M.O. 641

THE METEOROLOGICAL MAGAZINE

1958

Volume 87

INDEX

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

PUBLISHED FOR THE METEOROLOGICAL OFFICE BY HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, LONDON, W.C.2
423 Oxford Street, LONDON, W.1
13a Castle Street, EDINBURGH, 2
109 St. Mary Street, CARDIFF
39 King Street, MANCHESTER, 2
Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3
80 Chichester Street, BELFAST
or from any Bookseller

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,027, JANUARY 1958

SYNOPTIC STUDY OF THERMAL TROUGHS OVER THE ATLANTIC AND THE BRITISH ISLES

By M. K. MILES, M.Sc.

Introduction.—Thermal troughs or cold troughs as they are commonly called are now recognized as playing an important part in synoptic developments, but the enormous variety of structures that occur make it difficult to draw up any general rules of behaviour. Almost without exception a surface isobaric trough usually containing a cold front is found in advance of every thermal trough. It may be possible to interpret the characteristics of the front in terms of the structure and behaviour of the associated thermal trough.

Perhaps the most typical thermal trough is the fairly large amplitude confluent one with its axis generally tilted eastward a little in higher latitudes. It is a fairly stable feature moving east with a speed of the order 10°–15° longitude per day with no great change in structure. It usually has an anticyclone or a well marked ridge located some 10°–15° longitude behind its axis, a wavelength of the order of 40°–50° longitude and amplitude* of the order of 15°–20° latitude. It is thus somewhat smaller than the classical long waves.

An inspection of thickness maps reveals that there are many troughs of different size and structure from this, and it seems desirable to know what fraction these typical ones are of the total, and the principal factors which distinguish them from the others. This was the starting point of the investigation, but a preliminary study revealed three other fairly distinct types which occurred with comparable frequency, and it was decided to examine all thermal troughs occurring between longitude 50°W. and 10°E., north of latitude 30°N. during 1954 to find the relative numbers in each category, and thereby provide a basis for some sort of classification. The 1000–500-mb. thickness charts on a scale 1 : 10^7 were used for the study and a trough was included if two thickness lines at 200-ft. intervals were involved. The axis was taken as the line of maximum cyclonic curvature of the thickness lines.

Preliminary classification.—The four main types (see Fig. 1) are described below and it can be said that the principal differentiating factors are surface isobaric structure, amplitude and wavelength.

* This has been taken as the latitudinal separation of the trough bottom and the adjacent ridge crests.

Type 1 is the medium to long wave structure mentioned above with the following characteristics:—

(i) High cell or ridge some 10°–15° longitude behind the axis.

(ii) Amplitude greater than 10° latitude.

(iii) Wavelength greater than 30° longitude.

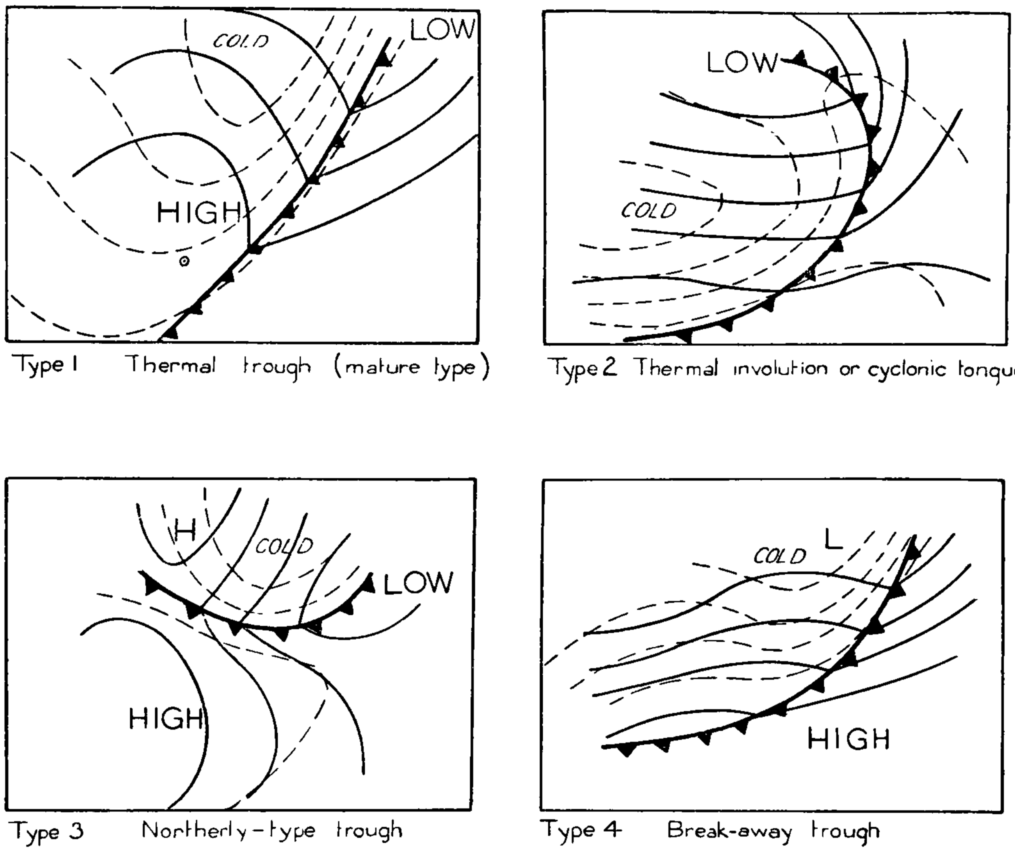


FIG. I—MAIN TYPES OF THERMAL TROUGH OCCURRING OVER THE ATLANTIC OCEAN AND THE BRITISH ISLES

Type 2 is the cyclonic tongue or cyclonic thermal involution[1] with these characteristics:—

(i) Belt of high pressure to south of tongue—low to north, i.e. well marked (usually westerly) flow along the axis of the tongue.

(ii) Usual length of tongue 10°–20° longitude, though this is very variable.

(iii) Moderate to strong thermal gradient on the south side of the tongue.

These cyclonic tongues are formed by the distortion of a broad, often ill-marked, cold trough produced by a strong cyclonic circulation which carries cold air forward in a tongue-like intrusion between warmer air to north and south of it.

Type 3 includes new troughs formed in a developing northerly flow behind an intensifying depression, often in a meridional or a "blocked" situation. The identifying characteristic of this type is that they are new features. They resemble type 2 in that advection is the dominant factor in distorting an initially nearly straight thickness pattern, but later have much more movement normal to the axis than the cyclonic tongue.

Type 4 are "break-away" troughs with the following characteristics:—

(i) Moderate to strong westerly flow normal to axis.

(ii) Small amplitude—usually less than 10° latitude.

(iii) Wavelength 20°–40° longitude.

It was found worthwhile in the course of the examination to note the occurences of anticyclonic tongues, and the formation of a recognizable trough as a result of warm advection into a region occupied by a broad mass of cold air. The position and orientation of the axis and the flow near it were noted on each chart where the trough existed and the distance to the upwind and downwind thermal ridges, where these were well defined. From this data the speed of movement could be obtained and the influence of advection qualitatively assessed.

Results of classification.—In all, 141 troughs were noted and Table I shows how they were distributed through the months by types.

TABLE I—DISTRIBUTION BY TYPES OF TROUGHS NOTED DURING 1954

	1954 Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
All Types	16	9	10	13	9	8	15	8	11	13	14	15
Type 1	5	4	4	8	2	2	2	4	3	3	5	4
Type 2	2	3	3	2	1	1	1	0	2	4	3	1
Type 3	4	2	3	0	2	4	7	2	6	2	3	4
Type 4	1	0	0	0	0	0	1	2	0	4	1	5

Apart from July when nearly half the troughs were small perturbations on the periphery of a very slow-moving larger trough there is a tendency for troughs to be rather more frequent in the winter half of the year. The number of type-1 troughs is noticeably lower in the four summer months—10 compared with 18 in the four months November to February inclusive, but further investigation would be required to establish that this is a usual occurrence.

The totals of all types on their first appearance is shown in the first line of the table below, and on the second line are the numbers of each which showed no change of type throughout its life.

TABLE II—NUMBER OF TROUGHS REMAINING UNCHANGED DURING THEIR LIVES

	Type 1	Type 2	Type 3	Type 4	All others
Number on first appearance ...	46	23	39	14	19
Number unchanged	21	19	17	14	11

This indicates that about a third of all the troughs could be described as the typical cold trough (type 1) on first appearance but about half of these suffered change. Even so, more of them travelled across to the British Isles with no essential change of structure than any other single type. The most common distortion was a cyclonic involution. This does not always permanently alter the essential structure, and this transition deserves more attention. The next most frequent changes were to type 3, and anticyclonic disruption[2]. These changes can be summarized as the effect of development in the pressure pattern in the vicinity of the trough.

Type 2 showed fewer changes but it will be necessary to discuss these in more detail later on because there are complications depending on the definition of the type.

Type-3 troughs were, as would be expected, often subject to change. The most frequent change was to type 1, with cyclonic or anticyclonic "tonguing" as the next most common change.

Type 4—the break-away troughs—travel fast, have a short life and always passed out of the area before losing their special characteristics.

A tendency was noted in a few cases for the surface isobaric trough to lag relative to the thermal trough until finally the two were nearly coincident producing a quasi-stationary state. The more usual tendency is, of course, for a rise of surface pressure to spread ahead of the trough axis with the result that the trough maintains its movement and becomes less intense. This other tendency tends to delay relaxation and seemed to be more common in the summer months, but this needs further investigation, since the summer of 1954 showed some unusual features[3].

Discussion of four main types of thermal trough.—It would appear from the foregoing study that type 1 is a mature type of structure often large enough to be stable but not entirely immune to changes should baroclinic developments, usually ahead of the axis, become very strong.

The existence of surface anticyclonic vorticity behind the trough axis is to be expected in view of the advection of negative thermal vorticity in this region[4].

With many troughs of this type there is little or no surface flow normal to the trough axis and their movement is probably to be explained by the divergence of the upper flow resulting from the change in vorticity of the air moving through the thermal trough. It is certainly noteworthy that many of them maintain the same speed over three or four days, even when strong cyclonic activity is resulting in temporary tongue formation in the thermal pattern ahead of the axis (Fig. 2). The mean speed of 23 cases in the months October to March inclusive was 15° longitude per day with only moderate scatter.

The type-1 troughs were all in existence at 50°W. or very soon after, and probably have their origin over America in winter, and Labrador and Davis Strait in summer when there is no source of cold air further west. The smaller number in summer may be the usual state of affairs and a result of the more limited source of cold air. When their amplitude is large these troughs are especially liable to anticyclonic disruption, with a cut-off surface low remaining associated with the southern part of the fractured axis as a belt of high pressure forms to the north of this. The majority of them decrease in intensity as they move east probably largely due to the non-adiabatic warming from the sea surface. (The mean thermal ridge in the east Atlantic in winter is probably indicative of this but may also indicate some dynamical warming.) It quite commonly happens that the upstream thermal ridge travels faster than the trough and when the separation of the two decreases to about 15° longitude (the mean value was about 25° longitude) a rapid warming of the trough usually occurs, often with some acceleration. The associated cold front in these cases becomes very weak with marked "kata" character. The few occasions when these troughs increase in intensity over the east Atlantic are interesting and deserve further study.

On account of their size these troughs are the ones most likely to provide the necessary length of baroclinic zone ahead of the axis found by Sawyer[5] to be a necessary condition for cold-front waves. This condition is commonly satisfied after cyclonic development running north-eastwards on the forward side of the trough has by its increasing cold advection changed the thickness pattern as shown in Fig. 2 and increased the length of the baroclinic zone ahead of the trough axis from AB to A'B'. The cold front passage associated with this cyclonic development may then occur up to 25° longitude ahead of the trough axis and the front itself is nearly always of kata type, with a strong rise of pressure behind it. This may soon (cf. September 3–4, 1954) give way to a fall of pressure spreading north-eastwards: the front changing temporarily to ana type with the formation of a flat wave.

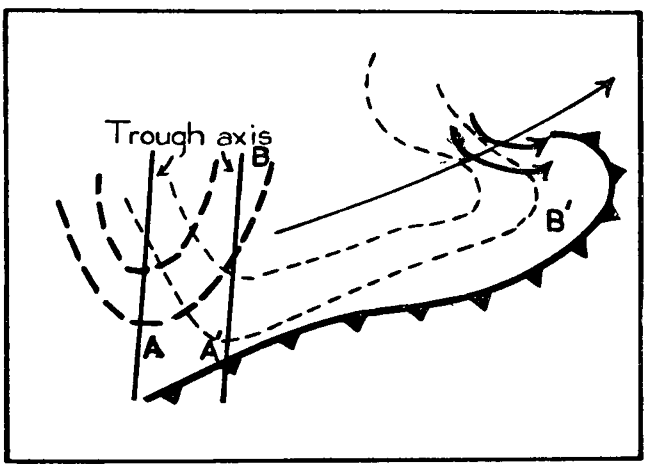


FIG. 2—DISTORTION OF TYPE-1 TROUGH BY CYCLONIC DEVELOPMENT

As mentioned in the introduction these troughs are typically confluent, a structure which makes them liable to the formation of a belt of high pressure across the axis. This process with a large amplitude structure may lead to anticyclonic disruption and the cutting off of a surface low to the south-east of the axis. The lack of a criterion to distinguish cases when this happens from those when it does not is a constant source of difficulty in forecasting.

In contrast with type-1 troughs where advection plays a minor role, type-2 troughs are directly due to the strong mainly westerly flow on the south side of a deep centre of low pressure, and are usually neither stable nor persistent features. They are found with many occlusion processes, and with very rare exceptions the associated surface fronts, occlusion and cold, have no frontal cloud or precipitation behind them. A rise of surface pressure usually occurs on the south side of the tongue and spreads across the axis which itself frequently moves northwards. The short life is due to a most marked tendency for a cold pool to be isolated at the forward tip of the tongue. This cutting off process is sometimes helped by warm advection in the northerly flow behind the low, but the more important factor is warming on the south side of the tongue. This warming usually appears most strongly some 20° longitude from the tip of the tongue (see Fig. 3 where point A is place of strongest warming).

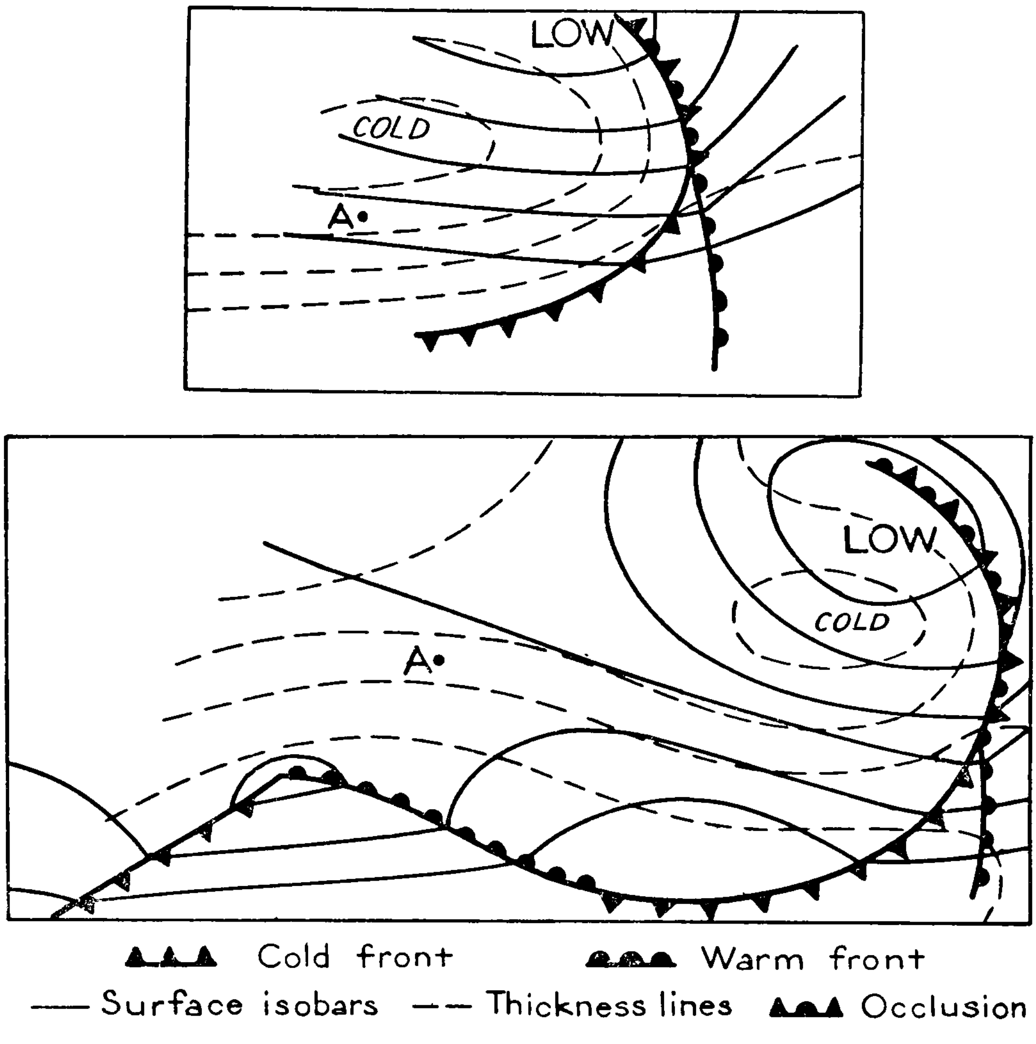


FIG. 3—TWO STAGES IN THE CUTTING OFF OF A COLD POOL AT THE TIP OF A CYCLONIC THERMAL TONGUE

It often appears to be dynamical though in some cases the development of a new low in the usually strong thermal gradient south of the tongue provides some warm advection though usually not enough, and sometimes the warming occurs well to the east and north of this growing southerly flow. This early appearance of a new low is very common following the development of a cyclonic cold tongue, and may well be an essential part of the process. Cold air is drawn away from a large cold trough at a rate quite often amounting to 20° longitude a day in the formation of these tongues and the zonal flow is not usually strong enough to accommodate such a movement of a large scale feature so that the early appearance of a new thermal ridge upwind of the tongue yields a shorter wave-length more in accordance with the high speed of travel. Many of the breakaway troughs, with their characteristic speed of about 30° longitude per day, show a somewhat similar feature.

A difficulty often arises in the analysis of cyclonic tongues on account of the rotation of a trough AA (see Fig. 4) in the thickness lines leading soon to a second trough line at BB which may be wrongly identified on a later chart with AA. Since the first frontal passage is usually associated with AA this may lead to errors in its forecasting and interpretation. It has been the practice in this investigation not to record this phenomenon as a change in type since it is in the nature of cyclonic tongues to display it very frequently. Similarly, while anticyclonic disruption of type 1 leading to a cut-off cold pool has been recorded as a change of type, the isolation of a cold pool with a type 2 has been taken to be the end of the trough's life.

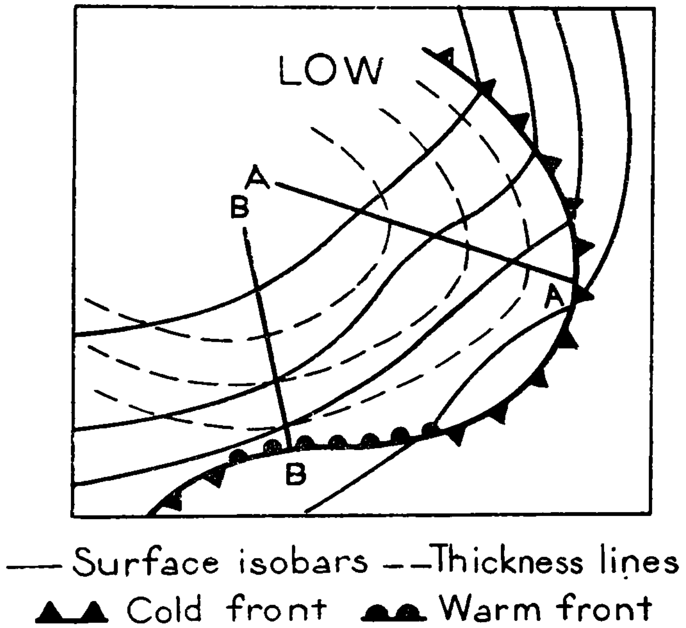
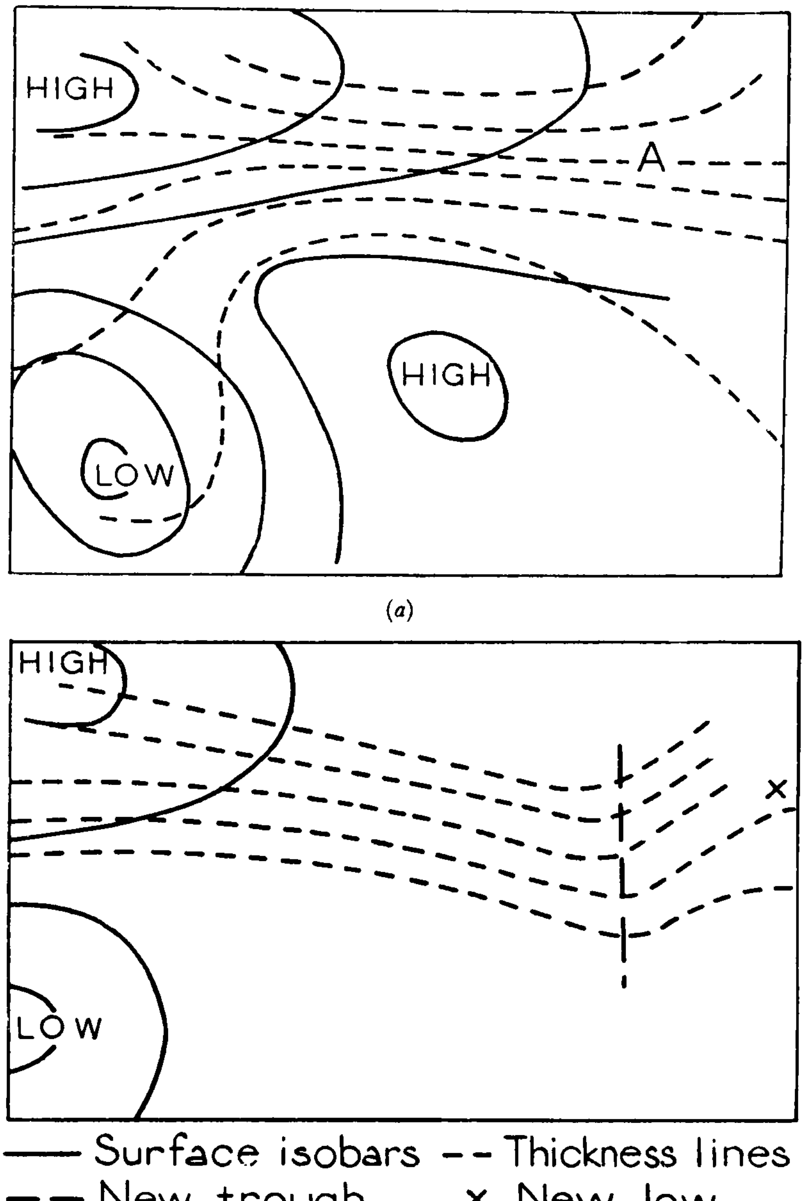


FIG. 4—DOUBLE AXIS IN A CYCLONIC TONGUE

It is difficult to assign characteristics to type-3 troughs beyond that mentioned earlier that they are new features. Perhaps for most of them the northerly surface flow in the vicinity of their axis is the most important common feature.

In meridional situations such as that illustrated in Fig. 1 (Type 3) the pre-existing anticyclone with its mainly north–south axis obviously provides a northerly gradient on its east side. This, in conjunction with some cyclonic development in high latitudes, readily produces a new thermal trough to the east of the anticyclone. Sometimes this cyclonic development can be associated with a thermal trough which has weakened almost to the point of extinction in travelling up the west flank of the large-scale thermal ridge. After rounding the crest of the ridge such troughs may intensify and since they are often



(*b*) 24 hr. after (*a*)

FIG. 5—TROUGH FORMATION IN A STRONG BAROCLINIC ZONE DOWNSTREAM OF A "BLOCK"

diffluent, a fall of pressure near their axis intensifies the existing cold advection. The resuscitated trough then either becomes absorbed in the quasi-stationary thermal trough of the large-scale pattern, or causes movement and relaxation of the existing trough and finally takes its place.

In the thermal confluence downwind of a block (see Fig. 5) the necessary northerly flow results from a fall of pressure in the region A. This soon produces a trough in the thickness lines upwind of the developing low. Rises of surface pressure then appear behind the new trough axis and the whole system moves eastwards. The wavelength, some 30°–40° longitude, tends to be rather small for the strength of the flow and such troughs often move at rates between 20° and 25° longitude per day. The associated cold fronts are not favourable for wave development, though the process described may be repeated within 24 to 48 hours (cf. period January 14–21, 1956).

These type-3 troughs appear to be very susceptible to modification. A substantial number developed towards the mature type 1, a smaller number became cyclonic tongues round the low ahead of them and one was transformed into an anticyclonic tongue. Three cases occurred in June and July of a type-3 trough becoming quasi-stationary usually because pressure failed to rise across the axis especially in the south and the surface isobaric trough became coincident with the thermal trough. This process may be a more likely one in summer than in winter, but it would be dangerous to draw any conclusions from events during the summer of 1954 which displayed some uncommon features.

The type-4 troughs occur in situations with a strong westerly or south-westerly surface flow. They usually break away from a large type-1 trough but sometimes form from a cyclonic tongue*, but in either case an essential feature is the occurrence of some warming to separate the break-away from the main trough. This can sometimes be attributed to the warm advection ahead of a new low, but in other cases a fast-moving cell of high pressure follows the axis of the break-away trough and the low humidities aloft in these cases suggest that there is dynamical warming. The appearance in a few cases December 14–16, 1954 and February 25, 1955 of a small thermal trough upstream from the newly formed thermal ridge suggests that the process is a dynamical one. A characteristic feature of these troughs is the high rate of movement (typically about 30° longitude a day), and a fast cold front clearance is invariable. There may often be a considerable fall of surface pressure ahead of the trough just before it breaks away and this leads to a relative surface ridge which can be thought of as aiding the break-away process but may be a dynamical accompaniment of it.

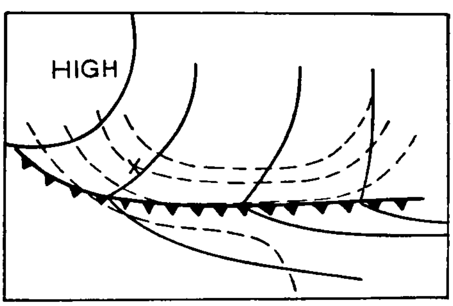
Cold tongues occurring on the south-east side of anticyclones are an interesting and by no means as common a feature as might be expected. Dynamical warming commonly acts against cold advection to prevent their formation, especially with moving anticyclones. In two cases August 17–19, 1954 and November 6–7, 1954 when large-amplitude type-1 troughs suffered distortion in this way the major axis of the anticyclone ended up by being north-east–south-west. In a rather similar case on October 21, 1955 there was this marked development of an anticyclone north-eastwards, so that soon a north-easterly surface gradient existed along and on the forward side of the now much tilted axis of the thermal trough. In the August 1954 and October 1955 cases, cut-off cold pools resulted, but though this probably very nearly happened in the November case no cut-off surface low developed.

Cold fronts in relation to the main types.—For the purpose of this discussion a cold front will be called "Kata" unless a belt of precipitation existed in the cold air, i.e. after the wind veer and tendency change. This criterion is of course not sufficient to ensure that it has the wind and humidity structure of katafronts as found by Sansom[6], but it is an important one for

* February 28–29, 1956.

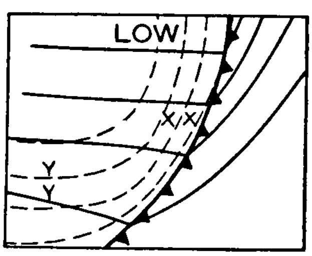
synoptic purposes and is probably always an indication of either forward wind shear or subsided air in the frontal zone.

Katafronts were found with all type-4 and with all but one of the type-2 thermal troughs. Occasionally with the latter class, precipitation did not cease immediately behind the front on the north side of the tongue, but in the strong southerly thermal gradient at the tip of the tongue complete clearances were the rule. Likewise, katafronts predominated with the other two types, and in view of the more nearly equal numbers of anafronts and katafronts found by Sansom[6] it may be that some, or indeed, many anafronts occur before a recognizable thermal trough exists, and so may have passed unnoticed in this study. Soon after distortion of the thickness lines occurs, factors may operate to destroy the special wind structure of the anafront except in the few cases where there are compensating factors.



—— Surface isobars – – Thickness lines
▲▲▲ Cold front

FIG. 6—BROAD COLD TROUGH ASSOCIATED WITH AN ANAFRONT OCTOBER 25–27, 1955



—— Surface isobars – – Thickness lines
▲▲▲ Cold front

FIG. 7—PATTERN LEADING TO DRY AIR ALOFT IN FRONTAL ZONE X—X

In the case of October 25–27, 1955 when anafront conditions persisted while a type-3 cold trough moved across the British Isles there were two significant features. Firstly, the trough started off by being very broad, with a long stretch of west–east baroclinic zone (see Fig. 6) and secondly the precipitation in the cold air ceased over southern England as the region of cyclonic thermal vorticity (marked X in Fig. 6) approached. These suggest that it was the broadness of the base of the trough which enabled anafront structure to be maintained so long. Another example of well marked "ana" structure occurred on November 6–7, 1954; this time in the later stages of a thermal trough's history and was associated with a large-amplitude (type 1) trough which slowed down and suffered distortion as a result of the anticyclone behind it developing north-eastwards across the axis giving a surface geostrophic north-east wind below the strong south-west thermal wind on the forward side of the trough. A slow-moving trough with a broad belt of thermal gradient on the forward side is generally recognized as a condition for anafronts but many large-amplitude type-1 troughs moving at only 10° per day failed to give anafront conditions during 1954, and some other conditions are clearly necessary. A clue is perhaps provided by the extreme rarity of these fronts with type-2 and type-3 troughs where the cold air is being carried forward by a moderate to strong flow, in the actual formation of the trough. It would appear that strong advection of cold air leads to displacement of the warm moist air from the region behind the front. Likewise if the thermal trough travels faster than the surface front there will be a tendency for the thermal wind to have a significant component normal to the front. Such a state of affairs arises from a strengthening of the upwind flow or, what probably comes to the same thing, the reduction in the separation from the upwind thermal ridge. Examples of this process can be found on the following dates: May 25–26, 1954, April 9, 1955, April 24–26, 1955 and September 8, 1955.

With type-2 and some type-1 troughs this displacement of warm air from the strong thermal zone on the forward side of the cold trough can be attributed to the fact that the thermal gradient in the cold air at YY (see Fig. 7) leads to air aloft moving into the zone XX faster than the surface front moves on. This air will normally suffer convergence* in going through a confluent trough and eventually the zone XX will be occupied by drier air aloft. The chance of anafront conditions would, on this hypothesis, be greater away from the bottom of a thermal trough. A large-amplitude type-1 trough obviously provides favourable conditions for anafront structure but the liability of these to anticyclonic disruption often limits the anafront conditions to the region on the south side of the developing anticyclone, where the cold front may be moving west or north-west as a warm front.

A confluent trough offers more favourable conditions than a diffluent trough and many type 3 are of this latter kind. But even so with many large-amplitude slow-moving troughs of favourable forward latitudinal tilt (of the axis) there appears to be no genuine anafront structure, and some further condition seems necessary. Inspection of surface isobaric structure suggests that a stronger geostrophic wind in the warm air than the cold, and a fanning out of the isobars in the cold air just behind the surface front may be an important further condition. This type of gradient in the cold air would act to keep the thermal gradient strong ahead of the trough axis and would perhaps lead to the low-level cold air immediately behind the front being supergeostrophic to a greater extent than the air moving in the strong thermal zone aloft. This air may well have an ageostrophic component backwards across the front if it has only recently come under the influence of the thermal gradient and is undergoing acceleration. This implies a distinction between cases where the air in the strong thermal zone ahead has just come under the influence of the thermal gradient of the trough and those in which it has moved from behind the trough axis.

In the former case it is likely to be moist air or will suffer lifting as it comes into the circulation and so become moist. In the latter it may very well start less moist—in consequence of having descended in moving towards the trough axis—and suffer very little lifting owing to continued convergence aloft.

This question deserves further study and its elucidation may be possible with the existing upper air network over the British Isles and north-west Europe.

Conclusion.—A study of all thermal troughs over the North Atlantic and the British Isles during the year 1954 shows that on the average there are about twelve distinct troughs each month. If July is excepted for the

---

* With many confluent thermal troughs the vector acceleration of the air must be too large for quasi-geostrophic accelerated motion and longitudinal convergence would occur as well as transverse.

reason that many of the troughs during that month were small distortions of a large quasi-stationary trough, then it appears that there are significantly fewer in summer than winter.

It was found possible to classify nearly 90 per cent of all thermal troughs under four main types, and nearly 80 per cent under the first three types. About one third were already in existence in a fairly mature state when they entered the area of study, i.e. type 1, and nearly as many (excluding cyclonic involutions) were formed by cold advection within the area, i.e. type 3. These two types usually exhibit significant differences of structure and behaviour, even though transitions from one to the other occur occasionally. The cyclonic involution, type 2 (perhaps not hitherto regarded as a thermal trough) has been included in the study because of its almost invariable association with katafronts. Type-2 troughs were much more frequent in the winter than in the summer, probably due to the higher frequency of deep cyclones in the area during the winter.

The fourth and smallest class of troughs studied are those which split off from a larger trough and have a very high speed. If they can be recognized in time there is a chance that the very quick cold front clearance may be forecast.

The summer and spring months with their higher frequency of meridional and blocking situations show a significantly smaller number of mature troughs. Especially in blocking situations troughs are liable to suffer distortion, cf. April with eight type-1 troughs of which only one reached the British Isles.

An interesting tendency for summer troughs to give rise to coincident surface isobaric troughs is noted, but without further study this cannot be regarded as a normal feature.

Several aspects of cold-front structure and precipitation appear to be capable of interpretation in terms of the accompanying thermal trough, but further synoptic studies are required.

REFERENCES

1. SUTCLIFFE, R. C. and FORSDYKE, A. G.; The theory and use of upper air thickness patterns in forecasting. *Quart. J. R. met. Soc., London,* **76**, 1950, p. 206.
2. SUTCLIFFE, R. C.; The formation of new anticyclones. *Met. Mag., London,* **82**, 1953, p. 163.
3. FORSDYKE, A. G.; Weather in 1954 in relation to northern-hemisphere circulation patterns. *Quart. J. R. met. Soc., London,* **81**, 1955, p. 504.
4. SUTCLIFFE, R. C. and FORSDYKE, A. G.; The theory and use of upper air thickness patterns in forecasting. *Quart. J. R. met. Soc., London,* **76**, 1950, pp. 205, 208.
5. SAWYER, J. S.; The formation and behaviour of cold front waves. *Met. Res. Pap., London,* No. 553, 1950.
6. SANSOM, H. W.; A study of cold fronts over the British Isles. *Quart. J. R. met. Soc., London,* **77**, 1951, p. 96.

A PRELIMINARY STUDY OF NIGHT COOLING UNDER CLEAR SKIES AT WITTERING

By K. POLLARD

Summary.—An attempt is made to forecast the cooling curve for a radiation night by estimating the night minimum temperature and then adjusting the appropriate "typical" cooling curve.

Introduction.—In aviation forecasting it is a requirement to estimate not only whether radiation fog or turbulent stratus will occur but the time at which it will occur. Numerous suggestions have been put forward for estimating the critical screen temperature at which radiation fog or turbulent stratus will form, most of them very sound and of great practical use to forecasters. This note is concerned with forecasting the time at which these critical screen temperatures will occur. With this in mind, observations made at Wittering during the period October 1953 to February 1956 inclusive, have been studied. Hourly observations have been made only during the last 13 months of the period but the full period has been studied to ascertain constants for use in the formula suggested by McKenzie[1].

Many previous writers have suggested that the cooling curve is not smooth but that there is a marked change in rate of cooling associated with dew formation. This has been considered very carefully; enlarged graphs of temperature against time have been drawn for all cloudless or near cloudless nights

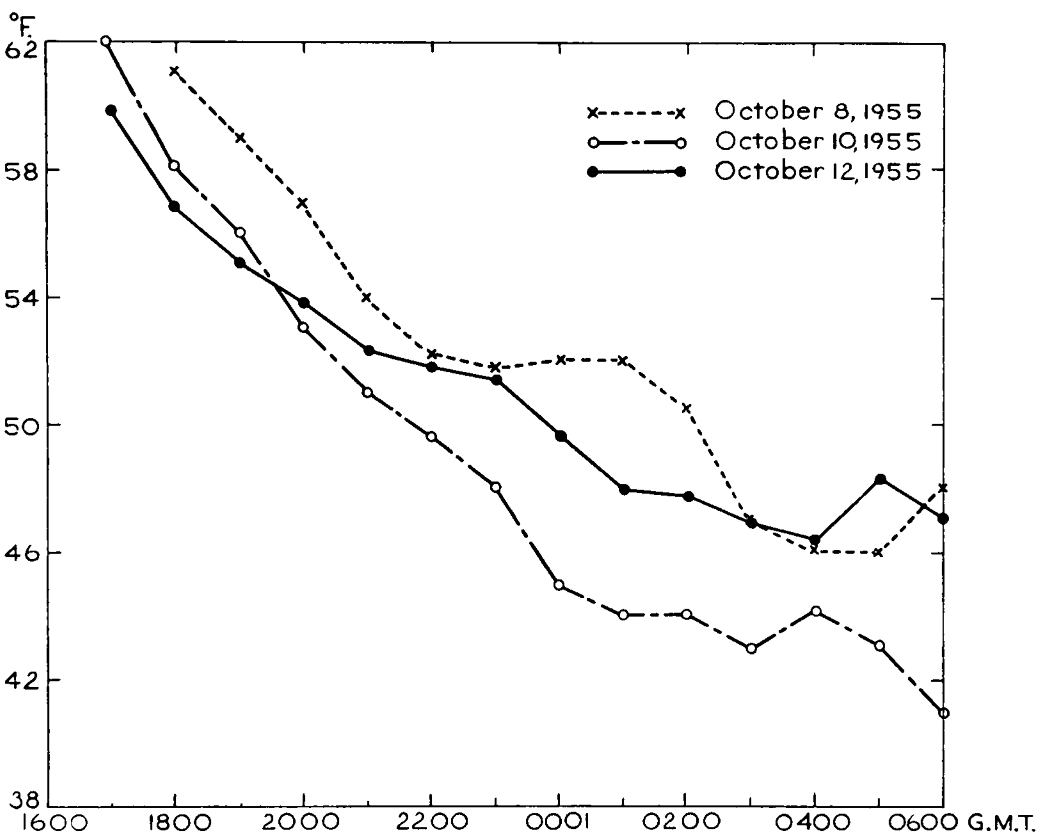


FIG. 1—HOURLY TEMPERATURES ON THREE OCCASIONS OF CLEAR SKIES DURING EARLY OCTOBER 1955

but no marked discontinuity is apparent and the time of any odd kinks in the graphs varies so much from day to day in the same month, that any suggestion of a fixed time would be valueless. Fig. 1, for three occasions in early October 1955, shows an example of this. Presumably this dissimilarity between stations is caused by differing soil and rock formations and local topographical features (see Appendix).

Two factors which have been considered are:—

(i) The longer nights during winter when the cooling period is longer. For convenience the year has been divided into three periods: winter, (November, December, January and Febuary), equinoctial months, (March, April, September and October) and summer, (May, June, July and August).

(ii) The nearness of the sea, relatively warm in winter and cold in summer. Again, for convenience, occasions when the surface wind was between northerly and south-easterly have been considered separately from those when it was westerly.

The present approach, therefore, is to adjust the "typical" curve for radiation nights, considering surface-wind direction and speed as well as the time of the year, by use of a forecast night minimum temperature. In this way the temperature at any time during the evening or night can be interpolated.

Construction of "typical" cooling curve.—Considering only cloudless or near cloudless evenings and nights the mean fall of temperature from 1600 G.M.T., for each hour, was calculated and presented as a graph (see Fig. 2). For each season of the year separate graphs for easterly and westerly surface winds and for winds of Beaufort force 0–2 and 3–4 have been constructed.

The cooling curves have been constructed from observations over a 13-month period only. This limited study is reflected in the few observations available in one or two of the sections considered. These particular sections, light westerlies and both light and moderate easterlies during winter, have been omitted.

Night minimum temperature.—For conditions peculiar to each of the graphs mentioned above, a constant, for use in the formula suggested by McKenzie for estimating the night minimum temperature, was evaluated (see Table I).

TABLE I—CONSTANTS TO BE USED IN McKENZIE'S FORMULA

Wind direction	Wind force 0–2	Wind force 3–4
Westerlies	13	9
Easterlies	12	11

(a) Equinoctial months

Wind direction	Wind force 0–2	Wind force 3–4
Westerlies	11	6
Easterlies	13	13

(b) Summer

Wind direction	Wind force 0–2	Wind force 3–4
Westerlies	12	10
Easterlies	14	7

(c) Winter

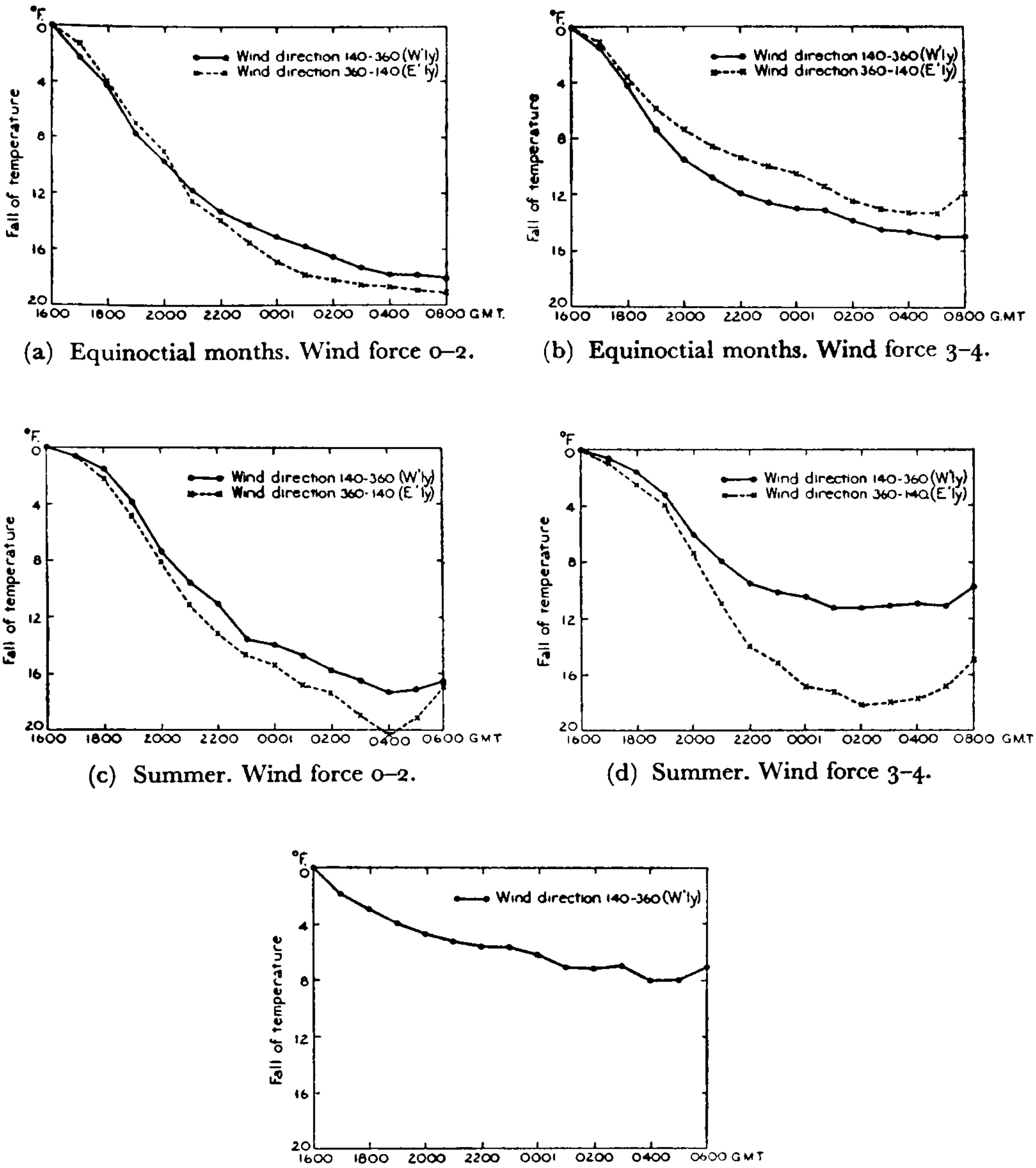
Application to forecasting.—The forecasting procedure is:—

(i) Take the observed maximum afternoon temperature and the dew-point at that time. Consider if they are representative of the air likely to be over the locality during the night. If not, make a judgement from observations upwind.

(ii) Calculate the night minimum temperature using the appropriate constant C for Wittering in McKenzie's formula,

$$T_{min} = \frac{T_{max} + T_{dew}}{2} - C.$$

(iii) On the appropriate "typical" cooling curve plot the calculated night minimum temperature.



(a) Equinoctial months. Wind force 0–2.

(b) Equinoctial months. Wind force 3–4.

(c) Summer. Wind force 0–2.

(d) Summer. Wind force 3–4.

(e) Winter. Wind force 3–4.

FIG. 2—MEAN FALL OF TEMPERATURE FROM 1600 G.M.T. FOR EACH HOUR

(iv) Adjust the "typical" cooling curve to fit the forecast minimum temperature. This adjustment should be made by joining the 1600 G.M.T. temperature and the forecast night minimum temperature by a curve similar to the "typical" cooling curve.

(v) Evaluate the temperature difference between the 1600 G.M.T. temperature and the forecast critical temperature.

(vi) Read off from the adjusted curve the time at which the difference evaluated in (v) above occurs.

Only ideal situations have been considered in deriving both the cooling curve and the night minimum constants.

Intelligent use of the forecast night minimum temperature must be stressed. For example, with a surface wind of 040° the sea, relatively cold in summer, is only 25 or so miles upwind and a temperature some two or three degrees below that calculated using the above method is possible. Again, when the mean wind speed is expected to be near the limits of the bands listed earlier, errors of two or three degrees are likely in the forecast night minimum temperature.

Discussion of results.—A comparison between the actual and the forecast night minimum temperature, temperature at 2100 G.M.T. and the temperature at 0001 G.M.T., for about 40 occasions, has been made. The occasions considered were those on which the sky was either clear in the afternoon or those on which the cloud was expected to clear to give a "radiation" night.

The results of this comparison (see Table II) show that, in general, the forecast of the time that the critical temperature will occur is premature, by an amount varying up to one hour during the late evening and two hours about midnight.

TABLE II—COMPARISON BETWEEN FORECAST AND ACTUAL TEMPERATURES

	Night minimum temperature	2100Z temperature	0001Z temperature
Mean difference between forecast and actual temperature	+0·2	−0·5	−0·8
Standard deviation about the mean	2·15	1·70	1·95

Conclusions.—The accuracy of forecasting night cooling is dependent upon many parameters of which a few have been considered here. As only occasions most conducive to radiation have been considered throughout this study, the effects of any errors in forecasting cloud amounts, for instance, are to make the forecast of the time of the critical screen temperature premature—the safe side.

When considerably more information is available, more representative cooling curves should be constructed, preferably for narrower wind speed and direction bands.

One particular feature revealed by this study, which appears to be quite conclusive, is that no discontinuity of the type mentioned by Saunders[2] and many other writers is apparent at Wittering.

Appendix

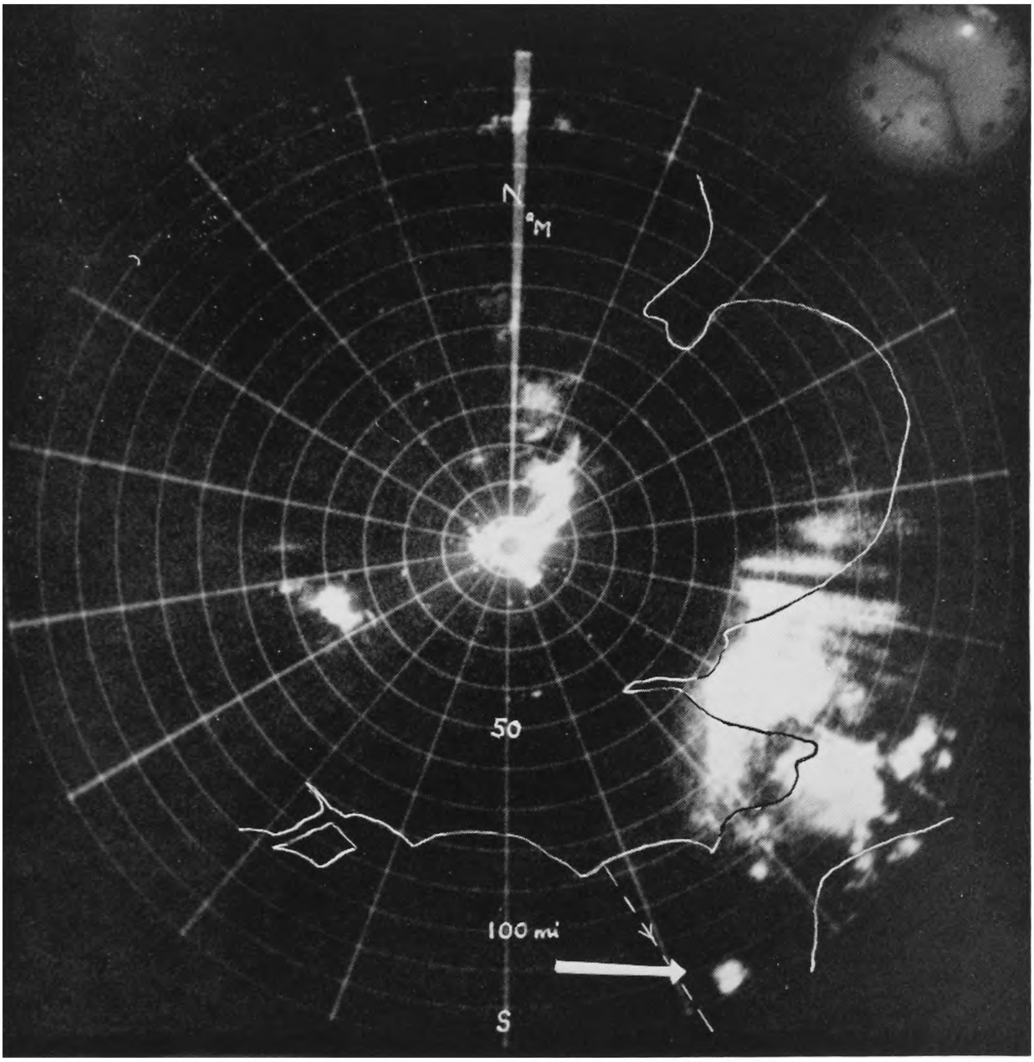
The airfield at Wittering is sited on a ridge extending from the main Northampton Edge to the west. The land immediately surrounding is some 30–50 ft. lower than the airfield.

The soil in this area consists of a one-foot layer of loam top soil upon 2 ft. of limestone or "brash" upon sand.

REFERENCES

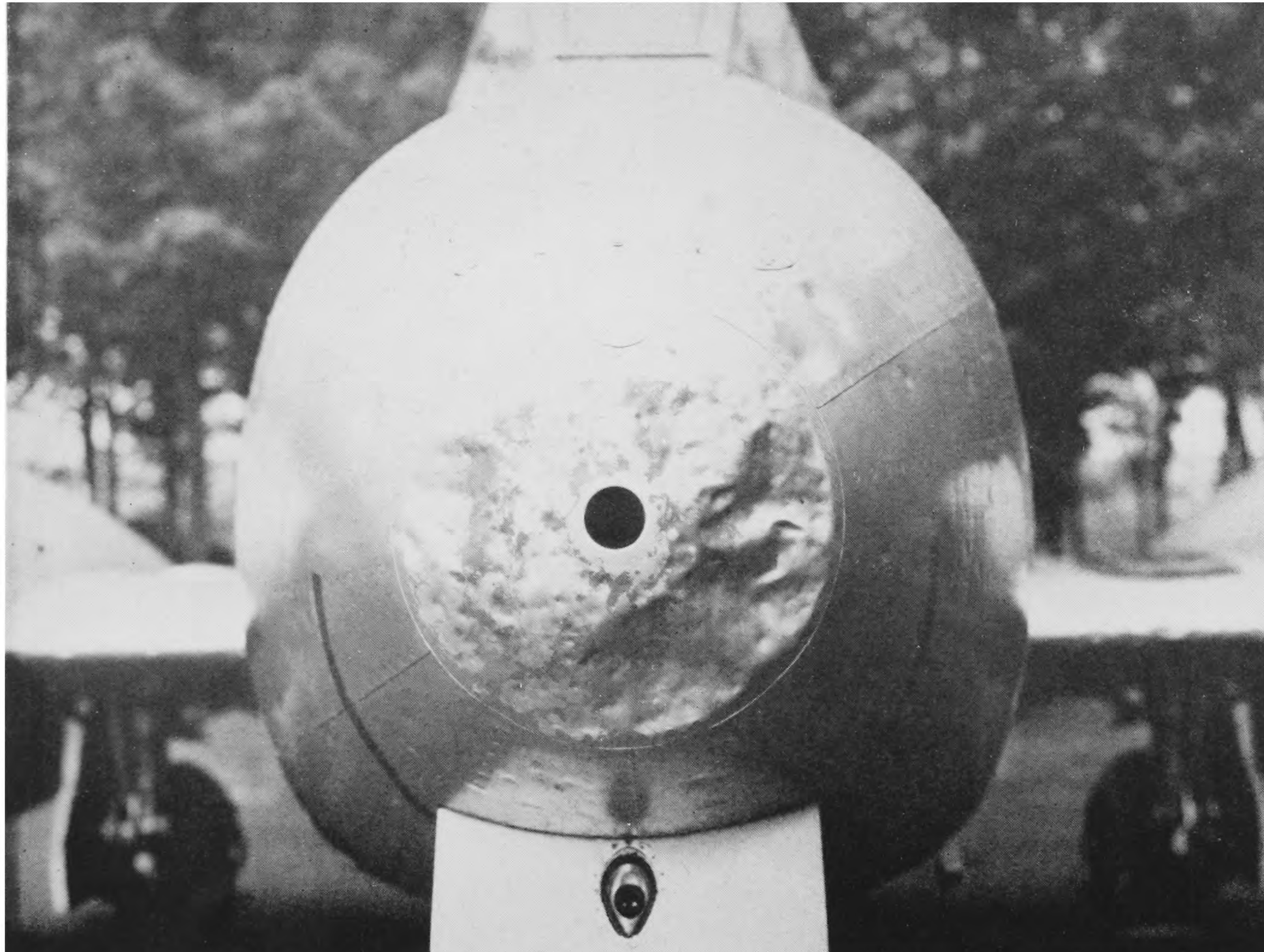
1. MCKENZIE, F.; A method of estimating night minimum temperatures. Unpublished; copy in Meteorological Office Library. London, 1943.

2. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 603.



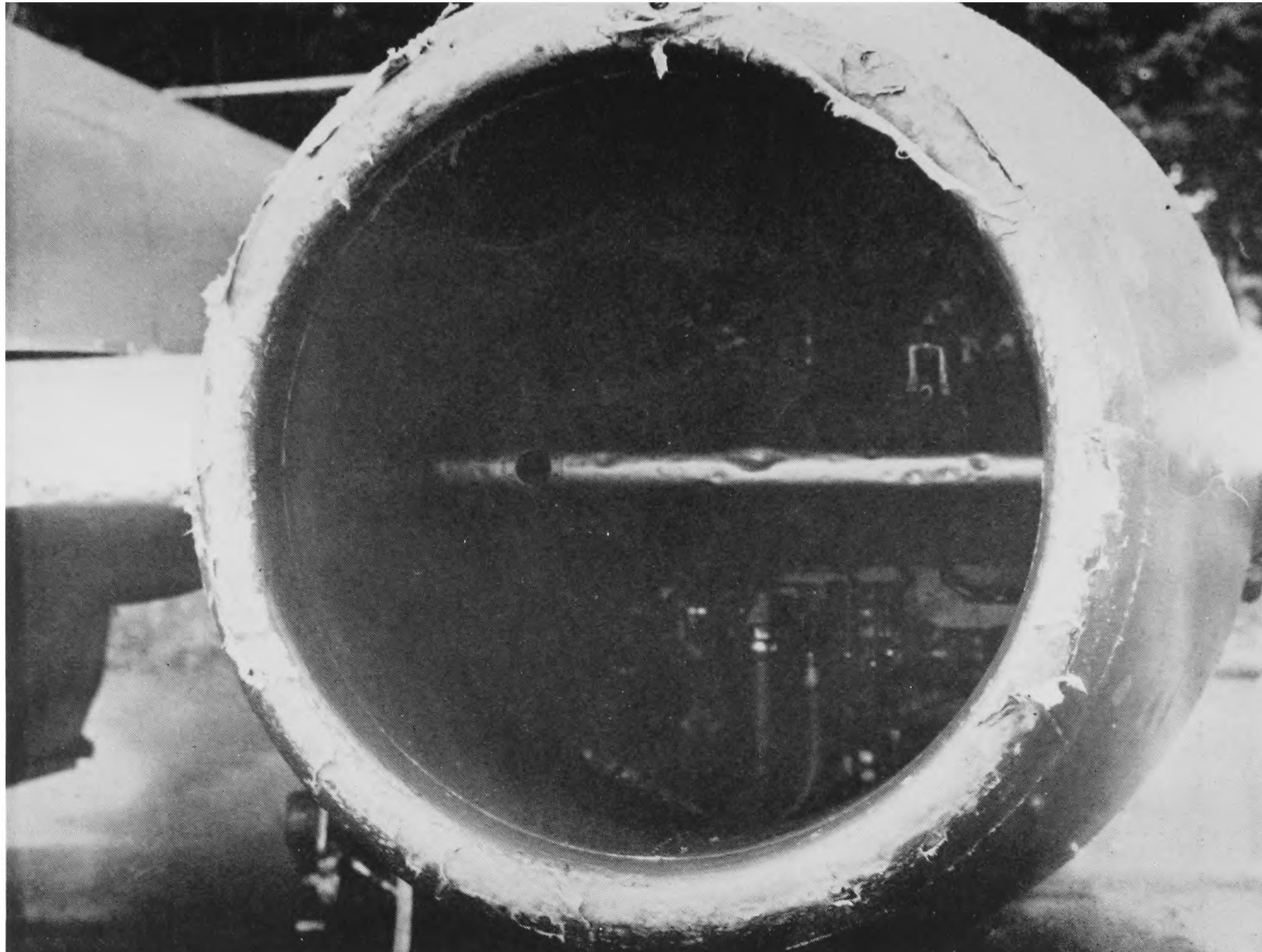
Crown copyright

RADAR PICTURE AT 0924 G.M.T. ON JULY 3, 1957
(see p. 25)



HAIL DAMAGE TO AIRCRAFT

(see p. 23)



HAIL DAMAGE TO AIRCRAFT

(see p. 23)

Reproduced by courtesy of the Gardeners' Chronicle and Gardening Illustrated

WATERING TRIAL IN STIRLINGSHIRE

During the summer of 1957 the paper *The Gardeners' Chronicle and Gardening Illustrated* ran a trial whereby certain vegetable crops in some 20 of their readers' gardens were watered solely on instructions by postcard from the paper. Their instructions were based on fortnightly advice of rainfall from the gardener (not always available) and on the potential transpiration figures calculated by the Agricultural Branch of the Meteorological Office.

The photograph shows the result of one of these trials. Taken at Kilsyth in Stirlingshire, the leek on the right was in the plot "watered by postcard", that next to it was on the dividing line between the plots; the leeks on the left were in the same row in the unwatered plot.

Calculated transpiration may not be meticulously accurate, but it is clearly operationally practicable.

L. P. SMITH

METEOROLOGICAL RESEARCH COMMITTEE

The Committee met on March 26, 1957. The annual reports of the Subcommittees were presented and discussed. Arising from representations from the Gust Research Committee of the Aeronautical Research Council it was recommended that consideration should be given to obtaining instrumental data on the spectrum of atmospheric turbulence during flights by the Meteorological Research Flight. The annual report to the Secretary of State for Air was considered.

Instruments Subcommittee

At the meeting on January 10, the progress on items of research was reviewed and research papers on measuring atmospheric attenuation of light, wind recording apparatus for the ballistic range at Shoeburyness and radio refraction in the free atmosphere were discussed. Further trial was recommended of the matching method of determining visibility at night, using two lights and a concave mirror as described in the first of these papers. The study of the effects of atmospheric refraction on the propagation of radio waves shows that the effects are unimportant in the normal practice of upper-wind measurement by radar but require consideration when the heights of a sounding balloon determined by radar and from radio-sonde data are compared to assess systematic errors in radio-sonde measurements.

On February 22, the Subcommittee made recommendations on the research programme for 1957–58 and agreed the terms of the annual report to the main committee. The relationships between the indications of photo-electric visibility meter Mk. II and eye observations of visibility at London Airport were discussed: the instrument was commended for use in further investigations and for use in indicating temporal and spatral variations in visibility. Anomalous features of vertical profiles of wind speed in the field by using a series of sensitive cup anemometers mounted at different heights on a mast led to wind-tunnel experiments which demonstrate the effect of the orientation of the instrument housing relative to the wind direction and the effect of the supporting mast.

ABSTRACTS

STEWART, K. H.; A simple method of measuring atmospheric attenuation of light ("meteorological optical range" or visibility) at night. *Met. Res. Pap., London,* No. 997, 1956.

An alternative to the Gold visibility meter is described, using two lights, one at a distance viewed directly, and the other carried on the observer's head and reflected in a small convex mirror on a stand. Observer varies his distance from the mirror until the two lights appear equally bright; the ratio of the two distances gives visibility. Tried out at Kew Observatory, it gave much smaller random errors and better agreement between different observers than the Gold meter.

HARTLEY, G. E. W.; Wind recording apparatus for the new Ballistic Range at Shoeburyness. *Met. Res. Pap., London,* No. 1010, 1956.

It was required to measure head and side wind components along a 3,000 foot trajectory. Five wind transmitters of windmill type, kept into wind by vertical fins, were mounted on 30-foot towers. Recording apparatus, in a hut at the base, included a run-of-wind recorder and wind direction component recorder; chart speed was 6 inches per minute.

HOOPER, A. H. and TAYLOR, A. P.; Radio refraction in the free atmosphere. *Met. Res. Pap., London,* No. 1021, 1956.

The theory of refraction, and the refractive index structure of the atmosphere, are set out. The refraction correction of radar heights is calculated for the International Commission for Air

Navigation moist atmosphere. Further corrections are considered for I.C.A.N. dry atmosphere, and for low level European and subtropical moisture discontinuities.

BIBBY, J. R.; Photo-electric visibility meter Mk.II *Met. Res. Pap., London*, No. 1033, 1956.

An instrument installed at London Airport in 1951 measures attenuation of a horizontal beam of light over 300 yards, using a selenium photocell recording on a Cambridge thread recorder. Set-up, operation and interpretation of results are described. Observations in 1954–55 are compared with visual observations for visibilities of 3,000–1,000 yards and 1,000–250 yards. Instrumental readings average too high by about 13 per cent.; large differences are probably due to atmospheric heterogeneity.

RAE, A. G. A.; Response characteristics of the sensitive cup anemometer Type IV. *Met. Res. Pap., London*, No. 1032, 1956.

Wind tunnel tests of the anemometer showed errors due to: (i) Orientation of contact housing relative to wind direction (2 per cent); the only satisfactory solution would be to redesign the instrument to be cylindrically symmetrical; (ii) orientation of supporting arm relative to wind (small); (iii) varying distance of anemometer from mast (decreasing with distance).

Synoptic and Dynamical Subcommittee

At the meeting on February 13, 1957, after consideration of items for the research programme 1957–58 and the annual report, the Subcommittee discussed *Meteorological Research Papers* 1015, 1016, 1020, 1022. The theoretical study in the first paper considered was held to provide greater understanding of the effects of the upper boundary and high-level conditions on the characteristics of air flow over a ridge. It was suggested in discussion that the method used in the paper might be extended to throw light on the circumstances in which mother-of-pearl clouds occur. The meeting recognized the value of the main result reported in *Meteorological Research Paper* 1022, namely, the high correlation and close agreement between the travel of precipitation belts (as observed by radar) associated with cold fronts and cold occlusions and the mean wind normal to the belt at 700 millibars, but considered that further evidence was required before the conclusion could be applied to the movement of the fronts themselves.

At the meeting on April 10, the first paper considered showed that on some occasions the 24-hour forecast chart of 500-millibar isopleths, obtained by numerical integration (finite differences), can be influenced significantly by the choice of the mesh dimension and orientation of the grid of the initial data. In discussion some suggestions were made for the further investigation of the effect reported and for the functional smoothing of the initial data from which integration proceeds. The second paper discussed examines the degree of success obtainable in the representation of hemispherical five-hundred-millibar charts by a series of spherical harmonics. It was noted in discussion that this method, using suitable harmonics, was of promise in relation to numerical forecasting: it would permit of longer time-steps in the integration process. The potential use for classifying charts was also noted. The study on serial correlations of mean daily temperature at Kew aroused interest in several features. It was noted that for statistical prediction of temperature for a given day (from the temperature on recent preceding days) little is gained by using a regression equation with more than one term, and there was no claim that this technique should replace the normal synoptic forecasting of temperature. Other matters discussed at the meeting included the accuracy of forecasts derived from 24-hour prebaratic charts and proposals for forecasting the mean temperature for the month ahead.

On June 6 two further papers on air flow over a ridge were before the Sub-committee. In each paper the operative differential equation is dealt with by numerical integration. The first paper deals with the lee-wave problem and is novel in the treatment of the upper boundary conditions. Observational data used were for the occasions studied by Corby and reasonably good agreement was found between computed wave-lengths (for compact groups of waves which varied only slowly with the upper boundary conditions) and the values arrived at by Corby from consideration of the rate of ascent of radio-sonde balloons. The second paper presents more general calculations of the air flow over a ridge, not restricted to lee-waves, for a number of temperature-wind distributions in typical air streams. Several technical points were discussed. During the discussion of *Meteorological Research Paper* No. 1045, which is a sequel to papers by the same author on the average height of isobaric surfaces from the North Pole to 55°N., it was stated that it is hoped also to prepare isotach charts. The "filter" analysis of meteorological time series for the purpose of examining the slower fluctuations (excluding strictly periodic ones) described in the last paper considered, was regarded as an important contribution in opening the way to the study of relative scale in space and time of the various types of atmospheric fluctuations and disturbances.

ABSTRACTS

CORBY, G. A. and SAWYER, J. S.; The air flow over a ridge—the effects of the upper boundary and high-level conditions. *Met. Res. Pap., London,* No. 1015, 1956.

The paper considers "what boundary conditions should be applied at great heights and whether the introduction of an upper boundary gives a justifiable approximation to the flow". Computations are made first on a two-layer airstream and then a four-layer airstream including a stable stratosphere surmounted by a layer of adiabatic lapse rate. It is concluded that "lee waves which have their largest amplitude in the upper troposphere and stratosphere can occur in certain airstreams . . . ; these are of somewhat longer wavelength and for their proper study require consideration of stability and wind in the stratosphere".

HUCKLE, V. M.; Numerical forecasts based on objectively analysed data. *Met. Res. Pap.,* London, No. 1016, 1956.

Four numerical 24-hour forecasts of 500- and 1,000 millibar contours and 1,000- to 500-millibar thickness were computed from data objectively analysed by the quadratic surface method, and from data analysed subjectively. Results were compared with actual charts by correlation and regression. Three cases showed little difference between objective and subjective methods; in the fourth the objective method (which is quicker) gave much better results.

HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in April and October. *Met. Res. Pap., London,* No. 1020, 1956.

Average heights of standard isobaric surfaces in January and July 1949–53 were given in Meteorological Research Papers 918 and 981. Those for April and October follow the same lines; contour heights (decameters) are given on circumpolar charts for 700-, 500-, 300-, 200-, 150- and 100-millibar and intervening thicknesses, and peculiarities discussed, especially of April.

HARPER, W. G. and BEIMERS, J. G. D.; The movement of precipitation belts as observed by radar. *Met. Res. Pap., London,* No. 1022, 1956.

Radar records of movement of 103 belts of precipitation at East Hill, Dunstable, in 1947–52, mostly associated with cold fronts or occlusions, were compared with radar winds at 50-millibar intervals from 950 to 500 millibars. Measurements were not possible on warm fronts. Correlation had a well-defined maximum of 0·928 with winds at 700 metres. This agrees with Ligda's correlations for movement of small storm areas. Wind behind fronts was stronger than wind ahead but the best correlation was with the mean. Strong support is found for the forecasting rule: cold fronts and cold occlusions move with a speed equal to the component of the wind across the front at the 700-millibar level.

KNIGHTING, E., JONES, D. E. and HINDS, MAVIS K.; Numerical experiments in the integration of the meteorological equations of motion. *Met. Res. Pap., London,* No. 1018, 1956.

Equations relating changes of vertical component of vorticity to advection and divergence, which form the basis of all practical methods of numerical weather prediction, can only be integrated by finite difference methods. The values of the vorticities and Jacobians were calculated for the 500-millibar surface over a mesh of 18 × 14 points with a grid length of about 160 miles, for 18 cases. Two sets of 24-hour forecasts were made by the same method, but with different orientations and sizes of the mesh. There were large differences amounting to 10 to 40 per cent in the calculated height tendencies.

GILCHRIST, A.; The representation of circumpolar five-hundred-millibar charts by a series of spherical harmonics. *Met. Res. Pap., London,* No. 1040, 1957.

Four 500-millibar circumpolar charts were represented by coefficients up to P_{12}^{12} (91 coefficients) and P_8^8 (45 coefficients). Variance of calculated charts averaged 99·15 per cent of total variance in first case and 97·2 per cent in latter. The representations could be used to select charts which have basic similarities, but even in using harmonics up to P_{12}^{12} some features which appear important synoptically are not reproduced.

CRADDOCK, J. M.; The serial correlations of daily mean temperatures at Kew Observatory. *Met. Res. Pap., London,* No. 1023, 1956.

Serial correlations were computed between Kew temperatures on each day 1900–1950 and following seven days. Results and standard deviations are plotted. Mean standard deviation varies from 2·33°C. in August to 3·40°C. in January. Mean correlation coefficients ranged from 0·7641 after 1 day to 0·1810 after 7 days; they are also given in terms of Fisher's z. Serial values are not independent and are used to divide the year into natural seasons. A statistical forecasting method is tried, and a number of regression equations using up to 4 preceding days are presented, but the results do not equal synoptic forecasts. Five-day non-overlapping periods are also tried, with moderate success.

WALLINGTON, C. E. and PORTNALL, J.; A numerical study of the wavelength and amplitude of lee waves. *Met. Res. Pap., London,* No. 1025, 1957.

The wavelength of lee waves was calculated by high speed computing, with artificial boundary assumptions at the upper limit of the layer considered. Results were compared with radio-sonde ascents at Leuchars. The amplitudes of the calculated waves differ greatly according to upper boundary conditions but compact groups of curves without large curvature at high levels are interpreted as real waves and agree more or less with observed waves. Estimated vertical speeds were reasonably consistent with observed vertical speeds.

SAWYER, J. S. and HINDS, M. K.; Numerical calculations of the air flow over a ridge for small amplitudes. *Met. Res. Pap., London,* No. 1041, 1957. The abstract of this paper is not yet available.

HEASTIE, H.; Average height of the standard isobaric surfaces over the temperate and tropical regions in January. *Met. Res. Pap., London,* No. 1045, 1957.

This paper extends the author's north polar charts for 1949–53 to 60°S. Method of construction from upper wind data and thickness charts is described. Average Mercator charts for 700-, 500-, 300-, 200-, 150- and 100-millibar levels, and intervening thicknesses, are given and discussed.

CRADDOCK, J. M.; A contribution to the study of Meteorological Time Series. *Met. Res. Pap., London,* No. 1051, 1957. The abstract of this paper is not yet available.

Physical Subcommittee

At the meeting on February 8 discussion of the first paper confirmed the view that it was desirable that five or six Meteorological Office stations in the United Kingdom should obtain regular samples of air and rainfall, for subsequent chemical analysis, as a contribution to the network of atmospheric chemical sampling stations in north-west Europe developed by Prof. C.-G. Rossby. The Subcommittee noted the useful information derived in *Meteorological Research Paper* No. 1017 from analysis of some hundreds of reports by aircrew of the icing of aircraft, but considered that further advance in the investigation of the problem will depend on the availability of appropriate instrumental data obtained during flight. Discussion of the preliminary report on cumulus investigations included suggestions on points to receive special attention during the proposed further collaboration between the Imperial College and the Meteorological Office. The Subcommittee considered also items for the research programme 1957–58 and the annual report.

The meeting on May 9 was devoted to work reported in the fields of atmospheric diffusion and turbulence. It was noted that the study of pollution around a power-station chimney led to values of diffusion parameters broadly consistent with experimental values obtained by other workers. Examples of simultaneous records of "vertical gustiness" at intervals of height up to 7,000 feet above ground indicated the type of information obtainable by the instrumental devices described earlier in the paper. Proposals for analysis of the observational data were dicussed. The associated report applies the Fourier-transform method (modified by J. W. Tukey) to the calculation of the energy spectrum (in the frequency range 1/75 to 1/5 cycles per second) from selected runs of vertical gustiness records at 2,000 feet. It was remarked in discussion that the results presented suggest that there is little energy in the part of the spectrum not dealt with by the instrumental technique used in obtaining the records. The Subcommittee welcomed the fourth paper which is a theoretical examination of the mean concentration downwind of matter emitted from a cross-wind source into a turbulent region below a stable layer, (a) when non-convective diffusion processes alone operate in the turbulent layer and (b) when, in addition, matter is transported by free convection. Idealized models are used.

On June 13 the Subcommittee considered problems in the determination of the surface wind and supported the suggestions that on-site investigations should be made at places where the anemometer exposure is not good, that further consideration be given to the accuracy with which wind speeds can be reduced to the conventional standard height in various conditions and that, when practicable, field investigations should be made into the effects of single obstacles on surface air flow and the extent to which it is possible to correct for these effects. The diversity of ways in which the problem of air flow near the ground enters into agricultural and comparable activities was discussed. Consideration of two papers relating to the problem of slant visibility near the ground as affecting the landing of aircraft in fog conditions, led to the suggestion that the implications of these papers and the justification on operational grounds for further observations of slant visibility should be discussed with aviation authorities.

ABSTRACTS

ODDIE, B. C. V.; A note on the published results of studies in atmospheric chemistry. *Met. Res. Pap., London,* No. 1014, 1956.

This paper is "intended as a basis for general discussion of policy with respect to chemical sampling". The history of atmospheric chemistry is summarized, including variations of the chlorine to sodium ratio in rainwater. Questions requiring elucidation are listed; they require an extensive network of observing stations. Suggestions for further work are made.

JONES, R. F.; Analysis of reports of ice accretion on aircraft. *Met Res. Pap., London,* No. 1017, 1956.

Subjective reports of 800 cases of icing, classified as low, moderate and high, are analysed for cloud type and temperature. Severe icing is most likely with cumulus or cumulonimbus but layer clouds also give significant frequencies. Some (235) reports of rate of ice formation are used to give rough values of water content. Clear ice, mixed ice and rime ice are then treated separately. The risk of severe clear ice formation is limited to temperatures of 0° to —15°C. and short distances of high water content. Conditions for mixed ice, rime ice and no icing are also discussed. Icing is very unlikely below —35°C. Synoptic conditions when cloud water content reached 1·0 grams per cubic meter are considered and some remarks made on forecasting.

HARPER, W. G., LUDLAM, F. H. and SAUNDERS, P.; Preliminary report on cumulus investigations, East Hill, June–August, 1956, and on plans for future similar work. *Met. Res. Pap., London*, No. 1019, 1956.

Evolution of cumulus clouds was followed visually with two theodolites and by 10-centimetre and 3-centimetre radar and aircraft soundings. Development of shower echoes and relation between cumulus properties and screen-level observations are discussed. Plans for future work are set out, including seeding experiments.

MEADE, P. J. and PASQUILL, F.; A study of the average distribution of pollution around Staythorpe. *Met. Res. Pap., London*, No. 1039, 1957. The abstract of this paper is not yet available.

JONES, J. I. P. and BUTLER, H. E.; Studies of eddy structure in the first few thousand feet of the atmosphere. Part 1. Measurements of the vertical and horizontal (longitudinal) components. *Met. Res. Pap., London*, No. 1038, 1957.

Details are given of minor modifications of the instrument described by J. I. P. Jones in *Meteorological Research Paper* No. 974, for measuring vertical gustiness by in inclination and speed of the wind. A modified Ower airmeter was used to record fluctuations of total wind speed. Both instruments were mounted on a captive balloon cable and gave a response of 90 per cent with a period of 2·4 seconds (70 per cent at 1·0 seconds) through an electronic integrator. Air temperature was measured with a thermistor. Some observations at Cardington up to 7,000 feet in 1956 are described and illustrated.

JONES, R. A.; Studies of eddy structure in the first few thousand feet of the atmosphere. Part 2. A preliminary examination of the spectrum and scale of the vertical component at 2,000 feet. *Met. Res. Pap., London*, No. 1044, 1957.

Data of wind inclination at 2,000 feet are used for a preliminary estimate of the energy spectrum of the vertical component of turbulence of frequency 1/75 to 1/5 cycles per second. Various methods of calculation are discussed. Appendices describe the Fourier-transform method after J. W. Tukey and errors and modifications in it.

SMITH, F. B.; Convection-diffusion processes below a stable layer. *Met. Res. Pap., London*, No. 1048, 1957.

The paper studies mathematically the distribution of non-buoyant matter when a turbulent layer has above is stable a layer in which diffusivity falls to zero. An idealised model is proposed. Dispersion is separated into two processes, mechanical turbulence and forced convection, large near the ground and falling to zero at the top of the layer, and free convection consisting of a succession of bubbles rising to the top of the layer where they mix with the surrounding air.

FRITH, R.; The measurement of surface wind. *Met. Res. Pap., London*, No. 989, 1956.

Problems discussed are assessment of wind at 10 metres in an open situation, and assessment of actual wind at any place or height taking account of terrain and obstacles. Accuracy of 5 per cent in speed and 5 degrees in direction cannot be achieved until more is known about effect of local obstacles. An investigation is proposed.

GLOYNE, R. W.; Problems of surface air flow and related phenomena in agriculture, horticulture and forestry. *Met. Res. Pap., London*, No. 1049, 1957.

Problems of wind breaks in relation to heat losses from glasshouses, wind and climatic hazards to forestry and agriculture, are discussed. Risk of smoke or dust deposits, disease spores and snow is considered. Wind surveys, ecological data, and studies of topography and obstructions are all necessary, but there are large gaps in our knowledge. A programme of investigations is laid down, including the general wind field over the British Isles, topographical influences on air flow, effect of types of roughness elements, and "exposure".

STEWART, K. H.; An approximate relation between slant visibility and horizontal visibility at ground level. *Met. Res. Pap., London*, No. 1046, 1957.

An expression is developed for variation of slant visibility with height in a water fog, using values for Cardington and London Airport. It was tested with a small lamp at Cardington and small balloons at London Airport. It gave a good representation on the average but large differences occurred on individual occasions.

STEWART, K. H.; A method for assessing the frequency of dangerous visibility conditions. *Met Res. Pap., London*, No. 1047, 1957.

Variation of slant visibility in and above a fog layer is shown schematically for two different fogs. The curves can be estimated from temperature and humidity soundings and horizontal visibility. A diagram gives for a critical height of 200 feet the lines separating "safe" and dangerous conditions. At Cardington the latter occur for about 7 hours a year. Uncertainty in this estimate arises from uncertainty in criteria for adequate visual guidance.

HAIL DAMAGE TO AIRCRAFT AT NEARLY 30,000 FEET ON JULY 3, 1957

The extent of the damage

Two Meteor aircraft from Royal Air Force station Benson flying in formation at 29,500 feet in route for Dijon were south-south-east of Beachy Head nearing the French coast at 0905 G.M.T. on July 3, 1957 in cirrus cloud and suddenly encountered severe turbulence while hail could be heard striking the aircraft. Unable to keep formation the aircraft turned out of the cloud. Rime ice which had formed on the leading edges quickly broke off and damage caused by the hail could be seen. Both aircraft returned safely to base. Some of the damage is shown in the photographs between pages 16–17.

Some five minutes buffeting was endured; at debriefing the pilots estimated hailstones as "one inch to golf ball size" though this impression was rather vague—their minds being fully occupied at the time. Both aircraft received almost identical damage—all leading edges were dented and noses battered, some of the larger depressions evident in the photographs being approximately 6 by 8 inches, and containing 30 to 40 separate indentations from striking hailstones. The outer protective sheathing on some electrical leads in the engine intakes of both aircraft had been frayed away.

Another pilot from Benson who investigated cloud in the area about an hour later reported dense cirrostratus with base at 28,000 feet, top 40,000 feet, which was " very black below" and about 50 miles across.

Notes on the synoptic situation by Mr. J. Harding and by Mr. W. G. Harper on the radar storm echoes observed at the time follow this report.

T. A. PAVELY

Thunderstorms over north-west Europe

Thunderstorms occurred on July 1, 1957 over the Low Countries, Germany and eastern districts of France along and ahead of a cold front moving from the north-west. On the 2nd a depression on the front moved northwards from Spain into Biscay and the front returned north-westwards over much of France and parts of Biscay as a warm front.

Thunderstorms developed ahead of the warm front and moved north or north-north-east across north-west France during the afternoon and evening of the 2nd and north-north-east or north-east across much of England and Wales during the night. Storms persisted throughout much of the night in parts of north-east France in the neighbourhood of the warm front. By 0600 G.M.T. on the 3rd the storms were mainly over Wales, the Midlands, south-east England and the eastern parts of the English Channel, and were moving north-north-east or north-east.

Upslide motion above the frontal surface must have been the main factor in the production of thunderstorms. In fact the earlier storms in the west on the 2nd developed over the sea before air heated over the land during the day was in a position to contribute to them. Surface temperatures on the 2nd in southern France in the warm air south of the warm front rose above the convection temperature as evidenced by the Nîmes midday ascent, but the air was dry, and weather there remained fine in most places throughout the day. Air contributing to the storms over south-east England and the English Channel on the 3rd was probably over south-west France or nearby Biscay early on the 2nd. The midday ascent at Bordeaux on that day indicates moister air there than at Nîmes, and layers of convectively unstable air. It is possible that the warm air to the west over Biscay, and nearer the centre of the depression, was moister than that at Bordeaux. It would appear that the thunderstorms were due to upslide motion above the frontal surface, with convectively unstable air producing layers of saturated unstable air. The Brest ascent at midday on the 2nd, made ahead of the warm front, and just before the arrival of storms from the south, shows a layer of some 5,000 feet of warm air just above the frontal surface which is saturated and unstable, whilst convective instability persists upwards for another 9,500 feet.

It would seem that the aircraft which experienced the hail damage over the English Channel were flying in anvil cirrus just prior to the incident, and we may assume that it was sufficiently dense to prevent the pilots from seeing the cumulonimbus which they undoubtedly encountered at 0905 G.M.T. Extensive and deep layers of cirrostratus with tops near the tropopause are commonplace in thundery conditions, and one or more cumulonimbus clouds may be feeding into one of these layers at a time during the developing stage. The severe turbulence and hail damage were experienced about 10,000 feet below the top of the cirrus cloud as reported within an hour of the event. These indicate very vigorous vertical currents in the convection cloud at this level, and penetrating well into the level of the associated cirrostratus. In fact, high level photography indicates that rising bubbles in vigorous convection clouds sometimes break quite vigorously through the flat top of the associated cirrostratus sheet, thereafter quickly losing their upward momentum in the stable surroundings.

The pilot who investigated the cloud within an hour of the incident has described the cirrostratus cloud as mushroom shaped. At least five cumulonimbus clouds existed below and penetrated into the cirrostratus. The bases of the cumulonimbus were at medium-cloud level. The tropopause height was about 40,000 feet, in agreement with the reported height of the top of the cirrostratus. The pilot saw no signs of rising bubbles at the top of the cloud. Radar echoes from as high as 39,000 feet were received at East Hill from the Channel area some time before the hail damage was experienced, but radar observations were not made on this particular cloud at the appropriate time.

The report of rime ice is interesting, as the temperature of the environment was about —35°C.

J. HARDING

Radar storm echoes

We have received a number of reports of hail in south-east England in the period 0530 to 0810 G.M.T. on July 3, but none of falls later in the day, though thunderstorms persisted. The hail was mainly concentrated near the coast of east Sussex from Pevensey to Winchelsea, the stones being reported as the size of peas and cherries. "Flat ice plates the size of half-crowns" fell at about 0540

G.M.T. at Westham near Pevensey. The hail was associated with thunderstorms and very heavy rainfall; 1·92 inches fell at Hankham, near Pevensey, between 0330 and 0800 hours.

The plate facing page 16 shows the precipitation areas at 0924 G.M.T., (19 minutes after the Meteors encountered the damaging hail), as seen by the 10-centimetre plan position indicator of the Radar Research Station of the Meteorological Office at East Hill, 30 miles north-west of London. The main area of thundery rain has completely cleared the East Sussex coast, and now extends from Kent to Suffolk, covering the Thames estuary. There are very heavy storms in the Straits of Dover (evidenced by the firm-edged echoes), but the storm further south, marked with an arrow, because of its hard edges and great range, 125 miles, is without doubt one of the heaviest on the display, the more so because the radar is obstructed in this sector by the Chiltern Hills, and only precipitation above the 20,000-foot level in the storm contributes to the radar echo. Extra-polation with the 10,000-foot wind to the time of the hail damage places this storm very close to the track to Dijon (the dashed line added to the photograph). This makes it almost certain that it was an earlier stage of this storm into which the aircraft flew.

Unfortunately we have no record of its earlier development, for it was only at 0924 that the range of the display was extended to 130 miles, bringing the storm into view, but between 0800 and 1000 we had recorded six separate storms in the Straits of Dover with maximum tops in the range 39,000 to 41,000 feet in close agreement with the cumulonimbus tops estimated by Mr. Pavely from the tephigrams.

This would seem to have been a case where airborne radar would have been of great value. The radar echo pattern suggests that high-flying aircraft equipped with airborne radar could probably have avoided the area of severe storms entirely by a diversion of 10 miles. W. G. HARPER

LATE RAINFALL REPORTS

Great Britain and Northern Ireland

1956

Month	County	Station	Inches	Per Cent of Average
November	*Bute*	Rothesay, Ardencraig ...	2·22	44
November	*R. & C.*	Inverbroom, Glackour ...	7·78	125

1957

Month	County	Station	Inches	Per Cent of Average
June	*Bute*	Rothesay, Ardencraig ...	2·45	80
August	*Argyll*	Islay, Eallabus	4·30	99
August	*Inverness*	Skye, Glenbrittle	6·71	94
September	*Inverness*	Skye, Glenbrittle	5·91	82
October	*Glam.*	Ystalyfera, Wern House ...	7·89	115
October	*Bute*	Rothesay, Ardencraig ...	5·74	130

NOTES AND NEWS

International Union of Geodesy and Geophysics General Assembly, Toronto, 1957

Every three years the International Union of Geodesy and Geophysics, more familiarly and conveniently known as the U.G.G.I., holds a general assembly and with the co-operation of governments manages to ensure that each assembly is associated with a different city from the others. Thus in 1951 the ninth general assembly was held in Brussels, the tenth in Rome three years later and from September 3 to 14, 1957 some 1,300 delegates and guests from more than 50 Countries attended the 11 general assembly in Toronto at the invitation of the National Research Council of Canada.

The U.G.G.I., which is a member of the International Council of Scientific Unions (I.C.S.U.), contains seven associations, one dealing with geodesy and six others which are each concerned with a particular branch of geophysics. These are:—

International Association of Seismology and Physics of the Interior of the Earth (I.A.S.P.E.I.).

International Association of Meteorology (I.A.M.)

International Association of Geomagnetism and Aeronomy (I.A.G.A.)

International Association of Physical Oceanography (I.A.P.O.)

International Association of Scientific Hydrology (I.A.S.H.)

International Association of Volcanology (I.A.V.)

The meetings of the assembly and of the individual associations were held in buildings of the University of Toronto and most of the visitors were accommodated in the halls of residence of the different colleges.

The formal opening of the assembly took place in Convocation Hall on the morning of September 3, when the Prime Minister of Canada, Mr. John Diefenbaker, paid the Union the signal compliment of attending in person and making the principal speech of welcome to the visiting delegates. Speeches in similar vein were also made on behalf of the Government of Ontario and of the City of Toronto. The President of the Union, Professor K. R. Ramanathan, replied in suitable terms and then gave his presidential address. Thereafter the associations were mainly occupied with their own separate, specialized activities but from time to time overlapping interests were acknowledged when two or more associations held a joint symposia.

The proceedings of the Association of Meteorology were clouded by the recent sudden and untimely death of its President, Professor C.-G. Rossby. At the opening session the senior Vice-President, Dr. J. Van Mieghem, gave a moving tribute to Professor Rossby whose stature in meteorology was shown by the fact that at almost every meeting, covering the widest possible field, some reference was made to work which he had carried out or directed.

The meteorological programme was a very full one, including a joint symposium on the water balance of the earth with I.A.P.O. and I.A.S.H., joint symposia with I.A.G.A. on atmospheric electricity and on ozone, as well as separate meetings on diffusion and convection; numerical methods of dynamical weather prediction; mesometeorology; radiation; fronts, jet streams and air masses; physics and dynamics of clouds; atmospheric chemistry, radioactivity and pollution; and on polar meteorology. Altogether the Association of Meteorology heard presented and discussed nearly a hundred scientific papers.

Among such a wealth of material it would be difficult and perhaps lacking in discretion to pick out the highlights. Comparatively new subjects like mesometeorology seemed to possess all the vitality of youth and much older subjects such as fronts and air masses were clearly not lacking in vigour and freshness of thought. Considered as a whole these meetings gave ample evidence that energetic and fruitful research is being carried on into every branch of meteorolgy and that most countries are joining in the total effort. During business meetings reports were received from the Association's Commissions on Radiation and on Atmospheric Ozone and it was decided to set up a new Commission on Atmospheric Chemistry and Radioactivity.

The closing session of the assembly took place on September 14 when it was announced that Professor J.T.Wilson of Canada would be the President of U.G.G.I for the next three years and that the next assembly would be held in Helsinki. Dr. J. Van Mieghem will be the President of the International Association of Meteorology and Atmospheric Physics (I.A.M.A.P.), which is the new name for the I.A.M., and Dr. R. C. Sutcliffe will continue as Secretary.

The main purposes of these general assemblies are the presentation and discussion of papers but equally valuable is the implicit objective of enabling scientists from all countries to make and renew acquaintance and to exchange points of view upon topics of common interest. Viewed from these angles the 11th general assembly was undoubtedly highly successful. Those who were privileged to attend will long remember not only the scientific activities but also the sincere welcome and generous hospitality of the host country. By means of receptions, film shows and organized visits to Niagara Falls, to the Stratford Shakespearean Festival and to Lakes Huron, Simcoe and Muskoka, the Canadian Government did everything to ensure that their guests would take away with them most pleasant memories of Canada as well as of the general assembly.

P. J. MEADE

Television forecasting

We have been informed by Dr. J. S. Farquharson that since writing his article, "Television forecasting by the British Broadcasting Corporation", published in the December 1957 *Meteorological Magazine*, the showing of a forecast chart on B.B.C. television has been introduced at 8 p.m., at the end of the "News flash".

OBITUARIES

Professor H. U. Sverdrup

We regret to report the death on August 21, 1957, of Professor H. U. Sverdrup the eminent Norwegian meteorologist and oceanographer.

Sverdrup was born in Sogndal, Norway in 1888 and graduated at Oslo in 1914. He was the assistant of Prof. V. Bjerknes in Oslo and Leipzig between 1911 and 1917. In 1917 he obtained the degree of Doctor of Science at Oslo for a thesis on the trade winds of the North Atlantic.

From 1918 to 1925 Sverdrup was scientist on Amundsen's expedition to the Arctic in the "Maud". On his return he became Professor of Meteorology at the

Geophysical Institute at Bergen leaving there in 1931 for further scientific exploration in the Arctic with Sir Hubert Wilkins and to investigate the heat balance of glaciers in Spitsbergen with H. W. Ahlmann. In 1936 he was appointed Professor of Oceanography at the Scripps Institute of Oceanography of the University of California and in 1948 Director of the Norwegian Polar Institute and Professor of Geophysics at Oslo University.

Sverdrup's researches covered a very wide field in meteorology from the structure of the trade winds and surface friction of atmospheric flow to evaporation from the sea, the forecasting of sea and swell, and the detailed discussion of the long record of meteorological observations of the "Maud" expedition. To many meteorologists he will be best known for his book *Oceanography for meteorologists.*

Professor Carl Störmer, Fr.Mem.R.S.

We regret to report the death on August 13, 1957 of Professor Carl Störmer the pioneer of both the electromagnetic theory of the aurora and of the exact observation of its shape and position by photography.

Professor Störmer began his scientific career as professor of pure mathematics at Oslo. His attention was directed to auroral theory by the experiments of his colleague, Professor Birkeland, on the motion of cathode rays around a magnetized sphere. Störmer's theoretical studies of the motion of charged particles in a dipole magnetic field found application to the problems of cosmic rays as well as those of the aurora.

The Clarendon Press published in 1955, *The polar aurora,* his account of his life-work.

REVIEW

The atmospheric diffusion of gases discharged from the chimney of the Harwell pile (BEPO). By N. G. Stewart, H. J. Gale and R. N. Crooks, (A.E.R.E. HP/R 1452), 13 in. × 8 in., pp. iv + 40, *illus.*, Atomic Energy Research Establishment, Harwell, Berkshire, 1957. Price: 9*s*.

This report was first issued in 1954 by the Health Physics Division of the Atomic Energy Research Establishment, Harwell. Its circulation was somewhat limited and we welcome the decision to make copies available for purchase through Her Majesty's Stationery Office because the paper contains much fundamental data of importance to micrometeorologists in their studies of diffusion problems.

The practice of discharging waste gases into the atmosphere is an old one and the dispersion of such gases is a familiar and extremely difficult problem. To the meteorologist the problem is essentially the same whether the gases are produced by the consumption of traditional sources of energy such as coal and oil or by the use of power from a nuclear reactor. In the case of the latter, however, considerations of special importance arise since some of the radioactive materials to be found in reactors are among the most powerful poisons known and precautions are necessary to ensure that the chimney effluents do not endanger the health of the community. For this reason the Atomic Energy Authority made a comprehensive series of measurements of the distribution of the gases discharged from the Harwell pile chimney. Surveys were carried out at ground level and at heights up to 300 metres at various distances to 10,000 metres downwind of the chimney. Concentrations and plume "widths" in the horizontal and vertical were measured with the aid of geiger counters using the radioactive argon content of the gases as a tracer.

The results of this research programme are given in full detail in this report which also contains an interesting discussion in terms of the well-known theories of Sutton and of Bosanquet.

P. J. MEADE

BOOKS RECEIVED

The Scanner. The House Journal of Decca Radar Ltd. No. 18, Spring 1957. 8¼ in. × 10½ in., pp. 25, *illus.*

La climatologie et les cultures. By E. Guyot. 9½ in. × 6¾ in., pp. 21, *illus.*, University of Thessaloniki, Meteorological Institute, 1956.

Annual Meteorological Tables Falkland Islands and Dependencies Meteorological Service, 1954. 13½ in. × 8½ in., pp. iv + 140, Falkland Islands Dependencies Survey, Stanley, 1956. Price 15/-.

HONOUR

President's Gold Medal of the Society of Engineers

Sir Graham Sutton, Director-General of the Meteorological Office, has been awarded the President's Gold Medal of the Society of Engineers for 1957.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. C. V. Ockenden, O.B.E.*, Senior Principal Scientific Officer, retired on November 30, 1957. He joined the Office as a Probationer in October 1913 at Kew Observatory. In 1916 he joined the Meteorological Section, Royal Engineers. At the end of the First World War he was granted special leave for the purpose of taking a degree. He recommenced duty in the British Rainfall Section in November, 1922. From 1924 until 1944, apart from a short period in 1925 in the Forecast Division, he served at aviation outstations including a tour of duty in the Middle East and another in Iraq. In 1944 he was posted to the Central Forecasting Office and from 1948 until his retirement he was Assistant Director (Observations and Communications). He was appointed an Officer of the Order of the British Empire in the New Year Honours List of 1957.

Mr. Ockenden has accepted a temporary appointment in the Meteorological Office.

Mr. R. M. Poulter, O.B.E., Principal Scientific Officer, retired on December 12, 1957. He joined the Office as a Probationer in August, 1914 in the Forecast Division. In 1917 he joined the Meteorological Section, Royal Engineers and was awarded the Meritorious Service Medal in 1919. At the end of the First World War he resumed duty in the Forecast Division and remained there until June 1927 when he was transferred to the General Services Division. From 1936 he has served continuously at aviation outstations and from 1952 until his retirement he was Chief Meteorological Officer at Headquarters, Fighter Command, Royal Air Force. Whilst he was at Headquarters, Fighter Command he was also Chief Meteorological Officer Royal Air Force Reserve. He was appointed an Officer of the Order of the British Empire (Military) in the Birthday Honours List of 1944.

Mr. F. W. Creek. On November 15, 1957 Dr. F. J. Scrase made a presentation to Mr. F. W. Creek, Leading Storeman in the Instruments Branch on his retirement after more than 50 years' service. Mr. Creek joined the Office when it was in Victoria Street in March 1907 as a Boy Messenger.

In 1912 he was transferred to the Instruments Branch as a packer, but in 1916 he was released to join the Duke of Cornwall's Light Infantry. He returned to the Office in 1918 to be a storeman packer and apart from short periods in the General Services Division and the Air Ministry Messenger Service he remained in the stores section of the Instrument Branch until his retirement. Mr. Creek is continuing his service in a disestablished capacity as a storeman.

