·21	79	*Angus*	Montrose, Sunnyside ...	1·26
Leics.	Thornton Reservoir ...	2·41	86	*Aberd.*	Braemar	2·18
Lincs.	Boston, Skirbeck ...	2·40	88	,,	Dyce, Craibstone ...	1·89
,,	Skegness, Marine Gdns.	2·50	91	,,	New Deer School House	1·61
Notts.	Mansfield, Carr Bank...	2·18	72	*Moray*	Gordon Castle	0·75
Derby	Buxton, Terrace Slopes	2·53	52	*Nairn*	Nairn, Achareidh ...	0·80
Ches.	Bidston Observatory ...	1·18	36	*Inverness*	Loch Ness, Garthbeg ...	1·58
,,	Manchester, Ringway...	2·08	67	,,	Glenquoich	11·23
Lancs.	Stonyhurst College ...	1·86	41	,,	Fort William, Teviot ...	5·68
,,	Squires Gate	1·70	48	,,	Skye, Broadford ...	11·84
Yorks.	Wakefield, Clarence Pk.	1·45	51	,,	Skye, Duntuilm ...	7·20
,,	Hull, Pearson Park ...	1·60	54	*R. & C.*	Tain, Mayfield... ...	1·06
,,	Felixkirk, Mt. St. John...	2·01	70	,,	Inverbroom, Glackour...	2·22
,,	York Museum	1·59	59	,,	Achnashellach	6·57
,,	Scarborough	1·45	46	*Suth.*	Lochinver, Bank Ho. ...	2·94
,,	Middlesbrough... ...	1·50	50	*Caith.*	Wick Airfield	1·17
,,	Baldersdale, Hury Res.	1·67	45	*Shetland*	Lerwick Observatory ...	3·51
Norl'd.	Newcastle, Leazes Pk....	1·29	42	*Ferm.*	Crom Castle	1·82
,,	Bellingham, High Green	1·39	35	*Armagh*	Armagh Observatory ...	2·09
,,	Lilburn Tower Gdns. ...	1·71	46	*Down*	Seaforde	2·54
Cumb.	Geltsdale	1·84	49	*Antrim*	Aldergrove Airfield ...	2·06
,,	Keswick, High Hill ...	3·35	60	,,	Ballymena, Harryville...	2·53
,,	Ravenglass, The Grove	2·50	58	*L'derry*	Garvagh, Moneydig ...	2·91
Mon.	A'gavenny, Plâs Derwen	5·29	115	,,	Londonderry, Creggan	2·84
Glam.	Ystalyfera, Wern House	5·64	82	*Tyrone*	Omagh, Edenfel ...	2·92

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

Wt-34. K16.