Royal Air Force Volunteer Reserve (Meteorological Section).—*Awards.*—It was announced in Air Ministry Orders dated October 30, 1957 that the undermentioned officers in the Meteorological Section of the Royal Air Force Volunteer Reserve had been granted the following awards. We offer them our congratulations.

Flight Lieutenant E. Southall, Air Efficiency Award.

Flight Lieutenant P. S. Hobbs, D.F.C., Clasp to the Air Efficiency Award.

WEATHER OF NOVEMBER 1957

Great Britain and Northern Ireland

The British Isles, during the first five days of the month, came under the influence of a complex low pressure area in the western Atlantic with small depressions from time to time moving north-east across the country. Weather was generally unsettled with periods of rain and frequent showers which were heavy locally with hail and thunder. The most vigorous of these depressions was the one which, approaching from the south-west on the 3rd, deepened considerably as it reached Devon at midnight that night and Lincolnshire six hours later. Pressure fell at the rate of 10 to 15 millibars in three hours as the depression approached and rose just as rapidly behind and wind increased to gale force over a wide area. Gales were severe in places, causing considerable structural damage, particularly in Hertfordshire where at Hatfield the roofs of a number of houses were blown off. A gust of 67 knots was recorded at nearby Stevenage and one of 90 knots at West Raynham in Norfolk. Torrential rain led to floods in many areas especially in the Midlands; at Dudley, Staffordshire more than half an inch of rain fell in 7 minutes. There was snow over high ground in Yorkshire.

The remainder of the month was dominated by anticyclones over or near the British Isles. On the 6th weather became quieter. An anticyclone, which was centred to the south of Iceland on the 7th, moved to Scotland two days later and pressure remained high to the north of Scotland until the 15th with winds over most of the British Isles predominantly easterly. Weather was fine and cold on the 7th and the following morning frost and fog was widespread in the north-east and Midlands; screen temperature fell to 20°F. locally in Yorkshire, and although fog was dense in places it cleared from most places during the morning, forming again at night. From the 10th to 15th weather was dull and generally mild, especially at night, and slight rain occurred here and there but amounts were small. Some stations in south-east England had no sun for six days. Between the 16th and 20th southerly winds were established over the British Isles, strong in western districts with gales at times, and there was rain in the west and north but it was mainly dry elsewhere. An anticyclone which was in the region of Newfoundland on the 19th became situated off the west of Ireland by the 22nd and cold northerly winds and brighter weather spread to the whole of the British Isles. On the 24th the anticyclones moved south-east to the region of the English Channel and remained there until almost the end of the month. Weather was mainly dry and dull over most of England and Wales but rain or drizzle fell at times over Scotland, Northern Ireland and north-west England and it became milder, especially in the west and north; temperature reached 59°F. at Aberdeen. On the 28th a new anticyclone moved southward from the Norwegian Sea intensifying as it came, and on the last day of the month temperature fell about 10°F. as cold air spread from the Continent into England.

The predominance of south-westerly winds in the north and of easterlies in southern districts resulted in mean temperatures for the month being rather above average in Scotland, Northern Ireland and parts of Northern England, but somewhat below average elsewhere. It was the driest November since 1945 in Northern Ireland and absolute droughts were recorded in the Dee basin (Cheshire) and locally in Southern England, while during the period 6th to the 30th, the 21st was the only day with measurable rain at many places in England. Rainfall was 72 per cent of the average in England and Wales, 55 in Scotland and 33 in Northern Ireland. After a good start to autumn cultivations the storms at the beginning of the month interrupted work and few farmers, especially in eastern districts, can have escaped the effects of gales and heavy rain. For growers the absence of killing frosts in many places was all important and many tender plants lingered on long past their normal departure dates. A feature of the month was the high relative humidity which provided very suitable conditions for the spread of diseases in cultivated mushroom and other crops.

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 ...	60	19	0·0	72	−7	109
Scotland	59	16	+1·1	54	−4	71
Northern Ireland ...	57	24	+0·3	41	−9	98

RAINFALL OF NOVEMBER 1957
Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	2·40	102	*Glam.*	Cardiff, Penylan ...	2·76	68
Kent	Dover	5·45	172	*Pemb.*	Haverfordwest ...	2·57	51
„	Edenbridge, Falconhurst	3·94	111	*Radnor*	Tyrmynydd	4·12	62
Sussex	Compton, Compton Ho.	2·90	76	*Mont.*	Lake Vyrnwy	2·82	49
„	Worthing, Beach Ho. Pk.	2·96	93	*Mer.*	Blaenau Festiniog ...	4·24	40
Hants.	St. Catherine's L'thouse	2·55	82	„	Aberdovey	2·36	52
„	Southampton (East Pk.)	2·64	84	*Carn.*	Llandudno	2·03	70
„	South Farnborough ...	2·98	112	*Angl.*	Llanerchymedd ...	2·16	51
Herts.	Harpenden, Rothamsted	2·06	78	*I. Man*	Douglas, Borough Cem.	3·94	84
Bucks.	Slough, Upton	2·37	107	*Wigtown*	Newton Stewart ...	2·20	44
Oxford	Oxford, Radcliffe ...	1·99	87	*Dumf.*	Dumfries, Crichton R.I.	2·02	55
N'hants.	Wellingboro' Swanspool	1·77	82	„	Eskdalemuir Obsy. ...	2·35	41
Essex	Southend, W. W. ...	2·39	108	*Roxb.*	Crailing...	1·05	44
Suffolk	Felixstowe	1·65	80	*Peebles*	Stobo Castle	1·91	58
„	Lowestoft Sec. School ...	1·46	62	*Berwick*	Marchmont House ...	1·67	56
„	Bury St. Ed., Westley H.	1·81	79	*E. Loth.*	North Berwick Gas Wks.	1·27	57
Norfolk	Sandringham Ho. Gdns.	1·49	60	*Midl'n.*	Edinburgh, Blackf'd. H.	2·28	102
Wilts.	Aldbourne	2·31	75	*Lanark*	Hamilton W. W., T'nhill	1·48	41
Dorset	Creech Grange... ...	2·15	52	*Ayr*	Prestwick	1·91	59
„	Beaminster, East St. ...	2·39	60	„	Glen Afton, Ayr San. ...	3·06	56
Devon	Teignmouth, Den Gdns.	2·35	73	*Renfrew*	Greenock, Prospect Hill	2·51	41
„	Ilfracombe	2·60	66	*Bute*	Rothesay, Ardencraig ...	2·59	51
„	Princetown	3·79	43	*Argyll*	Morven, Drimnin ...	4·18	62
Cornwall	Bude, School House ...	1·93	54	„	Poltalloch	3·05	54
„	Penzance	3·04	66	„	Inveraray Castle ...	3·41	40
„	St. Austell	3·32	67	„	Islay, Eallabus	2·57	48
„	Scilly, Tresco Abbey ...	2·40	70	„	Tiree	2·36	49
Somerset	Taunton	2·11	78	*Kinross*	Loch Leven Sluice ...	2·02	56
Glos.	Cirencester	1·81	59	*Fife*	Leuchars Airfield ...	1·25	55
Salop	Church Stretton ...	2·90	94	*Perth*	Loch Dhu	2·39	28
„	Shrewsbury, Monkmore	1·69	75	„	Crieff, Strathearn Hyd.	1·32	30
Worcs.	Malvern, Free Library...	2·54	101	„	Pitlochry, Fincastle ...	·67	18
Warwick	Birmingham, Edgbaston	2·07	79	*Angus*	Montrose Hospital ...	1·37	52
Leics.	Thornton Reservoir ...	1·92	85	*Aberd.*	Braemar	1·32	34
Lincs.	Boston, Skirbeck ...	1·83	92	„	Dyce, Craibstone ...	1·66	51
„	Skegness, Marine Gdns.	1·97	91	„	New Deer School House	2·78	82
Notts.	Mansfield, Carr Bank ...	1·74	72	*Moray*	Gordon Castle	3·27	114
Derby	Buxton, Terrace Slopes	2·39	51	*Nairn*	Nairn, Achareidh ...	1·56	69
Ches.	Bidston Observatory ...	1·22	49	*Inverness*	Loch Ness, Garthbeg ...	2·41	58
„	Manchester, Ringway...	1·35	52	„	Loch Hourn, Kinl'hourn	4·87	41
Lancs.	Stonyhurst College ...	1·79	40	„	Fort William, Teviot ...	2·96	36
„	Squires Gate	1·57	48	„	Skye, Glenbrittle ...	7·39	82
Yorks.	Wakefield, Clarence Pk.	1·69	80	„	Skye, Duntulm... ...	3·70	62
„	Hull, Pearson Park ...	2·23	102	*R. & C.*	Tain, Mayfield... ...	1·39	47
„	Felixkirk, Mt. St. John...	1·69	69	„	Inverbroom, Glackour...	4·11	66
„	York Museum	1·47	70	„	Achnashellach	6·12	71
„	Scarborough	2·54	103	*Suth.*	Lochinver, Bank Ho. ...	4·36	86
„	Middlesbrough... ...	1·65	78	*Caith.*	Wick Airfield	2·15	68
„	Baldersdale, Hury Res.	2·03	56	*Shetland*	Lerwick Observatory ...	4·12	97
Norl'd.	Newcastle, Leazes Pk....	1·43	61	*Ferm.*	Crom Castle	...	...
„	Bellingham, High Green	1·29	38	*Armagh*	Armagh Observatory ...	0·99	35
„	Lilburn Tower Gdns. ...	1·92	57	*Down*	Seaforde	2·97	78
Cumb.	Geltsdale	1·70	52	*Antrim*	Aldergrove Airfield ...	1·07	33
„	Keswick, High Hill ...	2·11	37	„	Ballymena, Harryville...	1·46	36
„	Ravenglass, The Grove	1·49	33	*L'derry*	Garvagh, Moneydig ...	1·49	38
Mon.	A'gavenny, Plâs Derwen	2·79	67	„	Londonderry, Creggan	1·37	33
Glam.	Ystalyfera, Wern House	3·85	59	*Tyrone*	Omagh, Edenfel ...	1·16	31

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,028, FEBRUARY 1958

DETERIORATION OF VISIBILITY IN RADIATION FOG

By E. EVANS, M.Sc., C. J. M. AANANSEN, M.Sc., and T. E. WILLIAMS

This statistical investigation was undertaken to examine how well founded is the impression, which is shared by many forecasters, that when radiation fog forms at inland stations the visibility passes quickly through the intermediate ranges and falls to a low value. And to see, at the same time, whether such behaviour of the visibility, if true, is related to the ambient temperature.

Sites and observations.—Hourly observations for the inclusive periods shown were examined for the following airfields which are not adjacent to any large town, and are thus largely unaffected by smoke, and which are located in three well-separated areas of the country:

Mildenhall, Suffolk	(30 feet above m.s.l.)	January, 1950–December, 1954
Scampton, Lincolnshire	(195 feet above m.s.l.)	September, 1953–May, 1955
Waddington, Lincolnshire	(235 feet above m.s.l.)	June, 1955–August, 1955
Shawbury, Shropshire	(248 feet above m.s.l.)	January, 1950–December, 1954

Results.—First, the frequency distribution among the 200-yard ranges 0–200, 2–400, 4–600, 6–800, 800–1,000 and 1,000–1,200 yards, was determined for (i) all hours and (ii) night-time, for the occasions when a visibility of 1,200 yards or less was reported under all conditions (radiation and non-radiation) at Mildenhall and Shawbury; and then a similar frequency distribution for only radiation nights for the four stations. The results in Table I were obtained, the values for Scampton and Waddington being combined.

These figures, which show such a uniformly high percentage for visibilities in the 0–200-yard range and a significant minimum in the 6–800-yard range under radiation conditions (for visibilities below 1,000 yards), make a prima facie case for the broad contention that when fog, particularly radiation fog, forms, the visibility falls rapidly through the intermediate ranges to a rather low value.

But the majority of radiation fogs form in the winter, when the cooling period still remaining after the fog has first formed is often sufficiently long for the visibility to ultimately reach a low value and to stay so for two or more hours—a cumulative process which gives bias to the frequency distribution in favour of a low visibility.

TABLE I—PERCENTAGE FREQUENCY DISTRIBUTION OF VISIBILITY IN DIFFERENT RANGES

Airfield	Visibility range 0–200	2–400	4–600	6–800	800–1,000	1,000–1,200 *yards*
	Percentage frequency distribution					
	All hours (all conditions)					
Mildenhall (2,363 occasions)	26·5	14·6	14·1	10·5	17·4	16·9
Shawbury (2,359 occasions)	31·1	9·1	11·9	11·7	18·1	18·0
	Night-time (all conditions)					
Mildenhall (1,522 occasions)	26·7	15·2	14·2	11·0	17·3	15·6
Shawbury (1437 occasions)	32·2	9·4	13·2	12·2	18·2	14·8
	Radiation nights					
Mildenhall (677 occasions)	38·0	16·1	10·6	6·9	14·0	14·3
Shawbury (964 occasions)	31·3	12·6	14·4	11·9	19·9	9·9
Scampton/Waddington (492 occasions)	33·1	19·3	13·6	11·2	13·0	9·8

To determine the true reality of the effect, therefore, the investigation was carried a stage further by examining how visibility in radiation fog varies progressively from hour to hour whilst radiation continues. For this, examination was made of the hourly observations from the first (hourly) observation after sunset until the last before sunrise on radiation nights at Mildenhall for the inclusive months and years January–April and September–December, 1950–55; and the examination was restricted to those occasions when a deterioration of the visibility to 1,200 yards or less occurred within this period. The following results were obtained, "1st Hour" meaning that at which a visibility of 1,200 yards or less first occurred, and the 2nd, 3rd .... hours being those subsequent to this:

TABLE II—PERCENTAGE FREQUENCY DISTRIBUTION OF HOURLY OBSERVATIONS OF VISIBILITY AT MILDENHALL

Visibility range	Hour 1st	2nd	3rd	4th	5th	6th	7th
	Percentage frequency distribution						
1,000–1,200 *yards*	23	12	6	7	9	8	7
800–1,000	33	24	24	14	3	4	5
600– 800	11	13	12	11	16	11	5
400– 600	11	8	11	11	3	6	7
200– 400	10	13	9	13	16	17	15
0– 200	11	30	38	43	53	54	60
No. of occasions (Visibility<1,200 yds.)	154	115	88	70	57	52	48

Whilst this table shows a marked hourly increase in the percentage of visibility below 200 yards (the hourly variation even for the adjacent 200–400-yard range is small and irregular), it also shows very significantly the absence of any well marked maximum in any of the intermediate ranges 2–400, 4–600 and 6–800 yards at any hour: when the visibility deteriorates further after the initial formation of radiation fog it tends to pass rapidly through the intermediate bands and to fall quickly to a low value.

The persistence of a high value in the 800–1,000-yard range for the first few hours suggests some reluctance on the part of the visibility to deteriorate further after the initial formation of radiation fog. But when further deterioration does take place, then it is likely to be serious.

Relation to temperature.—The statistics extracted did not exhibit, until at least after the 3rd hour, any connexion between the tendency for radiation fog to thicken rather quickly and the ambient temperature.

ABNORMALLY LOW HUMIDITY IN SCOTLAND

By R. C. SMITH, Ph.D.

Frequency of occurrences.—Since 1900 there have been recorded at least seven occasions when the humidity in the British Isles fell below 20 per cent. These have been listed by, among others, Bilham[1,2], Hawke[3,4] and Needham[5]. The lowest on record are shown to be 9·5 per cent. at Parkstone, Dorset in 1901 and 10 per cent. at Kew on the afternoon of April 15, 1942. The synoptic situations associated with these were of the type–large high over Scandinavia with the air having a long land track and presumably subsiding as well. One has to be careful to make comparisons with stations near sea level as it would be expected that at the mountain stations a larger number of exceptionally low humidities would be reported coinciding with the larger number of subsidence inversions getting below the level of the station.

On the afternoon of June 10, 1956 the exceptionally low humidity of 18 per cent was recorded at Kinloss in Scotland. There were also reports from other stations in the area of very dry air during the same day. As occasions of such dry air reaching the surface are rare, the circumstances surrounding this phenomenon are examined more closely.

Synoptic situation.—On June 7 a depression of 1000 mb. moved south-east across the Southern Highlands into the North Sea and brought deep cold air into Scotland behind it. A sharp ridge ahead of a warm front over the Atlantic, moved slowly east on the 8th. On the 0001 G.M.T. surface chart of the 9th, a separate high centre of 1029 mb. was drawn south of the Faroes. This moved slowly east-north-east and intensified. A ridge extended south-south-west over Scotland from it and, by 0001 G.M.T. on the 10th, a separate centre of 1029 mb. was positioned east of Scotland with the main high over north Norway; central pressure was 1033 mb. By midday on the 10th the warm front was lying along a line Western Isles–60°N., 5°W.–65°N., 1°E.

Upper air situation.—On examining the tephigrams of the previous few days, it became fairly obvious that the air had originated from the region of the tropopause. The radio-sonde ascents from Lerwick, Aldergrove, Leuchars and Stornoway at 1400 G.M.T. on June 7 showed a fairly typical polar maritime air mass over the region. The tropopause at Lerwick was at 24,000 ft.

The Lerwick ascents were chosen for closer examination as they seemed to typify best the main subsidence area. Fig. 1 shows sections of these ascents from 1400 G.M.T. on June 7 to 1400 G.M.T. on June 10. To avoid confusion, only the section of each temperature curve between the 20°C. and 30°C. potential temperature lines was plotted together with the corresponding humidity readings.

The upper winds for Lerwick for the same period have been plotted in Table I, and the sections, corresponding to the parcel being dealt with on the tephigram, marked off. As can be seen by inspection, after June 7 the winds

TABLE I—UPPER WINDS FOR LERWICK JUNE 7–10, 1956

The values between the horizontal lines correspond to the parcel being followed on the tephigram for that time.

	June 7th		June 8th				June 9th				June 10th			
	Greenwich mean time													
mb.	1400	2000	0200	0800	1400	2000	0200	0800	1400	2000	0200	0800	1400	2000
900	190 20	190 16	120 07	010 13	250 17	360 16	030 16	030 06	300 05	240 06	220 08	220 07	200 06	180 06
850	190 20	180 16	120 08	020 09	350 13	350 24	010 12	040 05	220 05	230 06	220 10	220 11	200 08	180 07
750	180 18	190 19	210 06	030 07	320 11	350 12	330 06	040 04	170 06	210 07	190 05	200 09	200 14	180 13
700	180 18	200 18	270 03	040 06	300 10	340 09	340 06	030 04	170 08	180 06	180 03	190 09	200 15	190 17
600	190 21	200 22	240 07	220 07	260 07	340 16	360 07	030 03	170 09	180 05	150 06	200 12	190 15	190 14
500	190 19	230 25	210 10	210 16	250 14	350 25	350 09	160 04	230 06	220 07	200 06	190 11	200 15	200 15
400	190 24	220 19	200 11	200 53	360 32	340 28	350 10	190 05	240 16	240 07	030 03	130 15	170 11	200 18

Wind direction in degrees from true north. Wind speed in knots were light and variable throughout the layer thus increasing confidence in the selection of the one station to represent the situation.

Fig. 1 shows what might be a typical example of subsiding air in the atmosphere. The temperatures in each successive sounding move down the dry adiabatics regularly with the exception of the sounding for 0200 G.M.T. on June 9. The dew points move down the water-content lines with the exception of the sounding for 1400 G.M.T. on June 9 when the air is relatively more moist.

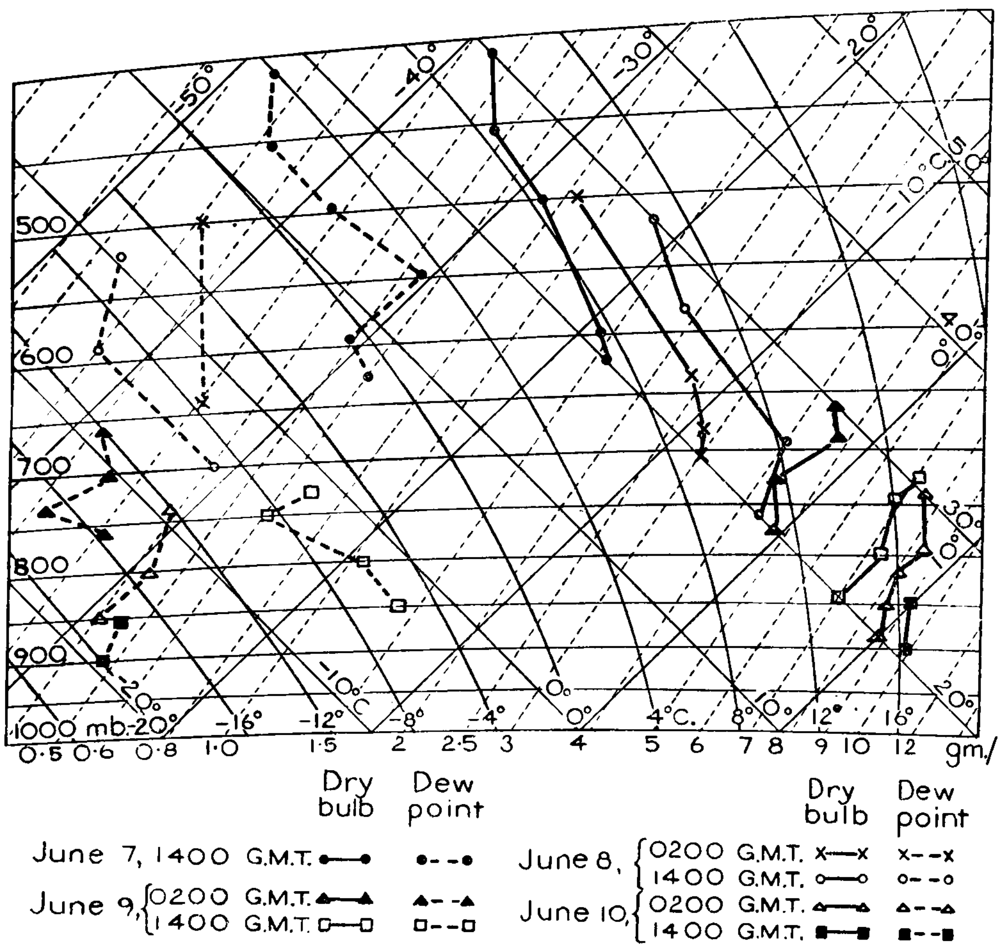


FIG. 1—SECTIONS OF TEPHIGRAMS FOR LERWICK JUNE 7 TO JUNE 10, 1956

This last feature can be explained as follows:—during the morning and afternoon of June 9 the wind direction at Lerwick, at the appropriate level, changed by approximately 180° to a direction of 230° as the axis of the ridge passed through the station. This direction introduced relatively moister air, as is indicated by the Stornoway ascent of 1400 G.M.T., until the new high centre was formed off east Scotland. This fed in the drier air from the east although maintaining a south-westerly air-stream at Lerwick.

The soundings at Leuchars over the period also showed signs of the dry air although not so consistently as those at Lerwick. In particular, at 1400 G.M.T.

on June 10, there was a dew-point of −18°C. at the 970-mb. level. Above the 800-mb. level the air was considerably moister.

Surface reports.—

(i) Kinloss reported a fall in humidity on the afternoon of June 10 to a minimum of 18 per cent at 1600 G.M.T. The dew-point fell from 6·5°C. at 1400 G.M.T. to −5·8°C. at 1600 G.M.T. Wind veered from 010°/11kt. at 1400 G.M.T. to 080°/12kt. at 1600 G.M.T.

(ii) At Dalcross, near Inverness, a minimum humidity of 34 per cent occurred just after 1400 G.M.T. This was taken from a hygrograph trace as the station was not manned during the week-end.

(iii) At Wick, 119 ft. above sea level, there was a rapid fall of humidity at 1230 G.M.T. to 72 per cent despite the wind blowing directly from the sea at 130°.

(iv) Green[6] records that between 1030 and 1130 G.M.T. on June 10 the humidity fell to 8 per cent at a height of 1,000 ft. in the Cairngorm Nature Reserve.

As a value for comparison, the humidity at the 900-mb. level for the sounding at 1400 G.M.T. on June 10 is 5 per cent.

Conclusion.—It appears that the dry air, which eventually reached the surface in places, originated near the tropopause and descended almost *in situ*. From the Lerwick soundings the vertical velocity is roughly 3 ft. per min. for the first falling to 2 ft. per min. on the last day. Using the observations (i) and (iv), the vertical velocity of the air was also 3 ft. per min.

Another interesting associated feature at Kinloss was that, after the time of minimum humidity had been passed, the inversion still persisted over the Moray Firth giving an inverted mirage of the mountains at the far side as shown in Fig. 2. The fact that the dry air ever arrived at the surface at Kinloss is probably connected with the local sea-breeze circulation as is indicated by the sudden wind veer accompanying the humidity change.

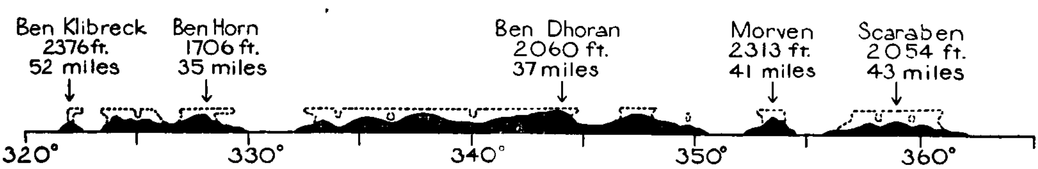


FIG. 2—MIRAGE AT KINLOSS, 2045 HR. JUNE 10, 1956

Heights of mountains and distances away from the mountains are given underneath their names.

By late evening on the 10th the dry air over Scotland had been replaced by moister air from the south, although a shallow layer of the dry air was still apparent on the morning ascent at Lerwick on June 11.

REFERENCES

1. BILHAM, E. G.; Climate of the British Isles. London, 1938.
2. BILHAM, E. G.; "Desiccated" air. *Quart. J. R. met. Soc., London*, **73**, 1947, p. 464.
3. HAWKE, E. L.; The incidence of extremely low humidity in southern England. *Quart. J. R. met. Soc., London*, **70**, 1944, p. 274.

4. HAWKE, E. L.; A near approach to zero humidity at ground-level in England. *Quart. J. R. met. Soc., London*, **72**, 1946, p. 173.
5. NEEDHAM, G.; Low humidity. *Met. Mag., London*, **79**, 1950. p. 326.
6. GREEN, F. H. W.; Another remarkable low humidity. *Weather, London*, **11**, 1956, p. 300.

THE OCCURRENCE OF VERY HIGH SURFACE TEMPERATURES

By H. H. LAMB, M.A.

It is reasonable to suppose that, as a general principle, the occurrence of outstanding or extreme values of any meteorological element anywhere requires the operation of several favourable circumstances, the effects of which are superposed. Absolute extremes may require the conjunction of all possible favourable influences, so far as these are all compatible.

Outstandingly high surface temperatures are favoured by

(i) Strong heating of the surface, most effective on dry desert sand or bare rock, when the sun is high and when the atmosphere is specially clear.

(ii) Long sojourn or long passage of the air over the warmest surface available.

(iii) Subsidence, which inhibits both vertical convection and local circulations, such as sea breezes, that have a three-dimensional development.

(iv) Föhn effect or passage of the air stream over mountains, most effective when condensation and rainfall produced during ascent result in latent heat of condensation being stirred into the air. (The word stirred is appropriate because the air parcels receiving the liberated heat must be dispersed through many layers of the atmosphere in the overturning which occurs after the crest is passed.) Föhn effect also helps to intensify the insolation received at places to the leeward, because rainfall during ascent washes suspended impurities out of the air, thereby tending to produce ideal transparency of the atmosphere after crossing the mountains.

(v) Advection from regions where the air has already been heated.

Reasoning from this basis, the writer hazarded the opinion some time ago that all five effects listed above might have played a part in producing the world's highest temperatures so far recorded near the fringe of the deserts of north Africa and south-western United States of America. It now seems possible to supply a little corroborative evidence.

Requirements (i) and (ii) above are obvious enough to need no justification. They are expressed by the occurrence of the highest temperatures over deserts and by the fact, which can be asserted on the basis of a sufficient network of observing stations for sampling the Sahara, that the highest individual values in north Africa, though not the highest average temperature, occur towards the leeward coast, i.e. near the end of the run of the air stream over the heated desert.

The following notes serve to illustrate the manner in which the less obvious, in some cases surprising, items (iii), (iv) and (v) seem to come into the picture.

The United States Weather Bureau's "Historical Daily Weather Maps of the Northern Hemisphere, 1899–1939", the *Tägliche Synoptische Wetterkarten für den*

Nordatlantischen Ozean und die anliegender Teile der Kontinente of the Danish Meteorological Institute and Deutsche Seewarte, 1880–1912, the weather maps in the *Daily Weather Reports*, London, and observing stations' data in *Réseau Mondial* and in various countries' daily weather reports were briefly examined to discover the synoptic circumstances in which the highest-reported surface air temperatures in the world, in Europe and in Britain occurred. Additionally the highest temperatures in the 20-yr. period 1919–38 at Cairo and Malta were similarly examined. The results are listed in note form below.—

(i) The absolute extreme for the world accepted in the "Meteorological Glossary" is 57·7°C. (136°F.) at Azizia, Tripolitania on September 13, 1922. The "Historical Daily Weather Maps" leave much room for alternative explanations of the situation over the Sahara about this time, being unsupported by plotted observational data south of the coastal region. The maps are drawn with pressure gradients for westerly winds in the north and easterly winds in the south of the desert; but a cold front was advancing east from Algeria, actually passing Azizia, 32°32′N., 13°01′E., either late on the 13th or early on the 14th, and advection of warm air from the Saharan interior with southerly and south-westerly winds was in fact established some distance ahead of the cold front. Tripoli had strong southerly winds for two successive days before the front passed. No reports of observations made at stations in the interior could be found, but by chance a British expedition to the Sahara was operating at the time in the mountains north of Agadèz in the northern part of the French Niger territory. These mountains are more or less surrounded by desert, but themselves experience from 10 to over 30 days with rain in the average year. The expedition reported heavy, sometimes torrential, rain at Auderas, 17°N., 8°E., and north of there for many hours on September 8 and 9, and rivers in high flood. No noteworthy rain fell for some days before or afterwards. The rainfall on the 8th and 9th fell from evidently extensive cloud travelling with an easterly wind. The air in which this rainfall occurred could have reached Tripolitania three to five days later after following an anticyclonically curved path of some 1,500 miles: this path is the simplest assumption for the origin of the southerly surface winds observed at Tripoli and is certainly the likeliest course for the air moving in the middle and upper troposphere around the warm area over the central desert. Warmth derived from the latent heat of condensation of the moisture which fell near Auderas was almost certainly present, at least in some of the upper levels, over Tripolitania on September 13, 1922. The hot wind of that date may in this sense be regarded as a föhn wind.

Maurice Bérenger has described a case in which moist air from the equatorial Atlantic reached the central Sahara, missing the southern mountains[1]. A Saharan depression, with a centre of 998 mb. near 30°N., 0°E., drew in a tongue of equatorial air from the south-south-west "with high temperature, great humidity and pronounced convective instability" between March 13 and 15, 1953. Abundant rain fell in the Algerian part of the Sahara in amounts up to 20 mm. in 24 hr. There were thunderstorms and blowing sand, both in the Sahara and on the north African coast, as the depression developed. It is described as rare for the equatorial air mass to reach the north coast; by implication it is less rare in the interior of the Sahara and some föhn effect over the southern mountains must be commoner than intrusion of the moist air mass itself. The cases discussed in these notes, in (i) and (vii), did not, however, involve the equatorial air mass from the Gulf of Guinea.

(ii) 56·6°C. (134°F.) was reported in Death Valley, California (37°N., 117°W.) on July 10, 1913, this being the second highest reading claimed anywhere in the world. Authenticity has been officially accepted in this and the Azizia case only after some discussion, but there is no doubt that both were extreme days. The station at Greenland Ranch, Death Valley, is 178 ft. below sea level, surrounded by deserts some thousands of feet above sea level. On July 10, 1913, a cold occlusion was passing east across the Rockies in 35°–50°N. There was anticylonic curvature in the air streams on both sides of the front and clear skies, probably with subsidence, over the deserts. It was blowing very hard on the day in question in Death Valley, the hot wind must inevitably have had its temperature further raised by adiabatic compression in the abrupt descent from the surrounding highlands.

(iii) 50·5°C. (123°F.) at Seville, Spain on August 8, 1881, is believed to be the highest temperature ever reported by a European station. 50·0°C. was also reported at Seville on July 12, 1897. In both cases it is probable that the very high temperatures occurred in air which had come from the Sahara, crossing the Atlas mountains one to two days previously between 0° and 10°E. The temperatures reported at Seville, after the air had crossed the mountains of southern Spain, were higher than the highest temperatures, 35° to 45°C., reported in northern Algeria. In both cases the air had been brought across the Atlas mountains by a shallow low-pressure system over Algeria with an extension to the west of Portugal. In the case of July 1897 there had been rainfall on the 10th and 11th at many stations in the Atlas mountains, up to 20 to 40 mm. in the day at Constantine and Géryville and at one place on the south side. It seems possible that föhn effect may be invoked, but the reported surface winds were rather erratic, as so often on the coasts of this part of the Mediterranean, and the pattern of high surface temperatures suggests that there may have been a steadier south-easterly wind at levels above about 5,000 ft. Anticyclonic curvature was probable at most levels over south Spain.

(iv) 38·0°C. (100·5°F). at Tonbridge, Kent on July 22, 1868, 75 ft. above sea level in a part of the Medway valley almost surrounded by hills, is accepted as the highest temperature so far recorded in England. The thermometers were 4 ft. above the ground in a ventilated north-east facing screen in a garden site with trees[2]. This was the culminating point of a remarkable summer in which, at Tonbridge, there were 66 days with maximum temperature over 80°F.; there had been 1 day over 90°F. in May and 8 in June; there were 9 in July, 5 in August and 2 in September. There was little thunder and "a great scarcity of rain"; drought affected vegetation and horticulture to an abnormal degree, cattle being given winter provender. The soil must have been so far dried over England and neighbouring parts of the continent that the southerly air stream of the 20th–22nd was being heated over a surface approximating to desert conditions. The synoptic situation during July was characterized by anticyclones covering a wide area of north-west Europe and occasionally linked with the Azores system. High-pressure centres were particularly frequent near Valentia, over the Scottish highlands, over the region south Norway–Zuyder Zee and south-east of Lyon. The last-named region was continuously in evidence from the 7th to the 23rd and became the dominant centre on the 18th and 19th. On the 20th cool north-westerly winds began to encroach over the north-western part of the British Isles and a more southerly air stream became general over the rest of the country, bringing still warmer air over England from the south. The anticyclone centre itself shifted north to the Channel for a time on the 20th and 21st. On the 22nd there was a ridge from a high-pressure centre near the Alps as far as central England and Holland; in this ridge subsidence must have been still occurring, the sky at Tonbridge being clear and the wind light, but cool, north-westerly winds were spreading further south over Britain and the cold front passed Tonbridge without rain on the 23rd. By the 24th a new anticyclone, 1035 mb., was centred over Fife and with a north-easterly air stream from the North Sea the maximum temperature at Tonbridge only reached 23°C. (73°F.), this being the coolest day for over a month.

(v) 37·8°C. (100°F.) at Greenwich on August 9, 1911 is the second highest accepted temperature reading in Britain. This occurred about 50 miles east of the cold front, orientated north–south of a depression between the Hebrides and Iceland. There was a wide area of warm air and light winds over central Europe south of an anticyclone over Scandinavia, but just ahead of the cold front still warmer air was drawn on an anticyclonically curved track from France and the Alps. Subsidence is suggested by the highest temperatures of the month at French mountain stations up to 2,500 m. above sea level. Prolonged warm weather beforehand was probably important in this case as in 1868.

(vi) Cairo's highest temperatures in the years examined were 47·5°C. on June 13, 1933 and 46·1°C. four days earlier, on June 9, 1933. These occurrences were with a fresh southerly wind, associated respectively with the warm and cold frontal troughs of a depression passing over the Balkans towards the north European plain. Temperatures at Cairo were appreciably higher than at desert stations before the air reached Cairo, but very high values spread as far as Palestine. There was some anticyclonic curvature of the air path. It is well known that Cairo's highest temperatures commonly occur early in the season with the southerly winds ahead of Khamsin depressions, i.e. ahead of tongues of cold air which have reached the Mediterranean.

(vii) In Malta the importance of both subsidence and advection is unmistakable. The island, 18 by 8 miles, is too small for sea breezes to be well developed except under favourable conditions: a subsidence inversion at any height between 900 and 600 mb. usually means that no sea breeze will occur, and, with little general wind, at the height of summer this condition is liable to give a hot, still day with temperatures well over 30°C. The highest temperatures in the 20-yr. period 1919–38 examined, in each case approximately 40°C. (104°F.), on July 12, 1919, July 7, 1931 and August 7, 1931, all occurred with a small anticyclone centred over the sea area of the Gulf of Sidra, 200–300 miles south-east of the island, which was experiencing a drift of air from Africa. In all three cases the advection from Africa was increasing on the day in question with the approach of a cold front or frontal trough from the west. Temperatures over 35°C. (95°F.) in Malta are commonly followed within a day or two by much cooler air from the north-west.

The summer of 1931 was of special interest both in Malta and in the central Sahara. Over Africa continual south-easterly winds from mid June to mid September brought very high temperatures, commonly 45° to 48°C., to places in the desert in south-eastern Algeria, downstream from the mountains of the Sahara. As we have mentioned, rainfall is not rare in the southern ranges near Agadèz. The position of the warmest patch shifted with the day-to-day changes in orientation of the wind stream, being always downstream from the mountain massifs. Temperatures in the Sahara in southern Algeria were much lower, about 35°C., on the days when a north-easterly air stream was between the Atlas and Ahaggar ranges, but rose to 40° to 45°C. in this area on those days which had northerly or north-westerly winds from across the Atlas range.

The very warm air was diverted as a south-westerly or southerly wind out into the central Mediterranean, bringing outstandingly high temperatures to Malta and Italy, each time a cold front penetrated across the Atlas mountains, notably about July 5–7, August 6–8, and September 11–13, 1931.

These notes appear to confirm the importance of the factors named at the outset and further suggest that very many of the peak temperatures, even in and near north Africa and the deserts of south-western United States of America are associated with the speeding up, and longer fetch, of warm air advection just ahead of a cold front. The writer was left with the further impression that in most, perhaps all, cases here examined the actual peak temperatures may have been very local and associated with some locally forced turbulence—for instance, in air descending some sort of declivity or merely passing over town buildings—the circumstances being such as to raise adiabatically by a degree or two the temperature of already very warm air at a slightly higher level.

The evidence of föhn effect in the central Sahara in air streams crossing the mountain ranges in the French Niger territory, the Ahaggar massif and the Atlas range, is of interest because it indicates that even in the central Sahara the maximum effect of solar heating is not simply and directly a measure of the intensity of the incoming radiation, but also depends to some extent upon the circulation patterns prevailing in the atmosphere. The same conclusion is implied by the considerable variations from haze to clear air reported over the desert.

REFERENCES

1. BÉRANGER, M.; Essai d'étude météorologique du bassin mediterranéen. *Mémor. Off. nat. mét. Fr., Paris*, No. 40, 1955.
2. FIELDING, G. H.; On the summer of 1868. *Proc. met. Soc., London*, 5, 1869, p. 2.

THE EVALUATION OF WINDS AT 200 MILLIBARS FROM CONTOUR CHARTS

By R. F. ZOBEL, B.Sc.

Introduction.—Both the upper air forecaster and the climatologist may frequently be confronted with the problem of the evaluation of upper winds from contour charts. In regions where a dense network of radar wind measurements is available the problem is much simplified, but where such does not exist, complete reliance must be placed on the contour gradient. This is also always the case when interpreting prognostic contours. It then becomes necessary to make a decision as to the method of interpretation of the contours that shall be adopted. In other words should one adopt geostrophic values as the best approximation to the actual wind, or should one attempt corrections for curvature of the contours and use what will be referred to as gradient wind?

In view of the uncertainty as to the answer to the above question (*vide*, for example Murray[1]) it was decided to carry out a careful comparison between measured winds and corresponding geostrophic and gradient winds as deduced from 200-millibar contour charts. This report describes the results of the comparison using 0200 G.M.T. observations for Crawley during the 12-month period December 1954 to November 1955. It is shown that, on the whole, the gradient wind gives the best approximation to actuality.

Technique for obtaining gradient winds.—The relationship expressing the difference between gradient wind and geostrophic wind, where the motion is balanced, is

$$V_g - V_o = \pm \frac{V_o^2}{\lambda r}, \qquad \ldots\ldots (1)$$

(*vide*, for example Petterssen[2]) where V_g and V_o are geostrophic and gradient winds respectively, λ is the Coriolis parameter and r the radius of curvature of the trajectory.

For the purpose of this trial the curvature of the trajectory was considered to be equal to that of the instantaneous contour at any point. The approximation was imperative, because charts were not available at week-ends and certain other times, so that it was not possible to determine trajectories on a regular basis. It may be expected, however, that the effect of the approximation would not be large at 200 millibars. For example, Petterssen[3] shows, in relation to the circulation patterns of strong winds aloft, that it is satisfactory to equate the curvature of the contour to that of the trajectory. This procedure also greatly reduces the amount of labour involved in making the gradient approximation, which is one of its greatest drawbacks.

If one is dealing solely with a single point, as in this instance, that is, Crawley it is not unduly laborious to solve equation (1), but where gradient approximations are required for a number of places having different latitudes, it has been found more convenient to construct tables, for day-to-day use. Gilbert[4] has produced tables based on a theoretical approach by Petterssen[5]. These tables may readily be adapted to suit the extra assumption that the curvatures of the trajectory and contour are equal. This is tantamount to considering the pressure systems as stationary, so that Gilbert's value of the speed of a pressure system (c) may be equated to zero. Gradient approximations for Crawley were actually deduced from tables constructed in this way, since they were already available. It has been ascertained that the method of correction adopted gives approximations to the gradient wind in close agreement with those derived by the use of the method due to Silvester[6], but it is considered that the use of tables is more expeditious.

It should be noted that no consideration was given throughout to unbalanced accelerational terms, since these cannot be evaluated from synoptic charts.

Accumulation of the data.—During the period December 1954 to November 1955 inclusive, the geostrophic wind over Crawley at 200 millibars was measured from contour charts for 0200 G.M.T. on 236 occasions. Corrections to gradient wind were made on 164 occasions and of those 101 were cases of cyclonic curvature whilst 63 were anticyclonic. The remaining 72 occasions were those on which the contours over the region of Crawley were regarded as straight. Entries of the necessary parameters were extracted from the charts and recorded daily. The actual wind as measured at Crawley was not plotted on the chart until the above entries had been made. Winds and 200-millibar heights were plotted at all other available stations. Contours were drawn with respect primarily to the height values, but the interpolation of lines between stations was assisted to some extent by the measured wind values. In this way the contours over the United Kingdom were drawn as accurately as possible, so that errors in geostrophic wind values should tend towards the minimum. This was considered to be the most useful procedure, since the results would then also be applicable to prognostic contours, which must be accepted as accurately portraying the anticipated wind field.

Results of the comparisons of geostrophic, gradient and actual winds.—Each day the vector differences in knots, between the actual wind and the geostrophic wind, as well as the difference between the actual wind and the gradient wind, were computed. At the end of the period of comparisons daily results were combined for the whole period, occasions of straight contours, anticyclonic and cyclonic curvatures being treated separately. Table I shows the number of occasions on which the departure from actuality attained given values.

TABLE I—NUMBER OF OCCASIONS ESTIMATED WINDS WITHIN GIVEN LIMITS OF VECTOR ERROR

Errors within given range	Cyclonic Geostrophic	Cyclonic Gradient	Anticyclonic Geostrophic	Anticyclonic Gradient	Straight
kt.					
0– 5	27	43	17	24	20
6–10	23	33	18	16	29
11–15	26	12	12	10	13
16–20	9	6	4	5	6
21–25	8	3	5	7	4
26–30	4	2	4	1	0
31–35	3	1	2	0	0
36–40	0	1	1	0	0
>40	1	0	0	0	0
Total occasions	101	101	63	63	72

Frequency–error curves were computed from Table I and these curves are shown at Figure 1. It is apparent that on an over-all basis, the errors associated with the estimates of gradient winds are appreciably less than these associated with the geostrophic estimates.

It was considered to be a worth-while study to ascertain if the over-all superiority of the gradient wind applied generally, or whether this superiority was confined to winds from particular directions, to certain ranges of wind speed or to certain ranges of curvature. Consequently further analysis was undertaken for this purpose.

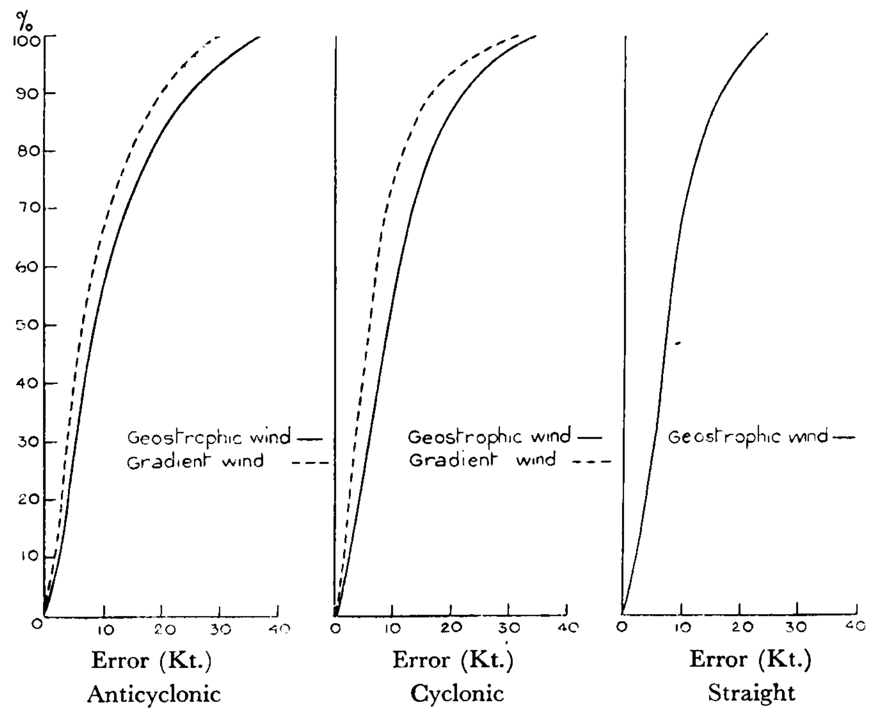


FIG. 1—FREQUENCY OF ERRORS NOT GREATER THAN GIVEN LIMIT

Relationship of geostrophic and gradient winds to radius of curvature.—The root mean square vector errors of the geostrophic and gradient winds were computed for three ranges of curvature of the contours for both cyclonic and anticyclonic occasions and these are shown in Table II.

TABLE II—ROOT MEAN SQUARE VECTOR ERRORS OF GEOSTROPHIC AND GRADIENT WINDS IN RELATION TO VARIOUS RADII OF CURVATURE OF THE CONTOURS

	Radius of curvature (nautical miles) Cyclonic				Anticyclonic				Straight contours
	⩽499	500–999	1000–3000	All	⩽499	500–999	1000–3000	All	
					knots				
Geostrophic	15	13	16	15	13	17	13	15	11
Gradient	10	10	13	11	12	14	11	12	

It is apparent that the over-all advantage of the gradient wind is maintained through all ranges of curvature whether cyclonic or anticyclonic and that the corrections applied are such as to reduce the vector errors associated with curved contours to the same order as for straight contours. It is also of interest to note that the values of 11 knots, 12 knots, and 11 knots shown respectively for all cyclonic, anticyclonic and straight contours are appreciably less than the value of 18 knots quoted by Murray[1] for the "apparent departure from geostrophic values on working charts" for the 200-millibar level. At the same time the corresponding values for geostrophic winds in Table II are, when combined (14 knots), also less than Murray's figure of 16 knots for "overall inherent technique errors". Although Murray's charts were replicas of working charts showing plotted wind data, it is believed that his figures were based on observations during a single spring month and that he included data from stations such as weather ships where the average wind is greater and the network less dense than at Crawley. Strict comparisons are not therefore possible.

Relationship of geostrophic and gradient winds to wind speed.—Table III shows root mean square vector errors for cyclonic, anticyclonic and straight contours for various ranges of measured (actual) wind speed.

TABLE III—ROOT MEAN SQUARE VECTOR ERRORS FOR VARIOUS RANGES OF MEASURED (ACTUAL) WIND SPEED

	Range of wind speeds (knots)					
	Cyclonic					
	0–19	20–39	40–59	60–79	80–99	⩾100
Geostrophic	10 (19)	13 (40)	18 (32)	17 (9)	... (0)	14 (1)
Gradient	9 (19)	9 (40)	13 (32)	18 (9)	... (0)	10 (1)
Straight	8 (17)	9 (18)	11 (19)	13 (11)	15 (4)	16 (3)
	Anticyclonic					
	0–19	20–39	40–59	60–79	80–99	⩾100
Geostrophic	11 (8)	9 (15)	12 (22)	16 (11)	21 (2)	30 (5)
Gradient	12 (8)	12 (15)	12 (22)	10 (11)	16 (2)	18 (5)
Straight	8 (17)	9 (18)	11 (19)	13 (11)	15 (4)	16 (3)

Number of occasions shown in brackets

Values for straight contours have been shown under both cyclonic and anticyclonic headings for comparative purposes. It is clear that the advantage of the gradient wind is fairly evenly spread through all ranges of speed, in cyclonic cases, whereas in anticyclonic cases it is confined to winds in excess of 60 knots. In such instances the advantage of the gradient wind is considerable. Although the analysis is unfortunately confined to eighteen cases of anticyclonic winds in excess of 60 knots, the effect is probably real, since the root mean square errors of these gradient winds are of the same order as for straight contours.

Relationship of geostrophic and gradient winds to wind direction.—A comparison of errors in relation to wind direction was felt to be likely to afford an indication of the effect of neglecting the movement of pressure systems. For example the trajectory of air on the north side of a moving depression may be considerably different from the instantaneous stream-line, so that errors in curvature are likely to occur and these may completely nullify the advantage of the gradient wind in certain wind directions. That this tends to be so is apparent from Table IV. For other than straight contours the values in the table have been plotted on polar diagrams in Figures 2 and 3 (facing p. 48). In constructing these diagrams values have been smoothed between directions and two obviously fortuitously low values, based on a small number of observations (north-north-east cyclonic and south-south-west anticyclonic) have been more or less disregarded. The diagrams indicate that for cyclonic curvatures the gradient wind is the better approximation for winds between south-east and north-north-east through west, whereas the geostrophic is a better approximation for winds from between south-east and north-north-east. For anticyclonic curvatures the gradient wind approximation is superior for all directions, except between east-north-east and east-south-east, where the geostrophic wind approximation is equally good. In both diagrams regions have been hatched where the geostrophic wind is apparently superior to the gradient.

TABLE IV—ROOT MEAN SQUARE VECTOR ERRORS OF GEOSTROPHIC AND GRADIENT WIND IN RELATION TO WIND DIRECTION

	Range of wind direction (degrees from north)							
	001–045	046–090	091–135	136–180	181–225	226–270	271–315	316–360
				knots				
Cyclonic								
Geostrophic ...	6 (7)	14 (9)	11 (1)	11 (2)	12 (19)	16 (25)	18 (25)	17 (13)
Gradient ...	3 (7)	15 (9)	13 (1)	9 (2)	9 (19)	9 (25)	15 (25)	14 (13)
Anticyclonic								
Geostrophic ...	13 (10)	12 (5)	... (0)	13 (1)	7 (4)	19 (10)	12 (21)	14 (12)
Gradient ...	11 (10)	12 (5)	... (0)	14 (1)	8 (4)	13 (10)	13 (21)	11 (12)
Straight								
	12 (12)	... (0)	8 (1)	14 (3)	7 (6)	10 (19)	10 (18)	12 (13)

Number of occasions shown in brackets

Detailed re-examination of the individual cyclonic occasions shows however that there were eleven occasions of winds from between 025 and 135 degrees. Of these, there were nine occasions when the gradient wind was more accurate than the geostrophic. One of the remaining two occasions was that shown under heading 091–135 degrees in Table IV. The other was an occasion when both the gradient and geostrophic winds were considerably in error (namely, 38 and 30 knots respectively). This probably indicates an unusually large error in chart drawing, so that the shaded area on Figure 2 may be largely spurious, being based on a small number of observations. This is supported by the fact that differences under discussion (Table IV, cyclonic) are not statistically significant. The inference is therefore, that in general the gradient approximation will be at least as accurate as the geostrophic for easterly winds, and appreciably better for winds from other directions, irrespective of curvature.

Summary of conclusions.—The comparisons indicate that:

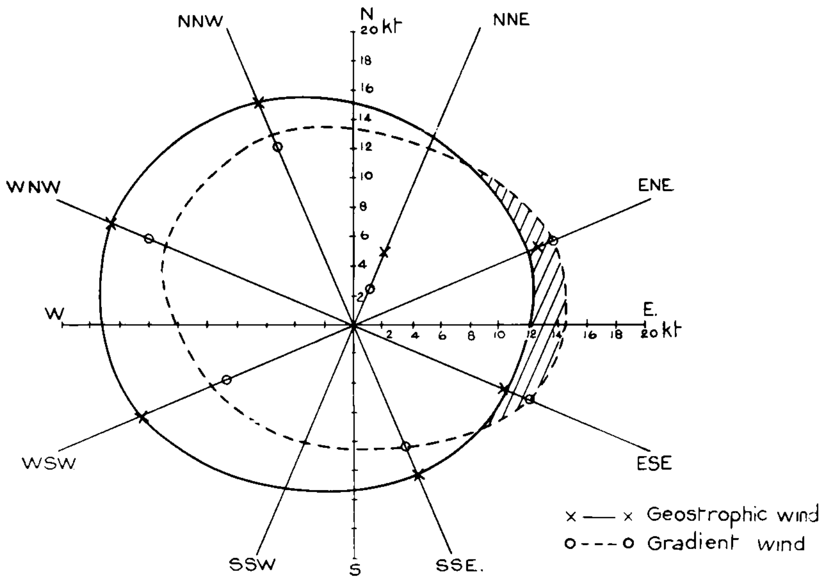
(i) There is a general over-all increase of accuracy of wind estimation from contour charts at 200 millibars when the geostrophic wind is corrected to gradient wind by means of a correction for curvature of the contours.

(ii) The increase of accuracy applies to both types and all degrees of curvature.

(iii) Accuracy is most markedly improved if the curvature is anticyclonic and the wind speed in excess of 60 knots.

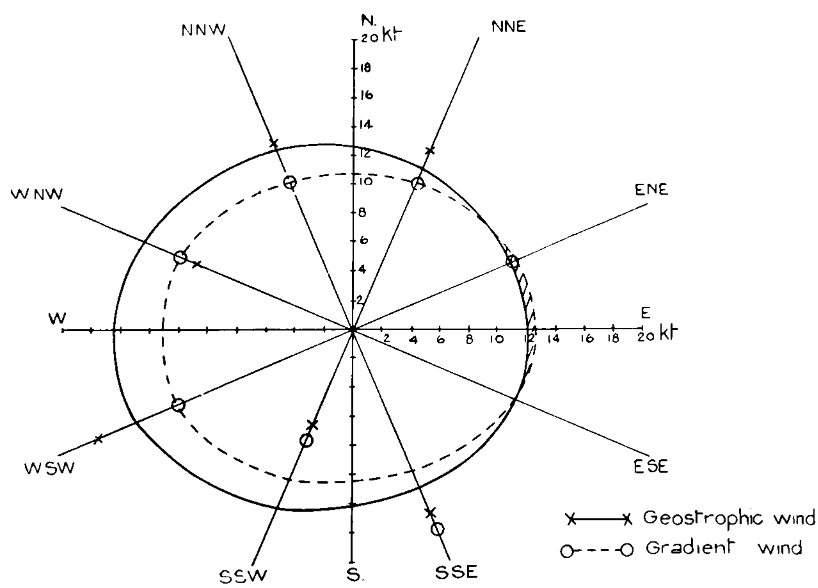
(iv) The improvement of the gradient approximation over the geostrophic is appreciable for wind direction of either curvature between south-east and north-east through west. For other directions the accuracy of both is approximately the same.

In view of the previous paragraph it is concluded that work of the highest accuracy requires that geostrophic winds derived from contour charts at 200 millibars should be corrected for the cyclostrophic term. By this means errors may be appreciably reduced.



Cyclonic

FIG. 2—ERRORS IN RELATION TO WIND DIRECTION



Anticyclonic

FIG. 3—ERRORS IN RELATION TO WIND DIRECTION

(see p. 47)

Photograph by R. Cranna

WAVE CLOUD AND VIRGA OVER GLEN AFFRIC, INVERNESS-SHIRE

The photograph was taken from Carn Loch na Gobhlaig, a hill to the north of Glen Affric, on June 1, 1955 at 1140 G.M.T. The camera was at a height of 2,000 feet and the bearing of the leading edge of cloud from the camera was south west by west. The elevation of the leading edge varied between 15° and 6°. The winds over the area at the time were of the order of 140° 30 knots.

STATIONARY STRATOCUMULUS ROLLS

We are indebted to Mr. J. Dowding of the Photographic Section at Defford, Worcestershire and Mr. H. Bird, Meterological Officer there, for a series of 96 photographs taken at 10-second intervals showing two approximately stationary cross-wind rolls of stratocumulus cloud to the west of Defford in a westerly wind. One of the photographs is reproduced above.

The photographs were taken between 1002 and 1021 G.M.T. on December 5, 1956. The surface wind was 260° 22 knots and the gradient wind 285° 35 knots. The rolls appear to be of the Helm cloud type produced by lee waves from the Welsh mountains. Conditions were favourable for the formation of lee waves as Scorer's parameter increased with height from 0·84 mi^{-1} between 1,000 and 900 millibars, to 1 mi^{-1} between 800 and 600 millibars and over 2 mi^{-1} at greater heights.

To face p. 49]

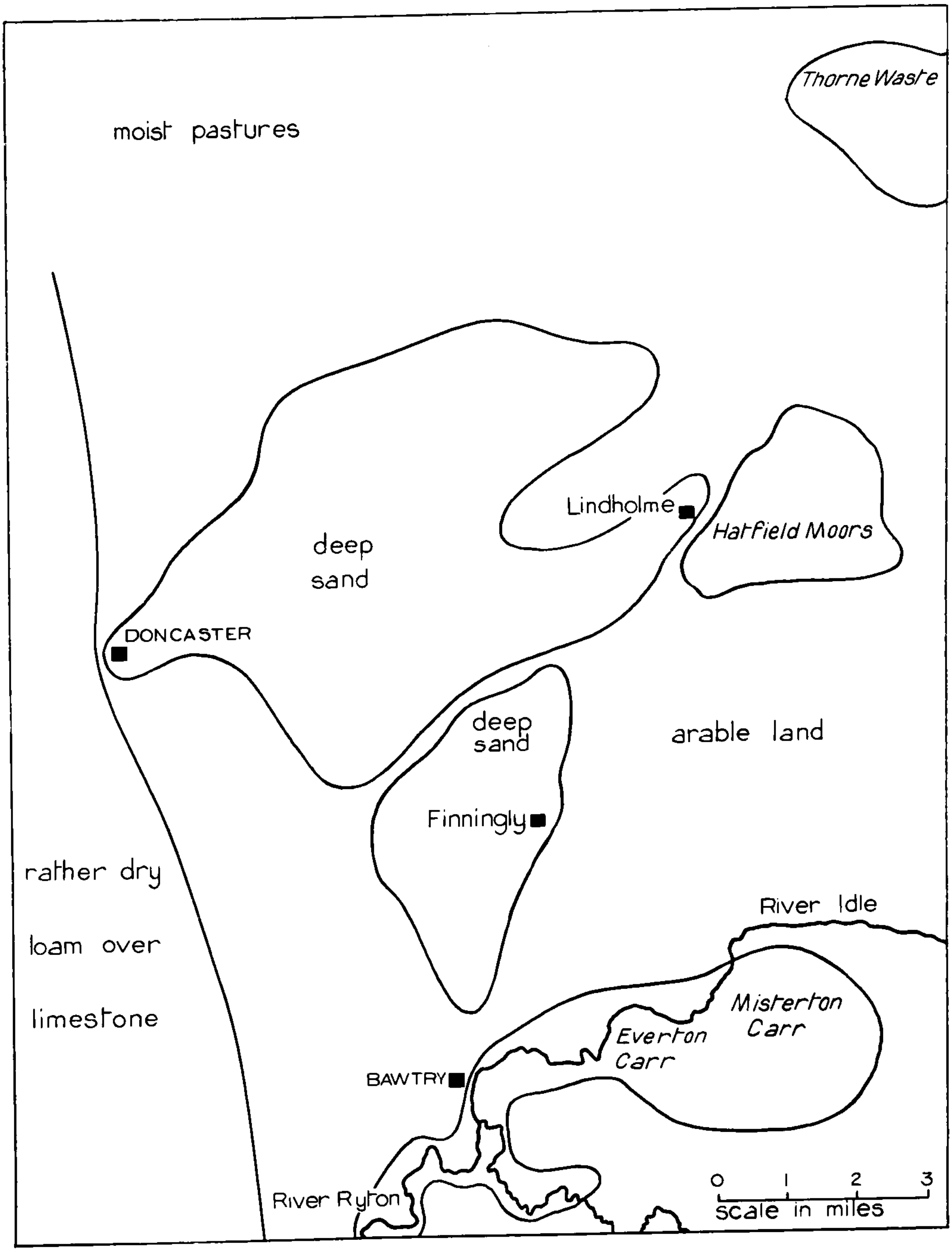


FIG. 1—SOIL TYPES IN THE AREA

(see p. 49)

Acknowledgement.—The necessary correction tables were prepared by Mr. B. G. Wales-Smith. He also made many of the day-to-day wind estimates, corrections, and determinations of individual vector errors.

REFERENCES

1. MURRAY, R.; On the accuracy of contour charts in forecasting upper winds. *Prof. Notes met. Off., London*, **7**, No. 110, 1954.
2. PETTERSSEN, S.; Weather analysis and forecasting. London, 1st edition, 1940, p. 208.
3. PETTERSSEN, S.; Weather analysis and forecasting. London, 2nd edition, 1956, Vol. I, p. 65.
4. GILBERT, G. H.; Note on graphical methods for determining the curvature correction to the geostrophic wind. S.D.T.M. No. 98. Copy available in Meteorological Office Library.
5. PETTERSSEN, S.; Computation of winds in the free atmosphere. S.D.T.M. No. 78. Copy available in Meteorological Office Library.
6. SILVESTER, R.; Method of obtaining the gradient wind from the geostrophic wind. *Met. Mag., London*, **84**, 1955, p. 348.

LETTER TO THE EDITOR

Effect of soils on the duration of high humidity

In a recent paper[1] by L. P. Smith on the duration of high relative humidities in summer, attention was drawn to the apparently higher duration at Lindholme as compared with Finningley five miles to south-south-west; Lindholme 1029 hours, Finningley an estimated value of 589 hours. To a meteorologist stationed in the area it is hard to believe that such a difference could be associated with a diminution in the effect of the Pennines at Lindholme as compared with Finningley. Finningley is 22 miles from the Pennines and Lindholme is 1 mile further east: the dry zone behind a hill would, as Smith says, have to have sharp edges indeed to produce so great a difference.

The writer has examined the humidities recorded in the summer of 1945 when both stations kept full observations throughout the 24 hours, although only 3-hourly in the case of Lindholme. The numbers of hours during which the relative humidity was 90 per cent or above during June–September, 1945, prove to be

Lindholme	924 hours
Finningley	921 hours

(based on 3-hourly observations at both stations, trebled, as are all the statistics which follow). As the prevailing wind during the period was westerly (see Table 1), it is clear that in fact the two stations benefit equally in this context from lee effects.

TABLE I—DISTRIBUTION OF SURFACE WINDS, FORCE 1 AND CALMS BEING GROUPED SEPARATELY, IN HOURS

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	Calms and force 1
Lindholme	123	129	120	123	237	369	444	342	1041
Finningley	342	138	192	186	507	402	408	276	477

The area is covered with drift soils which exhibit large and abrupt changes of type and characteristics (see Figure 1, facing). The two airfields are located on deep sand with a low capacity for moisture, and through which water drains rapidly—farmland on these islands of sand is often described locally as the "poverty acres". By contrast, immediately to east of Lindholme and also about 6 miles to north-north-east are areas of deep peat fen which are permanently saturated, even in the driest summer, and are unfit for cultivation. Additionally, there is to south and south-east of Finningley another area of deep peat, initially fen, which has been brought into cultivation by draining and warping and this also is permanently wet—chiefly because the embanked River Idle which flows through it maintains a high water table in the peat.

Although Mr. Smith[1] appears to consider that proximity to hill masses and to the sea is the only factor significantly varying the frequency of high humidity in a given air mass, he has found considerable inexplicable differences between stations in comparable locations[2], for example, Finningley and Church Fenton. It seems likely that the wet and dry areas shown in Figure 1 have some effect on the humidity régime at the two airfields. The observations of June–September, 1945, have been examined to seek some idea of its magnitude.

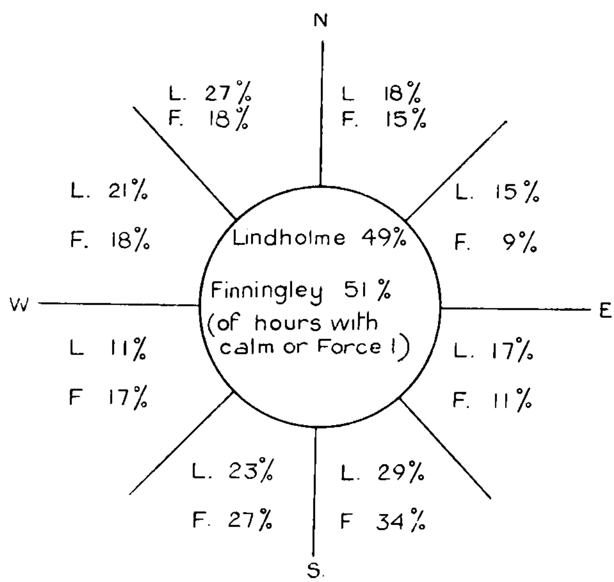


FIG. 2—FREQUENCY OF HIGH HUMIDITY, EXCLUDING OBSERVATIONS WITH RAIN OR DRIZZLE FALLING AT THE TIME, DURING JUNE–SEPTEMBER, 1945, AT LINDHOLME AND FINNINGLEY, REFERRED TO THE WIND REPORTED BY FINNINGLEY

Figure 2 has been constructed by

(i) excluding observations which were accompanied by rain or drizzle, as the effects due to transpiration and evaporation from soils are being sought,

(ii) tabulating the occasions when the relative humidity was 90 per cent or above according to the accompanying wind direction, the inner circle being utilized when the wind was calm or force 1, and

(iii) expressing these occasions as percentages of the total number, regardless of humidity, of such winds unaccompanied by precipitation. But as Table I shows that in 1945 the anemometers at Lindholme and Finningley were not equally sensitive and well exposed, and that the anemometer at Finningley was the more sensitive, the humidities reported from each airfield have throughout been referred to the wind observations from Finningley in order to avoid distortion of the statistics, and to facilitate comparison.

In drawing the following conclusions from Figure 2, it should be borne in mind that the rainfall during the period under consideration was 85 per cent of the normal value of 6·5 inches:

(i) Diurnal cooling results in high humidity at both airfields during 50 per cent of the periods of light winds, from June to September.

(ii) The driest winds were from NE. to SE., despite their track over the North Sea: this conflicts with Mr. Smith's findings[2]. But Lindholme was appreciably damper than Finningley, the air having passed over Hatfield Moor.

(iii) NW. to SW. winds were also dry after crossing the Pennines, but W. to SW. winds were much drier at Lindholme than at Finningley, the air having passed over some six miles of dry sand.

(iv) The most moist winds were from SE. to SW.: this is not surprising as they would have been mainly with subtropical air masses approaching from S. to WSW., but it again conflicts with Mr. Smith[2]. It is interesting to note the extremely high value of 34 per cent at Finningley after the air has passed over the fen-like "carrs" alongside the River Idle.

(v) With winds from NW. to N. there is a substantial drying out at Finningley, as compared with Lindholme, after the air has passed over some seven miles of dry sand.

It is considered that the statistics above demonstrate that the characteristics of the soils, in this area at least, substantially modify the frequency of high humidities which may be expected in an air mass, and that the order of magnitude of the modification is comparable with that due to hill masses. This may well be the cause of the anomalies mentioned by Mr. Smith[2].

A. M. YOUNG

Royal Air Force, Bawtry, Yorkshire, 8 March 1957.

[Mr. J. Findlater has independently drawn attention to the possible effect of the marshland near Lindholme on the relative humidity at that place. —Ed. *M.M.*]

Reply by L. P. Smith

I am very pleased that Mr. Young has found an explanation for these local differences. Clearly, the effect of the surrounding vegetation would be greatest at the end of a dry summer. It would be interesting to know whether the difference in relative humidity is due to a change in temperature or a change in water vapour content—presumably both? The agricultural branch of the Meteorological Office are at present examining the hourly humidities from 30 stations in the north-west Midlands during the years 1942–46, and it is to be hoped that similar results will be found.—L. P. SMITH.

REFERENCES

1. SMITH, L. P.; Duration of high relative humidities. *Met. Mag., London,* **85**, 1956, p. 229.
2. SMITH, L. P.; Humidities in the lee of hill masses. *Met. Mag., London,* **83**, 1954, p. 1.

METEOROLOGICAL OFFICE DISCUSSION

Fog forecasting

The discussion held at the Royal Society of Arts on Monday, 21 October 1957, was opened by Mr. W. E. Saunders and Mr. R. J. Ogden.

Mr. Saunders dealt with forecasting the onset of water fog, the rate of decrease of visibility once fog has formed, and the clearance of fog. Purely theoretical approaches to the problems could be made, but led to equations which were cumbersome for ordinary use and which contained constants which were difficult to determine. Our methods were therefore based as far as possible on the known physics, but we used quantities which were known or measured. Experiments by L. P. Smith[1] comparing different specimens of the thermometers in use at outstations had suggested we might not be able to obtain forecast errors of less than about 1°F. Mr. Saunders then described various methods which had been evolved in this country during and since World War II. With regard to the method due to W. C. Swinbank[2], he was not aware of any wide testing, but it seemed it might make insufficient allowance for the actual water vapour content of the air. A more popular approach had been that of forecasting the fog point and night cooling by separate methods. After explaining the reasons for careful definition of the fog point, Mr. Saunders suggested it should be "the screen level temperature at which the general visibility falls within the fog range with relative humidity 95 per cent or more, or at which, with visibility already in the fog range, the relative humidity rises to 95 per cent or more". A slide was shown illustrating that the fog point is an air-mass property, nearly the same from place to place over large areas. Details were then given of the condensation level method[3] for forecasting the fog point, which Mr. Saunders said had been developed from an earlier method proposed by Briggs[4]. Details were given of the main results of a test of the condensation level method[5,6] carried out at 63 United Kingdom airfields in 1956. 28 stations had obtained mean forecast errors of not more than 1°F., and at 48 stations it did not exceed 2°F. The frequency of various errors at these 48 stations showed that 1°F. was not exceeded on 67 per cent of the nights, while one could expect errors of not more than 2°F. 87 per cent of the time. Variation with temperature showed that errors increased slowly with decreasing temperature below 32°F. State of ground is important—errors over both frozen and snow covered ground were nearly twice as great as over dry or wet soil. Rainfall in the afternoon caused some decrease in accuracy. Turning to forecasting methods for night cooling, Mr. Saunders described McKenzie's[7] method, and an adaptation of this type of method by J. M. Craddock and D. Pritchard[8] for forecasting the night minimum over a large area. This latter approach had led to mean square errors of 3·4°F. when applied to the records for 25 stations. K. Pollard[9] had shown that the McKenzie method could be applied to Wittering, with seasonal constants, giving a mean square error of 2·15°F. Mr. Saunders thought all these methods might omit some significant parameters. He spoke next of the method[10,11] based on the evening temperature discontinuity near the ground. It was stressed that this change in rate is very pronounced at the grass level. At Exeter, for 46 clear sky and light wind evenings in 1954, the average grass level change of rate was from 7·2 to 0·2°F. an hour. There could be no doubt that a major change takes place at that time in the conditions promoting cooling near the ground, and that we should treat the screen level cooling before and after this time by different methods. The annual variation of the time of discontinuity was illustrated by a diagram produced by W. J. Bruce[12] for Wahn, Germany. The screen level temperature (T_r) of the change of rate is given by a regression equation in the form $T_r = \frac{1}{2} (T_{max} + T_d) + C$, where the constant C varies according as there is or is not a subsidence inversion near the ground, and also varies slightly from place to place. Details given for five airfields showed that in general this method gives T_r within one degree. In our treatment of the subsequent cooling (that is after the change of rate) account was taken of soil characteristics by preparing individual sets of curves for each station. For the light wind cases we regarded the temperature itself as the main parameter, by plotting T_r againt T_{min}. The resulting curves were then used for forecasting T_{min} from the forecast value of T_r. This approach takes account[13-16] of three physical facts—the decrease in the net outgoing radiation with decreasing temperature (2½ per cent per °C.), the latent heat difference between dew and hoar frost, and the additional latent heat release which commences as soon as freezing of the soil moisture begins. The importance of these factors was brought out strongly by the Exeter T_r — T_{min} curves for winter. The curvature of these showed that if T_r is 50°F. the amount of subsequent cooling is 16 degrees; if T_r is 40°F. it is reduced to 14 degrees; if T_r is 30°F. it is only 10 degrees. These curves did not allow for snow cover—this had been investigated for Alston, Cumberland, by W. E. Richardson[17]. Corrections for cloud cover were given in a paper by W. D. Summersby[18]. Tests of this method had given mean square errors of 1·28 at Northolt, and 1·4°F. at Weston Zoyland (using Exeter curves). In all these methods the accuracy depends, of course, on accurate cloud and wind speed forecasts. Turning to the rate of decrease of visibility in fog, Mr. Saunders said one result of Dr. Stewart's[19] analysis of Cardington data had been that in water fog there is an abrupt change from visibility above 1500 yards to 50 to 200 yards. This was largely borne out by general experience. At Exeter he had found[20] visibility had fallen to 550 yards or less within one hour of fog formation in 96 cases out of 112. The present position seemed to be that one had to forecast visibility falling into the lower part of the fog range from the time fog was expected to form. Two circumstances which aid a rapid fall of visibility are a short land track of the air mass and a wet ground. Regarding fog clearance, Mr. Saunders drew attention to the fact that on 40 nights out of 50 at Exeter water fog had cleared soon after the arrival of a sheet of cloud over the fog during the night. The cloud was not due to lifting of the fog. The significant temperature change was a marked rise at the grass level after the arrival of the cloud. The figures given were not the complete picture, because the fog had to be thin enough vertically for the arrival of the cloud to be observed. This probably meant that every case in which the depth of fog had exceeded about 300 feet had been omitted. Going on to the diurnal clearance of water fog, Mr. Saunders gave details of G. J. Jefferson's[21] method. This gave good results, but there were difficulties associated with the lack of reports of the depth of fog. Mr. Saunders then showed a diagram in which the time interval between sunrise and fog clearance was plotted against the date. The cases were separated according as the sky was or was not reported as obscured at 0600, as some criterion of the vertical thickness. This gave a reasonable separation, and the resulting curves could be used to forecast clearance times within one hour in a large proportion of cases from March to early November. In winter it had to be faced that fog which was initially thick would not clear at all through diurnal heating, and clearance could only be forecast when some general synoptic change could be foreseen. Mr. Saunders thought further progress in this field would depend on methods being developed for measuring the depth of fog at airfields.

Mr. Ogden spoke of the problem of forecasting visibility in smoke.

Visibilities of less than 200 yards had been observed with low relative humidities at Northolt[22] and at London Airport, and no doubt other airfields had similar troubles.

Dealing first with the smoke itself, Mr. Ogden described some results of the Leicester Report based on 1937–1939 data[23]. This showed that smoke which causes visibility reductions is partly industrial and partly domestic in origin. The larger particles, due to incomplete combustion, were more important than the smaller combustion nuclei[24,25]. In 1925 it had been found that over two-thirds of London smoke was due to domestic fires [26] and a similar result emerged at Leicester. These figures do not depend entirely upon the amount of coal burned; in the Leicester suburbs about twice as much smoke was produced per ton of coal burnt as in the city centre because of the inefficiency of the domestic grate, particularly after it has just been lit. Over the country as a whole, about one-third of the coal was used domestically, so that about half the smoke was of domestic origin. These figures are all pre-war, and one can only guess at the extent to which recent efforts to reduce industrial smoke and to use smokeless fuel domestically may have been offset by the post-war spate of house building.

Dealing with the seasonal variation of smoke, Mr. Ogden said the curve of mean monthly concentration showed a maximum in December and a minimum in June to July. The year could conveniently be divided into winter (November to March) and summer (May to September) with April and October as intermediate months in which artificial heating is in partial use. The winter: summer ratio of mean monthly smoke concentration at stations a few miles from a town centre is about 2 : 1 and of maximum monthly concentration to minimum about 3 : 1. This accords with general experience of smoke visibility troubles.

In addition to the yearly cycle of smoke pollution there is a weekly cycle due to human habits. At weekends industrial smoke is curtailed particularly in the city centre, but in the suburbs the Sunday to weekday ratio of smoke is about 8 : 10. Figures comparable with this latter reduction have been published for the visibility at Finningley [27]. However, in a purely domestic area, more smoke might be produced on Sundays than on weekdays; this was borne out in a report on Seattle, Washington [28]. Introduction of a five-day week suggests that Saturday will be different from other weekdays.

Turning to diurnal variations, Mr. Ogden said there was a pronounced smoke maximum at about 0800 and a minimum at 0100 to 0500, with a secondary maximum at about 1800 and a secondary minimum in the early afternoon. This cycle is caused by diurnal variations of insolation and smoke emission. The diurnal variations of the amount of smoke and the amount of sulphur dioxide in the air were then shown in graphical form [23]. It is normally assumed that the amount of sulphur dioxide present is proportional to the weight of coal burnt. The curves for smoke and sulphur dioxide were in close agreement for most of the day, but there was excessive smoke between about 0600 to 0700 and 0900 to 1000 on weekdays. This is due to freshly lighted domestic fires which are the prime cause of the morning smoke maximum, but the absence of excessive smoke in the evening indicates that the evening smoke maximum is attributable to meteorological causes. A separate analysis of Sundays indicated rather smaller total amounts of smoke; the morning smoke maximum was at about 1000 and smoke was excessive even until 1500 but there was a very great reduction over amounts on weekdays between 0600 and 0800.

Turning next to meteorological factors affecting the daily smoke cycle, Mr. Ogden said that of the various movements of smoke once it had left the chimneys, the important ones were its translation down wind and vertical diffusion. This latter is controlled by turbulence, which for forecasting purposes is probably best dealt with through wind speed and vertical stability. With constant gradient wind there is a turbulence cycle corresponding with the insolation cycle. The late afternoon temperature fall increases the stability near the ground, and accounts for the evening visibility deterioration. The presence of an inversion at a low level but not on the ground will also inhibit upward smoke diffusion and could lead to unusually heavy smoke concentrations which might not have been expected if only suface conditions had been considered and this case requires special care[24].

As to the dependence of smoke concentration on position relative to source, the Leicester Report showed that between about 4 and 10 miles from the city centre the concentration decreased inversely as the distance; beyond about 10 miles, the rate of decrease follows an inverse square law. Clearly, the likelihood of smoke being thick enough to produce fog decreases rapidly down wind. The surface wind direction is a critical factor in visibility forecasting but the air trajectory becomes important in cases of very light wind, when smoke may be brought to an airfield from an unusual direction. Apart from position relative to smoke sources there may be special features about the position of an airfield which affect the smoke concentration there; valley sites for example, experience higher concentrations than open country, particularly if an inversion exists below the valley top[24].

The main factors which have a direct bearing on the amount of smoke at a particular station may be summed up as follows:

(i) the amount of smoke emitted, depending on the season, day of week and time of day,

(ii) the position of the station relative to smoke sources and topography,

(iii) the wind direction,

(iv) the turbulence, depending on wind speed and stability and the thickness of the turbulent layer.

It follows from consideration of these that random variations in visibility in smoke are due primarily to wind direction and turbulence.

Hence the best approach to smoke visibility forecasting seems to be a statistical one in which the parameters are wind direction, wind speed and stability near the surface, together with the depth of the turbulent layer in cases of turbulent flow beneath a low inversion. Such an approach does not seem to have been tried for smoke only although it has been tried for general visibility at La Guardia[29]. It only achieved marginal success there, but the method might give better results if applied to cases of smoke visibilities only. In the absence of statistics, the forecaster must fall back on experience, but it was stressed that this must be backed by a thorough understanding of the underlying physical processes. The exact times at which visibility deteriorations occur must be to some extent a function of the station itself since the smoke which causes deteriorations has to travel from the source to the station; this will affect particularly the times of the morning smoke maximum whereas the time of the evening maximum, being dependent on the insolation cycle will be fairly closely related to sunset at all stations. One difficulty about a statistical approach is that this calls for observations over long periods, but that over such periods we have secular changes. This is particularly true of smoke emission. Reference was made to changes as evidenced by observations in London[30] and Los Angeles[31] and a very striking example from Atalanta, Georgia[32] was cited. Hence statistical methods will have to be applied with great care, but it was thought that a selection of suitable periods for study should be possible.

Opening the general discussion, the *Director-General* said the theoretical formulae were useful for showing what is relevant, rather than for daily use. He asked the reason for the use of the expression given for the temperature of the evening discontinuity (T_r). Mr. Saunders said the change of rate was believed to mark the commencement of condensation at ground level. The expression seemed a suitable hygrometric one to begin with, and it had been retained because of the satisfactory results obtained with it at a number of outstations.

Mr. Evans showed slides giving the mean variation of frequency of visibility less than 220 yards, and of visibility 220 to 1100 yards at London Airport, and also the relation of fog to the day of week.

Mr. Veryard thought fog clearance due to the arrival of a cloud sheet should be predictable from earth temperatures. He asked if the theoretical equations could be used if we had adequate observations. Mr. Saunders agreed with the first point. He thought we might do better with a more comprehensive observational programme. The methods he had outlined were an attempt to make the best use of the present instrumentation and observing programme.

Mr. H. H. Lamb spoke of fog clearance. He thought night clearances under a cloud sheet might really be due to wind. He referred to an unpublished method for forecasting diurnal clearance of fog at Shannon, which seemed rather similar to the method outlined by Mr. Saunders. He had also noted cases of fog clearing under clear skies during the night, which might have been due to subsidence. In reply to the first point mentioned, Mr. Saunders stressed that cases of freshening wind had been carefully excluded.

Mr. F. Davies said that use of a thermogram on the ground had stressed the magnitude of the changes at that level.

The *Director-General* asked why it was so often forecast that fog would be slow to clear from industrial areas. The amount of radiation cut off is very small. Mr. Gold thought it might be that evaporation from droplets containing pollution may be less than from clean water particles. He asked if we had any observations of the sizes of the particles. Mr. Ogden replied that laboratory experiments in the U.S.A. had shown that increasing the pollution content of a water fog delayed its clearance and that this effect was most marked if the pollution was caused by incomplete combustion products such as are produced by a domestic grate[24]. In reply to Mr. Gold he said that he had no information about the sizes of the water droplets in a polluted fog.

Mr. Gifford spoke of the good results obtained with the Exeter cooling curves.

On occasions when the forecast night minimum for Exeter failed because of an inaccurate forecast of cloud amount or wind speed, it could often be seen that the anticipated night minimum did in fact occur at other stations where the cloud and wind conditions had been as expected for Exeter.

Mr. May said that fog persists longer in industrial districts because of insufficient wind to clear the smoke. Mr. Ogden replied that this was often so; the dispersal of a water fog as evidenced by a drop in relative humidity frequently left the visibility unchanged or even reduced due to a simultaneous increase in smoke concentration.

Dr. Stagg asked if there could be an examination of occasions of widespread fog on a synoptic scale. He thought we should study the broad factors first, before coming down to the local methods.

Mr. Sawyer said failures of forecasts of widespread fog were due to failure to forecast cloud amounts and winds accurately enough. He queried the statement by Mr. Evans that if thick fog had not formed by midnight it was then unlikely. Mr. Evans admitted that there were a few occasions when a clearance in the middle of the night due to synoptic reasons were balanced by occasions when fog developed late in the night, but felt that the majority of cases supported his statement.

Dr. Sutcliffe said fog point was an air-mass property. The use of upper air temperatures to find the fog point was in fact a generalized method, as required by Dr. Stagg. He did not think it would be a useful approach to try to produce generalized cooling curves. With regard to the delay in the clearance of smoke fog, it was due to the fact that solid particles do not evaporate.

Dr. Stewart spoke of observations of fog droplets at Kew. There were large droplets of size 20μ, and small ones of less than 10μ. Each contributed half to the opacity. After dawn the large drops evaporated first. Smoke alone cannot account for the observed visibilities. The Director-General asked if atmospheric pollution causes fogs to be more frequent. Dr. Stewart had the impression it does, but he was not sure.

Mr. Veryard asked what was the relation between fog densities in town and country. Mr. Craddock said there was always some pollution in this country, and local factors are vital. Mr. Unwin spoke of cases where fog built downwards from a smoke layer over the airfield at Catterick.

Mr. Imrie mentioned the case where, with forecast fog point below freezing, no fog formed during the night as temperature fell through the fog point, but fog did form when the fog point was reached on rising temperature after sunrise. Mr. Saunders recalled cases of this type at Northolt. It was difficult to sort out causes and effects there, because it happened about 0800 hours, which was the time of the morning smoke maximum. It was a point which could be better investigated at a rural airfield.

Mr. Bradbury spoke of the critical nature of wind direction for smoke fog. Mr. Ogden said that was certainly borne out at London Airport.

Mr. Wallington spoke of the additional parameters included in the methods discussed. One reason for the usefulness of the expression adopted for T_r might be that it gave a value very near the wet bulb temperature. He asked if there was any definition of the fog dispersal temperature. Replying to the last point, Mr. Saunders suggested it should be the surface temperature given on the tephigram by the dry adiabatic through the top of the fog layer.

Closing the Discussion, the *Director-General* recalled an occasion when on receipt of a forecast of fog in the evening a transatlantic liner berthed and discharged at once instead of waiting until the following morning, when much delay and inconvenience would have been caused. It was an example of the usefulness of fog forecasts.

REFERENCES

1. SMITH, L. P.; Random errors in standard observations. *Met. Mag., London*, **80**, 1951, p. 236.
2. SWINBANK, W. C.; Prediction diagrams for radiation fog. *Prof. Notes met. Off., London*, **6**, No. 100, 1949.
3. SAUNDERS, W. E.; Method of forecasting the temperature of fog formation. *Met. Mag., London*, **79**, 1950, p. 213.
4. BRIGGS, J.; Notes on the temperature at which radiation fog forms. *Met. Mag., London*, **79**, 1950, p. 343.
5. CORBY, G. A. and SAUNDERS, W. E.; Water fog point—a further test. *Met. Mag., London*, **81**, 1952, p. 225.
6. SAUNDERS, W. E.; Water fog point—a further test. (Unpublished).
7. MCKENZIE, F/O.; A method of estimating night minimum temperatures. S.D.T.M. No. 68. Unpublished. Copy available in Meteorological Office Library.
8. CRADDOCK, J. M. and PRITCHARD, D.; Forecasting the formation of radiation fog—a preliminary approach. *Met. Res. Pap., London*, No. 624, 1951.
9. POLLARD, K.; A preliminary study of night cooling under clear skies at Wittering. *Met. Mag., London*, **87**, 1958, p. 12.
10. SAUNDERS, W. E.; Night cooling under clear skies. *Quart. J. R. met. Soc., London*, **75**, 1949, p. 154.
11. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 603.
12. BRUCE, W. J.; Night cooling curves for Wahn, Germany. *Met. Mag., London*, **84**, 1955, p. 105.
13. PARRY, T. H.; Night cooling under clear skies at Shawbury. *Met. Mag., London*, **82**, 1953, p. 368.
14. SAUNDERS, W. E.; Night cooling under clear skies at Exeter Airport. *Met. Mag., London*, **83**, 1954, p. 9.
15. ROBERTS, E. D.; Night cooling under clear skies at Mildenhall. *Met. Mag., London*, **84**, 1955, p. 48.
16. SAUNDERS, W. E.; Night cooling under clear skies at a coastal station. *Met. Mag., London*, **84**, 1955, p. 76.
17. RICHARDSON, W. E.; Night cooling under clear skies at high level stations in Cumberland. *Met. Mag., London*, **84**, 1955, p. 301.
18. SUMMERSBY, W. D.; Night cooling under cloudy skies. *Met. Mag., London*, **82**, 1953, p. 210.
19. STEWART, K. H.; Radiation fog. Investigations at Cardington, 1951–1954. *Met. Res. Pap., London*, No. 912, 1955.
20. SAUNDERS, W. E.; Variation of visibility in fog at Exeter Airport, and the time of fog dispersal. *Met. Res. Pap., London*, No. 971, 1956.
21. JEFFERSON, G. J.; Method for forecasting the time of clearance of radiation fog or low stratus. *Met. Mag., London*, **79**, 1950, p. 102.
22. SAUNDERS, W. E. and SUMMERSBY, W. D.; Fog at Northolt Airport. *Met. Mag., London*, **80**, 1951, p. 255.
23. London, Atmospheric Pollution Research Committee. Atmospheric pollution in Leicester, *Tech. Paper Atmos. Pollut. Research, London*, No. 1, 1945.
24. Air Pollution. Proceedings of the United States Technical Conference on air pollution, 1950. Papers and Discussion of the Meteorology Panel, 1952.
25. London, Meteorological Office. Meteorological Office Discussion. Diurnal and seasonal variation in visibility. *Met. Mag., London*, **81**, 1952, p. 174.
26. SHAW, N. and OWENS, J. S.; The smoke problem of great cities. London, 1925, p. 131.
27. RATCLIFFE, R. A. S.; Differences in visibility between a weekday and Sunday near to an industrial area. *Met. Mag., London*, **82**, 1953, p. 372.
28. CHURCH, P. E.; Some new developments in micrometeorological studies of the atmosphere. Second National Air Pollution Symposium, Pasadena, 1952.
29. MILLER, J. E. and MANTIS, H. T.; An objective method of forecasting visibilities. *Bull. Amer. met. Soc., Lancaster, Pa.*, **29**, 1948, p. 237.
30. MARSHALL, W. A. L.; A century of London weather. London, 1952, p. 42.
31. NEIBURGER, M.; Visibility trend in Los Angeles. Los Angeles, 1955.
32. BLOODWORTH, S. H.; The decreasing importance of smoke in reducing visibilities at Atalanta, Georgia. *Bull. Amer. met. Soc., Milton, Mass.*, **34**, 1953, p. 78.

NOTES AND NEWS

Courses of training for climatological observers

Two courses, each lasting $4\frac{1}{2}$ days, were held in October 1957, at the Meteorological Office Training School, Stanmore. 45 observers attended, the largest number in recent years.

Instruction and discussions covered all aspects of weather observing and recording. Films and slides were shown, and talks given on some of the applications of climatological data. Special attention was paid to the work at Crop Weather and Health Resort Stations. The observers were introduced to the new forms for climatological returns which it is proposed to bring into use in 1959 to facilitate the punching of the data from climatological stations on to Hollerith cards. Visits were made to the London Forecast Office and also to Harrow where the work of the British Climatological Branch, the recording of data on punched cards in the Marine Branch, and the testing of instruments were seen and discussed. The courses are designed to help the observers with their specific work, to broaden their interest in meteorology, and to give them an insight into the ultimate value of the observations. It is hoped to arrange similar courses in October 1958.

REVIEWS

Physics in Meteorology, By A. C. Best, O.B.E., D.Sc., 8 in. × 5 in., pp. viii + 159, *illus.*, Sir Isaac Pitman and Sons Ltd., London, 1957. Price: 18*s*.

Physics in Meteorology by Dr. A. C. Best is a recent addition to Pitman's "Applied Physics Series". The book has the purpose of "describing and explaining a selection of meteorological phenomena in terms familiar to the student of physics". A book which has this purpose has long been needed and in general the book satisfies the need. The chapter headings indicate the topics dealt with and are (i) meteorological instruments, (ii) the microphysics of cloud, precipitation and fog, (iii) radiation, (iv) atmospheric electricity, (v) wind, (vi) meteorological optics and acoustics, (vii) radio meteorology, and (viii) weather control. The order of the chapters is probably related to the author's interests, otherwise for example winds would ordinarily take precedence over atmospheric electricity. The chapters are, in general, independent reviews of the various subjects and their small relations to each other, and indeed often between different parts of each chapter demonstrate what a loosely knit subject meteorology is and how it must incorporate widely different fields of physics within itself.

For a book which covers such a wide range of topics the standard is high. In reading some chapters one gets the impression that the author has drawn heavily on standard texts or monographs, especially in fields where he is not himself an authority. This dependence is generally implied in the short but useful bibliography at the end of each paragraph.

The first chapter, on meteorological instruments, demonstrates most clearly the book's main defect. This is that too much has been attempted in too little space, and this chapter degenerates into a list of meteorological measurements rather than the account of meteorological instruments which the chapter heading suggests. One could make some detailed criticism of the chapter, but having regard to its condensed nature this might not be fair.

The second chapter on the microphysics of cloud, precipitation and fog, both by its position in the book and by its quality show Dr. Best's interest in this subject, but the next, on radiation, is not so up to date. Indeed, this chapter contains little of the advances which have been made in this subject since 1939. Since no review of more recent work written at the undergraduate level and making clear the physical processes involved has been made by anyone, Dr. Best is perhaps wise to treat the subject in the way he does.

Atmospheric electricity is well reviewed and the salient features are well brought out, but in chapter (v), the difficult but important topic of air movement is disposed of in only 13 pages. Meteorological optics and acoustics and radio meteorology are dealt with in a balanced way.

The final chapter on weather control is especially welcome. It is well done and strongly recommended.

To repeat, the main defect of the book is that too much is attempted and it is usually condensed and abridged too much. Perhaps the book ought to be reviewed by a student, rather than a teacher, because it is possible that condensation has been carried to the point where a student's interest is not held. There is so much in the book that serious omissions are rare; but surely it should have contained something about vertical stability and lapse rates? There is a short index in which, believe it or not, the word "latent heat" does not appear; does latent heat play so small a part in the physics of meteorology? The production of the book is good, but for its size, the price is high.

A. W. BREWER

Hygrometry. By H. Spencer-Gregory and E. Rourke. $8\frac{1}{2}$ in. $\times$ $5\frac{1}{2}$ in., pp. xv + 254, *illus.*, Crosby Lockwood, 26 Old Brompton Road, London, S.W.7. 1957. Price: 36*s.*

It was a shock to learn of the recent death of Dr. H. Spencer-Gregory and it has made this review harder to write.

The authors, who begin by dismissing the measurement of humidity in meteorology as "of little significance", claim to "examine the scientific principles involved in every known type of hygrometer". In point of fact several well known and important types of hygrometer are not even mentioned, the most striking omission being the infra-red absorption hygrometer. On the other hand the examination of the scientific principles of those instruments which do find a place is sometimes seriously misleading—notably so in the case of the dew-point hygrometer. It is deduced that, with all normal dew- or frost-point hygrometers, "errors (of vapour pressure) of as much as 25 per cent are to be expected". This result depends on an assumption that there is no movement of air near the cold surface other than molecular diffusion. No justification is given for this assumption; in every dew-point hygrometer known to the present reviewer it is certainly not true.

The treatment throughout is theoretical, not practical, and the mathematical argument can often not be followed in detail without a fairly wide physical background—including, for example, such things as "Pollitzer's quantum relation for this specific heat of ice".

The style in which this book is written is best illustrated by two examples: "Polarization effects are eliminated by virtue of the use of A.C. practice" and

"At temperatures below 190° abs. an effect has been noticed in the case where the thimble surface was cooled down to about 160° abs. relevant to moist air whose frost point was about 194° abs."

R. FRITH

METEOROLOGICAL OFFICE NEWS

Sports Activities.—*Athletics.*—In the Air Ministry Cross Country championship held at Epsom on November 30, 1957, the first and third places were gained by Messrs. R. A. Stratton and M. K. Garrod respectively. The team race was won by the Meteorological Office.

Corrigendum.—In the October 1957 number under *Academic successes* D. E. Lantry should read D. E. Langley.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Air flow over mountains. By G. A. Corby, B.Sc.

A brief survey is first given of the observational evidence regarding special air-flow effects in the neighbourhood of mountains, as provided by the visual evidence of clouds, the experiences of glider pilots and effects noted by the pilots of powered aircraft. In the discussion of theoretical work, mathematics has been avoided so far as possible, the emphasis being on the interpretation and implications of theory. The application of this knowledge to aviation forecasting is considered in some detail with the aid of numerous actual examples of the experiences of pilots in flying over mountainous terrain. Advice is given on the recognition of air streams favouring the occurrence of waves to the lee of mountains and, to the extent that the present state of knowledge permits, on the prediction of the characteristics of any such waves. The effect of mountains in generating turbulence and in modifying the liability to aircraft icing is also considered. In the final section, some further information, which is intended specifically to assist pilots, is given.

Some typical weather maps.

For many years the Meteorological Office has published a pamphlet called *Examples of weather maps*, which, effectively, is an extract from the *Weather map*. The pamphlet has proved valuable to schools and other institutions concerned with the teaching of meteorology, since it conveniently displays some typical examples of barometric distributions.

A new edition of *Examples of weather maps* under a new title *Some typical weather maps* has now been produced to meet the continuing demand. It incorporates the latest developments in meteorological practice and provides an excellent handbook in miniature to the student beginning his studies in synoptic meteorology. Coding and plotting are briefly described and salient points in the weather maps noted.

WEATHER OF DECEMBER 1957

Great Britain and Northern Ireland

In the British Isles December began with five days of fine, generally quiet, weather followed by an equal number of wet, stormy days. Thereafter a rather dull period with cool north-easterly winds was gradually replaced, between the 15th and 17th, by a south-westerly régime with changeable weather which dominated the second half of the month.

It was sunny in many places from the 1st to the 5th with widespread frost and fog during the early mornings. Air temperature fell to 19°F. at Birmingham on the 2nd, and on the 4th and 5th fog persisted throughout the day over much of the Midlands and southern England and became especially dense around London. In these foggy areas temperature remained about the freezing point all day—at Ross-on-Wye it did not rise above 29°F. On the 6th milder air accompanied by rain spread over the country from the north-west, clearing the fog, and that night, in sharp contrast to recent low temperatures, temperature at many places in southern England did not fall below 50°F. Vigorous depressions moved eastwards across Scotland on the 7th and 8th giving gales in all parts of the British Isles with gusts of 60 knots as far south as the Cornish coast. Rain was widespread and locally heavy; both Stornoway and Aberdeen recorded about $1\frac{1}{2}$ inches in 24 hours. On the 11th an intense and complex depression was situated to the west of the British Isles, and small depressions formed on an associated occlusion as it moved slowly across the country. Gales were again widespread and rain heavy in places. Wind rose to 70 knots at Plymouth and during the afternoon a minor tornado, with violent winds, moved north-east to Devonport. At Scilly $1\frac{1}{2}$ inches of rain fell between 0900 and 2100 G.M.T., and in 24 hours a similar amount was recorded at Leuchars and Aberdeen. After a temporary period of colder, dry weather during which high pressure spread south-east from Scotland, and many stations reported a return of frost and fog—temperature fell to 18°F. at Yeovil on the 15th and 16th —milder air from the Atlantic began once more to invade our north-western districts on the 15th, and two days later had spread to the whole country. Mild cloudy weather, with temperature locally rising into the upper fifties, persisted for nearly a week. On the 23rd a depression formed off our south-west Approaches giving rain with local thunderstorms in the south-west and Midlands, but in the north weather was mainly dry with light north-easterly winds, though there were areas of mist or fog; Glasgow was fog-bound for much of the 23rd and 24th. Christmas Day was bright and dry at many places in the British Isles, but cloudy rainy weather spread to our north-west districts during the afternoon with winds reaching gale force locally. Weather during the remainder of the month was changeable and generally mild, but cooler air, accompanied by sleet and snow, spread into Scotland during the last three days.

Temperature was above average in Scotland, taking the month as a whole, but slightly below average in England and Wales where the deficit was greatest during the first week. During the last week of the month temperature in England and Wales was somewhat above the average and more than 7°F. above the average in Scotland. Sunshine was above the average nearly everywhere. During the first week most districts of England and Wales had nearly twice their normal amount, but during the last half of the month there was a deficit in Scotland. Rainfall was generally below the average south of a line drawn from the Mersey to the Wash, in north-east England, the border counties of Scotland, locally in Lanarkshire and Perthshire, and over much of south-west Scotland.

Most out-door farm work was reasonably advanced at the end of the month, especially in the south. Winter spraying and pruning and general clearing of orchards were well up to schedule. Very advanced greens showed quite heavy frost damage early in the month, but later planting appeared untouched. In general, early winter work in the countryside was well in hand.

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 ...	60	12	0·0	83	−3	123
Scotland	58	10	+0·1	114	−2	139
Northern Ireland ...	57	20	+0·5	132	−1	125

THE WEATHER OF OCTOBER 1957

Northern Hemisphere

The Icelandic depression was near its normal position but much deeper than normal, whilst the Azores high was a little north of its normal position and of about normal intensity. The Siberian anticyclone was near normal, in both position and intensity. Pressures were, however, above normal over Europe so that a ridge of high pressure linked the Siberian and Azores anticyclones. In the Pacific sector the Aleutian low was a little to the west of the normal position but of average intensity. The Pacific anticyclone centre was weaker and further south than is normal.

The pressure was higher than normal over the greater part of North America and in the extreme north-west of Canada anomalies reached + 10 millibars. Pressure was about 6 millibars higher than normal off north Siberia and there was an anomaly of − 15 millibars north of Jan Mayen.

The north-westerly air flow over Labrador was much more pronounced than is usual. Over the North Pacific Ocean and over much of Asia the circulation was sub-normal.

The largest temperature anomalies occurred in polar regions and in the extreme north of Siberia reached −6°C. although temperatures were about 5°C. above normal between Spitsbergen and East Greenland. Over most of northern and central Europe temperatures were a little above normal but the air was slightly cooler than usual over the western Mediterranean and North Africa. Over the Rocky mountains and most of the United States temperatures were generally below normal.

Rainfall was less than normal over Central Europe but more than normal over the Mediterranean lands and North Africa. Rainfall was also more than normal in a well marked zone extending from Scandinavia across Siberia.

RAINFALL OF DECEMBER 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·68	70	*Glam.*	Cardiff, Penylan ...	2·40	48
Kent	Dover	1·72	56	*Pemb.*	Haverfordwest	4·22	74
,,	Edenbridge, Falconhurst	2·73	83	*Radnor*	Tyrmynydd	5·17	63
Sussex	Compton, Compton Ho.	3·64	87	*Mont.*	Lake Vyrnwy	5·55	79
,,	Worthing, Beach Ho. Pk.	1·79	59	*Mer.*	Blaenau Festiniog ...	11·04	87
Hants.	St. Catherine's L'thouse	3·44	109	,,	Aberdovey	2·75	58
,,	Southampton (East Pk.)	2·10	57	*Carn.*	Llandudno	2·48	86
,,	South Farnborough ...	2·20	76	*Angl.*	Llanerchymedd ...	4·42	101
Herts.	Harpenden, Rothamsted	2·25	79	*I. Man*	Douglas, Borough Cem.	4·10	83
Bucks.	Slough, Upton	1·85	73	*Wigtown*	Newton Stewart ...	5·70	105
Oxford	Oxford, Radcliffe ...	2·53	103	*Dumf.*	Dumfries, Crichton R.I.	4·72	110
N'hants.	Wellingboro' Swanspool	2·31	98	,,	Eskdalemuir Obsy. ...	6·22	89
Essex	Southend, W. W. ...	1·70	86	*Roxb.*	Crailing...	1·96	73
Suffolk	Felixstowe	1·94	93	*Peebles*	Stobo Castle	4·38	115
,,	Lowestoft Sec. School ...	1·79	77	*Berwick*	Marchmont House ...	2·16	77
,,	Bury St. Ed., Westley H.	2·08	86	*E. Loth.*	North Berwick Gas Wks.	2·29	107
Norfolk	Sandringham Ho. Gdns.	2·45	96	*Midl'n.*	Edinburgh, Blackf'd. H.	2·11	90
Wilts.	Aldbourne	3·59	105	*Lanark*	Hamilton W. W., T'nhill	3·88	90
Dorset	Creech Grange... ...	2·73	62	*Ayr*	Prestwick	2·40	69
,,	Beaminster, East St. ...	3·81	80	,,	Glen Afton, Ayr San. ...	7·37	115
Devon	Teignmouth, Den Gdns.	2·35	56	*Renfrew*	Greenock, Prospect Hill	7·70	103
,,	Ilfracombe	2·43	50	*Bute*	Rothesay, Ardencraig ...	4·91	90
,,	Princetown	8·48	73	*Argyll*	Morven, Drimnin ...	7·35	94
Cornwall	Bude	1·89	43	,,	Poltalloch	5·71	89
,,	Penzance	4·64	82	,,	Inveraray Castle ...	12·10	122
,,	St. Austell	3·62	59	,,	Islay, Eallabus	5·55	94
,,	Scilly, Tresco Abbey ...	3·96	84	,,	Tiree	5·52	106
Somerset	Taunton	2·57	78	*Kinross*	Loch Leven Sluice ...	5·68	144
Glos.	Cirencester	2·61	75	*Fife*	Leuchars Airfield ...	3·10	126
Salop	Church Stretton ...	2·52	71	*Perth*	Loch Dhu	11·95	119
,,	Shrewsbury, Monkmore	·95	39	,,	Crieff, Strathearn Hyd.	5·20	116
Worcs.	Malvern, Free Library...	2·24	81	,,	Pitlochry, Fincastle ...	3·30	82
Warwick	Birmingham, Edgbaston	2·37	80	*Angus*	Montrose Hospital ...	3·11	112
Leics.	Thornton Reservoir ...	2·28	85	*Aberd.*	Braemar	2·89	81
Lincs.	Boston, Skirbeck ...	1·99	93	,,	Dyce, Craibstone ...	3·99	118
,,	Skegness, Marine Gdns.	2·30	105	,,	New Deer School House	4·39	128
Notts.	Mansfield, Carr Bank ...	1·89	65	*Moray*	Gordon Castle	4·34	161
Derby	Buxton, Terrace Slopes	6·33	112	*Nairn*	Nairn Achareidh ...	2·55	124
Ches.	Bidston Observatory ...	2·29	86	*Inverness*	Loch Ness, Garthbeg ...	5·77	125
,,	Manchester, Ringway...	2·70	89	,,	Loch Hourn, Kinl'hourn	17·50	127
Lancs.	Stonyhurst College ...	6·87	142	,,	Fort William, Teviot ...	13·93	137
,,	Squires Gate	...	...	,,	Skye, Glenbrittle ...	6·71	70
Yorks.	Wakefield, Clarence Pk.	3·05	126	,,	Skye, Duntulm... ...	7·18	115
,,	Hull, Pearson Park ...	2·19	91	*R. & C.*	Tain, Mayfield... ...	5·22	184
,,	Felixkirk, Mt. St. John...	2·21	92	,,	Inverbroom, Glackour...	11·17	152
,,	York Museum	2·32	104	,,	Achnashellach	14·09	148
,,	Scarborough	2·04	86	*Suth.*	Lochinver, Bank Ho. ...	8·46	152
,,	Middlesbrough... ...	1·24	64	*Caith.*	Wick Airfield	4·04	131
,,	Baldersdale, Hury Res.	4·30	112	*Shtland*	Lerwick Observatory ...	4·73	99
Norl'd.	Newcastle, Leazes Pk....	1·71	73	*Ferm.*	Crom Castle	...	...
,,	Bellingham, High Green	2·22	61	*Armagh*	Armagh Observatory ...	4·30	137
,,	Lilburn Tower Gdns. ...	2·50	95	*Down*	Seaforde	6·01	146
Cumb.	Geltsdale	3·79	99	*Antrim*	Aldergrove Airfield ...	4·75	138
,,	Keswick, High Hill ...	6·99	104	,,	Ballymena, Harryville...	5·66	127
,,	Ravenglass, The Grove	6·00	131	*L'derry*	Garvagh, Moneydig ...	5·70	142
Mon.	A'gavenny, Plâs Derwen	4·83	98	,,	Londonderry, Creggan	5·51	126
Glam.	Ystalyfera, Wern House	4·94	59	*Tyrone*	Omagh, Edenfel ...	5·18	122

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

Wt-36. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,029, MARCH 1958

WATER-FOG POINT—A FURTHER TEST

By W. E. SAUNDERS, B.Sc.

Introduction.—A technique for forecasting the temperature at screen level at which water fog forms was described by the writer in 1950[1], and amplified by Corby and Saunders, 1952[2]. This note describes the results of a test made at a large number of United Kingdom meteorological offices during the early months of 1956.

Scope of the test.—Stations were asked to test the method on all suitable nights during the period January 1–April 15, 1956. In the selection of suitable nights the following conditions had to be satisfied:

(i) An upper air ascent representative of the air stream over the station had to be available the previous afternoon.

(ii) Water fog had actually to form during the night, or the evening conditions had to be such that the forecaster would seriously consider the risk of fog.

(iii) Visibility during the night should not be seriously affected by smoke.

The water-fog point was to be as defined by Corby and Saunders[2].

Preliminary treatment of the results.—63 stations gave details of actual fog cases, and a further 10 stations gave data for nights on which fog was considered but did not form.

Stations differed widely in their interpretation of conditions (i) and (iii) above. Cases which were reported, but with a comment that the ascent used was not properly representative, were omitted from the analysis. With regard to condition (iii), all cases reported were included in the analysis, although some were much affected by smoke. A few stations included cases which were not radiation fog, such as occasions of sea fog on coasts, and visibility falling into the fog range in precipitation, and where these cases could be identified from the accompanying remarks they were omitted.

The analysis of results is discussed in subsequent paragraphs.

Fog point as an air mass property.—The method is based on the idea, derived from observation, that the water-fog point is an air mass property—over an area in which there has been fairly uniform heating and in which the humidity distribution with height in the lowest few thousand feet shows little change from place to place, the fog point can be regarded within close limits as a fixed property of the air mass. Spatial variations in the time of onset of fog are due to differences in the cooling rate and not in the fog point.

The period of this test was not particularly suitable for illustrating this general principle, since many of the fog cases reported referred only to small localized areas. Two occasions, however, did produce fairly widespread fog, and the actual and forecast fog points on these nights have been plotted on Figures 1 and 2.

On January 16, 1956 (Figure 1) there was a light west to west-north-west air stream over southern districts. Fog was reported at 13 stations, and the forecast errors are seen to average not much more than one degree. Seven stations reported no fog, and in each case the minimum screen temperature exceeded the forecast fog point.

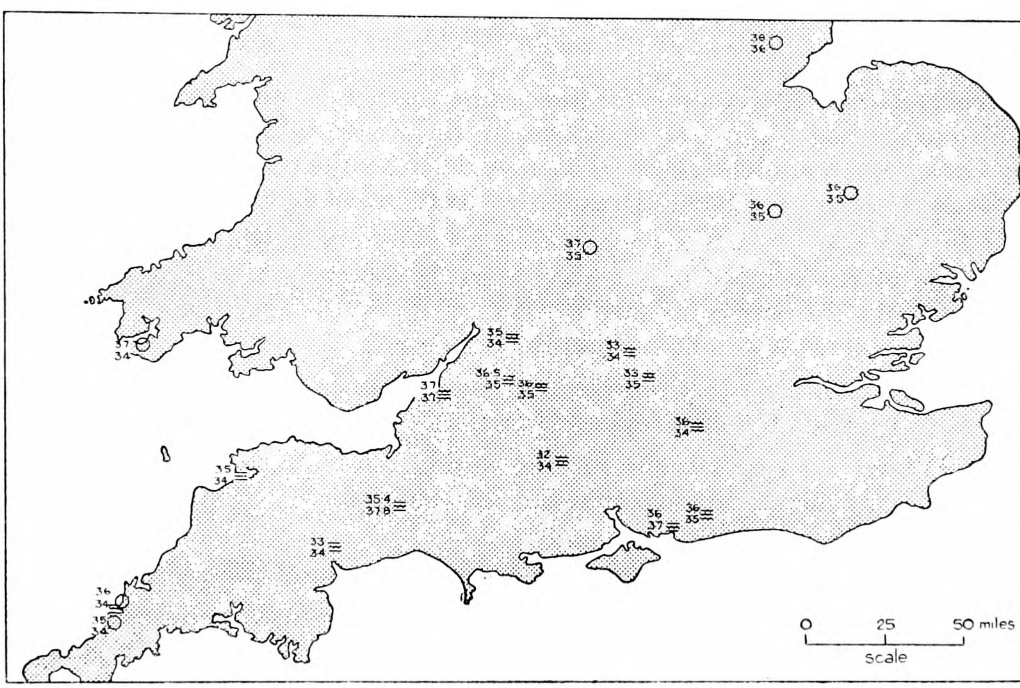


FIG. 1.—FORECAST AND ACTUAL FOG POINTS, JANUARY 16, 1956

Fog cases are plotted $\frac{T_{f'}}{T_f}\equiv$ where $T_{f'}$ is the actual and T_f the forecast fog point

Cases of no fog are plotted $\frac{T_{min}}{T_f}$ O where T_{min} is the screen minimum temperature and T_f is the forecast fog point

There was a light south-east to south air stream on March 12, 1956 (Figure 2). The actual fog points show that there were localized areas near the Thames Valley, and in north Yorkshire, with fog point 30°–31°F. Elsewhere it was mainly 27°–28°F. These differences may well have been due to variations in the length of sea track of the air mass, an effect which was appreciated and correctly allowed for in the Abingdon forecast. Three stations appeared to make forecasting errors of a type discussed below but the remaining 15 stations obtained errors averaging only a degree or so.

Variation of forecast errors.—The standard of accuracy obtained varied somewhat between stations, but 48 out of 63 obtained mean deviations not exceeding 2·0°F., and 28 not exceeding 1·0°F. The mean deviations were taken as the mean forecast errors, disregarding the signs.

In order to see the frequency of actual errors in the forecasts the records of the 48 stations referred to above were examined, and the frequencies of various errors are given in Table I.

TABLE I—FREQUENCY OF VARIOUS ERRORS IN FOG POINT FORECASTS

	Errors in forecast fog point, °F.					
	0·0–1·0	1·1–2·0	2·1–3·0	3·1–4·0	4·1–5·0	5·1–6·0
Number of occasions ...	120	36	13	7	2	2
Percentage frequency ...	67	20	7	4	1	1

Variation of forecast errors with temperature.—The forecast errors of the 48 stations were analysed according to the temperature of T_f—the forecast fog point—and the results are given in Table II. $T_{f'}$ refers to the actual fog point. Mean deviations are the forecast errors disregarding the signs, and mean errors the mean of $T_{f'} - T_f$ taking account of the signs. The small number of cases with T_f above 43° or below 20°F. were omitted.

TABLE II—VARIATION OF FOG-POINT ERRORS WITH TEMPERATURE

	Forecast fog point (T_f) °F.					
	43–40	39–36	35–32	31–28	27–24	23–20
Number of cases	19	53	48	29	21	7
Mean deviation (°F.) ...	1·3	1·0	1·3	1·3	1·4	1·5
Mean error $T_{f'} - T_f$ (°F.) ...	−0·9	−0·5	−0·1	+0·6	+0·9	+1·1

Table II shows that the forecast T_f is on average nearly one degree too high in the range 43–40°F. This error decreases with decreasing temperature, and changes sign near freezing. When the forecast T_f is below freezing it is to low, the mean error being about one degree for temperatures 27–20°F.

Variation of forecast errors with type of dew-point curve.—Stations included the type of dew-point curve used, as classified by Saunders[1]. Errors associated with each type of curve are given in Table III.

TABLE III—VARIATION OF FORECAST ERRORS WITH TYPE OF DEW-POINT CURVE

	Type of dew-point curve			
	I	II	IIIA	IIIB
Number of cases	95	36	34	10
Mean deviation (°F.)	1·2	1·2	1·1	0·7
Mean error $T_{f'} - T_f$ (°F.)	0·0	0·0	−0·5	0·0

This shows that the more general types of dew-point curve give much the same accuracy. The greatest accuracy is obtained with type IIIB, when the air is exceptionally stagnant and the afternoon dew-point is the fog point, but the proportion of cases in which this can be applied is very small.

Variation of forecast errors with state of ground.—Notes of the state of ground were included in a limited number of cases, and the forecast errors were analysed separately in these cases. The results are given in Table IV.

TABLE IV—VARIATION OF FORECAST ERRORS WITH STATE OF GROUND

	State of ground		
	Dry or moist	Frozen	Snow covered
Number of cases	37	16	11
Mean deviation (°F.)	1·2	2·1	2·1
Mean error $T_{f'} - T_f$ (°F.)	−0·1	−0·3	+0·8

Table IV shows that forecast errors increase significantly under wintry conditions with frozen and snow-covered ground.

Forecast errors following recent precipitation.—The reports included notes on precipitation at the stations, with special reference to precipitation after midday preceding fog cases. The forecast errors were considered separately for cases in which precipitation was reported at the station in the period from midday to the time of fog formation. Dew was not counted for this purpose. There were 59 such occasions, giving mean deviation 1·9°F., and mean error of $T_{f'} - T_f$, + 1·3°F.

Occasions when fog did not form.—Some stations included details of the forecast fog point and night minimum temperature—T_{min} on nights when fog was considered but did not form. These were analysed, with the state of ground, for all cases where the latter was included in the report, and the results are given in Table V.

TABLE V—RELATION OF NIGHT MINIMUM TEMPERATURE TO FORECAST FOG POINT AND STATE OF GROUND ON OCCASIONS WHEN FOG DID NOT FORM

	$T_{min} \leqslant T_f$		
$T_{min} > T_f$	Ground dry or moist	Ground frozen	Ground snow covered
	No. of occasions		
84	7	5	14

Table V shows that on most of the occasions when the fog point was reached, but no fog formed, there was snow cover.

Main sources of errors in forecasting.—Table II shows that there are small errors at low temperatures. These were, however, based on the records of the stations taken together, and will not necessarily apply at all stations. Stations who are satisfied that the mean errors are relevant to them could apply them as corrections in future work.

It is not suggested that any corrections should be made based on the results given in Tables III and IV, but Table IV emphasizes that there is some decrease in accuracy over frozen or snow covered ground.

The results mentioned earlier suggest a correction of + 1·3°F. should be made to the forecast T_f when there has been recent precipitation at the station, but this is another circumstance which leads to decreased accuracy.

Apart from the points mentioned above, which arise from the statistical tables produced, an examination was made of the larger errors reported on individual occasions, and the following appeared to be the main sources of errors:

(i) The effect of rainfall at the radio-sonde station.—Occasional large errors (forecast T_f too high) were due to the radio-sonde ascent having been made in rain, and the ascent then being used to forecast the fog

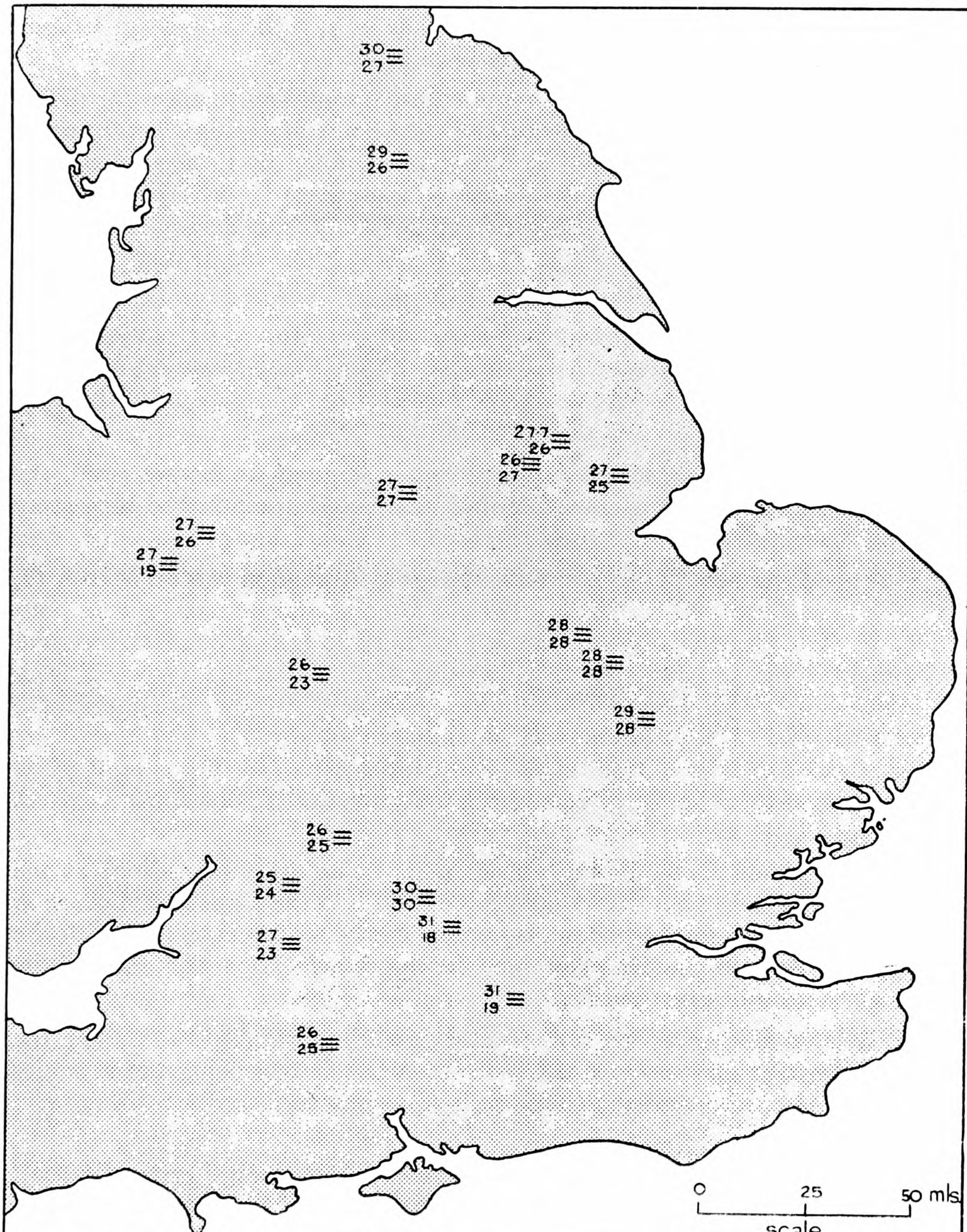


FIG. 2.—FORECAST AND ACTUAL FOG POINTS, MARCH 12, 1956

Fog cases are plotted $\frac{T_{f'}}{T_f}\equiv$ where $T_{f'}$ is the actual and T_f the forecast fog point

Cases of no fog are plotted $\frac{T_{min}}{T_f}$ O where T_{min} is the screen minimum temperature and T_f is the forecast fog point

point at a station in dry air. The humidity element of the radio-sonde is of course screened from the direct effects of rain, but the dew-points reported will correspond to the moist air in the rain. If the precipitation is of an intermittent or showery type it may be difficult for forecasters to decide whether or not the ascent was made in rain without communicating directly with the radio-sonde station. It would be helpful if radio-sonde operators would whenever possible observe whether or not the afternoon balloon passed through precipitation in the lowest 3,000 feet.

(ii) Modification of the most representative sounding to allow for differences in the surface temperature and dew-point at or up-wind from the station. The most successful results were obtained by those stations who when necessary amended the tephigram to accord with their own or other more representative up-wind temperatures and dew-points. Some rules formulated by Mr. W. L. Andrew (Abingdon) for dealing with this problem are given below:

(*a*) If conditions are fairly stagnant, and the air over the station seems likely to be representative of the air the following morning, then the most representative ascent is used, modified to take account of the 1400 G.M.T. temperature and dew-point at the station.

(*b*) If the air in which fog might form is going to be advected, the representative ascent is used, either as it stands, or adapted to a more representative up-wind surface temperature and dew-point.

A good example of type (*b*) amendment at Abingdon was on March 12, (the case illustrated in Figure 2) when forecast and actual T_f were both 30°F. The Crawley ascent had been modified to take account of reported temperatures and dew-points along the south coast and up-wind from Abingdon, which differed from those at Crawley. Another useful example of this type of adjustment was amendment of the Hemsby ascent by Stradishall to take account of the temperature at a North Sea light vessel when the air was being advected from that direction, so obtaining a correct forecast T_f.

The method of modifying an ascent is to adjust the readings at the lower heights to what they would have been had the ascent been made at 1500 hr. at the station whose fog point was being forecast, and with the assumption that the air mass over the upper air station had reached the "fog" station before 1500 hr.

Detailed analysis of the surface chart is an important aid to finding the most representative ascent, the main feature to stress being the necessity for retaining fronts on the charts so long as any surface discontinuity can be traced.

(iii) The type II dew-point construction.—A few large errors (forecast T_f too low) were noticed in cases where a type II dew-point curve was not produced upwards in the manner suggested. It should be emphasized that type II dew-point curve is not found only with an inversion of the dry-bulb temperature. It may occur when there is any decrease in the temperature lapse rate. With this distribution the hydrolapse in the upper part of the dew-point curve may be very steep, and if the lower part of the curve is not produced upwards for the fog-point construction it is apparent that large errors are readily incurred. The reason for this construction is that in this type the upper part of the dew-point curve represents air which obviously is not being mixed with the surface air, and must therefore be left out of account.

Use of the technique for forecasting the temperature of formation of stratus cloud.—In the original paper a construction was suggested for forecasting T_s, the screen level temperature at which low stratus cloud would form, when it was thought there was too much turbulence for fog at ground level[1].

A number of stations reported successful use of this construction. At Little Rissington (in the Cotswolds, 751 feet above mean sea level), owing to the altitude of the station, radiation fog is rare, but low stratus often forms on the surface. Mr. B. F. Westwater reported using T_f modified to T_s to allow for about 300 feet uplift above the surrounding countryside. On 8 occasions when there was a representative ascent the mean error was just over one degree.

The usefulness of the technique modified in this way for stratus cloud serves to emphasize that it is essentially a method for *water* fog.

Conclusion.—A number of stations commented that the period chosen for the test was unfavourable for accuracy because it included a severe wintry spell, and in some cases much smoke. In support of this view Mr. E. B. Tinney (Merryfield, near Taunton, Somerset) produced the results of a similar test carried out under local initiative during the previous autumn. This showed that for 11 cases in the period July 1–October 11, 1955 the mean error for Merryfield was about half its value for eight cases in the present test. Having seen in Table IV that the relation between mean deviations over dry or wet ground as compared with frozen or snow covered ground tended the same way, we may perhaps conclude that most stations would have obtained rather better results in an autumn period. However, the test has been a useful supplement to the autumn one described by Corby and Saunders[2], and it has suggested some small corrections which should lead to greater accuracy in future.

REFERENCES

1. SAUNDERS, W. E.; Method of forecasting the temperature of fog formation. *Met. Mag., London,* **79**, 1950, p. 213.
2. CORBY, G. A. and SAUNDERS, W. E.; Water fog point—a further test. *Met. Mag., London,* **81**, 1952, p. 225.

TEMPERATURES AND TOPOGRAPHY ON RADIATION NIGHTS

By E. N. LAWRENCE, B.Sc

Introduction.—An area forecast of minimum temperature can be interpreted satisfactorily only by the aid of formulae relating minimum temperatures to topography, especially to altitude. These formulae would be useful also for the purpose of estimating long term frost risks over areas where a sufficiently detailed network of measured observations is not available.

Method.—Ideally an investigation into the relation between topography and meteorological elements such as temperature and wind, requires a large number of meteorological stations within a small area. In the present survey, this difficulty was overcome by fitting instruments to a car, and making observations at some 70 points along a route of about 11 miles (see Figure 1) over a period of about 1½ hours at the end of each night of the survey. This route covered three main hills and the surrounds of Aldenham Reservoir. The height variation is over 200 feet with slopes up to about one in nine. The three hills are Brockley Hill (Middlesex), Elstree Hill and the double-humped hill of Allum Lane (Borehamwood, Hertfordshire).

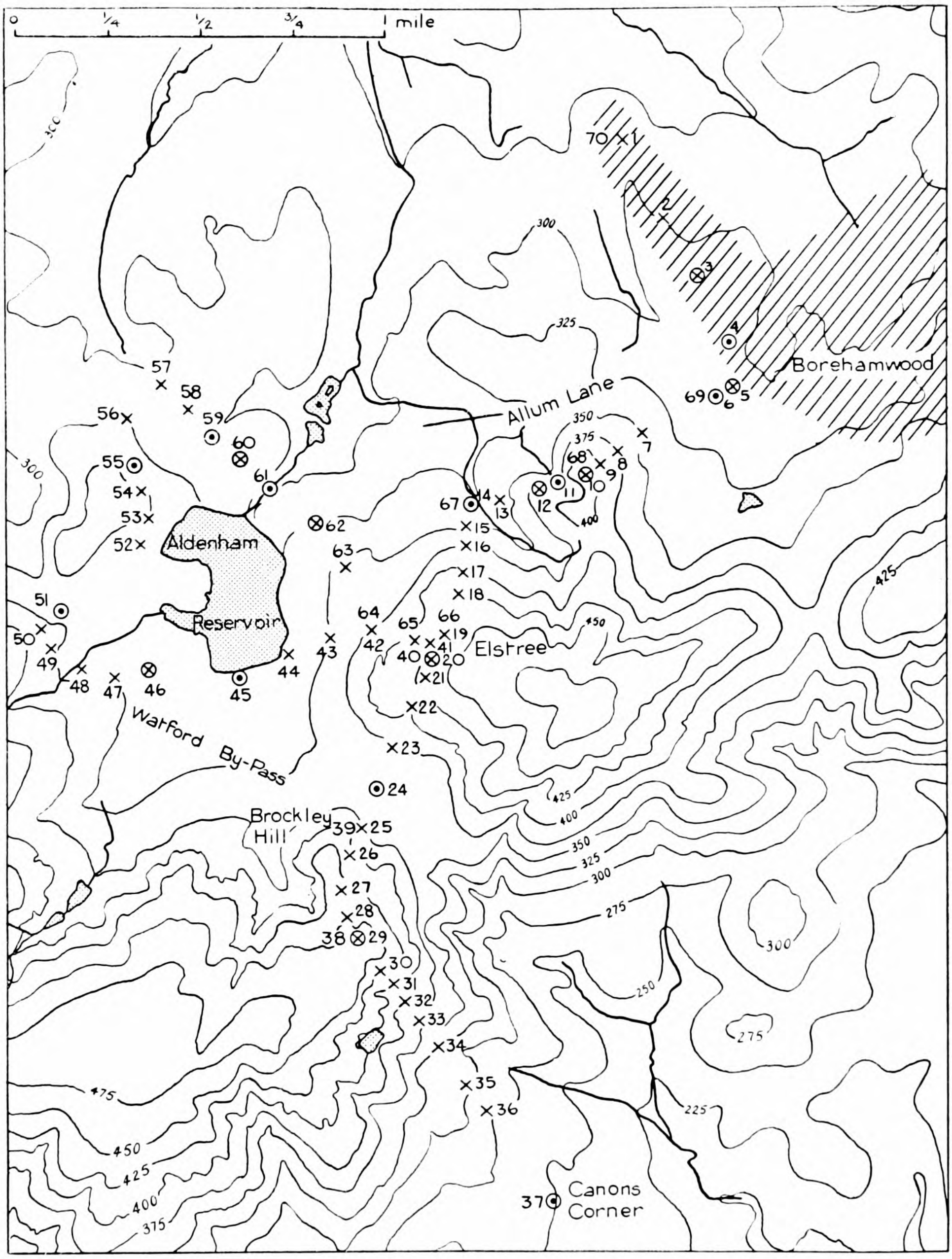


FIG. 1—AREA OF MOBILE METEOROLOGICAL SURVEY

Crosses mark points of observation.
Encircled crosses mark observations made at "main" crest points.
Encircled dots mark observations made at "main" trough points.

The instruments employed are illustrated in photographs between pp. 80–81. Temperatures were measured by means of balanced-bridge platinum resistance thermometers attached to the front of the car by means of aluminium strut supports so that the responding surfaces were at heights of 1 foot and 4 feet above the ground. Wind speed was measured with a magnetic drag hand anemometer; wind direction was measured (during the 1955 surveys) by means of streamers attached to a mast fixed to the rear of the car but later (during the 1956 surveys) wind direction was measured by means of a fine powder ejected from a flexible-ended container. Observations were made at all "main" crest and trough points, and also, where the latter points were widely separated, at intervals of 1 millibar—measured by an aneroid barometer (Mk. II). Temperature observations were made immediately before stopping the car, while wind was observed with the car at rest.

Because of the vital importance of May frosts to agriculture, the month of May was selected for experiment and several surveys were made in each of the months May 1955 and May 1956. The time of observation was during the latter end of the night so that the temperatures recorded would indicate the approximate night minimum temperatures. The nights selected were anticyclonic nights with little or no cloud and no pressure gradient—only local winds prevailing.

TABLE I—THE RELATION BETWEEN EARLY MORNING TEMPERATURE (T) IN DEGREES FAHRENHEIT AND THE HEIGHT (H), IN FEET, ABOVE MEAN SEA LEVEL, ON RADIATION NIGHTS

Date	Locations	Height–temperature correlation	Regression equations
May 22, 1955	Points 1–70 (Height range: 210 ft.)	0·66	$T = 0{\cdot}016\, H + 34$ $H = 26{\cdot}9\, T - 716$
May 27, 1956	Points 1–70 (points 33, 45 missing) = 68 points (Height range: 210 ft.)	0·33	$T = 0{\cdot}010\, H + 34$ $H = 10{\cdot}7\, T - 36$
May 27, 1956	Points 42–68 inclusive (point 45 missing) = 26 points (Height range: 120 ft.)	0·75	$T = 0{\cdot}035\, H + 24$ $H = 16{\cdot}1\, T - 230$

Results.—There was little difference between the 1-foot and 4-foot temperatures, probably due to the fact that inversions are much less marked over road surfaces because of the higher conductivity of road building materials and possibly also because of the turbulence produced by traffic. In the following results, the temperatures referred to are the means of the temperatures at the two levels; and may be regarded rather more like screen minimum temperatures than grass minimum temperatures. The mean of the extreme temperatures (average of 1-foot and 4-foot temperatures) obtained on May 22, 1955 was 40°F. while elsewhere, minima were 39°F. at Southgate, Oakwood (screen), and 35°F. at Wealdstone, Kodak (screen) with 29°F. (grass minimum). On May 27, 1956, the corresponding values were 36°F. (present survey), 37°F. at Southgate (screen), 40°F. at Wealdstone (screen) and 30°F. at Wealdstone (grass minimum).

The results for two of the best radiation nights are given in Table I. Further detail for one of these occasions is given in Figure 2. Slope winds were fairly general during both these occasions and ground mist and fog were present (see photograph facing p. 80).

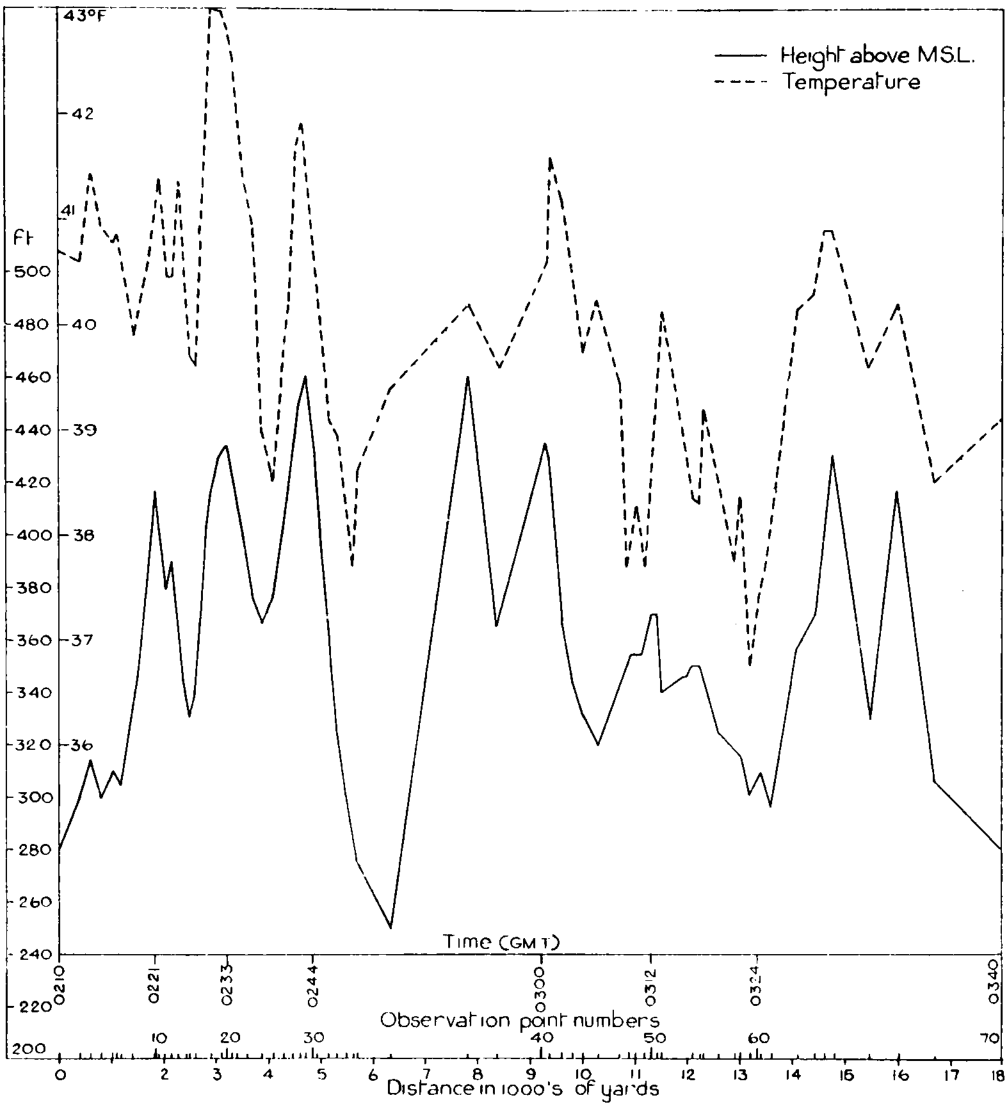


FIG. 2—RELATION BETWEEN HEIGHT AND EARLY MORNING TEMPERATURE ON MAY 22, 1955

The results show that on a radiation night, the average increase of temperature with height may be of the order of 1°–2°F. or more per hundred feet and over shorter distances (see Table I and Figure 2) very much numerically higher lapse rates may occur. For example, on the outward journey on May 22, 1955 (see Figure 2), over seven points with a height range of 75 feet on the north side of Elstree Hill, the mean rate of increase was (numerically) $4\frac{1}{2}$°F. per hundred feet; on the same outward journey, down the south side of Brockley Hill, through a height range of 160 feet, the mean rate of increase was about $2\frac{1}{2}$°F. These figures are in general agreement with other surveys: for example at Much Birch[1] in Herefordshire over eleven radiation nights in 1954 and through a height range of 20 feet, the average minimum temperature (at 4 feet above the ground) increased with height at the rate of 5°F. per hundred feet: while Geslin[2] in Champagne, on the radiation night of April 29–30, 1951, recorded up to approximately 8°F. per hundred feet through a height of 16 metres, at 40 centimetres above the ground. On the surveys carried out in Champagne, there was an indication of a "constant temperature" cold air pool in hollows. In the present survey, however, there was a fairly general temperature response to change in height, and any exceptions could usually be explained by an increase in turbulence, or by the proximity of built-up areas or of Aldenham Reservoir near which temperatures were some 1°–2°F. higher than that which would be expected from the general height–temperature pattern (see Figure 2). It is possible, however, that the "constant temperature cold pool" was not well marked because there was always a sufficient run off of cold air to lower areas surrounding the area of survey.

On the assumption that a difference of 0·5°F. in the average minimum temperature is associated with a significant difference in frost liability[3], the results of this experiment indicate that a height difference of 10 feet leads to significant differences in frost liability.

The temperature lapse rates of $2\frac{1}{2}$° and $4\frac{1}{2}$°F. per hundred feet recorded in the present survey (see above) were associated with slopes of 0·06 and 0·08 respectively. Data was insufficient to draw any firm conclusions concerning the relation between slope and either the rate of increase of temperature with height or the slope wind.

The results of the present experiment may be contrasted with the results of a previous investigation[4] in which the sites (at varying heights) were widely scattered so that the topographies were "unrelated". In the latter survey, the height–minimum temperature correlation was somewhat masked by the introduction of other variables, and whereas no firm conclusions could be drawn, a tendency for a positive correlation might have been inferred.

I am grateful to Mrs. K. Spencer and Mr. D. Tribble for help in observing and to Mr. D. Tribble for the use of his car.

REFERENCES

1. LAWRENCE, E. N.; Minimum temperatures and topography in a Herefordshire valley. *Met. Mag., London*, **85**, 1956, p. 79.

2. GESLIN, H., BOUCHET, R., DURAND, R. and NIGOND, J.; A propos des gélees de printemps nouvelles observations microclimatiques et biologiques en Champagne. *P. V. Acad. Agric. France, Alençon*, 1952.

3. LAWRENCE, E. N.; Estimation of weekly frost risk using weekly minimum temperatures. *Met. Mag., London*, **81**, 1952, p. 137.

4. LAWRENCE, E. N.; Frost investigation. *Met. Mag., London*, **81**, 1952, p. 65.

SEASONAL INCIDENCE OF RAINY CALENDAR MONTHS WITH MORE THAN AVERAGE SUNSHINE DURATION IN ENGLAND AND WALES

By E. L. HAWKE, M.A.

The *Monthly Summary* of the British *Daily Weather Report* for January 1956 contained the following statement: "This changeable month produced the unusual combination of high rainfall and an excess of sunshine." Summarized data subsequently published in the *Monthly Weather Report* indicated that over England and Wales as a whole January 1956 gave 167 per cent. of the average, 1881–1915, precipitation and 117 per cent. of the average, 1921–1950, duration of sunshine. "Changeable: wet but sunny" was the headline describing the month's general character.

Is it unusual for January to couple high rainfall with a quota of sunshine above normal? Such a combination might well be rare in summer, one would suppose, but it might seem, at first sight, no matter for special comment in winter, when anticyclonic conditions are so often associated in Great Britain with persistent canopies of low cloud and widespread fog, whereas during a predominantly cyclonic régime there are, as a rule, frequent sunny spells separating the successive intervals of rain or snow. Direct evidence on this point appears to be lacking from climatological literature. An attempt to remedy the defect has therefore been made. The material used comprised general values of monthly precipitation for England and Wales over the 40 years 1909–1948, published in the annual volumes of *British Rainfall*, and general values of monthly sunshine duration for England and Wales over the same 40 years given by D. S. Hancock[1,2]. Values for both elements are expressed as a percentage of average, the averages employed being the standard period 1881–1915 in respect of rainfall and 1909–1933 in respect of sunshine. Relevant data are set forth in Tables I and II.

TABLE I—MEAN GENERAL DURATION OF SUNSHINE OVER ENGLAND AND WALES FOR THE SEVEN WETTEST OF EACH OF THE CALENDAR MONTHS DURING THE PERIOD 1909–1948

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Percentage of 1909–1933 average	93	101	78	82	92	88	90	84	87	92*	84	98

* This value is derived from eight instead of seven months because three Octobers, 1917, 1924, and 1938, tied for the positions of sixth and seventh wettest in the period under review.

TABLE II—NUMBER OF OCCASIONS ON WHICH MARKEDLY WET CALENDAR MONTHS GAVE GENERAL SUNSHINE DURATION WITHIN SPECIFIED LIMITS ABOVE AND BELOW AVERAGE OVER ENGLAND AND WALES, 1909–1948

	Percentage							
	<61	61–70	71–80	81–90	91–100	101–110	111–120	>120
Oct.–Mar.	0	5	8	10	5	3	3	2
Apr.–Sept.	2	2	8	13	1	1	2	1

This Table shows that out of 43 markedly wet winter months during the 40-year period there were 33 with sunshine below or equal to average and only 10 with sunshine above average. In Summer the tendency for markedly wet months to give sunshine below average was decidedly more pronounced, with 38 instances against four*.

* The footnote to Table I explains why 43 winter months and 42 summer months were considered.

TABLE III—CALENDAR MONTHS FROM 1909 TO 1948 COMBINING MORE THAN AVERAGE GENERAL SUNSHINE WITH GENERAL RAINFALL EXCEEDING THE AVERAGE BY AT LEAST 40 PER CENT. OVER ENGLAND AND WALES.

Year	January Percentage of average Rainfall	Sunshine	Year	February Percentage of average Rainfall	Sunshine	Year	April Percentage of average Rainfall	Sunshine
1928	213	120	1915	200	119	1922	147	114
1930	170	106	1925	192	104			
			1910	159	125			

Year	May Percentage of average Rainfall	Sunshine	Year	July Percentage of average Rainfall	Sunshine	Year	December Percentage of average Rainfall	Sunshine
1942	177	108	1918	160	115	1914	205	108
1943	143	122				1929	188	139
						1909	147	108

This table contains evidence in support of the statement quoted from the *Monthly Summary* of the British *Daily Weather Report* at the beginning of this article. Only two Januarys between 1909 and 1948 had more than average sunshine with a general rainfall exceeding the average by at least 40 per cent. The table excludes the two wettest Januarys, the three wettest Februarys, the two wettest Mays and the second wettest December, as well as the wettest of each of the calendar months through the remainder of the year. Months of especial interest in the table are January 1928, February 1915 and December 1929, which were outstanding in the unusual class of excessively wet but notably sunny months. July 1918 was the sole example of a very wet but sunny month in high summer; it is to be noted that most of the rain over England and Wales in that month came from heavy and widely distributed thunderstorms.

Correlation coefficients for monthly general rainfall and monthly general sunshine duration over England and Wales have also been evaluated. Herein the individual data and derived averages were confined to the 25 years 1909–1933. Rigid accuracy is not ensured by the quick method which was adopted for the calculations, but the margin of uncertainty is believed to lie within about +0·03 in every case. A few misprints in the published sunshine data have been corrected after consultation with Capt. Hancock.

TABLE IV—APPROXIMATE VALUES OF THE CORRELATION COEFFICIENT BETWEEN MONTHLY GENERAL RAINFALL AND MONTHLY GENERAL SUNSHINE DURATION OVER ENGLAND AND WALES, 1909–1933.

	Correlation coefficient	Standard error		Correlation coefficient	Standard error
January	−0·03	0·20	July	−0·62	0·12
February	+0·08	0·20	August	−0·56	0·14
March	−0·67	0·11	September	−0·46	0·16
April	−0·71	0·10	October	−0·29	0·18
May	−0·61	0·13	November	−0·15	0·20
June	−0·55	0·14	December	−0·10	0·20

No statistical significance attaches to the coefficients for November, December, January and February, since all are smaller than their respective standard errors. Thus in any of these four months the general character of the weather as regards wetness or dryness appears to be unrelated to the general prevalence of day-time cloud. In this connexion it may be remarked that in the extremely dull December of 1890, when totals of less than ten hours sunshine were recorded over much of Britain, and less than half an hour at London stations, England and Wales as a whole had only 35 per cent. of the average precipitation. The small positive coefficient found for February, though without significance statistically, is of interest as supporting the evidence of Table I, derived from data covering a longer period, that a slight trend existed during the first half of the 20th century for marked excess of rainfall to be associated with excess of sunshine in that month. The tendency towards combination of wet weather and high prevalence of clouded skies by day appears to reach a maximum in mid-spring. Presumably the reason is that March and April are, as a rule, not only much more immune from anticyclonic cloud and fog than the winter months but also much less liable than the summer months to have their rainfall dominated by thunderstorms.

REFERENCES

1. HANCOCK, D. S.; General sunshine values England and Wales, Scotland, Ireland and the British Isles for the period 1909–1933. *Quart. J. R. met. Soc., London.* **61**, 1935, p. 45.
2. HANCOCK, D. S.; An analysis of sunshine values in the British Isles for the period 1909–1948. *Quart. J. R. met. Soc., London,* **77**, 1951, p. 127.

EXTRAORDINARY STRONG WINDS AT NORTH WEALD

By R. DALGLEISH

On January 8, 1957, between 0707 and 0717 G.M.T. extraordinary strong winds were experienced at North Weald, north-west Essex (320 feet above sea level), grossly exceeding the gradient wind and far greater than reported from any other station in southern England.

At the time of the routine observation at 0656 G.M.T., the surface wind velocity was 215 degrees 20 knots, with gusts up to 28 knots. At 0707 G.M.T. the distant reading anemometer registered a sudden gust of 56 knots from direction 265 degrees and during the subsequent 10 minutes, up to 0717 G.M.T., a mean velocity of 265 degrees 35 to 40 knots was maintained. Thereafter the wind quickly backed to 210 degrees and moderated to 20 knots. During the period of the wind increase the barograph trace showed an upward kick of nine tenths of a millibar. No significant temperature change was recorded on the thermograph in the Stevenson Screen.

No wind speed approaching the magnitude of that observed at North Weald during the 10 minutes described above was reported from anywhere in southern England, and Stansted Airport, some 12 miles to the north-north-east, did not record any speed exceeding 20 knots between 0700 and 0730 G.M.T. that morning. A mild, moist south-westerly air stream, with a well marked inversion between 850 and 900 millibars, covered all southern England and there was a fairly uniform layer of stratocumulus. Slight drizzle outbreaks were frequent along the south and west coasts and scattered inland. The gradient wind over the area was 250 degrees 30 to 35 knots.

The excess of the wind speed, during the period between 0707 and 0717 G.M.T., over the gradient wind measured from the synoptic chart and also over the wind speeds generally reported that morning was too great to be attributed simply to convectional or frictional eddies. The combination of wind veer and extraordinary increase, simultaneously with the sharp pressure rise, suggests a downdraft associated with the eastward passage of a minor cold front; the discontinuity being confined to the lowest layers.

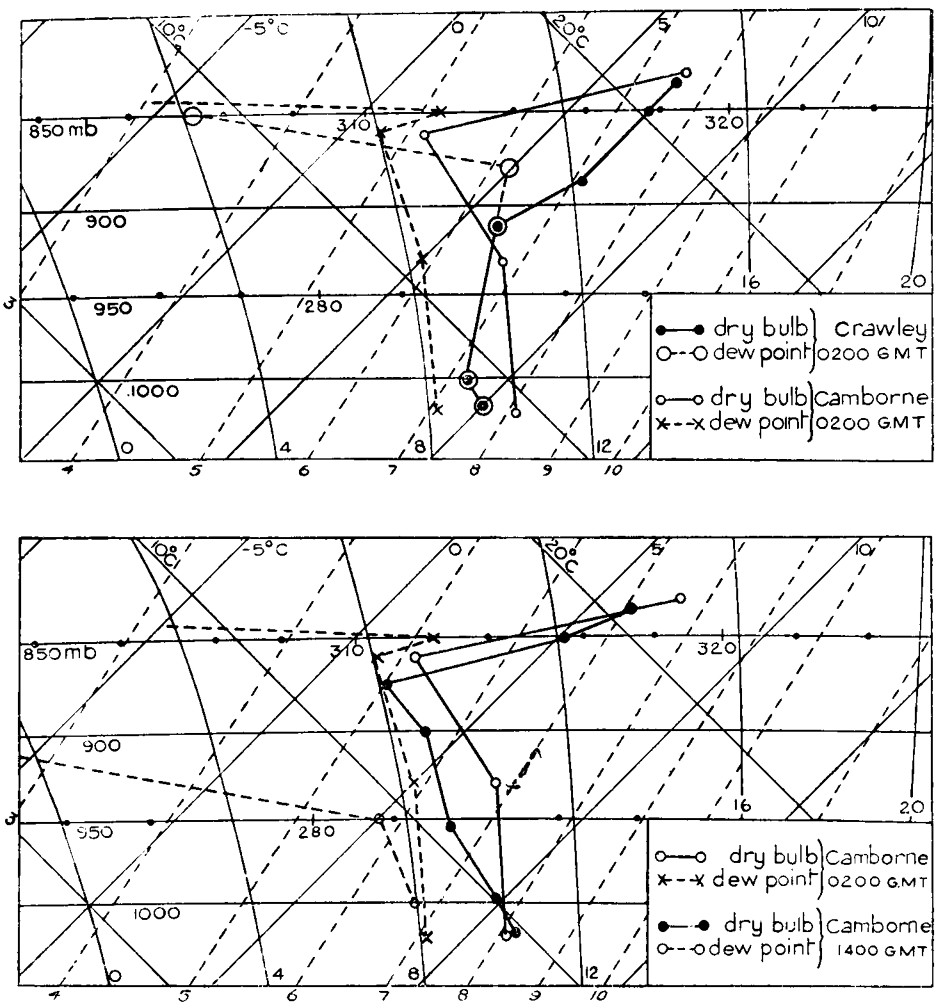


FIG. 1—UPPER AIR SOUNDINGS, CRAWLEY AND CAMBORNE, JANUARY 8, 1957

Although no clearly marked cold front or trough can be detected with any certainty from the synoptic charts the marked westward increase in conditional instability up to the 5,000-foot level is evident from the upper air soundings from Camborne and Crawley (Figure 1). The south-westerly air stream, although superficially uniform, was in fact becoming colder and less stable from the south-west in the layer below the inversion.

A further confirmation of the passage of a minor cold front is given by the Shoeburyness anemogram, (the nearest in the general direction of the wind flow to North Weald) extracts from which are given in Table 1. Positions A, B, C, and D in Table 1 correspond to the same positions in Figure 2.

TABLE I—SHOEBURYNESS ANEMOGRAM

Time (G.M.T.)	0700–0750	0750–0805	0805–0915	0915–0940
Direction (degrees)	230	250	210	230
Speed (knots)	14	18	12	12
Maximum gust	20	28	...	16
Position (Figure 2)	A	B	C	D

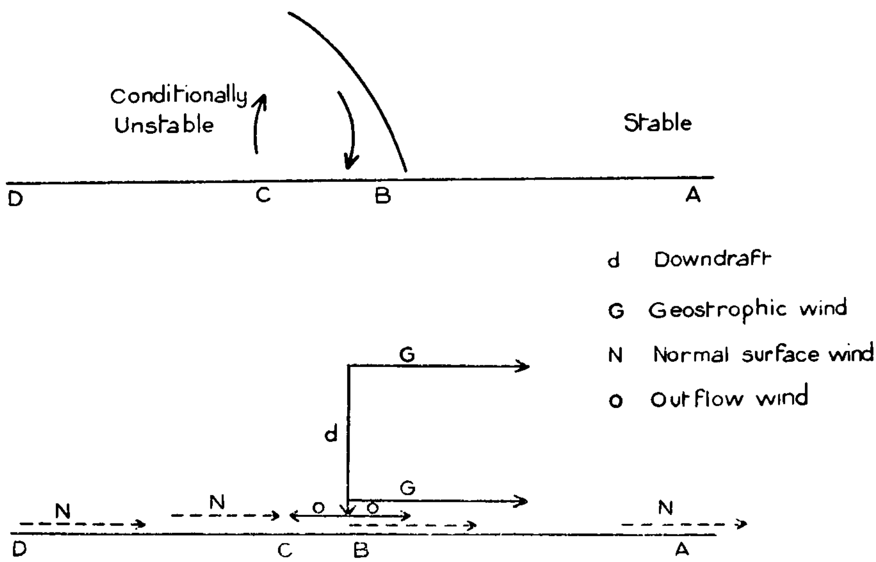


FIG. 2—EASTWARD PASSAGE OF THE MINOR COLD FRONT

Figure 2 illustrates the probable mechanism which resulted from the eastward passage of the minor cold front. The outflow following the downdraft aggravated the effect of the downward displacement of the geostrophic wind from the "frictionless" layer at position B, and momentarily reduced the normal surface wind in the "friction" layer at position C. Positions A and D are respectively well ahead of and well behind the axis of the front.

The foregoing accounts for the general sense of the phenomenon but it does not adequately explain the magnitude of the wind increase. In this respect it is postulated that a local increase in pressure gradient, undetected on the synoptic chart, uniquely coincided with the downdraft associated with the minor cold front described above.

METEOROLOGICAL OFFICE DISCUSSION

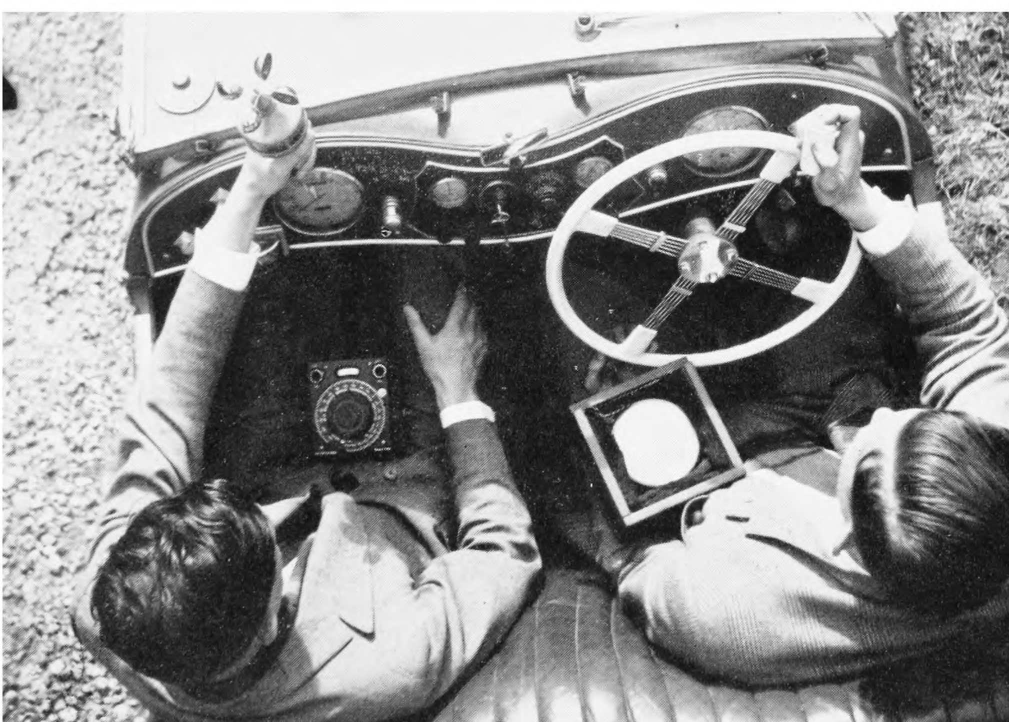
Orographic waves—form, forecasting and effect on aircraft

Opening the Meteorological Office Discussion at the Royal Society of Arts on November 18, 1957, Mr. C. E. Wallington illustrated the nature and characteristics of orographic wave flow by describing some aspects of research into the subject during the last ten years. The existence of waves had, of course, attracted attention long before this decade: plenty of stationary, lenticular

GROUND FOG AT 0330 G.M.T. ON ROUTE OF THE MOBILE METEOROLOGICAL SURVEY ON MAY 27, 1956
(see p. 74)

METEOROLOGICAL INSTRUMENTS USED IN A MOBILE METEOROLOGICAL SURVEY

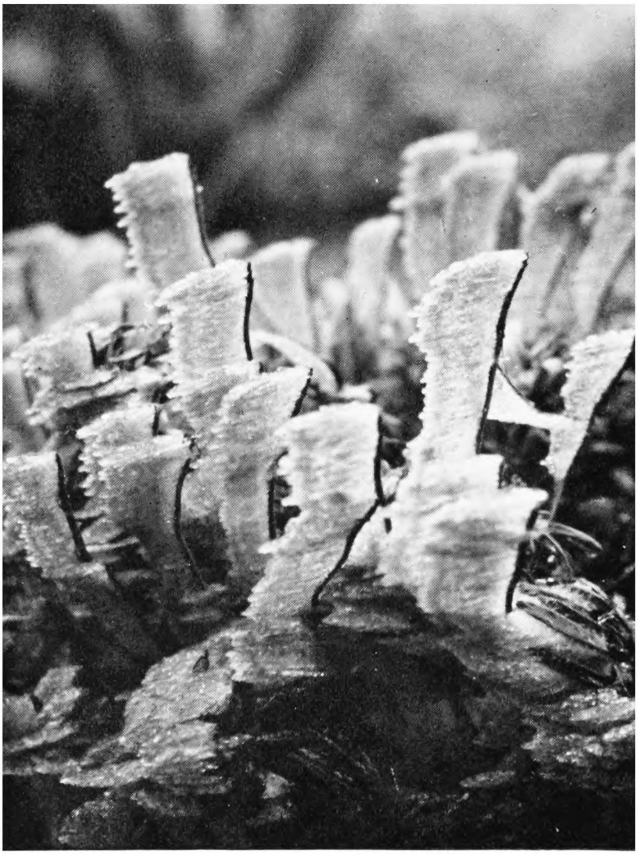
Crown copyright



Crown copyright

DISPOSITION OF METEOROLOGICAL INSTRUMENTS IN A MOBILE METEOROLOGICAL SURVEY

To face p. 81]



Photograph by J. M. Bayliss

RIME ACCRETION

(see p. 90)

clouds had been observed; glider pilots had soared to great heights in waves and Professor Manley, the late Terence Horsley and others had written graphic accounts of wave phenomena[1,2]. But it was Scorer's theoretical study published in 1949 that provided the frame within which all these divers observations could be fitted into a coherent pattern of lee-wave flow[3].

The "natural wavelength".—When discussing wave flow it is often expedient to describe the wind and stability characteristics of an air stream in terms of a particularly relevant parameter. A function of wind speed, U, temperature, T, the lapse rate, $\partial T/\partial z$, and the acceleration due to gravity, g, this wave flow parameter, denoted by λ, is defined by the equation

$$\lambda = 2\pi\left[\frac{g}{U^2T}\left(\frac{\partial T}{\partial z} + \Gamma\right) - \frac{1}{U}\frac{\partial^2 U}{\partial z^2}\right]^{-\frac{1}{2}}$$

where Γ denotes the appropriate adiabatic lapse rate. (λ is another version of a parameter denoted by l in much of the literature on lee waves.) The last term in the formula is often small and its omission reduces the equation to form

$$\lambda = 2\pi U\sqrt{\frac{T}{g\left(\frac{\partial T}{\partial z} + \Gamma\right)}}\,.$$

The significance of the stability factor may be appreciated by considering the buoyancy force on a parcel of air displaced vertically from its equilibrium level in a stable environment. It can be shown that for small displacements this force would cause the parcel to oscillate about its equilibrium level with a period of oscillation equal to

$$2\pi\left[\frac{T}{g\left(\frac{\partial T}{\partial z} + \Gamma\right)}\right]^{\frac{1}{2}}.$$

The greater the stability the shorter the period.

Now vertical oscillation plus horizontal motion leads to a wave-like flow whose wavelength is the period of oscillation multiplied by the horizontal wind speed, in other words the wave length is equal to λ. Thus λ may be regarded as the natural wavelength of the layer of air in which it is measured.

A real air stream usually contains several natural wavelengths; for example, λ may be large in a low-level layer of small stability, small (say about 2 miles) in a layer of great stability with light winds and large (say 15 miles) in a high layer of lesser stability and strong winds. In wave-flow parlance such an air stream as this is called a "three layer" air stream—three separate layers can be distinguished by values of λ . If this air stream is disturbed by crossing a mountain ridge the three layers do not oscillate up and down independently on their own natural wavelengths; this type of motion would not satisfy conditions for physical continuity at the boundaries between the layers. The wavelength of the motion which does maintain this continuity at the boundaries is a complicated function of the distribution of λ with height.

Lee-wave flow.—In 1949 Scorer devised a method of calculating not only the wavelength on which oscillations could take place in an airstream but also the two-dimensional pattern of stream-lines in an air flow crossing a mountain ridge. He computed that a train of lee waves could form downwind of the ridge provided that λ increased with height over some depth of the atmosphere. Observations by Turner[4] and others showed lee-wave effects to be commonly associated with air streams comprising stable air sandwiched between two layers of lesser stability, or more precisely, a three layer troposphere with λ smallest in the middle layer (Figure 1). These observations confirmed Scorer's criterion for the existence of lee waves but it was difficult to make quantitative tests of the calculated flow pattern itself.

A start was made by focussing observational attention on several of the distinctive features which could arise from the motion illustrated in Figure 1. Further deductions relating to diurnal variations in wave flow were made from the theoretical study.

Diurnal variations.—Theoretical study showed that when an early morning inversion was gradually transformed by insolation into an unstable layer at low levels then the lee wavelength of the air stream would increase and that subsequent cooling by radiation during the late afternoon and evening would lead to a decrease in wavelength. It could also be deduced that lee waves would be most pronounced during the morning and evening and relatively weak, or even non-existent during the early afternoon. These deduced diurnal tendencies were supported by many observations made by glider pilots and others whose business or pleasure kept them acutely aware of waves and their habits (see, for example, evidence by Manley and Roper[1,5]).

The effect of synoptic changes.—An investigation by Wallington showed that, ahead of a well marked warm front, lee waves were likely to be significant in two zones[6]. Ahead of the warm front featured in this investigation lee waves were calculated and observed to be particularly pronounced at low levels in a zone between about 150 and 250 miles ahead of the surface position of the front. Pronounced lee-wave flow was also possible at both high and low levels at distances between about 400 and 600 miles ahead of the front. Between these zones short lee waves were possible but their amplitudes would not have been significant.

This study drew attention to the short-comings of the lee-wave criterion; an increase of λ with height denoted the possibility of lee waves forming but gave no indication of the magnitude of the waves. The next step, therefore, was to examine more closely the factors controlling lee-wave amplitude in the hope that some more useful forecasting rules could be evolved. But a study by Corby and Wallington revealed the wave flow to be even more sensitive to synoptic changes than had been supposed and no simple criteria for large amplitude waves could be formulated[7].

The effect of mountain shape and size.—The study by Corby and Wallington also investigated the effect of mountain size and shape. To ease computing problems it is convenient to study lee-wave flow downwind of a long ridge whose height, h, at horizontal distance, x, from its summit is given by

$$h = \frac{Hb^2}{b^2 + x^2},$$

where H denotes the height of the ridge and b is a width parameter. The lee-wave amplitude may then be considered as the product

$$\left[Hb \exp\left(-2\pi\frac{b}{W}\right)\right] \times \left[\begin{array}{l}\text{an air-stream factor determined entirely}\\ \text{by upper winds and temperatures}\end{array}\right]$$

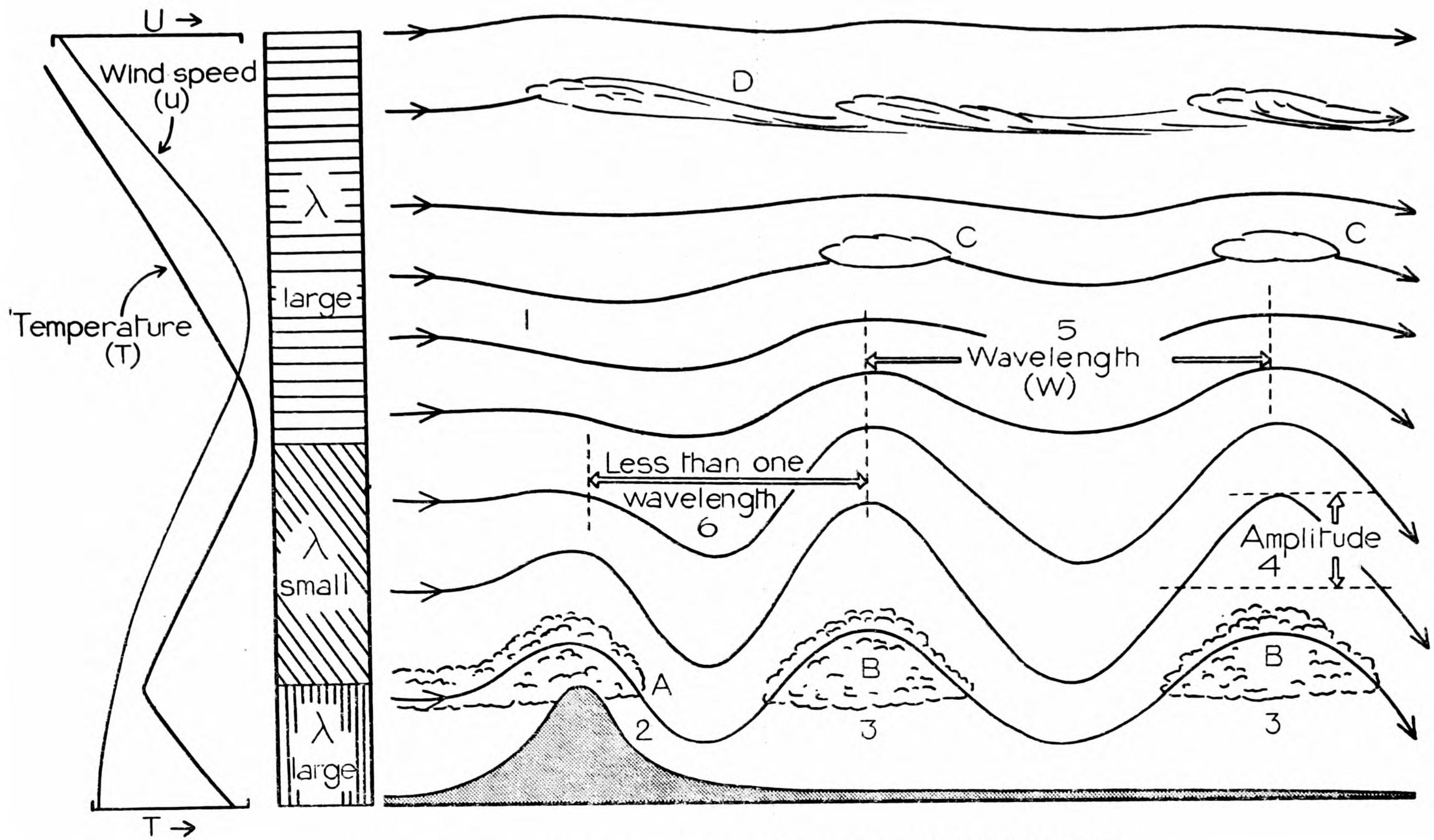


FIG. 1—FEATURES OF AIR FLOW ACROSS A LONG MOUNTAIN RIDGE

"Three layer" troposphere

1. Down draught may occur at some levels to windward of ridge. 2. Strong surface wind down lee slope. 3. Variable surface wind. 4. Maximum amplitude in stable layer. 5. Order of wavelengths: 2–20 miles. 6. First wave crest usually less than one wavelength downstream of ridge. A. Föhnwall. B. Roll cloud. C. Altocumulus lenticularis. D. Cirrus.

The first factor of the product, the mountain factor, which incorporates the lee wavelength W, reveals that the higher the ridge the bigger the wave amplitude. But the width is also important; the parameter b is incorporated in the mountain factor in such a way that, if H is kept constant, the term has a maximum when $2\pi b = W$. This means that if an air stream passes over a number of ridges all of the same height then the biggest waves will occur in lee of the ridge whose width parameter is equal to $W/2\pi$. Narrower or broader ridges will produce waves of lesser amplitude. There is, in fact, a resonance effect between the air stream and the mountain width, and on occasions this resonance even swamps the effect of mountain height. The height of a large mountain will be of little use in setting off lee waves if the mountain width is too great for resonance with the wavelength in force.

Observations of wave phenomena.—Theoretical study directed observational effort to better effect and by 1955 Pilsbury had collected and analysed 66 reports of wave phenomena encountered in flight by British European Airways pilots[8]. His analysis showed these wave effects to be associated with:

(i) a high lapse rate from ground level to at least 2,000 feet,

(ii) a stable layer (depth 800 to 10,000 feet) above the less stable air,

(iii) an upper layer of low stability,

(iv) a wind speed of at least 15 knots at the 950-millibar pressure level,

(v) a wind direction almost constant up to the top of the stable layer.

The wave effects occurred in a variety of synoptic situations. Wavelengths were of the order of 3 to 8 miles below 10,000 feet with indications of longer waves at higher levels. Vertical speeds were often 300–500 feet per minute, occasionally 700–900 feet per minute and on one occasion over 2,000 feet per minute was reported. Slight turbulence was noted on one third of the cases and moderate turbulence in two out of the 66 reports.

Some pilots gave particularly detailed accounts of the wave phenomena they encountered. A contribution of special interest was made by Captain Mason who encountered orographic wave effects with vertical speeds of more than 1,000 feet per minute over Spain[9]. The air flow containing these effects was a north-north-westerly stream with an isothermal layer from 8,000 to 11,000 feet.

In America men and equipment were available for exploring the frequently observed wave flow in lee of a Rocky Mountain range called the Sierra Nevada[10]. Using gliders, powered aircraft, radio-sonde and radar equipment this intensive field project not only supported much of the theoretical study into the subject but also revealed the order of magnitude at several features of the flow. One of the features explored by the Sierra Wave Project was the turbulent region sometimes found at low levels at wave crests. Wave cloud in this region looks like ragged stratocumulus but it harbours severe turbulence. Turbulence associated with wind shear and the variation with height of wave amplitude also occurs at high levels but this type is not usually so severe as the low-level variety.

In the British Isles intensive field study was not a practical proposition but Corby used routine radio-sonde observations for detecting wave flow[11]. His investigation strengthened the growing conviction that waves are often associated with a shallow stable layer in the lower half of the troposphere and that the vertical speeds were at a maximum in this stable layer. Furthermore he was able to deduce the wavelength of waves affecting the balloons during their ascent.

In addition to the British European Airways pilots' reports, the Sierra Wave Project, and the radio-sonde study, a number of local investigations added to the observational data collected by 1955. Turner reported an example of severe turbulence in low-level wave cloud over the Inner Hebrides; Ward described the effects of lee waves on the surface winds at Ronaldsway[12,13]. Studying the low-level turbulence in lee waves in Czechoslovakia, Förchtgott noted the tendency for some wave clouds to move slowly downstream, covering about 1 mile in 5 minutes before jumping back up stream to their initial positions[14]. Harrison illustrated this periodic movement by time lapse films taken near Denver, U.S.A.[15]

Numerical study.—With abundant observations available it became worth while to undertake the mathematical labour of a numerical study of the lee wavelength and air stream amplitude factors of a wide variety of air streams. At Dunstable a numerical study of two-dimensional flow is shedding more light on the relationship between lee wavelength and amplitude and upper winds and temperatures and on the effect of the stratosphere on lee waves in the troposphere[16].

Forecasting wave effects.—The details of orographic wave flow are very difficult to predict but forecasters can to some extent be prepared for their occurrence by recognizing the conditions favourable for wave flow in general. Broadly these conditions are those implied by the analysis of the British European Airways reports. In routine forecasting there are several observational aids which can be used to confirm the presence of wave flow but these aids cannot prove the non-existence of waves. A forecaster can say with reasonable confidence that waves associated with a stable layer will be most effective in that layer and that if waves occur in the presence of marked wind shear, such as in a jet stream, then there will probably be some turbulence. Probably the best way of attempting more than this is to calculate values of λ (using a special scale[17]) at several levels in situations of particular interest and to build up some experience at assessing the relationship between these values and the observed effects.

In addition to attempting to predict the likelihood of wave effects the forecaster can do aviators a great service by explaining to them the nature and characteristics of lee-wave flow in general. Besides producing wave cloud, turbulence, variable winds and increased icing risk, orographic wave flow can also cause fluctuations in airspeed and lead to difficulties in maintaining vertical separation of aircraft in air lanes. Altimeter errors can occur in wave flow but usually they are small and insignificant compared to the effects of vertical motion and turbulence.

The Chairman, *Dr. Stagg* opened the subsequent discussion by asking out-station forecasters to relate some of their experiences in coping with orographic wave problems.

Mr. F. Davis described the hazards to parked aircraft of sudden and erratic changes of surface wind which had been noted at Sealand. It appeared likely that these changes were due to wave flow. Was there a method of predicting the time and duration of such changes? Mr. Wallington replied that while forecasters had a reasonable chance of recognizing the general types of conditions favourable for such effects there was, at present, no practical way of predicting details.

Dr. Stewart asked what was the nature of the airflow when no waves were present. The reply suggested that waves could exist in many, if not most, air streams. When they did not occur the air stream was either convectively unstable or slow moving.

Dr. Scorer emphasized the danger of turbulence in "roll" cloud by calling attention to the exceptionally large instability which can be produced in the overturning motion in the turbulent region. He also discussed the distinction between the eddies which sometimes form on lee slopes and the "rotors" which require a stable layer for their formation.

Mr. Gloyne wondered whether hill shape and in particular the steepness of the lee slope determined the likelihood of lee eddies. Was there some steepness criterion with which to predict steady or eddying flow down the lee slope?

Mr. H. H. Lamb remembered seeing high-level wave cloud over Scotland; the position and orientation of these clouds bore no simple relationship to the topography or to the low-level winds. There appeared to be rather long waves at these high levels which may have been associated with the broad features of the high ground rather than with the smaller and more recognizable ridges.

Mr. Findlater, in reply to a query by Dr. Stagg, said that modern views on mountain air flow are mentioned in various Training School courses, the main purpose being to acquaint trainees with the nature and effects of mountain air flow.

Mr. Lee asked whether Comets flying at 55,000 feet over the Central Massif and the French Alps would be affected by orographic wave flow. In reply to this Mr. Wallington said that wave effects, including turbulence, had been reported as high as 44,000 feet in the Sierra Wave Project. Evidence suggested that long waves may not be uncommon in the stratosphere but this evidence was based mainly on theoretical study and more actual observations were needed to support or modify these deductions. The French Meteorological Service have carried out field studies of air flow over the French Alps and a preliminary report has just been published[18].

Mr. Sawyer reminded the meeting that real atmospheres and real topography are not so simple as most of the models used for numerical study. It may be impossible to set an upper limit to vertical currents when all conditions are favourable.

Mr. C. V. Smith enquiring about the effect of wave flow on contour height was told by Mr. Sawyer that variations of about 50 feet at the 500-millibar level might be expected from wave effects.

Mr. Jacobs drew attention to local wind effects near Edge Hill which would probably be worth investigating.

Mr. Richardson, asking whether or not convection could take place from the top of cloud in the wave crests, was told that such a process had been observed.

Mr. L. Jacobs wondered what had become of the model experiments. Were they now out of fashion? Mr. Wallington replied that it was practically impossible to achieve strict similarity between model experiments and a real air flow extending over appreciable vertical depth. The numerical study now being carried out could be considered as a type of model experiment in which conditions were easily controlled. Dr. Scorer added that model experiments sponsored by the Meteorological Office are being conducted at Imperial College.

Mr. Gold suggested that an elaborate field survey of the air flow across the Welsh Mountains or across the Pennines in just a few synoptic situations would be useful.

Dr. Stagg replied that a scheme such as this had been considered and rejected as economically impractical some years ago. He then summed up some of the points raised and thanked Mr. Wallington for opening the discussion.

REFERENCES

1. MANLEY, G.; The helm wind at Crossfell. *Quart. J. R. met. Soc., London,* **71,** 1945, p. 197.
2. HORSLEY, T.; New light on the standing wave. *Aeronautics, London,* **11,** 1945, p.38.
3. SCORER, R. S.; Theory of waves in lee of mountains. *Quart. J. R. met. Soc., London,* **75,** 1949 p. 41.
4. TURNER, H. S.; Standing waves and powered flight. *Met. Mag., London,* **80,** 1951, p. 106.
5. ROPER, R. D.; Evening waves. *Quart, J. R. met. Soc., London,* **78,** 1952, p. 415.
6. WALLINGTON, C. E.; Lee waves ahead of a warm front. *Quart. J. R. met. Soc., London,* **81,** 1955, p. 251.
7. CORBY, G. A., and WALLINGTON, C. E.; Airflow over mountains: the lee-wave amplitude. *Quart. J. R. met. Soc., London,* **82,** 1956, p. 266.
8. PILSBURY, R. K.; Preliminary analysis of standing-wave reports received at Northolt during the winter of 1953–54. *Met. Mag., London,* **84,** 1955, p. 313.
9. MASON, D.; Hill standing waves and safety heights. *Weather,* **9,** 1954, p. 45.
10. HOLMBOE, J., and KLIEFORTH, H.; Investigations of mountain lee waves and the airflow over the Sierra Nevada. University of California, Department of Meteorology. Final report of contract AF 19(604)—728. Los Angeles, 1957.
11. CORBY, G. A.; A preliminary study of atmospheric waves using radio-sonde data. *Quart. J. R. met. Soc., London,* **83,** 1957, p. 355.
12. TURNER, H. S.; Severe turbulence over the Inner Hebrides. *Met. Mag., London,* **81,** 1952, p. 239
13. WARD, F. W.; Helm-wind effect at Ronaldsway, Isle of Man. *Met. Mag., London,* **82,** 1953, p. 234.
14. FÖRCHTGOTT, J.; The active turbulent layer in lee of mountain ridges. *Schweiz. Aerorev., Berne.,* **32,** 1957, p. 324.
15. HARRISON, H. T.; Synoptic features of the mountain wave at Denver, Colorado. *United Air Lines Met. Circ., Denver,* **41,** 1956.
16. WALLINGTON, C. E., and PORTNALL, J.; A numerical study of the wavelength and amplitude of lee waves. *Quart. J. R. met. Soc., London,* **84,** 1958, p. 38.
17. WALLINGTON, C. E.; A lee-wave scale. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 545.
18. BÉRENGER, M., and GERBIER, N.; Les mouvements ondulatoires à Saint Auban-sur-Durance. *Monographie de la Météorologie Nationale, Paris,* 1957.

LETTERS TO THE EDITOR

Night cooling under clear skies at Wittering

Further study of the temperature graphs produced by Mr. Pollard in Fig. 1 of his article[1] suggests that his conclusion that there is no evening temperature discontinuity at Wittering is not entirely correct. If the temperatures for these occasions are plotted from mid-afternoon instead of from 1700–1800 G.M.T., as in Fig. 1, it is obvious that on two of the occasions there was a discontinuity (approximately 4°F./hr. changing to 2°F./hr.). The time was 1800 G.M.T., the recognized time for early October.

It is also noted that the temperatures at this time would have been readily predictable by the discontinuity method, as shown overleaf:—

Date	T_{max}	T_d at time of T_{max}	T_r (calculated)	1800 G.M.T. temperature
	°F.	°F.	°F.	°F.
October 8, 1955	69·0	58·0	62·5	61
October 10, 1955	67·0	51·0	58·0	58
October 12, 1955	64·0	52·5	57·2	57

In this table T_r was calculated using the Mildenhall equation $T_r = \frac{1}{2}(T_{max} + T_d) - 1\cdot0$°F., on the assumption that Wittering and Mildenhall might not differ materially. The Daily Aerological Records show that the three afternoons were "non-inversion" having regard to Wittering. The case of October 12, 1955 shows that the forecast T_r was reached at 1800, despite the fact of having no marked discontinuity at screen level.

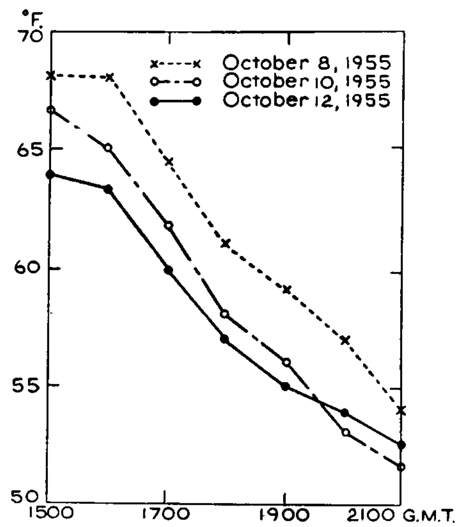


FIG. 1—EVENING TEMPERATURES AT WITTERING

It is thought the difficulty at stations like Wittering is not that the discontinuity does not occur, but that in the screen-level observations it often appears insignificant compared with some of the random irregularities which are liable to occur later in the night due to air-mass heterogeneities. At Exeter hourly readings are being made of a thermometer (with the bulb screened) exposed at the grass level. These confirm that the evening change in cooling rate is much more pronounced at grass level than in the screen. Although at Exeter the discontinuity is generally clearly recognizable at screen level, there are a few occasions when it is only shown at grass level. An example is given in Fig. 2. This shows that the discontinuity (from 12°F./hr. to 2°F./hr.) occurred at grass level at the time for early September given by the published Exeter curve[2], although there was no corresponding change at screen level. As in the case of October 12, 1955 at Wittering, the screen-level temperature at the time of the grass-level discontinuity corresponded very closely with the theoretical value (forecast T_r 59·9°F., actual 1900 G.M.T. temperature 60·2°F.). This suggests that if at some sites the discontinuity cannot readily be discerned at screen level it may still be quite pronounced nearer the ground. Whether or not there is a marked change of rate in the screen, the screen temperature at that time is significant for forecasting purposes, because a different set of conditions becomes operative near the ground.

In the forecasting technique proposed by Mr. Pollard it is considered that the adoption of constants, which give the best fit for Wittering and which vary seasonally, improves McKenzie's formula. Allowing for this, the McKenzie method still seems open to two criticisms. It does not provide for the fact that the lower the initial temperature of a period of cooling the smaller, in general, is the amount of cooling. In the T_r/T_{min} cooling curves this is brought out by the shape of the curves, e.g. at Northolt in winter, if T_r is 50°F. the subsequent

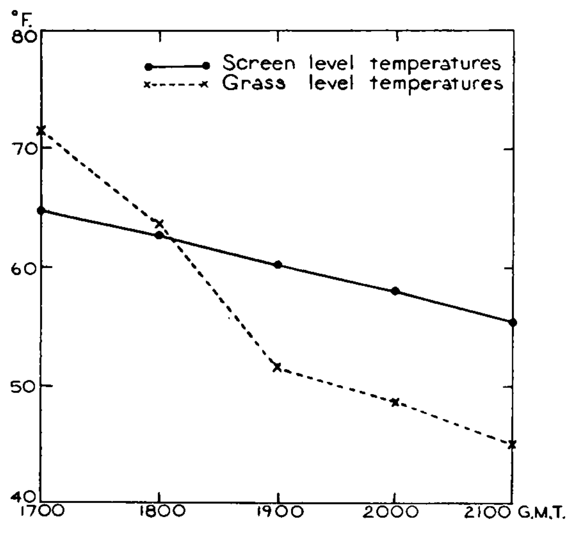


FIG. 2—EVENING TEMPERATURES AT EXETER, SEPTEMBER 7, 1955

cooling is on average 18°F.; if T_r is 30°F. it is only 11°F. Secondly, McKenzie's formula does not allow for the difference between cases in which a subsidence inversion is or is not present near the ground. In the T_r/T_{min} method this is allowed for in the regression equations for T_r, and also, at some stations, in the curves expressing the T_r/T_{min} relations. Since the inversion case dealt with here is obviously identical with the inversion fog case reported at Cardington by K. H. Stewart[3], in which early night cooling affects a deeper layer than usual and in which vertically thick fog forms suddenly, it is not a matter which the aviation forecaster can ignore.

With regard to the results quoted by Mr. Pollard in Table II, it is only possible to make comparisons by using the mean square difference between the forecast and actual T_{min}. At Northolt, using Northolt curves,[4] a test on thirty clear nights gave mean square difference 1·28°F. At Weston Zoyland, using Exeter curves[2] together with the correction:— T_{min} (Weston Zoyland) = T_{min} (from Exeter curves) − 0·9°F., a test on thirty-two clear nights gave mean square difference 1·40°F. The difference between these results and Mr. Pollard's mean square difference 2·15°F. is presumably due to the parameters mentioned above which McKenzie's method does not take into account.

It is considered that, now that the general form of the regression equations for T_r and the shape of the T_r/T_{min} curves has been well established, the main requirement for local study appears to be in marginal matters such as the effective dates for introduction of winter and summer curves on different sites. For use in fog forecasting there is much scope for preparation of curves similar to those of Mr. Pollard's Fig. 2, but covering the period from the time of the evening discontinuity to sunrise for the separate seasons, and for different ranges of gradient wind speed (gradient wind in preference to surface wind). There should be no need to separate according to wind direction, since with an on-shore wind the effects of relatively warm or cold sea should be taken into account at the outset, in the selection of the most representative maximum temperature and the corresponding dew-point.

W. E. SAUNDERS

Mt. Batten, Plymouth

REFERENCES

1. POLLARD, K.; A preliminary study of night cooling under clear skies at Wittering. *Met. Mag., London*, **87**, 1958, p. 12.

2. SAUNDERS, W. E.; Night cooling under clear skies, Exeter Airport. *Met. Mag., London*, **83**, 1954, p. 9.

3. STEWART, K. H.; Radiation fog. Investigations at Cardington, 1951–54. *Met. Res. Pap., London*, No. 912, p. 8.

4. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 603.

Rime accretion

The accompanying photograph of rime accretion on the dead flower stalks of a rock plant was taken at 1000 G.M.T. on December 22, 1956 at Bedale in the North Riding of Yorkshire. At this time the rime had grown to a length of 1 inch on the south-eastern sides of the stalks, which were 3–5 inches high and averaged one sixteenth of an inch in diameter. The rime, which was dirty white in colour due to industrial smoke mixed with the fog, was firm and hard, probably due to the fluctuation of the temperature about the freezing point, thus causing alternate partial melting and freezing.

The freezing fog which caused this accretion had been persistent since the evening of December 18, with visibility in the range 30–100 yards for the majority of the time; the air temperature being between 27 and 33 degrees Fahrenheit. The surface wind velocity varied from calm to 10 knots from between 090 and 170 degrees.

The photograph was taken on a Soft Gradation Panchromatic plate and was given an exposure of 2 seconds with lens aperture f.11. J. M. BAYLISS

NOTES AND NEWS

The Abnormal Summer of 1956 at Bahrain

There were several features of the weather at Bahrain during the summer of 1956 which were unusual and deserve recording.

May was a cold month: it was the coldest since systematic daily records began at Muhurraq Airport in 1946; the average temperature was 4½°F. below the normal for the ten-year period 1946 to 1955. It was also the windiest on record, with abnormally strong north-westerly winds—gusts of 30 knots or more being recorded on seven days. The period of strong north-westerly winds, known locally as the 40-day Shamal, usually starts in June and continues into July.

June was 3°F. colder than normal, but the outstanding feature of the month was the thick dust haze during the first week. This thick dust haze originated from duststorms over southern Iraq and persisted over Bahrain and the Persian Gulf area from the 2nd to the 6th. Towards the end of the period the dust cloud extended from southern Iraq as far south as the southern coast of Arabia and as far east as Karachi. This exceptional spell, according to local residents, was the worst in living memory.

July was characterized by light and variable winds instead of the usual north-westerlies and by abnormal cloud amounts (daily average 3·2 oktas compared with an average of 0·7 oktas for the previous ten years). These clouds were of the altocumulus–altostratus or altocumulus castellanus types. No rain was actually recorded at the Meteorological Office, but a little rain fell at Manama some three miles away at 4 a.m. on July 30. No rain has ever been recorded during the summer months since observations began at the Airport. August was normal in all respects except that the maximum temperature of 113°F. on the 5th was the highest ever recorded. September was apparently normal in all respects.

It is probable that the weather during the summer of 1956 was abnormal over a large part of the neighbouring region of the Middle East. Certainly there were some interesting and unusual aircraft reports received during July. A selection of these is given.

July 23, R.A.F. Pembroke (Flying Officer Watt), flight Sharjah to Ibri (40 miles north-east of Fahoud), p.m.: Cumulonimbus whole route with heavy rain. Flood water on the desert isolated the airstrip at Ibri.

July 16, Aryana, flight Bahrain to Kabul: Towering cumulonimbus in all directions around Kandahar, tops generally 13,000 feet, many thunder heads above.

July 25, British Overseas Airways Corporation, Cairo to Bahrain p.m., flight level 15,500 feet: At 28°N. 43°E. 5 oktas layered altocumulus with isolated cumulonimbus top 23,000 feet. 8 oktas altostratus and rain at 28°N. 44°E.

It is difficult to give any satisfactory explanation of these events other than to say that they were due to the unusually early onset of the Indian Monsoon, and to its penetration far northwards into the subtropical belt to an extent hitherto unrecorded.

F. E. DINSDALE

[The unusual amount of rainfall at Sharjah, Oman, Persian Gulf in the summer of 1956 was described, with a photograph of a line of cumulonimbus clouds, by Mr. E. W. Smith in the May 1957 number of the *Meteorological Magazine*. Ed. M.M.]

REVIEWS

Empire Forestry Review, **36**, 1957, No. 1, London.

The March 1957 number of the *Empire Forestry Review* includes two articles of meteorological interest. Mr. M. V. Laurie, Chief Research Officer, Forestry

Commission, writes on the effect of forests in water catchment areas on the water losses by evaporation and transpiration and Mr. A. Bleasdale of the Meteorological Office on the physicist's approach to problems of water loss from vegetation. Mr. Laurie is satisfied that Penman's evaporation formula is accurate over wide areas of mixed vegetation but considers that experiments are highly desirable for water supply planning to ascertain the differences in the evapo-transpiration from different types of vegetation, notably the differences between the water loss from forests and from areas of short vegetation. He states that it has been suggested that evapo-transpiration is 10 per cent higher from trees than from grass, a very large difference to the water engineer.

The methods suggested are:

(i) comparison of rainfall, run-off etc. from two similar areas neither of which is forested, and then growing trees on one of them and comparing rainfall and run-off again, and

(ii) exact measurement of the water balance of two areas covering rainfall, fog drip, run-off, accumulation of water in the soil with lysimeters. As Mr. Laurie remarks these are costly in time and effort and uncertain in result.

Mr. Bleasdale agrees that there can never be a comprehensive instrumental comparison between the hydrological balance of forested and open spaces since measurements of the terms of the water balance equation, in particular of the evaporation loss, must be based on sampling methods. He accordingly devotes his paper to a review of the existing information on the physical factors concerned. The experimental evidence is contradictory, some workers in different countries and climates having found little difference between types of vegetation cover and others appreciable differences. Mr. Bleasdale points out the opposing factors concerned such as the larger area of exposed surface at the windward side of a forest followed by a reduction of evaporating power in the damper air as it moves inward, and the "fog drip" in fog or cloud on the windward edge followed again by a downwind compensating effect of higher evaporation into air cleared of fog. He believes that the methods of calculating evapo-transpiration based on Penman's work (with energy balance consideration dominating the broad-scale results) will remain valid over large forested areas but that there may be scope for arranging vegetation types to take advantage of the edge processes.

G. A. BULL

Geophysical Institute, Faculty of Sciences, University of Zagreb, Yugoslavia.

We have received three papers written in this Institute as follows:

Geoph. Inst. Papers, IIIrd Series, No. 5. On the discontinuity in the curve of the fall of temperature on cloudless nights. By Ivo Penzar.

Geoph. Inst. Papers, IIIrd Series, No. 7. Microclimatological investigations of the Geophysical Institute made at Krizevci in 1953. By Ivo Penzar.

Rad jug. Akad. Znam. Umj. **302,** 1956. A method of reducing the barometer to mean sea level. By B. Maksic.

They are all in Croat with long German summaries.

The first of these is of most interest. The author compares the differences in occurrence of times of the evening "cooling curve" discontinuity at three stations, one the Zagreb Observatory on rising ground at Gric, height 162·5 metres, one in the Botanic Garden in the plain 1 kilometre away at 116 metres, and the third the mountain observatory at Sljeme, 999 metres. The discontinuity occurred at Sljeme at most ½ hours, in the Botanic Garden ¾ to 1½ hours, and at Gric an hour or more after sunset. The difference between the Botanic Garden and Gric is ascribed to the nocturnal fall of temperature beginning earlier in the plain than on small hills. It is stated that thermographs used in the microclimatic investigation at Krizevci showed that discontinuity occurred earlier in valleys than on slopes or hills. It was also found at Krizevci that the discontinuity occurred 8 minutes later in the layer up to 1 metre above the ground than on the surface but in the layer 1 to 2 metres the delay was only 6 minutes. This effect may play a part at Gric where the thermograph is on a north wall 4 metres above the surface. Formulae are given for computing the temperature at the time of discontinuity from midday temperatures and humidities and the night minimum from the "discontinuity" temperature. The writer rejects the dew-point and transpiration theories of the discontinuity but has no alternative to offer.

G. A. BULL

Fortschritte in der meteorologischen Forschung seit 1900. By B. Neis. 9 in. × 6 in., pp. xviii + 238, *illus.*, Akademische Verlagsgesellschaft M.B.H., Frankfurt am Main, 1956. Price: 28 *DM.*

This book, based on a course of lectures given in 1953–54 at the Free University of Berlin, is stated in the preface to be an account of those researches of the present century which have contributed to the development of meteorology as a branch of mathematical physics. Papers are quoted in the book to 1953.

The two major previous histories, those of Sir Napier Shaw in Volume I of the *Manual of Meteorology* (1931) and K. Schneider Carius in *Wetterkunde Wetterforschung* (1955), began with the Babylonians and so could devote only a relatively small part of their texts to the 20th century. Dr. Neis's book is naturally much fuller than theirs.

Dr. Neis describes the history of each part of the subject more or less separately. The book is divided into four parts covering subjects as follows:

Part I: General state of physics and meteorology in 1900 and changes in basic physical ideas (causality etc.) since then.

Part II: Aerology and its methods, aerosols, synoptic models, wind structure and turbulence, physics of radiation.

Part III: Weather as the process of transformation of solar radiation into other forms of energy covering matters such as radiative equilibrium theory, vorticity, general circulation.

Part IV: Weather forecasting, climatology and climatological services.

There are good photographs of eighteen eminent meteorologists including Sir Napier Shaw and W. H. Dines.

1900 is a good time to start a history as it was just before the first flowering of upper air observation with its discovery (1902) of the tropopause. The author has well succeeded in his enormous task of giving an account of the development of meteorology from, as Sir D. Brunt has said, an arithmetical exercise to a branch of physics. Some sides are more thoroughly covered than others. Radiation and aerology are thoroughly treated but the post-1945 history of cloud physics is scarcely touched on. In dynamical meteorology the account extends to Rossby's constant-vorticity and Sutcliffe's development theorems but there is no mention of Charney. There is a tendency to give more space to German than foreign meteorologists. Thus the history of ozone research makes no mention at all of Dobson's work.

There are numerous references to accounts of the state of knowledge of various parts of the subject. Thus for numerical forecasting there is a reference to a review by K. Hinkelmann and others published in 1952.

G. A. BULL

HONOURS

The following awards were announced in the New Year Honours List, 1958:

O.B.E.

M. H. Freeman, M.Sc., Principal Scientific Officer, Meteorological Office.

M.B.E.

W. R. Hanson, B.Sc., Senior Experimental Officer, Meteorological Office.

METEOROLOGICAL OFFICE NEWS

Retirement.—*Mr. H. T. Smith*, Chief Experimental Officer, retired on 28 January, 1958. He joined the Office as a Boy Clerk in April 1914 in the Administrative Division. He was transferred to the Marine Division in May 1915 but shortly afterwards he joined the Civil Service Rifles for service during the First World War. On his return to the Office in February 1919 he resumed duty in the Marine Division where he remained for the next 22 years. In 1941 he was posted to the Instruments Division and he served in that Division until his retirement. From December 1956 he was Head of the Branch dealing with instruments supply.

Obituary.—*Miss D. K. Lamport.*—We regret to learn of the death on 20 January, 1958 of Miss D. K. Lamport who until 1937 was a temporary assistant in the British Climatology Division.

THE WEATHER OF NOVEMBER, 1957

Northern Hemisphere

A broad trough of low pressure in mid-Atlantic extended from the Icelandic depression, which was in the normal position, to latitude 40°N. Pressure was higher than average over an area which extended from Iceland across the Faroe Islands into central Europe. These higher pressures were associated with blocking anticyclones to the west and north of the British Isles during the period from the 8th to the 15th of the month and near Spain from the 17th to the 29th. The low pressure area centred near Spitsbergen, although less deep than usual, extended into northern Russia. The main Siberian anticyclone was divided; one centre being just east of the Sea of Aral and the other in eastern Siberia. The Azores anticyclone was apparent only as a ridge and the area of maximum pressure was further to the south than usual. The North Pacific high was a little further east than the normal position and extended into the United States.

The largest pressure anomalies were + 8 millibars over Scotland and southern Norway. In North America the mean pressure distribution for the month was near normal. There were, however, areas of positive pressure anomaly in the west of the United States and Canada and also in the Baffin Island area. A slight negative pressure anomaly in the Great Lakes region was associated with an eastward displacement of the anticyclone normally situated a little to the south. The pressure distribution over the Arctic during November was nearly normal but the central pressure of the anticyclone extending north from north-east Siberia was + 8 millibars above normal.

In the Atlantic–European sector, blocking produced meridional rather than zonal flow and the normal westerly flow across the Atlantic between latitudes 40°N. and 60°N. was interrupted.

The largest area of negative temperature anomaly was in north Siberia. Centres of positive temperature anomaly of 3°C. occurred in Russia at the southern extremity of the Ural Mountains, over the west of Hudson Bay, in New Mexico and in the West Indies. The mean temperature for the month was more than 5°C. above normal in Alaska, Manchuria, Baffin Island and the Kamchatka Peninsula.

Precipitation exceeded the normal over northern Europe and also over some Mediterranean lands. Rainfall was greater than normal over most parts of North America although the weather was drier than usual along the west coasts of the United States and Canada. In India rainfall was generally less than average except in coastal regions and in West Pakistan.

WEATHER OF JANUARY 1958

Great Britain and Northern Ireland

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 ...	61	−3	−0·9	98	−1	108
Scotland	62	−7	−1·7	100	0	110
Northern Ireland ...	56	9	−1·1	100	−1	128

RAINFALL OF JANUARY 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	2·26	100	*Carm.*	Pontcrynfe	4·56	67
Kent	Dover	3·80	136	*Pemb.*	Maenclochog, Ddolwen B.	4·73	67
,,	Edenbridge, Falconhurst	3·87	122	*Radnor*	Llandrindod Wells ...	4·38	96
Sussex	Compton, Compton Ho.	5·21	123	*Mont.*	Lake Vyrnwy	6·83	85
,,	Worthing, Beach Ho. Pk.	4·38	149	*Mer.*	Blaenau Festiniog ...	9·29	73
Hants.	St. Catherine's L'thouse	4·48	133	,,	Aberdovey	3·64	84
,,	Southampton, East Pk.	4·64	135	*Carn.*	Llandudno	2·66	90
,,	South Farnborough ...	2·41	89	*Angl.*	Llanerchymedd ...	3·21	75
Herts.	Harpenden, Rothamsted	2·76	102	*I. Man*	Douglas, Borough Cem.	5·45	109
Bucks.	Slough, Upton ...	2·82	117	*Wigtown*	Newton Stewart ...	5·40	95
Oxford	Oxford, Radcliffe ...	3·54	150	*Dumf.*	Dumfries, Crichton R.I.	5·23	110
N'hants.	Wellingboro' Swanspool	2·55	111	,,	Eskdalemuir Obsy. ...	6·45	85
Essex	Southend W.W. ...	2·03	109	*Roxb.*	Crailing...	1·62	67
Suffolk	Ipswich, Belstead Hall	2·51	115	*Peebles*	Stobo Castle	3·68	84
,,	Lowestoft Sec. School	2·19	99	*Berwick*	Marchmont House ...	1·91	66
,,	Bury St. Ed., Westley H.	2·40	103	*E. Loth.*	N. Berwick	0·85	40
Norfolk	Sandringham Ho. Gdns.	2·86	114	*Midl'n.*	Edinburgh, Blackf'd H.	1·37	56
Dorset	Creech Grange... ...	4·95	118	*Lanark*	Hamilton W.W., T'nhill	4·43	99
,,	Beaminster, East St. ...	4·94	113	*Ayr*	Prestwick	3·32	90
Devon	Teignmouth, Den Gdns.	3·57	95	,,	Glen Afton, Ayr San. ...	7·54	109
,,	Ilfracombe	3·92	95	*Renfrew*	Greenock, Prospect Hill	7·27	93
,,	Princetown	9·06	84	*Bute*	Rothesay, Ardencraig...	7·65	127
Cornwall	Bude	3·48	94	*Argyll*	Morven, Drimnin ...	7·63	112
,,	Penzance	6·06	121	,,	Poltalloch	6·33	99
,,	St. Austell	6·74	120	,,	Inveraray Castle ...	8·06	77
,,	Scilly, St. Mary ...	4·02	113	,,	Islay, Eallabus ...	6·51	113
Somerset	Bath	2·60	87	,,	Tiree	5·73	121
,,	Taunton	2·42	81	*Kinross*	Lock Leven Sluice ...	2·26	60
Glos.	Cirencester	3·25	97	*Fife*	Leuchars Airfield ...	1·68	68
Salop	Church Stretton ...	3·08	87	*Perth*	Loch Dhu	10·41	103
,,	Shrewsbury, Monkmore	1·72	72	,,	Crieff, Strathearn Hyd.	4·23	95
Worcs.	Worcester, Diglis Lock	1·96	77	,,	Pitlochry, Fincastle ...	2·51	60
Warwick	Birmingham, Edgbaston	2·61	88	*Angus*	Montrose Hospital ...	3·46	140
Leics.	Thornton Reservoir ...	2·72	102	*Aberd.*	Braemar	3·77	92
Lincs.	Cranwell Airfield ...	2·14	103	,,	Dyce, Craibstone ...	3·52	116
,,	Skegness, Marine Gdns.	1·99	95	,,	New Deer School House	5·07	163
Notts.	Mansfield, Carr Bank...	2·64	99	*Moray*	Gordon Castle	3·19	135
Derby	Buxton, Terrace Slopes	5·38	98	*Inverness*	Loch Ness, Garthbeg ...	3·20	67
Ches.	Bidston Observatory ...	2·45	96	,,	Fort William	7·69	77
,,	Manchester, Ringway...	3·00	100	,,	Skye, Duntulm... ...	7·24	124
Lancs.	Stonyhurst College ...	3·53	71	,,	Benbecula	7·74	164
,,	Squires Gate	3·30	103	R. & C.	Fearn, Geanies ...	1·78	95
Yorks.	Wakefield, Clarence Pk.	2·49	98	,,	Inverbroom, Glackour...	6·59	104
,,	Hull, Pearson Park ...	2·17	92	,,	Loch Duich, Ratagan...	10·89	118
,,	Felixkirk, Mt. St. John...	2·50	89	,,	Achnashellach	11·83	133
,,	York Museum	2·24	96	*Suth.*	Stornoway	6·74	161
,,	Scarborough	2·96	117	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough... ...	1·58	74	,,	Wick Airfield	4·10	140
,,	Baldersdale, Hury Res.	2·88	73	*Shetland*	Lerwick Observatory ...	5·61	124
Nor'l'd	Newcastle, Leazes Pk....	1·67	67	*Ferm.*	Belleek	5·39	115
,,	Bellingham, High Green	2·51	69	*Armagh*	Armagh Observatory ...	3·40	104
,,	Lilburn Tower Gdns. ...	2·71	93	*Down*	Seaforde	3·62	83
Cumb.	Geltsdale	2·96	85	*Antrim*	Aldergrove Airfield ...	3·45	94
,,	Keswick, High Hill ...	6·31	94	,,	Ballymena, Harryville...	4·34	101
,,	Ravenglass, The Grove	4·50	102	*L'derry*	Garvagh, Moneydig ...	5·27	127
Mon.	A'gavenney, Plâs Derwen	3·94	77	,,	Londonderry, Creggan	5·25	117
Glam.	Cardiff, Penylan ...	4·23	92	*Tyrone*	Omagh, Edenfel ...	4·03	93

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,030, APRIL 1958

CHARLES ERNEST PELHAM BROOKS, I.S.O., D.Sc.

Dr. C. E. P. Brooks, an Editor of the *Meteorological Magazine* for some 22 years, died on December 14, 1957, at the age of 69, after being confined to his home at Ferring, Sussex, for a few months with heart trouble.

For 41 years Dr. Brooks worked full time in the Meteorological Office, retiring as Assistant Director in charge of the Climatological Division. Initially he was allocated to the Library, where his wide reading and remarkable memory made him of particular service to his colleagues and also enabled him to develop his main interest in World Climatology. Author of numerous papers he was awarded the Buchan Prize of the Royal Meteorological Society in 1931. His published books include: *The evolution of climate* (1925); *Climate through the ages* (1926, second edition 1948); *British floods and droughts* (1928) with Dr. J. Glasspoole; *Climate* (1929); *Climate in every-day life* (1950); *Handbook of statistical methods in meteorology* (1953) with Miss N. Carruthers; and *The English climate* (1954). He gained an international reputation, notably in the field of climatic change, and has left the results of his life work for the benefit of present and future generations.

Dr. Brooks put forward the theory that the dominant factors in producing climatic changes were geographical, including variations in the distribution of land and sea, systems of ocean currents, the vertical circulation of the sea, the elevation of the land and the amount of explosive volcanic activity. Along these lines he gave an explanation of the Permo-Carboniferous glaciation over low-lying areas in equatorial regions.

Dr. Brooks had the responsibility of moving the Library and the Climatological Records to Stonehouse, near Stroud, at the beginning of the war, and afterwards to Harrow. He had a reputation for swift action, but the sudden arrival of a large consignment of packing cases at the Office at South Kensington at the beginning of hostilities surprised even those familiar with his way of cutting through any red tape. He also did much to keep the staff happy, while in billets, and during the enforced long hours of work during the war. Then he had the responsibility of preparing climatological reports on various parts of the world, coping with many war-time climatological problems and also keeping together the corps of voluntary climatological and rainfall observers. Towards the end of the war he was directed to devote his full time to long-range forecasting, a problem in which he was especially interested. He did not spare himself, although this investigation did not produce the hoped-for results. Some indication of the scope of the work for which he was responsible is reflected by the various separate Branches which emerged under post-war conditions:—British Climatology, Rainfall of the British Isles and Hydrology, Agricultural Meteorology, Overseas Climatology, Upper Air Climatology, Library and Editing, and the Machine Pool using Hollerith cards for climatological data.

Dr. Brooks always had time to help and encourage his colleagues, and with his ready wit and understanding made even the most laborious extractions or computations of live interest to his staff. He set an example of energetic application to his work. He lived a full life, often claiming that he produced more useful work in his train journeys to and from Ferring than in the routine of Office administration. Following a short period of part-time employment at the Meteorological Office he found congenial work at home in abstracting meteorological literature for the American Meteorological Society, which later resulted in a visit to Washington.

Dr. Brooks' energies were not entirely confined to work. He started the Air Ministry Chess Club after the First World War and under his guidance the team moved steadily to the first division of the Civil Service Tournament. He was keen on swimming, lawn tennis, and on contract bridge.

Dr. Brooks was Secretary of the Royal Meteorological Society from 1928 to 1932 and later Vice-President. He served as the Meteorological Office representative of the International Meteorology Organization Commissions for Climatology, Hydrology, Agricultural Meteorology and Bibliography and Publications at Toronto in 1947.

Dr. Brooks married Miss Dora Buckeridge, whom he met at the Meteorological Office, and whose constant help he acknowledged in his books and papers. She survives him, as does also their son, and they have the sympathy of his wide circle of friends.

J. GLASSPOOLE

THE FORECASTING OF DAILY MEAN SURFACE TEMPERATURE FROM 1000–500 MILLIBAR THICKNESS LINES

By C. J. BOYDEN, B.A.

A broad relationship between upper air temperature and the temperature at screen level has long been recognized. Nevertheless, for any given level of temperature in the upper air there can be wide fluctuations of temperature near the ground, depending on the surface transfer of heat as determined by such factors as wind speed, cloud cover and time of day. The present investigation was undertaken in the belief that a fairly high correlation would be found between the general level of upper air temperatures and the mean surface temperatures over 24 hours. The supposition was that to some extent the factors resulting in a high day temperature would also favour a low night temperature: thus in a dry air mass, with small amounts of cloud, a high lapse rate by day is often accompanied by a marked inversion at night, and one might therefore expect the mean temperature to be much the same as during 24 hours of moist air and persistent cloud, when the diurnal range of temperature and lapse rate is much smaller.

No account was taken of the vertical distribution of upper air temperature but only of the mean temperature of the layer between 1000 and 500 millibars, which is directly proportional to the thickness of the layer between these two isobaric surfaces. The 1000–500-millibar thickness rather than that for, say, 1000–700-millibars was chosen simply because it has become a standard isopleth on upper air charts. The mean daily screen temperature to which the thickness has been related was the mean of maximum read at 2100 G.M.T. and the minimum read at 0900 G.M.T.

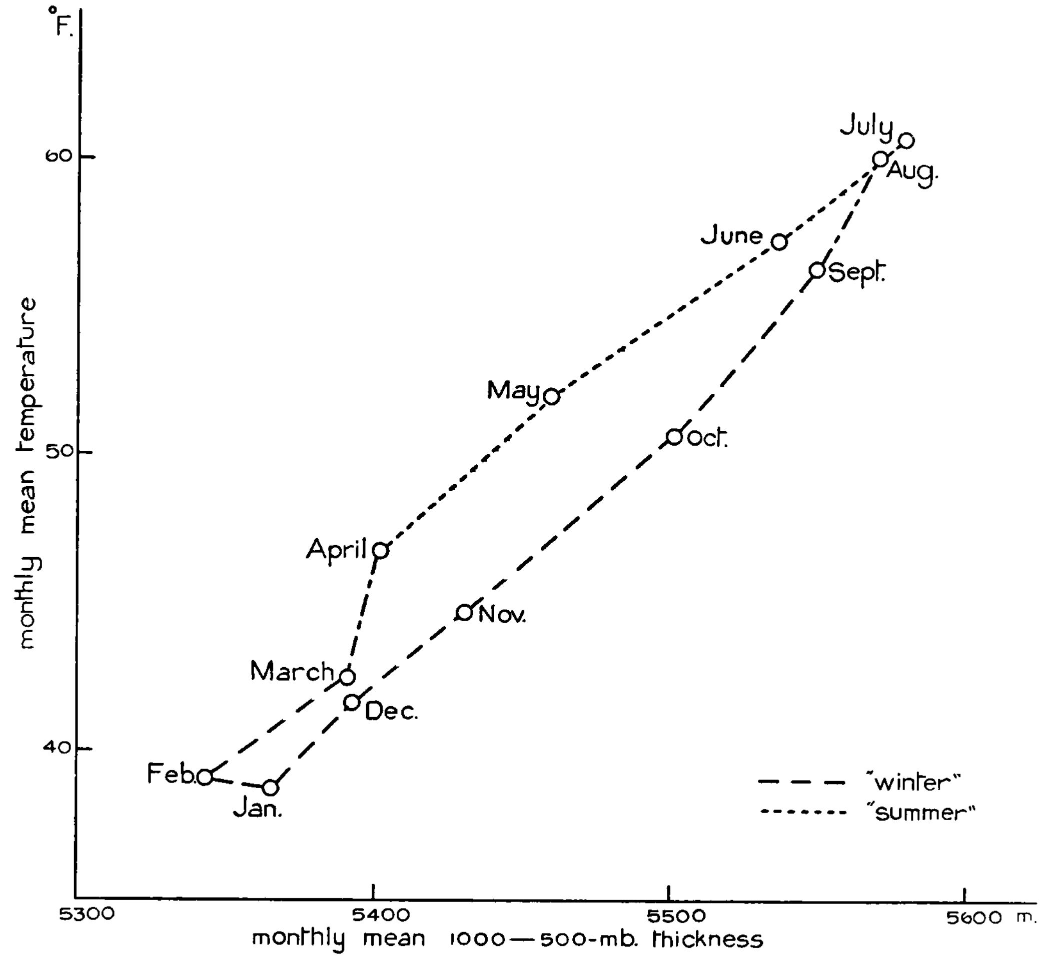


FIG. 1—RELATIONSHIP BETWEEN MONTHLY MEAN SURFACE TEMPERATURE AND MONTHLY MEAN 1000–500-MILLIBAR THICKNESS AT CRAWLEY/LARKHILL, 1948–55

The first step was to plot the monthly mean temperatures for Crawley (Larkhill in earlier years) against the monthly mean 1000–500-millibar thickness for the longest available period, 1948–55. The result, shown in Figure 1, is of considerable interest. Taken collectively the years show two distinct seasons, a "summer" from April to August, when the mean temperature was high for the thickness, and a "winter" lasting for the remaining seven months, though January is not a good fit. In order to make certain that these features did not arise from one or two exceptional years, the month-to-month variation of thickness throughout each of the eight years was examined. In five of these years a decrease of mean thickness from March to April was confirmed, in one the rise between

January and March was slightly checked in April, and in the other two years, following a cold February, there was a sustained rise in thickness which was maintained into April. The discontinuity in the autumn, on the other hand, was less consistent and was somewhat more variable in the month of occurrence. Another feature of the months from April to August is that over the waters around the British Isles the air is normally warmer than the sea. There is thus reasonable support for the two seasons chosen, but the abrupt change between March and April presents its problems. Outbreaks of cold air from the north and north-west are common in April, but it is not clear how the surface temperature is accommodated to the reduced 1000–500-millibar thickness so as to retain the smooth upward trend of monthly mean temperature, particularly as there is no corresponding discontinuity in average monthly totals of sunshine.

Table I shows the variation throughout the year of the maximum and minimum lapse rate as given by the Kew normal monthly mean of daily maximum and minimum temperature minus the Crawley/Larkhill mean 700-millibar temperature over the years 1948–55.

TABLE I—MAXIMUM AND MINIMUM LAPSE RATES BETWEEN THE SURFACE AND 700 MILLIBARS IN °F.

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	27·2	30·3	31·0	35·7	38·2	38·1	37·6	37·4	33·7	29·4	26·6	25·7
Minimum	18·4	20·5	18·0	21·4	21·8	21·8	21·8	21·8	19·4	16·8	17·0	17·3

From these figures it is seen in what manner the lapse rates segregate the months April to August from the rest of the year. April to August, and to some extent September, show rather higher lapse rates at night than do the remaining months, but relative to the air mass temperature the rise in mean temperature in the summer was due primarily to the maximum temperatures.

A nearly linear relationship (Fig. 1) between thickness and surface temperatures during the months of each season does not postulate a linear relationship between daily values. The next step taken was therefore to plot daily mean temperatures for London Airport throughout 1956 against the mean of the thicknesses measured twice daily (at 0300 and 1500 G.M.T.) over Crawley. The relationship for summer, defined as April to August, and winter, the seven months September to March, is shown by the two curves of Fig. 2 (the coordinates are given in an appendix). The scatter was analysed, but for the purpose of verifying the relationship the Crawley thicknesses were used to forecast the temperature for each day in 1955, the preceding year, using the curves established from the 1956 data.

Table II gives the root mean square errors for each month together with the root mean square of the 2-day change, in other words the corresponding errors of 2-day forecasts if no change of temperature had been predicted.

A study of the daily forecasts showed no systematic error apart from unreliability in the forecasting of low temperatures in stagnant air in January. Even this was not a consistent error, for in such conditions the surface temperature was determined largely by the cumulative effect of cloud, prolonged radiation and the state of the ground, and with the extreme stability the surface air became virtually divorced from the air mass as defined by the 1000–500-millibar thickness. When forecasting surface temperature during persistently still weather in winter (normally in January) one must therefore be prepared for lower temperatures than the thickness suggests, and an accurate forecast of other elements is necessary for a closer approximation. Some caution is also required in April, where more positive than negative errors occurred because the change from the winter to the summer curve is not necessarily applicable as soon as the month opens. It may be found that the summer curve becomes the appropriate one when thicknesses are below normal.

TABLE II—ROOT MEAN SQUARE ERRORS OF DAILY FORECASTS OF MEAN TEMPERATURE TOGETHER WITH ROOT MEAN SQUARE OF 2-DAY CHANGE

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Root mean square forecast error	7·76	3·54	4·23	3·37	3·09	3·50	3·25	3·29	4·70	5·60	5·92	4·74
Root mean square variance	5·50	4·83	5·94	5·18	5·08	5·54	3·59	4·85	4·25	5·89	5·88	8·14

It was found that this method of forecasting the mean temperature for London gave for 1955 a probable error of 2·8°F. in winter and 1·8°F. in summer. These may be regarded as satisfactorily small errors for forecasting purposes, particularly when one takes into account that no allowance is made for cloud, precipitation or fog. Another point to be noted is that whereas the mean temperature is based on the highest and lowest points of a continuous record, the mean thickness is the mean of values at two fixed times: there were, for example, occasions on which the passage of a tongue of warm air raised the mean temperature but escaped detection in the 12-hour gap between successive upper air temperature soundings.

This investigation was begun primarily to improve forecasts of mean temperature, or at least to make them more objective. Whether this can be done depends partly on the criteria one adopts in assessing the success of a forecast. Taking first the question of objectivity, one must bear in mind that with the aid of the numerical computer an eventual increase in the accuracy of forecasts of thickness is to be expected. But objectivity is intended also to include the advantages to be gained by forecasting without reference to the present or past values of the element involved. In present practice the accuracy of mean temperature forecasts for one or even two days ahead is dependent to no small degree on the temperature distribution when the forecast is made, and may be biassed by such factors as the climatological mean. The forecasting of any element by an assessment of the change from the present value is not the most desirable method, though over short periods it is probably the most successful so far. For longer periods some general parameter which can be advected from chart to chart is an essential basis for temperature forecasting, and the thickness between isobaric surfaces, in view of the close relationship with mean surface temperature, must be regarded as the only suitable parameter available. In other words, the problem of forecasting the mean temperature is substantially the problem of forecasting the thickness.

It is as well to consider at this stage how a temperature forecast should be verified. No forecast verification has absolute significance unless it is considered in relation to the purpose of the forecast. The verification of forecasts which can be expressed numerically, as can temperature, is often based on root mean square errors, and comparison is sometimes made with the root mean square error which would have occurred if no change in the element had been forecast.

Table II showed that temperature forecasting by thickness gave a substantial improvement over persistence forecasting in seven months of the year, was of comparable standard in four and was worse in one. If the error in forecasting the thickness were added, persistence forecasting would stand in a better light. This is not so much a criticism of the accuracy of forecasting, as an illustration of the limitations of the root mean square error as an index of success. The average user of a temperature forecast is most concerned with the amount and the sign of the change from the present level. Forecasting by persistence may produce a quite respectable root mean square error, but since it never predicts a rise or fall of temperature it is a method that is clearly worthless. A measure of persistence of temperature should therefore be regarded as a measure of variability, not as a yardstick for assessing a method of forecasting. That can be judged only by studying the nature of the errors.

The daily routine at the Central Forecasting Office includes the construction of forecast 1000–500-millibar thickness charts over an area which includes North America, the Atlantic and Europe. Once daily, on most days of the week, these are constructed for one, two and three days ahead. The main purpose is to help in the forecasting of pressure systems on a broad scale, and no particular attention is given to the forecast of thickness over any one place. Nevertheless the charts give some indication of the accuracy at present attainable in a forecast of thickness. From these charts the thickness at Crawley forecast one, two and three days beforehand was read for the 192 days on which it was available in 1956. The root mean square errors (in metres) for each season are shown in Table III together with the root mean square errors that would have occurred if no change from the latest actual thickness had been forecast on each occasion. F_r is the root mean square error of the forecast made r days ahead, and P_r the corresponding error of a persistence forecast. The temperatures shown beneath each thickness are the corresponding errors in mean surface temperature based on the approximate equivalence of 100 metres to 8°F., as given by Fig. 2.

TABLE III—ROOT MEAN SQUARE ERRORS OF FORECAST THICKNESSES AND EQUIVALENT MEAN TEMPERATURES

	Winter (Jan.–March, Sept.–Dec.)		Summer (Apr.–Aug.)	
	metres	°F.	metres	°F.
F_1	54	4·3	44	3·5
F_2	85	6·8	65	5·2
F_3	108	8·6	72	5·8
P_1	71	5·7	63	5·0
P_2	99	8·0	77	6·2
P_3	112	9·0	91	7·3

Combining the error in the forecast thickness with the error in the mean temperature as forecast from that thickness, one obtains root mean square

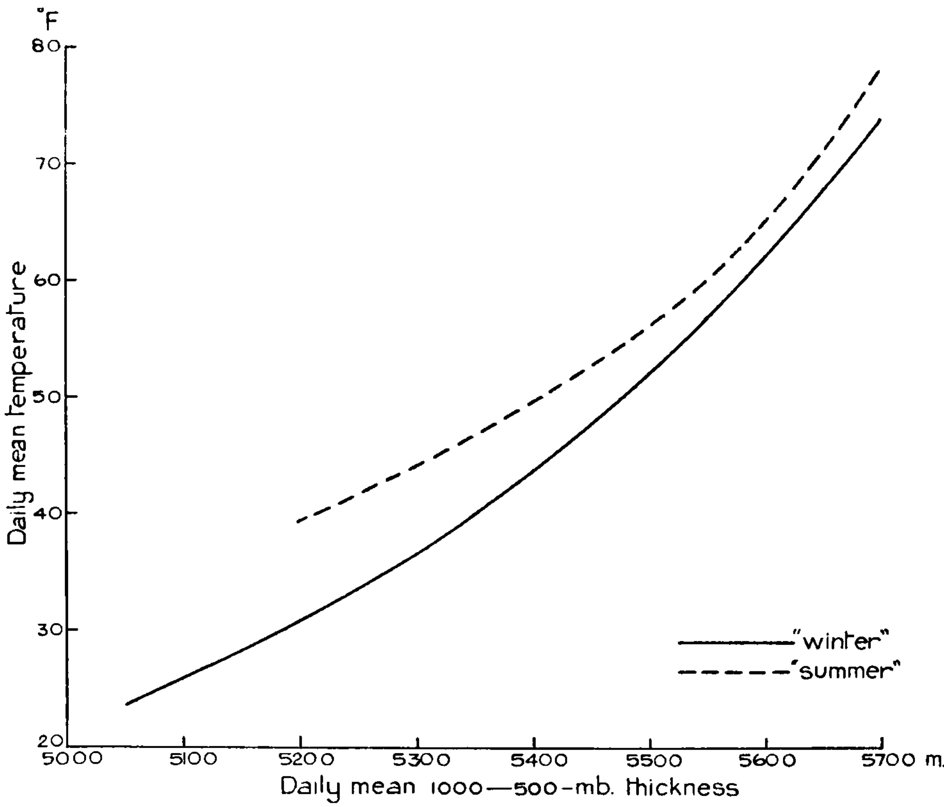


FIG. 2—RELATIONSHIP BETWEEN DAILY MEAN SURFACE TEMPERATURE AT LONDON AIRPORT AND DAILY MEAN 1000–500-MILLIBAR THICKNESS AT CRAWLEY, 1956

errors in the forecast temperature about 2°F. larger than those obtained by assuming the surface temperature is unchanged from its value two days before.

The limited significance of these figures is illustrated by an analysis of the forecasts of temperature changes of varying magnitude, given as a contingency table in Table IV. The temperature-change equivalents of forecast thickness

TABLE IV—DISTRIBUTION OF MEAN TEMPERATURE ERRORS RESULTING FROM FORECASTS OF THICKNESS

	Actual change (°F.) Winter							Summer						
Forecast change (°F.)	R_L	R_M	R_S	S	F_S	F_M	F_L	R_L	R_M	R_S	S	F_S	F_M	F_L
	number of occasions													
R_L	2	3	1	0	1	0	0	2	1	0	1	1	0	0
R_M	2	10	5	0	2	1	0	0	6	3	1	0	0	0
R_S	1	6	14	1	7	1	1	0	4	12	3	6	2	1
S	0	0	4	0	2	0	0	1	1	3	1	3	0	0
F_S	1	0	3	0	12	4	4	0	0	3	2	6	4	2
F_M	0	0	5	0	4	3	1	0	0	2	0	6	0	2
F_L	0	0	1	0	1	4	3	0	0	0	0	1	2	1

changes over a 2-day period were classified as follows:—

Large rise (R_L) or fall (F_L)	... more than	10°F.
Medium rise (R_M) or fall (F_M) ...		6–10°F.
Small rise (R_S) or fall (F_S)	...	1–5°F.
Steady (S)...	...	0°F.

It will be seen that the forecast change was correct on 44 of the 110 winter occasions and on 28 of the 82 summer ones. Taking the medium and large changes together, these were forecast to occur the right number of times in each season so the general variability of temperature was not underestimated. Nevertheless, about one third of the forecast rises and one half of the forecast falls of this magnitude did not fully materialize or were wholly in error. The forecasts which might be regarded as worthless are those outside the zigzag lines; these totalled 20 out of 110 in winter and 13 out of 82 in summer. It should be noted that these figures are based on the success with which thickness lines were forecast. Contingency tables for the corresponding temperatures should not be significantly different apart from some modification due to the over-estimation of some of the low January temperatures. It is therefore reasonable to conclude that forecasts of mean temperature based on forecasts of the 1000–500-millibar thickness are much more successful than Table III might suggest.

Forecasting the mean temperature has been considered primarily for the purpose of issuing forecasts for 2 days ahead, for in that period substantial changes of air mass often have to be considered. The accuracy of the method over a longer period is limited only by the accuracy with which the thickness can be predicted. It could be applied equally well to monthly anomalies of thickness should they ever become available. The possibility of using the forecast mean temperature as a basis for a forecast of the maximum or minimum temperature is not promising, for the reason that an accuracy in cloud forecasting is required which in many synoptic situations is unlikely to be attained.

Appendix

MEAN SURFACE TEMPERATURE AT LONDON CORRESPONDING TO THE 1000–500-MILLIBAR THICKNESS AT CRAWLEY

Thickness	Winter*	Summer†	Thickness	Winter*	Summer†
m.	°F.	°F.	m.	°F.	°F.
5050	24	...	5210	31	40
5060	24	...	5220	32	40
5070	25	...	5230	32	41
5080	25	...	5240	33	41
5090	25	...	5250	34	42
5100	26	...	5260	34	42
5110	26	...	5270	35	43
5120	27	...	5280	35	43
5130	27	...	5290	36	44
5140	28	...	5300	37	44
5150	28	...	5310	37	45
5160	29	...	5320	38	45
5170	29	...	5330	39	46
5180	30	...	5340	39	46
5190	30	...	5350	40	47
5200	31	40	5360	41	47

(Continued on next page)

Thickness	Winter*	Summer†	Thickness	Winter*	Summer†
m.	°F.	°F.	m.	°F.	°F.
(Continued from previous page)					
5370	41	48	5540	56	59
5380	42	48	5550	57	60
5390	43	49	5560	58	61
5400	44	50	5570	59	62
5410	44	50	5580	60	63
5420	45	51	5590	61	64
5430	46	51	5600	62	65
5440	47	52	5610	63	66
5450	48	53	5620	64	67
5460	48	54	5630	65	68
5470	49	54	5640	67	70
5480	50	55	5650	68	71
5490	51	55	5660	69	73
5500	52	56	5670	70	74
5510	53	57	5680	71	75
5520	54	58	5690	72	76
5530	55	59	5700	74	78

*Winter = Jan.–March, Sept.–Dec.
†Summer = Apr.–Aug.

A CROSS-SECTION OF EQUATORIAL UPPER WINDS AT 103°E.

By L. S. CLARKSON, M.Sc. and L. W. LITTLEJOHNS

Introduction.—Daily radar wind ascents at 0400 G.M.T. undertaken by the Royal Naval Weather Service at Christmas Island (105° 36′E., 10° 31′S.) from April 22 to June 21, 1956 have been utilized in conjunction with routine 0300 G.M.T. radar wind reports over the same period from Singapore (103° 54′E., 01° 21′N.), Songkhla (100° 36′E., 07° 13′N.) and Bangkok (100° 30′E., 13° 44′N.) to construct a cross-section of mean zonal flow at 103°E.

Although necessarily representative of one specific and rather limited period, the cross-section is based on sufficient observations above the equatorial tropopause (believed to be around 60,000 feet) to show interesting features of the extent of the easterlies in the upper troposphere, and of the overlying westerlies in the lower equatorial stratosphere.

Observations and analysis.—Results of the evaluation at 5,000-foot height intervals of the mean westerly component of the 0300–0400 G.M.T. observed winds over the period April 22 to June 21, 1956 are shown in Table I, and in the form of a cross-section along the 103°E. meridian at Fig. 1. The numbers of available observations from which the means have been derived are included in brackets within the Table.

The mean zonal flow.—In the lower troposphere over Bangkok the deep westerly flow of the south-west monsoon extended to over 20,000 feet; prevailing light equatorial westerlies to which Watts[1] has drawn attention were evident up to 15,000 feet at Singapore, but south of the equator towards Christmas Island there was little mean zonal flow in the lower troposphere except for signs of the south-easterly trade below 5,000 feet.

In the upper troposphere a broad belt of equatorial easterlies overrides the westerlies in the northern hemisphere, increasing with height to a maximum around 50,000 feet. For the particular period of the cross-section, the core of the high-level easterlies appeared to be located over or to the north of Bangkok, where the mean east to west component reached 46 knots at 54,000 feet, no observations being available at higher levels. The easterlies decreased in

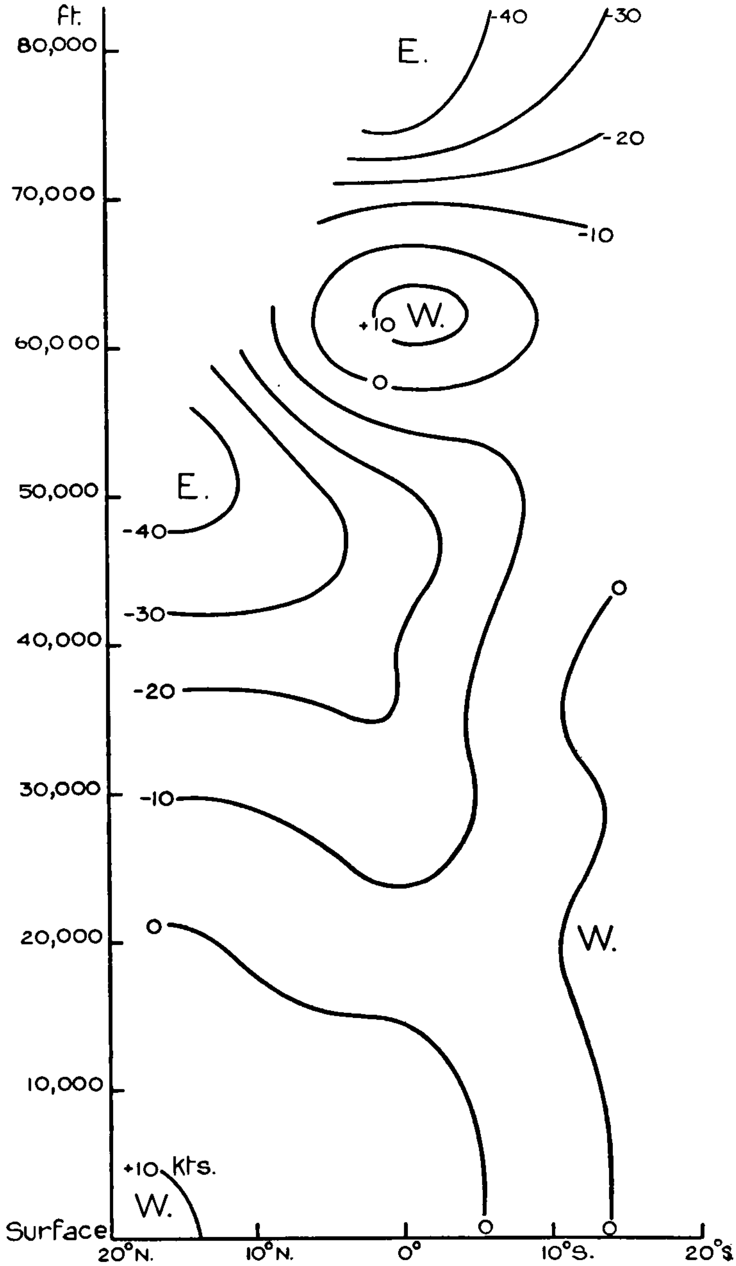


FIG. 1.—MEAN CROSS-SECTION FOR 103°E. FOR APRIL–JUNE, 1956

strength southwards, but were still evident at 50,000–55,000 feet over Christmas Island.

Although data in the stratosphere are restricted to Christmas Island and Singapore, there are enough observations available to indicate the existence over or just to the south of the equator of a layer of lower stratospheric westerlies which, during this particular period, lay between 58,000 feet and 68,000 feet. Above them, and increasing with height, the well-known Krakatoa easterlies were in evidence.

The westerlies were no doubt the Von Berson westerlies discussed by Palmer[2] but considered to be too light and of insufficient extent to be shown in world-wide charts of the average wind at 60 millibars[3].

TABLE I—MEAN WESTERLY COMPONENT ALONG 103°E., APRIL 22 TO JUNE 21, 1956

Height	Bangkok		Songkhla		Singapore		Christmas Island	
feet			*knots*					
85,000	...		...		...		−36	(10)
80,000	...		...		...		−34	(29)
75,000	...		...		−43	(5)	−25	(36)
70,000	...		...		−13	(18)	−12	(43)
65,000	...		...		+ 8	(40)	− 2	(51)
60,000	...		...		+ 9	(52)	0	(59)
55,000*... ...	−46	(40)	...		− 9	(58)	− 5	(60)
50,000	−43	(48)	...		−24	(59)	− 5	(60)
45,000	−37	(50)	...		−27	(59)	− 2	(60)
40,000	−26	(51)	...		−23	(60)	− 1	(60)
35,000	...		...		−20	(60)	0	(60)
30,000	−11	(53)	−11	(14)	−16	(60)	− 2	(60)
25,000	− 3	(53)	− 8	(17)	−11	(60)	− 1	(60)
20,000	+ 1	(53)	− 2	(19)	− 5	(60)	0	(61)
15,000	+ 4	(55)	0	(19)	− 1	(60)	− 1	(61)
10,000	+ 6	(56)	+ 4	(20)	+ 6	(60)	− 1	(61)
5,000	+ 7	(56)	+ 5	(22)	+ 7	(60)	− 5	(61)

*54,000 ft. at Bangkok

Number of observations from which the means have been derived are shown in brackets.

Comparison with other equatorial cross-sections.—The cross-section for April–June 1956 at Fig. 1 is very similar to that given by Ramsey[4] for the 110°E. meridian for July 1953; unfortunately this latter includes no data above 50,000 feet and hence gives no indication of the existence of the Von Berson westerlies. A cross-section at 45°E. in July given by Gilchrist[5] is also broadly similar, although with a weaker westerly monsoon flow in the lower troposphere north of the equator, and stronger overriding easterlies. Gilchrist's July cross-section shows westerlies in the lower stratosphere above 57,000 feet with their centre just south of the equator.

Summary and conclusions.—During the period April 22 to June 21, 1956 the mean zonal wind structure across the 103°E. meridian near the equator was as depicted in Fig. 1, interesting features of which are the broad belt of easterlies just below the tropopause, the band of stratospheric westerlies near the equator, and the overlying Krakatoa easterlies.

REFERENCES

1. WATTS, I. E. M.; Equatorial Weather. London, 1955.

2. PALMER, C. E.; The general circulation between 200 mb. and 10 mb. over the equatorial Pacific. *Weather London*, **9**, 1954, p. 341.

3. BANNON, J. K., and JONES, R. A.; Average wind at 60 mb. *Met. Mag., London*, **85**, 1956, p. 194.

4. RAMSEY, B.; Upper winds in the South-East Asia – West Australia region. *Met. Mag., London*, **84**, 1955, p. 372.

5. GILCHRIST, A.; Wind between 300 and 100 mb. in the tropics and subtropics. *Met. Rep., London*, **2**, No. 16. 1955.

METEOROLOGICAL OFFICE DISCUSSION

Atmospheric chemistry

The discussion held on Monday, December 16, 1957, at the Royal Society of Arts was opened by Mr. B. C. V. Oddie.

Although atmospheric chemistry comprises a very wide variety of subjects, the greatest and most systematic effort made hitherto has been devoted to the study of a group of simple inorganic salts which together rarely amount to one millionth part by weight of the atmosphere. Two methods of study are employed. In the older and more widely used, rain-water is collected for analysis using a glass funnel and collecting bottle; in the other method, air is drawn through a solvent solution. In either case the sample is collected over a period of one calendar month. The rain-water is analysed for chloride, sulphur (SO_4 and SO_3), nitrate (including nitrite), bicarbonate, sodium, potassium, calcium, magnesium and ammonium. The results are usually expressed in milligrams deposited per square metre of surface. Acidity (pH) and conductivity are also measured. The air sample is analysed for all the same constituents except bicarbonate and nitrate, and the results are expressed in microgrammes per cubic metre.

The nitrogen compounds in rain-water are valuable as plant foods, and have have been studied by agriculturists for over a century. The present network for atmospheric chemistry is indeed merely a considerable extension of a nation-wide system set up in Sweden just after the last war, which was originally intended for purely agricultural purposes.

At present it consists of about eighty stations distributed over Finland, Sweden, Norway, Denmark, Holland, Belgium, north-west Germany, and Great Britain. The existing British stations are Aberdeen, Edinburgh, Leeds, Rothamsted and Newton Abbot (all set up in 1954–55 by the Meteorological Department of Imperial College) and four Meteorological Office stations—Lerwick, Eskdalemuir, Stornoway and Camborne—set up in the last few weeks. One additional station will be opened at Aldergrove very soon.

Slides of the sampling equipment were shown. The rain-water is collected by a funnel and bottle, while the essential parts of the air sampler are a continuously acting air pump, a gas-meter to measure the quantity of air sampled (normally about 40 cubic metres per month) and the absorbing column in which the air bubbles through 125 millilitres of a dilute solution of nitric acid and hydrogen peroxide. The whole apparatus is contained in a cabinet which is automatically warmed in cold weather to prevent freezing. The main precautions aim at avoiding contamination of the samples, a point of especial importance since the quantities of solute are extremely small. In particular the apparatus must be of materials which are very insoluble: ordinary glass is unsuitable and the materials used in the British equipment are polythene for the collecting funnel and tubes, and Pyrex glass for storage bottles and blown-glass parts.

The present international network is barely three years old, and no detailed study of its results has yet been published. There have been several papers concerned with results obtained from the smaller, mainly Swedish network which operated before 1954, but these are based almost entirely on rain-water samples. The most obvious point revealed by these studies is that in Scandinavia the sea is the principal source of the inorganic matter in the air. Except for calcium and ammonium, all the ions are deposited in quantities which are greatest on the south-west, or windward, coasts, and decrease rapidly towards the north-east. Thus in one year (August 1955 to July 1956) the total amount deposited at Askov near the west Danish coast was about 17 grammes per square metre, whereas at Flathult, 130 miles inland in Sweden, it was about 3 grammes. The difference here is not due to a difference in the amount of rain, which was almost exactly the same at the two places. Presumably the material enters the atmosphere in the form of spray: and as a rule it will remain in the form of small droplets, since the air is generally too moist to allow crystallization to occur, at any rate in the lowest few thousand feet. Later, these droplets must be washed out by rain, the constitution of which may therefore be expected to resemble that of very much diluted sea-water.

In fact, near windward coasts, this is nearly true—the ratios between the amounts of sodium, potassium, magnesium and chlorine are much the same in rain-water as in sea-water. As however one goes inland, one finds that the proportions change. In particular the ratio, weight of chlorine:weight of sodium, which is about 1·8 on the windward coasts and in sea-water, decreases inland and is as low as 0·6 at some eastern stations. There are thus two parts to the problem:

(i) Why does the total amount of inorganic matter brought down by rain decrease so rapidly with increasing distance inland?

(ii) Why does the Cl:Na ratio in rain-water decrease with increasing distance inland?

The second part is at first sight the more difficult, because salt, (NaCl) is a very stable compound, which must be decomposed somehow before its elements can be physically separated.

One solution, proposed originally by Cauer[1] and developed by Rossby and Egner[2], assumes that the general decrease in the amount of matter deposited is due to simple washing-out by rain. The change in constitution is explained by supposing that some other constituent of the atmosphere (either ozone or sulphuric acid, both of which are present) reacts with the droplets of salt solution so as to release hydrochloric acid (HCl) into the air. Thus when these droplets are brought down as rain they will be deficient in chlorine, which is in accordance with the observations.

This view of the matter is no longer tenable now that the results of air analysis are available. For clearly, if the chlorine remains in the air while the sodium is washed out, the ratio of Cl:Na *in the air* must increase steadily as one goes inland, and of this increase there is no sign whatever. Moreover, it is impossible to explain the observed decrease in the total amount of material in the air as due to washing by rain, because rain falls for only a fraction of the time and could not greatly affect the *average* concentration.

An argument essentially similar to this last has recently been developed by Junge and Gustafson[3], who were led to the same conclusion that wash-out could not greatly affect the constitution of the air. Their suggested explanation of the observed changes, based on measurements in the trade-wind belt, is that salt particles while over the sea are confined to the lowest two or three thousand feet by the inversion which is normally present: and are therefore in high concentration. Over the land, the inversion breaks down, and the salt particles are free to spread upward. They ascribe the change in the Cl:Na ratio to particles picked up from the ground by the wind, and consisting mainly of sodium salts other than the chloride. It is thus unnecessary to invoke the kind of physical-chemical separation imagined by Cauer.

It seems unlikely that this mechanism is really the principal one in Scandinavia. In the first place, the inversion does not normally break down soon enough after passing the coastline to explain the observed decrease in total concentration. Moreover the amounts of sodium which would have to be transferred from the ground to the air to explain the observed change in the Cl:Na ratio are quite implausible. It is clear too that some kind of chemical decomposition of the salt must occur, because even on windward coasts the Cl:Na ratio in rain-water often departs appreciably from the normal value, and the differences are too large to be accounted for by material transferred from the ground.

The speaker suggested that the principal, or at least a very important, means by which inorganic salts are removed from the air is by direct deposition, particularly on plants. It is a matter of common observation that plants near the coast collect considerable amounts of salt; moreover Eriksson has shown that the Scandinavian rivers carry down to the sea an amount of chloride considerably greater than that brought down by rainfall, and attributes the difference to direct dry-deposition of salt on trees etc. The change in the Cl:Na ratio may similarly be explained by assuming that chlorine or hydrochloric acid released by oxidation of sea-salt is removed from the air by reaction at the surface. We know that plants remove from the air every day, on average, an amount of carbon dioxide equal to all that contained in the lowest 500 metres of the atmosphere, so that it is evident that this kind of scavenging can be very rapid and effective.

In conclusion, a brief account was given of one or two of the many other subjects in the field of atmospheric chemistry which have recently been studied. A small network of fifteen stations was set up in Scandinavia in 1954 to study the distribution and seasonal changes in the amount of carbon dioxide in the air, but the data so far obtained have not revealed any very clear-cut or systematic variations. Another subject of great importance concerns the exchange of carbon dioxide between the atmosphere and ocean. If carbon dioxide continued to be generated by human activities at the present rate, and if it all remained in the air, there would be a change in the world's climate which within a few centuries might be disastrous: however carbon dioxide is soluble in water, and in equilibrium the amount in solution in the sea is nearly fifty times the amount in the air. The important thing is to know how rapidly any excess in the air will be taken up by the sea. A number of studies have been made of this subject, the more recent ones relying on the use of radioactive carbon, which is always present in natural carbon dioxide. The results which have been obtained have however been very discordant, the estimates of the exchange time varying from a few days to many years.

These are problems of great interest and importance. The behaviour of the simple inorganic salts in the air is still, however, the central problem of atmospheric chemistry. Whether it justifies the permanent maintenance of the present considerable network of stations is somewhat doubtful. The immediate intention is to continue the work until the results gathered during the International Geophysical Year have been examined, and then to take stock.

Mr. Durbin described work currently being carried out at the Meteorological Research Flight on the sampling of atmospheric chloride particles. This work is being done principally for cloud physics studies but results obtained from it are clearly of great value to the study of atmospheric chemistry.

The method of sampling is based on the discovery due to Liesegang that when a chloride particle impinges on a surface coated with a layer of gelatine impregnated with silver nitrate a ring forms. If the surface be then exposed to a bright light for a few hours the area within the ring goes brown and is clearly seen. The chemical reaction is not fully understood but probably involves the formation of silver chloride and subsequent reduction of the silver chloride to metallic silver.

Sampling in flight is carried out using an impactor, which is simply a metal pole with a shutter arrangement on one end, and small perspex slides which are coated and kept in a light-tight box before the aircraft takes off.

Three pictorial slides were shown and these illustrated:

(*a*) the stages of the reaction between the gelatin-silver-nitrate solution and droplets of sodium chloride solution, obtained during a laboratory calibration of the technique.

(*b*) a typical sample obtained in flight and having a mean particle mass of about 5×10^{-11} grammes.

(*c*) a series of samples obtained on a flight from Farnborough to Northern Ireland, the outward leg being at 1,000 feet and the return leg at 2,000 feet. The track lay through a weak cold front and the slide clearly showed how the sizes and concentrations of the particles increased in the vicinity of the front.

Three other slides shown gave results obtained from twelve flights made to sample chloride particles at heights between 100 and 10,000 feet over the sea and to obtain comparative samples at selected heights over the land.

The evidence was that particles having masses greater than the smallest that the impactor could collect, about 10^{-13} grammes, occurred in concentrations up to about 2000 per litre, the highest concentrations usually being at the sea surface indicating that this is their source. The mean value at the surface for seven flights was about 500 per litre while the corresponding concentrations for particles having masses greater than about 10^{-11}, 10^{-10} and 10^{-9} grammes were up to about 60, 12 and 1 per litre respectively. For these three sizes there was no significant difference between concentrations over the land and over the sea but for particles of all sizes the land concentrations were higher. This suggests that the land itself produces particles having masses of 10^{-11} grammes or less.

Examination of the trajectories of the air during the three days preceding the flights indicated that in general the land acts as a sink while the sea acts as a source. This was not always so however but attempts to correlate particle concentrations with wind speed, lapse rate and state of sea did not provide a simple explanation of the observed particle concentrations.

Usually, particle concentrations became quite low above haze layers and cloud tops and there were usually strong resemblances between the vertical profiles for concentrations of particles having masses greater than certain specified values. There was also a strong resemblance of these profiles with the vertical frost-point profile indicating that the chloride particles, having been produced by whatever method, are distributed throughout the atmosphere by diffusion.

Mr. Durbin concluded by remarking that this kind of technique can be used to sample particles other than chlorides and that Vittori[4] had recently given details of several such reactions. Particle sampling of this kind could be carried out on a routine basis from the ground at relatively little expense.

Dr. Harrison noted that polythene was used for the rain funnel of the sampling equipment because glass was insufficiently inert. Why was glass used for the collecting bottle and for the air-sampling equipment? In reply, Mr. Oddie said that Pyrex glass was quite satisfactory, and was used in the equipment. The polythene funnel was used mainly because a suitable Pyrex one was unobtainable.

Mr. Craddock asked whether there was any information on the Cl:Na ratio in the air at greater distances from the sea; and what happened to the considerable amounts of carbon monoxide now being pumped into the air by petrol and Diesel engines? Mr. Oddie replied that very little information on the Cl:Na ratio in the air was available except from the Scandinavian network. Carbon monoxide cannot be detected except in cities and is probably very quickly oxidized.

Mr. D. D. Clark asked whether any significant part of the matter brought down by rain consisted of meteoritic dust; and whether there was a reasonably close balance between measured amounts of anions and cations in rain-water? Mr. Oddie said the amount of meteoritic dust was insignificant; the ionic balance in rain-water was as a rule quite good, indicating that the analyses were reliable. It could not be determined for the air samples because of the nitric acid used as a solvent.

Dr. Stagg found some difficulty in visualizing the nature of the reactions, and the relationship between the air samples and the rainfall samples. It seemed from Mr. Durbin's remarks that most of the material was present in the form of crystalline particles and therefore would be relatively inert. Mr. Durbin replied that laboratory calibration experiments showed that Liesegang rings were produced by sodium chloride crystals as well as by drops of solution. It had been assumed in the calibration that at relative humidities below about 75 per cent the particles were in the form of crystals while above this value they were in the form of droplets. This involves the supposition that atmospheric chloride particles are essentially compounds of sodium and that Dessen's observations that such particles had been observed in the laboratory to occur as drops of supersaturated solution at relative humidities as low as 40 per cent would not apply in a turbulent atmosphere.

Mr. Sawyer pointed out that the maps of distribution of Na and Cl which had been shown have a marked resemblance to the rainfall maps of the same area. To what extent was the decrease in the amount of material brought down inland merely a consequence of the decrease in rainfall? Mr. Oddie replied that the amount deposited was of course dependent on rainfall, but that if maps were drawn of the mean concentration of ions in the air, there was still a very striking decrease from west to east.

Photograph by C. B. Gavin-Robinson.

DUSTSTORM OVER THE QATAR PENINSULA, PERSIAN GULF, SEPTEMBER 4, 1957

(see p. 116)

Photograph by W. G. Pendleton

Photograph by W. G. Pendleton

CLOUD AT TERNHILL, OCTOBER 18, 1957

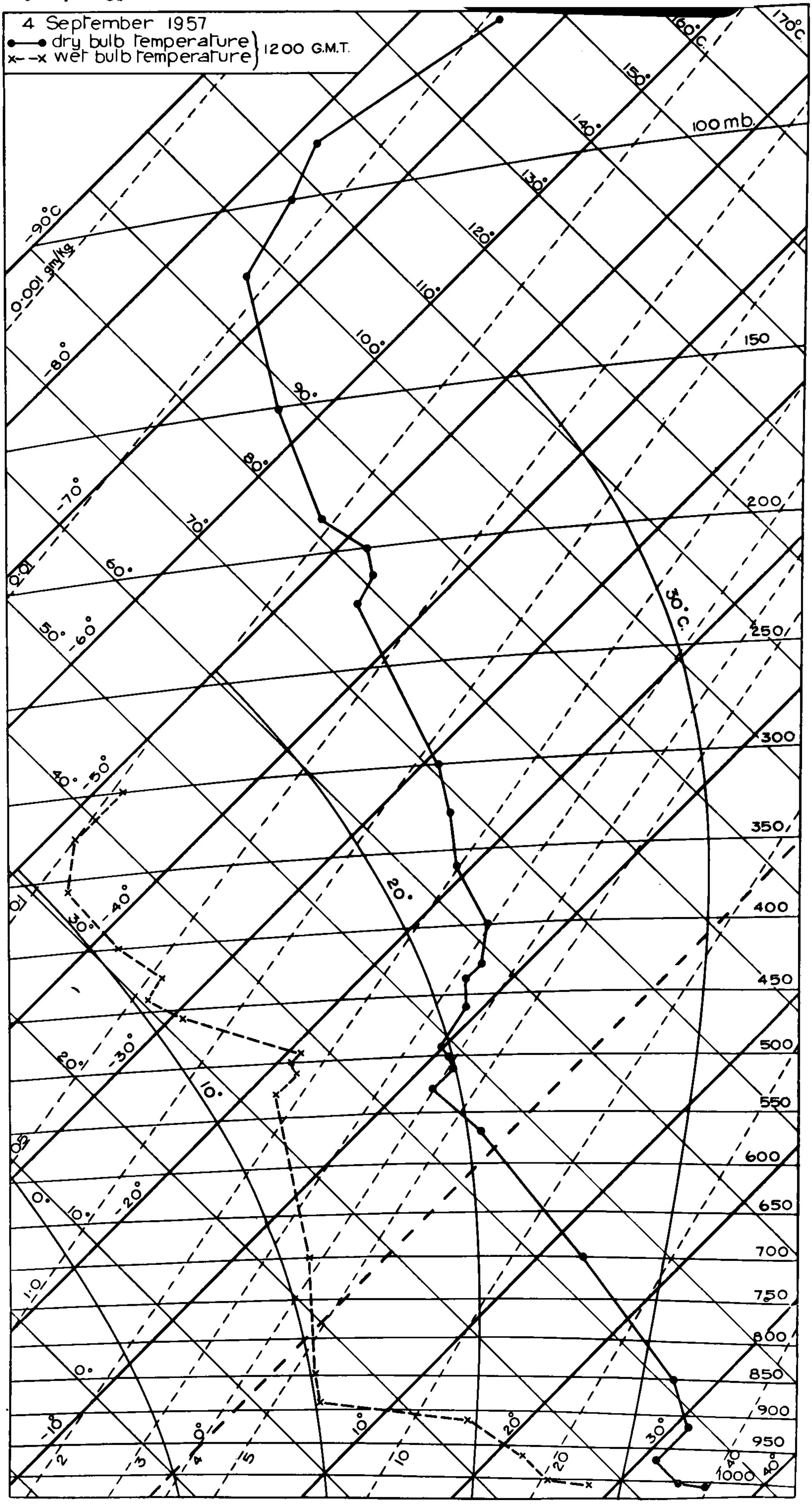
(see p. 116)

Photograph by W. G. Pendleton

CLOUD AT TERNHILL, OCTOBER 18, 1957

(see p. 116)

To face p. 113]



TEPHIGRAM FOR BAHRAIN, SEPTEMBER 4, 1957

(see p. 118)

Dr. Stagg asked whether any analyses had been made of different kinds of rain; for example, was there any difference in constitution between thunderstorm rain and warm-front rain? Was there any possibility that the electric field of a thunderstorm might have some effect on the separation of ions? He asked the opinion of Dr. Robinson who replied that as the ions were in solution in droplets it must be possible for them to react with gases in the atmosphere, but that they could not be physically separated by an electric field.

A speaker remarked that a dry crystal would not readily enter into reactions: presumably however since salt is hygroscopic each crystal would be covered with a film of solution and reactions would take place in this film. He wondered whether the release of chlorine might be due to its displacement by carbon dioxide from the air. Mr. Oddie replied that the salt was normally in the form of droplets of solution, crystallization only occurring in very dry air. The bicarbonate ion could not directly displace chlorine from sodium chloride, although when hydrochloric acid had been displaced by oxidation, carbon dioxide was absorbed by the droplets.

Dr. Stagg wondered how it came about that the Cl:Na ratio in rain-water according to the slides which had been shown, was only 1·2 even on the windward coasts. In reply Mr. Oddie said that probably later and more reliable measurements would show rather higher values, but that in any case, if the ratio was modified by a process of chemical dissociation, there was no reason why some of the change should not occur over the sea.

Mr. Shellard thought it would be interesting to collect rainfall on an Ocean Weather Ship. Experiments with rain-gauges had shown that provided they were set high on the mast they did not collect sea-spray. Mr. Oddie agreed that it would be an interesting experiment, but thought that too much spray would enter the collector, as it evidently did on many occasions at coastal stations such as Lista.

Mr. H. L. Wright asked whether there was any evidence of the presence of significant amounts of nitrous acid in the air: some early experiments which he had performed had shown that it is always formed when combustion takes place.

In reply Mr. Oddie said that Junge had recently made some careful analyses of airborne particles. Following up Mr. Wright's well-known work, Junge had paid particular attention to nitrite, and had concluded that there was no detectable quantity in aerosols. This might be because it was all oxidized to nitrate: however Junge does not consider that combustion is an important source of nitrate, most of which he believes originates on the coasts. But his evidence is not conclusive.

Mr. Craddock, referring to the exchange of carbon dioxide between the sea and atmosphere, suggested that only a shallow surface layer of the sea, that is, that which is disturbed by the action of waves and tides, took an active part in the process, and that therefore the ability of the sea to absorb excess carbon dioxide generated by human activity was much less than had been suggested. In reply, Mr. Oddie agreed that only the top 70–100 metres of the ocean took a part in the direct absorption of carbon dioxide: but there was some transfer to the deep ocean, and a principal object of some of the current research was to discover how this occurred. It is a curious fact that the concentration of carbon dioxide in the ocean increases downward, so that any mixing process would transfer carbon dioxide upwards. There must therefore be some compensating downward transfer, but it was not yet understood.

Mr. Hamilton asked whether there had been any attempts made to compare the concentrations of inorganic salts in rain with those in snow. Mr. Oddie replied that he did not know of any. A comparison of the summer and winter maps of amounts deposited in Scandinavia did not reveal any immediately obvious effects.

A speaker asked whether it was not possible to take air samples in exclusively anticyclonic conditions and compare them with samples taken in exclusively cyclonic conditions. Mr. Oddie replied that the existing organization was based on monthly samples, and would be difficult to modify in the way suggested.

Mr. Hay (referring to Mr. Oddie's earlier reply to Mr. H. L. Wright) said that Porton had recently developed a method of estimating nitrous fumes in the air. Their measurements had shown amounts of about 6 microgrammes per cubic metre: and it was clear that these were not generated locally. Mr. Oddie replied that this seemed a very large amount, in view of Junge's findings.

A speaker referred to some work in India suggesting that nitric or nitrous acid was formed directly by lightning flashes, in quantities sufficient to be measurable and significant in agriculture. Mr. Oddie replied that lightning flashes and, probably, continuous discharges in the high atmosphere, did cause some combination of atmospheric oxygen and nitrogen, and it had even been suggested that the Chile nitrate beds originated in this way.

A speaker pointed out that rainfall was not the only natural way by which nitrogen was transferred from the atmosphere to the soil: nitrogen-fixing bacteria also played an important part.

Mr. Hamilton thought it would be interesting to analyse the ice which frequently collects on high radio masts in winter, since this would presumably represent the material actually present in cloud particles.

A speaker asked when the results of the United Kingdom analyses would be published. Mr. Oddie replied that the present intention was to publish them in *Tellus* along with those from the rest of the European network; but arrangements could no doubt be made for a separate circulation to interested parties in this country if it were thought worth while.

Mr. Gold felt that the discussion had brought out the great need for more frequent analyses, so that differences between, for example, thunderstorm rain and other rain, or between rain from the sea and rain from inland could be studied. He complimented Mr. Durbin on the slide showing the distribution of salt particles along a flight track. This was a new and promising study, and a most effective presentation of the results. He wondered however how effective these gelatin covered slides were in collecting salt particles: and what effects temperature and humidity had on the records. In particular, what differences are there between the stains produced by a crystal and by the same amount of salt in solution as a droplet?

Mr. Durbin replied that particles having chloride masses of down to 10^{-13} grammes could be detected using this gelatin technique. No accumulation of the smallest particles near the edges of the slides had been noticed and it had therefore been assumed that the efficiency of catch for all identifiable particles was unity. He did not know what effect temperature would have on the reaction between the chloride particles and the gelatin-silver-nitrate coating and thought that this aspect was worth investigating. Regarding the effect of humidity, the calibration showed that above a relative humidity of about 75 per cent the stain diameter due to a given mass of sodium chloride depends on the relative humidity at which the impaction was made.

REFERENCES

1. CAUER, H.; Ergebnisse Chemisch—Meteorologischer Forschung. *Arch Met., Wien,* Serie B, Band I, 1949, p. 221.
2. ROSSBY, C. G. and EGNER, H.; On the chemical climate and its variations with the atmosphere circulation pattern. *Tellus, Stockholm,* 7, 1955, p. 127.
3. JUNGE, C. and GUSTAFSON, P. E.; On the distribution of sea salt over the U.S.A. and its removal by precipitation. *Tellus, Stockholm,* 9, 1957, p. 164.
4. VITTORI, O.; 1956, Research in Chemical Composition of some forms of Atmospheric Particles. Tech. Note No. 5, University of Chicago, Dept. of Met., 1956.

WORLD METEOROLOGICAL ORGANIZATION

Commission for Bibliography and Publications

The second session of the Commission for Bibliography and Publications of the World Meteorological Organization was held in Paris from November 5 to 22, 1957. Representatives of Belgium, the United States, France, West Germany, Holland, Great Britain, the Soviet Union, Spain and Venezuela were present.

The President of the Commission, M. M.Mézin, was in the chair.

The major subjects considered were the revision of the meteorological section (551.5) of the Universal Decimal Classification and the publication of a World Meteorological Bibliography and an International Meteorological Vocabulary and Nomenclature.

551.5 was brought right up to date by adding a number for observations by artificial satellites. Numerous improvements in detail were made notably in atmospheric radioactivity, radiation and atmospheric electricity. Suggestions from the Scott Polar Research Institute for changes in the classification of snow cover to agree with general proposals made by the Institute for revision of the classification of the properties of snow and ice were considered and mostly adopted. These U.D.C. proposals have to be accepted by the Executive Committee of W.M.O. and by the International Federation of Documentation before they come into force.

It was agreed to recommend that the monthly accessions list of the Library of the Meteorological Office, London, should be used as the basis of a provisional World Meteorological Bibliography. Members of W.M.O. would be asked to supply monthly lists of books and articles published in their respective countries which are not in the monthly accession lists with a view to the publication of six-monthly amendment lists. Later, using experience gained with the provisional Bibliography, it was considered it should be possible for W.M.O. to publish a bibliography compiled from national lists of published books and articles.

A working group on the International Meteorological Vocabulary completed its work with the preparation of a draft Vocabulary with terms in French, English, Spanish and Russian and definitions of the terms in French and English.

The draft is to be submitted to Members and Presidents of Technical Commissions of W.M.O. for criticism. It is hoped, after co-ordination of the comments by the Working Group, that the Vocabulary will be published late in 1958. Later a polyglot nomenclature giving equivalents in the four official languages of W.M.O., English, French, Russian, Spanish, will be published. It should be noted that the terms "Vocabulary" and "Nomenclature" are terms agreed by the International Standardization Organization (I.S.O.) for the kinds of publication described.

Another decision of general interest is the one to recommend Members to use the I.S.O. system of Cyrillic transliteration in all documents intended for international use.

M. Mézin retired as President at the end of the meeting and was succeeded by Dr. A. Vandenplas of Belgium.

Visits were paid to the Bibliothèque Nationale, the International Business Machine Computing Centre in Paris, and the Documentation Centre of the National Centre for Scientific Research. At the Computing Centre was seen the latest I.B.M. electronic computor—the 704, and at the Documentation Centre the Filmorex document selector which using a photo-electric device can scan, by subject or combination of subjects, 600 microfiches a minute, separating those desired from the others. G. A. BULL

LETTER TO THE EDITOR

Cloud photographs taken at Ternhill

The photographs between pp. 112–113 were taken about 1645 G.M.T. on Friday, October 18, 1957, looking south-west from Ternhill. The tip of a warm sector, or the occlusion, had passed through Ternhill about an hour before the photograph was taken. I think it is probable that the cloud was formed originally over the Welsh hills in the warm air, and then streamed away in the wind direction, developing and producing the trails of falling crystals.

The main cloud sheet on the left of the photograph was altocumulus–altostratus with a more or less uniform base of about 12,000–13,000 feet. To the west was some high, thin, filmy cirrus.

Ternhill, Salop, November 27, 1957. W. L. LINEHAM

NOTES AND NEWS

Duststorm, Qatar Peninsula, Persian Gulf

We are indebted to Captain C. B. Gavin-Robinson of Gulf Aviation Ltd. for the photograph (facing p. 112) of a duststorm around the base of a cumulonimbus cloud observed by him when flying over the Qatar Peninsula, which extends northwards into the Persian Gulf east of Bahrain, on the afternoon of September 4, 1957.

Captain Gavin-Robinson first saw the storm, a well developed cumulonimbus with the base obscured by rising dust, while en route from Dukhan to Umm Said at 1600 local time, see Fig. 1; he then writes:—

"I took off from Umm Said for Dukhan (Fig. 2) at about 1650 local time and climbed to 3,000 feet. The cumulonimbus was in the same position, but surrounding it in an arc, convex to the north and terminating 5 miles west of Umm Said at one end and just east of Dukhan at the other, was a solid wall of dust, rising from the surface of the desert to 5,000 feet. I altered course to the northward to avoid the dust, and kept close to the wall. At one point I came within about ½-mile of it. Here I was carried from 3,000 feet up to 5,000 feet quite smoothly at about 1,000 feet per minute, see Fig. 3; I then headed away from the wall, reduced power, and decended to my cruising altitude of 3,000 feet.

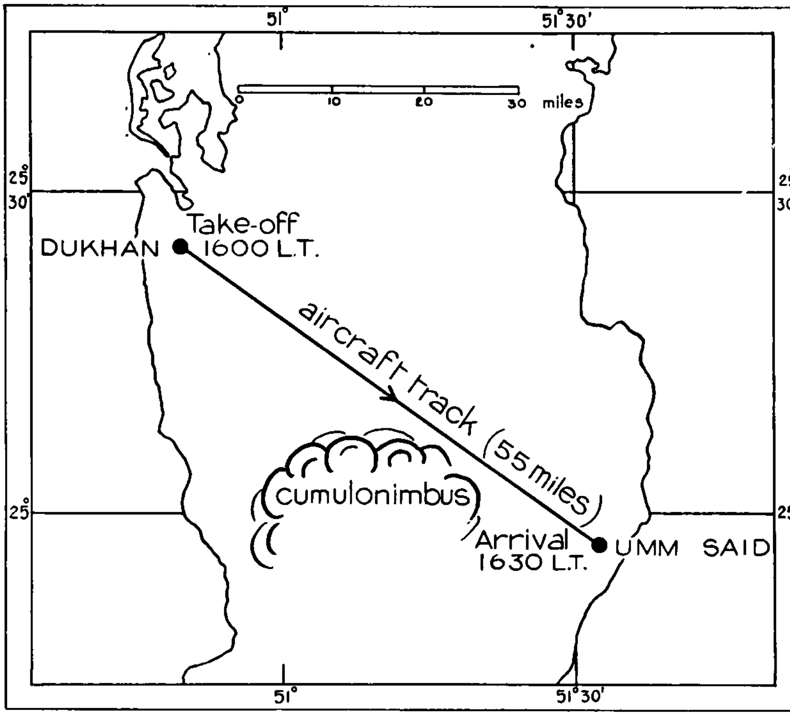


FIG. 1—FIRST FLIGHT OF AIRCRAFT OVER THE QATAR PENINSULA FROM DUKHAN TO UMM SAID, 1600–1630 LOCAL TIME

Sky clear; visibility 30 miles

At the half-way mark to Dukhan, that station reported that the dust had reached the airfield, that the visibility had fallen to 10 yards, and that the wind had changed from northerly at 18 knots to southerly at 25 knots. I therefore decided to divert either to Bahrain or Doha. I could see the latter place quite clearly at 20 miles range, the visibility north of the dust being excellent and the sky clear. At the request of the passengers I chose Bahrain for my diversion and set course for that place. Ten minutes later I received a message from Dukhan to say that the visibility there had improved to 2–3,000 yards "in bands". In view of the probable turbulence associated with the "dust front" I decided to continue to Bahrain.

On the way I passed 10 miles north of Dukhan, which was invisible behind the dust wall, and saw the dust solid down to the surface of the sea on which it appeared to float like an immense brown pillow.

I landed at Bahrain at about 1730 local time, and was then informed that the dust had reached Doha where the visibility had dropped to 100 yards."

Mr. F. E. Dinsdale, Meteorological Officer at Bahrain, writes:—

"This cumulonimbus was observed at Bahrain and the suggested height of 20,000 feet is almost certainly an under-estimate. Probably 35,000–40,000 feet is nearer the mark. There was some indication on the 1200 G.M.T. chart of a shallow surface depression over the desert south of Qatar, and as the radar wind at Bahrain for 1200 G.M.T. gave speeds of less than 22 knots to 60,000 feet there was little tendency for the upper part of the cloud to sheer off. The tephigram (dry- and wet-bulb temperatures) for 1200 G.M.T. is shown facing p. 113. The surface temperature over southern Qatar during the early afternoon was probably around 110°F.

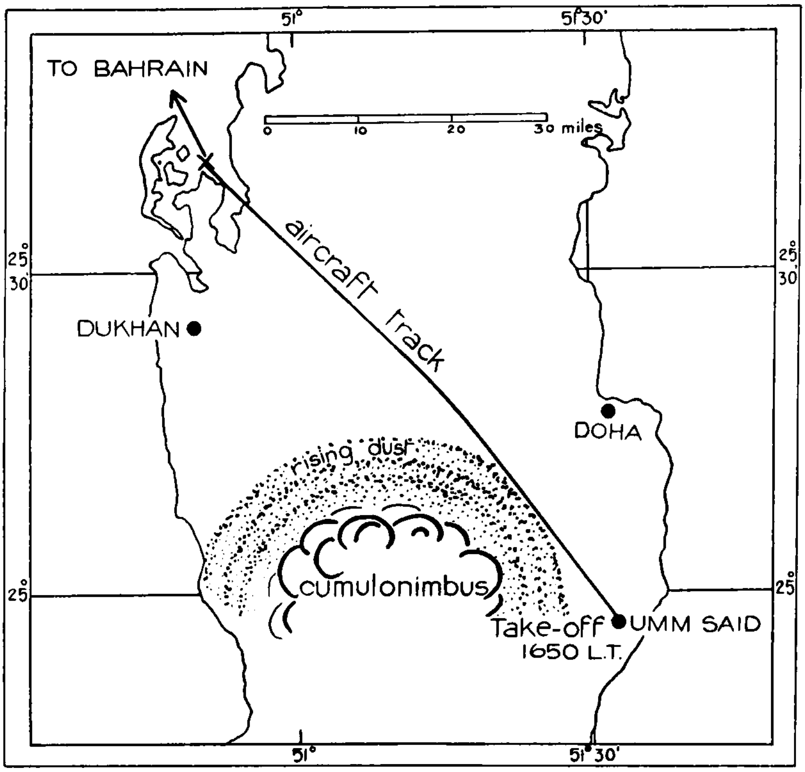


FIG. 2—SECOND FLIGHT SHOWING POSITION OF DUST AT 1700 LOCAL TIME

Sky clear; visibility 30 miles

The photograph was taken from the aeroplane at the position marked with a cross in Fig. 2, facing south, and shows the wall of dust billowing out over the shallow waters of El Hasam Bay with Ras Abaruk just visible in the right foreground.

Isolated cumulonimbus clouds are observed from time to time in this locality, but never before has one of this size and intensity been reported."

Mr. R. Murray, Senior Meteorological Officer, Aden, notes that the upper air soundings at Bahrain generally indicate very dry air away from the surface layer, tending to inhibit the growth of cumulus cloud. The reason for development of a large cumulus near Bahrain on September 4 is not clear as the sounding shows very dry air aloft.

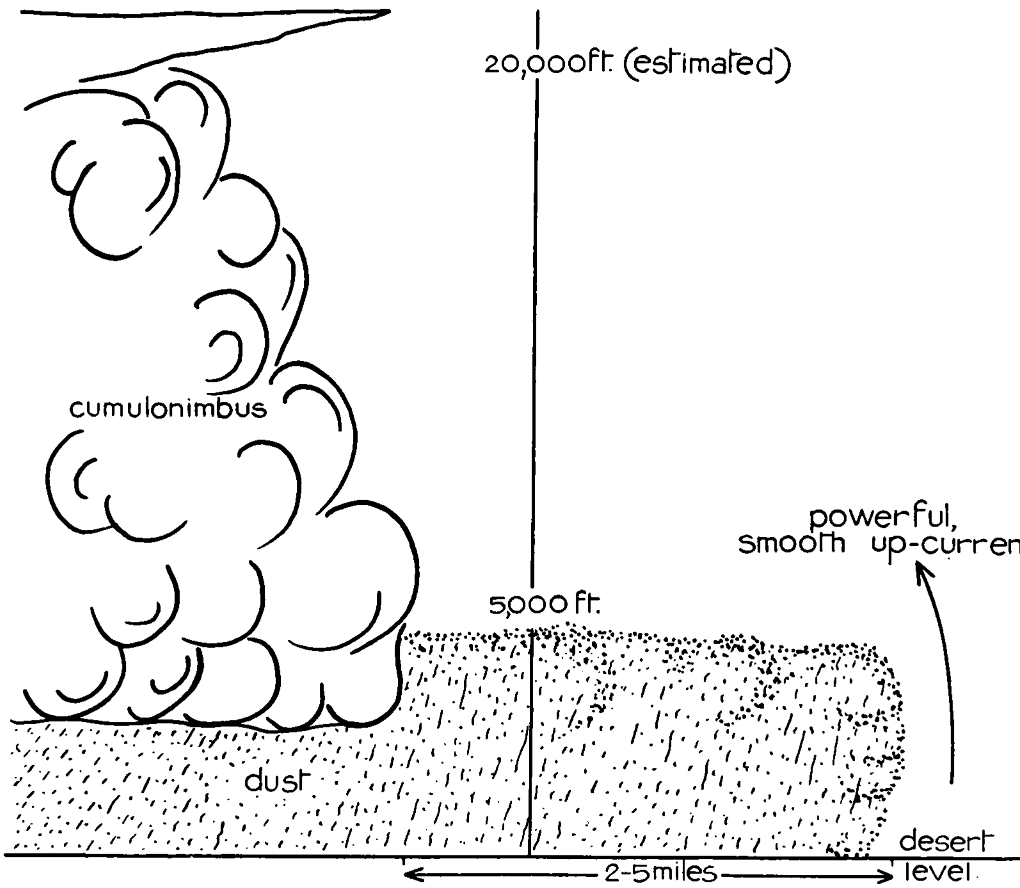


FIG. 3—VERTICAL SECTION OF DUST LOOKING WEST, 1700 LOCAL TIME

OBITUARY

James Strachan Farquharson, M.A., D.Sc.

The tragic death of Dr. Farquharson in a road accident on January 31, 1958 brought to a sudden and untimely end a career in the Meteorological Office covering more than 32 years.

James Farquharson was born on June 30, 1904 and educated at Robert Gordon's College and Aberdeen University, from which he received the degree of D.Sc. in 1944. He joined the Meteorological Office in July 1925, and the first ten years of his service were spent partly at Headquarters in London and partly at various outstations, including Lerwick and Croydon Airport. In 1935 he was posted for duty at Khartoum for a year to advise on the organization of the Sudan Meteorological Service which was being established in connexion with the development of Empire Air Routes, and he subsequently contributed to the Quarterly Journal of the Royal Meteorological Society two studies of the meteorology of that region, namely: *Haboobs and instability in the Sudan*, and *The diurnal variation of wind over tropical Africa.* On returning from Khartoum he worked again at Headquarters until on the outbreak of war he went to Paris as Meteorological Liaison Officer. In 1940 he was seconded to the Iraq Government as Director of the Iraq Meteorological Service and this was followed by a period as Meteorological Adviser at Air Headquarters India. In 1943 he was posted to Supreme Headquarters Allied Forces in Europe with the rank of

Wing Commander. At the end of the war he held, successively, the posts of Chief Meteorological Officer Royal Air Force Coastal Command, and of Royal Air Force Bomber Command, until in 1948 he was transferred to the Central Forecasting Office, Dunstable, with promotion to the rank of Senior Principal Scientific Officer. This was followed in 1954 by his appointment to the newly created Headquarters post of Assistant Director (Public Services), in which capacity he was responsible for the development of television weather forecasting, and the automatic telephone weather service. In December 1957 he returned to Dunstable as Assistant Director (Observations and Communications).

Throughout his career he was a vigorous thinker, often inclined to be impatient with the existing order, but nevertheless imbued with a keen urge to make constructive and, if necessary, unorthodox contributions towards greater efficiency within his sphere of responsibility as he felt the need. Although this inevitably brought him, on occasions, into disagreement with the more cautious of his colleagues, his genial personality and ready and infectious humour commonly won for him a tolerance, and indeed an affection, even from those who did not share his views, as well as a host of friends.

In a period of tendency towards a decay of standards in many spheres of human activity the loss can be ill-afforded of such a one as Dr. Farquharson, in whom was displayed a youthful zest and energy, combined with a deep-seated concern, of which only his really intimate associates probably knew, for the preservation of certain fundamental principles of conduct in everyday life.

Our deepest sympathy is extended to his widow, and to his family of two sons and three daughters.

S. P. PETERS

RETIREMENT

John Glasspoole I.S.O., Ph.D.

Dr. J. Glasspoole retired on December 31, 1957 after nearly 38 years service in the Meteorological Office during which period he had the unique good fortune to be able to study continuously the distribution in the British Isles of one particular element, rainfall.

Dr. Glasspoole started his career in the British Rainfall Organization which he joined in 1916. At that time the British Rainfall Organization, under the control of Dr. H. R. Mill, was still a private concern. During 1919, however, the organization was taken over by the Meteorological Office (which had just been transferred to the Air Ministry) and Dr. Glasspoole was appointed Junior Professional Assistant on August 18, 1919. Prior to this Dr. Glasspoole served for a period, during the first World War, in the Chemical Inspection Department of the War Office at Woolwich, where he carried out analytical and research work. In April 1920 Dr. Glasspoole was promoted to a Senior Professional Assistant.

For several years, the British Rainfall Organization remained a separate unit of the Office, firstly under Mr. Carle Salter and later under Dr. F. J. W. Whipple. The organization, which had suffered a setback during the war years, was firmly re-established under the guidance of Dr. Glasspoole. He initiated and published a series of studies of the rainfall distribution in the British Isles and for this original work he was awarded the degrees of M.Sc. and Ph.D. in the University of London in 1922 and 1925 respectively.

In May 1925 the British Rainfall Organization was absorbed in the British Climatology Division, known in those days as M.O.7, and Dr. Glasspoole whilst continuing his special work on rainfall became associated with the more general climatological work in respect of the British Isles. Dr. Glasspoole remained in M.O.7. until 1939 when M.O.7 was absorbed by M.O.3 then called the Climatological Division with Dr. C. E. P. Brooks in charge. During an earlier reorganization, Dr. Glasspoole had been assimilated as a Technical Officer and in January 1939 he was promoted to Senior Technical Officer. In November of that year he went with M.O.3 and the other Divisions located at South Kensington, to the evacuation headquarters at Stonehouse near Stroud. There, during the Second World War, he was busily engaged not only in keeping the British Rainfall Organization a going concern, but in assisting with the many climatological investigations required by the Fighting Services.

After the War, in September 1945, M.O.3 was moved to its present location at Harrow and in 1946 Dr. Glasspoole was appointed a Principal Scientific Officer. He became Head of M.O.3 in 1948 and remained so until the last re-organization of the Office in July 1957 when Branch structure was abandoned.

Although Dr. Glasspoole, especially in co-operation with Dr. C. E. P. Brooks, carried out many studies concerning the climatology of the British Isles and made an important contribution to the production of the *Climatological atlas of the British Isles*, his main interest was always in the rainfall of the British Isles. He wrote very many papers on the subject and became the recognized authority on the incidence and distribution of rainfall in this country. He became particularly well known to Water Engineers, River Boards and all those who require rainfall data and advice thereon. In October 1957, in recognition of his services, the Institution of Water Engineers made him an Honorary Member of the Institution. A little earlier he was appointed a Companion of the Imperial Service Order for long and meritorious service in the Meteorological Office. These honours may well be said to set the seal of achievement on his work.

At a crowded gathering on December, 31 at Harrow, Dr. Glasspoole was presented with a cheque by Mr. R. G. Veryard, Assistant Director, on behalf of the many colleagues who wished to express their esteem and appreciation of Dr. Glasspoole and his work in the Meteorological Office. In expressing his thanks, Dr. Glasspoole recalled some of his interesting experiences in the Office and emphasized his gratitude to the staff who had worked with him during his career.

REVIEWS

Atlas Middellandse Zee (The Mediterranean). $11\frac{1}{2}$ in. × $11\frac{1}{2}$ in., pp. xix + 91, *illus.*, Koninklijk Nederlands Meteorologisch Instituut, De Bilt, 1957. Price: *F*20.

There is inevitably some duplication by maritime nations of atlases of marine climatological charts but no other recent one has been produced specifically for the Mediterranean. These monthly charts therefore meet the need of anyone making a detailed study of the climate or surface ocean currents of this area. The only recent comprehensive atlases which included the area did so with the representation of this sea as a small adjunct to the North Atlantic or even the whole Atlantic; most of the charts of this area were on so small a scale that they could not be used for an exhaustive study in an area where local variations necessitate more detailed charts than for the open ocean.

Some of the data in this atlas have been computed for one-degree squares and some for 47 larger areas into which the Mediterranean has been divided, partly on a geographical and partly on an arbitrary basis. The information computed for one-degree squares is vector means of sea-surface currents and winds, mean pressure, mean air and sea-surface temperature, the percentage duration of fog and the percentage duration of precipitation. The information given for the 47 areas is sea-surface current roses, wind roses and tabulated data for mean air and sea temperature and pressure and their standard deviations, duration percentage of fog and precipitation, the percentage frequency of gales, mean cloud amount and mean cloud amounts worked separately for day and night.

The advantage of using such a small basic area as a one-degree square instead of a larger area is that the statistics so obtained are more akin to those for a land station or fixed ship, particularly for those areas where there are strong horizontal gradients of the elements being considered: the use of a one-degree square also has the advantage that if data are required for a large area they can generally be obtained by combining those given for the one-degree squares which the area incorporates. Observations available however in each one-degree square are often very few, particularly in the less frequented ocean areas and in this atlas there are many for which no data are available.

A gale is defined in this atlas as Beaufort force 8 or more and this definition is now in fairly general use in marine climatology. The United Kingdom hitherto used force 7 or more as the definition of gales for the preparation of marine climatological charts.

The standard deviations of air and sea-surface temperature as given in this atlas are generally more convenient for scientific use than the 5-percentile maximum and minimum, but the latter (which are used in the United Kingdom marine atlases) doubtless mean more to the average mariner.

Even where isopleths are drawn, it is advantageous to print in the actual data on which they are based as is done in this atlas. Not only can this procedure be useful when one has to carry out a study requiring exact values but it also gives some idea of the confidence that can be placed in the isopleths by showing the number of observations in each square.

The printing and whole production of this publication is first-class as is always so with Dutch marine atlases. The inclusion of 12 pages of blank overlay maps at the back of the atlas is a new and useful idea. It should be noted when using the charts on fog that the word "mist" is the Dutch for fog and has no connexion with the English definition. P. R. BROWN

Cloud study. By F. H. Ludlam and R. S. Scorer, (foreword by R. C. Sutcliffe). $9\frac{1}{2}$ in. × 6 in., pp. 80, *illus.* John Murray, London, 1957. Price: 12*s.* 6*d.*

It was a happy thought for the Royal Meteorological Society to have arranged for the publication of a selection of its large collection of cloud photographs, and Ludlam and Scorer were the only possible choice as authors and selectors. The resulting book is remarkably good value for 12*s.* 6*d.* in these days. There are 74 excellent reproductions, of which five are coloured, in addition to the frontispiece and the beautiful picture on the jacket, which illustrates the high standard of modern techniques.

In the Introduction much useful information has been included in twelve pages. It is written very simply, but only experts could have provided the quality. The book deals mainly with the processes of cloud formation, and only indirectly with their appearance from the ground, on which their classification is based. A list of the names appropriate to each photograph is given in pp. 19–20. There are a few photographs from the air, but most are from the ground, and the Arctic and Antarctic are represented. All are of interest, and many are of striking beauty.

The copious descriptive notes provide a mine of information, some of it not readily available elsewhere. There is little to disagree with, but on a few points there is inevitably some room for difference of opinion. I should have called the very tall left hand tower of No. 10 cumulonimbus calvus. The detail is less clear than that of the right hand tower, and this blurring is usually soon followed by a change to a fibrous structure, and therefore presumably indicates the first stage of glaciation. In the case of No. 23, there is no evidence in the photograph that the base consists of evening stratocumulus; similar clouds can develop without having been reached by any recent convection from the ground, at any time of day or night. For the sake of completeness, a sheet of simple stratocumulus of the type which gives us so much dull weather in the winter might have been included. These are minor points, and there can be no two opinions about the high quality of the book, which should do much to stimulate interest in cloud study. C. K. M. DOUGLAS

Klima und Bioklima von Wien. II Teil. By Prof. Dr. F. Steinhauser, Dr. O. Eckel and Dr. F. Sauberer. 9½ in. × 6½ in., pp. 136, *illus.*, Verlag, Österr. Gesellschaft für Meteorologie, Wien, 1957.

Part I of this publication, the tabulations of the observations made in Vienna since 1775, was reviewed in the *Meteorological Magazine* of December 1955.

This second part deals with secular changes in the meteorological elements, with special investigations of importance in building and in hygiene, and with the temperature distribution in the city and its surroundings.

It is a work of the highest importance in the study of the climatic changes of the past 200 years and in the climatology of great cities. It describes probably the most intensive investigations of the kinds concerned which have ever been performed.

The first section deals with secular changes of temperature, precipitation, number of rain-days, snow cover, sunshine and wind. For temperature, annual means and both 5 year and 30 year overlapping means are provided with much information on warmest years, warmest lustrum (5 years), length of winter, and so on. It is instructive to be able to compare directly three types of smoothing. An interesting fact revealed is that all but one of the warmest years, defined as a mean temperature greater than over-all mean plus twice the standard deviation, occurred before 1863. The exception was 1934.

All the coldest years, defined similarly, occurred before 1872 except for 1940. The 30 year overlapping means, which are given for every month, season and year, show the period 1811–1840 to have been warmest followed by a fall and then a rise after about 1891–1920 in all seasons except winter which was intermediate at first, then fell and rose to a maximum between 1891 and 1940.

Data on periodicities show the sudden appearance and similar end of individual frequencies and show, as the authors say, how little a period can be relied on.

The observations of temperature on which these statements are based were not all made at the same site. Full details of the three sites concerned are given in Part I. The values, except for the absolute extremes, have been reduced to those of the site in use since 1872 at Hohe Warte. The two sites used between 1775 and 1872 were in the city itself. Hohe Warte is in a less densely built over park quarter. One might expect therefore the absolute maxima and minima to be rather high in the earlier years by comparison with those of the later period.

Similar information is given for the secular variations of other elements.

The second part deals mainly with frequencies of combinations of elements such as the precipitation with different wind directions, with the distribution of fog, smoke, and dust according to wind and weather type, with accumulated temperatures, with amount of solar radiation on walls etc.

The third part gives a detailed account of the distribution of temperature over the city and its suburbs. There are tables of mean daily and hourly temperatures at different stations and the records of thermometers in motor cars giving cross-sections in different weather types; frosty night, warm winter's day, hot summer day, etc. The greatest temperature differences between the city centre and the suburbs occur in the evenings in clear quiet weather and reach 6° to 8°C.

The work is written from a very practical angle. Thus very cold days in winter are discussed in the greatest detail because it is then that small temperature differences are of the greatest importance.

A third part is promised to appear later which will deal with the distribution over the city of meteorological elements other than temperature, with the effect of different weather types on the city climate, with illumination and street climate.

G. A. BULL

Physical Meteorology. By John C. Johnson. 9 in. × 6 in., pp. xii + 393, *illus.* The Technology Press of the Massachusetts Institute of Technology and John Wiley & Sons, Inc. New York. Chapman and Hall, Ltd., London. 1954. Price: $8.50, 60*s.*

This book is a valuable addition to meteorological text books with much in it of value to both the degree student and research worker. It brings together in one volume topics which are only sketchily treated, if at all, in the usual meteorological text book and is confined to "phenomena not directly linked with the circulation of the atmosphere".

The first two chapters deal with the refraction and scattering of electromagnetic waves in the atmosphere. A useful feature is that the discussion is not confined to wave-lengths in the visible part of the spectrum but deals with the whole range of wave-lengths from the ultra-violet to the broadcast radio wave-lengths. This makes a useful preliminary to the discussion of radar meteorology in Chapter 8. It would seem to have been more logical to follow these chapters immediately with the sixth chapter which deals with refraction and diffraction by atmospheric suspensoids including the theories of rainbows, haloes and coronae.

The third chapter is a very useful discussion of visibility theory including the difficult problems of slant and horizontal visual range. Radiation and the heat budget of the earth are dealt with adequately in the fourth and fifth chapters.

Chapters 7 and 8 deal with the subject of cloud physics and the author is commendably cautious in distinguishing between experimental facts and the theories which have been devised to account for these facts. The two and a half pages devoted to the stimulation of precipitation by artificial means are in striking contrast to the vast amount of literature which has been published on the subject, but are certainly none the worse for that. Those pages do in fact summarize very fairly the present position in this much publicized field of operation. The section on radar meteorology is rather sketchy and deals mainly with the possibility of quantitative measurements of rain-water content of clouds without, however, dealing thoroughly with the many difficulties encountered in making and interpreting such measurements. The uses of radar in delineating precipitation patterns, in storm detection and in forecasting are presumably regarded as being outside the scope of the book. One statement should not however be allowed to go uncorrected (pages 250, 251); it is stated that half the power radiated by the antenna flows through the cross-section of the beam as usually defined. In fact virtually all the transmitted power is confined within the beam width.

Remaining chapters deal with atmospheric electricity, the ionosphere and ozonosphere and the upper atmosphere (that is, above about 25 kilometres).

The information is clearly presented, although occasionally an attempt at over-simplification makes the text rather discursive, and the numerous figures and diagrams are an asset. In all chapters use is made of papers published almost up to the date of publication of the book and the references and source books given are comprehensive and a useful guide to further study. The printing is excellent and almost entirely free from errors and the figures are particularly well reproduced. The problems set at the end of each chapter will no doubt be welcomed by examiners and are based on experimental results rather than artificially contrived. R. F. JONES

OXFORD UNIVERSITY

Jesus College.—The following election has been made:

Honorary Fellow.—Sir Graham Sutton, F.R.S.

THE WEATHER OF DECEMBER 1957

Northern Hemisphere

The Icelandic and Aleutian depressions were deeper than usual. The centre of the former was situated over the extreme north of Scandinavia and that of the latter over the Gulf of Alaska. Both the Azores anticyclone and the North Pacific anticyclone were more intense than usual and were displaced to the west. The centre of the Siberian high appeared to be near normal both in position and intensity but a marked ridge extended north-east from the centre.

Negative pressure anomalies were well-marked over northern Scandinavia and northern Russia and reached 16 millibars at a position 65°N. 60°E. A pressure anomaly of -13 millibars occurred over the Gulf of Alaska and associated negative anomalies extended across Western Canada into the centre of the United States. Pressure was higher than normal over a large part of the North Pacific Ocean; the greatest anomaly was + 13 millibars at approximately 40°N. 180°W.

Flow around the Canadian cold trough was weaker and of smaller amplitude than that usual for December. It is also to be noted that the north-westerly flow in the vicinity of the Davis Strait was rather weaker than usual.

The Arctic region was unusually cold and anomalies of −7°C. were reported in both Novaya Zemlya and Alaska. The main regions of positive temperature anomaly were across central Asia and across North America. The largest positive temperature anomalies in America occurred in the northern part of the United States; temperatures were 7°C. above normal just to the east of the Rocky Mountains. Similar anomalies were reported by a number of stations in Russia near the Urals at about 55°N. and also further east near Irkutsk. Other regions in which temperatures were 3°C. or more above normal were in eastern Europe, parts of India, parts of Japan and in Panama. Temperature anomalies over Europe and in the Mediterranean area were generally of the order of 1°C. either positive or negative.

The rainfall distribution over Europe was rather irregular but the amounts were near or greater than normal. Precipitation was appreciably greater than normal in Russia north of latitude 60°N. and also on the east of Asia as far south as 40°N. Over most of India, Burma and Indo-China rainfall amounts were negligibly small. The extreme northern regions of Canada and Alaska were drier than normal. Elsewhere in the North American Continent precipitation was rather above the average for the month.

WEATHER OF JANUARY 1958

Great Britain and Northern Ireland

For the first 11 days of the month frontal troughs and vigorous depressions moved eastwards across the British Isles but anticyclonic conditions prevailed from the 12th to the 16th. Northerly winds on the 18th initiated a week of freezingly cold weather with severe night frosts until, around the 25th, a southerly airstream brought a spectacular rise in temperature. Cold anticyclonic weather returned during the last two days of the month.

The fine, rather cold weather with which the year began in Scotland spread southwards across the whole country on the 2nd, but an unsettled milder type set in on the 4th as a large and deep depression from the Davis Straits reached the Iceland area, and associated troughs brought widespread rain and drizzle to most districts and snow to parts of northern England and Scotland. Changeable, rather stormy conditions were maintained for about another week by depressions which moved eastwards across the northern part of the British Isles on the 6th, 9th and 10th. Rain was widespread and locally heavy and wind frequently reached gale force, especially on the north and west coasts, during the passage of these depressions, but showery spells, with local hail and thunder, occurred between. The depression of the 6th brought an influx of very mild air with temperatures reaching the middle fifties over much of southern England, and on the 9th wind reached 81 knots in gusts at Tiree. An anticyclone moved towards the British Isles from the Azores on the 12th and weather was quieter for the next few days with fog in many areas. A vigorous depression near northern Scandinavia deepened further on the 16th and 17th, while an unusually intense anticyclone formed over Greenland. Northerly winds between these two features brought exceptionally cold air and snow showers to all parts of the British Isles while shallow polar depressions, embedded in the airstream, gave areas of more general snow. Temperatures in many northern districts remained below freezing day and night for nearly a week and there were severe night frosts generally. Negative air temperatures are rarely recorded in the British Isles, but on the 20th temperature fell to −2°F. at Driffield and on the 23rd, the coldest night of the spell, to −3°F. at Shawbury; −2°F. was also recorded the following night at Dyce near Aberdeen. Southerly winds soon afterwards brought a dramatic rise in temperature and a rapid thaw which, coupled with heavy rainfall, led to floods in many parts of the country; on the 25th, afternoon temperatures rose above 50°F. over the whole of the south-western part of the country and were maintained at that value throughout the night at some places and on the following day 60°F. was reached in North Wales. The mild weather, with rain, drizzle and hill and coast fog continued for three or four days but an anticyclone from the south-west became centred over England and Wales on the 30th and 31st and the month ended with a return to colder weather with widespread fog which was dense and persisted in some areas.

Temperature for the month was between one and three degrees below normal, both by day and night, over much of the country; in parts of Yorkshire it was nearly 5°F. colder than normal at night. The warmest day was the 6th in southern England but the 27th in the Midlands and North, when Llandudno, with 61°F. had the highest January temperature recorded in England and Wales since 1940. Rainfall was slightly below the 1916–50 average in England and Wales and also in Northern Ireland, but a little below in Scotland. Less than half the average occurred in East Lothian. Amounts elsewhere were mainly less than the average, but the average was exceeded over Cornwall, and over much of other southern counties and some eastern counties of England, and locally on the west and east coasts of northern England and Scotland. More than 150 per cent of the average was recorded in Oxfordshire and over the north-eastern part of Aberdeenshire.

Normal cultivation for all outdoor crops was held up to some extent during the first two weeks of the month by wind and rain, and it came to a standstill during the snow of the third week. The soil was well saturated throughout the month and flooded locally, following the rapid thaw around the 25th, but on the whole, work at the end of the month was fairly well up to date for the time of year. In the fruit orchards pruning and spraying was well in hand and prospects for spring vegetables appeared generally good.

WEATHER OF FEBRUARY 1958

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 ...	60	13	+1·2	179	+5	86
Scotland	56	−2	−1·7	115	+3	86
Northern Ireland ...	57	12	0·0	145	+2	85

RAINFALL OF FEBRUARY 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	2·55	153	*Carm.*	Pontcrynfe	8·02	174
Kent	Dover	3·60	175	*Pemb.*	Maenclochog, Ddolwen B.	5·23	112
„	Edenbridge, Falconhurst	2·85	116	*Radnor*	Llandrindod Wells ...	7·52	234
Sussex	Compton, Compton Ho.	3·25	113	*Mont.*	Lake Vyrnwy	9·03	151
„	Worthing, Beach Ho. Pk.	2·60	130	*Mer.*	Blaenau Festiniog ...	15·20	158
Hants.	St. Catherine's L'thouse	3·02	140	„	Aberdovey	7·77	236
„	Southampton, East Pk.	2·85	123	*Carn.*	Llandudno	5·04	232
„	South Farnborough ...	2·36	123	*Angl.*	Llanerchymedd ...	5·91	210
Herts.	Harpenden, Rothamsted	3·06	163	*I. Man*	Douglas, Borough Cem.	6·37	204
Bucks.	Slough, Upton ...	2·77	161	*Wigtown*	Newton Stewart ...	4·32	123
Oxford	Oxford, Radcliffe ...	2·57	144	*Dumf.*	Dumfries, Crichton R.I.	3·95	138
N'hants.	Wellingboro' Swanspool	3·10	183	„	Eskdalemuir Obsy. ...	5·03	109
Essex	Southend W.W. ...	1·89	136	*Roxb.*	Crailing...	2·18	125
Suffolk	Ipswich, Belstead Hall	2·59	164	*Peebles*	Stobo Castle	3·35	121
„	Lowestoft Sec. School	3·11	202	*Berwick*	Marchmont House ...	2·09	96
„	Bury St. Ed., Westley H.	3·32	195	*E. Loth.*	N. Berwick	2·55	174
Norfolk	Sandringham Ho. Gdns.	4·08	214	*Midl'n.*	Edinburgh, Blackf'd H.	1·65	98
Dorset	Creech Grange... ...	3·47	126	*Lanark*	Hamilton W.W., T'nhill	2·23	79
„	Beaminster, East St. ...	4·17	138	*Ayr*	Prestwick	3·32	140
Devon	Teignmouth, Den Gdns.	3·28	122	„	Glen Afton, Ayr San. ...	5·65	129
„	Ilfracombe	6·16	220	*Renfrew*	Greenock, Prospect Hill	3·46	68
„	Princetown	10·18	149	*Bute*	Rothesay, Ardencraig...	3·73	91
Cornwall	Bude	4·10	163	*Argyll*	Morven, Drimnin ...	3·88	86
„	Penzance	5·84	167	„	Poltalloch	4·10	92
„	St. Austell	6·59	162	„	Inveraray Castle ...	4·19	58
„	Scilly, St. Mary ...	4·13	152	„	Islay, Eallabus ...	4·92	129
Somerset	Bath	3·69	162	„	Tiree	3·48	112
„	Taunton	3·05	145	*Kinross*	Lock Leven Sluice ...	3·30	123
Glos.	Cirencester	4·00	163	*Fife*	Leuchars Airfield ...	2·34	137
Salop	Church Stretton ...	4·70	180	*Perth*	Loch Dhu	3·83	55
„	Shrewsbury, Monkmore	3·16	186	„	Crieff, Strathearn Hyd.	1·84	61
Worcs.	Worcester, Diglis Lock	4·12	242	„	Pitlochry, Fincastle ...	2·21	80
Warwick	Birmingham, Edgbaston	4·94	224	*Angus*	Montrose Hospital ...	2·34	125
Leics.	Thornton Reservoir ...	3·09	147	*Aberd.*	Braemar	3·30	123
Lincs.	Cranwell Airfield ...	2·69	162	„	Dyce, Craibstone ...	3·90	173
„	Skegness, Marine Gdns.	3·48	227	„	New Deer School House	3·68	155
Notts.	Mansfield, Carr Bank...	3·54	174	*Moray*	Gordon Castle	3·23	176
Derby	Buxton, Terrace Slopes	7·77	196	*Inverness*	Loch Ness, Garthbeg ...	2·21	67
Ches.	Bidston Observatory ...	4·00	207	„	Fort William	3·58	50
„	Manchester, Ringway...	4·34	183	„	Skye, Duntulm... ...	3·25	83
Lancs.	Stonyhurst College ...	8·96	246	„	Benbecula	4·28	142
„	Squires Gate	5·73	263	R. & C.	Fearn, Geanies ...	1·89	143
Yorks.	Wakefield, Clarence Pk.	4·34	205	„	Inverbroom, Glackour...	7·34	156
„	Hull, Pearson Park ...	4·22	231	„	Loch Duich, Ratagan...	6·00	95
„	Felixkirk, Mt. St. John...	3·80	187	„	Achnashellach	7·26	107
„	York Museum	3·56	212	*Suth.*	Stornoway	3·54	132
„	Scarborough	4·10	228	*Caith.*	Lairg, Crask	4·54	106
„	Middlesbrough... ...	2·84	180	„	Wick Airfield	5·01	251
„	Baldersdale, Hury Res.	6·32	201	*Shetland*	Lerwick Observatory ...	2·31	70
Nor'l'd	Newcastle, Leazes Pk....	4·67	265	*Ferm.*	Belleek	4·76	145
„	Bellingham, High Green	2·82	110	*Armagh*	Armagh Observatory ...	3·90	176
„	Lilburn Tower Gdns. ...	3·53	160	*Down*	Seaforde	4·77	167
Cumb.	Geltsdale	4·16	170	*Antrim*	Aldergrove Airfield ...	3·76	157
„	Keswick, High Hill ...	5·99	143	„	Ballymena, Harryville...	4·35	149
„	Ravenglass, The Grove	5·32	184	*L'derry*	Garvagh, Moneydig ...	5·05	178
Mon.	A'gavenney, Plâs Derwen	7·30	214	„	Londonderry, Creggan	4·84	153
Glam.	Cardiff, Penylan ...	5·75	192	*Tyrone*	Omagh, Edenfel ...	3·68	116

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,031, MAY 1958

ESKDALEMUIR OBSERVATORY—THE FIRST FIFTY YEARS

By M. J. BLACKWELL, M.A.

This month fifty years ago, on May 11, 1908 to be exact, it is recorded[1] that the first Superintendent of Eskdalemuir arrived to take up duties at the newly built Observatory of the National Physical Laboratory, set in the remote north-east corner of Dumfriesshire. Now, on the occasion of the golden jubilee, we can look back with not a little pride at the sequence of events and changes which have transformed an eleven acre site of wind-swept moorland into a modern geophysical observatory.

Past.—It is well known[2] that the westward extension of the London electric tramways prevented the continuance of magnetic recording at Kew Observatory, just as the electrification of the suburban railways caused the transfer of magnetic work from Abinger to Hartland, nearly fifty years later.[3] But though it was clearly desirable to establish another observatory in an undisturbed area, to carry on the work, it was probably the £10,000 compensation received from the tramway company which made the scheme a reality.

Thus, in due course, a committee of the Royal Society selected a suitable alternative site – reputedly by placing a coin on a map so as not to intersect any towns, industrial areas or railways within a radius of some ten miles. Past and present staff of the Observatory can bear witness to the thoroughness with which the committee performed their task.

Leaving behind the railhead at the Border towns of Langholm or Lockerbie, the visitor must follow the winding hill roads for fourteen miles until they meet at the small cluster of dwellings which is Eskdalemuir; here he must strike north, along the road to Ettrick and Selkirk, for a further three miles, to reach the tiny hamlet of Davington with its Kirk of Covenanter memories. A short spur road was laid up to the new site – the first metalled road in the district, and not before time, considering that Telford was born and bred in Eskdale.

We can hardly comprehend the isolation of those days: the horse-drawn transport bringing most provisions only once a month; yet such an existence made for complete acceptance of local conditions and a zest for any activities in the area. The telephone at the Observatory was the first in the district and, indeed, it was nearly decided to place the Post Office there also. Inside the enclosure, the early photographs[4] show the three buildings: Rayleigh House (Superintendent's quarters), Office Block and Schuster House (Assistants' quarters), standing out in stark relief against the barren foothills of the Southern Uplands. The names of the houses commemorate the scientists who were associated with the foundation of the Observatory.

The scientific programme of work, as it evolved over the first forty years, has already been described[5] in some detail by Mr. J. Crichton, who was Superintendent throughout the difficult years of World War II and the immediate post-war period. Apart from its original function as a geomagnetic station, the Observatory has always been concerned with meteorology, atmospheric electricity, and seismology (until 1925, when the equipment was transferred to Kew); this programme owes much to the guidance and influence of the Gassiot Committee, which administers a trust devoted to the furtherance of these subjects.

The recording of the earth's magnetic field by the original Adie magnetographs was extended, from the time of the 1932–33 International Polar Year, by the more sensitive La Cour magnetographs; at the same time, the acetylene gas supply was replaced by large storage batteries which are now used to supply recording apparatus in many parts of the establishment. A few years later, in 1936, came a further change when the Observatory was connected to the main electricity supply: thermostatically controlled electric radiators could then be used in the underground magnetograph house. A not unwelcome by-product of the change was the rapid disappearance of the oil lamps used for illumination. The basic absolute instruments, declinometer, coil-magnetometer and dip-inductor, were supplemented from about 1949 by portable sub-standards, the quartz horizontal magnetometer (Q.H.M.) and the balanced magnetometer for vertical force (B.M.Z.), for facilitating inter-observatory comparisons. For some years also, the rate of change of vertical force was detected by a large loop laid round a height contour on the moor outside the grounds.

In 1910, the Observatory came within the control of the Meteorological Office and became a first-order synoptic and climatological station. In addition to the standard equipment, a photographic barograph and thermograph, a Hellman-Fuess snow-gauge and a Jardi rate of rainfall recorder were installed. Later came the atmospheric pollution recorder, run in cooperation with the Fuel Research Station, and for a long time the night-sky recorder. In atmospheric electricity, potential gradient records have been obtained with a Dolezalek electrograph, originally using a water-dropper and later a polonium collector.

In a commemorative article such as this, we are more concerned with the broader aspects of the history and development of the Observatory; for greater detail, reference can be made elsewhere[6], and we therefore turn to the last decade of our story.

Present.—With the steady growth of the scope and detail of the work, more accommodation had to be found. Additional married quarters were built in 1928, and are now occupied by the deputy Superintendent and Mechanic; more recently, the old acetylene house was converted for use as the Handyman's Cottage. Now, in our jubilee year, the former schoolhouse at Davington has become yet another married quarter.

The stables and coach-house now house the batteries, charging room and garage. The original De Dion motor car, acquired before World War I, was followed by a wealth of makes and types of vehicle, ending in an up-to-date estate car, which brings a welcome measure of comfort to staff and families making the long journey to the nearest towns. The phonographs and early battery portables in the living quarters have given way to the latest tape-recorders, V.H.F. radios and television sets. Amidst all these changes lived the late Mr. J. B. Beck, who served from 1913 to 1950 with but a short break for war service, and Mr. W. J. Hogg, who joined the staff as Mechanic in 1920 and whose length of service is approaching the remarkable total of forty years, practically all of it spent at Eskdalemuir.

As recent photographs (between pp. 144–145) of the Observatory show, the shelter belt of Norwegian and Sitka spruce is nearing maturity; planting, which began on a large scale with a gift of sixteen hundred trees in 1911, was followed by topping and lopping of the taller trees at intervals in the 1930's. In the last few years, we have had to consider the risk of over-sheltering, particularly of the anemograph, thermometer screens, rain gauges and sunshine recorder. As a result, a co-ordinated programme of felling, thinning and re-planting was put into effect in 1956 with a view to maintaining the exposure of the instruments at a constant level in years to come. This work has led to the addition of a full time Groundsman to the staff.

The basic instrumental work in geomagnetism has changed little in recent years. Theoretical studies have been set aside so as to make more efficient use of staff arriving fresh from meteorological work elsewhere. The analysis of the magnetic records, however, becomes more involved year by year: to the daily character figures (C-figures) were added the three-hourly disturbance ranges (K-indices) and, for the International Geophysical Year, the quarter-hourly disturbance ranges (Q-indices). The magnetograms are scrutinized for sudden commencements, solar flare effects and micro-pulsations; even rudimentary attempts at forecasting magnetic storms and aurorae have been made, using the direct-vision photo-electric variometer.

There has always been a close link between the Observatories and the current scientific expedition of the day. During the International Geophysical Year, we have a particular interest in the Royal Society base at Halley Bay since all the members of the geomagnetic group received preliminary training at Eskdalemuir, and the instruments used were calibrated here. Yet, if there has been a significant trend in the scope of our geophysical work in the last decade, it has surely been in the growth of the meteorological relative to the geomagnetic aspects.

Following the extensive post-war work, in solar and terrestrial radiation, of our sister observatory at Kew, total and diffuse radiation solarimeters were installed on top of the tower stairhead in 1950; until this time, little use had been made of the tower, an ideal observational platform. Indeed, the duty observer had to climb a narrow stair and two ladders before emerging on to a square yard of icy, wind-swept roof. In 1956, the stairhead was cut away to give an uninterrupted horizon; the ladders were replaced by normal flights of stairs, and a platform of angle iron was constructed on the tower roof. To the solarimeters have been added a bimetallic actinograph and the sunshine recorder, now with a much improved exposure.

Mention has been made of our additional instruments for measuring precipitation; this branch of the work is still growing steadily: an open-scale rain recorder was installed in 1957, together with a standard Canadian snow-gauge and two experimental snow-gauges, one with a rotating head, the other with a specially designed wind-shield. For the International Geophysical Year, an American Class "A" evaporation pan was installed, and apparatus for the chemical sampling of air and rain-water.

At the outbreak of the last war, a Dobson spectrophotometer, for the determination of total atmospheric ozone content, was diverted to Eskdalemuir for several years. Now, as part of our International Geophysical Year programme, another instrument has been installed; but in addition to the standard measurements, attempts will also be made to determine the vertical distribution of ozone by means of "Umkehr" observations.

Future.—The rate of expansion in recent years has been too rapid to permit more than a hurried glance into the future. Suffice it here to mention but a few changes which are already imminent.

The staff continues to grow and, fortunately with it, so does the accommodation. The nine or ten synoptic reports of today are being increased to sixteen hourly reports, from 0600 to 2100 G.M.T., and it has been agreed in principle to extend this programme still further to cover the full 24 hours; this is only to be expected when one realizes that Eskdalemuir is almost the only inland first-order station in Scotland.

On the instrumental side, the recording of daylight illumination is being added to the radiation programme, and after that the measurement of total net flux using ventilated flux plate radiometers. An attempt to calibrate snow recorders by measuring snow depth profiles will be made. The replacement of outdated mechanical time-shutters by relays in the lamp circuits, and installation of a centralized Observatory time system has been started.

The cumbersome, photographic electrograph will be replaced by a valve-voltmeter circuit and recorder; less immediate, but nevertheless desirable, is the use of the new nuclear-precession magnetometer for inter-Observatory comparisons. Lastly, with radiation, evaporation, wind and temperature records available, we are well under way towards the setting up of an ideal hydrological experiment, for which nature has provided us with the nearby Davington burn and its well defined catchment area. So—here's to the next fifty years! May we be worthy of those who led the way.

REFERENCES

1. London, National Physical Laboratory, Observatory Dept.; Report for the year 1908. London, 1909, p. 14.
2. London, Meteorological Office; Observatories' Year Book 1938. London, 1955, p. 84.
3. London, Royal Astronomical Society; Report of the Astronomer Royal for the year 1954–55. London, 1955, p. 4.
4. London, Meteorological Committee; Report for the year 1910–11. London, 1911, facing p. 48.
5. CRICHTON, J.; Eskdalemuir Observatory. *Met. Mag., London,* **79,** 1950, p. 337.
6. London, Meteorological Office; Annual Reports of the Director of the Meteorological Office. London.

HEAT SOURCES AND SINKS AT THE EARTH'S SURFACE

By D. M. HOUGHTON, M.Sc., D.I.C.

Summary.—A study has been made of the spatial and temporal variations in the surface character of the earth which can result in increases or decreases in

the heat supply to the atmosphere. For the sea areas the changes in surface temperature and in the ice limits are considered and for the land the changes in albedo, evaporation and evapotranspiration, state of surface, heat-storage capacity and conductivity are dealt with. Some of these factors are found to be unimportant, while others can exert an appreciable and sometimes long-term influence upon the heat supply to the atmosphere.

Introduction.—The solar radiation received at the outside of the atmosphere is 800 to 900 calories per square centimetre per day throughout the year at the equator and at the poles it is 1070 cal. $cm.^{-2}$ day^{-1} in midsummer, falling to nil in winter. If we take a long period average covering the northern hemisphere then approximately 47 per cent of this radiation reaches the earth's surface and about 19 per cent is directly absorbed by the atmosphere and clouds.[1] Some of the radiation received at the earth's surface is reflected back to space, some is absorbed and stored and some is passed to the atmosphere by convection and radiation. All of these processes are affected by the physical character of the surface, with the result that the amount of heat reaching the atmosphere either immediately or by the subsequent transfer of stored heat from the surface may be significantly affected. Here we are concerned with those effects which may be sufficient to affect the circulation of the atmosphere over a substantial area for a period of days. Such effects must occur over a substantial area and persist for a few days at least. We therefore limit the study to changes which can affect an area of a minimum of 10^4 square kilometres for 5 days at least.

The magnitudes of the variations in heat supply to the atmosphere may be compared with the outgoing long-wave radiation to space (500 cal. $cm.^{-2}$ day^{-1} in low latitudes, 380 cal. $cm.^{-2}$ day^{-1} in high latitudes), or with the change in the heat reflected to space (and consequently lost to the atmosphere) due to a change in cloudiness from nil to 8 oktas (100 to 200 cal. $cm.^{-2}$ day^{-1} in low latitudes). However, it is probably safer to compare the variations with one another and see which are the most important.

The energy of the atmospheric circulation is derived primarily from horizontal differences of temperature. These horizontal temperature gradients may be affected by variation in the supply of either sensible or latent heat to the atmosphere. There is however the important difference that the modification to the temperature field resulting from variations in supply of latent heat will take place when condensation occurs and this may be at a distance of several hundred kilometres from the source of evaporation.

The Oceans.—Of all the heat stored and released by the earth's surface during the course of the annual temperature cycle 86 per cent is stored by the oceans.[2] Most of this is released in winter months and at a rate which depends upon the temperature difference between the sea and the air above. As far as the sea itself is concerned the determining factors in its heat output are its surface temperature and whether or not it is frozen.

Sea surface temperature.—When the sea surface is warmer than the air above it, heat is transferred upwards by convection and long-wave radiation. Convective processes are also set up in the sea itself so that the sea surface temperature changes little.

When the sea surface is colder than the air above it, stable conditions are established in both media and heat is transferred downwards by long-wave radiation and turbulent diffusion. Cloudy conditions are likely and there will be net downward radiation from the cloud base, but even for a cloud–sea temperature difference of 5°C. (which is rare) this is only about 25 cal. cm.$^{-2}$ day^{-1}.

A relationship between the flux of heat and water vapour to the atmosphere and the air–sea temperature difference has been suggested by Jacobs[3] but is applicable only to mean values over a period of about a season. Special cases covering shorter periods have also been analysed from time to time and provide some indication of the variation in intensity of convective heat transfer over the oceans.

(i) The long-term heat budget:

Jacobs gives the empirical relation

$$Q_e = 0{\cdot}143\,(e_w - e_a)\,W_a$$

where Q_e = heat equivalent of evaporated water (calories)

W_a = wind speed (metres per second)

e_w = saturation vapour pressure at sea surface temperature (millibars)

e_a = vapour pressure of the air at deck level (millibars).

The associated transfer of sensible heat (Q_c) is then found using Bowen's ratio. No distinction is made between rough and smooth conditions. Jacobs' charts showing the mean seasonal values of Q_c and Q_e over the North Pacific and North Atlantic Oceans give winter values for Q_c of 20 to 80 cal. cm.$^{-2}$ day^{-1} to the west of Ireland rising to over 200 cal. cm.$^{-2}$ day^{-1} off the east coast of North America. The annual means for Q_c are 20 and 100 cal. cm.$^{-2}$ day^{-1} respectively. Corresponding values for Q_e are about $2\frac{1}{2}$ times Q_c and the annual means for $(Q_c + Q_e)$ rise from about 70 cal. cm.$^{-2}$ day^{-1} off western Ireland to 350 cal. cm.$^{-2}$ day^{-1} off eastern America.

The observed annual amplitudes of sea surface temperature variation at the weather ship stations "I" and "J" support these figures. The mean amplitude through the top 100 metres is about 4·5°C., so that the heat given up by the sea over the six winter months is about 45,000 cal. cm.$^{-2}$, an average of about 250 cal. cm.$^{-2}$ day^{-1}. Of this about half is accounted for by long-wave radiation. Sverdrup[4] quotes similar figures for the Bay of Biscay. Over these areas of the eastern Atlantic the annual mean of the air–sea temperature difference is between −1°C. and −2°C.

(ii) Shallow convection:

Riehl[5] has studied the atmospheric heat balance over a period of a few days in the trade wind regions of the North Pacific Ocean. His data satisfy the empirical equation

$$Q_c = 0{\cdot}036\,(T_w - T_a)\,W_a,$$

with values of Q_c ranging from 10 to 30 cal. cm.$^{-2}$ day^{-1} for an air–sea temperature difference of 0·5 to 1·0°C.

Data for the Baltic are contained in a paper by Hela[6] who studied the heat exchange at *Finngrundet* (a lightship). He gives the mean input of sensible heat to the atmosphere during winter months as about 50 cal. cm.$^{-2}$ day^{-1}. It is probable that shallow convection obtained on the majority of occasions, so that this figure is applicable here. He suggests the equation

$$Q_c = 0{\cdot}032\ (W_a + 0{\cdot}3)^{\frac{1}{2}}(T_w - T_a)\theta_w$$

to fit his data, where θ_w is the sea surface temperature in degrees absolute.

For cases of shallow convection over the North Sea but with a much larger temperature difference (about 10°C.) the author has found the sensible heat input to be about 40 to 80 cal. cm.$^{-2}$ day^{-1}. The data used were for very cold easterlies circulating around a Scandinavian anticyclone.

(iii) Strong convection:

Craddock's[7] paper on the modification of polar airstreams contains useful data. He shows that the sensible heat input to the atmosphere can reach values as high as 1400 cal. cm.$^{-2}$ day^{-1}, while 300–500 cal. cm.$^{-2}$ day^{-1} is probably quite normal in direct airstreams from the north. These figures are not strictly comparable with those already given, as an unknown proportion of the observed heating is due to release of latent heat in the shower precipitation during the passage of the air over the sea. The equations

$$Q_c = 0{\cdot}064\ (T_w - T_a), \text{ and}$$
$$Q_e = 0{\cdot}017\ L\ (T_w - T_a)$$

fit his graphs relating the sensible heat and water vapour transfer to the air–sea temperature difference.

A similar type of air mass is studied by Burbidge.[8] Using his data for the modification of continental polar air crossing the Hudson Bay in the late autumn the input of sensible heat is at least 344 cal. cm.$^{-2}$ day^{-1}. No account has been taken by Craddock or Burbidge of the long-wave radiational cooling of the atmosphere for which the relevant figure is of the order of 150 cal. cm.$^{-2}$ day^{-1}.

Winston[9] relates intense cyclogenesis in the Gulf of Alaska with areas of rapid heating from the sea surface. He finds the non-adiabatic component of heating in the five cases of cold air masses studied to lie between 400 and 2210 cal. cm.$^{-2}$ day^{-1}. Unfortunately values of sea and air temperature are not given.

(iv) Estimation of the effect of an anomaly of 1°C. in sea temperature on the heat transport to the atmosphere:

Several relationships have been suggested which give some indication of the dependence of the supply of sensible and latent heat to the atmosphere upon the sea surface temperature. For the mean effect over a period of months the partly empirical equations derived by Jacobs and Hela indicate that an anomaly of ± 1°C. in air–sea temperature difference will give ± 30 cal. cm.$^{-2}$ day^{-1} in sensible heat, and ± 60 cal. cm.$^{-2}$ day^{-1} in latent heat available to the atmosphere. A relationship based on Craddock's analysis suggests values up to ± 80 cal. cm.$^{-2}$ day^{-1} for the increase in the supply of sensible heat corresponding to ± 1°C. in strongly convective situations, while the latent heat supply will change by ± 160 cal. cm.$^{-2}$ day^{-1}.

Now a change in the temperature of the sea surface is always accompanied by a change in the temperature of the air immediately above it. It is reasonable to suppose that in the case of off-shore advection of comparable air masses over sea areas close to continents an anomaly of 1 °C. in sea surface temperature will correspond to an anomaly of 1 °C. in air–sea temperature difference. The above figures can then be applied as they stand and they may be assumed to indicate the maximum effect on the heat input to the atmosphere of a 1 °C. sea temperature anomaly. In all other cases the air–sea temperature difference anomaly will be some fraction of the sea temperature anomaly. An independent estimate of the size of this fraction may be obtained by considering the change in heat storage capacity of the sea itself. Anomalies in sea surface temperature are sometimes observed to last for several months. If, as is reasonable, a positive anomaly of 1 °C. extends to 50 metres depth and disappears after 5 months then the atmosphere has received an additional 50 cal. $cm.^{-2}$ day^{-1} (corrected for approximately 5 cal. $cm.^{-2}$ day^{-1} lost as additional long-wave radiation). This suggests that the mean effect of a 1 °C. anomaly is appreciable over quite a long period and somewhere near half the maximum effect indicated by the empirical equations.

Ice.—

(i) Freezing:

When the sea freezes the transfer of heat from the sea to the air is very much reduced. This is demonstrated most markedly in observations of the modification of polar continental air over Hudson Bay before and after freezing.[8] The daily input of heat to the air crossing the Bay before the surface freezes is at least 344 cal. $cm.^{-2}$ (see p. 135). After the Bay freezes in December hardly any modification can be observed.

(ii) Conduction:

If the temperature of the water beneath the ice is 0°C. and the air temperature well below this value, the rate of heat transport through the ice may be estimated for various thicknesses of ice. For ice 1 metre thick and a temperature difference across the ice of 10°C., assuming a thermal conductivity of 0·005 cal. (sec. cm. $°C.)^{-1}$, it is about 20 cal. $cm.^{-2}$ day^{-1}. In areas where the sea freezes the atmosphere loses heat by long-wave radiation at the rate of about 380 cal. $cm.^{-2}$ day^{-1}. Hence any heat received by conduction through the ice is negligible in comparison with the loss of heat by radiation.

(iii) Albedo:

Changes in the albedo of the sea through freezing need not be considered, as the incident solar radiation in the areas concerned is either nil or too small to matter.

Ocean currents.—The subject of ocean currents is beyond the scope of this paper, but it must be noted that it is these currents which largely determine the latitudinal and longitudinal distribution of sea temperatures. A sea temperature anomaly is normally due to either an anomaly in absorbed radiation or an anomaly in the direction or rate of flow of ocean currents. Also, as a result of ocean currents the areas of anomalous radiation and resulting anomalous sea temperature may become far removed from one another. The time lapse is important. For instance a large sea temperature anomaly in the Caribbean Sea and off the coast of Florida may be expected to be transferred north-eastwards in the Gulf Stream and to reach the north-eastern Atlantic in the course of a year. The maximum flow which is found off Chesapeake Bay is about 3 knots, while over most of its course the Gulf Stream transports water at about $\frac{1}{3}$ to $\frac{1}{2}$ knot.[4]

Heat exchange between atmosphere and ocean—summary.—The exchange of heat (sensible and latent) between the sea and the atmosphere is negligible when the sea is frozen, and small ($\sim$ 20 cal. cm.$^{-2}$ day^{-1}) when it is colder than the air. It is significant ($\sim$ 50 cal. cm.$^{-2}$ day^{-1}) when mechanical turbulence and shallow convection pass heat to the air and it is very large (up to 1,200 cal. cm.$^{-2}$ day^{-1}) in strongly convective situations. Downward long-wave radiation may supplement the small turbulent heat flux when the sea is colder than the air but is normally much smaller than 25 cal. cm.$^{-2}$ day^{-1}.

The maximum change in heat supply to the atmosphere over the open ocean resulting from an anomaly of ± 1°C. in sea surface temperature is estimated at ± 15 cal. cm.$^{-2}$ day^{-1} for sensible heat and ± 45 cal. cm.$^{-2}$ day^{-1} when latent heat is included. This applies to conditions averaged over a period of months. The latter figure is confirmed by an estimate based upon maximum observed sea temperature changes. In strongly convective situations these values may be increased to ± 40 and ± 120 cal. cm.$^{-2}$ day^{-1} respectively.

Observed sea temperature anomalies of the order of 1 to 3°C. and the corresponding increase or decrease in energy made available to the atmosphere must have some effect on subsequent synoptic developments.

The freezing of the sea surface, although it has been shown to be important, only occurs on a comparatively small scale. The freezing of large areas of partially enclosed seas which is an annual occurrence in high latitudes is most important in connexion with the modification of local air masses. It is possible that the late freezing of areas such as Hudson Bay might also hinder the establishment of the semi-permanent continental cold troughs in the troposphere, and the abnormal freezing of any such area should also have an observable effect on the subsequent thickness pattern in the troposphere. However, there are few areas in which the dates of freezing of substantial areas of the sea have significant variations. For instance the Baltic Sea is subject to a certain amount of freezing every winter, but it seems improbable that a variation of 20 to 50 miles in the freezing limit can exert any appreciable large scale control on the atmospheric circulation.

The Continents.—The non-uniformity of the land surface and its comparative inability to store and conduct heat necessitate a different approach to the question of whether any changes in its character can appreciably change the heat supply to the atmosphere.

Little of the heat which is received by a land surface from the sun is stored in the ground for more than 24 hours. Some of it is returned to space by reflection and radiation, some passes to the atmosphere by long-wave radiation or convection and some is used in evaporation, in the melting of snow, etc. Any increase in the amount of heat reflected or in the amount used in evaporation will reduce the amount of sensible heat made available to the atmosphere and it is therefore convenient to think of the increase of heat dissipation by any such process as a potential local loss to the atmosphere.

Heat conduction and storage.—

(i) Unfrozen ground:

Heat flow to and from the surface depends upon the thermal conductivity of the materials in the surface layers, on the seepage of water downwards associated with rainfall and on the temperature gradients which are established primarily as a result of incoming and outgoing radiation. All these are very variable but the purpose of this study will be achieved if extreme values can be estimated.

Using known values of thermometric conductivity (K) density (ρ) and thermal capacity (c), the following values of heat flux are calculated assuming a temperature gradient of 10°C. per metre (Table I).

TABLE I—VALUES OF HEAT FLUX CALCULATED FROM THERMOMETRIC CONDUCTIVITY (K) DENSITY (ρ) AND THERMAL CAPACITY (c)

	ρc	$K \times 10^{-2}$	Flux
			cal. cm.$^{-2}$ day^{-1}
Wet sand	0·53	0·60	28
Dry sand	0·30	0·16	4
Dry loam	0·4	0·2	7
Marsh	1·00	0·12	10
Clay	1·4	0·2	24
Rock	0·5	1·2	52
Snow	0·12	0·2	2
Ice	0·45	0·78	30

Temperature gradients of the order of 10°C. per metre are only found in conditions of strong insolation, or radiation under clear skies at night, but for short periods they may be considerably greater in the top few centimetres. On a hot summer's day at Dresden, Schreiber[10] found the maximum midday heat flux into the sandy soil to be about 70 cal. cm.$^{-2}$ day^{-1}. Roach[11] using a flux plate at 6 centimetres depth at Kew measured a maximum flux of 5 milliwatts (100 cal. cm.$^{-2}$ day^{-1}) which lasted for about 3 hours on a hot June day. With the same instrument he measured a maximum upward flux of 1 milliwatt during a very cold easterly outbreak in January 1954. This flux persisted for at least 24 hours. Confirmatory evidence is obtained by examining earth temperature records for Berlin and Dublin which show that the maximum 24-hour temperature changes recorded with warm air flowing over cold land or vice versa are about 3°C. in the top half metre which correspond to a maximum heat flux of 30 cal. cm.$^{-2}$ day^{-1}. For a long period average the total change in the heat content of the soil at Berlin between October and March gives a value of about 1,700 cal. cm.$^{-2}$. This may be compared with the corresponding figure for the eastern North Atlantic which is about 45,000 cal. cm.$^{-2}$ (see Sea surface temperature). Thus we see that the modification of air masses by sensible heat stored in the ground is not an important process in the general circulation.

(ii) Frozen ground:

Normally the ground is moist before winter freezing takes place and the soil is maintained for a period at 0°C. while heat is abstracted from or communicated to it during freezing or thawing. Higher temperature gradients than are normally observed may thus be established above a frozen layer of soil and may persist for considerable periods.

Let us consider a square centimetre of earth 10 centimetres in depth which contains 4 grammes of liquid water. The heat liberated during the freezing process is about 320 calories and the normal time taken to freeze to this depth is 4 to 10 days, giving a maximum heat flux over 4 days of 80 cal. $cm.^{-2}$ day^{-1}. Thawing may proceed rather more rapidly as solar heating of the soil surface gives higher temperature gradients. At Berlin 10 centimetres are observed to thaw in as little as 2 days and 25 centimetres in 7 days. The heat absorbed is a maximum of about 150 cal. $cm.^{-2}$ day^{-1}, some of which is directly removed from the atmosphere and the rest would otherwise have been transmitted to the atmosphere by convection from the heated ground. Thawing by the advection of a warm cloudy airstream proceeds at about half this rate and the maximum heat lost from the atmosphere by radiation and diffusion is about 80 cal. $cm.^{-2}$ day^{-1}.

These fairly high values of heat flux are important because of the length of time for which they may persist. They suggest that frozen ground could prevent normal atmospheric heating to a significant extent, so that variations in the semi-permanent limits of frozen ground could be important.

Radiative properties.—Albedo.—Reasonably accurate measurements of albedo are available for most types of vegetation and bare earth surfaces, though the dryness of the vegetation or earth can give quite wide variations. The following values are to be found in other publications.[1, 4, 12, 13, 14, 15]

TABLE II—PERCENTAGE OF INCIDENT RADIATION WHICH IS REFLECTED

	%
Forest	3–10
Snow covered forest	10–25
Grass fields dry	20–30
Grass fields wet	8–20
Bare ground dry	10–25
Bare ground wet	8–10
Sand	20–25
Rock	12–15
Snow new	70–80
Snow old	55
Water	5–50 (depending on solar elevation)
Desert	24–30

In order to estimate the maximum effect of a change in albedo on the heat supply to the atmosphere it is reasonable to assume that all the radiation absorbed at the ground is redistributed to the atmosphere during 24 hours.

The largest albedo change is from a normal grass or earth surface (15 to 20 per cent) to a snow covered surface (70 to 80 per cent). Much winter snowfall occurs when the incoming solar radiation is so small that a change in albedo is insignificant in its effect on the heat supply to the atmosphere. However some areas as far south as 50°N., notably the southern shores of Hudson Bay[16] and parts of central Siberia receive their first snowfall towards the end of September, when the mean sun and sky radiation is 180 cal. $cm.^{-2}$ day^{-1}.[17] In this case the 60 per cent increase in albedo consequent on snowfall will reduce the heat supplied to the atmosphere by 108 cal. $cm.^{-2}$ day^{-1}.

These same areas are the last to lose their snow cover in such southern latitudes and substantial areas of snow covered ground may persist until late April when the mean incident sun and sky radiation is as much as 300 cal. cm.$^{-2}$ day^{-1}; 180 cal. cm.$^{-2}$ day^{-1} is then denied to the atmosphere. Between these extremes the importance of snow cover decreases with increasing latitude and increasing proximity to the winter solstice. Snow cover in Scandinavia for instance will only be important before the end of October or after the end of February.

Of other possible changes in albedo the most important is from 15 per cent with green grass to 25 per cent with parched earth. This may occur in areas where the incident radiation is 500 cal. cm.$^{-2}$ day^{-1}, when the 10 per cent change in surface reflectivity will increase or decrease the heat available to the atmosphere by 50 cal. cm.$^{-2}$ day^{-1}.

Snow.—The change in albedo due to snowfall has already been discussed. There remains the effect of the absorption of latent heat on melting. A maximum rate of melting is about 5 centimetres of snow per day (about 0·5 grammes) and the corresponding absorption of latent heat is 40 cal. cm.$^{-2}$. As in the case of thawing earth this is a loss to the atmosphere.

Evaporation and evapotranspiration.—The thermal effects on a land surface as a result of evaporation and evapotranspiration are substantially different from the corresponding effects on a sea surface. By means of convection in the sea surface the temperature remains almost constant throughout the evaporation process. Over land the latent heat of evaporation must be supplied either by the sun, by the atmosphere or by conduction through the surface. As we have seen, the heat made available by conduction from that stored in the soil is negligible and the heat required for evaporation can be regarded either as a direct loss to the atmosphere or deducted from the solar energy which would otherwise have been communicated to the air by convection.

Numerous measurements indicate that the normal daily evaporation varies from 0·6 centimetres per day from a moist surface in the tropics to 0·05 centimetres per day from a dry surface in high latitudes. Table III gives a selection of values from the literature for evaporation and evapotranspiration.

TABLE III—A SELECTION OF VALUES FOR EVAPORATION AND EVAPOTRANSPIRATION AS GIVEN IN OTHER PUBLICATIONS

Surface and vegetation	Evaporation	Source (see References)
	cm. per day	
Grass, Toronto, November	0·05	18
Very dry soil, California	0·06	19
Bare soil, Toronto, November	0·07	18
Dry soil with vegetation, Florida	0·2	18
Bare soil, Toronto, July	0·4	18
Moist soil with vegetation, Florida	0·5	18
Grass, Toronto, July	0·5	18
Moist sand, California	0·63	18
Grass, British Isles (annual mean)	0·14	20
	cm. per year	
Savanna, tropics	92·5	18
Very wet rain forest	152·9	18

If all the latent heat of evaporation is considered to be a loss for the atmosphere then the deficit can be as much as 260 cal. cm.$^{-2}$ day^{-1}. This deficit will vary according to the vegetation or crops growing and the moisture available. After a prolonged drought the heat available to the atmosphere may be as much as 200 cal. $cm.^{-2}$ day^{-1} more than after a prolonged wet spell. This is partly offset by the increase in the albedo; but even so the net result should be evident in a much greater heating of the atmosphere over deserts in subtropical regions than over areas covered in green vegetation. The temporary formation of a new desert or vegetation over a normally desert area should be significant.

It has been assumed in the foregoing paragraphs that the heat used in evaporation is not returned to the atmosphere by re-condensation in the same region. If showers occur this will not be true nor if the evaporation is balanced by deposition of dew. However in many circumstances the air will be transported hundreds of kilometres before the latent heat is released in some region of generally ascending air such as the frontal system of a depression. Under these circumstances any variation in the evaporation in a particular area may be regarded as providing an abnormal heat sink for the atmosphere in the area of evaporation and a corresponding abnormal heat source in some other region. The net world-wide effect over a period will always be nil.

Summary.—The probable maximum effects of variations in land surface conditions on the heat supply to the atmosphere are as follows:—

TABLE IV—THE PROBABLE MAXIMUM EFFECTS OF VARIATIONS IN LAND SURFACE CONDITIONS ON THE HEAT SUPPLY TO THE ATMOSPHERE

Method	Source	Magnitude
		cal. $cm.^{-2}$ day^{-1}
Conduction	Calculated—wet sand; temperature gradient 10°C. per metre	±28
	Observed—Berlin; glacial sand and gravel... ...	±30
Freezing	Latent heat liberated: calculated: water content 0·4 gm. per c.c.	+80
Thawing ground ... (sunny conditions)	Latent heat absorbed: same water content	−150
Thawing ground ... (cloudy conditions)	Latent heat absorbed: same water content	− 80
Thawing snow ...	Latent heat absorbed in melting 5 cm. per day ...	− 40
Albedo	Change due to snow: middle latitudes late autumn and early spring	−180
	Change due to drought on green vegetation	− 50
Evaporation	Possible change due to drought or vegetation on desert	±200

Conclusion.—Before reviewing the ability of the earth's surface to modify through various means the working of the atmospheric heat engine, mention must be made of the solar constant. For many years it has been suggested that variations in the solar constant can give rise to large scale climatic changes and that small variations due to sunspot cycles are responsible for shorter fluctuations in world weather. Krivsky[21] purports to find a definite relationship between sunspot cycles and the position of the jet stream. The most useful summary of the present state of this subject is by Wexler.[22] Although he is probably more disposed than many to advocate a relationship between sunspot cycles and the subsequent weather he states that there is as yet no proof of one and, what is more, that no proof can be readily produced. Correlations between random factors have been found which are equal to those found between weather phenomena and sunspot cycles.

The foregoing survey has covered the principal ways in which variations in the state of the earth's surface can change the energy available to the atmosphere. The following appear to be the most important:

(i) an anomaly in sea surface temperature

(ii) variations in the limits of frozen land and sea

(iii) early and late snowfall in middle latitudes

(iv) change from moist land or land covered in green vegetation to desert and vice versa.

A natural sequel to the present investigation would be to seek evidence in the behaviour of the atmosphere of the effect on subsequent weather of anomalies of surface conditions of the kind listed above. The effects of the limits of arctic ice have already been considered by Schell[23] and Walker[24] but the relations with subsequent weather have been found to be weak. Possibly this might be expected from the very limited variations in the boundary of arctic ice.

A summary of other attempts to find associations between sea surface temperature, sea ice anomalies and subsequent weather has been made by Baur.[25] In particular Sandstrom suggested that a warm Gulf Stream should result in a warm winter over Europe. However the winter which followed a peak in the Gulf Stream in 1939 was the coldest in Europe for 110 years and the above-normal sea temperatures of 1955 were also followed by an abnormally cold February. Thus the search for such relations will not be easy and the effect of anomalous heat sources and sinks may be found more easily in anomalies of the atmospheric circulation over a wide area rather than in direct effects on local temperature.

REFERENCES

1. HOUGHTON, H. G.; On the annual heat balance of the Northern Hemisphere. *J. Met., Boston,* **11,** 1954, p. 1.

2. SCHUMANN, T. E. W. and BURDECKI, F.; The seasonal storage of heat in the surface layers of the earth. Pretoria, 1953. Notos **2,** p. 4.

3. JACOBS, W. C.; On the energy exchange between sea and atmosphere. *J. Mar. Res., New Haven,* **5,** 1942, p. 37.

4. SVERDRUP, H. U.; The Oceans. New York, 1940.

5. RIEHL, H., YEH, T. C., MALKUS, J. S. and LA SEUR, N. E.; The northeast trade of the Pacific Ocean. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 334.

6. HELA, I.; On the energy exchange between sea and atmosphere in the Baltic. *Mitt. met. Inst. Univ. Helsingf., Helsinki,* 1951, No. 70.

7. CRADDOCK, J. M.; The warming of Arctic air masses over the eastern North Atlantic. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 355.

8. BURBIDGE, F. E.; The modification of continental polar air over Hudson Bay. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 365.

9. WINSTON, J. S.; Physical aspects of rapid cyclogenesis in the Gulf of Alaska. *Tellus, Stockholm,* **7,** 1955, p. 481.

10. SCHREIBER, P.; Micrometeorology. See Sutton (15).

11. ROACH, W. T.; Measurements of atmospheric radiation and the heat balance at the ground at Kew. *Met. Res. Pap., London,* No. 936, 1955.

12. BUDYKO, M. I., BERLYAND, T. G. and SUBENOK, L. I.; Heat balance of the surface of the earth, Leningrad 1954. Izvestiya, Akademii Nauk U.S.S.R. Seriya Geograficheskaya, No. 3.

13. FRITZ, S.; The albedo of the ground and atmosphere. *Bull. Amer. met. Soc., Boston,* **29,** 1948, p. 303.

14. Smithsonian Institution Meteorological Tables. Washington, D.C. 1952.

15. SUTTON, O. G.; Micrometeorology. New York, 1953.

16. THOMSON, A.; The climate of the Hudson Bay region. *Trans. roy. Soc., Can., Ottawa,* **48,** 1954, Ser. III, p. 1.

17. BLACK, J. N.; The distribution of solar radiation over the earth's surface. *Arch. Met., Hamburg,* **7,** 1956, Ser. B., p. 165.

18. MATHER, J. R.; Micrometeorology of the surface layers of the atmosphere. Johns Hopkins University, Publications in Climatology, **7,** Seabrook, N.J., 1954.

19. VEIHMEYER, F. J. and BROOKS, F. A.; Measurements of cumulative evaporation from bare soil *Trans. Amer. Geophys. Un., Washington*, **35**, 1954, p. 601.
20. PENMAN, H. L.; Survey of meteorology in agriculture. *Quart. J. R. met. Soc., London*, **75**, 1949, p. 293.
21. KRIVSKY, V.; Variation of the frontal zone in relation to solar activity. Czech. Acad. Sci., Astrophysical Obsns. Pub. No. 23, Prague, 1953.
22. WEXLER, H.; Radiation balance in climatic change. Climatic change. Edited by Harlow Shapley, Cambridge, 1953.
23. SCHELL, I. I.; Polar ice as a factor in seasonal weather. *Mon. Weath. Rev., Washington*, Supplement No. 39, 1940, p. 27.
24. WALKER, SIR GILBERT; Arctic conditions and world weather. *Quart. J. R. met. Soc., London*, **73**, 1947, p. 226.
25. BAUR, F.; Extended range weather forecasting. Compendium of Meteorology. Boston, 1951, p. 814.

VARIATION WITH TIME AND DISTANCE OF HIGH-LEVEL WINDS OVER MALAYA

By L. S. CLARKSON, M.Sc.

Summary.—Based mainly on an analysis of the statistical parameters characterizing the distribution and variation with time and distance of radar-observed winds at 40,000 feet and 50,000 feet over Singapore and Songkhla, data is deduced from which future winds at places in Malaya may be predicted by means of a simple regression on the latest Singapore observation.

Introduction.—Within about 10° latitude of the Equator, where geostrophic control is lacking, no relationship between wind and pressure gradient has been found suitable for practical application[1]. In the Malayan area there are insufficient wind observations at high altitudes to permit instantaneous stream-lines and isotachs to be drawn objectively in accordance with the methods developed by Bjerknes[2] and Sandström[3] and applied to the tropics by Palmer[4]. Furthermore, no synoptic dynamical principles have been established by means of which the future wind flow may be anticipated from that depicted on a current stream-line chart. In these circumstances the statistical methods developed by Durst[5], and shown by Johnson[6] to yield results comparable in accuracy with the orthodox forecasting techniques applicable in temperate latitudes, are applied to the practical problem of high-altitude wind prediction for aviation in Malaya.

Observations.—The only observations of radar winds at 40,000 feet and 50,000 feet in the Malayan area from which the statistical parameters in the regression equation expressing the most probable variation of wind with time and distance may be evaluated are:—

(i) the Singapore observations analysed earlier[7], but including all data for 1955,

(ii) observations from Songkhla at 0300 G.M.T. kindly supplied by the Director, Meteorological Department of the Royal Thai Navy. Songkhla is 390 nautical miles north-north-west of Singapore.

Tables I and II give the mean monthly components from the north and east, V_N and V_E, mean scalar and vector winds, V_S and $\mathbf{V}$, standard vector deviation, σ, and constancy, α, derived from the Singapore and Songhkla observations at 40,000 feet and 50,000 feet respectively.

As is to be expected, the Songkhla winds show similar general features to those found for Singapore[7]. However, mean easterly components are appreciably less at Songkhla than at Singapore in the months from November through to April; at neither place is there much evidence for the winter maximum referred to by Hay[8] and Gilchrist[9]. At 50,000 feet the sharp increase in easterly component from April to May is especially pronounced: the strong summer east-north-easterlies at Songhkla are as remarkably steady in direction as those at Singapore, with a constancy exceeding 90 per cent, but show a rather greater variability about the vector mean.

The data in Tables I and II point to the onset of summer strong high-level easterlies over Malaya being due to a developmental process rather than to a seasonal displacement over the territory of a pre-existing belt of strong easterlies lying to the north or south in the winter months.

TABLE I—STATISTICS OF MONTHLY MEAN WINDS AT 40,000 FEET AT 0300 G.M.T. OVER SONGKHLA (*B*) AND SINGAPORE (*A*)

			No. of obs.	V_S	V_N	V_E	$\bar{V}$		σ	α
					knots		°	kt.	kt.	
Jan.	1955	*B*	11	22·0	−12·5	12·4	135	18	17·3	80
	1951–55	*A*	65	23·3	− 7·2	20·2	110	21	13·1	92
Feb.	1954–55	*B*	19	19·5	−10·1	3·7	160	11	19·3	55
	1951–55	*A*	78	28·0	−10·7	23·3	115	26	17·2	92
March	1954–55	*B*	27	16·8	− 6·8	6·5	135	9	16·4	56
	1951–55	*A*	85	20·8	− 6·4	15·1	110	16·5	16·2	79
April	1954	*B*	16	16·5	− 3·6	7·0	115	8	17·0	48
	1951–55	*A*	79	19·4	− 2·0	16·3	110	16	14·1	85
May	1954–55	*B*	39	22·8	6·2	18·4	70	19	18·7	85
	1951–55	*A*	81	24·0	3·7	20·2	80	20·5	16·2	86
June	1953–55	*B*	31	32·2	9·8	27·2	80	29	20·2	90
	1951–55	*A*	81	35·9	10·5	32·3	70	34	15·6	95
July	1953–55	*B*	64	41·7	14·7	35·3	70	38	19·1	92
	1951–55	*A*	84	40·2	9·5	36·8	75	38	16·4	95
Aug.	1953–55	*B*	45	39·2	11·6	36·1	70	38	16·7	97
	1951–55	*A*	77	43·1	11·7	39·7	75	41	16·7	96
Sept.	1953–54	*B*	29	40·4	12·5	36·9	70	39	19·1	97
	1951–52, 54–55	*A*	71	39·8	11·4	36·2	70	38	18·0	95
Oct.	1953–54	*B*	39	27·8	3·8	24·1	80	24	18·3	88
	1951–52, 54–55	*A*	81	26·3	4·4	24·1	80	24	15·0	93
Nov.	1954–55	*B*	27	26·4	− 6·2	21·2	105	22	17·8	84
	1951–55	*A*	96	26·5	− 1·6	24·7	95	25	14·3	93
Dec.	1954–55	*B*	43	24·6	−11·8	13·4	130	18	16·4	67
	1951–55	*A*	78	23·5	− 7·0	20·1	110	21	14·5	90

The analysis.—For the purpose of calculating stretch vector correlation coefficients it was decided, in view of the few simultaneous observations at Singapore and Songhkla in certain months, to combine the observations into four seasons. Because of the apparent marked change in wind régime from April to May, it seemed inappropriate to combine data for these two months: consequently the periods February–April, May–July, August–October and November–January were chosen.

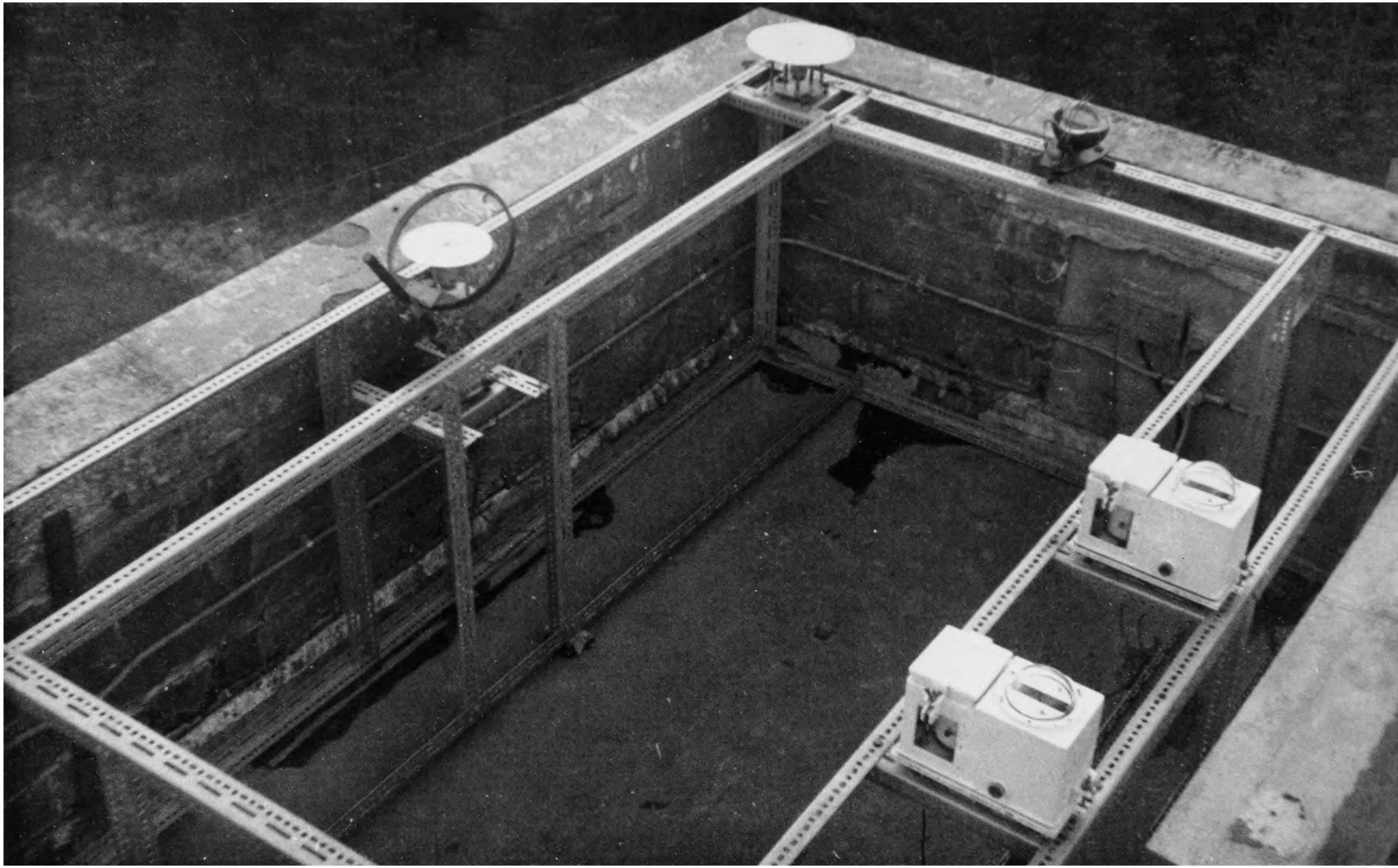
ESKDALEMUIR OBSERVATORY—GENERAL VIEW OF MAIN BUILDING

The workshop and laboratories are on the ground floor, offices and computing room on the first floor, and observational platform on the tower. In the foreground are the instrument screen, evaporation tank and cabinet containing apparatus for chemical sampling of air and rain-water. (see p. 129)

ESKDALEMUIR OBSERVATORY—FRONT VIEW OF MAIN BUILDING

Rayleigh House (Superintendent's quarters) is at extreme left.

(see p. 129)



OBSERVATIONAL PLATFORM ON TOWER

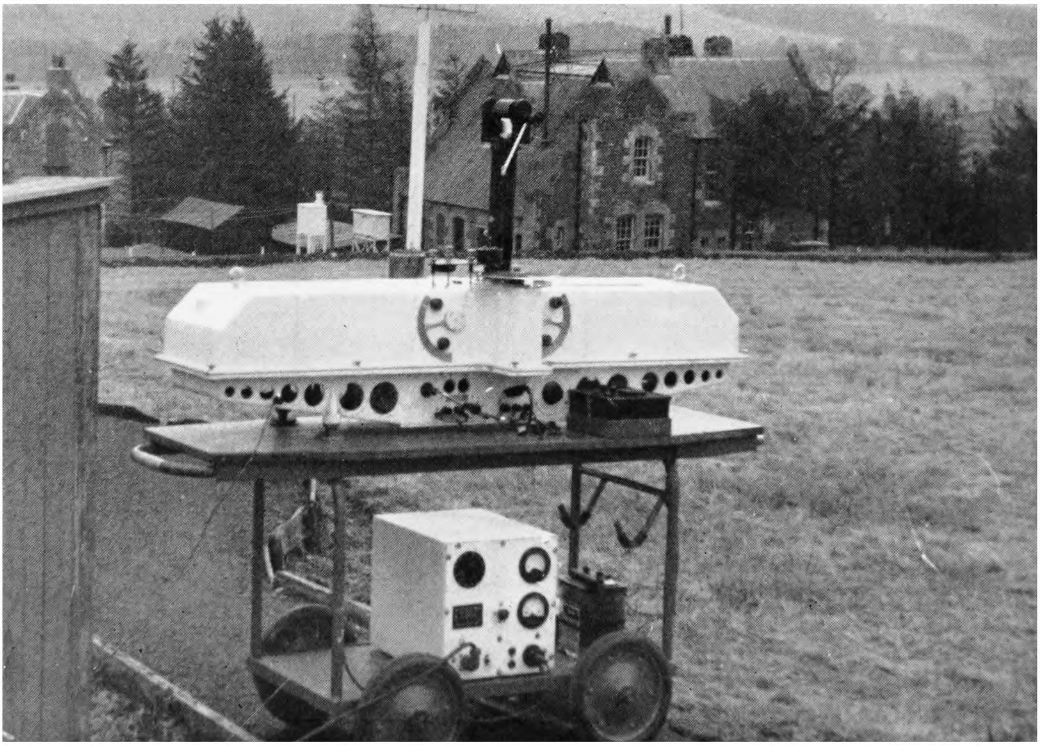
Total and diffuse radiation solarimeters, sunshine recorder and two bimetallic radiation recorders are shown.

(see p. 129)

RAIN-GAUGES

A view of some of the rain-gauges and experimental snow-gauges, with atmospheric electrical pit further back.

(see p. 129)



OZONE SPECTROPHOTOMETER

Close-up of ozone spectrophotometer, showing Schuster House (hostel) in background.

(see p. 129)

For each period, vector means were derived from the north and east components of the individual observations, and standard vector deviations computed by finding the mean square of the modules of the vectors, subtracting the square of the module of the mean vector, and taking the square root of the resulting difference[10].

TABLE II—STATISTICS OF MONTHLY MEAN WINDS AT 50,000 FEET AT 0300 G.M.T. OVER SONGKHLA (*B*) AND SINGAPORE (*A*)

			No. of obs.	V_S	V_N	V_E	$\overline{V}$		σ	α
					knots		°	kt.	kt.	
Jan.	1955	*B*	11	19·9	− 0·5	16·6	90	17	15·8	83
	1951–55	*A*	64	39·7	− 6·0	36·3	100	37	22·1	93
Feb.	1954–55	*B*	19	25·0	− 3·9	6·1	125	7	29·8	28
	1951–55	*A*	75	38·6	− 7·7	28·7	100	30	33·9	77
March	1954–55	*B*	26	19·2	− 6·5	7·0	135	10	21·8	50
	1951–55	*A*	85	23·9	3·7	9·4	70	10	26·0	42
April	1954	*B*	10	19·6	− 3·6	7·5	115	8	21·2	42
	1951–55	*A*	78	23·9	2·9	19·5	80	20	19·6	82
May	1954–55	*B*	34	40·6	5·8	38·0	80	38	24·1	95
		A	78	30·9	9·0	26·0	70	27·5	19·3	89
June	1953–55	*B*	24	49·8	13·4	43·4	75	45	29·2	91
	1951–55	*A*	75	39·5	9·3	34·9	75	36	24·1	91
July	1953–55	*B*	59	61·0	17·4	55·4	75	58	30·4	95
	1951–55	*A*	76	43·3	8·6	39·9	80	41	23·2	94
Aug.	1953–55	*B*	46	52·3	10·8	49·3	80	51	27·3	97
	1951–55	*A*	64	52·3	12·0	49·4	75	51	22·0	97
Sept.	1953–54	*B*	25	57·0	3·7	52·7	85	53	28·6	93
	1951, 52, 54, 55	*A*	65	43·9	7·7	40·9	80	42	27·7	95
Oct.	1953–54	*B*	37	41·2	5·3	38·8	80	39	21·5	95
	1951, 52, 54, 55	*A*	77	38·9	5·1	36·7	80	37	19·2	95
Nov.	1954–55	*B*	24	33·2	−10·6	29·4	110	32	21·7	97
	1951–55	*A*	97	41·8	1·8	40·4	90	40	21·6	97
Dec.	1954–55	*B*	40	28·8	− 8·6	22·7	110	24	22·5	84
	1951–53, 55	*A*	70	33·6	− 4·1	29·5	100	30	23·8	89

For each pair of simultaneous observations at Singapore and Songhkla the vector difference was determined, and the root mean square, σ_x, computed for each season. Stretch vector correlation coefficients were then evaluated from the relation

$$r_x = \frac{\sigma_A{}^2 + \sigma_B{}^2 - \sigma_x{}^2}{2\sigma_A\sigma_B}$$

where suffix *A* refers to Singapore, and *B* to Songhkla.

The annual values and the 5 per cent confidence limits of r_x were obtained by applying Fisher's z' transformation in the way described by Brooks and Carruthers[10].

The results of this analysis are contained in Tables III and IV.

TABLE III—STATISTICS OF SEASONAL WINDS AT 40,000 FEET AT 0300 G.M.T. AT SONGKHLA (*B*) AND SINGAPORE (*A*)

		No. of obs.	$\overline{V}$		σ	No. of pairs of obs.	Standard vector difference σ_x	Stretch vector correlation coefficient r_x	Confidence limits of r_x	Regression coefficient $\sigma_B / \sigma_A \, r_x$
			°	kt.	kt.					
Feb.–Apr.	*B*	62	140	9	17·7	61	18·8	0·40	0·17–0·59	0·42
	A	242	110	19	16·7					
May–July	*B*	134	70	31	20·8	116	21·3	0·40	0·24–0·54	0·47
	A	246	75	31	17·7					
Aug.–Oct.	*B*	113	75	33	19·4	67	19·2	0·48	0·27–0·65	0·51
	A	229	75	34	18·2					
Nov.–Jan.	*B*	81	120	19	17·7	52	19·6	0·27	0·00–0·51	0·33
	A	239	105	23	14·5					
Annual	...					296		0·40	0·30–0·49	

TABLE IV—STATISTICS OF SEASONAL WINDS AT 50,000 FEET AT 0300 G.M.T. AT SONGKHLA (*B*) AND SINGAPORE (*A*)

		No. of obs.	$\overline{\mathbf{V}}$		σ	No. of pairs of obs.	Standard vector difference σ_x	Stretch vector correlation coefficient r_x	Confidence limits of r_x	Regression coefficient $\sigma_B/\sigma_A\, r_x$
			°	kt.	kt.					
Feb.–Apr.	*B*	55	125	8	24·8	53	21·2	0·69	0·52–0·81	0·60
	A	238	90	19	28·6					
May–July	*B*	117	75	50	29·8	98	30·4	0·36	0·17–0·52	0·47
	A	229	75	35	23·0					
Aug.–Oct.	*B*	108	80	47	26·6	64	29·5	0·32	0·08–0·53	0·36
	A	206	80	43	23·8					
Nov.–Jan.	*B*	75	110	25	22·8	45	25·5	0·38	0·10–0·61	0·37
	A	231	93	36	23·2					
Annual	...					260		0·43	0·33–0·53	

Discussion.—When wind observations at 40,000 feet and 50,000 feet are lacking from Songhkla, the most probable high-level wind, $\mathbf{V}_B$, to be expected 400 nautical miles to the north-north-west of Singapore at the same time as an observed wind, $\mathbf{V}_A$, at Singapore may be determined by solving the vector regression equation

$$\mathbf{V}_B = \overline{\mathbf{V}}_B + {}^{\sigma_B}\!\big/_{\sigma_A}\, r_x\,(\mathbf{V}_A - \overline{\mathbf{V}}_A)\ ,$$

appropriate values for $\overline{\mathbf{V}}_A$, $\overline{\mathbf{V}}_B$ and the regression coefficient ${}^{\sigma_B}\!\big/_{\sigma_A}\, r_x$ being selected from Tables III and IV.

Because of the relatively small correlation between simultaneous high-level winds at Singapore and Songhkla in most seasons, adopting the appropriate vector mean for Songhkla as a prediction of the wind in that region will invoke a standard vector error, σ_B, generally only about 2 knots greater than the alternative of using the regression equation.

From the data in Tables III and IV there can be little doubt that Singapore and Songhkla are in the same high-level wind régime of steady strong east-north-easterlies from May to October: but within the general stream there are evidently variations on a horizontal scale slightly less than that of temperate latitude disturbances, such that simultaneously occurring winds at places separated by about 400 nautical miles lying normal to but in the same easterly high-level stream show only a rather small correlation.

Extension of the analysis.—It is desired to develop a statistical method of predicting the most probable vector wind at a place distant x nautical miles from Singapore at a time t hours after an observation of high-level wind over Singapore itself.

We have

$$\mathbf{V}_{A\,,\,\mathbf{t}} = \overline{\mathbf{V}}_A - r_t\,(\overline{\mathbf{V}}_A - \mathbf{V}_{A\,,\,o})\ , \qquad \ldots\ldots\ (1)$$

where $\mathbf{V}_{A\,,\,\mathbf{t}}$ is the probable wind at Singapore t hours after an observed wind $\mathbf{V}_{A\,,\,o}$ and r_t is the appropriate temporal vector correlation coefficient as evaluated earlier.[11]

Also,

$$\mathbf{V}_{B\,,\,\mathbf{t}} = \overline{\mathbf{V}}_B - {}^{\sigma_B}\!\big/_{\sigma_A}\,.\, r_x\,(\overline{\mathbf{V}}_A - \mathbf{V}_{A\,,\,\mathbf{t}})\ , \qquad \ldots\ldots\ (2)$$

where $\mathbf{V}_{B\,,\,\mathbf{t}}$ is the probable wind at Songkhla t hours after an observed wind at Singapore, and r_x is the stretch vector correlation coefficient between simultaneously observed winds at, and at x nautical miles from, Singapore.

Eliminating $\mathbf{V}_{A\,,\,\mathbf{t}}$, we obtain

$$\mathbf{V}_{B\,,\,\mathbf{t}} = \overline{\mathbf{V}}_B - {}^{\sigma_B}\!\big/_{\sigma_A}\,.\, r_x\,.\, r_t\,(\overline{\mathbf{V}}_A - \mathbf{V}_{A\,,\,o}). \qquad \ldots\ldots\ (3)$$

In most cases the vector mean wind and the standard vector deviation at place B will not be known exactly, but it is legitimate to assume that at least within about 400 miles of Singapore $\overline{\mathbf{V}}_B$ and σ_B will be approximately equal to $\overline{\mathbf{V}}_A$ and σ_A respectively.

With the assumption that $\overline{\mathbf{V}}_B \simeq \overline{\mathbf{V}}_A = \overline{\mathbf{V}}$ and $\sigma_A \simeq \sigma_B$, equation (3) becomes:—

$$\mathbf{V}_{B\,,\,\mathbf{t}} = \overline{\mathbf{V}}_B - r_x\,.\, r_t\,(\overline{\mathbf{V}}_A - \mathbf{V}_{A\,,\,o})\ . \qquad \ldots\ldots\ (4)$$

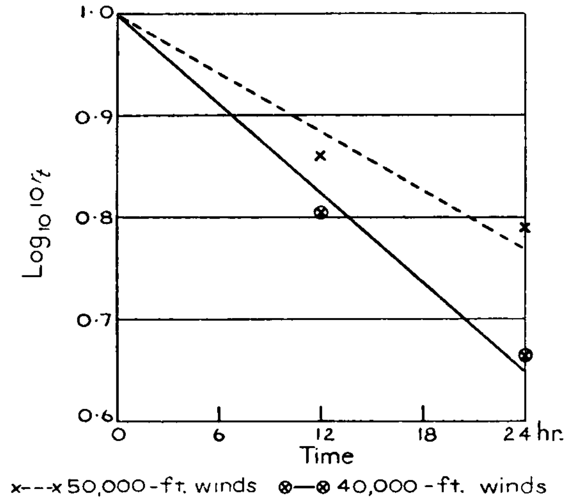


FIG. 1—PROBABLE VARIATION OF r_t WITH TIME OVER MALAYA

Mean values of r_t for $t = 12$ and 24 hours for Singapore have been found[11] to be:—

	r_{12}	r_{24}
50,000 ft.	0·73	0·615
40,000 ft.	0·64	0·46

Assuming, with Durst[5] a logarithmic variation of r_t with time, values of $\log_{10} 10 r_t$, and hence r_t, for various time intervals may be obtained from the graph at Figure 1 for winds at 40,000 feet and 50,000 feet over Singapore.

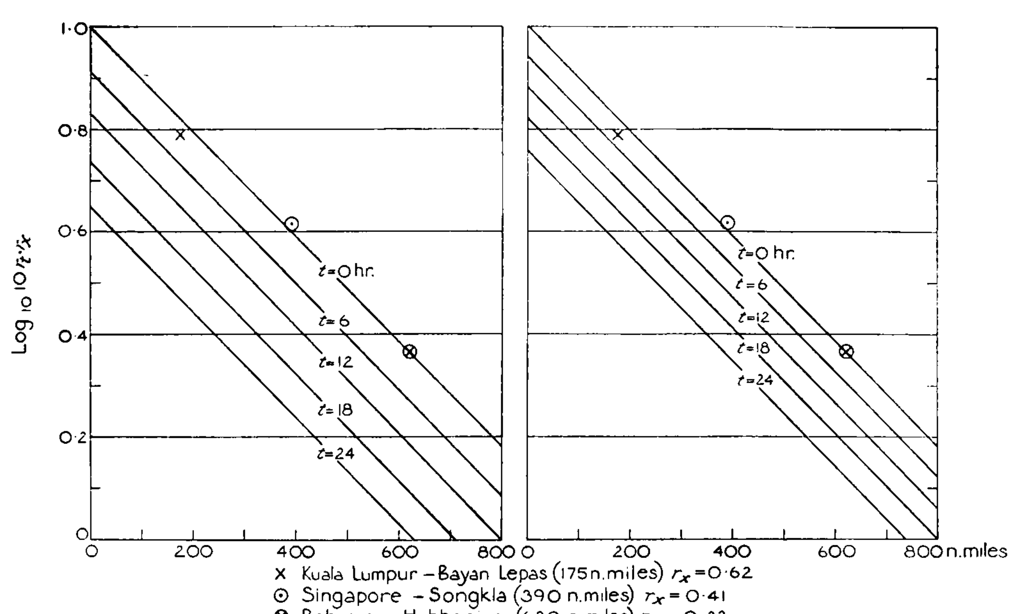


FIG. 2—PROBABLE VARIATION OF $r_t.r_x$ AT TWO HEIGHTS OVER MALAYA

Bearing in mind the confidence limits of the seasonal values found for r_x in Tables III and IV, a representative mean for r_x of 0·41 may be taken for a distance of 390 nautical miles at 40,000 feet and 50,000 feet. For 6,000-foot winds separated by 175 nautical miles in Malaya, Durst[5] quotes $r_x = 0{\cdot}62$, and also $r_x = 0{\cdot}23$ for 300-millibar winds between Bahrain and Habbaniya, 620 nautical miles apart. Converting these values to $\log_{10}10r_x$ and plotting against distance, the uppermost curves on each graph in Figure 2 have been drawn as the best-fitting straight line to represent the most probable variation of the stretch vector correlation coefficient with distance over Malaya.

From Figure 1 and the uppermost curves in Figure 2 the derived curves for the variation of $\log_{10}10r_x \, . \, r_t$ with distance over Malaya when $t = 6$, 12, 18 and 24 hours are plotted at Figure 2 for the 40,000-foot level, and for 50,000 feet. Using these graphs and the vector means in Tables I and II values of $r_x \, . \, r_t$ and $\bar{\mathbf{V}}$ may be obtained for solving regression equation (4) by the convenient graphical method set out earlier.[11]

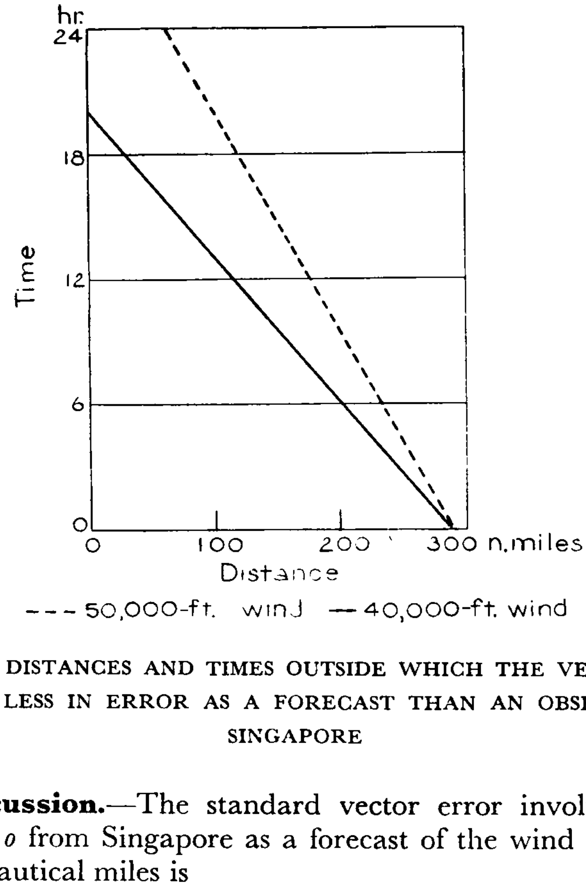


FIG. 3—LIMITING DISTANCES AND TIMES OUTSIDE WHICH THE VECTOR MEAN WIND IS LIKELY TO BE LESS IN ERROR AS A FORECAST THAN AN OBSERVATION AT SINGAPORE

Further discussion.—The standard vector error involved in using an observation $\mathbf{V}_{A,0}$ from Singapore as a forecast of the wind t hours later at a place distant x nautical miles is

$$E' = \sigma_A \sqrt{2(1 - r_x \, . \, r_t)} \, .$$

When $r_x \, . \, r_t$ is less than 0·5, this expression for E' is always greater than $E'' = \sigma_A$, the standard vector error of taking the vector mean as a forecast.

Now even for comparatively brief time intervals, Figure 2 shows that $r_x \, . \, r_t$ becomes less than 0·5, or $\log_{10}10r_x \, . \, r_t < 0{\cdot}7$, at quite short distances from Singapore. Thus the fairly common practice of using a stale radar wind observation for Singapore as a prediction of the wind at places 200–300 nautical miles or more away is not justified. Indeed, in all cases where the combination of staleness of observation and distance exceeds the limiting values in Figure 3, the unmodified observation is worse than useless as a forecast.

The standard vector error of predictions using equation (4) is

$$E''' = \sigma_A \sqrt{1 - (r_x \, . \, r_t)^2} \, ,$$

and this must always be less than $E'' = \sigma_A$ or the expression for E'. For example, from Figure 3, for $x = 150$ nautical miles and $t = 12$ hours, at 50,000 feet $r_x \, . \, r_t = 0{\cdot}53$, so that

$$E' = 0{\cdot}97\sigma_A$$
$$E'' = 1{\cdot}00\sigma_A$$
$$E''' = 0{\cdot}72\sigma_A \, .$$

Conclusions.—The high-level easterlies at Songkhla and Singapore show broadly similar features: their sudden onset in strength in May appears to be the result of development rather than advection.

In view of the lack of synoptic dynamical principles for wind forecasting and the observed rapid variation of wind with time and particularly distance in Malaya, an application of Durst's regression technique offers at present the best practical method for high-level wind prediction in the equatorial region of south-east Asia.

REFERENCES

1. WATTS, I. E. M.; Equatorial Weather. London, 1955.
2. BJERKNES, V. et alii; Dynamic meteorology and hydrography, Part II. Kinematics, Washington D.C., 1911.
3. SANDSTRÖM, J. W.; Über die Bewegung der Flüssigkeiten. *Ann. Hydrogr., Berlin,* **37,** 1909, p. 242.
4. PALMER, C. E.; Tropical meteorology. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 126.
5. DURST, C. S.; Variation of wind with time and distance. *Geophys. Mem., London,* **12,** No. 93, 1954.
6. JOHNSON, D. H.; The success achieved in forecasting upper winds by orthodox and statistical techniques. *Met. Res. Pap., London,* No. 953, 1955.
7. CLARKSON, L. S.; Analysis of winds at 40,000 ft. and 50,000 ft. over Singapore. *Met. Mag., London,* **85,** 1956, p. 1.
8. HAY, R. F. M.; Winds at high levels over Singapore (1950–52). *Met. Res. Pap., London,* No. 770, 1952.
9. GILCHRIST, A.; Winds between 300 and 100 mb. in the tropics and subtropics. *Met. Rep., London,* **2,** No. 16, 1955.
10. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, pp. 196, 222.
11. CLARKSON, L. S.; Variation with time of winds at 40,000 ft. and 50,000 ft. over Singapore. *Met. Mag., London,* **85,** 1956, p. 99.

METEOROLOGICAL OFFICE DISCUSSION

Forecasting low cloud conditions at airfields

The subject of the Monday Discussion of January 20, 1958 was dealt with under the following four headings by the openers noted against each one:

Frontal cloud: C. P. Soppet, B.Sc.

Orographic cloud: H. F. Hollands.

North Sea stratus: D. W. Johnston, B.Sc.

Non-frontal cloud in south-westerly airstreams: T. Johnston.

A discussion was held on each part after the opener's statement.

Frontal cloud

Mr. C. P. Soppet opened with a discussion of low cloud associated with warm and cold fronts approaching south-west England from a westerly quarter. The problem is primarily the successful forecasting of movements of fronts requiring current charts carefully analysed, particularly in regard to minor discontinuities, and a sound appreciation of likely development over the forecast period.

The differences of technique between coastal and inland stations were illustrated by reference to St. Mawgan and Exeter respectively.

Warm frontal low cloud at St. Mawgan is adequately forecast by advecting the cloud sequence over the sea or the change in the condensation level at the speed of the front.[1, 2] The important feature is the "stepped" character of these changes. Corrections are made for trajectory and wind speed. Diurnal and seasonal effects are small and little or no improvement occurs at the passage of warm fronts.

At Exeter shelter effects are considerable and upstream cloud reports are of little value. Lapse and hydrolapse rates upstream are useful for short period forecasts. Shelter effects are much reduced with slow moving fronts. Diurnal and seasonal effects are considerable. In summer cloud base is not very low and there is usually a rapid clearance following a warm front passage. In winter when the ground is frozen, very low cloud develops abnormally far ahead of a warm front and clearance to the rear is slow.

Cold fronts usually move at the speed of the geostrophic component. Sansom's[3] study is a useful aid in deciding whether post cold-frontal cloud decrease is likely to be rapid or slow and for short term forecasting, reference is made to cloud sequences from Irish stations. Timing both onset and clearance on these considerations is normally satisfactory for Exeter but breaks down for the north coast of Cornwall where clearance is usually delayed and in practice found almost impossible to forecast. Convection off the sea was suggested as a cause for this. Not directly associated with cold fronts but of considerable significance is the rapid development of fog or low stratus in radiation conditions following cold front clearances.

Examples were given of how certain types of low-level circulations and general development affect the above general considerations. Meteorological characteristics of airfields, frequency tables and other statistical data are all useful but should be applied in the context that each situation is unique. While there are rules to cover some aspects of forecasting frontal low cloud, much depends on the experience and judgement of the forecaster especially in regard to early recognition of development and also to the correction to be applied on account of site of airfield etc.

In the subsequent discussion agreement was expressed by several speakers with Peterssen's views that a "stepped" rise of dew-point ahead of a warm front could be due to falling rain. Hodographs were mentioned as useful tools for frontal analysis.

Mr. Illsley, while agreeing with the significance of discontinuities in surface layers, could not agree to their being given the status of fronts and said that at the Central Forecasting Office, forecasters could be concerned with "major" fronts only.

Several speakers, including Mr. Lamb, agreed with the difficulty of forecasting the clearance following a cold front but considered that orographic effects were the major cause of delay. In tracing weak fronts it was suggested that examination of wet bulb potential temperatures at 850 millibars would be useful.

Mr. Bradbury enquired how an increase in humidity over the English Channel was allowed for in a southerly airstream from France. In reply Mr. Soppet gave illustrations of how low-level circulations affect this issue. Another speaker suggested that the predominance of south to south-east winds at Exeter may be due to the deflection of south-westerlies by the Dartmoor mass.

Orographic cloud

The process of formation of orographic cloud is that of cooling by adiabatic expansion. For forecasting its occurrence it is necessary to know the moisture content of the air and the amount of lifting which will be given to it. The direction of the wind is clearly important, also. It is normal in determining the lifting condensation level to assume an adiabatic lapse rate of 5·4°F. per thousand feet, using the surface temperature and dew-point and assuming also that there is no entrainment. Precipitation on windward slopes gives a lowering of the cloud base due to the evaporation of water into the lower layers. To the lee of high ground the loss of moisture will be shown in the lowering of the dew-point and the raising of the condensation level.

Manchester shows some orographic effect in north-westerly winds, with larger amounts of cloud and a lower cloud base than places near the coast. It also has a somewhat greater frequency of showers in an unstable air mass and more prolonged precipitation, particularly of drizzle, in a stable air mass.

At Ronaldsway cloud may form over the low hills to the west and south-west. Over a very small range of wind direction this cloud may stream downwind over the airfield itself.

Over Anglesey low cloud in moist west or south-west airstreams will normally increase in amount and lower over the gently rising ground inland, particularly with a surface wind of 12 to 18 knots and the dew-point below the sea temperature. Here it is difficult to separate the orographic effect from the effect of turbulence. At Harlech, at 769 feet above mean sea level, separation of these effects seems possible at times when the calculated lifting by turbulence is insufficient by itself to reach the lifting condensation level. In such a case low cloud may be formed at Harlech by orographic uplift, but there will be none at Valley.

Frequency tables can be a useful forecasting aid. Low cloud frequency tables for Valley, for instance, show an almost complete absence of cloud below 1,000 feet in east or south-east winds, due to the shelter of the Welsh Mountains. Local knowledge, too, plays its part in the recognition of orographic effects and will be shown in area forecasts issued by most stations, but may not involve the use of any particular forecasting technique.

North Sea stratus

The next speaker, Mr. D. W. Johnston, dealt with the problem of North Sea stratus. He pointed out that stratus originating from the North Sea is a more serious menace to much of the country than stratus from other directions, because of lack of topographic protection. Owing to diurnal temperature variations there is a higher incidence of North Sea stratus by night and in the morning than in the afternoon, and owing to the seasonal lag of sea-surface temperature there is a relatively high incidence of stratus over the sea in spring and early summer.

Mr. Johnston then dealt with the manner of the onset of stratus in two simple types of situation. The first was that in which an air mass, initially cloud free, both over the land and over the sea, spreads inland from the North Sea during the cooling period. Cooling of the atmosphere originates at the ground, and is propagated upwards by turbulent diffusion through a layer, the depth of which depends largely on the wind speed. A lapse rate approximating to the dry adiabatic is maintained in the turbulent layer while it remains unsaturated, but if the temperature curve cuts the original dew-point curve, cloud will begin to form at this level, with saturated lapse rate thence to the top of the turbulent layer. Once the cloud has formed it quickly becomes a complete cover, and further cooling is at a much reduced rate causing a slow deterioration.

Since the stratus develops towards the top of the turbulent layer, its height should be closely related to the wind speed, so that, with a certain wind speed it should be possible to say that the stratus, if in fact it does occur, will develop at a certain corresponding height. An approximate forecasting rule embodying this idea is as follows:

Wind at anemometer level 10 knots: height of stratus 800 feet, and so on in proportion.

The temperature at which stratus should form can be found by drawing on the appropriate tephigram the dry adiabatic from the dew-point curve at the height of stratus formation down to the surface isobar. Assessments as to whether the temperature will fall to this value, and if so at what time, can be made using cooling curves or night minimum prediction formulae.

It was emphasized that the process outlined above is one of local development, and that cloud forming in this way does not spread downwind in any regular fashion, but can develop over large areas almost simultaneously.

The next type of situation to be dealt with was one with winds blowing inland off the North Sea and with clear skies over the land initially, but with stratus over the sea. The forecaster's first requirement for dealing with such a situation is a complete picture of cloud conditions over the North Sea. The information available obtained from light vessels, trawlers and various aircraft operating in the area, always falls very far short of this requirement. In the absence of all information regarding cloud conditions over the North Sea near our coasts, the forecaster has to make an estimate based on the characteristics of the air mass when it left the continental coast, the duration of its travel over the sea, and the sea-surface temperature. The important case is a spring or early summer situation with a warm air mass flowing over a relatively cold sea surface. In such a case with slow travel of the air mass, cloud could develop down to very low levels approaching or even, in extreme cases, reaching the sea surface. The reasons for this are:

(i) The turbulent layer is much shallower than with air flowing at the same speed over the land.

(ii) The process of development goes on continuously, day and night, whereas over the land it is essentially a nocturnal process.

(iii) Water vapour is being continuously fed upwards from the sea surface.

Frost has worked out formulae for the modification of a cold air mass flowing over a relatively warm sea surface, but this is not very relevant to the stratus problem, and the forecaster, in an extreme case of lack of actual observations, would have to rely on his judgment and experience.

A layer of low cloud over the sea will spread bodily inland at a time when the inland temperature has fallen to a favourable level. A good guide to this temperature value is the sea-surface temperature, and the time at which it will occur can be estimated from cooling curves. The cloud as it spreads in will remain at much the same height as over the sea—this often being at a much lower level than for cloud developing over the land by nocturnal cooling plus turbulence. A complication can arise with a zone ahead of the North Sea stratus proper where stratus forms by local development, as in the first case dealt with, and at a somewhat higher level than the North Sea stratus. This complication has the effect of making the cloud appear to spread in an erratic fashion. Stations on or near the coast can experience in this type of situation a deterioration quite early—possibly in the latter part of the afternoon.

Mr. Johnston finally dealt with the important, though less vital, problem of the dissipation of North Sea stratus. Briefly, the suggested method of forecasting dispersal consists of determining from the tephigram the surface temperature which corresponds with the potential temperature at the top of the cloud, which may be known from aircraft reports or can be deduced from a tephigram. The rate of rise of surface temperature has to be estimated by the forecaster, taking into account the season and the thickness of the cloud layer. The cloud clearance at coastal stations is somewhat delayed owing to the continuous replenishment of cool air at the relevant heights, but a clearance normally spreads from inland backwards against the wind, and often crosses the coast and a strip of coastal water, although the low stratus persists well out to sea.

In the discussion which followed, *Mr. Fox-Holmes* drew attention to the importance of keeping track of weak inactive fronts over the North Sea, as these frequently had a belt of very low stratus associated with them.

Mr. Alexander made the point that, for the Cambridge area, the fen country was an important feature which could often be treated as an effective water surface, so increasing the stratus threat.

Mr. Hastings said that he had found that Frost's formula for the modification of an air mass crossing the North Sea worked quite well for a warm air mass flowing over a relatively cold sea surface, as well as for the reverse. As regards the warming of the surface air under a stratus sheet, he was of the opinion that the actual amount of water in the cloud sheet was of importance, as well as its thickness.

Non-frontal cloud in south-westerly airstreams

Mr. T. Johnston opened the aspect of non-frontal low cloud in a south-westerly airstream by discussing the forecasting problem for a single airfield rather than an area, the airfield being Prestwick. Because the aircraft using the field normally plan their flight some 15 to 18 hours ahead the forecaster must endeavour to give fairly long-range notice of the onset of poor cloud conditions.

There are two main sources of information about low cloud at Prestwick. One is a statistical survey of the incidence of fog and low cloud by Mr. N. E. Davis.[4] The other is a local, unpublished project into the problem of forecasting low cloud at the station. This local work being the basis of this opening statement, the speaker indicated the scope of the work. The approach was primarily synoptic on the grounds that practical forecasting usually begins with a prebaratic of some kind. All occasions of cloud at 600 feet or below were studied. Charts were examined and details of temperature, winds and clouds were recorded. The investigation covered two summers and one winter, from May 1949 to October 1950. The required conditions occurred on only 4 per cent of occasions. This figure was almost constant season by season and compares well with the longer-term average. Over half of the low cloud periods were directly associated with fronts and the number of air-mass cases was therefore limited, but certain features were common to both frontal and air-mass types.

After illustrating the topography of the area and pointing out the considerable shelter afforded by hills to the south and south-south-west of the field the speaker showed a diagram illustrating the strong predilection of very low stratus for a very limited range of surface wind direction. Well over half occurred in the range 230–250 degrees, with a rapid fall off to negligible figures on either side. The annual distribution of wind direction, shown on the diagram also, does not show a comparable extreme and the prevailing direction in fact lies at 180 degrees.

A further diagram showed the relation of the 230–250 degree range and the associated gradient range of 250–280 degrees in relation to the geography of the area. The former gives the longest possible unbroken sea track being reduced to one third or less by a 10-degree change outside it. The latter is the least broken flow from the Atlantic and again a small change outside the limits introduces large land masses upwind. Sea and air temperature comparison did not give very firm results, but it seemed that for cloud at 600 feet or lower the air mass should arrive in the Firth of Clyde with a dew-point not less than the sea temperature measured there daily.

The problem of cloud height was then noted and the great fluctuations over short periods of time discussed, and illustrated, to show the complexities and apparent intractibility of this aspect of the problem.

The speaker then summarised the tentative rules for the forecasting of cloud at 600 feet or below which were formulated as a result of the study. The most important first step is to make a prebaratic for the local area of an accuracy sufficient to give the gradient in the range 260–280 degrees. For an estimate of expected dew-point recourse must then be made to upwind ship reports, making adjustments for observed changes as the air moves northwards, inspection suggesting a fall of 3 to 4 degrees from position Juliett to the Firth of Clyde area. If the prebaratic can be made sufficiently accurate to about 25°W. it should be possible to differentiate between air with a source in the Biscay–Finisterre region which is usually too dry for low cloud and a source in mid-Atlantic which is much more likely to be sufficiently moist. For reasons mentioned earlier no firm aid could be found for forecasting cloud base beyond "600 feet or below" at any worthwhile range of time.

After pointing out that the remarks had been confined to a moving air mass and not to stagnant moist conditions which raised new issues and complications, the speaker then illustrated a recent random case, with the relevant charts and a description of events which conformed, in the important aspects, to the findings previously discussed.

REFERENCES

1. HINKEL, C. H. and SAUNDERS, W. E.; Speed of movement of warm fronts on the Atlantic. *Met. Mag., London,* **84,** 1955, p. 241
2. SUMNER, E. J.; A study of blocking in the Atlantic–European sector of the northern hemisphere. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 402.
3. SANSOM, H. W.; A study of cold fronts over the British Isles. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 96.
4. DAVIS, N. E.; Fog and low stratus at Prestwick Airport, with notes on the diurnal variation of surface wind and temperature. *Met. Mag., London,* **81,** 1952, p. 231.

NOTES AND NEWS

The movement of precipitation belts as observed by radar

Mr. W. G. Harper has pointed out that the maximum correlation between the movement of precipitation belts and radar winds is, in our January number (page 19), incorrectly stated to be at 700 metres. This should, of course, be 700 millibars. It should also be made clear that the correlations are with the components of the winds across the belts.

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. W. Andrews, Senior Experimental Officer, retired on February 20, 1958. He joined the Office as a Technical Assistant in January 1920 after service in the Royal Flying Corps and Royal Air Force from 1917 until the end of 1919. Apart from a period between 1934 and 1937 in the British Climatology Division at Headquarters, his 38 years' service has been spent at aviation outstations, including a tour of duty overseas. From 1945 until his retirement he served at Mildenhall.

Academic successes.—Information has reached us that the following members of the staff have been successful in recent examinations. We offer them our congratulations.

General Certificate of Education (Advanced Level): C. Alderson, P. N. Brown, Miss P. J. Carter, B. A. Cole, L. Fletcher, M. F. Gaskin, R. P. Healey, Miss A. S. Hill, N. Holdsworth, R. P. Johnson, M. J. Kerley, M. J. Llewelyn, Miss C. Lynch, K. Oram, B. N. Parker, Miss J. L. Platt and Miss B. F. Smith.

WEATHER OF JANUARY 1958

Northern Hemisphere

Both the Icelandic low and the Azores anticyclone were east of their normal positions; the former was less deep and the latter weaker than normal. An area of low pressure extended from the eastern United States seaboard to the Azores, interrupting the subtropical high pressure belt normally extending across the Atlantic in these latitudes. The Siberian anticyclone was only slightly north of its normal position, but the Aleutian low was displaced well to the east and was markedly deeper than normal.

An area of positive pressure anomalies covered Greenland, north-eastern Canada and the north-western Atlantic, the anomalies reaching +8 millibars in the Davis Strait. Asiatic Russia had pressure anomalies up to +8 millibars, and +7 millibars was reported in extreme north-east Asia. Pressure was also above normal in the northern Sahara, but in the North Pacific there were large negative anomalies reaching −18 millibars near 50°N. 150°W. Pressure was also below normal in the Atlantic, an anomaly of −10 millibars being recorded at Bermuda.

In the North Pacific exceptionally strong surface air flow occurred on the north-west side of the Aleutian low. By contrast, westerly surface air flow which is normally present in the Atlantic at about 50°N. in January, was substantially reduced.

Over the whole of North America, as far south as 35°N., temperatures were above normal. East of the Rocky Mountains anomalies reached +9°C., and +5°C. was reported from the Canadian Arctic. Elsewhere, temperatures were near normal; anomalies did not exceed 3°C. anywhere over Europe, the Mediterranean, North Africa and the North Atlantic.

Rainfall was above average over most of western and central Europe, northern Siberia, the coastal regions of North America, and over north-west Africa. Elsewhere in Europe and in central North America there was below average rainfall, and in the extreme north-east of Asia the month was unusually dry.

WEATHER OF FEBRUARY 1958

Great Britain and Northern Ireland

In the British Isles the predominantly mild and very wet weather of February was broken by short, unusually cold brighter spells.

During the first four days of the month pressure was high to the south of England and weather over the country was cloudy and mild with occasional rain, mainly in the north and west. On the 5th cold north-westerly winds spread over the whole country behind a vigorous depression over the North Sea, bringing a general fall of temperature of 10–15°F. and snow showers to many places. Temperature, which had risen to 56°F. at Aberdeen on the 4th, was below 29°F. throughout the 6th and fell to 2°F. early the following morning. On the 7th–9th there were heavy falls of snow in many parts of the country; in Scotland most of the main roads were blocked and many villages isolated, while snow lay 6–12 inches deep in many parts of northern England. Snow was up to 2 inches deep locally in the south-east but milder air had spread into south-west England, and on the 7th, temperatures in Cornwall rose to 50°F. in sharp contrast to the near freezing temperatures over the rest of the country.

From 8th–10th the cold air retreated slowly northward, and the belt of rain and snow which marked its departure was followed on the 10th and 11th by general and locally heavy rain associated with a deep depression off Ireland. Wind reached gale force in western districts and there was a rapid rise in temperature, especially in the south; 56°F. was reached at Herne Bay on the 10th. Weather remained mild generally until the 16th. In some southern districts temperature did not fall below 50°F. day or night for three days and nights and on the 14th, the warmest day of the month, reached 59°F. at many places in southern England and 60°F. at Cambridge. On the 16th and 17th northerly winds brought a sharp fall in temperature, but this was only a temporary interruption, and for the next few days there was slight rain in many places with temperatures near normal.

On the 24th a vigorous depression from the Atlantic was situated off south-west Ireland and a well marked frontal belt extended from east to west across the British Isles; snow was falling in the cold easterly winds to the north of the front. The depression moved eastwards across southern England during the night and winds reached gale force locally; gusts of 60 knots were recorded at Scilly and Felixstowe. Cold weather spread to the whole country in the rear of the depression, and temperature was near or below freezing everywhere throughout the following day, with widespread snow. Snow lay 6–12 inches deep in many parts of Scotland, northern England and the Midlands from 25th–27th and was 8 inches deep locally in Kent. On the 27th an anticyclone developed to the west of Ireland and milder air from the Atlantic spread over the country from the north-west, bringing widespread rain and drizzle and a general rise in temperature.

Mean temperature over the month was above average in the southern half of the country—about 2°F. above in the south-west of England—and below average further north—about 3°F. below normal in north-east Scotland. It was the wettest February over England and Wales since 1951 with 176 per cent of the average amount of precipitation. Twice the average was exceeded over the west coast of Wales, the Mersey Estuary, an area extending from mid-Wales to Warwickshire and over most eastern coastal districts. New records for February rainfall were established at Valley, Dishforth and Dyce.

The land was very wet in most places and outside work, including the planting of early potatoes, was held up. Winter spraying was rather behind schedule but glass-house work was going well. Cattle have, on the whole, come through the winter in good condition. Most districts seem to expect a good cropping season.

WEATHER OF MARCH 1958

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 ...	61	5	−4·0	83	—1	96
Scotland	59	—9	−4·4	89	—3	99
Northern Ireland ...	60	20	−4·0	63	0	88

*1916–1950 †1921–1950

RAINFALL OF MARCH 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square	1·19	75	*Carm.*	Pontcrynfe	1·04	28
Kent	Dover	2·26	126	*Pemb.*	Maenclochog, Dolwen Br.	2·07	53
,,	Edenbridge, Falconhurst	1·49	74	*Radnor*	Llandrindod Wells	1·03	40
Sussex	Compton, Compton Ho.	1·83	74	*Mont.*	Lake Vyrnwy	1·77	45
,,	Worthing, Beach Ho. Pk.	1·79	104	*Mer.*	Blaenau Festiniog	2·91	43
Hants	St. Catherine's L'thouse	1·50	77	,,	Aberdovey	1·30	49
,,	Southampton, East Pk.	1·53	73	*Carn.*	Llandudno	·69	37
,,	South Farnborough	1·84	108	*Angl.*	Llanerchymedd	·85	34
Herts.	Harpenden, Rothamsted	1·79	107	*I. Man*	Douglas, Borough Cem.	1·74	60
Bucks.	Slough, Upton	1·36	86	*Wigtown*	Newtown Stewart	1·23	40
Oxford	Oxford, Radcliffe	1·36	81	*Dumf.*	Dumfries, Crichton R.I.	1·54	56
N'hants.	Wellingboro' Swanspool	1·69	109	,,	Eskdalemuir Obsy.	1·94	49
Essex	Southend W.W.	·90	68	*Roxb.*	Crailing	1·23	73
Suffolk	Ipswich, Belstead Hall	·96	66	*Peebles*	Stobo Castle	1·38	57
,,	Lowestoft Sec. School	1·59	120	*Berwick*	Marchmont House	2·79	132
,,	Bury St. Ed., Westley H.	·76	47	*E. Loth.*	N. Berwick	...	...
Norfolk	Sandringham Ho. Gdns.	1·41	89	*Midl'n.*	Edinburgh, Blackf'd H.	1·97	123
Dorset	Creech Grange	1·68	67	*Lanark*	Hamilton W.W., T'nhill	·96	40
,,	Beaminster, East St.	1·69	63	*Ayr*	Prestwick	·93	44
Devon	Teignmouth, Den Gdns.	2·08	83	,,	Glen Afton, Ayr. San	1·22	33
,,	Ilfracombe	·93	38	*Renfrew*	Greenock, Prospect Hill	1·33	33
,,	Princetown	3·66	62	*Bute*	Rothesay, Ardencraig	1·01	30
Cornwall	Bude	1·09	51	*Argyll*	Morven, Drimnin	...	...
,,	Penzance	4·64	146	,,	Poltalloch	...	...
,,	St. Austell	4·09	117	,,	Inveraray Castle	1·87	34
,,	Scilly, St. Mary	4·34	172	,,	Islay, Eallabus	1·47	47
Somerset	Bath	1·27	63	,,	Tiree	·75	29
,,	Taunton	·80	41	*Kinross*	Lock Leven Sluice	2·72	121
Glos.	Cirencester	1·56	71	*Fife*	Leuchars Airfield	4·07	250
Salop	Church Stretton	1·53	65	*Perth*	Loch Dhu	2·37	44
,,	Shrewsbury, Monkmore	·92	57	,,	Crieff, Strathearn Hyd.	1·93	77
Worcs.	Worcester, Diglis Lock	1·36	86	,,	Pitlochry, Fincastle	1·24	57
Warwick	Birmingham, Edgbaston	1·43	76	*Angus*	Montrose Hospital	5·06	307
Leics.	Thornton Reservoir	1·50	81	*Aberd.*	Braemar	3·11	139
Lincs.	Cranwell Airfield	1·50	103	,,	Dyce, Craibstone	4·77	234
,,	Skegness, Marine Gdns.	1·79	137	,,	New Deer School House	4·01	181
Notts.	Mansfield, Carr Bank	1·81	103	*Moray*	Gordon Castle	1·66	98
Derby	Buxton, Terrace Slopes	2·37	82	*Inverness*	Loch Ness, Garthbeg	2·12	85
Ches.	Bidston Observatory	1·34	82	,,	Fort William	2·25	44
,,	Manchester, Ringway	1·76	99	,,	Skye, Duntulm	2·63	81
Lancs.	Stonyhurst College	1·66	63	,,	Benbecula	1·80	72
,,	Squires Gate	1·32	70	R. & C.	Fearn, Geanies	·95	77
Yorks.	Wakefield, Clarence Pk.	1·73	101	,,	Inverbroom, Glackour	2·67	64
,,	Hull, Pearson Park	1·99	134	,,	Loch Duich, Ratagan	3·05	59
,,	Felixkirk, Mt. St. John	3·00	172	,,	Achnashellach	3·36	60
,,	York Museum	2·01	141	*Suth.*	Stornoway	2·13	93
,,	Scarborough	2·90	191	*Caith.*	Lairg, Crask	4·22	114
,,	Middlesbrough	2·27	155	,,	Wick Airfield	2·93	162
,,	Baldersdale, Hury Res.	2·68	115	*Shetland*	Lerwick Observatory	1·65	53
Nor'l'd	Newcastle, Leazes Pk.	3·21	193	*Ferm.*	Belleek	2·50	90
,,	Bellingham, High Green	2·37	108	*Armagh*	Armagh Observatory	1·37	70
,,	Lilburn Tower Gdns	3·70	173	*Down*	Seaforde	2·24	83
Cumb.	Geltsdale	·78	34	*Antrim*	Aldergrove Airfield	1·46	73
,,	Keswick, High Hill	1·25	36	,,	Ballymena, Harryville	1·57	59
,,	Ravenglass, The Grove	1·68	62	*L'derry*	Garvagh, Moneydig	1·51	57
Mon.	A'gavenney, Plâs Derwen	1·75	58	,,	Londonderry, Creggan	1·89	68
Glam.	Cardiff, Penylan	1·01	40	*Tyrone*	Omagh, Edenfel	1·07	40

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,032, JUNE 1958

SOME OBSERVATIONS ON DEW

By I. F. LONG

General.—Dew may be defined as "the deposition of water drops by direct condensation of water vapour from the adjacent clear air", in general upon surfaces cooled by nocturnal radiation. In this definition the phrases "direct condensation" and "clear air" should be firmly adhered to. Deposition, or the appearance of water by other agencies should if possible be clearly indicated by observers in their records and if possible the source of the water noted, but these phenomena should not be recorded as dew. For example; large amounts of water are often deposited on plant and soil surfaces during overcast nights when a warm saturated air mass suddenly replaces a cool dry air mass, giving rise to mist and fog. The deposition in such cases is usually in the form of fog precipitation, the droplets formed becoming quite large especially upon grass and other non-wettable surfaces. These droplets coalesce and stream down the blades to wet the lower regions of the plant and the soil, a condition rarely found in true dew deposition. Plate 1 (between pp. 176–177) shows this form of fog precipitation upon short grass about 1½ inches high. Note the large amount of water and the general over-all covering of the droplets. Bare soil also becomes thoroughly wetted on such occasions whereas it is, relatively speaking, quite dry on nights of true dew deposition.

Another form of water on plant leaves, particularly on grass, which may be mistaken for dew, is the water exuded by the plants themselves and known as guttation[1]. Guttation will quite often occur on overcast nights when the soil is warm and at or near field capacity. The next morning the grass is covered with large glistening "dew drops" and many observers mistake these exuded drops for dew, but this is a physiological and not a meteorological phenomenon.

Dew and guttation often occur together and careful observation is needed to distinguish between the dew and guttation droplets. The water of guttation is exuded only at the tips of the blades in large drops which are generally about 2 millimetres in diameter and sometimes reach 3 millimetres diameter before trickling down the leaf surface. The dew droplets on the other hand rarely grow greater than 1 millimetre diameter, are spread fairly evenly over the leaf surface, are usually larger at the edges of the leaves than at the centre, and become smaller and smaller trailing off to nothing in the lower warmer depths of the plant. Plate II shows dew and guttation occurring together, and Plate III guttation alone.

Measuring dew.—Many instruments have been devised for the observation and measurement of dew, some by observation of the deposition of droplets upon a standard surface[2] and others by directly weighing an object or plant upon which dew is forming; each have their own advantages and disadvantages. Hirst[3] has devised a "dew balance" which weighs and records the deposition on a plant shoot, and Jennings and Monteith[4] a "dew balance" which weighs and records the deposition on a growing plant in soil. Hirst's balance weighs the total deposition of dew, and gives a good picture of the rate of dew formation, but it does not distinguish between dew deposited from vapour "rising" from the soil or from vapour "falling" from the air above the crop. The Jennings and Monteith balance, on the other hand, measures the total gain or loss of the plant–soil–water system as a whole, but does not measure the actual deposition of dew. It would seem that a combination of the two types of balance is desirable. A simple approximate method of measuring dew is to weigh the amount of water absorbed by pieces of filter paper of known area and weight, which have been carefully and firmly pressed on to a grass surface[5]. When guttation occurs with the dew this method measures the total surface water.

Source of dew.—The 2,000 year old argument as to whether dew "rises" or "falls" was re-vitalized when Wells wrote his famous "Essay on Dew" in 1812 (see Monteith[5] for brief historical review). Nearly all the arguments have been based upon observations or experiments on grassland, and the tendency has been to apply the conclusions reached to dew in general. One obvious experimental approach is to make a detailed examination of the temperature, vapour pressure and wind gradients above and inside various crops in the field, and of the temperature gradients and moisture content of the soil. To this end apparatus was set up in various crops at Rothamsted during the years 1950–1956. The apparatus consisted of miniature, non-ventilated, nickel resistance thermometers, mounted in pairs with one bulb dry and the other wet, resulting in a compact psychrometer. These units were mounted on light masts in and above the crops from the end of May to the middle of October. Soil temperatures were measured using nickel resistance thermometers and on some occasions leaf temperatures were measured using miniature resistance thermometers which were inserted in the leaves. Continuous recording was obtained using standard 12 point resistance recorders of the double-slidewire type. Wind gradients were recorded using modified sensitive cup anemometers and occasionally a "hot-wire" anemometer was used for spot readings. These instruments enable the onset and finish of dew to be determined to within 5 minutes, and an approximation of the dew intensity can be estimated. Checks against records from a dew balance[3] installed in a potato crop have been good. (For a full description of these instruments see, Penman and Long[6] and Long[7].) The crops examined were grass, potatoes, sugar-beet, Brussels sprouts and spring wheat.

The records obtained in these crops clearly confirm that for moisture to condense on a dry surface, the surface must be at a lower temperature than the dew-point of the air, but for a surface already wetted, the surface temperature need only be at the dew-point temperature. On clear nights the measured leaf temperatures of potatoes are usually 0·5 to 1·0°C. less than the air a few millimetres from their surface, and on occasions may be 2°C. less. The old idea that leaf temperature rises to the dew-point temperature of the surrounding air when condensation occurs is not supported by the records.

The available records also suggest that dew does not form unless an inversion of the vapour pressure gradient has occurred above the surface of the crops (but see Monteith[5]). When there is no inversion the vapour is transported up the normal gradient from the soil escaping into the upper air and no dew is deposited. Increased air movement in the crop generally results in a greater deposition of dew but only to the point where the increased turbulence does not decrease the slope of the vapour pressure gradient. When this happens, deposition becomes less as the air speed increases.

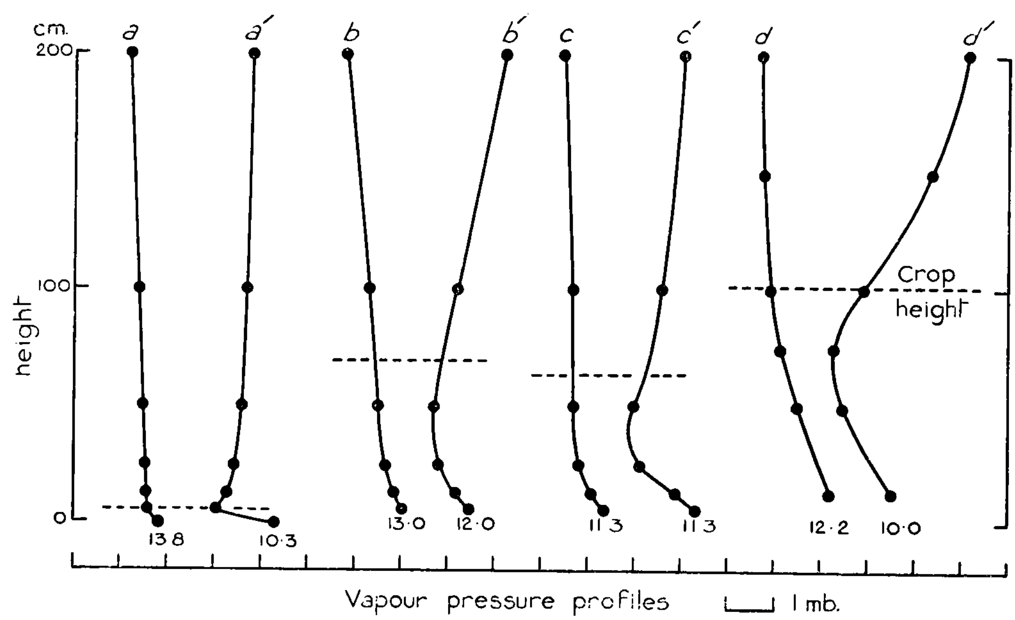


FIGURE 1—NOCTURNAL VAPOUR PRESSURE GRADIENTS IN AND ABOVE (*a*) GRASS, (*b*) BRUSSELS SPROUTS, (*c*) POTATOES, (*d*) SPRING WHEAT.

(*a*, *b*, *c*, *d*,) No dew. (*a*′, *b*′, *c*′, *d*′) Dew. Relative humidity at or near saturation.

Typical vapour pressure gradients during nights of dew formation, and nights with no dew formation are shown in Figure 1 for four different crops. In all four it can be seen that there is an upward decrease of vapour pressure within the crops, indicating that vapour is escaping from the soil continuously, whether or not dew is being deposited. The vapour pressure inversion during dew formation on grass (Figure 1 (*a*′)) occurs almost at the crop surface and sometimes just above, suggesting that much of the water deposited on grass could be obtained by upward transfer from the soil. This shape of vapour profile is typical of grass even when the soil is dry. In the taller crops however the down-coming gradient extends well into the crop. Maximum deposition in these crops is always in the upper two thirds of the crop, and the vapour pressure gradients indicate that in these cases much of the vapour must be transferred to the crop from the air above. Figure 1 is typical of gradients obtained when the soil is at or near field capacity. When the soil is very dry, the level of the vapour pressure inversion is much lower. The planting density will affect the gradients in and above the crop. For a dense stand with a nearly closed leaf canopy the effective radiating surface is near the top of the crop, so that on clear nights the cooling is more intense at canopy level than in a thin crop where the cooling is most intense at or near ground level. The dense crop also suppresses mixing and transfer processes within it. Both effects combine to move the level of zero vapour pressure gradient nearer to the top of the denser crop and to reduce dew deposition within the denser crop. To illustrate the effects of crop density upon the micro-climate in spring wheat, three plots, ten yards square, were planted or thinned to give densities 200 per cent, 100 per cent and 25 per cent of a normal crop, and the recording psychrometers were installed in and above them.

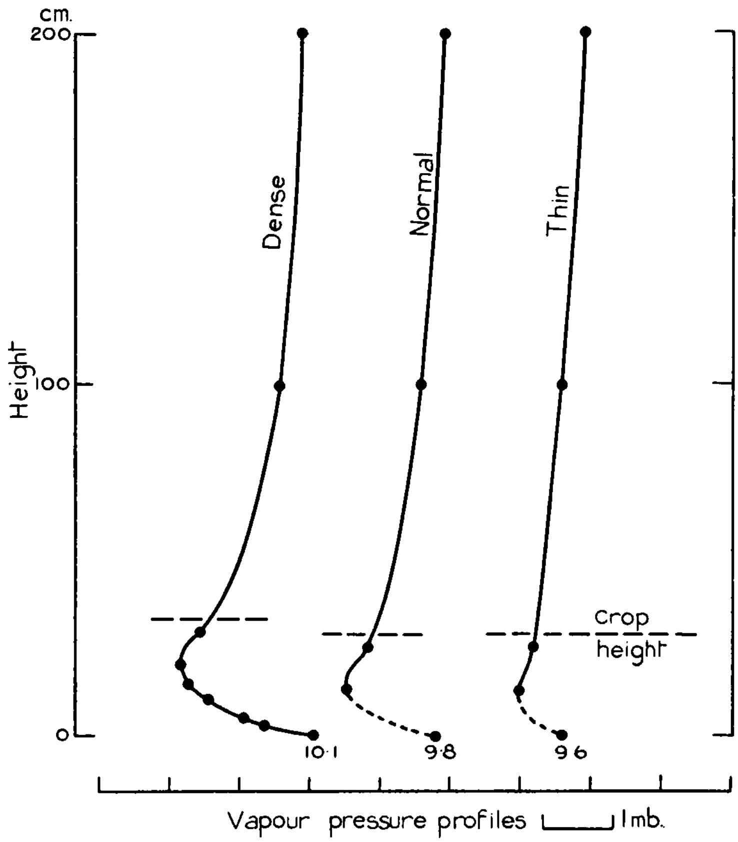


FIGURE 2—EFFECT OF CROP DENSITY UPON VAPOUR PRESSURE GRADIENT DURING DEW FORMATION.

Relative humidity at all levels is 100 per cent.

The three gradients of Figure 2 were obtained during a night of dew and are the average gradients over the period 0300–0400 G.M.T., 5 June 1956. Unfortunately there were only enough psychrometers to record detail in the dense crop, but the few points recorded in the less dense crops clearly indicate the decrease in the gradients above and below the crops, and also the lower height of the inversion point. The portions of the vapour pressure profiles in the less dense crops where no records were available have been approximated and plotted as a dotted line.

Does dew "rise" or "fall"? It would seem from the preceding observations that it does both, the amounts contributed from the two sources depending upon the relative position of the receiving surfaces to the level of the vapour pressure inversion, as well as the surface temperature and the ventilation.

Routine observations of dew.—The routine recording of dew by agricultural meteorological stations was recommended by the International Meteorological Organization in 1947 (resolution 7 of the Conference of Directors, Washington 1947) and has in fact been recorded by some of the stations under the Meteorological Office Agricultural Scheme in this country since 1924.

At many stations this observation is at 0900 G.M.T. only, and since any dew which may have occurred during the previous night may have evaporated by 0900, it is reasonable to assume that the advent of dew occasionally goes unobserved. The nine o'clock record is more truly an observation of the persistence of dew until 0900. To check this point a comparison has been made between dew occurrence as estimated from the continuous records of vapour pressure, humidity and wind gradients, with the routine meteorological observations taken at this station (Rothamsted) during the months of July and August 1956.

Analysis of the records shows that during this period, dew occurred on 31 occasions. The routine observations show 18 reports of dew for this period of which two reports were actually "guttation" and not dew.

TABLE I—ANALYSIS OF DEW RECORDS FOR AUGUST 1956

	Date	Dew			Gradients and evaporation 0600–0900 G.M.T.		
		Intensity	Duration	Finished	(e_1-e_2)	(u_2-u_1)	$E\times10^{-5}$
			hr.	G.M.T.	mb.	cm. sec.$^{-1}$	gm. cm.$^{-2}$ sec.$^{-1}$
(a)	8	M	7·5	0500	0·13	59	0·15
(a)	9	L	4·0	0430	0·03	36	0·02
(a)	12	VL	1·5	0330	0·05	66	0·07
(a)	22	H	9·5	0630	0·20	39	0·16
(a)	23	M	10·5	0515	0·15	25	0·08
(a)	29	L	7·0	0545	0·13	28	0·07
(a)	30	M	7·5	0545	0·13	38	0·10
(b)	1	L	2·25	0430	0·22	54	0·24
(b)	5	M	10·0	0515	0·17	33	0·11
(b)	7	L	8·5	0230	0·16	43	0·14
(b)	20	M	8·0	0530	0·12	82	0·20
(b)	21	H	10·0	0545	0·23	36	0·17
(b)	24	L	1·75	0530	0·13	62	0·16
(b)	27	M	9·0	0430	0·23	49	0·22

(*a*) Dates when dew occurred and was observed at 0900. (*b*) Dates when dew occurred and was not observed at 0900 G.M.T., possibly because of evaporation.

Dew occurred but was not observed, because of following rain on the 6th, 11th and 25th. Guttation was observed but recorded as dew on the 14th. The intensity of the dew is referred to in the table as follows: H–heavy, M–moderate, L–light, VL–very light.

Some of the August data are in Table I and Figure 3. There were 17 nights on which physical conditions were suitable for dew formation but only on 7 was "dew" reported at 0900 next morning. Three of the missing 10 are accounted for by rain falling an hour or two after the dew formation had come to an end (6, 11 and 25 August). Table I thus carries information about 7 occasions when dew was observed (*a*) and 7 occasions when it was not observed (*b*). Four occasions from each group are represented in Figure 3 which shows the vapour pressure profiles in a potato crop at the time of steepest gradients. There is no major difference between the groups and the explanation for non-observance of dew in group (*b*) must be found in persistence. Since it is possible that the condensed water may have evaporated by 0900 on mornings when dew was not observed, it was decided to estimate roughly the average rates of evaporation for the periods from sunrise (about 0600) to 0900 following each occurrence of dew. Rider's[8] equation for evaporation has been used, fully realizing that it is being applied under conditions of stability and fetch, and over a time interval

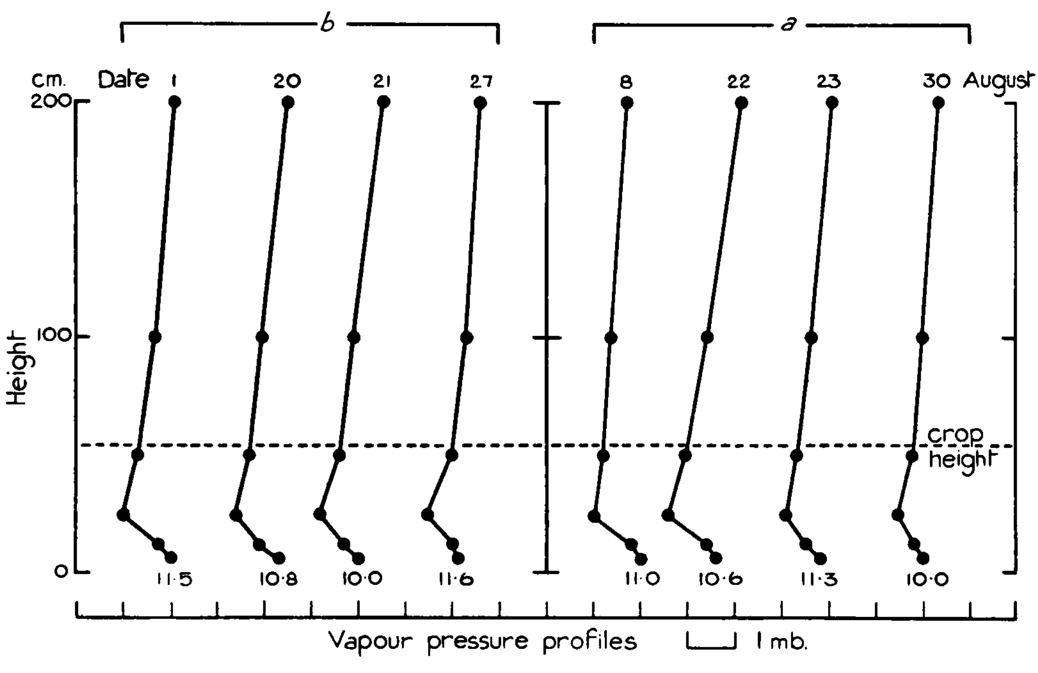


FIGURE 3—COMPARISON OF VAPOUR PRESSURE GRADIENTS FOR SOME OCCASIONS WHEN DEW WAS OBSERVED (*a*) AND WAS NOT OBSERVED (*b*).

Relative humidity at all levels is 100 per cent.

for which it was not designed. The plane of "zero displacement" has been taken as the level of zero vapour pressure gradient (for which there is some justification, not yet published) and in this potato crop the value was $d = 30$ cm. With observation levels at $z_1 = 100$ and $z_2 = 200$ cm., the Rider equation reduces to:

$$E \simeq 2\,(e_1 - e_2)\,(u_2 - u_1)\,10^{-7}\ \text{gm. cm.}^{-2}\ \text{sec.}^{-1}$$

The last three columns of Table I give the vapour pressure and wind velocity gradients per metre, and the derived estimate of evaporation rates. On the mornings of the 22nd and 23rd the period estimated starts on the cessation of dew, at 0630 and 0615 respectively. In comparing the evaporation estimates with dew intensities, two facts should be kept in mind:

(i) A moderate dew in southern England will deposit about 0·1 mm. of water. (A heavy dew may deposit 0·15 mm. or more.)

(ii) An evaporation rate of $0 \cdot 1 \times 10^{-5}$ gm. cm.$^{-2}$ sec.$^{-1}$ over a period of three hours is approximately 0·1 mm. of water.

It can be seen from the table that for all occasions where dew was not observed at 0900 this rate of evaporation was exceeded, and on five of the seven occasions when dew was observed at 0900 this rate of evaporation was not exceeded. Of the two exceptions, the 8th and 22nd, the latter was a night of very heavy dew, and on both nights guttation may have added to the accumulated surface water enough to permit persistence through a period of relatively high evaporation rate.

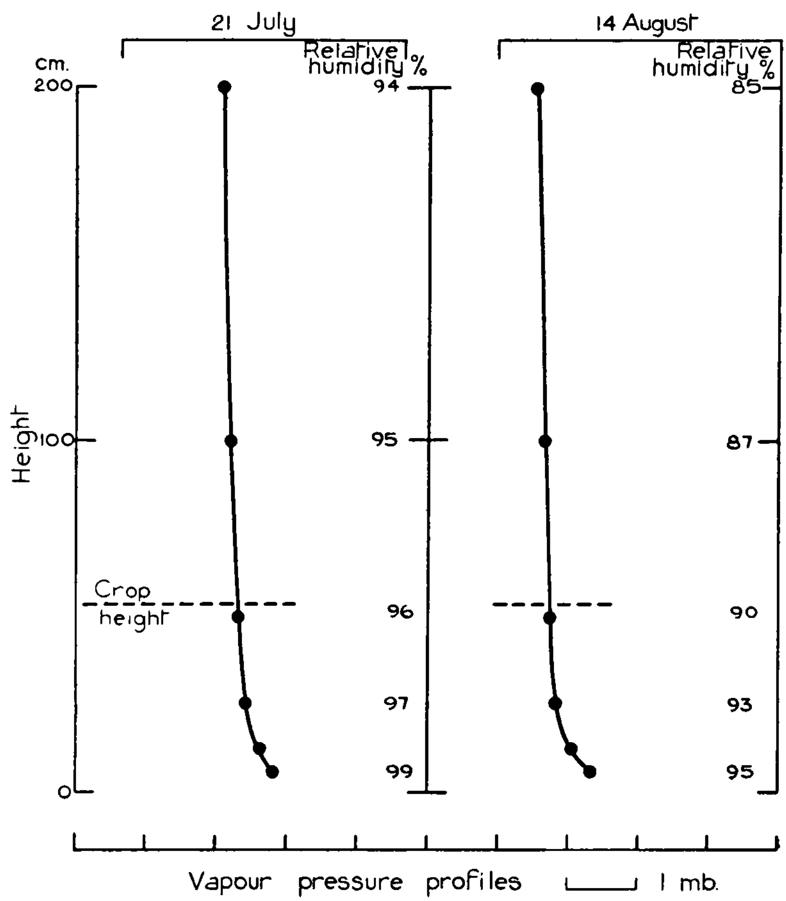


FIGURE 4—VAPOUR PRESSURE GRADIENTS FOR THE TWO OCCASIONS WHEN GUTTATION OCCURRED AND WAS REPORTED AS DEW.

On two mornings during July and August (21 July and 14 August) this guttation was observed but was mistaken by the observer as dew. To justify this verdict, Figure 4 shows the vapour pressure profiles for the previous nights at the times when they came nearest to favouring condensation: the relative humidity at the six heights of observation is also indicated. On both nights the wind at 2 metres was over 2·4 metres per second, and under these conditions it is fair to say that dew formation would not be possible.

Comment.—These notes have been written in an attempt to show that although the nine o'clock observations of dew are useful, the recording of dew is still not all that it might be. Dew can be an important factor in agriculture, for it is known to influence the development of certain plant diseases. Plant pathologists who rely upon routine records for their information on the advent of dew, may be getting misleading underestimates of the frequency of occurrence. Although only two month's records have been considered in these notes, a rough analysis of the records for the two summers 1955–1956 show that dew nights were twice as numerous as occasions when dew was recorded at 0900.

Acknowledgment.—The author wishes to thank Dr. H. L. Penman for guidance and advice during the course of this work.

REFERENCES

1. LONG, I. F.; Dew and guttation. *Weather, London,* **10,** 1955, p.128.
2. DUVDEVANI, S.; An optical method of dew estimation. *Quart. J. R. met. Soc., London,* **73,** 1947, p.282.
3. HIRST. J. M.; A method of recording the formation and persistence of water deposits on plant shoots. *Quart. J. R. met. Soc., London,* **80,** 1954, p.227.
4. JENNINGS. E. G., and MONTEITH, J. L.; A sensitive recording dew-balance. *Quart. J. R. met. Soc., London,* **80,** 1954, p.222.
5. MONTEITH. J. L.; Dew. *Quart. J. R. met. Soc., London,* **83,** 1957, p.322.
6. PENMAN, H. L., and LONG, I. F.; A portable thermistor bridge for micro-meteorology among growing crops. *J. sci. Instrum., London,* **26,** 1949, p.77.
7. LONG, I. F.; Instruments for micro-meteorology. *Quart, J. R. met. Soc., London,* **83,** 1957, p.202.
8. RIDER, N. E.; Evaporation from an oat field. *Quart. J. R. met. Soc., London,* **80,** 1954, p.198.

MOUNTAIN WAVES OVER SOUTHERN NORWAY, JULY 26, 1956

By Y. GOTAAS, *cand. real*

On July 26, 1956 mountain waves over southern Norway were investigated by means of a jet fighter aircraft (Sabre). The flight was carried out to see if it is possible to reveal main features of mountain wave patterns by the use of high-speed jet aircraft. The aircraft was flying constant attitude at about 25,000 feet and only one run was made. The flight was made between 1100 and 1200 G.M.T.

Synoptic situation, July 26.—The whole day a strong westerly current persisted over southern Norway at all levels. A cold occlusion moved eastwards and passed Gardermoen at 1400 G.M.T. The cloud cover over eastern and central parts of Norway was mainly broken to scattered. The air, being conditionally unstable, contained cumulonimbus clouds with rain showers all along the western coast and in the western mountains. The tops of the cumulonimbus clouds were less than 20,000 feet along the track.

Fig. 1 shows the 300-millibar chart at 1500 G.M.T. and the track of the plane. The flight was made at 7,600 metres, corresponding to the height of the 380-millibar level.

Fig. 2 shows the variation of temperature and wind with height as indicated by the radio-sonde ascent made at Sola Airport at 1500 G.M.T. The cold front is marked by a shallow inversion at about 5,000 metres. The flight was therefore made in the air above the cold front.

Observational flight data.—At the desired height of 25,000 feet the pilot trimmed the plane for straight and level flight and engaged the automatic

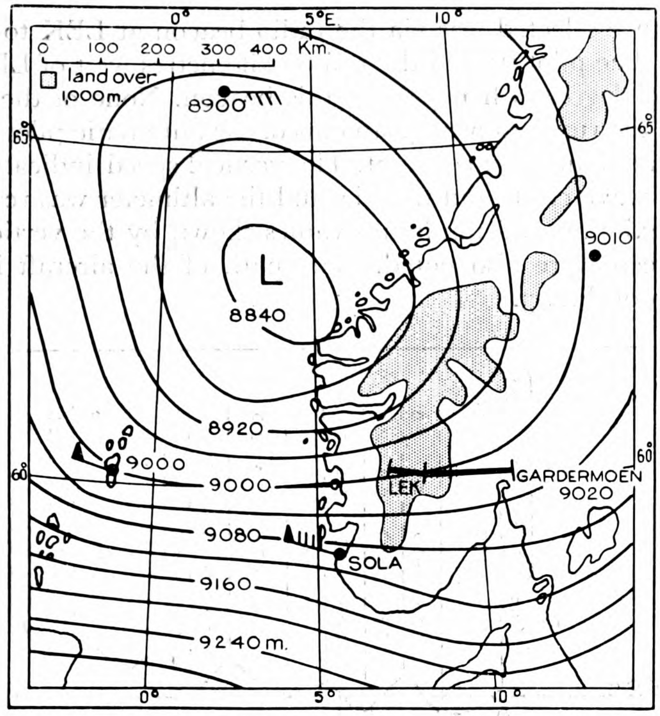


FIG. 1.—300-MILLIBAR CHART, JULY 26, 1956, 1500 G.M.T.

The broad line represents the track of the aircraft. 'LEK is the radio beacon (at Kalhovd).

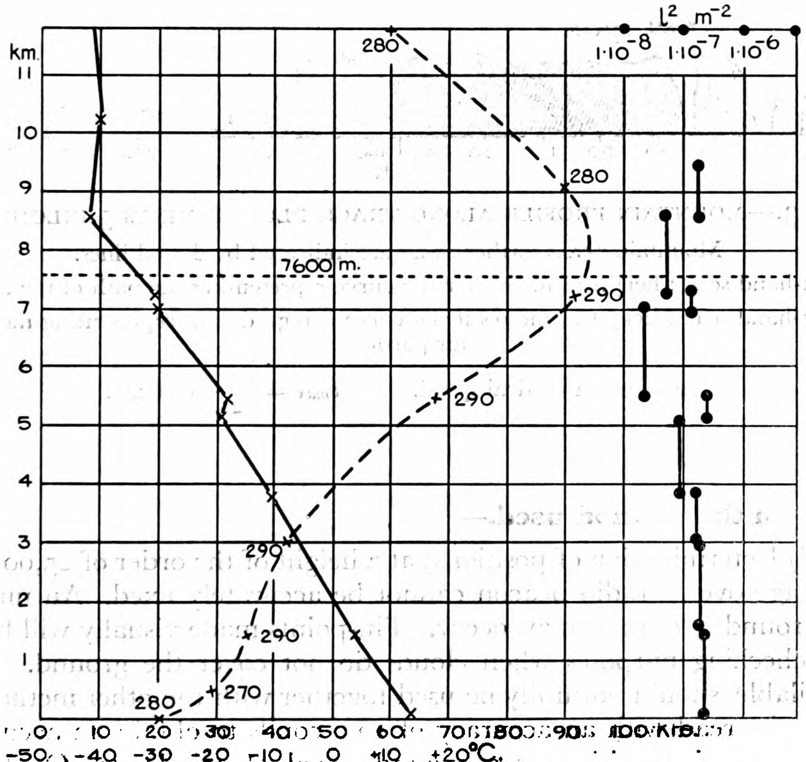


FIG. 2.—TEMPERATURE AND WIND PROFILE AS SHOWN BY THE RADIO-SONDE ASCENT AT SOLA, JULY 26, 1956, 1500 G.M.T.

Wind directions are indicated by figures along wind profile. l^2 is Scorer's parameter.

pilot. The course selected was via the radio beacon at LEK to the beacon at Gardermoen. The pilot started the run 60 kilometres west of LEK and had to alter course 10 degrees when passing this beacon. None of the controls were moved during the run, minor adjustments of the automatic pilot being made to keep the indicated airspeed constant. The vertical speed indicator was used to determine the wave crests and troughs and the altimeter was read at the same time. The maximum and minimum values shown by the vertical speed indicator in between were also noted. The path of the aircraft in the vertical plane is shown on Fig. 3.

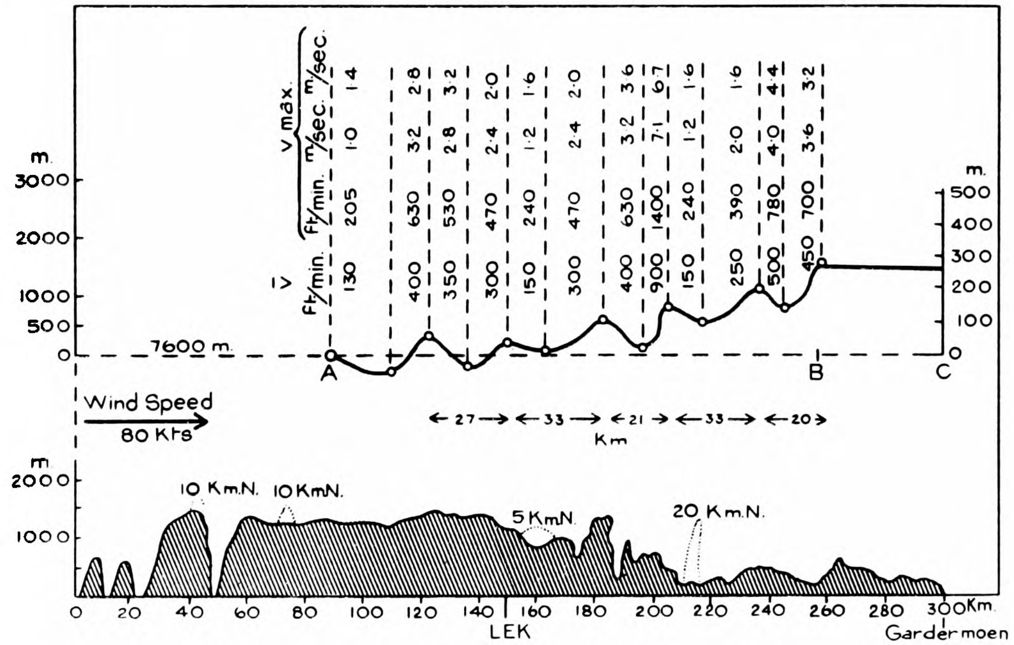


FIG. 3.—MOUNTAIN PROFILE ALONG TRACK PLUS OR MINUS 5 KILOMETRES

Mountain peaks further away are indicated by dotted lines.

Right-hand scale: height in metres for the curve representing the path of the aircraft.

Upper left-hand scale: height in metres if the curve is regarded as representing movements of air particles.

$\bar{v}$ = mean vertical speed. $v_{max} = \frac{\bar{v}\pi}{2}$ (see text).

Notes on the method used.—

(i) Determination of positions: at a height of the order of 25,000 feet the passage over a radio beacon cannot be accurately fixed. An uncertainty of around ½ minute may occur. Pin-points made visually will be helpful for checking purposes when clouds do not cover the ground. Radar, if available, should naturally be used together with the other methods. Time must be read with an accuracy of 10 seconds to obtain an accuracy of 2 kilometres in position at a ground speed of 450 knots. On Fig. 3 the accuracy is of the order of 4 kilometres.

(ii) It is difficult to trim the aircraft for level flight at the start of a run as the aircraft at that time may be situated in a main updraft or downdraft. The resultant mean ascent or descent of the plane, when within reasonable limits, can easily be calculated and should not seriously affect the result.

(iii) The vertical speed indicator has a lag of around 10 seconds. Readings will therefore be slightly out of phase with the vertical movements of the aircraft and the oscillations damped. Besides, the maximum and minimum values obtained will be smaller than the vertical velocities of the aircraft. It seems better to read off the altimeter every ½ minute and to note its extreme values in between. The pilot can then concentrate on the airspeed indicator and the altimeter only.

(iv) During the flight a certain amount of fuel is consumed. The total weight of the aircraft decreases and when the indicated airspeed is kept constant, this should result in a gradually increasing ascent of the aircraft. This effect, however, seems to be quite small, the ratio of the amount of fuel consumed to the total weight of the aircraft being of the order of a few per cent.

(v) On October 8 the same pilot, flying at 25,000 feet, kept the altitude within 20 feet for a period of 10 minutes, at a run when no waves were encountered. It will therefore be safe to assume that an aircraft can maintain its attitude for a long period, and further that the effect of fuel consumption and of "drift" of the altimeter due to elastic properties can be neglected. The latter condition assumes the pilot does not trim his aircraft for level flight immediately after a quick ascent to the desired altitude. It seems that normal corrections of altimeter readings due to deviations from the International Civil Aviation Organization standards and to changes in surface pressures are sufficient.

Discussion of data obtained.—Fig. 3 is a vertical cross-section showing the mountain profile along the track and the path of the aircraft.

Assume that the waves are stationary. Let $Z(x)$ denote the height of a streamline, and U the wind speed. The vertical velocity of the air particles is then $U(dZ/dx)$. On the other hand, if $Z_a(x)$ denotes the height of the aircraft and V the ground speed, then $V(dZ_a/dx)$ is the vertical velocity of the aircraft. Equating the two velocities, and assuming U and V to be constants, one finds:

$$Z(x) = (V/U)Z_a(x).$$

In the case considered, the ratio V/U is 5·5.

Let $\bar{v}$ denote the mean vertical speed, found by simply dividing change of height by time. Assume the curves to be sinusoidal; the ratio between the actual v_{max} and $\bar{v}$ becomes $\pi/2$. Unless the flight is made parallel to the wave crest, v_{max} will never be shown on the vertical speed indicator. The maximum figures read off the vertical speed indicator on the flight of July 26, all agree quite well with the computed values of $\bar{v}$. It seems justifiable to regard values of updrafts and downdrafts reported by pilots in connexion with mountain waves as being too low.

On Fig. 3 values of $\bar{v}$ in feet per minute, v_{max} in feet per minute, v_{max} in metres per second and a corrected value of v_{max} in metres per second are shown. A correction of $-0{\cdot}4$ metres per second is applied to v_{max} due to a possible incorrect trimming resulting in a mean ascent from A to B. It is a question whether a correction, and if so what, has to be applied to v_{max} as the aircraft actually descended from B to C instead of continuing the mean ascent. The aircraft may have been subjected to a wave motion of which the distance from A to B is only a quarter of the wavelength. But one flight only cannot be used to track this possible wave, especially as long as the expected vertical speeds are of the same order as the errors in the method employed.

As shown on Fig. 2, at all levels below the troposphere the actual lapse rate is equal or very close to the moist-adiabatic lapse rate, except in the shallow inversion and the thin isothermal layer. Dividing the sounding curve into different layers, Scorer's parameter, l^2, is calculated within each layer.

$$l^2 = \frac{g\,(d\theta/dZ)}{\theta/U^2} - \frac{(d^2U/dZ^2)}{U},$$

where θ denotes the potential temperature.

The second term is small compared to the first term and is therefore neglected at all levels, except in the layer between 7,000 and 8,000 metres. Here the strong curvature of the wind profile makes the two terms nearly equal, but of different signs. l^2 decreases gradually up to this level, from where it starts increasing. This variation is mainly due to the wind profile. There is no deep stable layer with corresponding higher values of l^2 in the lower troposphere.

The wave motion encountered must be due to a rather complex interaction of different mountain peaks and ranges. Direct testing of theories will be difficult. Further investigations may show if the waves are of a real standing type and also reveal main features of their vertical and horizontal structures.

HIGH CLOUD STRUCTURE IN EQUATORIAL SOUTH-EAST ASIA

By L. W. LITTLEJOHNS

Introduction.—Aircraft reports are of great assistance in the daily preparation of analyses and forecasts in equatorial South-East Asia where surface and upper air observations are extremely sparse. In view of the increasing amount of high-altitude flying now taking place it was thought worth-while to compile statistical summaries of the incidence and height of high cloud found in this region.

Data analysed.—The data used were pilots' reports recorded at Changi, Butterworth and Negombo after flights above 25,000 feet during the period from February 1954 to August 1956. These were verbal reports, mainly from the crews of Canberra aircraft operating in the vicinity of Malaya, or in transit. The flights were not evenly distributed throughout the year (see Table I). The majority of the flights were at heights between 44,000 and 48,000 feet. All heights in these summaries are indicated heights—true heights are approximately 1,500 feet greater at 26,000 and 52,000 feet, and 2,000 feet greater between 35,000 and 45,000 feet[1].

Treatment of the data.—The flights were divided into six areas as demarcated in Figure 1, in which the airfields used and the number of flights in each area are also shown. Flights with only an isolated patch of high cloud were regarded as flights with no high cloud and were not included in the height and thickness summaries. Average heights of the base and top of each cloud layer in each area were assessed for all flights. The heights of the bases and tops did not vary

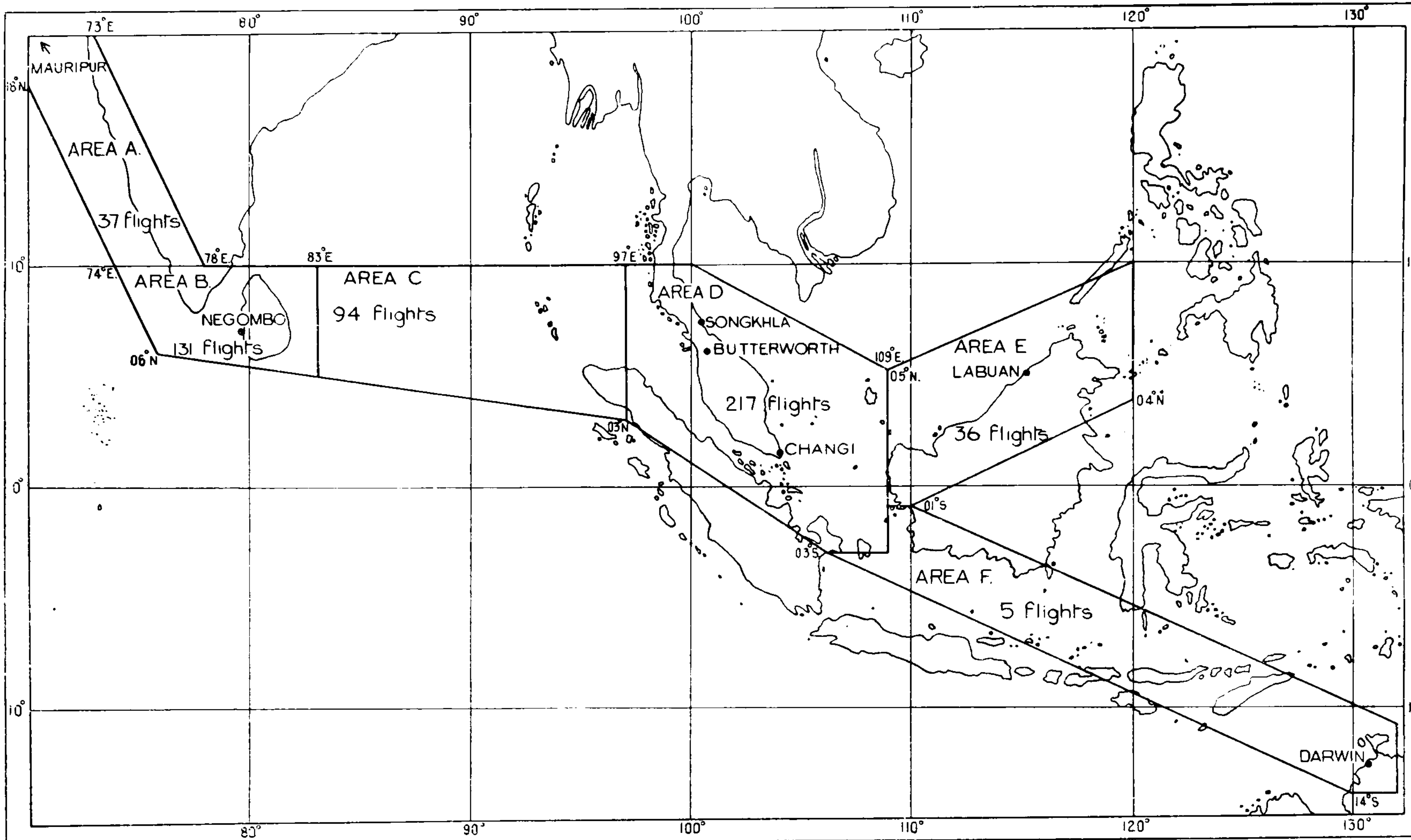


FIGURE I—AREAS COVERED IN ANALYSIS OF PILOTS' OBSERVATIONS FROM HIGH-ALTITUDE FLIGHTS appreciably from place to place, and the heights found on ascent or descent could usually be accepted as representative of the area.

June and March were used to compare the thickness and height of high cloud in the "cloudier" and "less cloudy" seasons since a similar large number of reports was available in each month. November was selected as a transition month.

Results and discussion.—Between Mauripur and 10°N. high cloud occurred on only 2 flights in 15 from January to April, but it was found on 11 flights out of 13 from June to September. The seasonal variation, indicated by this small number of reports, is in agreement with that revealed by the analysis of pilots' reports from Comet flights over India in 1952 and 1953[2]. Of the five flights between Darwin and 110°E. there was one in April and one in May with little cloud, and one in December with extensive sheets of cirrostratus and large amounts of cumulonimbus. Pilots' reports from the above two areas have not been further considered, and the tables which follow refer only to the remaining four areas which lie between the parallels 10°N. and 03°S., and between the meridians 75°E. and 120°E.

Incidence of high cloud.—

TABLE I—PERCENTAGE FREQUENCY OF OCCURRENCE OF HIGH CLOUD

	Area (See Figure 1)				
	B Ceylon	C Bay of Bengal	D Malaya	E North Borneo	B+C+D+E
			%		
Jan.	86 (7)	67 (3)	57 (7)	100 (1)	72 (18)
Feb.	47 (15)	89 (9)	73 (15)	100 (2)	68 (41)
March	54 (24)	50 (20)	61 (28)	100 (1)	56 (73)
Apr.	44 (9)	100 (5)	93 (14)	100 (2)	80 (30)
May	83 (12)	80 (10)	89 (28)	100 (5)	87 (55)
June	91 (23)	91 (12)	87 (32)	86 (7)	89 (74)
July	100 (6)	67 (3)	95 (21)	75 (4)	91 (34)
Aug.	77 (13)	91 (12)	79 (29)	75 (4)	81 (58)
Sept.	50 (4)	60 (5)	83 (12)	100 (5)	77 (26)
Oct.	71 (7)	57 (7)	92 (13)	33 (3)	73 (30)
Nov.	89 (9)	80 (5)	100 (8)	0 (1)	87 (23)
Dec.	50 (2)	67 (3)	80 (10)	100 (1)	75 (16)
Year	71 (131)	74 (94)	82 (217)	83 (36)	78 (478)

The number of reports available is shown in brackets.

Table I indicates that half of the flights across the Bay of Bengal in March were completely clear of high cloud; less than one in five were clear during the remainder of the year. Ship reports from the Bay of Bengal[3] confirm these minimum amounts of cloud in March. Over Ceylon high cloud was infrequent from February to April. At this time of year the north-east monsoon is weak, and the convergence zone between the monsoon and the equatorial westerlies normally lies to the south of Ceylon. The zone moves northwards over Malaya and the Bay of Bengal in April but does not actively affect Ceylon until the onset of the south-west monsoon in May. It usually returns to Ceylon and Malaya in October and November[4]. The frequency of high cloud increased during these transition months, but the maximum occurred in June and July. Little is known about the seasonal variation of wind at cirrus levels over Ceylon, but there is a pronounced minimum in the mean wind at 50,000 feet over Singapore in March; at 40,000 feet the minimum extends to April. Over Songkhla (South Thailand, 100° 36′E., 07° 13′N.) minima at both heights occur from February to April[5]. The period of maximum frequency of high cloud did not entirely coincide with the period of strongest winds, July to September; lightest winds, however, were associated with least cloud. The incidence of high cloud did not appear to be closely related to the presence of large cumulus and cumulonimbus which were observed as shown in Table II. These clouds were usually described as isolated or scattered; only on rare occasions were they frequent or widespread.

TABLE II—FREQUENCY OF TOPS OF CUMULUS AND CUMULONIMBUS

	Height of tops (thousands of feet) <30	30—39·9	40—49·9	≥50	All heights	Total flights
			Number of occasions			
March	8	4	23	7	42	73
June	16	3	17	6	42	74
November	8	2	2	4	16	23
Year	115	28	113	32	288	478

Cumulus and cumulonimbus were reported equally in March and June, but the tops were higher in March when high cloud occurred least frequently. The more prevalent sheets of high cloud possibly obscured several large tops in June.

TABLE III—FREQUENCY OF OCCURRENCE OF MEDIUM CLOUD

	Medium cloud reported	Thickness exceeded 5,000 feet	Total flights
		Number of occasions	
March	4 (5)	3 (4)	73
June	26 (35)	11 (15)	74
November ...	13 (57)	9 (39)	23
Year	113 (24)	52 (11)	478

Percentage frequencies shown in brackets.

The percentage frequency of medium cloud (shown in Table III) was greatest in November; little variation occurred from May to September when the frequency was considerably in excess of that in March. It follows therefore that the factors which contribute to an absence of high cloud may also lead to an absence of medium cloud, but they probably do not affect the incidence of large cumulus or cumulonimbus.

Types of high cloud.—

TABLE IV—FREQUENCY OF TYPES OF HIGH CLOUD

	Nil	Cirrus	Cirro-stratus	Cirro-cumulus	All types	Type un-specified	Two layers of high cloud
				Number of occasions			
March	32	28	10	1	39	3	1
June	8	39	32	0	71	0	5
November	3	8	9	1	18	2	0
Year	106	249	117	3	369	16	13

Table IV shows the number of occasions on which the different types of high cloud were reported. In March high cloud was most frequently in the form of cirrus. In June and November the denser sheets of cirrostratus were reported almost as often as cirrus. Cirrocumulus was extremely rare. Two layers of high cloud were seldom reported, but may of course have existed more frequently.

Bases and tops of high cloud.—

TABLE V—FREQUENCY OF HEIGHTS OF BASES OF HIGH CLOUD (CIRRUS, Ci; CIRROSTRATUS, Cs)

	Merged with medium cloud		Height (thousands of feet) 25—29·9		30—34·9		35—39·9		40—44·9		45—49·9		≥50		Number reported	
	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs
	Number of occasions															
March	1	0	0	0	3	2	15	1	3	3	2	1	1	0	25	7
June	1	1	7	2	4	2	10	6	4	5	5	8	1	0	32	24
Nov.	0	0	0	4	3	1	3	1	0	0	1	0	0	0	7	6
Year	2	6	14	10	29	13	81	20	46	16	25	13	2	1	199	79

TABLE VI—FREQUENCY OF HEIGHTS OF TOPS OF HIGH CLOUD (CIRRUS, Ci; CIRROSTRATUS, Cs)

	Height (thousands of feet) 30—34·9		35—39·9		40—44·9		45—49·9		50—54·9		Number reported	
	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs	Ci	Cs
	Number of occasions											
March	0	0	2	1	9	2	11	6	4	0	26	9
June	2	0	2	1	15	4	16	17	3	1	38	23
Nov.	1	0	2	0	1	1	2	7	0	1	6	9
Year	9	0	21	7	73	24	84	56	14	7	201	94

The base of cirrus (see Table V) was most frequently reported between 35,000 and 40,000 feet. In March the occurrence of the greatest frequency (mode) in this range was well marked, but over the remainder of the year there was more variation in the reported bases. The bases of cirrostratus were distributed with fairly equal frequency over a large range of height.

Table VI shows that approximately 80 per cent of the reported tops of both cirrus and cirrostratus were between 40,000 and 50,000 feet; the cirrus tops were spread evenly over this range, but the cirrostratus tops were more frequent between 45,000 and 50,000 feet especially in June and November. The maximum tropospheric wind over Singapore usually lies within this latter height range which is some 5,000 to 10,000 feet below the equatorial tropopause. James[6] also found, in middle latitudes, a rather similar relationship between the height of cirrus cloud tops and the height of the tropopause, and noted that other work on the subject suggests that the top of cirrus cloud is closely associated with the height of the horizontal wind maximum.

Thickness.—Unfortunately there were many occasions when the base or tops were unknown, and for which no reliable estimates can be made. The number of these occasions is shown in Table VII. Limiting values for thickness in some cases can, however, be determined from Table VIII which relates the missing observations to flight levels.

[*To face p. 176.*

Photograph reproduced by kind permission of The Belfast Telegraph

MAIL FOR "WEATHER RECORDER"

This photograph, taken from a Royal Air Force aircraft of Coastal Command on 20 December 1957, shows the bomb doors open, and a canister containing Christmas mail with parachute attached being dropped for *Weather Recorder*. The ship's logbook showed that the wind at the time was west-north-west force 9. The ship is obviously "lying stopped" or steaming very slowly.

Photograph by I. F. Long

PLATE I—FOG PRECIPITATION ON GRASS
(see p. 161)

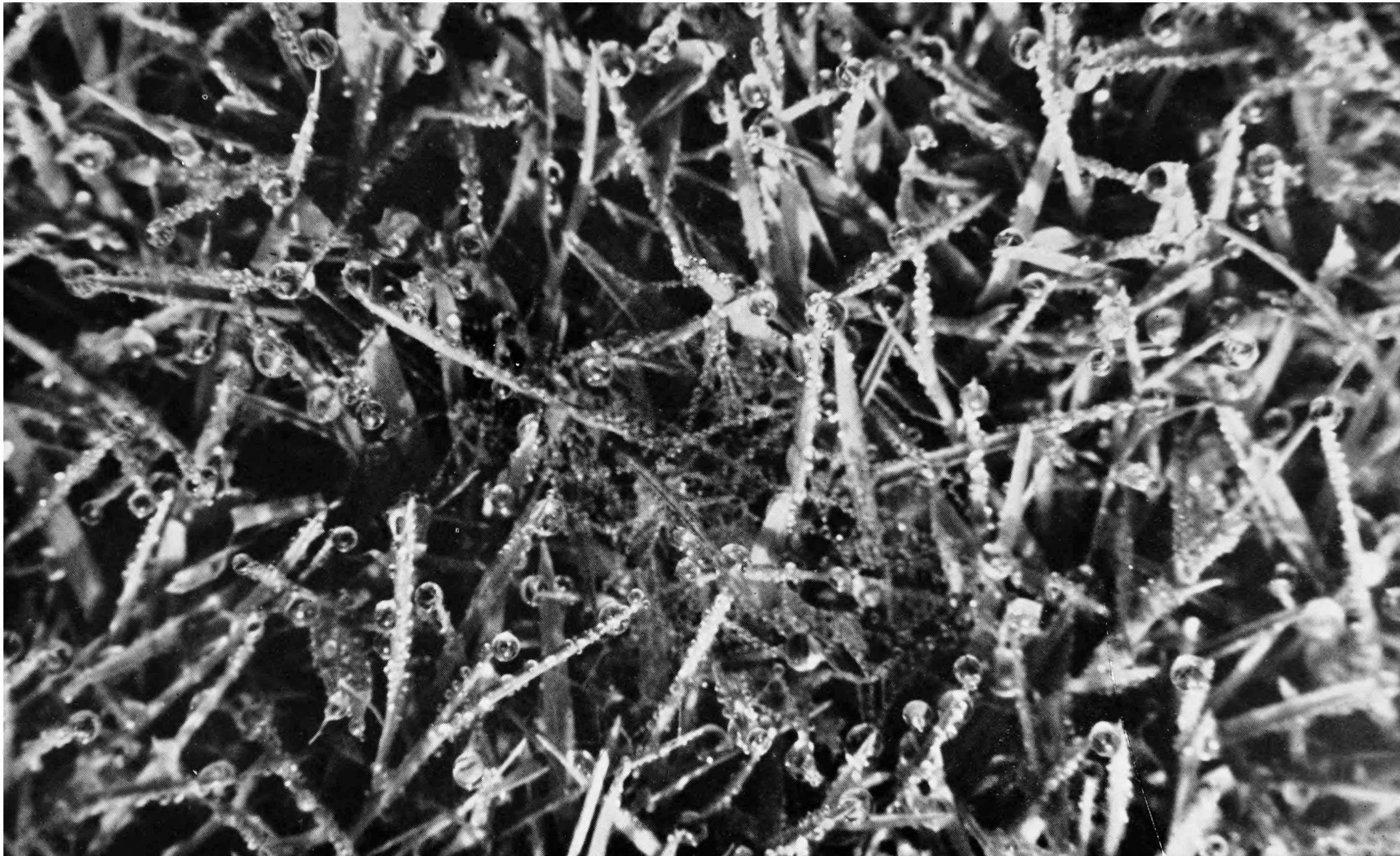


PLATE II—DEW, SMALL DROPS: AND GUTTATION LARGE DROPS, ON GRASS
(see p. 162)

Photograph by I. F. Long

To face p. 177]

Photograph by I. F. Long

PLATE III—GUTTATION DROPS ON GRASS

(see p. 162)

TABLE VII—NUMBER OF HIGH CLOUD BASES OR TOPS NOT REPORTED (CIRRUS, Ci; CIRROSTRATUS, Cs)

	Bases			Tops		
	Ci	Cs	Type not specified	Ci	Cs	Type not specified
	Number of occasions					
March	3	3	3	2	1	3
June	6	9	0	2	8	0
November	1	3	2	2	0	2
Year	49	39	16	49	22	16

TABLE VIII—FREQUENCY OF UNREPORTED HIGH CLOUD BASES OR TOPS AT VARIOUS FLIGHT LEVELS FOR ALL MONTHS (CIRRUS, Ci; CIRROSTRATUS, Cs)

		Flight level (thousands of feet)					
		<35	35—39·9	40—44·9	45—49·9	⩾50	All levels
		Number of occasions					
Base unknown, flight above cloud layer	Ci	0	4	15	21	5	45
	Cs	0	3	10	20	2	35
Top unknown, flight below cloud layer	Ci	5	20	10	10	0	45
	Cs	2	3	3	10	0	18
Base and top unknown, flight in cloud	Ci	0	2	2	0	0	4
	Cs	2	0	0	2	0	4
High cloud reported, but no details of type or height given		3	1	9	3	0	16

The 33 cases of flights below a cloud layer at heights above 40,000 feet must have been occasions of shallow cloud. It can be assumed that the average cloud thickness on the 20 highest flights was 5,000 feet or less, and that on the 13 next highest it was 10,000 feet or less. On the 16 occasions when no details

TABLE IX—FREQUENCY OF THICKNESSES OF HIGH CLOUD (ALL MONTHS)

Cloud Base (thousands of feet)	Thickness (feet)					
	2,500	5,000	10,000	15,000	20,000	25,000
CIRRUS	*Number of occasions*					
25—29·9	0	4	1	7	1	1
30—34·9	5	5	10	7 (+2)	0	0
35—39·9	12	19	27	3 (+2)	0	0
40—44·9	25 (+3)	15 (+4)	0(+3)	0	0	0
45—49·9	9 (+5)	6 (+5)	0	0	0	0
⩾50	1	0	0	0	0	0
Unknown (cloud too far from aircraft)	0 (+8)	0 (+8)	0	0	0	0
Total	47 (+16)	49 (+17)	38 (+3)	17 (+4)	1	1
CIRROSTRATUS	*Number of occasions*					
25—29·9	0	0	0	1 (+2)	14	1
30—34·9	0	2	4	5	2	0
35—39·9	2	10	5	2 (+2)	0	0
40—44·9	0 (+1)	12 (+1)	0 (+1)	0	0	0
45—49·9	2 (+5)	0 (+5)	0	0	0	0
⩾50	0	0	0	0	0	0
Total	4 (+6)	24 (+6)	9 (+1)	8 (+4)	16	1

Number reported: Cirrus 153 (+40) Cirrostratus 62 (+17).
Number with base and/or top unknown: Cirrus 110 (−40) Cirrostratus 57 (−17).
The figures in brackets refer to estimated thicknesses.

were given the cloud was usually too far from the aircraft for any estimate of its height to be made. It is unlikely that the cloud thickness exceeded 5,000 feet on these occasions. On the 8 flights in cloud the thickness probably exceeded 12,500 feet, otherwise the flight levels would have been changed to avoid the cloud. These estimated thicknesses are included (in brackets) in Table IX which shows the frequency of specified thicknesses of high cloud.

On approximately half the 263 occasions of cirrus the thickness was from 2,500 to 5,000 feet. The proportion of cirrostratus with this thickness was only one third, and a similar proportion consisted of thicknesses from 10,000 to 20,000 feet. There were 16 reports of cirrostratus being 20,000 feet thick, 5 of these being in November.

Summary.—In the region from South India to North Borneo high cloud was most prevalent from May to July, extending to April and August in some areas, with a further secondary maximum in November. Cirrostratus occurred almost as often as cirrus in the cloudier periods. Cirrocumulus was seldom encountered. Most of the tops lay between 40,000 and 50,000 feet, cirrostratus tops being slightly higher than cirrus. In March the base of cirrus was most frequently between 35,000 and 40,000 feet; in other months the bases of cirrus and cirrostratus were spread over a very large range of height.

Other interesting features in the pilots' observations.—*Cumulus or cumulonimbus.*—Cloud development over the sea in the vicinity of Malaya usually reaches a maximum during the night, and the cumulus normally disappears during the morning. This sequence was observed not to occur on three occasions. On 2 February 1956 and 12 June 1956 lines of cumulonimbus were reported to have developed over Malacca Straits (some 20 to 60 miles from the coast) between 0800 and 1100 hours, local time. On 16 May 1956 large cumulus was developing over the South China Sea off the coast of Trengganu between 0900 and 1000 hours, local time.

On one of the rare occasions of night flying (18 March 1955) scattered cumulonimbus extended along the west coast of Malaya; the effect of the associated lightning, observed from 48,000 feet, was described as most impressive, being compared with flak. On another night flight (5 April 1955) a Canberra penetrated a cumulonimbus top at 45,000 feet and was rapidly wafted up to 49,000 feet where the low temperature caused a "flame-out". Vigorous St. Elmos fire and moderate turbulence were experienced.

Probably the most severe conditions encountered (this report was by a pilot with fourteen years flying experience) were on a flight from Negombo to Changi on 25 April 1956. For much of the Bay crossing the aircraft was in cirrostratus at 40,000–45,000 feet. Cumulonimbus tops were encountered about mid-Bay, and turbulence, which had been slight to moderate, became extremely severe and was accompanied with hail. Damage was caused to the aircraft. Hail is a rarity in this equatorial region, but on the following day there was a surface report of hail at Terampa in the Anambas Islands.

Cumulonimbus tops, and indeed all cloud, were avoided when possible, and this may well account for the fact that there were more reports of turbulence in clear air than in cloud (see Table X).

Turbulence.—

Turbulence was experienced on at least 1 flight in 4; it was moderate or severe on about 1 flight in 8. Some of the occasions of turbulence occurred on the climb or descent otherwise frequency in the various height ranges would probably have been proportional to the number of flights in each height range.

TABLE X—FREQUENCY OF OCCURRENCE OF TURBULENCE

	Height (thousands of feet)								All heights	
	<40		40—44·9		45—49·9		≥50			
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	Number of occasions									
March	3 (2)	2 (1)	1	0	3	4 (1)	0	0	7 (2)	6 (2)
June	4 (2)	2 (1)	2 (1)	1	5 (3)	3 (2)	2 (1)	0	13 (7)	6 (3)
Nov.	0	2 (1)	0	2 (1)	2 (2)	2 (2)	0	0	2 (2)	6 (4)
Year	17 (6)	15 (10)	13 (5)	11 (3)	39 (20)	24 (11)	6 (2)	0	75 (33)	50 (24)

(*a*), clear air. (*b*), in cloud. Figures in brackets are when turbulence was moderate or severe.

Icing.—Light airframe icing was reported on 13 occasions; 9 of these were at heights above 40,000 feet.

Contrails.—The frequency of occurrence of contrails is given in Table XI.

TABLE XI—FREQUENCY OF OCCURRENCE OF CONTRAILS

	Height (thousands of feet)					
	<30	30—34·9	35—39·9	40—44·9	45—49·9	≥50
	Number of occasions					
All reports	1	4	5	13	30	2
Dense and persistent ...	0	1	1	5	15	2

There were 2 flights between 30,000 and 40,000 feet, and 3 flights above 40,000 feet when it was known that contrails were not made, but on the majority of flights it was not possible to say whether or not contrails were made.

REFERENCES

1. CLARKSON, L. S.; Note on the mean characteristics of the maritime equatorial troposphere over Singapore. *Met. Mag., London,* **86,** 1957, p. 273.
2. VENKATESWARA, RAO, D.; Heights of the base and top and thickness of tropical clouds. *Indian J. Met. Geophys., Poona,* 1955, p. 299.
3. SHARP, F. A.; Cloud over the open sea. (Communicated privately.)
4. WATTS, I. E. M.; Equatorial weather. London, 1955, p. 134.
5. CLARKSON, L. S.; Variation with time and distance of high-level winds over Malaya. *Met. Mag., London,* **87,** 1958, p. 143.
6. JAMES, D. G.; Forecasting cirrus cloud over the British Isles. *Prof. Notes met. Off., London,* No. 123, 1957.

METEOROLOGICAL OFFICE DISCUSSION

Forecasting precipitation

The Meteorological Office Discussion at the Royal Society of Arts on Monday, 18 February 1958 was on the subject of forecasting precipitation.

Mr. H. H. Lamb spoke first, dealing with the problem of whether rain, sleet, snow or hail should be expected. Conditions for hail are special, depending primarily on the vertical instability being enough to give the strong up-currents required to support growing hailstones. Those particularly concerned with hail were recommended to read the recently reviewed book by Flora[1]. Extreme hailstones measure several inches across and weigh several pounds. The United States Weather Bureau's Severe Weather Warning Centre, operating in the Great Plains where hail and tornado risks are greatest, finds that large hail is commonest when the "wet-bulb freezing level" is about 8,000 feet (2,500 metres approximately) above the ground. This corresponds quite well with experience in Britain in summer and in the Mediterranean in winter, where the worst hail occurs in unstable air with 1,000–500-millibar thicknesses about 5,500 metres. With higher temperatures than those corresponding to this thickness much of the hailstones melts during descent, and the smaller types of hail would melt with rather lower thicknesses.

To decide whether snow will melt before reaching the earth, one really needs to know not only the height of the freezing level but also the initial size of the individual snowflakes and mass of frozen water involved, its starting temperature or the level at which melting begins and the detailed thermal structure of the layers between this level and the ground. This thermal structure is constantly changing under the influence (amongst other things) of the varying intensity of the precipitation and attendant evaporation cooling.

In practice, of course, one must do one's best with the available tools in the forecaster's armoury. One can do a good deal with charts of 1000–500-millibar thickness alone. Reference was made to two papers[2,3], reporting studies of associations between the change-over from rain to snow and 1,000–500-millibar thickness, 1,000–700-millibar thickness, freezing level and surface temperature. The results for 1,000–700-millibar thickness were actually worked up mainly for the more maritime districts of the British Isles, and should be applied with caution in more extensive land areas.

Chances of rain or snow falling appeared from examination of 2,000 cases to be about equal at low-level inland stations in winter with 1,000–500-millibar thicknesses around 5,280 metres. The probabilities tilted sharply in favour of rain or snow according as the thickness increased or decreased much from this value. Important special cases arose in winter when long-continued precipitation was expected to fall from frontal medium cloud through air initially dry enough to give no low cloud. Cooling by evaporation from the falling rain progressively lowered the temperatures and the thickness: in one case in 1942 rain began with freezing level over 5,000 feet (1,500 metres) and thickness 5,400 metres, but ultimately changed over to snow which became deep before precipitation ceased. Once a snow cover was established there was a considerable chance of snow flurries from fairly low clouds, for example, stratocumulus beneath a subsidence inversion, with 1,000–500-millibar thicknesses up to 5,400 metres, though any precipitation originating in frontal medium cloud with this thickness would probably fall as rain.

In our more maritime districts, on small islands, and at sea where low temperatures generally imply unstable lapse rates, the thickness giving a fifty–fifty chance of snow is lower than the figure for inland districts. In these regions in winter and for late spring or early autumn snow inland, the critical thickness may be 5,250 metres or below. Corresponding criteria for snow at various upland places and on slopes of different aspect might profitably be derived from similar statistical investigations at the forecasting offices concerned with different hill districts.

In the ensuing discussion, *Mr. R. F. Jones* pointed out that hail need not be entirely supported by up-currents, since considerable amounts of ice could accrue to a hailstone during its fall through cloud.

Mr. Buchanan preferred the use of 1,000–700-millibar thicknesses and demonstrated a diagram on which a set of curves showed the percentage frequency of precipitation in frozen form plotted against thickness for different heights above sea level. This could be a valuable aid to precision in forecasts of snow on high ground: ideally the forecaster should be able to specify "snow above the (say) 500- or 1,000-foot level".

Mr. Craddock gave a warning that if one investigated in terms of two variables, in this case observing how the critical thickness value shifted when height above sea level also varied, one needed larger samples to avoid the risk of being misled by apparent associations which can arise by chance. This was an example of multiple regression analysis.

Mr. Veryard reminded the meeting of the old rule that snow should be expected if the initial surface temperature were below 40°F. The average surface temperature in inland districts corresponding to the critical thickness of 5,280 metres was about 38°F.

Mr. Wilson quoted a case noted at Renfrew when snow began when the temperature reached 39°F. Three hours later it was 33°F.

Mr. May asked whether the case of long-continued precipitation through dry air modifying the thickness could lead to snowfall over any great area, since presumably it would be a narrow belt of precipitation along a quasi-stationary front. In reply Mr. Lamb remarked that a belt at least 150 miles broad over southern England got heavy snowfall in this way at Christmas 1927.

Mr. Tunnell emphasized that the distribution of water vapour with height needed to be studied in this connexion. He pleaded for use of wet-bulb potential temperatures and regular study of the hydrolapse.

Mr. Miles added that in situations where warm air overran a shallow wedge of cold air, it might be that the lighter the precipitation the more liable it would be to reach the ground unmelted. If the precipitation melted completely, however, before reaching the surface freezing layer, he did not believe it could ever freeze again before reaching the ground.

Mr. Walker said that at Manby the first snow this winter fell with thickness as high as 5,340 metres. This was granular snow which became three inches deep before going over to ordinary snowflakes.

Mr. Gold asked Mr. Lamb to make it clear that forecast (not previously reported) values of thickness must be used in deciding whether snow should be forecast at a given place. Snow already falling in the same airstream upwind might be the best indicator of all. If the precipitation upwind were rain, one must be sure of a materially lower surface temperature before forecasting snow at one's own station.

The problem of research into frontal rainfall

Opening the second part of the discussion Mr. C. E. Wallington said that forecasting frontal rainfall may be considered as two distinct problems: one centres on the movement of fronts, the other concerns the distribution of rainfall with whatever front is being considered. In practice the movement of fronts is dealt with fairly methodically, and with moderate success. But comparatively little is known about forecasting the shape and size of the rain area associated with any particular front. Not enough is known about the mesoscale atmospheric motions which take place in the frontal zone; these mesoscale motions are particularly awkward for research. Furthermore, little observational experience has so far been accrued of motion on this scale. A mesoscale feature is too large to be adequately observed from any particular spot and too small to be portrayed by the routine synoptic charts. On 2 September 1949, for example, the rain area ahead of a warm front appeared as a broad belt. But records of measured rainfall per hour revealed, not a simple broad rain-belt, but several tongues of rainfall, as illustrated in Figure 1.

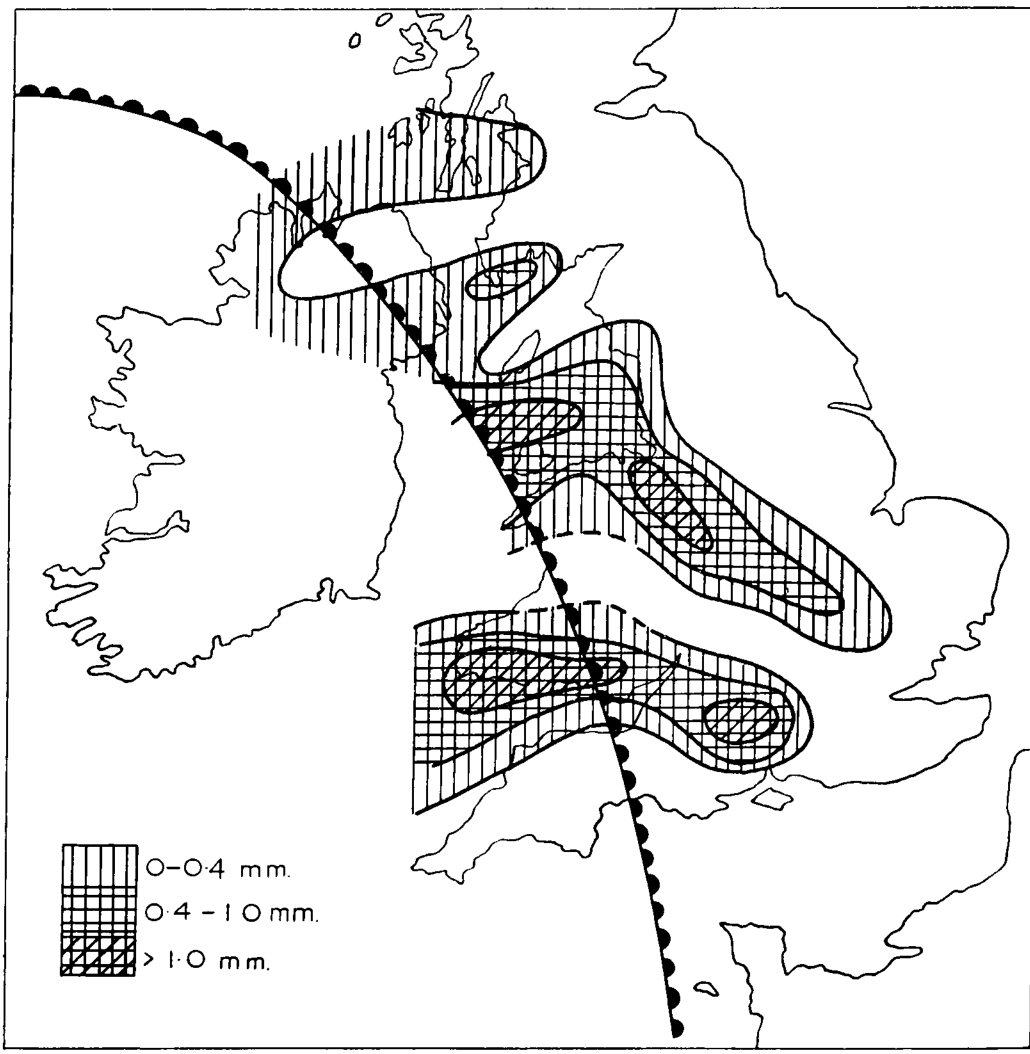


FIGURE 1—WARM-FRONT RAINFALL, 0300–0400 G.M.T., 2 SEPTEMBER 1948.
The mesoscale features illustrated on this hourly rainfall chart maintained too much continuity to be fully accounted for by local peculiarities or by subjective drawing of the charts.

Two problems arise from these rainfall observations. First, how does this type of distribution arise? It maintained too much continuity to be explained entirely by local effects or by subjective drawing of the hourly rainfall charts.

Secondly, how can we account for the reported rates of rainfall? It would be of interest to measure or calculate fields of vertical motion in detail. But this is difficult; the network of upper air observations is too coarse, and methods applicable to the study of broad-scale motions are of very doubtful accuracy when applied to regions in which stability is small and ageostrophic motion is important. So for the moment it seems more profitable to study more patterns of hourly rainfall with the object of accruing enough experience to devise and test more elaborate concepts than the basic frontal models.

Warm-frontal waves.—Perhaps we can obtain an insight into the dynamics of rain-belts by studying the relationship between rates of rainfall and small frontal waves. Warm frontal waves can often be classed as mesoscale phenomena and we have acquired some familiarity with their characteristics. Their formation is usually associated with a confluent ridge in the thickness lines. We know by experience and by theoretical reasoning that in such a situation "cyclonic development"—or ascending motion in the troposphere—is likely close to the warm front and some distance from the depression centre. Although it is not too difficult to recognize this warm-frontal wave type of situation, it is practically impossible to predict precisely when or whereabouts within the "development" region a wave will form. More experience and theoretical reasoning shows that stability plays an important part in the process. Vertical motion is damped by stability, especially in processes on the meso- and local scales. But in assessing this damping we should consider not just the static stability—that is the stability which can be seen at a glance on the tephigram—but the hydrodynamic stability, which takes into account the distribution of both temperature and wind. It is important that these items should be considered together.

Hydrodynamic instability.—Suppose that, in an airstream in which the wind speed increases with height, a parcel of air is displaced upwards without seriously distorting the general pressure and temperature patterns. If the airstream is statically stable then it might be supposed that the displaced parcel would promptly return towards its original level. But such a supposition neglects the wind shear. The displaced air has a lower speed than that required for geostrophic flow at its new level. So the parcel is diverted towards lower pressure. But the increase of wind with height owes its existence to a thermal field in which temperature decreases towards the region of low pressure. Thus the transverse displacement takes the disturbed parcel of air into a progressively colder environment, and the effective, or hydrodynamic, stability is less than the static stability. In fact this is one of the variety of ways in which hydrodynamic instability can occur. Unfortunately, we do not yet know enough about the concept of hydrodynamic instability to use it in routine forecasting. For the present, all we can do is to realize that many situations may not be quite as stable as we think they are.

Hourly rainfall patterns.—Vertical motion imposed by the broad-scale pressure and temperature fields is damped by hydrodynamic stability. But suppose that a damped upward motion is just sufficient to produce saturation. Such saturation will immediately reduce the stability and the upward motion will receive a sudden impetus.

So in the practical problem of locating or predicting small regions of ascending air there are several complications of which we can be aware but which we cannot yet resolve. The magnitude of such vertical motion depends upon the precise details of the thickness and contour charts, the hydrodynamic stability and the humidity. In view of these complications it may well be that a cyclonic "development" region contains not just one but several separate cells of rising air. Perhaps the more extensive cells betray their presence by distorting the frontal pattern while the intensive features generate frontal rainfall from behind the synoptic scenes.

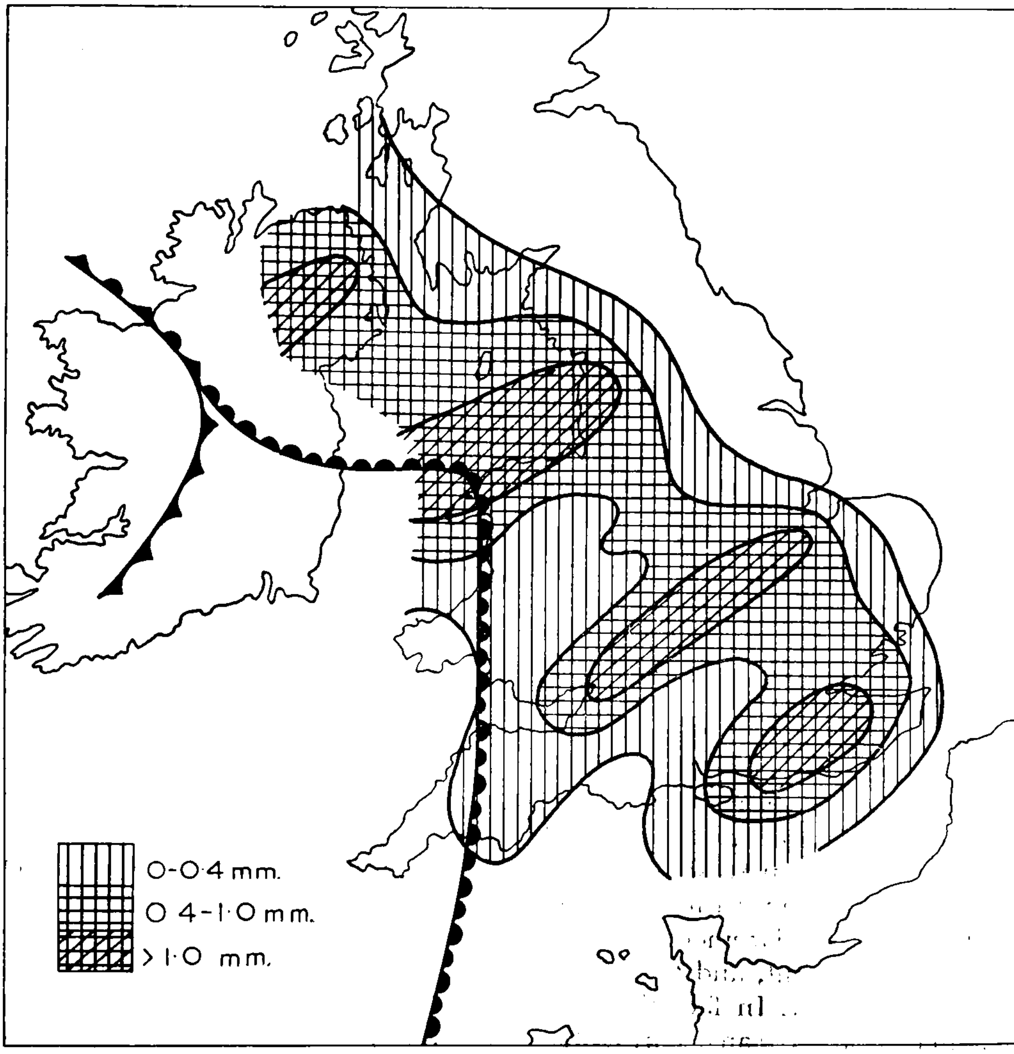


FIGURE 2—WARM-FRONT RAINFALL, 2100–2200 G.M.T., 1 JANUARY 1952.
The warm-front wave may have been a synoptic manifestation of just one of several cells in a broad development region.

The warm-front wave illustrated in Figure 2 may well have been a synoptic manifestation of just one of several cells in a broad "development" region. The rainfall pattern is suggestive of other cells, and this type of distribution is not uncommon. Figure 3 shows another situation with at least two separate cells of rainfall preceding a small wave across England. This cellular type of distribution is not always associated with small frontal waves. The situation illustrated in Figure 4, for example, shows three distinct cells of heavy rainfall with no apparent distortion of the frontal system. This and other charts of hourly rainfall suggest that slowly rising air in frontal zones is augmented in places by some sort of instability, either hydrodynamic instability in patches or instability of waves on wavelengths of about 100 to 300 miles. But before devising too elaborate a hypothesis for explaining the distribution and rates of frontal rainfall observed it seems advisable to acquire a greater familiarity with charts of hourly rainfall.

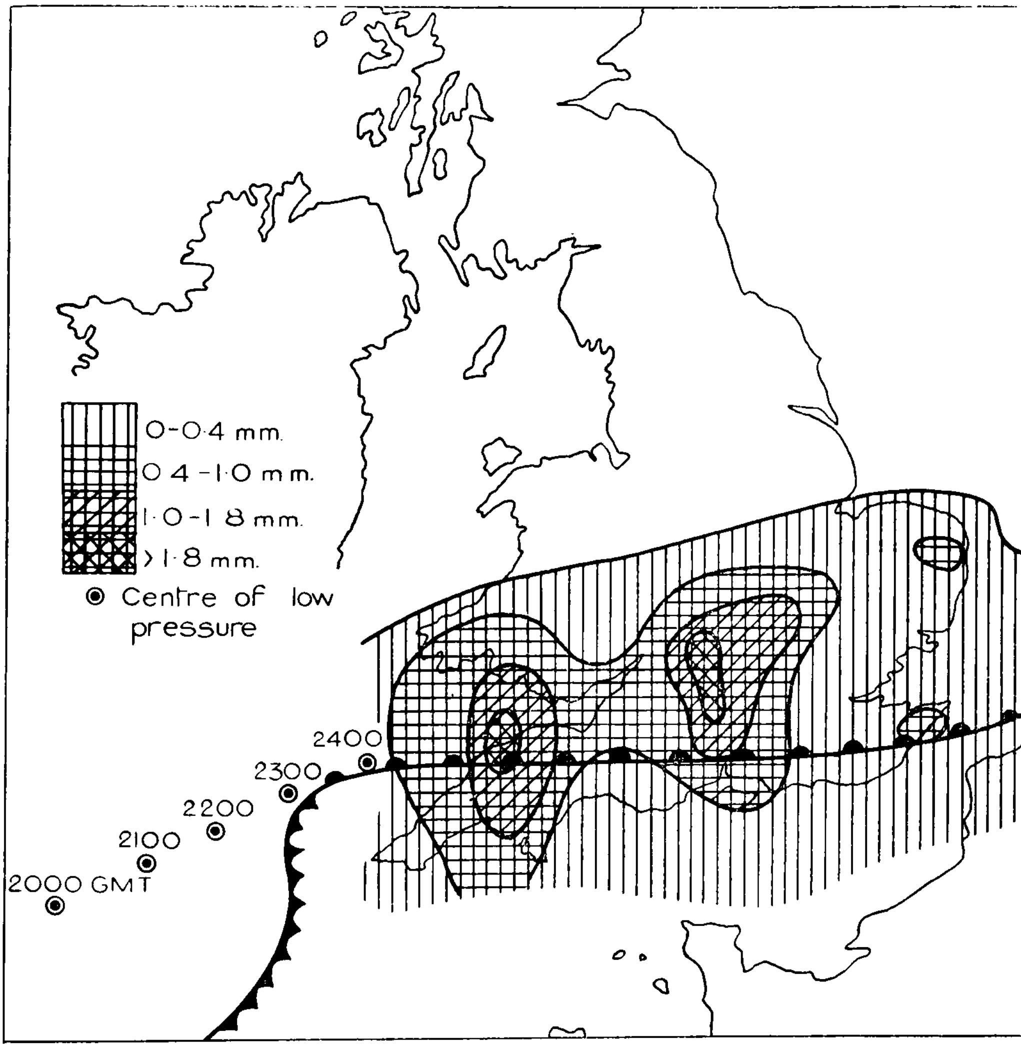


FIGURE 3—WARM-FRONT RAINFALL, 2300–2400 G.M.T., 6 APRIL 1952.
At least two separate cells of rainfall preceded a small wave across England.

Mr. Veryard stressed the need for caution in mapping rainfall over a coarse network of observations. Investigations at Cardington have shown considerable spatial and temporal variations in rate of rainfall over even a small, two mile square, area.

Later in the discussion *Mr. Cottis* and *Mr. Smith* also stressed the variability of rates of rainfall over a small area. Mr. Wallington replied that such varia-

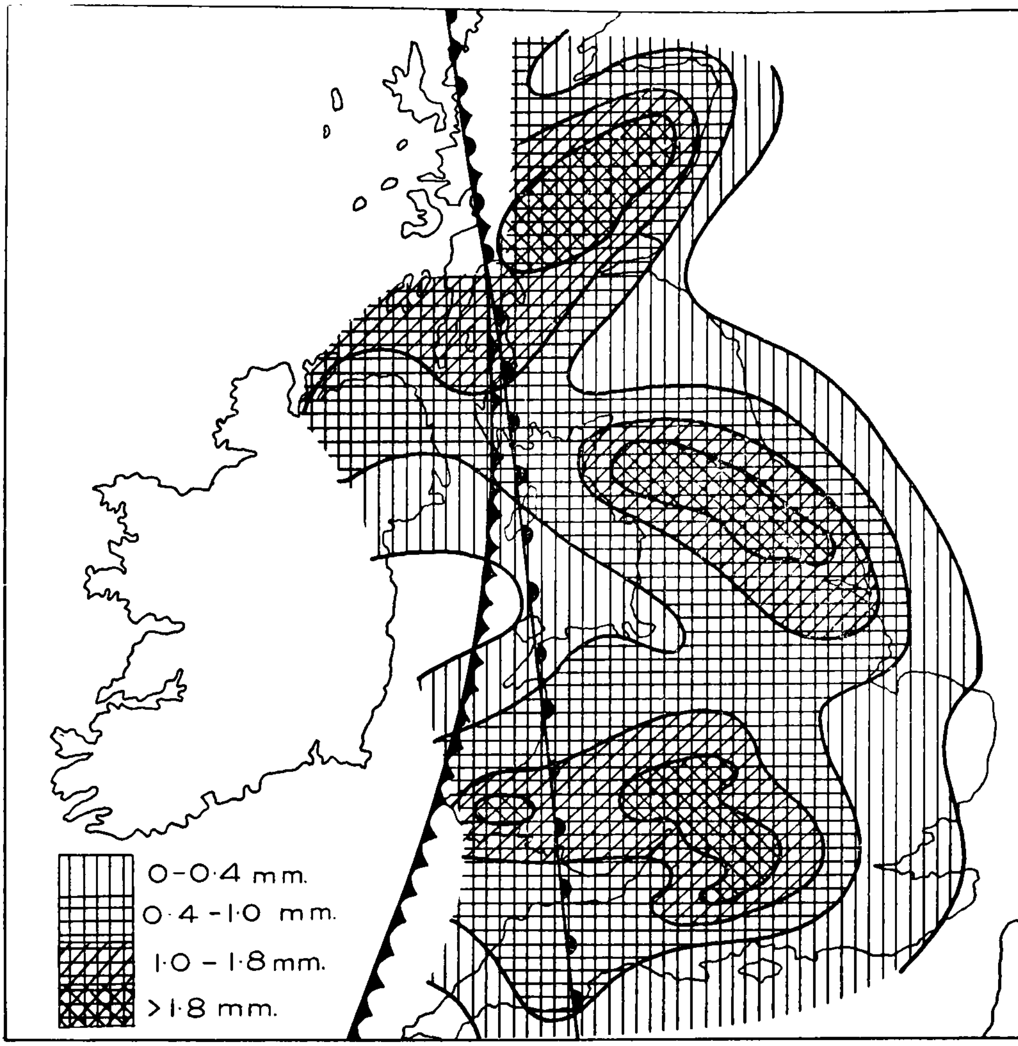


FIGURE 4—WARM-FRONT RAINFALL, 0100–0200 G.M.T., 31 JANUARY 1952.
The cellular type of rainfall distribution is not always associated with distortion of the frontal system into small waves.

bility does not preclude detection of the mesoscale features in the distribution of hourly rainfall on occasions when these mesoscale features predominate over local effects. The charts he had shown were extracted from sequences of hourly charts on which the mesoscale features maintained too much continuity to be explained by local effects or by subjective drawing.

Mr. Craddock considered that, although it is difficult to judge the relationship between variations on the micro- and meso-sides, the distinctive features of the hourly rainfall patterns were probably not due to chance.

In response to an enquiry by *Mr. Ratcliff*, *Mr. Harper* said that it was difficult to deduce rate of rainfall from the intensity of radar echoes.

Mr. Lamb recalled that Prof. Bergeron had identified frontal rainfall features over Sweden on a similar scale to that discussed by Mr. Wallington.

Mr. Saunders described the relationships between the amount of frontal rainfall received in south-west England and various parameters such as upwind pressure tendencies and the direction of the warm-sector isobars.

Mr. Tunnell called attention to the effects of turbulence and convective cells in warm frontal regions.

Mr. Jefferson said that distinctive mesoscale features could often be identified by careful analysis of routine synoptic charts.

The timing of precipitation

Opening the final part of the discussion, Mr. B. Ramsey said that one of the first points to be considered in the timing of precipitation is the forecasting of whether the depression concerned will pass to north or south of the area. With a depression passing to the south, timing of precipitation becomes a matter of forecasting the general movement of the precipitation area of the low. With centres passing to the North, the shear hodograph gives an indication of whether the fronts are anafronts or katafronts, with their wide variations in precipitation areas, for example, a warm anafront gives a wide area of rain well ahead of the surface position of the front. A change of shear could vitally affect the timing of precipitation. A point to note, mainly with warm fronts, is the state of the cold air ahead. A stable dry cold mass will inhibit precipitation for some time, due to the evaporation of rain or snow falling into it.

A good guide to the movement of cold fronts is the mean 600-millibar wind normal to the front, again due consideration being given to whether the front is ana- or kata-, the former giving marked rain behind the front. Open waves are closely associated with the 500-millibar flow aloft and move at about half the speed of this flow. Rain areas, however, appear to move in fairly close agreement with the 700-millibar flow.

Shower activity has its problems too and here the question of season arises. In winter, due to lack of insolation, showers will probably not develop overland and the only showers expected are advected from the sea. Another point is—how strong does the gradient have to be to maintain shower activity all night over a cold land area? Belfast, for instance, seems to need about a 50-knot westerly gradient and 25–30 knots from north-west, but oddly enough, only 20 knots from 330° maintains snow showers all night. Did anyone present use similar criteria for other areas?

Showers in spring and summer often do not occur over the sea due to the colder water, and hence over windward coastal areas too, although at the same time they might well be active inland. The timing of showers then becomes a matter of forecasting the wind direction. Sea-breezes are notable for the removal of showers from coastal areas. Summer showers can be difficult to forecast. A point noted at Aldergrove, and probably elsewhere inland, is the spell of showers often fairly early in the day in a north-westerly summer stream, and then no more for the rest of the day. Does the explanation lie in the fact that, with the evaporation of dew in the morning the condensation level is lower than in the afternoon when, with a higher condensation level, drier ambient air may be more easily entrained?

The timing of snow has its difficulties. These are, chiefly, the forecasting of the height at which snow will fall on hills and the change from rain to snow in frontal precipitation. In the former case a useful guide is the height of the wet-bulb freezing level in the cold air—the drier and colder the air, the lower down will snow fall. This also applies to rain turning to snow but, in addition, snow seems practically certain with a total thickness of 5,220 metres or less. Exceptions to the foregoing occur most frequently on windward coasts, depending on the sea temperature.

The distribution of rainfall.—This is one of the most complex and difficult of meteorological problems. A check was made of the 1957 rainfall at several gauges around Belfast. Those just to the east of the hills gave between 40 and 44 inches while Aldergrove and Nutts Corner, both to west of the hills, gave 34 and 38 inches respectively. With a prevailing westerly or south-westerly wind, this means that the lee stations experience greater rainfall than the windward stations. Corby[4] shows that under suitable conditions the wave crest may be displaced downwind of the mountain ridge by several miles. Thus, lifting would continue beyond the hills, possibly resulting in heavier rainfall to the lee. It would require a dense network of gauges in a suitable area to confirm this. With regard to shower distribution, Aldergrove seems to escape showers in a north-westerly stream, while Nutts Corner, to the south-east, and places upwind are more affected. This could be the effect of a large lee wave produced by the Sperrin range, a feature which may also account for Aldergrove's lower average rainfall compared with neighbouring gauges.

In the course of discussion, *Mr. Lamb* said that in winter, showers had been found to be ten times more frequent at Lerwick than at Mildenhall and that in all maritime districts the lower the total thickness the greater the chance of showers. In continental areas this does not apply. The probable explanation of the greater persistence of snow showers at night, in contrast to rain showers, is that the cold air needed to produce snow is normally the more unstable.

Mr. McCaffery said that one method used by the Central Forecasting Office for the transport of rain was to use the wind at the level of the rain-producing cloud, frequently the 700-millibar wind, with some added notions of development taking place. No numerical estimates were made.

Mr. Gold said he thought it impossible to follow the physics from the beginning of snowfall but one must go to the final patterns and then work back to what the initial situation was. He mentioned the difference between rainfall in January 1958 at Kew (49 millimetres) and Golders Green (69 millimetres). There was need of a thorough network of gauges for compiling distribution charts. Both dynamical irregularities and irregularities in temperature and humidity might be important in controlling the distribution.

REFERENCES

1. FLORA, S. D.; Hailstorms of the United States. Norman, Oklahoma, 1956.

2. LAMB, H. H.; Two-way relationship between the snow or ice limit and 1000–500 mb. thicknesses in the overlying atmosphere. *Quart. J. R. met. Soc., London,* **81**, 1955, p. 172.

3. MURRAY, R.; Rain and snow in relation to the 1000–700 and 1000–500 mb. thicknesses and the freezing level. *Met. Mag., London,* **81**, 1952, p. 5.

4. CORBY, G. A.; Air flow over mountains. *Met. Rep., London,* **3**, No. 18, 1957, Figure 4, p. 9.

OBITUARY

Dr. A. J. Bamford, M.C., V.D., Ph.D., M.A.—Dr. Alec Joscelyne Bamford died at Worthing, Sussex, on November 19, 1957, in his 73rd year, after a short illness.

Dr. Bamford was educated at Malvern and at Emmanuel College, Cambridge. After graduating, he obtained a post at the Colombo Observatory, as assistant to Mr. H. O. Barnard, the Assistant Surveyor-General of Ceylon, who was also Superintendent of the recently founded Observatory. Dr. Bamford landed in Ceylon in November 1908. He was the first full-time scientific officer of the Observatory and, when Mr. Barnard retired, he became its first full-time Superintendent, in January 1913.

Under the direction of Dr. Bamford, more rigorous methods of checking the observations taken at the meteorological and rainfall stations in Ceylon and of testing instruments were adopted. After returning from active service, he started a programme of pilot balloon wind observations and, later, a wireless time service for the benefit of shipping. He also devised a method of forecasting flood data for the Kelari River at Colombo from the rainfall figures reported daily in the Kelari Valley. This method was adopted officially by the Ceylon Government for flood warnings at Colombo.

Dr. Bamford carried out many investigations chiefly on the meteorology of Ceylon and published his results in scientific journals in Ceylon and Europe. In addition to his Observatory duties, on several occasions he acted as Professor or Lecturer in Physics at the University College, Colombo.

During the First World War, Dr. Bamford served with the Armoured Cars in German East Africa, and was later employed on sound ranging and army survey work in Palestine and Arabia. He received the Military Cross, and was twice mentioned in despatches. In 1919 he was demobilized with the rank of Captain.

Throughout his service in Ceylon, Dr. Bamford took a great interest in the Ceylon Planters' Rifle Corps. Joining as a rifleman, he retired from the Corps in 1931, on his final departure from Ceylon, as a Major.

On his return to England Dr. Bamford was for some years engaged in teaching, but in 1941 he accepted a post in the Meteorological Office, and was posted to the Marine Branch, which had been evacuated to Stonehouse, in Gloucestershire. There he was mainly engaged on the principal war-time activity of the Branch, the production of Meteorological Atlases covering all the oceans of the world.

Both before and after his arrival at Stonehouse, Dr. Bamford served with the Home Guard. He retired from the Meteorological Office in 1946, and moved to Ferring, in Sussex, where his wife died in 1954. He leaves a son and a daughter.

H. JAMESON

WEATHER OF FEBRUARY 1958

Northern Hemisphere

The mean pressure chart for the month showed a large low pressure area extending from the east coast of the United States across the North Atlantic between approximately 35° and 65°N., and another extending across northern Europe into north-west Russia. Associated with these low pressure areas were large areas of negative pressure anomaly, the largest anomalies being −13 millibars south of Nova Scotia and −13 millibars near Leningrad. The Azores high was displaced east of its normal position and appeared as a high over the northern Sahara. As a result of this unusual pressure distribution, the belt of surface westerlies across the Atlantic was further south than usual in February and narrower than usual. The westerlies also extended much further east across Europe and Asia than normal, penetrating as far as the Caspian Sea.

Both the position and intensity of the centre of the Siberian anticyclone were normal for the month, but the ridge extending northward from Siberia across the Arctic and linking with the high pressure region over central North America was stronger than usual, with pressure anomalies of up to +10 millibars in the Arctic. As in January, cyclonic activity was exceptionally intense in the North Pacific, where negative pressure anomalies as large as −15 millibars occurred.

Mean temperatures were generally 2° to 5°C. above normal for the month across central Europe and Asia between 40° and 50°N. as a result of the greater penetration of the westerlies, but north-east of the Caspian temperature anomalies of +7°C. occurred. To the north of this belt, over Scandinavia and northern Russia where the westerly or south-westerly flow was weaker than normal, mean temperatures were below the February normal.

The absence of the usual strong advection of cold air from the north-west resulted in mean temperatures up to 8°C. above normal in Labrador and north-east Canada. Smaller positive temperature anomalies were reported from western America but over central and south-eastern states of the United States temperatures were below normal, anomalies of −5°C. occurring in Florida.

The month gave above normal precipitation over central Europe and central Asia, with amounts up to four times the normal at a few stations, but elsewhere over Europe and the Mediterranean the month was drier than usual. Over the north-eastern states of America, where severe blizzards and deep snowdrifts were reported, the total precipitation was about twice the normal for February.

WEATHER OF MARCH 1958

Great Britain and Northern Ireland

The two most striking features of the very cold month of March were the persistent northerly winds from the 5th to the 11th and the equally persistent and cold south-easterly airstream which lasted from the 14th to the 24th.

With an anticyclone in the neighbourhood of south-west England, the opening days of the month were rather mild and mostly dry with a good deal of fog which, however, cleared from most places by midday. There were sunny periods, especially on the 3rd, and temperatures reached the upper fifties in places on the 4th and 5th. Fresh northerly winds reaching gale force locally in Scotland spread, with snow showers, southward across Scotland and northern England on the 5th and to the remainder of the British Isles the following day, bringing a general fall of temperature of about 10°F. There were sunny periods in most districts although moderate falls of snow occurred over parts of north-east England on the 8th, 9th and 10th. Temperature fell progressively and, on the 9th, was below freezing point throughout the day in many northern districts, and at the level of the average night minima for March. Widespread and locally severe frost occurred over the northern part of the country during the next five or six nights; early on the 12th air temperature fell to 2°F. at Aberdeen. A depression, which formed in the Denmark Strait on the 10th, moved across Northern Ireland and northern England late on the 12th and early on the 13th, giving some continuous snow which later turned to rain. There was a marked rise in pressure behind the depression over the North Sea and this proved to be the beginning of a high pressure area off Scandinavia which maintained a spell of south-easterly winds over most of the country with temperatures about 10°F. below the average, until the 24th. On the 14th air temperature at Aberdeen fell to 0°F. the lowest ever recorded there during March. For ten days a frontal belt lay north-east to south-west over or near south-west England giving prolonged periods of rain in its neighbourhood, but elsewhere weather was cold, fairly sunny and dry apart from snow showers which, however, were mainly slight. On the 24th milder air, which had been off south-west England for the previous ten days, began to move north-east across the British Isles. In the warmer airstream, weather was cloudy with rain at times; thunderstorms developed over south-east England on the 30th. On the 28th and 29th a depression moved north along the west coast of Great Britain and a slow moving associated front gave heavy rainfall in parts of north-east England and east Scotland. Temperature did not rise much above 40°F. in north-east Scotland, but in southern England 60°F. was reached in London on the 27th, at Mildenhall on the 28th and at Ross on Wye on the 30th.

Mean temperature for the month ranged from about 3°F. below average over Cornwall to more than 6°F. below average in the Aberdeen area; during the second and third weeks of the month temperatures were 8–10°F. below normal over much of the country. At Aberdeen temperature fell to freezing point or below on seventeen nights and was at this level continuously from the evening of the 7th until the afternoon of the 11th. Rainfall, expressed as a percentage of the 1916–50 average, was 86, 82 and 69 per cent over England and Wales, Scotland and Northern Ireland respectively. It was less than half the average over much of north-west England and south-west Scotland and was more than twice the average along the Northumberland coast and along the east coast of Scotland from St. Andrews to Peterhead. More than three times the average occurred in a small area around Montrose, Angus. Sunshine was near the average over much of the British Isles, but it was particularly dull over Cornwall and the Channel Islands.

The cold winds and night frosts during most of the month retarded the growth of, and did some damage to, spring crops including rhubarb, lettuce, spring greens and winter cauliflowers. Fuel used in heated glasshouses was correspondingly increased. Ground conditions, often frozen and snow covered and later very wet, continued to hold up much outside work, but towards the end of the month some districts reported the work, including potato planting, was progressing satisfactorily.

WEATHER OF APRIL 1958

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 ...	75	15	−1·6	51	−5	100
Scotland	68	15	−0·3	75	−2	100
Northern Ireland ...	66	24	−0·3	63	−2	95

*1916–1950 †1921–1950

RAINFALL OF APRIL 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	1·74	88	*Carm.*	Pontcrynfe	1·26	37
Kent	Dover	1·82	90	*Pemb.*	Maenclochog, Dolwen Br.	1·55	42
,,	Edenbridge, Falconhurst	1·29	56	*Radnor*	Llandrindod Wells ...	·94	36
Sussex	Compton, Compton Ho.	·82	33	*Mont.*	Lake Vyrnwy	2·19	54
,,	Worthing, Beach Ho. Pk.	·77	43	*Mer.*	Blaenau Festiniog ...	4·84	75
Hants	St. Catherine's L'thouse	·55	28	,,	Aberdovey	1·43	58
,,	Southampton, East Pk.	·59	27	*Carn.*	Llandudno	·85	50
,,	South Farnborough ...	·98	49	*Angl.*	Llanerchymedd ...	1·13	50
Herts.	Harpenden, Rothamsted	1·23	59	*I. Man*	Douglas, Borough Cem.	1·11	42
Bucks.	Slough, Upton ...	1·19	62	*Wigtown*	Newtown Stewart ...	1·35	50
Oxford	Oxford, Radcliffe ...	1·08	57	*Dumf.*	Dumfries, Crichton R.I.	·95	39
N'hants.	Wellingboro' Swanspool.	·79	42	,,	Eskdalemuir Obsy. ...	2·49	66
Essex	Southend W.W. ...	1·41	86	*Roxb.*	Crailing...	2·23	144
Suffolk	Ipswich, Belstead Hall	·89	50	*Peebles*	Stobo Castle	1·49	61
,,	Lowestoft Sec. School	1·13	68	*Berwick*	Marchmont House ...	2·33	125
,,	Bury St. Ed., Westley H.	1·30	61	*E. Loth.*	N. Berwick	2·09	144
Norfolk	Sandringham Ho. Gdns.	1·08	52	*Midl'n.*	Edinburgh, Blackf'd H.	1·38	85
Dorset	Creech Grange... ...	·61	27	*Lanark*	Hamilton W.W., T'nhill	1·16	52
,,	Beaminster, East St. ...	·97	39	*Ayr*	Prestwick	1·16	61
Devon	Teignmouth, Den Gdns.	·58	27	,,	Glen Afton, Ayr. San ...	1·98	58
,,	Ilfracombe	1·03	45	*Renfrew*	Greenock, Prospect Hill	2·35	66
,,	Princetown	2·29	44	*Bute*	Rothesay, Ardencraig...	0·00	00
Cornwall	Bude	·98	51	*Argyll*	Morven, Drimnin ...	2·83	77
,,	Penzance	1·63	65	,,	Poltalloch	2·54	76
,,	St. Austell	1·24	42	,,	Inveraray Castle ...	4·11	80
,,	Scilly, St. Mary ...	1·22	58	,,	Islay, Eallabus ...	1·59	52
Somerset	Bath	1·07	51	,,	Tiree	2·10	81
,,	Taunton	·55	28	*Kinross*	Lock Leven Sluice ...	1·74	81
Glos.	Cirencester	·83	36	*Fife*	Leuchars Airfield ...	1·73	113
Salop	Church Stretton ...	·47	18	*Perth*	Loch Dhu	3·10	63
,,	Shrewsbury, Monkmore	·51	28	,,	Crieff, Strathearn Hyd.	1·20	53
Worcs.	Worcester, Diglis Lock	·43	23	,,	Pitlochry, Fincastle	·82	43
Warwick	Birmingham, Edgbaston	·73	32	*Angus*	Montrose Hospital ...	1·70	92
Leics.	Thornton Reservoir ...	·78	36	*Aberd.*	Braemar	1·27	56
Lincs.	Cranwell Airfield ...	·46	28	,,	Dyce, Craibstone ...	1·67	76
,,	Skegness, Marine Gdns.	·90	56	,,	New Deer School House	1·49	67
Notts.	Mansfield, Carr Bank...	0·00	00	*Moray*	Gordon Castle	1·42	78
Derby	Buxton, Terrace Slopes	2·22	66	*Inverness*	Loch Ness, Garthbeg ...	2·35	85
Ches.	Bidston Observatory ...	·49	29	,,	Fort William	4·78	100
,,	Manchester, Airport ...	·76	40	,,	Skye, Duntulm... ...	2·54	75
Lancs.	Stonyhurst College ...	1·83	68	,,	Benbecula	2·09	82
,,	Squires Gate	1·20	65	R. & C.	Fearn, Geanies ...	1·16	79
Yorks.	Wakefield, Clarence Pk.	·42	23	,,	Inverbroom, Glackour...	4·03	95
,,	Hull, Pearson Park ...	1·29	70	,,	Loch Duich, Ratagan...	5·76	107
,,	Felixkirk, Mt. St. John...	1·05	57	,,	Achnashellach	5·48	98
,,	York Museum	·61	36	*Suth.*	Stornoway	1·76	76
,,	Scarborough	1·19	67	*Caith.*	Lairg, Crask	2·68	69
,,	Middlesbrough... ...	1·48	98	,,	Wick Airfield	1·48	73
,,	Baldersdale, Hury Res.	1·45	58	*Shetland*	Lerwick Observatory ...	1·63	60
Nor'l'd	Newcastle, Leazes Pk....	1·23	70	*Ferm.*	Belleek	2·29	80
,,	Bellingham, High Green	2·16	100	*Armagh*	Armagh Observatory ...	1·20	58
,,	Lilburn Tower Gdns ...	2·86	147	*Down*	Seaforde	1·61	64
Cumb.	Geltsdale	2·17	94	*Antrim*	Aldergrove Airfield ...	1·25	57
,,	Keswick, High Hill ...	1·70	52	,,	Ballymena, Harryville...	1·70	62
,,	Ravenglass, The Grove	1·45	59	*L'derry*	Garvagh, Moneydig ...	2·16	81
Mon.	A'gavenney, Plâs Derwen	·61	21	,,	Londonderry, Creggan	2·17	72
Glam.	Cardiff, Penylan ...	·74	29	*Tyrone*	Omagh, Edenfel ...	1·67	64

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,033, JULY 1958

VARIATION IN SUNSHINE AT GIBRALTAR

By G. W. HURST, B.Sc.

A standard Campbell-Stokes sunshine recorder has been in daily use at Gibraltar since 1938. Two sites (shown in Fig. 1) have been used in turn: Windmill Hill until 1947, and North Front near the Spanish border from 1948; there was no overlapping period. An enforced move of instruments of 300 yards to the south-west occurred on May 18, 1940 at Windmill Hill but examination of the records suggests no significant change in exposure characteristics; there was also a very minor change at North Front on May 1, 1955 of 100 yards to the north-east. The exposures both at Windmill Hill and North Front were very good, with uninterrupted horizons through the day in the winter and summer until the hills of Spain obscured the late evening sun.

Monthly and yearly average and extreme figures of daily sunshine are given for both stations in Table 1, together with the appropriate standard deviations.

It is obvious that there is far greater variation in winter than in summer – expected, of course, as a single winter month in the unsettled part of the year can enjoy particularly favourable, or suffer unusually adverse conditions. In summer on the other hand, even prolonged cloudy weather can only cause restricted effect on a Mediterranean-type summer climate. Thus the variation at Windmill Hill in February shows an average difference in daily sunshine of over four hours in the two years 1945 and 1947, whilst the much more sunny July shows a difference of less than two hours. The mean standard deviation for the period 1938–56 is ·70 hours or under from June to September, and is over 1·00 hours from November to April except for January when outstandingly high or low values have been unusual; in particular, January at North Front has been a month with remarkably little variation. In view of the January variation at Windmill Hill, this is thought fortuitous. Monthly sunshine averages form a frequency distribution which is closely akin to normal (except of course that it is bounded at both ends); the form of frequency distribution makes an interesting contrast with the trapezium shape of daily sunshine data.[1] The difference between the two distributions is analogous to that between yearly or monthly and daily rainfall data.

Average figures for sunshine for the two sites are shown in Fig. 2, which brings out more clearly several rather striking features; also shown in this figure are the mean monthly totals expressed as percentages of possible sunshine.

The main points of interest are the very marked difference between the two stations in November and December, and the marked deficiency of sunshine in March, especially at North Front. Agreement is fairly close from April to October, but the over-all total of sun during the year is over 120 hours less at North Front than at Windmill Hill. On the whole, the smoothness of both curves suggests that sufficiently long periods have been taken for them to be reasonably close to the truth.

TABLE I—COMPARISON BETWEEN SUNSHINE MEASURED AT WINDMILL HILL AND AT NORTH FRONT, 1938–56

	Windmill Hill (1938–47)				North Front (1948–56)			
Month	Average hours	Standard deviation of average	Highest daily average	Lowest daily average	Average hours	Standard deviation of average	Highest daily average	Lowest daily average
Jan.	5·93	·92	7·50 (44)	4·29 (47)	5·53	·38	6·34 (52)	5·09 (48)
Feb.	6·49	1·39	8·72 (45)	4·42 (47)	6·22	·60	7·37 (54)	5·61 (55)
March	7·01	·95	8·86 (39)	5·70 (43)	5·97	1·08	7·62 (52)	4·43 (53)
April	8·38	1·41	10·25 (40)	6·14 (46)	8·19	·86	9·81 (50)	6·83 (49)
May	9·89	1·10	11·08 (39)	7·51 (44)	9·84	·86	11·24 (53)	8·59 (48)
June	10·71	·87	12·01 (43)	9·67 (45)	11·17	·47	11·79 (50)	10·44 (55)
July	11·23	·65	12·17 (45)	10·23 (39)	11·30	·54	11·97 (51)	10·05 (55)
August	10·73	·68	11·75 (46)	9·19 (44)	10·57	·55	11·46 (50)	9·73 (53)
Sept.	8·59	·54	9·23 (38)	7·33 (42)	8·89	·64	10·39 (48)	8·09 (49)
Oct.	7·41	·82	8·68 (44)	6·25 (40)	6·90	·91	8·29 (51)	5·17 (53)
Nov.	6·01	1·23	7·88 (43)	4·07 (38)	4·81	1·12	6·53 (50)	3·28 (53)
Dec.	5·73	·99	7·24 (46)	3·73 (43)	4·53	1·19	6·48 (50)	3·45 (53)
Year	8·17	·27	8·53 (45)	7·57 (41)	7·83	·33	8·43 (50)	7·42 (53)

Figures in brackets give the years of occurrence of quoted highest and lowest daily averages.

The winter difference in sunshine characteristics between the two places is due to a combination of circumstances. A well known phenomenon which occurs in moist surface easterly winds is the levanter cloud forming a banner over and to the west of the Rock, of varying persistence, length and depth according to the history of the air. In summer, this cloud does not interfere with sun recordings at North Front more than at Windmill Hill as the sun's elevation is high, and cloud over the Rock does not throw shadow at North Front. In winter, however, the midday elevation of the sun is only about 30°, and there is some afternoon loss due to levanter cloud. This probably accounts largely for the persistently more sunny conditions at Windmill Hill throughout the season. November and December, the two months of relatively low sunshine at North Front (with totals 20 per cent less than at Windmill Hill) are prone to westerlies, with averages of 62 per cent and 64 per cent of winds from this quarter respectively, compared with 42 per cent in November, 53 per cent in January and 56 per cent in February. Westerly winds are often associated with cloud, either cumulus or stratocumulus in a well broken layer. Spain, five miles to the west of Gibraltar, is so placed that with winds between south-west and west cloud at 2,000–4,000 feet would be far more prone to throw shadow at North Front than at Windmill Hill to the south; this is seen in the Windmill Hill silhouette in Fig. 1.

The March minimum is probably due to the higher incidence of levanter conditions than in neighbouring months; on the average, levanter winds in

March total 43 per cent of the occasions, compared with 39 per cent and 31 per cent in February and April. Moreover, it is an unsettled transitional month with a secondary rainfall maximum, and the average cloud amount is higher than for any other month of the year (see Table II). It would therefore be expected that the percentage of sunshine in March would be lower than in February, though the actual daily average at North Front in March being less than that in February with its shorter days is surprising, as is the marked difference between North Front and Windmill Hill. The March minimum is not caused by one or two exceptional readings, because in five years out of nine at North Front and four years out of ten at Windmill Hill, the daily average for February was higher than that for March.

The closeness of accord between the two curves from April to September, the season of prolonged fine weather, is strong support for the accuracy of the mean. The only anomaly between the curves is the low value of the daily sun in June at Windmill Hill. This seems a real difference, as the two dullest Junes at the station (in 1944 and 1945) were not outstandingly dull, and their omission from the average still leaves Windmill Hill as appreciably less sunny than North Front. The most feasible explanation is that June represents the start of the really moist levanter season, with sea temperatures lower compared with air than later in the year, and that Windmill Hill itself at 400 feet suffered in this month. Interestingly June and July are almost equally bright at North Front.

A further minor factor contributing to the season differences lies in the different heights and locations of the two stations. There is of course always some uncertainty as to the elevation of the sun at which there is burn on the sunshine card, and variation can be in the range up to 4°–5° depending on haze conditions etc.; usually with clear skies burn occurs at Gibraltar with the sun below the generally accepted 3° elevation, particularly in the evening; definite measurable burns have been obtained in fairly clear air until the sun has been obscured by the Spanish hills at elevation down to about 1°.

The silhouette of these hills as seen from North Front, at 20 feet, and Windmill Hill, at 400 feet, are shown in Fig. 1; the limits of sunset are almost exactly 240°–300° true, but the silhouette is continued southwards to sea level for Windmill Hill. It is seen that there is more loss of sun at North Front than at Windmill Hill, especially in winter; the summer difference is not great, but there is a gain at North Front before the vernal and after the autumnal equinoxes. Precise numerical evaluations of the effects of these height and topographical factors is impossible, but potentially there is morning advantage of almost ·025 hours at Windmill Hill due to its greater height, and the evening advantage due to skyline at Windmill Hill is ·125 hours daily in winter; there is little difference in summer, and there is slight evening equinoctial gain at North Front of ·035 hours. Allowing that clear conditions obtain with an approximate frequency of two cloudless periods out of three, and taking the winter and summer average sunshine values of 60 per cent and 75 per cent, the over-all gain at Windmill Hill from topographical sources is about 10 hours annually.

It is of interest to consider the distribution of sunshine round the Rock as a whole. Records have been kept only for the two stations discussed, but allowance may be made for other locations. At Catalan Bay in the east the sun is cut off by the Rock at about 1400 sun time in winter, about 1515 in summer; bearing in mind that there is 10 per cent or rather more sun after noon than before, sunshine at Catalan Bay would be expected to be just under 70 per cent of that at Windmill Hill in winter, just over 70 per cent in summer, and the mean daily average 5·7 hours. On the west side, loss of sunshine is rather less as the slope of the ground is appreciably less steep; sunless conditions would last only up to about 0700 sun time in summer in the neighbourhood of the City Hall and 0900 in winter. There is, on the other hand, more loss from levanter cloud interference at this position than at other sites discussed (it is not particularly uncommon for levanter cloud over the Rock to persist for a prolonged part of the day in either summer or winter) so the percentages of sunshine at City Hall compared with those at Windmill Hill would be of the order of 80 per cent in winter and 85 to 90 per cent in summer, with a yearly average of about 85 per cent of the Windmill Hill daily mean: 6·9–7·0 hours.

No comparative data are available for the surrounding areas of Spain and Morocco, but in Table II are given the monthly cloud amounts for a number of stations in or near the Straits area.

TABLE II—AVERAGE MONTHLY AND YEARLY CLOUD AMOUNTS FOR SELECTED STATIONS IN SOUTH SPAIN AND NORTH-WEST AFRICA

Month	Gibraltar	Alicante	Granada	Malaga	Valencia	Cartagena	Oran	Cape Spartel
				oktas				
January ...	3·8	2·8	3·3	3·1	3·0	3·0	2·3	3·7
February ...	4·0	2·7	3·7	3·0	3·0	2·7	2·6	3·7
March ...	4·2	3·0	4·2	3·8	3·1	3·4	2·6	3·8
April ...	3·3	2·9	3·9	3·4	3·3	2·6	2·6	3·4
May ...	3·0	2·5	3·5	2·6	3·1	1·8	2·0	3·0
June ...	2·4	1·9	2·3	1·3	2·4	1·2	1·8	2·4
July ...	1·9	1·4	1·2	·6	2·0	1·0	1·8	1·4
August ...	2·3	1·6	1·4	1·0	2·3	1·0	1·8	1·4
September	3·3	2·5	2·9	2·2	3·0	2·4	2·1	2·6
October ...	3·7	3·0	3·6	2·8	3·1	2·9	2·5	3·3
November...	4·0	3·0	3·7	3·1	3·4	3·0	2·6	3·8
December...	3·7	3·0	3·7	3·1	3·2	2·6	2·6	3·9
Year ...	3·3	2·5	3·1	2·5	2·9	2·3	2·2	3·0

There are variations in the bases for the computation of these averages (most are based on two or three observations in the period 0900–2100 G.M.T.), but it is evident that Gibraltar is the most cloudy station in the area, and sunshine is probably lower than at any other low-level station within many miles except possibly in the Ceuta–Tangier area where cloud would often tend to lie to the south side of the station over the land and thus mask the sun. Malaga and southern Spain would for similar considerations be appreciably more sunny than the difference between the respective cloud totals would suggest.

The conclusions may be drawn that the sunniest part of Gibraltar is the southern tip, where effects of cloud (cumulus or levanter stratus) are less than elsewhere. The difference of annual totals of about 125 hours between favourably placed sites in the north and in the south of the colony underlines the difference which can arise in the records of nearby instruments, even when

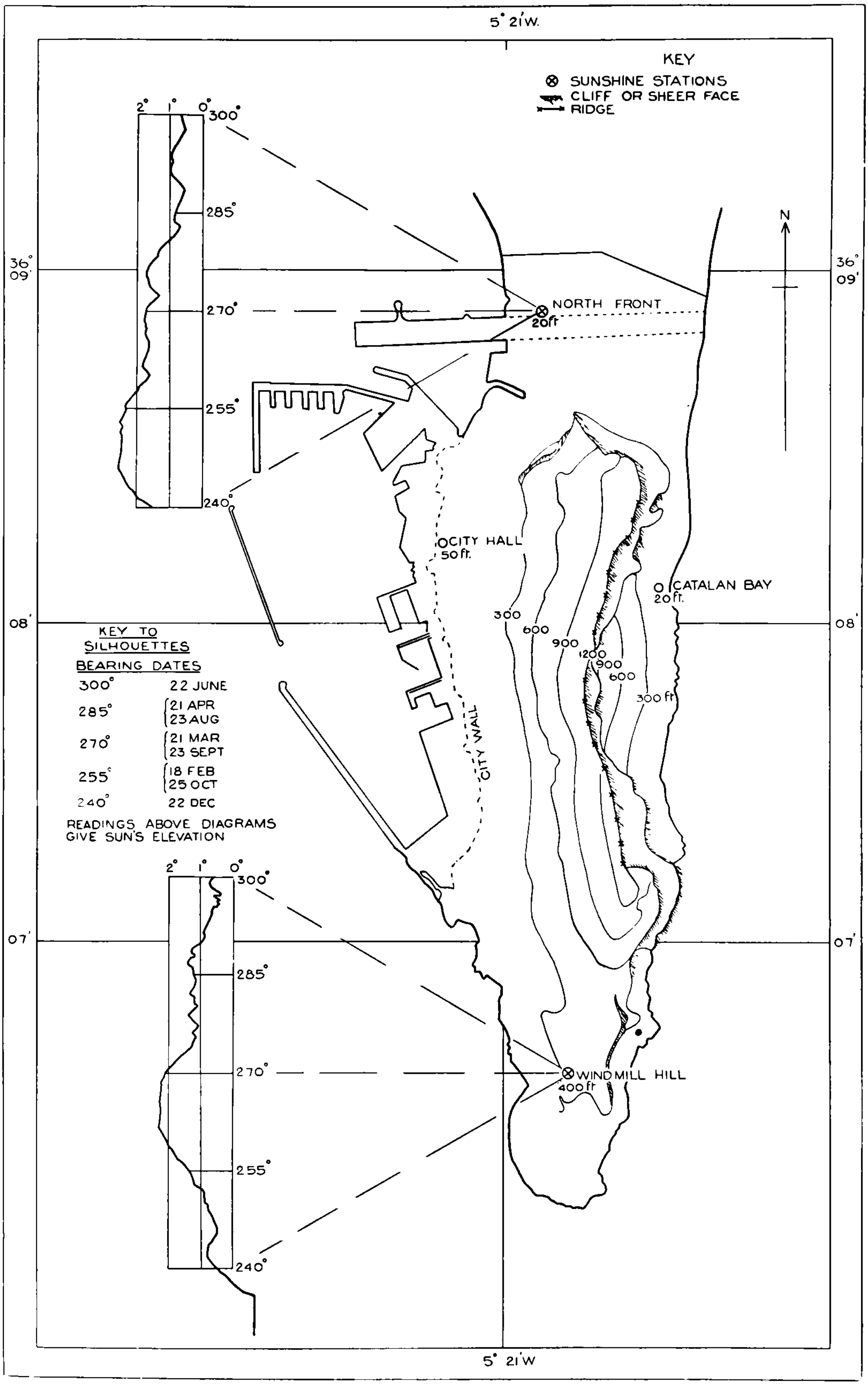


FIG. 1—GIBRALTAR: SUNSHINE STATIONS AND EXPOSURES

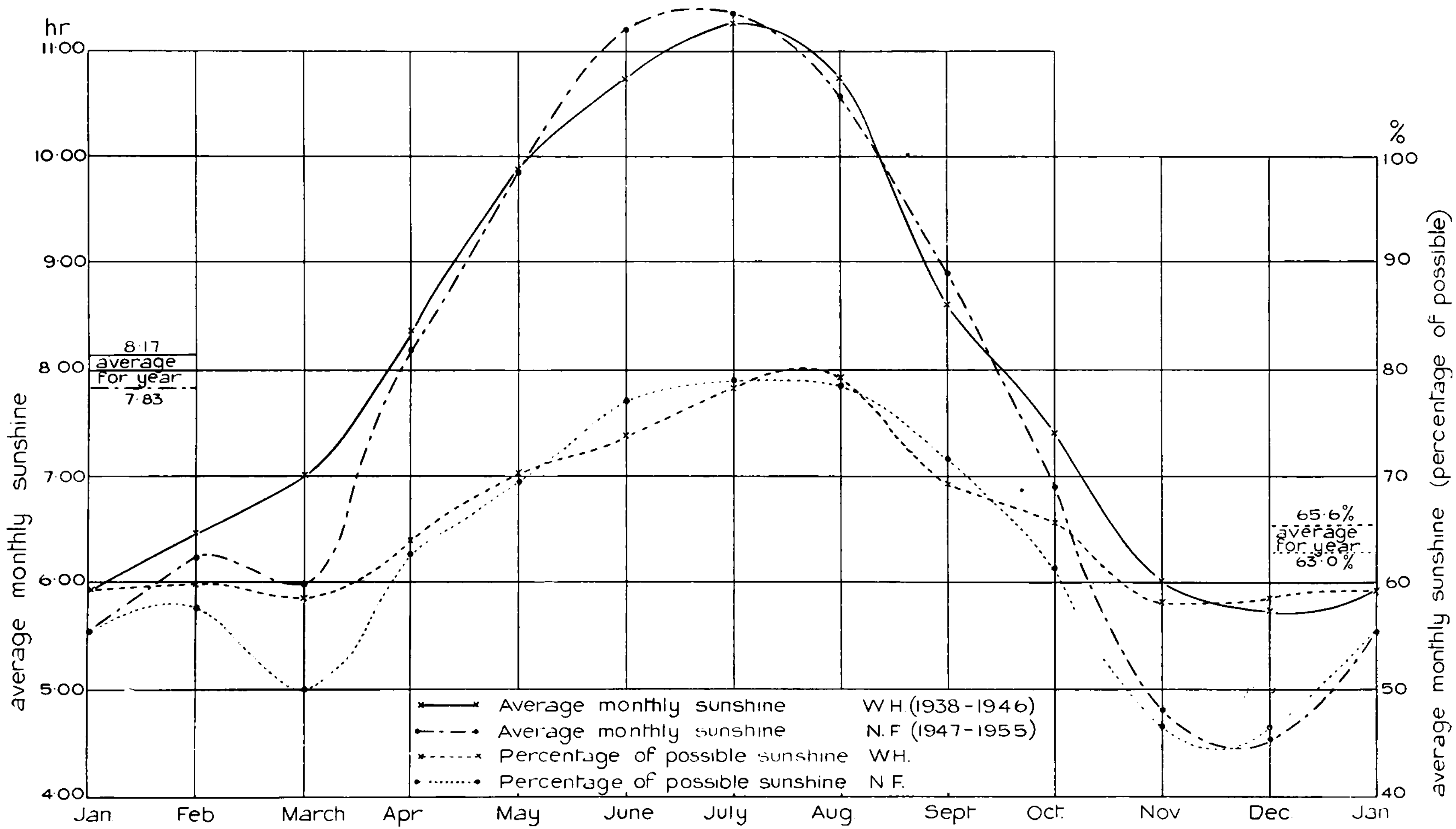


FIG. 2 COMPARATIVE SUNSHINE AT WINDMILL HILL AND NORTH FRONT, 1938–1956

superficially no great difference would be expected. Gibraltar is likely to enjoy less sun than any other coastal area in the vicinity except perhaps for certain areas on the Moroccan Coast between Tangier and Ceuta.

REFERENCE

1. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, pp. 122, 129.

AVERAGE UPPER AIR TEMPERATURES OVER ARGENTINE ISLAND

By D. DEWAR, B.Sc.

Upper air observations at stations in Antarctica for short periods have drawn attention to the greater coldness of the atmosphere in those regions compared with corresponding latitudes in the Northern Hemisphere. A British radio-sonde station was opened at Argentine Island (65°15'S., 64°16'W.) in July 1954 under the control of the Falkland Islands and Dependencies Meteorological Service; from the routine observations made since then, average monthly temperatures were computed for the period July 1954—June 1957 (Table I). For comparison with these values, average temperatures at 500 millibars and 200 millibars and average pressures at the tropopause for Stanley, Falkland Islands (51°42'S., 57°52'W.) were computed for the same period and use was made of the data readily available for two stations in similar latitudes in the Northern Hemisphere, Larkhill[1] (51°12'N., 01°48'W.) and Skattora (69°42'N., 19°02'E.). (Microfilm data for Skattora were supplied by courtesy of the Director of the Norwegian Meteorological Service.) It was not considered essential to use the same period to compare temperatures in the two hemispheres.

Data used.—As far as possible averages for Argentine Island and Stanley were computed from the daily values entered on climatological forms at these two stations; for January to June 1957, either CLIMAT TEMP[2] monthly means or values published in the Falkland Islands Daily Weather Report were used.

Prior to January 1956, British radio-sonde data were not corrected for the effects of radiation and lag on the instrument. Approximate corrections appropriate to monthly mean values were therefore applied to values for Argentine Island and Stanley for 1954 and 1955. The corrections used for Stanley are those given in *Upper air data*[3]. Sufficiently accurate corrections for the early Argentine Island data were obtained by computing radiation corrections for that station following the procedure set out in *Upper air data* and using the same lag corrections as for Stanley.

The averages for Skattora were computed for ascents made at 0300 G.M.T. but for the few occasions when these observations were missing the 1500 G.M.T. observations were substituted. For most months of the year, therefore, the observations are not liable to radiation errors; it is not known if the observations made in daylight in summer time require corrections. The average temperatures for Larkhill do not require such corrections. For Argentine Island and Stanley, the period is July 1954 to June 1957, except that for November and December 1954 there are no data for Argentine Island. For Larkhill the period is January 1946 to December 1950 and for Skattora, September 1950 to August 1954.

Average temperatures at specified pressure levels and average temperatures and pressures at the tropopause and at the surface for Argentine Island are given in Table I.

TABLE I—AVERAGES OF TEMPERATURE AND PRESSURE AT ARGENTINE ISLAND, JULY 1954 TO JUNE 1957

	Pressure (mb.)								Surface		Tropopause	
	60	100	150	200	300	500	700	850	Press.	Temp.	Press.	Temp.
	°C.								mb.	°C.	mb.	°C.
Jan.	−43	−43·4	−44·6	−45·7	−51·0	−27·8	−12·7	− 5·4	994	+0·9	277	−54·9
Feb.	−45	−45·1	−44·7	−44·7	−49·8	−31·0	−14·3	− 6·3	987	+1·0	299	−53·5
March	−51	−48·8	−47·0	−47·3	−51·3	−31·5	−15·9	− 7·3	984	−0·3	292	−55·3
Apr.	−56	−53·6	−52·4	−51·9	−51·9	−30·8	−15·1	− 7·3	989	−1·3	274	−57·7
May	−66	−61·7	−58·8	−57·7	−56·0	−32·4	−15·8	− 8·2	994	−3·0	266	−62·3
June	−72	−67·5	−64·8	−63·8	−57·9	−35·2	−19·1	−11·9	990	−7·6	257	−64·4
July	−75	−70·8	−68·7	−67·4	−58·6	−35·3	−18·7	−10·8	991	−8·7	244	−67·8
Aug.	−79	−76·0	−72·8	−70·4	−60·2	−35·8	−19·0	−12·0	994	−9·5	233	−70·2
Sept.	−75	−72·9	−72·0	−69·8	−58·8	−35·3	−19·1	−12·1	990	−8·1	235	−69·3
Oct.	−61	−63·0	−64·1	−63·7	−57·1	−34·6	−18·2	− 8·9	983	−2·5	271	−62·8
Nov.	(−49)	(−50·3)	(−52·7)	(−54·0)	(−54·6)	(−32·8)	(−17·6)	(− 9·6)	986	−1·7	(287)	(−57·7)
Dec.	(−42)	(−43·9)	(−46·1)	(−47·7)	(−53·3)	(−31·4)	(−16·5)	(− 8·7)	996	−0·0	(288)	(−55·9)
Year	−59·5	−58·1	−57·4	−57·0	−55·0	−32·8	−16·8	− 9·0	990	−3·4	269	−61·0

Values in brackets are for two years only

Comparison with other stations.—Average temperatures at 500 millibars and 200 millibars and average pressures at the tropopause throughout the year at Argentine Island, Stanley, Larkhill and Skattora are shown in Figure 1 for the periods specified above. The most interesting features shown by these graphs may be summarized as follows, temperatures at 500 millibars and 200 millibars being regarded as representative of the troposphere and lower stratosphere respectively.

Argentine Island and Skattora.—In the troposphere, temperatures are similar during the winter half of the year but Skattora becomes considerably warmer in summer, the maximum difference being a little over 10°C. The outstanding features of the graphs, however, are the differences between temperatures in the lower stratosphere and the differences between pressures at the tropopause in winter and spring. In the stratosphere in the late summer and autumn, the temperature at Argentine Island is a little above that at Skattora but during the winter and spring, the temperature at Argentine Island falls far below that at Skattora, the maximum difference being about 15°C. in spring. This coldness is accompanied by much lower pressures at the tropopause at Argentine Island than at Skattora during winter and spring. These low pressures at the tropopause at Argentine Island are not associated with high surface pressures; throughout the year the surface pressure at Argentine Island is much lower than that at Skattora.

Stanley and Larkhill.—In the troposphere, temperatures are around 5°C. warmer at Larkhill than at Stanley throughout the year. In the lower stratosphere, Larkhill is about 2°C. warmer in winter and 3°C. to 4°C. colder in summer. The tropopause at Larkhill is at a considerably lower pressure than the tropopause at Stanley for most of the year.

Larkhill—Skattora and Stanley—Argentine Island regions.—Temperatures in the lower stratosphere in these regions of the two hemispheres are much the same in autumn but not in spring. At Skattora the temperature at 200 millibars rises above that at Larkhill as early as March but it is not until a month before the summer solstice that a similar change occurs in the Southern Hemisphere. It is interesting to note that temperatures at all four stations are almost identical in the late autumn.

Variation of temperature with height in midsummer and midwinter months.—The temperature variation with height at the four stations in midsummer and mid-

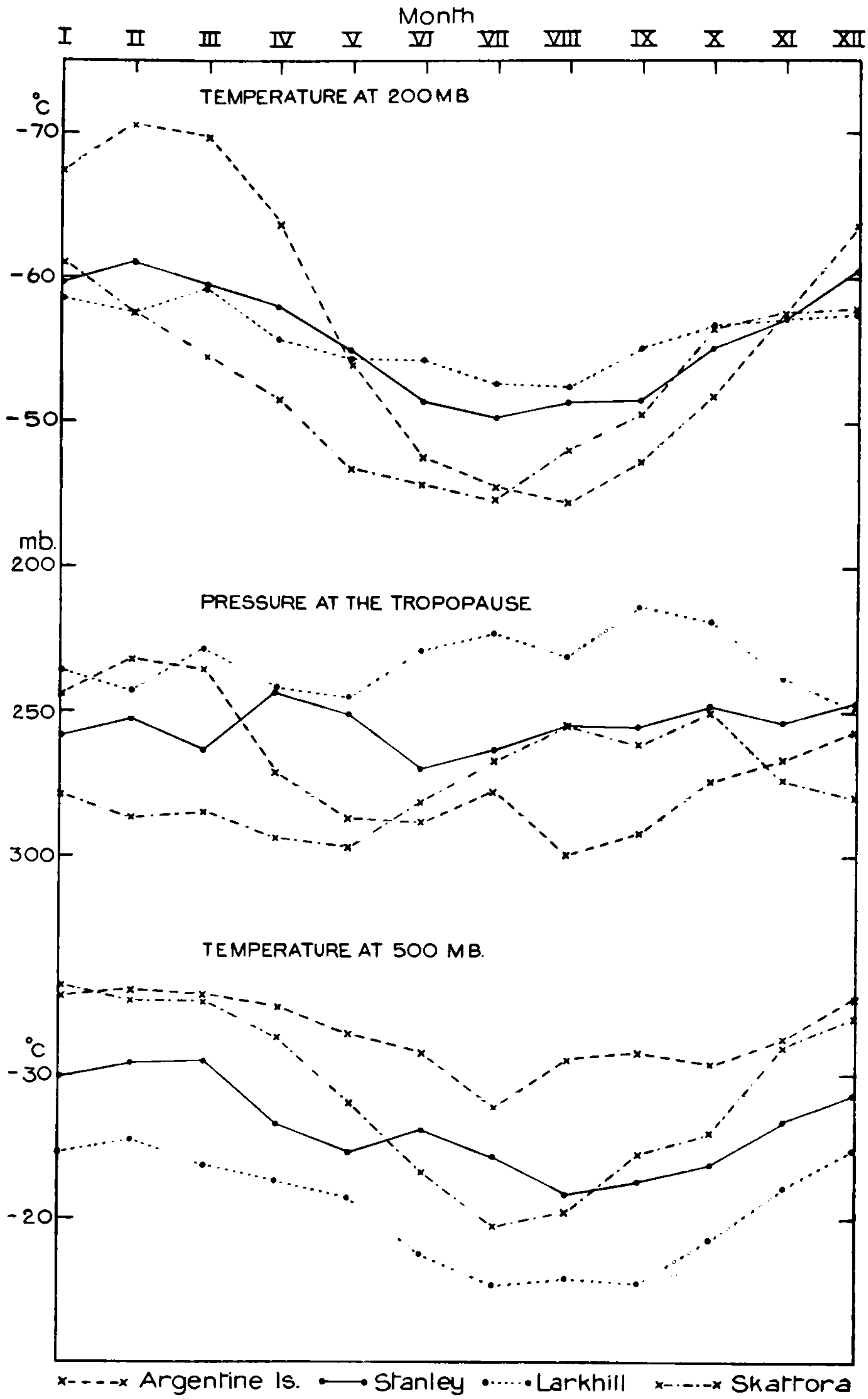


FIGURE 1—AVERAGE TEMPERATURES AT 500 MILLIBARS AND 200 MILLIBARS; AVERAGE PRESSURES AT THE TROPOPAUSE

Month I is January for Larkhill and Skattora, July for Stanley and Argentine Island, etc.

winter months is shown in Figures 2 and 3. The range of average temperature from January to July at the different stations is interesting. In the troposphere, Stanley and Argentine Island show roughly the same temperature range; at Larkhill it is somewhat larger and at Skattora it is nearly double that at the two Southern Hemisphere stations. In the lower stratosphere, however, the

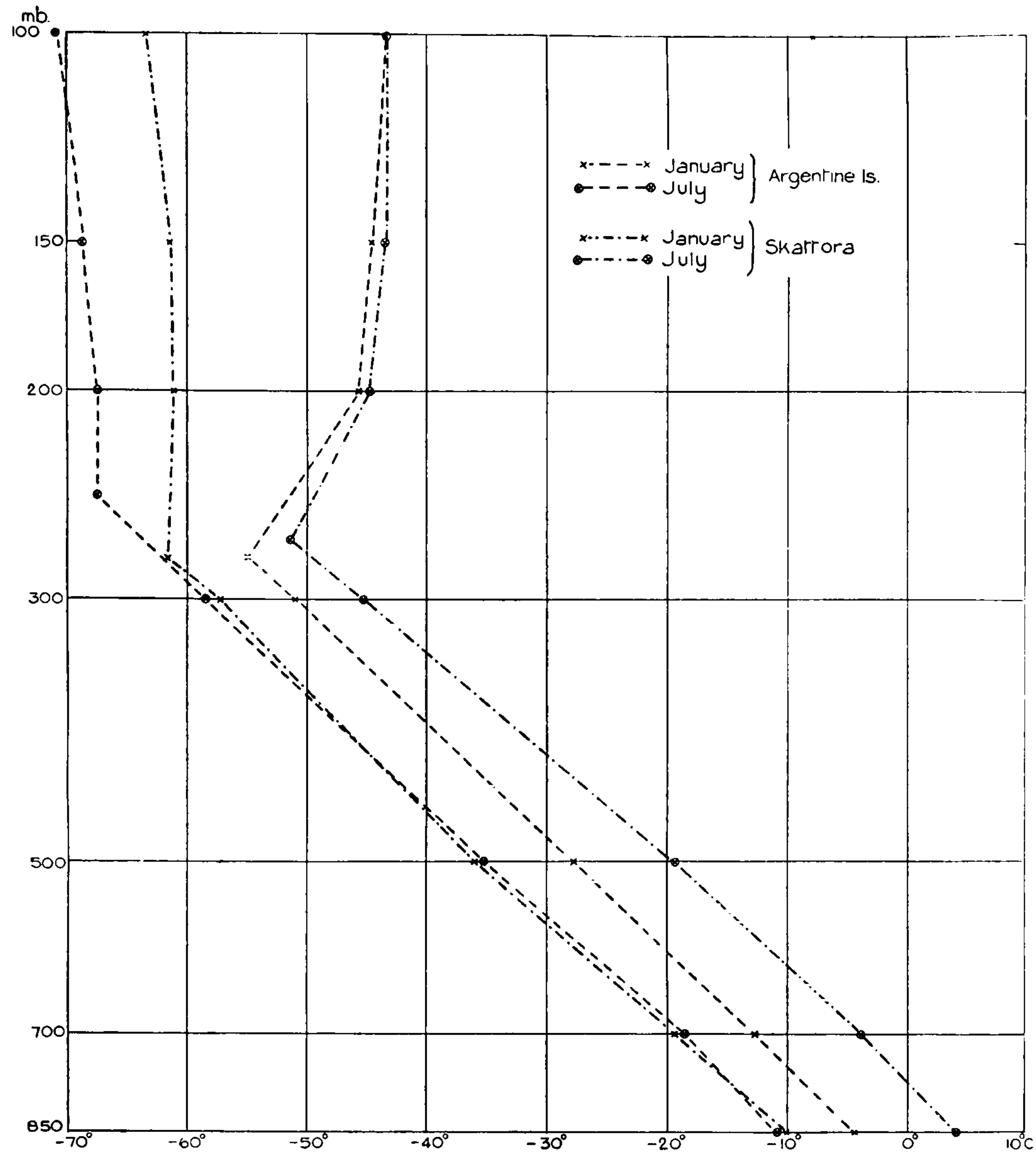


FIGURE 2—TEMPERATURE SOUNDINGS FOR ARGENTINE ISLAND AND SKATTORA

range at Larkhill is only about half that at Stanley; at Skattora it is nearly twice as great as at Stanley and at Argentine Island it is greater still. Average lapse rates in the troposphere are very similar at all four stations. It will be noted that midsummer temperatures in the troposphere at Stanley are about the same as those over Larkhill in midwinter although the two stations are in corresponding latitudes.

Extreme temperatures.—Extreme low temperatures during the three winter months (December, January, February at Skattora and July, August, September at Argentine Island) were extracted from the daily values. The lowest temperatures recorded at Skattora were −76°C. on one occasion (January 1952, at the tropopause where the pressure was 180 millibars) and −75°C. on three other occasions. At Argentine Island the lowest temperature recorded was −91°C. (August 1955 at 90 millibars) with a second lowest

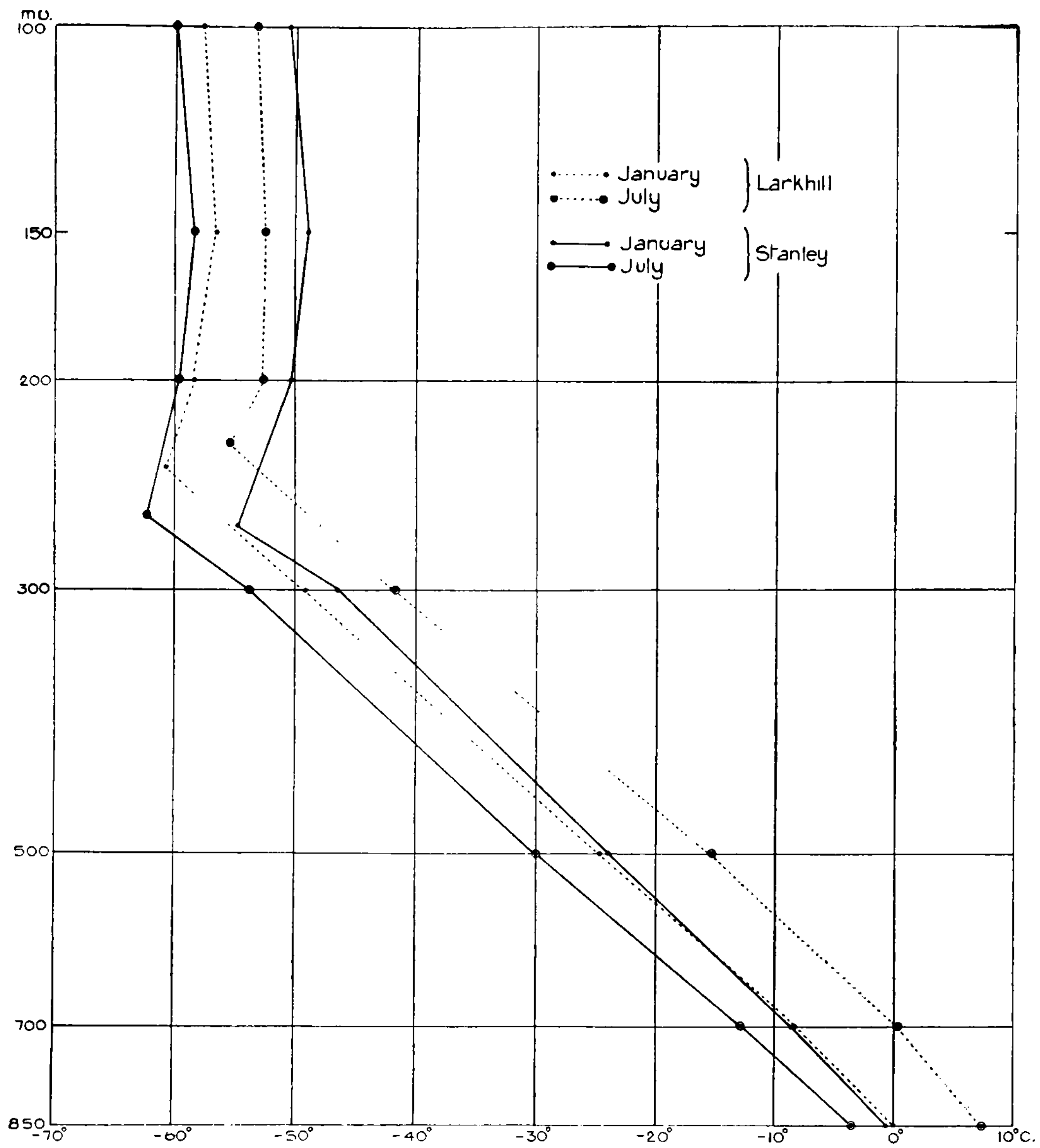


FIGURE 3—TEMPERATURE SOUNDINGS FOR LARKHILL AND STANLEY

temperature of −88°C. (September 1955 at 100 millibars). The application of an estimated radiation correction of −2°C. to the Argentine Island values gives extremes of −93°C. and −90°C. respectively. The minimum of −93°C. recorded during this short period of three years is lower than the extreme of −91°C. recorded at Batavia and regarded for many years as a world record. Other extreme values known to have been recorded during recent years are an isolated value of −97°C. at 100 millibars at Veraval (India) and −94°C. also at 100 millibars at Colombo (Ceylon), during the period 1944–1950.

REFERENCES

1. London, Meteorological Office; Upper air data for stations maintained by the Meteorological Office. 1946–50. Part I, Larkhill. Addendum. London, 1956.
2. World Meteorological Organization: Weather reports. Stations, codes and transmissions. Volume B, Codes. Geneva, 1954.
3. London, Meteorological Office; Upper air data for stations maintained by the Meteorological Office. 1951–55. Part I, Stanley, Falkland Islands. London, 1957.

CLOUD OVER THE OPEN SEA

By F. A. SHARP, B.Sc.

Introduction.—The following note describes an investigation into the diurnal variation of cloud over the open sea. It is found that this is negligible but that in the region discussed there is a seasonal variation of total cloud which might well be associated with an upper tropospheric easterly jet.

Data used.—The data were abstracted from the 0000, 0600 and 1200 G.M.T. surface charts drawn at Changi during 1955. Ships reports were used between Ceylon and the northern tip of Sumatra but extending northwards towards the Bay of Bengal and southwards towards the Equator. All ships used were in the open sea well away from land.

Analysis.—The observations are daylight ones and should therefore give a reliable estimate of cloud amounts. The 0000 G.M.T. observation over the sea is about dawn, the 0600 G.M.T. is midday and the 1200 G.M.T. is dusk. If there is any diurnal variation then these observations should reveal it.

Low cloud.—Table I below gives month by month the average amount of low cloud at 0000, 0600 and 1200 G.M.T. together with the number of reports used.

TABLE I—AVERAGE AMOUNT OF LOW CLOUD

	0000 G.M.T.	No. of obs.	0600 G.M.T.	No. of obs.	1200 G.M.T.	No. of obs.
	oktas		*oktas*		*oktas*	
Jan.	3·4	78	3·2	95	3·1	70
Feb.	2·7	71	2·8	73	2·8	75
March	2·5	105	2·5	106	2·8	97
Apr.	3·3	97	3·1	99	2·7	96
May	4·0	103	3·3	115	3·8	107
June	3·7	115	3·3	113	3·3	113
July	3·5	112	3·4	112	3·6	111
Aug.	3·3	105	3·3	108	3·5	109
Sept.	3·5	107	3·0	93	3·6	111
Oct.	3·6	111	4·0	105	3·8	100
Nov.	4·2	108	3·9	109	3·9	107
Dec.	3·3	107	3·2	98	3·5	108
All Year	3·4	1219	3·3	1226	3·4	1204

This reveals very clearly that there is no significant diurnal variation of low cloud. The amounts of low cloud are surprisingly small; there is a slight peak in May (3·7 oktas) and November (4·0 oktas) with the south-west monsoon season June–October (3·5 oktas) slightly cloudier than the north-east monsoon, December–April (3·0 oktas); but the over-all picture is that there is not a great deal of low cloud in the area and very little variation both during the day and throughout the year.

It would be a fair inference to suggest that at all times of the year over this vast area convergence is limited to a small fraction of the area. Some indication of this might be found by studying the cumulonimbus over the area and this is important from a practical forecasting point of view. There were 3,649 reports of low cloud throughout the year. Of these only 118 reported cumulonimbus. Table II gives a distribution of these 118 cases.

In only 48 cases out of 3,649 (1·3 per cent.) could the sky be said to be well covered with cumulonimbus. It is thus much less frequent than might have been expected. The infrequency supports what was said earlier; that in this very extensive area low-level convergence is very much the exception rather than the rule. An interesting feature was that in February and March together only six cases of cumulonimbus were reported but that otherwise over the whole year cumulonimbus occurred with almost constant frequency.

TABLE II—FREQUENCY DISTRIBUTION OF AMOUNT OF CUMULONIMBUS WHEN THAT TYPE IS OBSERVED

Oktas	No. of cases
1	2
2	15
3	18
4	15
5	20
6	19
7	11
8	18
Total	118

Before leaving low cloud an important corollary to the lack of diurnal variation should be noted. The figures reveal very clearly that there is no diurnal variation over the open sea. It follows that any diurnal variation noted elsewhere must be caused by adjacent land masses. Thus the well-known build-up of low cloud over the Straits of Malacca which is found there on most mornings must be attributed to the adjacent land masses. This corollary should be of wide application and need not be limited to the area discussed.

Total cloud.—Table III gives the average amount of total cloud month by month. There is no way of knowing how much medium and how much upper cloud is present. But having shown that there is very little variation in low cloud throughout the year it is thought that variation in total cloud is probably variation in the amount of cirrus.

TABLE III—AVERAGE AMOUNT OF TOTAL CLOUD

	0000 G.M.T.	0600 G.M.T.	1200 G.M.T.	All times
		Oktas		
Jan.	5·2	4·7	4·7	4·9
Feb.	4·3	4·7	5·1	4·7
March	3·5	3·7	4·2	3·8
Apr.	4·6	4·8	4·9	4·8
May	6·3	5·4	6·0	5·9
June	5·9	5·5	6·0	5·8
July	5·4	5·3	5·4	5·4
Aug.	6·0	5·7	6·1	5·9
Sept.	5·5	5·3	6·1	5·6
Oct.	6·1	5·8	6·1	6·0
Nov.	5·9	5·7	6·0	5·9
Dec.	4·6	4·7	5·2	4·8
Year	5·3	5·1	5·5	5·3

There is thus very little evidence for diurnal variation. However, from May to November inclusive, that is, during the south-west monsoon there is very nearly a six-okta average total cover of which 3–4 oktas is low cloud. It is thought that at this time of the year in addition to the low cloud there is usually at least 5 to 6 oktas of cirrus making up the reported average of 6 oktas total cloud.

In fact during May to November nearly one third of all observations give 8 oktas of total cloud and extensive cirrus sheets may well be very common. These cirrus sheets could be associated with the easterly jet discussed by Koteswaram[1] which he found extending along 15°N. latitude during this season.

Summary.—

(i) There is no diurnal variation of cloud over the open sea.

(ii) Any diurnal variation observed over water masses must be due to adjacent land.

(iii) Over the area discussed the low-level flow is very largely non-convergent. Convergent low-level air flow is very much the exception or when it does occur it affects a very limited area.

(iv) Cumulonimbus over the area is a rarity.

(v) Extensive cirrus sheets during the south-west monsoon may be associated with an easterly jet stream.

REFERENCE

1. KOTESWARAM, P.; The easterly jet stream in the tropics. University of Chicago, Department of Meteorology. Report on Research, 1956.

ON THE PRESENT CLIMATIC FLUCTUATION

By G. S. CALLENDAR

During the last few years much has been said and written about the present climatic fluctuation, and valuable summaries of its extent in various countries have been presented by Ahlmann, Lysgaard, Scherhag, and others[1-3]. Wexler[4] suggests that the rising trend of temperatures observed in many regions may be due to better atmospheric transparency for solar heat, owing to a reduction of volcanic activity in recent decades. Plass[5] and Callendar[6] have attributed this rising trend to back radiation from the carbon dioxide produced by full combustion. Others suggest variations of solar activity, or the chance result of perturbations in the general circulation. However, a great deal of confusion has arisen as to what the term "present climatic fluctuation" actually means, and in the following an attempt is made to show how this uncertainty has come about.

Only temperature trends are considered here because these are thought to be the most fundamental expression of climatic change, although, as Kraus[7] has pointed out, precipitation may be the more convenient indicator in some tropical and subtropical climates. The figures shown and discussed on the following pages are intended to illustrate the essential difference between the local fluctuations given by decadal averages (Figure 1) and long period trends over wide areas (Figure 2). Faegri[8] has aptly stated the importance of the time factor in climatic fluctuations when he wrote: "The longer the duration of a fluctuation the greater the area within which it is felt in the same way".

Only a few temperature records are used here, and the work of Kraus[9], Willett[10], Lysgaard[2], and Callendar[11], should be consulted for world-wide climatic trends.

Discussion of figures.—Figure 1 shows the decadal temperature fluctuations at three stations covering a fairly wide range of climate. From the upper two curves for Stornoway (58°N. 6°W.) and Kew it will be seen that even within the restricted area of Britain there may be quite a long interval between the dates when these fluctuations reach a maximum. Thus 1931–40 was the warmest decade in the extreme north-west, whereas it was not until 1943–52 in the south-east.

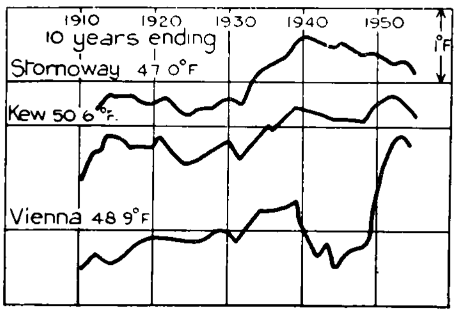


FIGURE 1.– DECADAL AVERAGES, SHOWING LOCAL TEMPERATURE FLUCTUATIONS

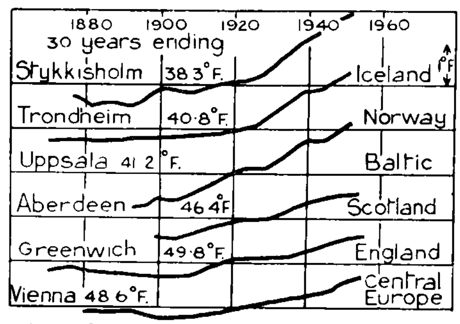


FIGURE 2.– 30-YEAR AVERAGES, SHOWING REGIONAL TEMPERATURE TRENDS

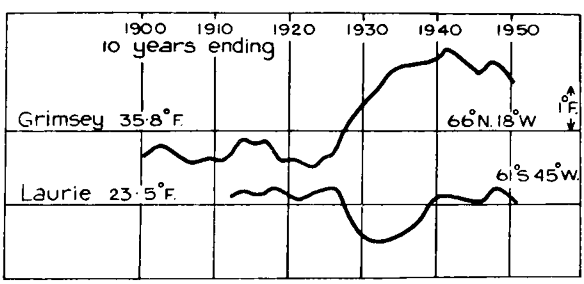


FIGURE 3 - CONTRASTING DECADAL AVERAGES, FROM THE FAR NORTH AND SOUTH ATLANTIC OCEANS

As regards the significance of this fluctuation, it may be noted that Professor Manley's researches on British temperature variations[12] indicate that we should have to go back to 1730–39 in order to find a decade as warm as 1943–52 in England. Naturally there is some uncertainty about the exact relationship of such early values to modern temperature standards, but Manley's researches, and those by Hesselberg and Birkeland[13] in Norway, make it very probable that recent averages in west Europe have been the highest for at least two centuries, perhaps much longer.

The lower curve of Figure 1 is of interest as showing the effect of the abnormally cold war years, 1940, 1941 and 1942, in central Europe, which knocked the decadal average right back to nineteenth century values for a short time, and makes the curve look very different from those at west coast stations. Subsequently, averages at the Höhe Warte observatory[14] have exceeded all previous values by a substantial amount. Here it is of interest to note that these three years 1940–42 (which were also very cold in south Scandinavia) do not seem to have caused any appreciable slowing down of the general retreat rate of Norwegian or Alpine glaciers[15].

A comparison of Figures 1 and 2 lends strong support to Faegri's maxim quoted above, for it will be seen that the temperature trend curves of Figure 2 show good qualitative agreement over a vast area, including much of Europe and the north-eastern Atlantic. All the records used here have been closely compared back to the 1860's or 1870's, with more than one independent series from the respective countries, and are considered to be reliable and free from "urban effects". However, it has not been thought advisable to carry these curves back beyond about a century because of the lack of reliable comparative material, and the serious danger that errors in reduction to modern standards may equal, or even exceed, any real trend. In this connexion it appears from Manley's work, mentioned above, that there was no over-all trend in English temperatures during the nineteenth century. On the other hand there is much evidence that the cold season was somewhat longer and more severe in the Baltic countries before about 1882[16].

Amongst the curves shown in Figure 2 that for Stykkisholm, west Iceland[17], has the largest range of thirty-year averages with 2½°F., Vienna the least with 0·9°F. In Britain this range increases slightly towards the north, from 1°F. at Greenwich to 1·2°F. at Aberdeen. In all cases the latest dates* give the highest thirty-year average, but the British curves are already running flat again now, as they were in the 1920's and the others may be expected to flatten off soon as the warm 1930's drop out. Turning to the nineteenth-century values, it will be seen that the early averages at Uppsala appear low in relation to the others. This is the result of the aforementioned cold seasons on the Baltic, at a period (*circa* 1857–77) when summers further south were decidedly warm.

It should be mentioned that the highest thirty-year averages recorded in the nineteenth century at the Vienna, Greenwich and Trondheim observatories, were not exceeded by a significant amount until those ending about 1930. This fact could be interpreted to mean that the "present climatic fluctuation" is a phenomena of the twentieth century. However, it is known that the glaciers of many regions had been retreating for a long time before 1900, some before 1800, and the general picture is one of a slow amelioration of climate, with many setbacks, which commenced about the middle of the eighteenth century in some regions (Alaska, Norway and New Zealand) and has been followed by a pronounced quickening in the last three or four decades. The curves of Figure 2 are representative of the latter in the North Atlantic region.

The reasons for including Figure 3 are firstly that it shows how much the decadal temperature averages can differ in widely separated regions, and secondly that Laurie Island, South Orkneys[18], is perhaps the most important single climatological station in the whole world, for it supplies the only continuous long record for the Antarctic zone—a region of special interest this year. Figure 3 compares the Laurie decadal averages with those from Grimsey (a small island some 40 kilometres north of Iceland) and it will be observed that a great oscillation occurred in the late 1920's, between the far north and south of the Atlantic Ocean. This amounted to 4½°F. over the years 1927 to 1930 inclusive.

The Laurie temperature averages reveal a point of considerable interest to the matters discussed here, for they are virtually flat over-all during the period, with the twenty years 1909–28 exactly equal to 1931–50. This is an unusual feature, and most probably due to the strongly thermostatic control on surface temperatures exercised by the vast areas (10 to 20 million square kilometres) of

* Greenwich and Aberdeen closed about 1950. They have been continued to latest date from nearby overlapping records.

melting pack ice in these southern latitudes. Such an interpretation is supported by the observed reactions of glaciers to north of the ice (*Journal of Glaciology* and other sources). For example, retreat appears to be less marked amongst the glaciers of South Georgia, 55°S. than by those from the Hielo Continental, 50°S., and both less than in the New Zealand Alps, 44°S., or the Cordillera de los Andes about 33°S.

On the Antarctic continent itself temperatures are too much below freezing at all seasons for small changes to have an observable effect on the ice thickness in a few decades. Moreover, what evidence there is from vertical temperature profiles in the firn[19], points to stable averages for a long time, and it would appear that the "present climatic fluctuation" has so far failed to penetrate the thermal barrier of melting pack ice which protects the great southern ice cap. If any positive influence has reached the latter, by way of advection at higher levels or directly from radiative changes, it is evidently too small to be observed as yet.

REFERENCES

1. AHLMANN, H. W.; Glacier variations and climatic fluctuations. *Bowman memor. Lect. Amer. geogr. Soc., New York*, Series 3, No. 3, 1953.
2. LYSGAARD, L.; Recent climatic fluctuations. *Folia. geogr. dan., Copenhagen*, **5**, 1949.
3. SCHERHAG, R.; Die Erwärmung der Arktis. *J. Cons. int. Explor. Mer., Copenhagen*, **12**, 1937, p. 263.
4. WEXLER. H.; Climate change. Boston, 1953, p. 73.
5. PLASS, G. N.; Effect of carbon dioxide variations on climate. *Amer. J. Phys., Lancaster, Pa.*, **24**, 1956, p. 376.
6. CALLENDAR, G. S.; Can carbon dioxide influence climate? *Weather, London*, **4**, 1949, p. 310.
7. KRAUS, E. B.; Secular changes of tropical rainfall régimes. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 198.
8. FAEGRI, K.; On the value of palaeoclimatological evidence. *Cent. Proc. roy. met. Soc., London*, 1950, p. 192.
9. KRAUS, E. B.; Secular changes of the standing circulation. *Quart. J. R. met. Soc., London*, **82**, 1956, p. 289.
10. WILLETT, H. C.; Temperature trends of the past century. *Cent. Proc. roy. met. Soc., London*, 1950, p. 195.
11. CALLENDAR, G. S.; The artificial production of carbon dioxide and its influence on temperature. *Quart. J. R. met. Soc., London*, **64**, 1938, p. 223.
12. MANLEY, G.; The mean temperature of central England, 1698—1952. *Quart J. R. met. Soc., London*, **79**, 1953, p. 242.
13. HESSELBERG, T., and BIRKELAND, B. J.; Säkulare Schwankungen des Klimas von Norwegen. Teil I. Die Lufttemperatur. *Geofys. Publ., Oslo*, **14**, No. 4.
14. Vienna, Österreichs Gesellschaft für Meteorologie. Klima und Bioklima von Wien. Teil I. Vienna, 1955.
15. AHLMANN, H. W.; Glaciological research on the North Atlantic Coasts. *R. G. S. Res. Ser., London*, No. 1, 1948.
16. LILJEQUIST, G. H.; The severity of the winters at Stockholm 1757—1942. *Geogr. Ann., Stockholm*, **25**, 1943, p. 81.
17. EYTHORSSON, J.; Temperature variations in Iceland. *Geogr. Ann., Stockholm*, **31**, 1949, p. 36.
18. Buenos Aires, Servicio Meteorologico Nacional. Datos climatologicos y geomagneticos Islas Orcadas del Sud. Serie B. Buenos Aires, 1951.
19. SCHYTT, V.; The Norwegian-British-Swedish Antarctic Expedition, 1949–52 .I. Summary of the glaciological work. Preliminary report. *J. Glaciol., London*, **2**, 1953, p. 294.

METEOROLOGICAL RESEARCH COMMITTEE

Synoptic and Dynamical Subcommittee

At the meeting on 9 October the report on progress (March–August, 1957) was reviewed and activities in the field of world climatology were noted. Features of the analysis of temperature and humidity data obtained from 1950 to 1955 in high altitude flights by the Meteorological Research Flight (M.R.P. 1052) were discussed. This paper is a continuation of *Geophysical Memoir* No. 88. The conclusions reached in the second paper from consideration of the detailed measurements of temperature and humidity obtained by the Meteorological Research Flight in the vicinity of stratocumulus cloud were noted as an important contribution to the problem of the maintenance and dispersal of this type of cloud, and as opening the way for further investigation, for example, on the mechanism of the mixing processes in the shallow turbulent layer in the temperature inversion immediately above the cloud top. The complexity of the long-standing question of adequate methods of checking the accuracy of forecasts, of different types and for different classes of user, was recognized in the discussion of the critical survey of the subject presented in the third paper.

ABSTRACTS

TUCKER, G. B.; An analysis of humidity measurements in the upper troposphere and lower stratosphere over Southern England. *Met. Res. Pap., London,* No. 1052. 399 high altitude ascents measuring temperature and frost-point, made by aircraft of the Meteorological Research Flight, were analysed and the results compared with previous conclusions. The extreme dryness of the stratosphere is a feature of all seasons, but summer is the most moist season (in terms of water content) in the stratosphere as well as in the troposphere. Above about 500 millibars the humidity mixing ratio lapse decreases with height, and above 150 millibars the humidity mixing ratio levels out to about ·002 grammes per kilogram. The tropopause does not coincide with any marked discontinuity in frost-point or humidity mixing ratio. A graphical method is devised to show the inter-relationships between season and the temperature, frost-point and pressure at the tropopause.

JAMES, D. G.; Observations from aircraft of temperatures and humidities near stratocumulus cloud. *Met Res. Pap., London,* No. 1055. Flights by aircraft of the Meteorological Research Flight near extensive layers of stratocumulus cloud beneath dry-type inversions suggest that the cloud is in a delicate state of balance with its environment. A rate of subsidence is suggested which is sufficient to maintain the profiles of both temperature and humidity above the cloud. Evaluation of the heat and water-vapour budgets of the cloud show that a nocturnal increase in the turbulent mixing at cloud top is required to dissipate the cloud sheet.

JOHNSON, D. H.; Forecast verification: a critical survey of the literature. *Met. Res. Pap., London,* No. 1056. Investigation of many proposed forecast verification techniques shows that methods are available which meet most of the likely contingencies. When fresh systems must be devised there exists a body of experience which should enable potential pitfalls to be avoided. An appendix discusses the conditions under which rigorous tests of the statistical significance of verification scores are possible at present.

Physical Subcommittee

At the meeting on 23 October 1957 the progress report from March to August 1957 was considered and four papers were discussed. The close agreement between values (about –82°C.) of frost-point at a height of 48,000 feet over North Africa and England (M.R.P. 1024) and the similar values found at corresponding heights in latitudes of Iceland and over Australia suggested the need for measurement of frost-point at high levels in the tropics proper. The use of a moving tape of thin aluminium foil (M.R.P. 1050) to obtain records in flight of cloud particles of diameter down to 80 or 100 microns was welcomed as a valuable adjunct to investigations of cloud and precipitation processes; and the preliminary results, obtained by the Meteorological Research Flight, on the distribution of drops and other particles in different types of cloud suggested the probable need for some revision of ideas on cloud processes. In the discussion of the analysis of the, probably unique, detailed measurements of humidity and temperature made by the Meteorological Research Flight in the vicinity of stratocumulus cloud (M.R.P. 1055) it was suggested that similar measurements on further occasions would be desirable for comparison with the data already obtained. The Subcommittee noted the skill with which in the fourth paper data from geostrophic air trajectories, constant-level ballon tracks and smoke-puff observations had been used to examine the applicability of an empirical exponential law and power law in the representation of horizontal diffusion in the atmosphere.

ABSTRACTS

HELLIWELL, N. C., and MACKENZIE, J. K.; Observations of humidity, temperature and wind at Idris, 23 May–2 June 1956. *Met Res. Pap., London*, No. 1024. Seventeen flights were made between 23 May and 2 June 1956 to investigate the humidity of the atmosphere at altitudes over North Africa. Ascents were made over Idris in Tripolitania in which frost-point, temperature and wind were measured at selected levels up to 48,000 feet. The mean frost-points were higher than those found over southern England except at 48,000 feet where the mean value (−82·6°C.) is nearly the same as that found in 1955 and 1956 over Britain (−82·0°C.). Three flights were made to the south of Idris reaching about 23°N. The out-bound legs were flown at constant height (35,000 feet or 40,000 feet and a cruise climb from 45,000 feet to 48,000 feet was flown on the return. These flights are treated synoptically and show that the variation of frost-point with latitude is rather small on these occasions.

GARROD, M. P.; Recent developments in the measurement of precipitation elements from aircraft. *Met. Res. Pap., London*, No. 1050. Two techniques of measuring precipitation from an aircraft are described. Initial investigations were made using sooted screens or plates, but a new method utilizing aluminium foil was found to be more practical. The results of calibrations of both techniques are presented. Some examples of snow and rain concentrations in frontal and shower clouds are included, and also numbers of drops greater than 100 microns in cumulus and stratocumulus clouds.

JAMES, D. G.; Observations from aircraft of temperature and humidities near stratocumulus cloud. *Met Res. Pap., London*, No. 1055. (see p. 208).

DURST, C. S., CROSSLEY, A. F., and DAVIS, N. E. Horizontal diffusion in the atmosphere in the light of air trajectories. *Met. Res. Pap., London*, No. 1058. The dispersion is examined of points reached after various times by geostrophic trajectories which originated at a fixed point; also the correlation coefficients are formed between the winds at that fixed point and those on the trajectories after various times. These correlation coefficients are found to obey approximately an exponential law, $r(t) = e^{-\alpha t}$. On the other hand if a relationship is sought between the scatter of the end points and their mean distance from the point of initiation, it is found that there is a close approximation to a power law of that mean distance. In the course of the calculations is it found that the value of α is dependant on $\frac{\sigma^2}{k}$ where σ is the standard vector deviation of wind and k is the coefficient of eddy viscosity for lateral mixing.

Synoptic and Dynamical Subcommittee

A fairly wide range of topics received attention at the meeting held on 13 November 1957. The first paper indicated the improvement, in the numerical prediction of a rapidly deepening small depression, which resulted from modifying the two-parameter model technique by taking into account the effect of latent heat released in the rain area, by reducing the size of the computational grid-mesh and by making some allowance for non-geostrophic motion. The next topic considered was the temperature and humidity distribution in and near frontal zones as shown by observations made by the Meteorological Research Flight in traverses at 600 millibars and 500 millibars through a number of fronts (M.R.P. 1064). A remarkable feature is the dryness of the air in the neighbourhood of fronts on a high proportion of the occasions, thus indicating the effects of subsidence of the air. The paper suggests that the temperature and humidity distributions observed are consistent with the effects of subsidence on the cold side of a jet stream. The field of view widened in the consideration of the third paper which assembles evidence on the predominance of the westerly circulation in the southern hemisphere over that in the northern hemisphere throughout most of the year, and discusses the features and probable courses of the mean ridges and troughs of the 500-millibar contour pattern in the southern hemisphere, and possible effects elsewhere in the world of changes in the southern hemisphere circulation system. The fourth paper, also near-global in scope, indicated a further stage in the assembly by the Meteorological Office of revised information on upper winds over the world. The marked difference, between the northern and southern hemisphere, in the air-flow pattern at the 100-millibar level was noted.

Recent work on the forecasting of the motion of fronts was also discussed.

ABSTRACTS

SAWYER, J. S.; Two parameter techniques of numerical forecasting applied to a small intense depression. *Met. Res. Pap., London,* No. 1063. Numerical calculations of the changes in the 1000- and 500-millibar contours on 28–29 July 1956 failed to indicate the very rapid deeping of a depression off south-west England when the methods previously used by F. H. Bushby and M. K. Hinds (*Quart. J. R. met. Soc., London,* **80,** 1954, p. 165) were applied. The calculations indicated more rapid deepening when (*a*) the static stability was treated as neutral in an area of about 100 miles extent known to be an area of heavy rain (*b*) the computational grid was given a finer mesh of 75 miles and (*c*) the "balance equation" was used to determine an initial stream function in place of the geopotential.

SAWYER, J. S.; Temperature, humidity and cloud near fronts in the middle and upper troposphere. *Met. Res. Pap., London,* No. 1064. The Meteorological

Research Flight of the Meteorological Office has made a number of exploratory flights through fronts beneath the jet stream. They confirm that a narrow "frontal zone", some 30 to 50 miles wide with sharp boundaries is often present at the 500-millibar level. On other occasions the temperature changes are more diffuse. The air in and near the "frontal zone" is usually very dry and must have undergone subsidence.

At 600 millibars the temperature gradients at fronts are somewhat less well defined than at 500 millibars, and, although dry subsided air is often found in the frontal zone, the air on the warm side of the frontal zone is usually relatively moist. Cloud occurs in this region but the boundary of the cloud appears to slope more steeply than the front itself.

Dynamical considerations suggest that the very strong temperature gradient of the frontal zone at 500 millibars arises from the differential subsidence of air on the cold side of the jet stream which leads to a tilting of the isentropic surfaces. The front-forming processes in the upper troposphere operate only where the jet stream is intensifying or becoming more cyclonically curved along its length, but the characteristic structure is carried forward into other weaker sections of the jet stream without degenerating completely.

LAMB, H. H.; The southern circumpolar westerlies, broad characteristics and apparent associations. *Met. Res. Pap., London,* No. 1065. 500-millibar topography over the southern hemisphere is studied principally by means of seasonal and yearly averages of data published in *Notos* (Pretoria). There are great differences from the trough–ridge system of upper westerlies in the northern hemisphere. The pattern is verified by reference to various observable climatic and glaciological associations. The southern westerlies are found to carry much more momentum than their northern counterparts, the ratio being 1·5 or more for the year and 4 in the northern summer. Anomalies and secular changes of the powerful southern circulation probably disturb the circulation over the rest of the world.

HEASTIE, H.; Average height of the standard isobaric surfaces over the temperate and tropical regions in July. *Met. Res. Pap., London,* No. 1066. Average heights of standard isobaric surfaces in January were given in M.R.P. 1045. Those for July follow the same lines; contour heights (in decametres) are given on Mercator charts from 75°N. to 60°S. for 700-, 500-, 300-, 200-, 150- and 100-millibar and intervening thicknesses. A brief discussion of the charts is included.

NOTES AND NEWS

Long-lived whirlwind on a mountain ridge

We are indebted to Mr. F. H. W. Green, The Nature Conservancy, for the following report of an unusual observation by Dr. D. N. McVean of the Conservancy's scientific staff:

"On August 3, 1957, I was traversing the ridge running north from Aonach Beag to Aonach Mor just east of Ben Nevis. The day was bright and sunny with an occasional light breeze from the east. At point 27/194719 (3,650 ft. O.D.) at about 1.30 p.m. my attention was caught by a whistling sound and I observed a patch of mat grass on the crest of the ridge being violently agitated.

The area of disturbance, which was about three metres in diameter, shifted slowly about on the main ridge keeping close to the angle formed by the spur ridge from the north-east. I was able to stand within a few feet of the whirlwind and feel only the faintest draught of air; on stepping into it I had the flap of my rucksack which was weighted with wallet, loose change and keys lifted over my head by the updraught.

Returning along the ridge about two hours later I was interested to see that the whirlwind continued to circle the same area although the intensity seemed to be slightly reduced."

On the day in question an anticyclone was centred over the North Sea between north-east Scotland and Holland. Over Scotland there was little cloud and the upper air winds at the height of Ben Nevis were about 5 knots from between 140° and 160°.

Averages of rainfall 1916–1950

Hitherto the standard 35-year period for averages of rainfall in Great Britain and Northern Ireland has been 1881–1915. Averages for a new 35-year period, 1916–1950, will be increasingly brought into use during the next few years beginning, wherever practicable, with publications which include data for January 1958. Thus the averages for the new period will be used as the basis for reckoning percentage rainfall amounts in the *Monthly Weather Report* and the *Monthly Summary of the Daily Weather Report* for January 1958, and in *British Rainfall* 1958.

Tables of rainfall data supplied for publication in various monthly journals, including the *Meteorological Magazine*, will be prepared on the same basis, that is, the new period averages will be introduced with the data for January 1958. Some rainfall data, however, are supplied for eventual incorporation in year books or annual reports which refer to a 12-month period differing from the calendar year. The data in the *Surface Water Year Book* are grouped in "water years" from October to September. For this grouping of data the new period averages will be introduced for the water year 1957–58, that is, beginning with data for October 1957. Other reports are based on the financial year April to March, and it is proposed that in these cases the new period averages should be introduced for the year 1958–59, that is, beginning with data for April 1958.

In recent years there has been a growing demand for more up-to-date averages of rainfall; there has also been increasing difficulty in referring back to the earlier standard period, because of the decreasing number of rainfall stations still in existence for which observations are available for that period. Both these factors have made it necessary to change to the new period. A new book of averages, *Averages of Rainfall for Great Britain and Northern Ireland* 1916–1950, will be published during 1958, containing monthly and annual averages for 719 stations and an Introduction which includes a brief discussion of the relationships between the averages for the old period and the new. More detailed information linking the averages for the two periods, with particular relevance to applications of rainfall data, will be made available later.

A. BLEASDALE

Course on "Weather and flight"

A course on "Weather and flight" will be held under the direction of Dr. R. S. Scorer and the auspices of Birmingham University at Preston Montford Field Centre near Shrewsbury from 20–27 September 1958. The lecture programme is an attractive one ranging from "Mountain waves" to "Bird navigation" while the projected field-work programme extends from "Observing clouds by moonlight" to the "Study of air motion over obstacles using balloons and soap bubbles". The fee is £8 8*s*. including board and lodging. Application should be made as soon as possible to the Director of Extra-Mural Studies, The University, Edmund Street, Birmingham, 3, from whom further details can be obtained.

The Geophysical Journal

The Royal Astronomical Society announces the publication of a new quarterly periodical, "The Geophysical Journal", which will incorporate the former "Geophysical Supplement" to the "Monthly Notices" of the Society. The subjects which will be covered in the new periodical will be the same as those of the Geophysical Supplement, namely: geodesy, gravity measurements, seismology, oceanography, atmospheric physics, terrestrial magnetism, physics of the earth's interior, other branches of theoretical and observational geophysics and related topics in physics, mathematics and statistics.

The Society in its announcement stresses the previous lack of a regular English periodical covering such subjects as geodesy, gravity, seismology and the physics of the earth's interior.

The editors are Dr. A. H. Cook and Dr. T. F. Gaskell working in collaboration with Dr. R. A. Lyttleton, F.R.S., the Society's Geophysical Secretary. The first number published in March 1958 included papers on seismology, geomagnetism, gravity and the physics of the earth's interior by scientists in Great Britain, Australia, Canada, the United States and the Union of Soviet Socialist Republics. The price will be £3 for a volume of at least four parts. Further particulars should be obtained from the Society at Burlington House, London, W.1.

Stationary stratocumulus rolls

The values quoted for Scorer's parameter under the photograph of stationary stratocumulus rolls in the February 1958 Meteorological Magazine are of l^{-1} and "mi^{-1}" should read "mi".

REVIEWS

Dynamic meteorology and weather forecasting. By C. L. Godske, T. Bergeron, J. Bjerknes, R. C. Bundgaard. 11 in. × 8½ in., pp. xvi + 800, *illus.*, American Meteorological Society, Boston, Massachusetts, and Carnegie Institution of Washington, Washington D.C., 1957. Price: $15.

The authors of this book have international reputations as meteorologists; two of them were co-authors of *Physikalische Hydrodynamik*, to which the present book is a sequel, and Dr. Godske is well known as Professor of Meteorology at Bergen. From such authors we expect an authoritative book, both as regards theoretical and practical aspects, for they have initiated much of the research which has been carried out into dynamical meteorology and weather forecasting. According to V. Bjerknes's Preface the preparation of this book was commenced in 1935; during the war little communication was possible between the authors and collaboration began again in 1946 continuing to 1949–1950, when the text was completed. Another seven years elapsed before publication. During this time there was an upheaval in meteorological ideas and rapid advances made in the science. The difficulty of writing a text under these conditions must be remembered if any disappointment is felt for the book.

The book subdivided itself naturally into two parts, one on theoretical meteorology and one on the practice of meteorology. I began by reading the latter first, starting at Part IV, because it is the more difficult to write and also to find how many back-references there were, an indication of the contribution of theoretical meteorology to the forecasting problem. The chapters on general climatology and air-mass analysis are clearly written descriptive meteorology, which leave little scope for fresh presentation but which must be included in any text pretending to completeness. Frontal analysis is well presented, as we might expect from these authors, and the chapter on "Dynamical Analysis of Cyclones and Anticyclones", a rather high-sounding title, gives a clear three-dimensional picture of the atmospheric motions in frontal regions using deductions from both models and statistics. Thus illustrative matter is particularly good and the authors clearly have a feeling for the physical aspects. Tropical meteorology does not always get a mention in textbooks which are primarily concerned with extratropical weather phenomena, but there is a section here. The last chapter of Part IV deals with more local meteorological effects, such as sea-breezes and föhn winds, and also with diurnal effects. To the present reviewer Part IV seemed the most satisfactory part of the book, complete enough and with very adequate references.

Part V, which completes the book, consists of two chapters, one on synoptic weather analysis and one on weather forecasting; neither of these chapters reaches the high standard of Part IV. There are accounts of the observations which are taken and of the synoptic codes now in use. Neither of these seems suitable in a book of this character; observations are treated much more adequately elsewhere while the synoptic codes are ephemeral and one expects this book to be in use for many years. The principal example of frontal analysis—some twenty pages are allotted to it—relates to that given by Bergeron and Swoboda in 1924 and refers to the surface only. It seems a pity that the authors should have chosen to analyse a situation for which there were no upper air data, thus giving the impression that the latter do not materially aid in analysing near the surface. Subsequently, upper air analysis is described as if proceeding from a given 1000-millibar chart; one might have expected a unified treatment of the analysis of surface and upper air charts together. English students will not readily recognize the proposed technical vocabulary of upper air terms and abbreviations; these latter are carried into the text which would have been better in full even at the expense of a few extra pages. The upper air analysis itself is very well treated and even if manpower and time frequently prevent the carrying out of some of the stages, it is good to see them in print for they may be the basis of future research. Understandably the last chapter on "Weather Forecasting" is rather diffuse. Some good points are made about the distribution of observing stations and the relation between the area of analysis and that of forecasting. For the rest the authors advocate forecasting the pressure distribution by extrapolation blended with experience, drawing attention to modifying effects such as orography. Who could do more? There are paragraphs on the prediction of more local phenomena but these cannot be comprehensive. There were few references to the dynamical part of the book and these were confined to formulae which had been developed under specially simple conditions. Dynamical thought in meteorology has had little impact upon the practice of forecasting, except perhaps in the last few years.

The earlier part of the book stems from *Physikalische Hydrodynamik*, of which it is a direct continuation. The chapters on thermodynamics, statics of the atmosphere and radiation are clearly written and move at a pace suitable for a student. These preliminaries to the study of dynamical meteorology are necessarily stereotyped, only lending themselves to individual treatment when more recent results are being discussed and the authors seem to write more entertainingly about newer developments, such as the Elsasser diagram, than about the older parts such as Kirchoff's Law, for example. The hundred pages devoted to the kinematics of the atmosphere have an old-fashioned appearance. There is a whole chapter devoted to vector analysis despite the many excellent texts which deal fully with this subject; there is nothing new in the presentation which is especially adapted to meteorology except a few remarks about map projection and these do not arise out of the discussion of vectors. The inclusion of non-meteorological material to be found elsewhere must increase the price of the book. The sections on kinematics of simple systems, such as the steady circular vortex, will be useful to students in that they give manipulative practice and illustrate physical concepts, for these simple systems do represent gross features of some atmospheric motions. The kinematical forecasting of the movement of troughs, ridges and other simple geometrical patterns which appear on weather maps has not proved satisfactory in practice and is now of historical interest only, hardly meriting a chapter.

Part III, "Hydrodynamics of the Atmosphere," represents the most important part of the theoretical treatment. It is conceived on the lines of the Scandinavian research and represents a summary to 1950 of that classical standpoint. The difficulty has always been the lack of theory about non-linear equations and the classical method has been the linearization of the equations by using perturbation theory. Providing that there is little interaction between motions of different scales, that is between the Fourier components of different wavelengths, the perturbation method can give fairly good results and the equations are often solvable by analytic methods. The interactions are important in meteorological phenomena. The advent of high-speed computers has made possible the integration by numerical methods of non-linear equations so that the trend of recent dynamical research has been away from the analytic solution of simplified equations towards the direct numerical solution of equations which are capable of representing the interactions of meteorological systems. The pendulum may swing again towards analytic solutions but it is unlikely that the equations will be of the same type as those considered here. This change in emphasis has taken place in the last few years and the authors are unfortunate indeed in that there was a lapse of seven years between completion of the manuscript and publication. In 1950 their review of dynamical meteorology would not have seemed out of date—in fact the reverse; to-day they seem to place emphasis on less important aspects of dynamics. Of course, much that is basic remains unchanged. There are excellent discussions of the equations of motion, stability criteria and of the linearized equations resulting from perturbation theory; the application of these equations in Chapter 10 goes far towards explaining simple atmospheric wave motions, and later to other well known meteorological phenomena, such as waves in the lee of mountains. Finally there is an adequate chapter on turbulence.

There are many excellent features both for the student and the research worker. Each chapter is divided into sections and commences with an introduction describing briefly the contents of the chapter. Each numbered section of the chapter starts with an outline of its contents; these outlines are an excellent guide and in themselves form a short course in meteorology. At the end of each chapter is a bibliography and one has the feeling that a lead can be found into almost any meteorological problem. The book is sumptuously produced and magnificently illustrated; the line diagrams are superb (perhaps their production contributed to the delay in publication) and the coloured charts are beautiful. There is an index of some 1,500 items which, upon test, proved true; there is no name index. The symbolism looks rather strange in one or two instances—the generally recognized symbols for density and temperature are ρ and T and it is distracting to have to think in terms of other symbols.

This book is going to be a reference for many years and meteorological libraries throughout the world will have, no doubt, already bought it. The price represents about half a week's salary to a young scientist in England (perhaps one quarter for his American counterpart) and I find I am unable to offer him advice as to whether to buy or not.

E. KNIGHTING

Einführung in die Optik der Atmosphäre. By Dr. Gerhard Dietze. 9 in. × 6 in., pp. xi + 263, *illus.*, Akademische Verlagsgesellschaft Geest und Portig K.-G., Leipzig, 1957. Price: *DM* 29.

The number of books or parts of books dealing seriously with atmospheric optics is small but the quality is high. Dr. Dietze's book is worthy of its predecessors.

It is in eleven chapters (with an Appendix) which cover:

1. Introduction, units.
2. Apparent form of the sky and apparent magnification of bodies near the horizon.
3. Refraction; curvature of rays, terrestrial and astronomical refraction, mirage, looming, scintillation.
4. Haloes and associated phenomena.
5. Rainbows.
6. Coronae, glories.
7. Extinction, absorption and scattering—descriptive and instrumental.
8. The light of the sky by day and night.
9. Polarization.

10. Theories of extinction, scattering and polarization and applications to the atmosphere.
11. Visibility.

Appendix of 9 tables, for example, spectral sensitivity of the human eye in light and dark adaptation, extinction coefficient of the Rayleigh atmosphere.

The author claims to have chosen always the method of explanation leading most surely to an understanding of the physics of the subject. This claim is fully justified. The excellent line-drawings are almost explanations by themselves.

The book calls for a knowledge of mathematics and the theory of light to about General Certificate of Education Advanced Level standard. Electromagnetic theory is not used though results derived from it have, of course, to be stated. So far as optical phenomena in the ordinary sense are concerned, haloes, mirages etc., the book is similar to but rather less mathematical than the corresponding chapters in Humphreys's *Physics of the Air.*

There are very few descriptions of actual observations of phenomena and the book would have gained in vividness if more had been included. We must turn to Pernter and Exner, Humphreys and Minnaert for them. There are five excellent reproductions of colour photographs of the 22° halo and mock suns, a sun pillar, corona, and twilight.

It is up to date, quoting the discussion on scintillation held at the Royal Meteorological Society at the end of 1954. The only omission noticed was lateral refraction, for example, from a heated wall. No novel theories are included which might help to explain the few inexplicable phenomena reported to the Meteorological Office in recent years from marine observers. There is a good index.

Dietze has not the detailed descriptions of observations of optical phenomena and the full mathematical treatment of Pernter and Exner or the charm of Minnaert. It is however up to date in those subjects, especially visibility, in which advances have been made since those classics were written and it is a model of clarity and precision in its physical explanations.

G. A. BULL

Linkes Meteorologisches Taschenbuch. Band III. (Hilfsmittel des beobachtenden Meteorologen). $8\frac{1}{4}$ in. × 6 in., pp. xvi + 441, *illus.*, Akademische Verlagsgesellschaft, Geest & Portig K.-G., Leipzig, 1957. Price: 28 *D.M.*

This, the third and last part of the new edition of the Taschenbuch, is described in the sub-title as an aid to the observing meteorologist. It is in six chapters dealing respectively with radiation, optical phenomena, atmospheric electricity, bioclimatology, "surface" meteorological instruments and, finally, aerological instruments.

The chapter on radiation, which includes visibility, is a very concise summary of physical principles with formulae and tables of the radiation balance of the Northern Hemisphere and of the *H* and *Ei* functions of transmission theory. Instruments are not dealt with except for some information on filters.

The chapter on atmospheric optics is a good survey for the observer.

Atmospheric electricity is dealt with comprehensively and practically from the instrumental point of view by Israël and Dolezalek. Instruments are described in detail with a useful section on "practical tips" for their proper working. There is a list of firms making such instruments and their components in Germany, The United Kingdom and the United States of America and a good bibliography of books and papers. Radioactivity of the earth and atmosphere and cosmic radiation are included in this chapter.

Bioclimatology is restricted to human reactions to the state of the atmosphere and radiation. The well established parts of the subject such as the heat balance of the body and reactions to radiation are described in detail and the more speculative matters of meteorotropy sketched with appropriate reservations. This is probably as good a general account of the subject as has ever been published but it is not clear why it appears in a guide for the observing meteorologist.

The chapter on surface meteorological instruments is a broad survey of the physical principles of the instruments used in measuring temperature, cooling power, pressure, humidity, precipitation, wind and aerosols. Some details of instruments used in Germany and their adjustment and calibration are included. It does not, however, give the "practical tips" the officer in charge of an observing station needs to keep his instruments in good working order.

The chapter on aerological instruments is similar to the preceding one. It includes detailed descriptions of the official German, Swiss, French, American, British (Kew), and Finnish radio-sondes and of the Mullard radar-sonde and a bibliography of 137 papers, nearly all published since 1946.

G. A. BULL

Oceanic observations of the Pacific 1949. Edited by N. W. Rakestraw, P. L. Horrer and W. S. Wooster. 11 in. × 9 in., pp. 363, *illus.*, University of California Press (agents: Cambridge University Press), 1957. Price: 34*s.* net.

In this volume, the Scripps Institution of Oceanography of the University of California has published the results of soundings at oceanographical stations in the Pacific during 1949; the observations were made by several organizations including itself. It is intended to publish a second volume containing observations made prior to 1949 and later to publish a volume for each year subsequent to 1949.

For each station, values of temperature, salinity, oxygen, phosphate, or other measured concentrations are tabulated at observed and at standard depths. Computed values of density, specific volume anomaly and geopotential anomaly are tabulated at standard depths. Charts of the station positions and positions of bathythermograph observations precede the tabulations.

The publication is well produced and will conveniently make available to the oceanographer a wealth of data for the Pacific which could hitherto only be consulted by a few.

P. R. BROWN

Solar control and shading devices. By Olgyay and Olgyay. 11 in. × 8½ in., pp. vi + 201, *illus.*, Princetown University Press, Oxford University Press, 1957. Price: £5.

If the azimuth and elevation of the sun be known, and also the intensity of the incoming solar radiation, both direct and indirect, then the extent to which a building would be shaded from radiation by other buildings, or by inbuilt "shading devices" can be computed. This book is mainly a survey of methods, for use by architects, for simplifying this computation.

In addition short chapters are devoted to a summary of the effects of temperature, humidity and air movement on comfort; and to the relative importance of direct and indirect radiation on the heat economy of a building. The chapter on comfort contains a "bioclimatic chart" which is described as for "U.S. Moderate Zone Inhabitants". The chart is markedly different, especially as regards the effect of humidity, from similar charts published in this country, and no reference is made to any British work – for example, that of L. Hill and D. Brunt. The chapter on the relative importance of direct and indirect solar radiation is pretty well limited to a discussion of a single example: that of a south facing wall in New York.

The book is well produced and lavishly illustrated by photographs and diagrams.

RONALD FRITH

Three steps to victory. By Sir Robert Watson-Watt, 9 in. × $5\frac{3}{4}$ in., pp. 480, *illus.*, Odhams Press, 96 Long Acre, London, W.C.2. 1957. Price: 30*s*.

In any history of the Second World War, two facts are beyond dispute. The first is that radar played a major part in the defeat of Hitler's plans for the subjugation of Europe. The second is that Sir Robert Watson-Watt, more than any other man, was responsible for bringing about the use of reflected radio impulses as a weapon of war, so that when the Battle of Britain was fought, this country then possessed the best radar defences in the world.

This book is the autobiography of Robert Watson-Watt, from the family home in Brechin, Scotland, to his present residence in Canada. As most of the readers of this Magazine know, Watson-Watt began his career as a professional scientist in the Meteorological Office, where he initiated work on the detection of thunderstorms (sferics). In describing this period he makes some very frank comments on the official attitude to research in meteorology in the years immediately following the First World War. One result was that radio research and Watson-Watt severed all connections with the Meteorological Office in the early twenties. In 1935, with the aid of A. F. Wilkins, he produced a memorandum, for the Committee for the Scientific Survey of Air Defence, which laid down, for the first time, the essential principles of what is now known as radar.

The remainder of this very long book is concerned with the struggle to bring the idea to the operational stage, the setting up of the early "chain" stations, the Battle of Britain, airborne radar and finally, the part played by radar in the final assault. These are matters in which not only the author, but all who worked in this field, can take legitimate pride.

The story of radar is that of a simple but extremely fruitful basic idea which was brought to final success by the skill of many scientists, backed by the determination of one "dour Scot" to see it through. As such it should not be too difficult to tell. Unfortunately, in this book the true greatness of the story is lost in a torrent of words, nearly a quarter of a million all told, of which, at a guess, a third are redundant. The style is unattractive, and the author would have been well advised to let the facts speak for themselves, and the reader to come to his own conclusions concerning the author's repeated claim to be the "Father of Radar".

But even if the book disappoints, the story of radar cannot. Here, if ever, is the unique example of the scientific idea coming to fruition in the hour of greatest need. That we live today in freedom, and not under the yoke of a madman in Berlin, is due primarily to the men and women who fought and died in our defence. But courage is not enough—it must be backed by knowledge, and radar is an example of knowledge rightly applied and of the good that can come from single-mindedness and unshakeable belief in a cause. Those who took part in the development of radar before and during the war will discover much of interest in this book. For others it may be tedious, but everyone will find it revealing.

O. G. SUTTON

Weather record chart and calendar. By Reginald G. Cook. 14 in. × $9\frac{1}{2}$ in., pp. viii + 24, *illus.*, Edward Mortimer Ltd., 12, Thayer St., London, W.1. 1958. Price: 8*s.* post free.

This extremely well printed and produced Record Chart has been devised so that almost anyone interested in the weather can keep a systematic and permanent observational record. The general arrangement is good and consists of a four-page Introduction and one ample page for each month of the year, held together with a continuous wire "lay-flat" binding and provided with a metal loop for hanging. Perhaps a firm cardboard back, so that one need not always write flat against the wall, would be a minor improvement.

The vertical rulings on each page provide for daily observations of barometric pressure, wind, temperature, rainfall and sunshine, and the reverse side of each page is ruled for a daily weather diary. Suggestions for completing the various columns are contained in the Introduction. A map showing the various divisions of the British Isles and the adjacent sea areas used in forecasts broadcast by the British Broadcasting Corporation is also included.

The introduction would be improved by the inclusion of some advice on the siting of instruments and the taking of observations. It should, for example, indicate that for the readings to be comparable even among themselves they should be taken at the same time each day necessitating change of routine during British Summer Time. Mr. Cook offers to supply normals appropriate to the observer's locality (in the United Kingdom) but these will be of little use to the observer for comparative purposes if his instruments are not reasonably well exposed. Provision is made for recording wind direction but not speed; an observer, interested enough to install an expensive sunshine recorder, would no doubt welcome a reference in the Introduction to the Beaufort Scale with specifications of equivalent wind speeds. The average number of "rain-days" and "wet-days" quoted with the monthly normals would probably be more interesting to the amateur meteorologist than the average number of hours of rain as at present given. In the reference to the Beaufort notation it seems a pity that the letter *g*, which is now understood to stand for gale in the Meteorological Office, is given its old meaning of gloom. Some observers, no doubt, would not realize that the repetition of certain of the letters neatly denotes continuity. One more suggestion: the international symbols for drizzle and

Photograph by Betsy Woodward

WAVE CLOUD OVER SIERRA NEVADA, CALIFORNIA

Photographed from a glider at 6,500 metres, these wave clouds in lee of the Sierra Nevada show the turbulent "rotor" flow at low levels in contrast to the smooth stream aloft. With ice crystals being rather slow to evaporate, the wave cloud at cirrus tends to stream out farther downwind than the compact lenticular shaped altocumulus.

This photograph is reproduced from *Cloud study* by F. H. Ludham and R. S. Scorer. Publishers: John Murray, London, W.1.

Photograph by G. Nicholson.

INTERMITTENT CONTRAIL

We are indebted to Mr. G. Nicholson, 133, Stanley Road, Teddington, Middlesex, for this photograph of an intermittent contrail. It was taken at 3.43 p.m. on 6 January 1958 at Fulwell, Middlesex, looking south-west. Mr. Nicholson saw that it was being formed in steps. He reports the trail was non-persistent, disappearing within two minutes.

[Mr. R. F. Jones comments that since the trail was non-persistent conditions for its formation were marginal. Any one of the following explanations might be the right one:

(*a*) atmospheric temperature and humidity variations,
(*b*) variation of throttle setting by the pilot,
(*c*) variation of height by the pilot who may have noticed he was making a trail and deliberately ascended and descended through the trail-forming layer. Ed. *M.M.*]

showers, phenomena which are easily identified by the amateur, could with advantage be added to the list given.

The publishers are to be congratulated for producing a Calendar which serves such a useful purpose. It will no doubt find a ready sale to schools and farmers, and will also perhaps be found in many a private house near the beloved barometer. R. E. BOOTH

HONOURS

The following awards were announced in the Birthday Honours List in June, 1958:

O.B.E.

D. N. Harrison, D.Phil., Principal Scientific Officer, Meteorological Office.

M.B.E.

C. E. Jowitt, Senior Experimental Officer, Meteorological Office.

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. F. G. Hawkins, Experimental Officer, retired on 31 March 1958. He joined the office from the Air Ministry in January 1924 and was posted to the British Rainfall Division. In March 1924 he was transferred to the Climatology Division where he remained until 1930 when he was posted to the Forecast Division. In 1934 he was transferred to the Instruments Division and from 1939, until his retirement, he served continuously in the Administrative Division. Mr. Hawkins served in the Royal Flying Corps, later the Royal Air Force, from 1917 to 1920.

Social activities.—In connexion with the opening of a Meteorological Office at Gatwick Airport, the Meteorological Office Staff at Croydon Airport held a farewell dinner and dance in the Croydon Terminal Building on 11 April 1958 for the staff who were to be transferred to Gatwick. The guests included members of the Air Traffic Control, Telecommunications and Customs and their friends. Mr. T. N. S. Harrower was the guest of honour. Tribute was paid to the happy relations which had always existed between the Meteorological Office staff and the Airport staff and the hope was expressed that this family spirit would be carried on at Gatwick.

Sports activities.—*Boxing.*—Mr. J. Keers, Assistant (Scientific) at London Airport won the Civil Service Light Weight Boxing Championship. In the final Mr. Keers won in the first round. This is the first time a member of the Air Ministry staff has won a Civil Service Boxing Championship.

WEATHER OF MARCH 1958

Northern Hemisphere

The main region of cyclonic activity over the North Atlantic was much further south than usual for March. On the mean monthly pressure chart the main low pressure area was situated to the north-west of the Azores at about 45°N., 40°W., where pressure was 15 millibars below normal. Associated negative pressure anomalies occurred in a belt extending from the eastern states of the United States across the Atlantic south of 50°N., and across central and southern Europe. A small anticyclone of 1020 millibars was situated over central Scandinavia, and consequently the mean flow during the month across Europe between approximately 45°N. and 60°N. was easterly or north-easterly instead of the more normal south-westerly flow.

A large anticyclone of 1030 millibars was centred over Hudson Bay and extended over nearly all Canada and the central states of the United States. Mean pressures were above normal in this region and over all the Arctic, the maximum anomaly being +16 millibars a little north of Hudson Bay. Iceland and Spitsbergen both had pressure anomalies of +11 millibars.

The Siberian anticyclone was near normal in position, but the central pressure was 3 millibars below the normal. Over the Pacific, the Aleutian low was 5 millibars deeper than the average for March, and displaced to a position over the Kamchatka Peninsula. The North Pacific high was near normal in intensity but a little further north than usual.

Mean temperatures for the month were below average over all Europe, apart from Spain, largely as a result of the abnormal easterly flow during the month. The greatest reported anomalies were −5°C. and occurred in southern Sweden, southern Germany and Austria. Weaker flow than usual over northern Asia, allowing stagnation of the air over a snow covered surface, gave surface temperature anomalies of up to −5°C. in that region.

There were positive temperature anomalies throughout Canada, with temperatures as much as 9°C. above the average in Quebec where the usual north-westerly advection of cold air was absent. Over the United States temperatures were generally 2°C. or 3°C. below normal, although in Kansas anomalies of −5°C. occurred.

Rainfall amounts were less than normal over most parts of Scandinavia, central Europe, and the British Isles, but up to three times the normal over the Balkans. There were some unusually large totals for the month in California, but in other parts of North America amounts were generally near or below the average for March.

WEATHER OF APRIL 1958

Great Britain and Northern Ireland

April began with cold easterly winds which had been a characteristic of the last two weeks of March; winds backed to a north-easterly direction on the 6th and weather remained cold until the middle of the month, with temperature mostly below 50°F. Westerly winds and mild changeable weather prevailed during the second half of the month; temperature exceeded 70°F. during the last few days.

With high pressure over north-east Europe the air reaching the British Isles during the first three days of the month was cold and dry apart from a few snow showers in eastern districts. On Good Friday, the 4th, a depression moved into the North Sea from France and turned west across northern England, later filling as it moved southwards over the Irish Sea. The following day a second depression performed a similar rotation over southern England and northern France. These depressions were accompanied by widespread rain and snow with strong winds in some northern districts which caused considerable drifting. The week-end was one of the coldest Easter week-ends on record and, in some areas, the wettest; at Kew, with afternoon temperature only reaching 45°F., it was the coldest Easter Saturday of the century. Settled weather was re-established on the 6th as high pressure developed to the north-west of the British Isles. From the 7th to the 12th there were scattered showers of rain and snow but sunshine was fairly plentiful, although on the 10th a small depression gave heavy rain for a time in Devon and Cornwall. On the 12th warmer air from the Atlantic reached northern Scotland and spread slowly south into northern England; temperature at Edinburgh reached 63°F. on the 14th, more than 20°F. higher than at Margate. A fresh outbreak of northerly winds brought a temporary return of cold weather to all districts on the 15th and 16th with scattered rain and sleet showers but there were long sunny periods. On the 16th Aberporth had 13·5 hours of sunshine, the highest daily total of the year so far, but thereafter weather was generally changeable and mild. From the 21st temperatures reached the sixties in many places, but it was cool along parts of the west coast, where sea fog was persistent from 19th–22nd. Rain was fairly widespread from 24th–26th. For the last two days of the month a warm anticyclone covered much of the country giving sunny weather generally with temperatures of over 70°F. locally; 75°F. was reached at Hampton, Middlesex.

Over the month as a whole temperature was mostly below average except in northern Scotland. In most places the warmer weather of the latter half of the month failed to compensate for the cold of the first two weeks when temperature locally was as much as 7°F. below the April normal. Rainfall was 52 per cent of the average in England and Wales and 75 per cent in Scotland, where, following the spell of dry April months, it was the wettest April since 1953. Sunshine was about average in most places but slightly below in the south-west.

The long cold spell at the beginning of the month delayed most crops and reports of frost damage to salad crops, cabbage and early potatoes came from many districts. Top fruit also was behind, but it was hoped that the delayed flowering might give some chance of escape from late frosts. The warmer weather at the end of the month brought very rapid growth, especially in the stages of fruit blossoming.

WEATHER OF MAY 1958

Great Britain and Northern Ireland

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 ...	80	25	0·0	133	+5	94
Scotland	75	19	−1·3	132	+3	108
Northern Ireland ...	71	29	−1·5	108	+1	103

* 1916-1950 † 1921-1950

RAINFALL OF MAY 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	2·25	127	*Carm.*	Pontcrynfe	5·09	143
Kent	Dover	2·20	126	*Pemb.*	Maenclochog, Dolwen Br.	5·82	165
,,	Edenbridge, Falconhurst	1·84	86	*Radnor*	Llandrindod Wells ...	2·79	103
Sussex	Compton, Compton Ho.	3·38	137	*Mont.*	Lake Vyrnwy	6·54	179
,,	Worthing, Beach Ho. Pk.	2·60	158	*Mer.*	Blaenau Festiniog ...	9·55	150
Hants	St. Catherine's L'thouse	2·80	152	,,	Aberdovey	3·80	130
,,	Southampton, East Pk.	2·15	106	*Carn.*	Llandudno	2·37	115
,,	South Farnborough ...	2·16	113	*Angl.*	Llanerchymedd ...	4·59	170
Herts.	Harpenden, Rothamsted	1·98	96	*I. Man*	Douglas, Borough Cem.	3·35	116
Bucks.	Slough, Upton ...	2·44	124	*Wigtown*	Newtown Stewart ...	2·76	92
Oxford	Oxford, Radcliffe ...	2·13	105	*Dumf.*	Dumfries, Crichton R.I.	3·88	142
N'hants.	Wellingboro' Swanspool	2·12	105	,,	Eskdalemuir Obsy. ...	4·34	115
Essex	Southend W.W. ...	1·75	112	*Roxb.*	Crailing...	2·43	121
Suffolk	Ipswich, Belstead Hall	2·35	142	*Peebles*	Stobo Castle	2·47	95
,,	Lowestoft Sec. School	2·82	189	*Berwick*	Marchmont House ...	2·73	124
,,	Bury St. Ed., Westley H.	2·24	121	*E. Loth.*	N. Berwick	1·96	93
Norfolk	Sandringham Ho. Gdns.	3·31	161	*Midl'n.*	Edinburgh, Blackf'd H.	1·97	89
Dorset	Creech Grange... ...	2·54	109	*Lanark*	Hamilton W.W., T'nhill	2·76	105
,,	Beaminster, East St. ...	3·61	138	*Ayr*	Prestwick	2·59	116
Devon	Teignmouth, Den Gdns.	2·68	118	,,	Glen Afton, Ayr. San ...	3·54	105
,,	Ilfracombe	3·20	142	*Renfrew*	Greenock, Prospect Hill	4·50	125
,,	Princetown	8·19	167	*Bute*	Rothesay, Ardencraig...	3·71	106
Cornwall	Bude	2·55	121	*Argyll*	Morven, Drimnin ...	3·38	101
,,	Penzance	3·22	132	,,	Poltalloch	2·95	85
,,	St. Austell	5·13	168	,,	Inveraray Castle ...	6·16	132
,,	Scilly, St. Mary ...	2·66	123	,,	Islay, Eallabus ...	2·63	87
Somerset	Bath	2·24	98	,,	Tiree	2·70	106
,,	Taunton	2·21	99	*Kinross*	Lock Leven Sluice ...	2·39	88
Glos.	Cirencester	2·55	98	*Fife*	Leuchars Airfield ...	1·97	89
Salop	Church Stretton ...	2·23	84	*Perth*	Loch Dhu	5·93	131
,,	Shrewsbury, Monkmore	1·92	91	,,	Crieff, Strathearn Hyd.	3·25	114
Worcs.	Worcester, Diglis Lock	...	...	,,	Pitlochry, Fincastle	3·29	129
Warwick	Birmingham, Edgbaston	2·18	84	*Angus*	Montrose Hospital ...	2·83	125
Leics.	Thornton Reservoir ...	1·78	78	*Aberd.*	Braemar	...	...
Lincs.	Cranwell Airfield ...	2·14	108	,,	Dyce, Craibstone ...	3·28	122
,,	Skegness, Marine Gdns.	2·54	154	,,	New Deer School House	2·90	115
Notts.	Mansfield, Carr Bank...	2·37	111	*Moray*	Gordon Castle	2·73	131
Derby	Buxton, Terrace Slopes	4·72	163	*Inverness*	Loch Ness, Garthbeg ...	3·63	132
Ches.	Bidston Observatory ...	2·30	102	,,	Fort William	6·50	163
,,	Manchester, Airport ...	2·31	103	,,	Skye, Duntulm... ...	6·87	239
Lancs.	Stonyhurst College ...	5·86	210	,,	Benbecula	4·08	149
,,	Squires Gate	3·22	137	R. & C.	Fearn, Geanies ...	...	...
Yorks.	Wakefield, Clarence Pk.	2·51	113	,,	Inverbroom, Glackour...	6·11	237
,,	Hull, Pearson Park ...	2·23	115	,,	Loch Duich, Ratagan...	7·04	179
,,	Felixkirk, Mt. St. John...	3·15	156	,,	Achnashellach	8·20	215
,,	York Museum	3·40	173	*Suth.*	Stornoway	5·06	221
,,	Scarborough	2·43	132	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough... ...	2·47	145	,,	Wick Airfield	3·25	180
,,	Baldersdale, Hury Res.	4·68	199	*Shetland*	Lerwick Observatory ...	3·92	178
Nor'l'd	Newcastle, Leazes Pk....	3·08	147	*Ferm.*	Belleek	3·27	114
,,	Bellingham, High Green	3·38	150	*Armagh*	Armagh Observatory ...	2·64	112
,,	Lilburn Tower Gdns ...	2·77	133	*Down*	Seaforde	4·41	150
Cumb.	Geltsdale	3·34	135	*Antrim*	Aldergrove Airfield ...	2·76	112
,,	Keswick, High Hill ...	5·02	157	,,	Ballymena, Harryville...	2·57	85
,,	Ravenglass, The Grove	4·03	144	*L'derry*	Garvagh, Moneydig ...	2·42	88
Mon.	A'gavenney, Plâs Derwen	4·20	143	,,	Londonderry, Creggan	3·29	115
Glam.	Cardiff, Penylan ...	4·32	148	*Tyrone*	Omagh, Edenfel ...	2·70	96

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,034, AUGUST 1958

AN EXPEDITION TO THE HIGH ANDES IN SOUTHERN PERU: SOME NOTES ON THE PARTY'S WEATHER LOG

By H. H. LAMB, M.A. and J. JEWELL, B.Sc., A.R.C.S., A.R.I.C.

In 1956 a small British climbing party visited the high Cordillera Vilcanota, occupying a base camp about 5,050 metres (16,600 feet) above sea level at 13°51'S., 70°53'W., from 22 May to 4 July (southern winter). Three members, Messrs. J. Jewell, P. O'Donoghue and R. Whitling, sailing from Liverpool on the S.S. *Reina del Pacifico* in April, were joined in Peru by Mr. C. Darbyshire, a British mountaineer living in Lima. Jewell and Whitling had had Himalayan experience. Very few British expeditions have ever visited the Andes.

A small selection of meteorological instruments, chosen with an eye to portability, were loaned by the Meteorological Office. Because the area is so little-known meteorologically, considerable interest was taken in the weather observations which the party were able to make. The venture went without any financial grants from official bodies, but was supported by provisioning given free by several British and one Swiss firm through their agents in Lima. The party travelled by public transport, road and rail, the 900 miles from the port Callao near Lima to Sicuani over 3,500 metres up in the Vilcanota Valley, 70 miles south-east of Cusco. From this point the base camp was reached by a 3½ days' trek with hired mules up the mountain towards the Chimboya pass (5,235 metres), a route to the Amazon which is said to be never blocked by snow.

The Cordillera Vilcanota (see Plate I), of which the highest peak is Ausengate (about 6,400 metres), drops away steeply on its north-eastern side to the Amazon basin and the jungle. To the south-west between this area and the Pacific are other great ranges with peaks of similar height and extensive ridges above 5,000 metres, whilst about a hundred miles south-south-east is Lake Titicaca and the beginning of the broad Altiplano with its hundreds of miles of country above 3,000 metres in Bolivia and the borders of Peru. The nearest geographical and climatic analogies are with the Himalaya, Tibet and the lowlands of northern India and Assam, but the disposition of surrounding continent and ocean is quite different.

The base camp was on the floor of a high valley, half a mile wide, about two miles south-west of the pass and with snow-capped peaks rising directly above it (see Plate II). There is also an extensive ice-cap (Quenamari Ice Plateau) at 5,500–5,800 metres on the Cordillera south of the Chimboya Pass (see Plate III): the western edge of this hitherto unmapped ice plateau was surveyed by the expedition. There appeared to be evidence that the ice-sheet is receding.

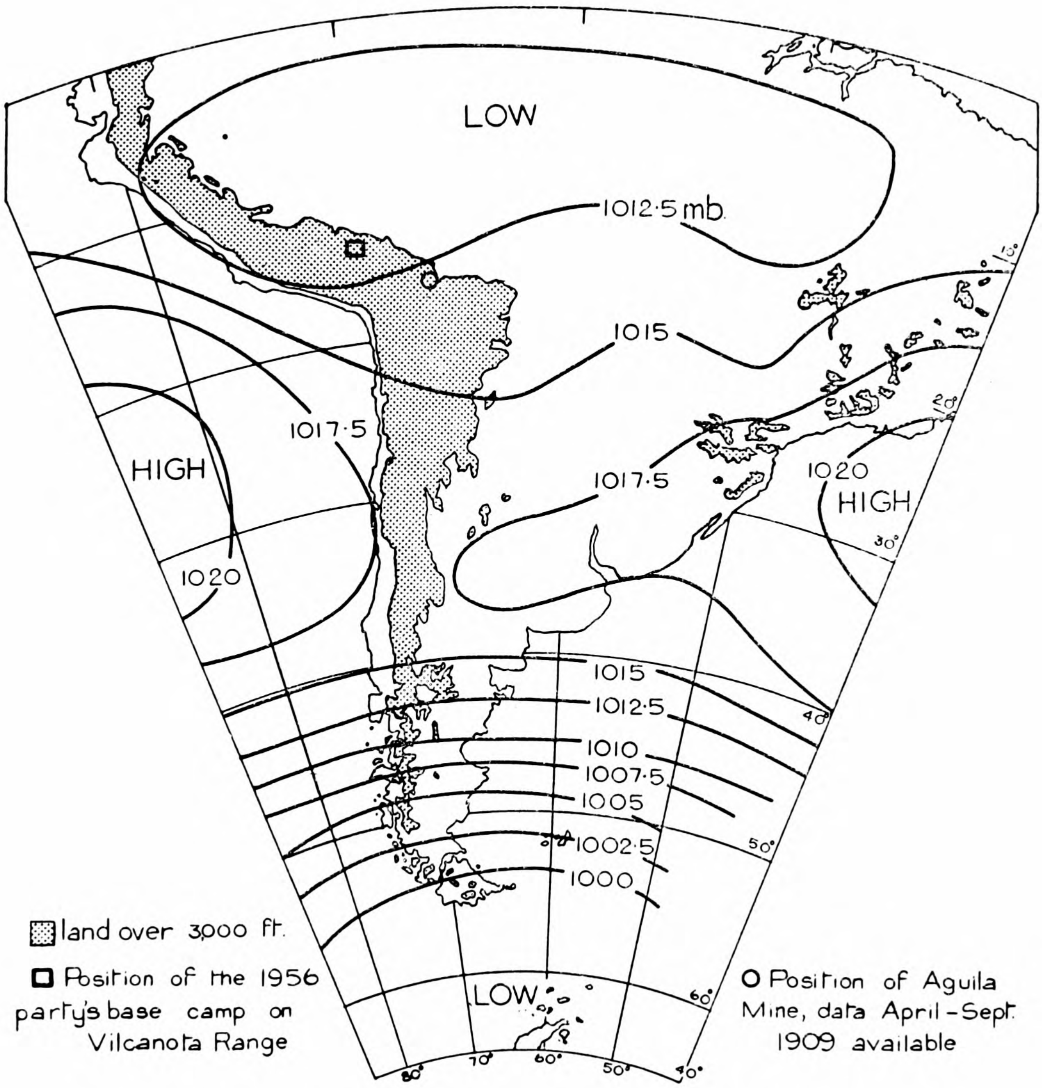


FIGURE I—NORMAL MEAN-SEA-LEVEL PRESSURES IN JUNE

Weather on the outward journey.—The voyage across the Atlantic between 10 and 18 April from Vigo, north-west Spain direct to Trinidad, passing near 29°N. 40°W., was made in constant south-westerly breezes without ever encountering the trade wind—an experience which is liable to occur at times when the usual Azores anticyclone is much displaced or non-existent. Air temperatures, which had been 27° to 30°C. in the Caribbean and Panama, fell on the Pacific side as the equator was approached and the cold water of the Humboldt Current was encountered: at local noon on 25 April in 7°S. off the coast of Peru the dry-bulb temperature was 19°C.

Near Lima in the coastal desert strip in early May, and again on returning in July, the party experienced the thick low overcast, locally known as *garua*, which is a persistent winter condition there. At the end of April, however, the

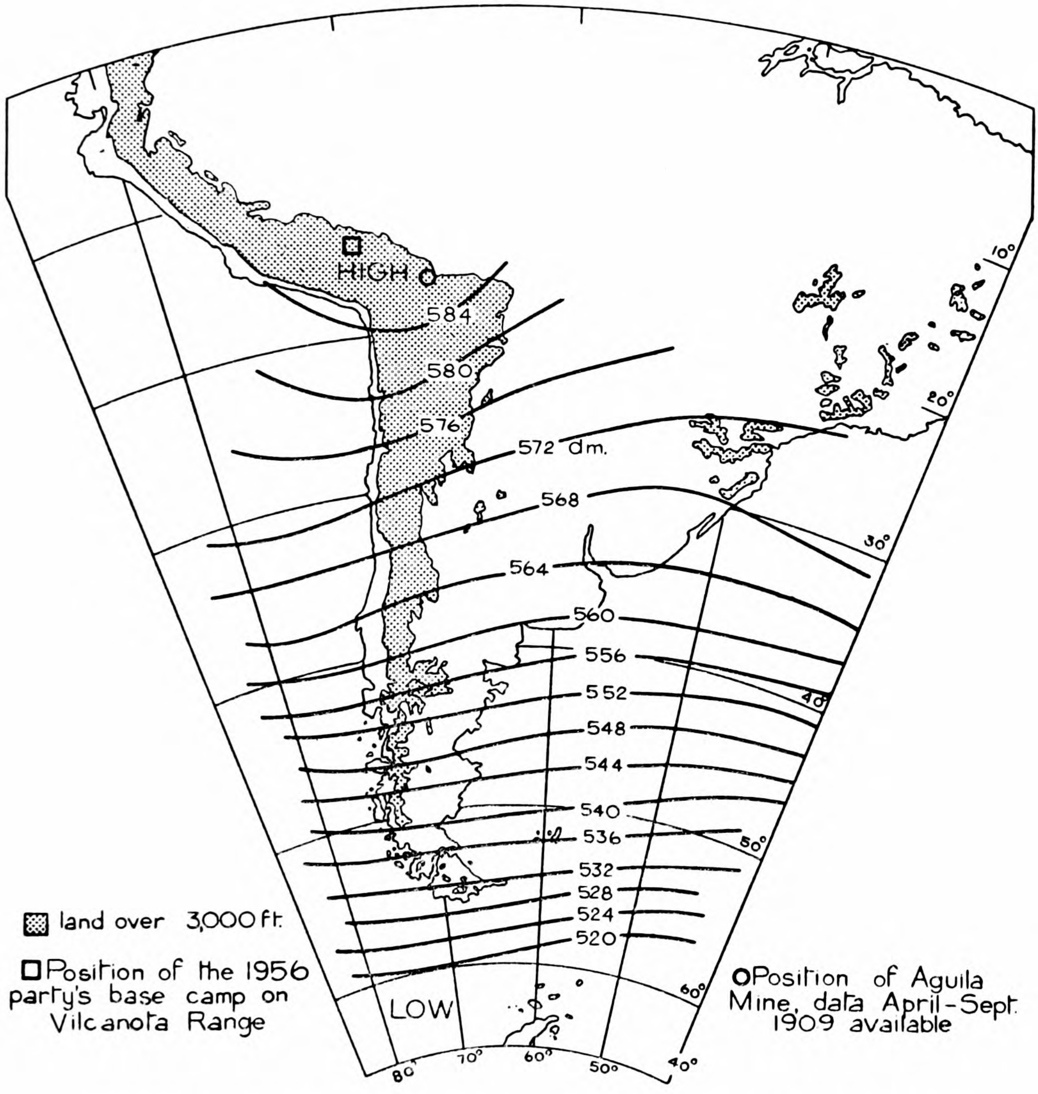


FIGURE 2—MEAN 500-MILLIBAR HEIGHTS (DEKAMETRES) IN WINTER

weather at Lima had been fine. The highway to Arequipa, Peru's second city (height about 2,500 metres above sea level), climbed through the low cloud into a region where the winter is pleasantly cool and sunny. Day temperatures at Arequipa were 20° to 22°C. Relative humidities almost constantly in the range 20 to 50 per cent pointed to the influence of subsiding air in this climate of the levels above the inversion, stratus and sea-breezes of the coastal strip. There is more rainfall in summer when thunderstorms are normally frequent over the mountains: the snow-line falls lower in summer in consequence.

In 1955–56 the summer rains had failed in the area about Lake Titicaca and the region was suffering from severe drought. Sunshine continued while the expedition was in the main Vilcanota Valley, though this valley running north-west between Sicuani and Cusco is narrow, well watered and agricultural in contrast to the arid Altiplano. The winds at these levels in winter normally blow from the north-east quadrant across the mountains from the Amazon side with frequent snowfall on that side of the peaks. Lightning was often seen from the base camp at night over the mountains to the north. The normal mean-sea-level pressure pattern in June and the average winter 500-millibar contours are shown in Figures 1 and 2 on which the position of the expedition's base is also marked.

Observations at the base camp on the Vilcanota range: 22 May–4 July.—Temperatures and humidities summarized in Table 1 were taken with a whirling psychrometer. Some days were missed when the party was out climbing, but in all cases observations on 30 to 40 days were included. The values undoubtedly give a reasonable impression of the prevailing conditions and of the range of variation, which was considerable in all items. The diurnal range of temperature clearly betokened fierce radiation at this height over a snow-free, dry surface: the average rise of temperature from 0800–1300 local time was about 8°C. and the range between the extreme air temperatures during the six weeks probably approached 30°C. Wind speed was observed by hand anemometer. Winds blew only up or down the valley. The wind direction showed no diurnal changes, being predominantly north—that is, down valley—at all hours of observation; however there was a spell of seven days from 10 to 16 June when the wind was consistently from the south and two other observations of south winds on the 18th and 23rd. Prevailing cloud amounts were small on the base camp (southern) side of the range, but much greater on the other side.

TABLE I—SUMMARY OF OBSERVATIONS AT BASE CAMP

(a) Air temperatures and humidities

	Local time	Mean	Highest	Lowest
		°C.	°C.	°C.
Air temperature ...	0800	0·7	10·0 (16/6)	−7·2 (3/7)
	1300	8·9	14·7 (27/6)	3·3 (29/5)
	1730 (about)	1·5	5·8 (31/5)	−3·6 (30/6)
Grass minimum temperature		−11·8	−5·3 (30/5)	−20·3 (4/7)
		%	%	%
Relative humidity	0800	74	100 (25, 26, 29/5 and 2, 3/6)	36 (15/6)
	1300	56	93 (30/6)	25 (14/6)
		mb.	mb.	mb.
Vapour pressure ...	0800	5·3	6·9 (24/6)	3·7 (8, 13/6)
	1300	6·5	13·9 (30/6)	3·0 (14/6)

Figures in brackets give the date of occurrence.

Time of observation (local time)	(*b*) *Percentage frequency of various Beaufort wind forces* Beaufort force								
	0	1	2	3	4	5	6	7	8
					%				
0800	68	3*	16	5	3	0	0	0	0
1300	13	7	7	43	20	7	3	0	0
1730 (about)	21	5	41	18	15	0	0	0	0

* This figure should probably be amended to 8 per cent to take account of several mornings when wind speed was not recorded but in fact very light.

Time of observation (local time)	(*c*) *Percentage frequency of various (total) cloud amounts* Oktas								
	0	1	2	3	4	5	6	7	8
					%				
0800	48	26	10	8	0	3	3	3	0
1300	10	33	10	13	13	13	0	3	3
1730 (about)	23	26	15	21	0	8	0	8	0

	(*d*) *Prevailing cloud types (percentage of days)* Cloud types			
Time of observation (local time)	Cumulus, cumulonimbus or fractocumulus	Stratocumulus	Cirrostratus or altostratus	Cirrus or cirrocumulus
		%		
0800	11	16	18	8
1300	33	43	10	3
1730 (about)	26	39	3	3

Only the one predominant cloud type was entered at each observation.

Discussion.—Table II shows the course of the weather during the period at base camp. The variability noted in Table I is seen to have been to a considerable extent associated with different spells each of several days duration. The first week was cold, calm and moderately cloudy. 30 May to 3 June was a period of higher temperatures and unsettled, with maximum cloudiness and precipitation liability. There followed some clear, cold days with little wind. The period of southerly winds from 10 June brought, on the whole, the finest weather, the air being at first notably dry and of moderate temperature, but temperatures and humidities rose by the end of the spell to higher values than had been observed before: this period seems to have been used for most of the climbing and it may be presumed that the usual clouds were missing from the Amazon side of the mountains. The returning northerly winds from 24–30 June were stronger than before and brought high temperatures and high humidity. Temperatures fell sharply in the first days of July, apparently with lighter northerly winds, and there was rather frequent snowfall on the Amazon side of the mountains.

Observations, including direction of motion of cloud at various levels, were made between April and September 1909 at the mine Aguila (17°5′S. 67°15′W.; height 5,233 metres) (see Figures 1 and 2), near the top of the north-east face of the mountains at the edge of the broadest part of the Altiplano in Bolivia, by the German meteorologist Knoche. These observations, which relate to a point about 300 miles south-east of the present climbing party's base camp, have been

TABLE II—DAILY VALUES AT BASE CAMP
(Mean or range of three observations per day)

Date	Mean air temperature	Mean vapour pressure	Wind Direction	Wind Beaufort force	Mean cloud amount	Weather
	°C.	mb.			oktas	
May 23						10 cm. snow night of 22–23rd.
24	2·5	5·3	N.	0–2	3·0	
25	2·7	...	N.	0–2	4·7	
26	2·8	...	N.	0–2	2·3	
28	2·9	...	unknown	0–3	2·0	
29	2·6	5·6	unknown	3	2·0	
30	3·2	5·4	N.	0–3	5·7	Slight snow morning.
31	4·3	5·1	N.	0–3	5·3	¾ hr. snow afternoon.
June 1	3·9	5·0	N.	3–4	2·3	
2	3·2	...	N.	0–4	2·0	
3	4·4	5·9	N.	0–2	4·7	Hail twice in afternoon.
4	4·2	5·1	N.	0–4	0·7	
6	2·9	...	N.	0–3	0·0	
7	3·7	...	Calm		1·3	
8	2·7	3·5	N.	0–2	0·7	
9	1·8	5·1	N.	0–3	2·0	
10	3·6	4·1	S.	0–3	3·0	
11	3·9	3·5	S.	0–5	0·7	
18	6·8	6·8	S.	0–3	2·7	
23	5·3	7·5	S.2 became N.6		0·3	
24	5·5	8·2	N.	0–3	0·7	
26	6·8	...	N.	2–4	2·0	
27	6·2	5·3	N.	2–3	1·7	
28	7·2	8·2	N.	2–3	2·0	
30	5·4	...	N.	3–4	0·0	
July 1	4·0	...	N.	2–3	2·0	Snow morning of 2nd.

submitted to an interesting analysis by Flohn[1]. We know from this analysis that at Aguila the prevailing north-east wind was usually replaced by a down-slope (here south-westerly wind) at night, and that at 17°S. at no great height above the Altiplano the prevailing upper westerlies (actually blowing from west-south-west) were encountered. The high peaks south of about 17°S. are probably affected by prevailing west-south-west winds throughout the year, and in 23°S. climbers have reported that the peaks (5,750 to 6,750 metres above sea level) are liable to westerly storms "of fearful violence"—evidently associated with the subtropical jet streams of higher levels.

The Cordillera Vilcanota in Peru (13–14°S.) is probably too near the equator to come frequently within the régime of upper westerlies. Summit observations from El Misti (16°S. 71°W.; 5,850 metres) near Arequipa show 80 per cent northerly winds in winter, but more variable winds in summer with a small predominance of southerly (see Flohn[1]). The Vilcanota range probably enjoys a similar régime. The daily mean temperatures at the base camp suggest heights of the 500-millibar pressure level (5,800 to 5,900 metres) which must be always near the maximum of the daily distributions occurring over the Southern Hemisphere in midwinter, so that the alternately northerly and southerly air motion marks the passage of cell divisions in the belt of maximum pressure.

The expedition observations indicate

(i) very high levels for both 500-millibar pressure and the freezing level in this region and

(ii) a considerable magnitude of fluctuation during the six weeks.

From examination of the synoptic charts for each day published in the *Chilean Daily Weather Reports* it seems possible that the few occasions when precipitation fell on the south side of the Vilcanota range, and some of the other variations at the base camp, may be connected with trailing cold fronts penetrating the area from the south and west about 22, 31 May, 9, 22 June and 2 July: in most cases these disturbances were preceded by a day or two in which cirrostratus was in evidence and were followed by more stratocumulus. In all cases the snow or hail was accompanied by cloud noted as cumulus, cumulonimbus or nimbostratus. The case of 31 May was special in that precipitating clouds hung about for several days afterwards, and in the case of 22 June there was no precipitation reported. This general interpretation seems to have been first put forward by Coyle[2] and agrees with the general implication of one of the present authors' study of the Atlantic and African sectors[3]. All precipitation at base-camp level fell as snow or hail. Only once (22 May) was any appreciable depth reported: even then the snow soon melted in the next day's sunshine, though it continued lying two miles further up a valley directly north of the camp—this valley led to a glacier pass over the main Vilcanota range and down to the jungle.

REFERENCES

1. FLOHN, H.; Zur vergleichenden Meteorologie der Hochgebirge. *Arch. Met., Wien*, **6**, 1955, p. 193.
2 COYLE, J. R.; A series of papers on the weather of South America. Pan American Airways System, Rio de Janeiro, 1943.
3. LAMB, H. H.; Fronts in the intertropical convergence zone: an observer's log and some reflections thereupon. *Met. Mag., London*, **86**, 1957, p. 76.

ERRORS IN THE GEOSTROPHIC VORTICITY CALCULATED AT 100 MILLIBARS

By D. W. MARTIN, D.Phil.

Summary.—The standard error in the geostrophic vorticity at 100 millibars in the neighbourhood of the British Isles, due to errors in the winds used in drawing the contour charts, is estimated to be about 10 per cent of the Coriolis parameter.

Introduction.—The geostrophic vorticity is normally derived from the field of contour height, and the errors in the calculated vorticity can be deduced if the errors in the contour heights used are known. However, it is not easy to assess the errors in contour heights interpolated from a contour chart since the contour lines give a partially smoothed field and are not drawn strictly to the height observations. The problem becomes acute at 100 millibars where the height observations contain serious errors. Fortunately, the 100-millibar wind can be measured with reasonable precision and due to the steadiness in space and time of the 100-millibar wind field, the ageostrophic components of motion are thought to be small. In consequence the gradients and directions of 100-millibar contour lines are drawn to the winds rather than to the heights. So, although the errors in the interpolated contour heights cannot be related to the errors of the observed contour heights, it is possible to estimate the errors of the drawn contour gradients from the known errors of the observed winds. In the following section, the finite difference formula used in calculating geostrophic vorticity from the contour height field is re-written in terms of gradients, so that the errors in the calculated vorticity may be expressed in terms of the errors of the observed winds.

Expressions for the vorticity.—The geostrophic relative vorticity on an isobaric surface is

$$\zeta_p = \left(\frac{\partial}{\partial x}\right)\left\{\frac{g}{l}\left(\frac{\partial h}{\partial x}\right)\right\} + \left(\frac{\partial}{\partial y}\right)\left\{\frac{g}{l}\left(\frac{\partial h}{\partial y}\right)\right\} \doteq \frac{g}{l}\nabla^2 h,$$

where g is the value of gravity, l the Coriolis parameter, and h the height of the isobaric surface, derivatives being in the isobaric surface.

It is customary to evaluate this expression by means of the finite difference approximation,

$$\nabla^2 h = \frac{1}{b^2}\Delta,$$

where Δ is $\sum_A^D h - 4h_O$, and is calculated from the contour chart, h_O and h being the contour heights at the centre O, and extremities A, B, C, D of a cross of semi-arm b (taken here in the order left, right, bottom, top).

If h is measured in hundreds of feet, and b in nautical miles at latitude 55°, then the vorticity thus calculated is

$$\xi = \frac{g}{lb^2}\Delta \text{ in units } 10^{-5} \times \text{sec}^{-1} : \qquad \ldots\ldots\ldots\ldots(1)$$

$g/lb^2 = 1$ and 2 for $b = 280$ and 200 nautical miles respectively.

Now, if U, V, are the components of the wind at the mid-points of the arms of the cross indicated by the suffices (α, β, γ, δ) then the geostrophic approximation gives

$$\frac{h_A - h_O}{b} = -\frac{l}{g}V_\alpha;\ \frac{h_B - h_O}{b} = \frac{l}{g}V_\beta;\ \frac{h_C - h_O}{b} = \frac{l}{g}U_\gamma;\ \frac{h_D - h_O}{b} = -\frac{l}{g}U_\delta.$$

Since $\Delta = (h_A - h_O) + (h_B - h_O) + (h_C - h_O) + (h_D - h_O)$, we see that

$$\xi = \frac{1}{b}\left\{(V_\beta - V_\alpha) - (U_\delta - U_\gamma)\right\}. \qquad \ldots\ldots\ldots\ldots(2)$$

Expression for the standard error.—We write the true geostrophic vorticity as the sum of the calculated geostrophic vorticity, ξ, and an error, θ, and the true south wind at α as the sum of the wind given by the chart V_α (whether it is a reported wind or not) and an error $\varepsilon_{y\alpha}$, etc. Thus, analogous to (2), we have

$$b(\xi + \theta) = (V_\beta - V_\alpha) - (U_\delta - U_\gamma) + \varepsilon_{y\beta} - \varepsilon_{y\alpha} - \varepsilon_{x\delta} + \varepsilon_{x\gamma},$$

where, from (2)

$$b\theta = \varepsilon_{y\beta} - \varepsilon_{y\alpha} - \varepsilon_{x\delta} + \varepsilon_{x\gamma}. \qquad \ldots\ldots\ldots\ldots(3)$$

Similarly we may write the true vector wind at any point of the chart as the sum of wind vector from the chart, $\mathbf{Q}$ and an error $\boldsymbol{\varepsilon}$. Thus

$$Q^2 = U^2 + V^2$$

and $$Q^2 + 2\mathbf{Q}.\boldsymbol{\varepsilon} + \varepsilon^2 = (U + \varepsilon_x)^2 + (V + \varepsilon_y)^2.$$

Subtracting, $$2\mathbf{Q}.\boldsymbol{\varepsilon} + \varepsilon^2 = 2U\varepsilon_x + \varepsilon_x^2 + 2V\varepsilon_y + \varepsilon_y^2,$$

so that $$2Q\varepsilon + \varepsilon^2 \geqslant 2U\varepsilon_x + \varepsilon_x^2 + 2V\varepsilon_y + \varepsilon_y^2 \geqslant -2Q\varepsilon + \varepsilon^2.$$

If it be assumed that the magnitude of the wind Q and its components U, V at any place are negligibly correlated over time with the corresponding errors ε, ε_x, ε_y, and in such a manner that, summing with respect to time,

$$\Sigma Q\varepsilon = \Sigma U\varepsilon_x = \Sigma V\varepsilon_y = 0;$$

then $$\Sigma\varepsilon^2 = \Sigma\varepsilon_x^2 + \Sigma\varepsilon_y^2.$$

If also the errors at different places on the charts are uncorrelated, and $\Sigma\varepsilon_{xy}^2 = \Sigma\varepsilon_{x\delta}^2$ etc., then squaring (3) and summing for all points O and for all charts examined

$$b^2\Sigma\theta^2 = 2\left\{\Sigma\varepsilon_x^2 + \Sigma\varepsilon_y^2\right\} = 2\Sigma\varepsilon^2,$$

and $$\frac{1}{N}\Sigma\theta^2 = \frac{2}{b^2}\frac{1}{N}\Sigma\varepsilon^2,$$

where N is the number of sets of variables summed.

Evaluation of the standard error.—Johnson[1] has shown, on the assumption that the vector errors in wind at any one point are independent of those at other points, that, in the neighbourhood of the British Isles, $\frac{1}{N}\Sigma\varepsilon^2 < (5\text{kt.})^2$ in summer, $(6\text{kt.})^2$ in winter, if the winds used are reported winds; and that $\frac{1}{N}\Sigma\varepsilon^2 < (6\text{kt.})^2$ in summer, $(7\text{kt.})^2$ in winter, if the winds used are interpolated from the reported winds.

Hence the root mean square error in geostrophic vorticity is

$$\left[\frac{1}{N}\Sigma\theta^2\right]^{\frac{1}{2}} = \frac{\sqrt{2}}{b}\left[\frac{1}{N}\Sigma\varepsilon^2\right]^{\frac{1}{2}}$$

$$< \frac{7\sqrt{2}}{3600}\frac{1}{b}\ \text{sec.}^{-1}$$

$$= 9\cdot 8 \times 10^{-6}\ \text{sec.}^{-1}\ \text{for}\ b = 280\ \text{n.m.};$$

$$\text{or}\ 13\cdot 8 \times 10^{-6}\ \text{sec.}^{-1}\ \text{for}\ b = 200\ \text{n.m.}$$

This is about 10 per cent of the Coriolis parameter at latitude 55°: while it should not obscure the vorticity pattern at any one point, it might obscure vorticity changes much less than 15 per cent of the Coriolis parameter.

REFERENCE

1. JOHNSON, D. H.; Accuracy of 100-mb. winds. *Met. Mag., London*, **82**, 1953, p. 44.

METEOROLOGICAL OFFICE DISCUSSION

The discussion held at the Royal Society of Arts on 17 March 1958 was on "The use of radar in forecasting precipitation", opened by Dr. P. G. F. Caton, and was followed by an informal talk on "Research in the Meteorological Office concerned with long-range forecasting", given by Mr. J. M. Craddock.

The use of radar in forecasting precipitation

Dr. Caton considered that there were two main uses of weather radar information:

(i) to prepare detailed forecasts of precipitation for particular localities for short periods ahead; and

(ii) to improve the accuracy of general forecasts, through the filling of gaps in the synoptic network.

He concentrated on the first aspect—the preparation and assessment of forecasts of the type: "Shower expected at 2.30 p.m., lasting 20 minutes; otherwise dry until 4 p.m.". The forecasts were prepared using the East Hill plan position indicator radar, for which the ranges of detection on moderate rain or showers are approximately 60–70 nautical miles, and on slight rain or showers 25–50 nautical miles.

Shower situations.—Considering first shower situations, Dr. Caton explained that the forecasts were prepared for a period determined by the expression

$$\frac{\text{distance of reliable detection upwind}}{\text{controlling wind speed}}$$

rounded to the nearest half-hour. Items in the forecast were of one of the forms:

(i) Dry—confidence *A*,

(ii) Shower expected, commencing . . . . , ceasing . . . . ,—confidence *A*, or

(iii) Shower may occur, with time information when justified—confidence *B*.

The forecasts were based on extrapolation of the motion of existing echoes, allowing for the uncertainty regarding the controlling wind and such changes in echo area as may reasonably be expected. Confidence *A* was aimed at whenever possible and no lowering of confidence was permitted on account of new echoes which might appear after the time of the forecast.

The controlling wind was either the latest 700-millibar wind from radar-wind soundings or, whenever possible, the wind deduced from the average movement of echoes approaching the target stations. A reliable wind could usually be deduced from echo movements over a half-hour interval, but it was necessary to maintain a continuous check on the wind direction; a 10° error in the estimated wind direction had a disastrous effect on the accuracy of the forecasts. The range of reliable detection from East Hill was arbitrarily assumed to be two-thirds of the range of the furthest echoes, subject to a maximum of 60 nautical miles.

The forecasts were prepared at half-hour intervals for Dunstable, Cardington (12 nautical miles north-east of East Hill) and Victory House (28 nautical miles south-east of East Hill). All of the forecasts were made in conditions when showers were present near the target station during the forecast period. They were from 29 dates, covering a wide variety of wind directions and strengths and shower frequencies, throughout the four seasons.

The forecasts were assessed by division into half-hour intervals and comparison of each interval with the actual conditions as indicated by the relevant autographic rain-gauge record. A shower was identified by its time of commencement and its duration. A shower forecast to commence in a half-hour interval was verified as regards occurrence by a shower commencing in that interval or in those immediately before or after; that is, an error up to 0·5 hour (and in some cases up to 0·9 hour) was accepted as being of timing only. The errors in the forecast times of commencement and duration were subsequently investigated. The results were presented in a series of slides, and can only be summarized here.

Duration-of-shower forecasts.—At Dunstable and Cardington 97 per cent of the forecasts were of at least one hour's duration. At all three stations 65 per cent of the forecasts were of at least two hours' duration and 38 per cent of the forecasts reached three hours' duration. The median durations were greater in summer than winter, due to the generally higher ranges of detection and lower average wind speeds in summer.

Forecasts of dry conditions.—Ninety-five per cent of the forecasts were correct in the first hour, 87 per cent in the second hour, 81 per cent in the third hour and 79 per cent in the fourth hour. A figure of 78 per cent correct was to be expected by chance during the test period. The differences between the results at the three stations were small. About one-half of the errors were associated with timing errors on showers forecast to commence or cease in an adjacent half-hour and the remainder to other causes, for example the development of a new echo.

Forecasts of showers.—Sixty-one per cent of the forecasts of "shower expected" were correct in the first hour and 50 per cent in the second hour. This category of confidence was inappropriate to forecasts in the third and fourth hours. Some 33 per cent of forecasts of "shower may occur" were fulfilled in the first, second, third and fourth hours. A figure of 26 per cent was expected by chance with application of the checking system. The proportion of showers occurring which were forecast either as "expected" or as "may occur" was 90 per cent, 59 per cent, 37 per cent and 19 per cent in the first, second, third and fourth hours respectively.

Variations in the accuracy of the forecasts.—The data were subdivided according to shower frequency and wind speed. A higher standard of forecasting was achieved on wet days than dry and for wind strengths of 6–50 knots compared with 5 knots or less. The poor results at low wind speeds were due to the importance of development and decay processes relative to the advection of existing echoes.

Timing errors.—These increased with time forward. Broadly, within the first two hours, two-thirds of the errors in the time of commencement and in duration were less than or equal to 0·2 hour.

Causes of error.—

(i) Shower occurring, not forecast. The main causes of error were development (80 per cent of cases) and use of a wrong wind (15 per cent of cases). The errors due to development were most frequent when the wind speed was less than 5 knots and the time of forecast was between 1200 and 1500 G.M.T.

(ii) Shower expected, did not occur. The principal causes of error were

(*a*) that the echo passed over the station without precipitation in the gauge (50 per cent of cases),

(*b*) use of a wrong wind (20 per cent of cases) and

(*c*) decay of the echo before reaching the station (30 per cent of cases).

The last-mentioned cause was relatively important in the second hour. The cases under cause (*a*) represented 21 per cent of the shower forecasts made. An investigation covering three summer months showed that slightly over 50 per cent of reported slight showers failed to record in an autographic gauge. If such very slight showers occurred in any of the cases above, the forecast which had been marked incorrect should have been classed correct. It was estimated that very slight showers occurred in at least one half of the cases and this led to substantial increase in the percentage correct of forecasts of "shower expected"—from 61 per cent to 74 per cent for the first hour.

Belts of precipitation.—Dr. Caton next considered forecasts involving belts of precipitation. These forecasts were prepared in an essentially similar way to those in shower situations. Items in the forecasts were of one of the forms:

(i) Dry—confidence *A*,

(ii) Rain expected to commence, to be continuous, to be intermittent or to cease, with times where appropriate—confidence *A*, or

(iii) Rain may commence, be continuous, etc.—confidence *B*.

The scheme of assessment was also similar to that for shower forecasts. Rain commencing or ceasing within 0·5 hour (and in some cases within 0·9 hour) of the forecast time verified the appropriate forecast and constituted a timing error.

Forecasts of the duration of belts of precipitation.—About 30 per cent of the forecasts reached two hours' duration at Dunstable and Cardington, but only 16 per cent did so at Victory House. The short durations compared with shower situations were due to the smaller ranges of detection and greater average wind speeds associated with precipitation belts. The durations were calculated by the formula

$$\frac{\text{distance of reliable detection}}{\text{700-millibar wind speed}}.$$

It was frequently possible to make accurate forecasts for longer periods by using the apparent speed of movement perpendicular to the belt. However, this assumed that the belt continued downward beyond the radar range.

Accuracy of forecasts.—Ninety-six per cent of the "dry" forecasts were correct in the first hour, 85 per cent in the second hour and 83 per cent in the third hour. About 70 per cent of the "rain to commence" and "rain to cease" forecasts were correct in the first hour and 40 per cent in the second hour. Confidence *A* was inappropriate to these forecasts in the third hour. About 75 per cent of the "rain to be continuous" forecasts were correct in the first two hours and 45 per cent in the third hour. Lower percentages were obtained for the confidence *B* forecasts.

Timing errors.—On average, the rain commenced 0·25 hour later than forecast. The bias was associated with a longer average duration of overhead radar echo compared with measureable surface precipitation. If an arbitrary correction of +0·2 hour were applied to all forecast values, 65 per cent of the errors would be less than or equal to 0·2 hour. One might reasonably expect to improve on this figure and to eliminate the arbitrary correction if information from a range-height radar display were also available. On average, the rain ceased 0·09 hour earlier than forecast. If an arbitrary correction of −0·1 hour were applied to all forecast values, 77 per cent of the errors would be less than or equal to 0·2 hour.

Dr. Caton next compared the accuracy of radar forecasts for belts of precipitation with those possible from a careful examination of hourly charts. On occasions when an identifiable area of precipitation was expected to reach Dunstable within six hours, the Central Forecasting Office had forecast the time of onset of the precipitation each hour until rain commenced. Their forecasts were checked against the Dunstable autographic rain-gauge record. The results indicated that the time of commencement of precipitation could be forecast two to three hours ahead with an average error of about one hour. For forecasts made one hour before the commencement of rain, the median error was 0·5 hour. The forecasts from synoptic charts could be made for a longer period ahead than those from radar, but within the radar range the latter were the more accurate. This was due to the greater ease of positioning the belt edges with a radar screen, and the elimination of the delay due to transmission and plotting of synoptic observations.

Summary.—Dr. Caton considered that, given an adequate range of radar detection, detailed forecasts of a useful standard of accuracy were possible for two hours ahead, both for forecasts of showers and of precipitation belts. Some accuracy was possible in the third hour. The two to three hour limit was imposed primarily by the development and decay of the echo pattern.

Discussion.—In reply to a question concerning the use of the 700-millibar wind, Dr. Caton explained that this was used only until a wind could be deduced from the actual movement of the echoes. He agreed that the wind at 850 millibars might be more appropriate in the case of snow showers.

Mr. Bradbury enquired concerning the results of forecasts of snow showers. Dr. Caton replied that the duration of such forecasts was generally short because of low detection ranges, but he did not think that the accuracy was necessarily less than for rain showers.

Mr. Wearmouth spoke of experience at Sylt using techniques similar to those of Dr. Caton. He thought that his timings of showers had not been quite as accurate as those presented.

Mr. Holgate asked whether difficulties could not arise through the radar beam intersecting different portions of the clouds at varying ranges. Dr. Caton replied that the practical difficulties were not significant with plan position indicator equipment having a vertical beam-width of 6°. The lower edge of the beam should normally be tangential to the earth's surface.

Mr. Bushby asked whether an echo was possible from clouds which were not precipitating.

Mr. Harper said that, except possibly with high-power 3-centimetre equipment, echoes would not be received from drops of less than raindrop size. The echo from a single drop was proportional to the sixth power of the diameter. It was possible to have echo without surface precipitation if the drops were held aloft by ascending air currents or if the drops were evaporating before reaching the ground.

Mr. Bushby then said that he was sure that echoes had been observed at Singapore from clouds which were not precipitating and which did not precipitate during at least the next two hours. A range–height indicator display had shown an echo base of about 4,000 feet.

Mr. Timms suggested that some of the echoes might have come from lee waves. He thought he had observed echoes from this cause using 3-centimetre equipment at Hemsby. Dr. Caton considered that this phenomenon had not occurred during his work, and Mr. Wallington pointed out that such echoes, if genuine, would remain stationary whilst convective echoes moved downwind.

Mr. Rackliff spoke of experiences at Uxbridge where radar information on storms moving from the English Channel at night had been particularly valuable.

Mr. Wallington asked whether the development or decay of echoes had been observed to occur in any systematic way, for example, on the low-pressure side of existing echoes. Dr. Caton replied that he had not noticed any such regularity. He had investigated the location of first appearance of non-forecast showers affecting Victory House in north-west winds, but had found no association with the Chiltern Hills. Radar could provide the tool for many investigations on the "mesoscale", but he did not think that underlying regularities would easily emerge.

Mr. Harper said that he was puzzled by the poor results for forecasts of showers at Cardington. He thought that this might be due to the fact that, in the prevailing south-west winds, the echoes were generally close to the radar site at the time of forecast and thus were sometimes from showers of smaller intensity than usual. Dr. Caton commented that two-thirds of the cases of overhead echo without measureable surface precipitation were at Cardington. He wondered whether there was some topographical feature affecting the rainfall from showers at Cardington.

Mr. Hunt spoke of his experience with the Decca radar scanner at Victory House. He stressed that 3-centimetre and 10-centimetre scanners would not detect fog or drizzle. He spoke of an occasion at London Airport when radar information had been most valuable, but commented that the conditions in this case were ideal as showers were forming only over the sea. He thought that the potentialities of radar should not be exaggerated.

Mr. Houghton remarked that the lifetime of many showers was only one to two hours. He thought that the forecast successes in the third hour must have been for showers associated with trough lines. He mentioned an occasion when the development and decay of rain areas had been observed on the Victory House radar in much greater detail than could be inferred from synoptic reports. In reply Dr. Caton said that Mr. Beimers at East Hill had found that the average lifetime of small shower echoes was about one hour. However, when conditions favoured heavy showers or thunderstorms, new cells tended to develop to replace those decaying and the life of the shower complex was considerably greater. Dr. Caton said that his results represented an average over a wide variety of conditions; the third hour successes were probably associated with heavy showers or thunderstorms. He agreed that the immediate and detailed observation of new developments was a most valuable use of radar.

Research in the Meteorological Office concerned with long-range forecasting

This account is concerned with some of the more important results of work carried out at Dunstable during the last four years. The item of most interest to most people is probably our experiment in monthly forecasting, but I must emphasize that this is only one item of a programme of systematic research into the slower variations of the atmosphere.

Our work proceeds from the standpoint that any predictable element there may be in the weather over long periods ahead is likely to be associated with the function of the atmosphere as the working substance of a heat engine, transferring energy from source regions in low latitudes near the ground to the sink regions mostly in high latitudes. This heat transfer is associated, mainly, with the planetary circulation which is most intense in the upper troposphere, and changes in the weather at the earth's surface are mainly the incidental consequences of the character and changes in the planetary circulation. Hence we should use as our basic variables for long-range prediction quantities which measure the intensity and position of the source and sink regions of the earth's surface, or are related to the character of the planetary circulation.

If we are to study atmospheric variations on the planetary scale, and wish to obtain results of statistical validity, then we must concentrate on those measurements which have been made regularly for many years over a network of stations extending over a large part of the earth's surface: the only such measurements are the rainfall and atmospheric pressure and temperature near the ground. In choosing where to start we rejected rainfall because its distribution patterns do not show the stability necessary in any element which is to form the basis for prediction, and air pressure because its claims seemed less strong than those of air temperature, which is more obviously connected with the thermodynamic processes of the atmosphere and which seems to have received less attention from earlier workers.

Choice of a time unit.—Our first objective was to study the patterns of temperature anomaly over as much as possible of the earth's surface. Before starting, however, we had to decide on our time unit. I thought that if we used data averaged over calendar months, we would probably lose in the averaging features which we ought to study, while using daily charts would entail too much paper work, so we compromised by using as our time unit the five-day period, of which 73 cover the year. We then faced the difficulty that before we can estimate anomalies, or departures from normal, we have to know what the normal is, and that although we can easily obtain monthly mean temperature normals for any number of stations, we cannot generally obtain normals for five-day periods. A satisfactory and objective method of overcoming this difficulty which has been described by Craddock[1,2] is by replacing each set of monthly mean temperatures by the best-fitting two-term harmonic form. When this work had been completed we were able to draw patterns of the five-day mean temperature anomaly pattern for the Atlantic half of the Northern Hemisphere, and this has been done as a routine since 1 May 1955.

Anomaly patterns.—The features of the first year's charts have been discussed by Craddock and Lowndes[3]. It appears that many areas of positive (or negative) anomaly are surprisingly intense, large in geographical extent, and often very persistent in time, lasting up to a month or two. Further work by Lowndes[4], has shown that the patterns of the surface air temperature anomaly when averaged over a month are very similar to corresponding patterns of the 1,000–500-millibar thickness anomaly which approximate to the departure from normal of the mean temperature distribution in the troposphere. The upper tropospheric air flow follows the mean tropospheric temperature distribution far more closely than it does the pressure pattern at the earth's surface, so the existence of persistent anomalies of air temperature at the earth's surface may be an indication of persistent anomalies in the planetary circulation. The identification of persistent anomalies of the general circulation may not be the whole solution to the problem of long-range forecasting, but if persistent anomalies occur, and the above evidence suggests that they do, then it is hard to believe that they are irrelevant to the forecasting problem.

One way of finding whether patterns of temperature anomaly are of any prognostic value is to match recent patterns with patterns from the past, and to see if the sequels show any similarity. We cannot do this for five-day mean patterns, because we have very little five-day mean data for back years, but we can for monthly mean patterns, because we can prepare monthly mean temperature anomaly charts for back years by using the data summarized in the *Smithsonian World Weather Records* and elsewhere. Our experiment was started to test this hypothesis, but before describing the experiment I must mention some considerations which apply to any and every system of analogue forecasting.

Analogue forecasting.—Forecasting by means of analogues is less elegant than arguing from general scientific principles, but it has the advantage that it can be used on problems so complex that we do not know which principles to apply. Further, if by an analogue method of forecasting we achieve a "better than chance" standard of success, we know that among the quantities we compare in choosing the analogues there is something which is related by physical processes to whatever we predict. Thus success in analogue forecasting may help us in our struggle toward general principles.

By using analogue methods, we avoid the mathematical difficulties of applying general equations to a particular case, and have the comforting knowledge that our forecast necessarily represents a possible state of the atmosphere, whereas no such certainty exists if general principles are applied in inappropriate circumstances. Against this we have the problem of handling, not a tidy and coherent set of principles, but a multitude of particular instances.

When discussing the possibilities of analogue forecasting it must be emphasized that there is never any possibility of matching a complicated situation in

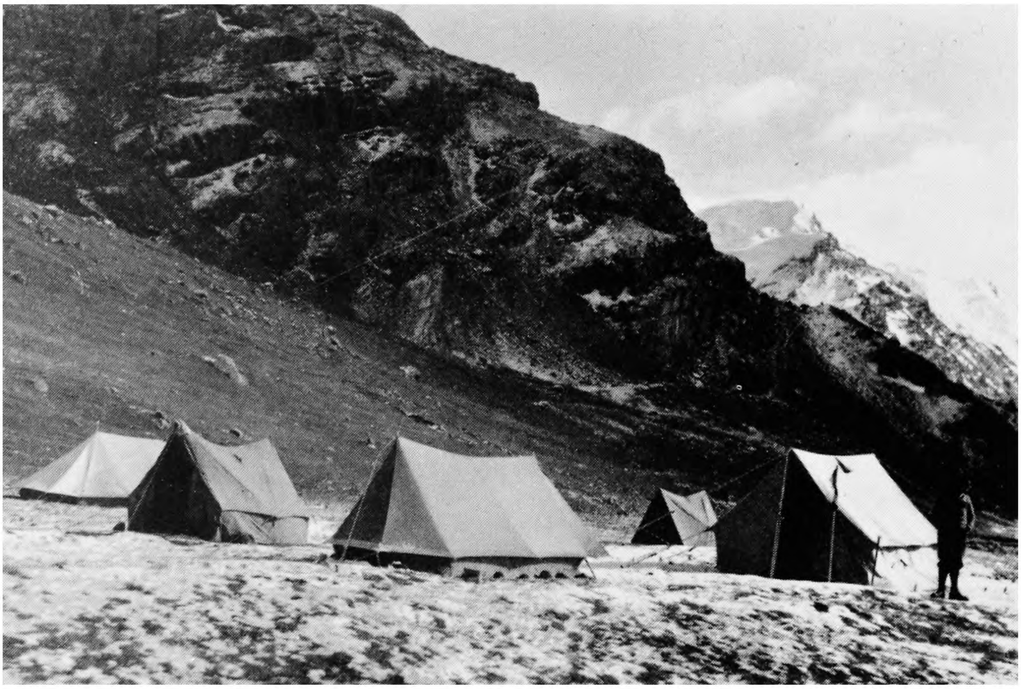
[*To face p.* 240

Photograph by J. Jewell

PLATE I—THE VILCANOTA RANGE

View looking towards the Vilcanota range of the Andes near the expedition's base camp which was situated in a small side-valley to the left of the picture. The main valley here seen leads to the Chimboya Pass (5,235 metres) to the Amazon basin off the right of the picture. The general orientation of the range at this point is north-west to south-east and the picture is taken facing north or north-east. The cloud masses blowing against, and partly over, the mountains from the Amazon side are seen both in this picture and in Plate II.

(See p. 225)



Photograph by J. Jewell

PLATE II—BASE CAMP

The Andean expedition's base camp, 13°51'S. 70°53'W., about 5,050 metres (16,600 feet) above sea level, in the Cordillera Vilcanota in southern Peru. This camp was occupied by the party from late May to early July 1956. The peaks hereabouts rise to 5,750 to about 6,400 metres.

(See p. 226)

Photograph by J. Jewell

PLATE III—THE QUENAMARI ICE PLATEAU

General view of the south-west side of the little known Quenamari Ice Plateau at 5,500–5,800 metres above sea level in southern Peru (approximately 14°5′S. 70°50′W.). The picture was taken during the 1956 expedition looking east from a point south of the Chimboya Pass and six miles distant from the ice-sheet.

(See p. 226)

Photograph by Berry Studio, Delhi

SECOND SESSION OF THE COMMISSION FOR SYNOPTIC METEOROLOGY

Standing (Back row): U Hla (Burma), Harding (United Kingdom), Ananthakrishnan (India), Krepkogorski, *Interpreter*, Bhawan Ram, *Interpreter*, Po E (Burma), Soliman (Egypt), Walker (Ghana), Khan (Pakistan), Kabakibo (Syria), Naguib (Egypt), Durget (France), Pittavino (French Cameroons), Ribault (France), Das (India).

Standing (Second row): Bharucha (India), Ito (Japan), Ratisbona (Brazil), Grandoso (Argentina), Hannay (Australia), Klamer (Netherlands), Ramaswami (India), Lal (India), Sen (India), Bijvoet (Netherlands), Sengupta (India), Gadadhar (India), Montalto (Italy). Burnett (United Kingdom), Frolow (Madagascar), Nayakov, Nadarassin.

Standing (Third row): Rath (I.C.A.O.), Wusthoff (Germany), Haefelin (Switzerland), Snellman (U.S.A.), Pisharoty (India), Reeves (U.S.A.), Soontarotok (Thailand), Andualem (Ethiopia), Tschistiakov (U.S.S.R.), Thrane (Norway), Crone-Levin (Denmark), Desi (Hungary), Sallouhi (Lebanon), Mull (India), Koulakov (U.S.S.R.), Benum (Canada).

Standing (Fourth row): Chang (China), Inan (Turkey), Meyer, *Invited expert*, Navai (Iran), Koteswaram (India), Vesilovali (Turkey), Krishna Rao (India), Drouilhet (U.S.A.) Barbagallo (U.S.A.), Bunnag (Thailand), Mittner (France), Lonngvist (Sweden), Berggren (Sweden), Cheng (China), Ortmeyer (Germany).

Sitting: Ockenden (United Kingdom), de Sousa (Portugal), Mazumdar (Secretariat), Sundaram (Secretariat), Dufour (Belgium), Lugeon (Switzerland), Kutschenreuter (U.S.A.), Bleeker, *President*, McTaggart-Cowan (Canada), Leclercq (France), Basu (India), Logvinov (U.S.S.R.), Megenine (Secretariat), Boyden (United Kingdom), Mathur (India).

(See p. 249)

its entirety from past records. Indeed, the best we can hope for in most meteorological problems is to match approximately the values of four or five independent parameters or a rather larger number of interdependent ones. Hence the real problem of analogue forecasting is to decide on the essential features of any particular situation (these need not be the same in all cases) and to match these essentials as well as possible, while tolerating differences in features which have no prognostic value. To make progress with this problem our technique does not lay down hard and fast rules but includes the preparation for each past case of a much more complete description than can ever be expected to recur. The forecaster then has to use his judgement and experience in deciding the relative importance of agreement on different features.

The present experiment was to find whether, by matching the up-to-date pattern of the monthly mean temperature anomaly over a large part of the Northern Hemisphere with similar patterns from the past, it was possible to deduce anything useful about weather conditions over the British Isles during the coming month. The choice of the month as the time interval over which data are averaged was, as mentioned earlier, decided by the availability of data for past years, rather than on strictly scientific grounds. In trying to match a given monthly mean chart we restrict ourselves to charts for the same month in previous years, to ensure that the heat sources and sinks are about the same. This means that a current chart can be compared with not more than 100–200 earlier charts.

Selecting the analogues.—If a forecast is to be produced by the end of a calendar month, then the temperature anomaly pattern for that month must be estimated a few days earlier. This is done by using the five-day mean temperature anomaly charts, which are also intended for research purposes, an average being taken of as many as possible of those lying within the calendar month. The resulting chart (an average over 25 days) is usually a good approximation to the true monthly mean anomaly chart, at least as regards the positions and intensities of the main features. The current synoptic charts are also consulted as necessary to see whether any important changes are in progress during the last few days.

The work of producing the current monthly anomaly chart to time, which is basically a matter of extracting data from meteorological broadcasts made for synoptic purposes, is much the most laborious part of preparing these long-range forecasts. It would be made much easier if international agreement could be reached on an exchange of data for long-range forecasting purposes embodied in a short collective broadcast.

The selection of analogues from past years was originally carried out by scanning the tabulated data in the *Smithsonian World Weather Records*, a laborious and unsatisfactory process. It is now based on a very efficient edge-punched card index. One card is prepared for each calendar month, and on it are written the values of many meteorological variables during that month. The edge-punchings, when used in the way described later, enable us to choose from a pack of such cards all those in which the value of one of the variables lies in a particular range. The card is designed to receive the values of many more variables than can be matched from a limited number of past years, so that the forecasting possibilities of different groups of parameters could be compared. On the front it has spaces for the temperature anomaly at about 30 stations forming an open network over the area extending from the Rocky Mountains across North America, the Atlantic Ocean and Europe into Central Siberia. To each station on the card two edge-holes are assigned. If the anomaly on the card is negative, the first hole is cut open, while if the anomaly is positive the second hole is cut open. Thus, if it is desired to find from a pack of cards all those in which a particular station had, say, a negative temperature anomaly, a sorting needle is passed through the appropriate hole and the pack is lifted and shaken. All the cards which fulfil the condition will fall clear, while the remainder stay on the sorting needle. The cards falling clear can then be collected and sorted again on the anomaly at a different station.

The cards bear on the reverse a chart on the scale of 1:100 million, on which are plotted the temperature anomalies appearing on the front, and there is also a group of holes showing the year and the month, by means of which the pack can be got back into order after use.

The pack of anomaly cards was originally completed for the years 1881 to 1940, and is kept in 12 sections, one for each calendar month. When a chart for the current month, say, September, has been prepared in the way described already, a choice is made, out of the stations which appear on the anomaly cards, of a few which represent the most important features on the current September chart. The pack of the September cards for previous years is then sorted on these key stations, in turn, in order of importance. Since only the cards which agree on the first station are sorted on the second, the number of cards remaining is reduced at each sorting, but it is a mistake to continue fitting more and more stations until only a single analogue is left. Better results are obtained by stopping sorting when at least five to ten cards remain, and giving individual attention to each of these.

The charts on the reverse of the anomaly cards were intended to allow a detailed comparison between cases. They have not proved adequate for this purpose, because owing to the small scale and the wide spacing between stations, patterns may appear to be similar although closer examination reveals important differences. However, the card index is an excellent device for reducing the original list of years to perhaps a dozen or fewer which are possible analogues. These cases are then examined in greater detail. For each of them the temperature anomaly pattern is drawn on a much larger scale (1:30 million) using data for as many stations as possible. In the final choice among analogues, the comparison is extended to include the synoptic weather sequences over the eastern Atlantic and western Europe as well as the temperature anomaly pattern. This is logical, because agreement between synoptic weather sequences is evidence that the similar temperature anomaly patterns were arrived at in the same way, by similar changes in the upper air flow.

The choice of the best among a group of possible analogues is a matter for personal judgement. In matching anomaly charts, more weight is placed on agreements in the better-marked features of the patterns than on agreements in absolute magnitudes of the anomalies and more on agreements within the home sector (extending, say, from Labrador to the Urals) than on agreements in more distant regions. In matching synoptic weather sequences agreement is sought only in the features related to the state of the general circulation, while differences which can occur with the same pattern of general circulation are disregarded. In practice the choice is made by a panel of three or four meteorologists, who examine all possible analogues, and then follow a principle of exclusion, weeding out the least satisfactory until those which remain are of about equal merit.

The next step is to examine the weather sequence and the temperature and rainfall characteristics of the next month in the British Isles in each of the analogue years. Sometimes these sequels show a good deal of agreement among themselves, and then the forecast will be that the features which show agreement will recur. More often, the sequels vary considerably among themselves. The forecasters may then go over their analogues again and try, by applying more rigid criteria, to reduce the group until it shows some measure of consistency, or their forecast may follow the average or modal conditions of the group of analogues.

Although the selection of analogues depends so much on personal judgement, if the process is carried out independently on the same case by different forecasters, their selections are usually in good agreement. If the selection is made as we usually do, by scientists in consultation, the choice is not, of course, unique or infallible, but it has the same type of validity as a medical diagnosis made by an experienced physician or an analysis of a synoptic chart made by a practising forecaster. The most difficult problem is apt to arise at the next stage, when the forecasters may have to decide what if anything can safely be deduced from a number of analogues in which the subsequent weather developments vary a good deal from one case to another. Such divergences are evidence that the similarities between the analogues are not in themselves sufficient to determine the future developments, and the bigger the divergences are, the wider the margin of uncertainty which must be attached to any forecast based on such similarities. It is conceivable that the divergences might be so large that the forecasting panel would conclude that no useful deduction of any kind could be drawn from the analogues; however, this possibility has not occurred during the 29 months since the start of the experiment.

Example of forecasting techniques.—A good example of the technique is provided by the forecast for March 1957 prepared on 27 February 1957 in the following terms.

"*Forecast for March* 1957

The best analogues for the temperature anomaly pattern in February 1957 seem to be 1882, 1894, 1903, 1915 and 1935. These suggest mean temperature above normal and rainfall below normal at London.

Normal London temperature in March ... 42·2°F.

Normal London rainfall in March ... 41 mm.

Comment

The principal features of the temperature anomaly chart for February 1957 are a warm area over Europe, cold areas over south Greenland and the Atlantic and warm areas over the United States and east Canada.

Four of the five analogue years were warm (in March), the remaining one having near normal temperatures. Four of the years were dry, the other having slightly above normal rainfall.

In all of these years pressure was high near the British Isles for a large part of the month (March). Examination of the synoptic types suggests that there will be considerable periods with an anticyclone centred over or near the British Isles, but that there will also be periods with westerly winds. During the latter, however, pressure will remain relatively high in the south of the country and rainfall will probably be light in the south-east.

During the anticyclonic period, wind directions are uncertain but direct northerly outbreaks from the Norwegian Sea seem unlikely."

For comparison with this statement, made before the event, a scientist not otherwise connected with the experiment summarized the actual weather as follows:

"Exceptionally mild weather during the first fortnight was replaced by wetter though still mild weather on the 14th. During the last three days of the month temperatures fell steadily and although cloud increased, the weather was dry. Mean London temperature well above normal; rainfall below normal."

This example shows many of the difficulties and possibilities inherent in the problem.

The anomaly patterns for 1957 and the five chosen analogue years are shown in Figure 1. In each of these years there was also, in February, some similarity in the general synoptic sequence of weather over the British Isles: there were other years which might have been included on the strength of the anomaly patterns alone, but which showed no real resemblance in the synoptic weather sequence.

Once the forecaster has selected the possible analogues he has to decide how much he can safely say about the features which all or most of these years have in common. It follows that the forecasts differ a good deal in content from one month to another, depending on the number and goodness of the analogues, and also on the experience of the forecaster.

With forecasts having a period of validity as long as a month, the sum of personal experience mounts very slowly, and even the forecasters who have taken part in the experiment from the beginning have carried out forecasts for only a few of the possible monthly weather situations. It follows that each forecast, as it is made, is something of an experiment, and that when faced with a difficult situation a forecaster may have to rely on some argument which he has never used before and which may or may not be justified in the event. For these reasons it is difficult to produce a method of verifying monthly forecasts which will measure anything except the standard attained on some particular date. However, a comparison between the forecast and actual temperature anomaly and percentage rainfall anomaly at London for each month from the start of the experiment up till July 1957 is shown in Figure 2. The results are put in numerical form in Table I.

It appears from Table I that over these 27 months the method has had a degree of success significantly higher than the chance expectation, and that practically no contribution to this success has been made by "persistence". These figures may be compared with those published by Hofmann[5] for the similar experiment which is being carried out in Germany. The problem of checking long-range forecasts is one which troubles all workers in this field, and I do not regard the correlations as necessarily telling the whole truth. Nevertheless I do not think we should be dissatisfied with our results so far.

TABLE I—CORRELATIONS BETWEEN FORECAST AND ACTUAL TEMPERATURE ANOMALIES (r_{AF}) AND BETWEEN "PERSISTENCE" FORECASTS AND ACTUAL ANOMALIES (r_{AP}) FOR TEMPERATURE AND RAINFALL AT GREENWICH FOR THE 27 MONTHS OCTOBER 1955 TO DECEMBER 1957

	r_{AF}	r_{AP}
Temperature	+·46	+·03
Rainfall	+·41	−·01

Analogues used in recent forecasts.—An interesting result is shown in Table II, which gives the number of times that a year from a given decade has been chosen for an analogue for a month in the years 1956 and 1957. The total number of analogues chosen was 56, and if these had been equally likely to come from any decade, the expected number per decade would be 9·3. Table II shows that most analogues were chosen from the earlier years 1881 to 1910, and it is easy to show, by the χ^2 test that if all years were equally likely to be chosen, discrepancies as great as these would occur in fewer than one in one hundred trials.

TABLE II—THE OCCURRENCE BY DECADES OF ANALOGUES FOR MONTHS OF THE YEARS 1956 AND 1957

Decade	Number of analogues
1881–1890	19
1891–1900	10
1901–1910	11
1911–1920	8
1921–1930	3
1931–1940	5
Total	56

It seems probable therefore that a temperature anomaly pattern of the 1950's is more likely to be matched by a pattern from the 30 years 1881 to 1910 than it is by a pattern from the years 1911 to 1940. This result would be expected if, as has been suggested on other grouds, the climate passed through a stationary state in the period 1921 to 1940, and the present conditions resemble those preceding the optimum rather than conditions during the optimum. Even if this is a bit far-fetched, the figures certainly suggest that the years which are likely to be analogues are grouped together in time, so that the decades 1861 to 1880, and the most recent years 1941 to 1957 may prove more fruitful sources of analogues than the years 1911 to 1940.

Present day development and research.—Before leaving the monthly analogue forecasting I should mention that work is going ahead as fast as possible to develop and improve the present technique. The main lines are:

(i) The collection of temperature data for more years, so that analogues can be chosen from the largest possible field.

(ii) The collection of other data such as atmospheric pressure values to see whether they will yield any information besides what we get from the temperatures.

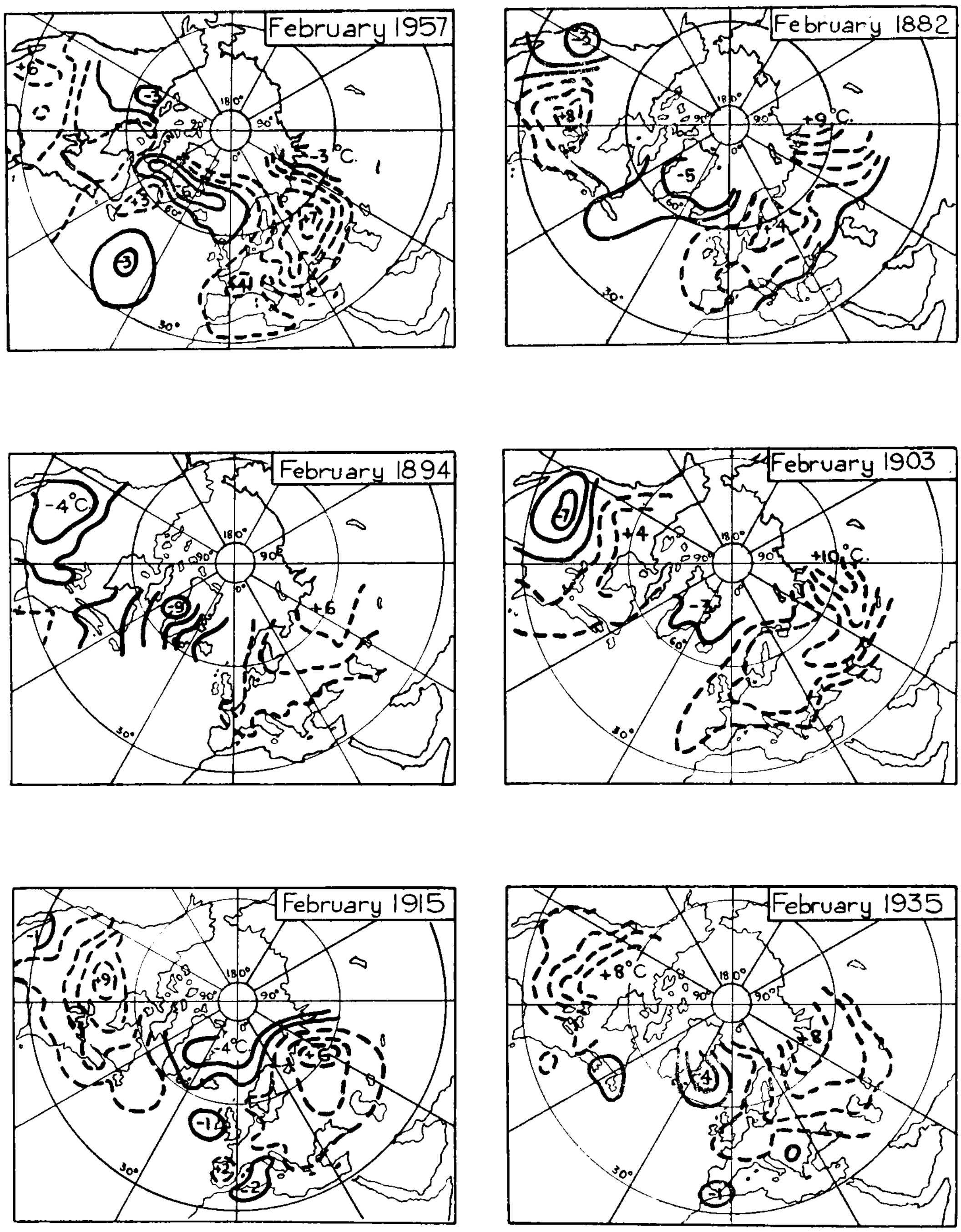


FIGURE I—TEMPERATURE ANOMALY PATTERNS FOR FEBRUARY 1957 AND FIVE ANALOGUE YEARS

The isopleths are for odd numbers of degrees

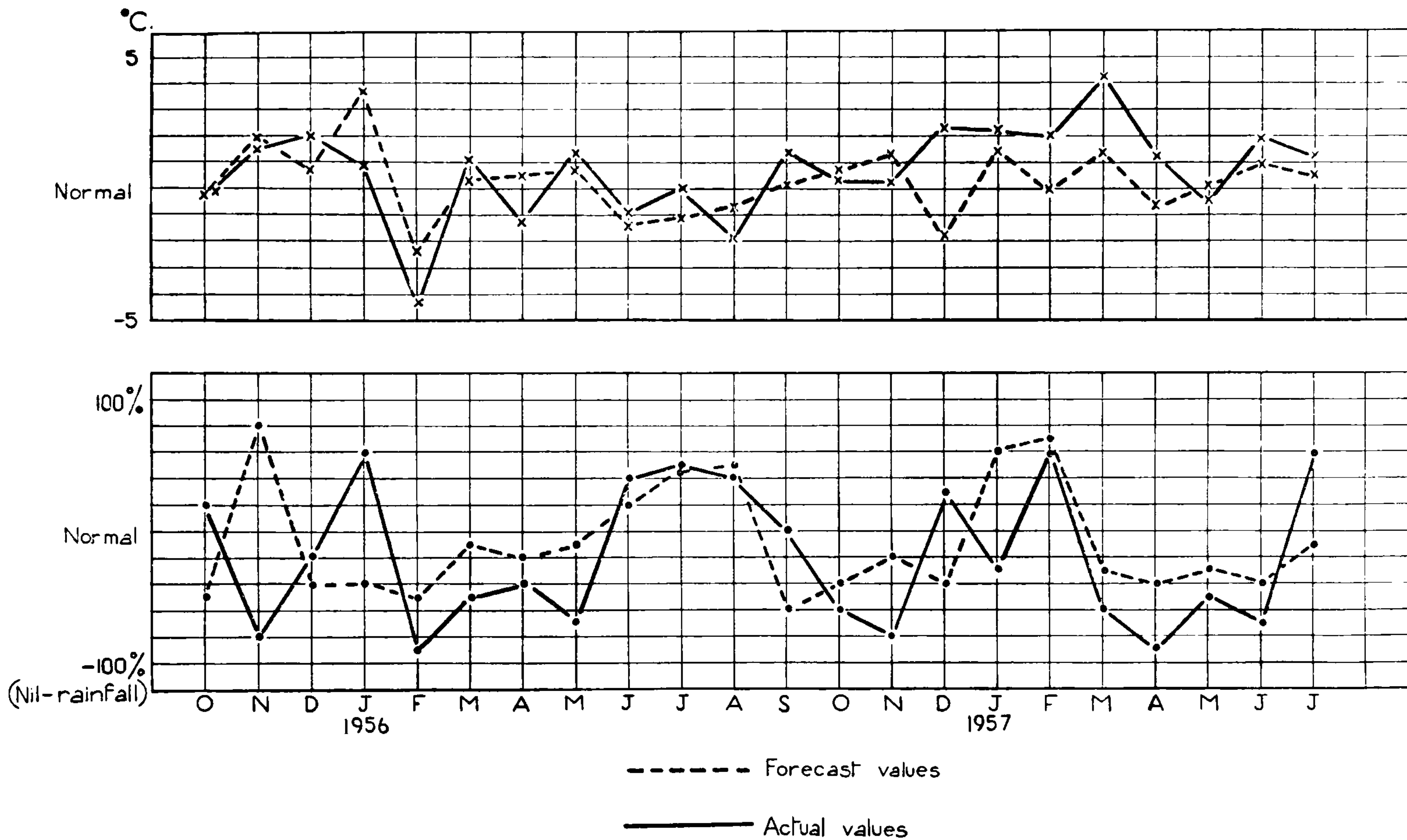


FIGURE 2—EXPERIMENTAL MONTHLY TEMPERATURE AND RAINFALL FORECASTS AT LONDON, OCTOBER 1955–JULY 1957

(iii) The preparation of a forecaster's brief, describing every outstanding month during the 108 years since 1850 with hints as to how it might have been forecast.

(iv) The collection of data to enable the system to be used to produce forecasts for periods other than calendar months.

Apart from this work which is going on within the Directorate of Research, the Director-General of the Meteorological Office has initiated a form of consumer research. The present experimental forecasts contain as much or as little detail as the forecasters think can, in each particular month, be inferred from the analogues. The questions whether this is the information required by any particular user, and whether the standard of accuracy attained is good enough to benefit the user cannot be answered by research within the Meteorological Office. To answer these questions the experimental forecasts are now being circulated in confidence to a number of authorities (outside the Meteorological Office) who are representative of various classes of potential users. These authorities have agreed to comment on the forecasts received during a period of, say, a calendar year, and future work will take account of their suggestions.

The monthly forecasting experiment is, of course, not the only research project in the field of long-range forecasting. It is an attempt to get to grips with the problem at the most convenient place while work proceeds on other projects of a more fundamental character which require more time spent on them before they can be expected to show a useful return. Among such fundamental projects I should mention one described by Gilchrist[6] who set out to apply numerical forecasting methods over the longest possible time scale by the use of spherical harmonics, and another described by Houghton[7] who set out to find what variations of the state of the earth's surface were capable of making a significant difference to the heat economy of the atmosphere. My own efforts to tackle fundamental questions have been concerned, largely, with the statistical problem. "What period of validity should we use if our long-range forecasts are to have the best prospects of success?" This leads to another: "Given a geophysical time series, with no prior knowledge of the processes generating the series, how should we set about analysing the series to learn as much as possible about the generating processes?" A first attempt which has been described by Craddock[8] involved calculating the correlation between the temperature at Kew on each calendar day with those on each of the seven following days for every day of the year. This investigation showed beyond doubt that the time series we had to study might be non-stationary, in the sense that their statistical properties varied from one time of year to another. This meant that we could not rely on methods such as those described by Wiener[9] which deal only with stationary time series. After considering several alternatives, I arrived at the idea of analysing the time series with a set of mutually exclusive band-pass filters. The result of this analysis, which has been described by Craddock[10, 11] is that the original series is resolved by linear operations into a series of components uncorrelated with one another and each composed of oscillations lying within a definite restricted wave-band. It is easy to calculate what the average amplitude of the oscillations in each wave-band should be, on the assumption that the original series is of a random nature, and if the actual amplitude of the oscillations in some wave-band is much larger than the chance expectation there is a presumption that some process is at work tending to generate oscillations in that wave-band. The method was applied to analyse the temperature variations at Kew with periods lying between two days and 50 years and showed that, apart from the annual variation the periods of the oscillations of largest amplitude tended to cluster in one of two ranges, namely, about ten days and near 30 days. The oscillations on longer time scales become progressively smaller.

The extension of this work to other meteorological variables, and to data for other stations should enable us to isolate and study the features which matter to the long-range forecaster in a way which has been impossible hitherto.

REFERENCES

1. CRADDOCK, J. M.; The variation of the normal air temperature over the Northern Hemisphere during the year. *Met. Res. Pap., London*, No. 917, 1955.
2. CRADDOCK, J. M.; The representation of the annual temperature variation over central and northern Europe by a two term harmonic form. *Quart. J. R. met. Soc., London*, **82**, 1956, p. 275.
3. CRADDOCK, J. M. and LOWNDES, C. A. S.; A synoptic study of anomalies of surface air temperature over the Atlantic half of the Northern Hemisphere. *Met. Res. Pap., London*, No. 994, 1956.
4. LOWNDES, C. A. S.; The relation between anomalies of surface air temperature and 1000–500 mb. thickness over the Atlantic sector of the Northern Hemisphere. *Met. Res. Pap., London*, No. 1080, 1958.
5. HOFMANN, A.; Monthly forecasts for Germany—6 year verifications. Forschungsabteilung des Deutschen Wetterdienstes. Scientific Report No. 3. Frankfurt am Main, 1956.
6. GILCHRIST, A.; The representation of circumpolar 500 mb. charts by a series of spherical harmonics. *Met Res. Pap., London*, No. 1041, 1957.
7. HOUGHTON, D. M.; Heat sources and sinks at the earth's surface. *Met. Mag., London*, **87**, 1958, p. 132.
8. CRADDOCK, J. M.; The serial correlations of daily mean temperatures at Kew Observatory. *Met. Res. Pap., London*, No. 1023, 1956.
9. WIENER, N.; Extrapolation, interpolation and smoothing of stationary time series. New York, 1950.
10. CRADDOCK, J. M.; A contribution to the study of meteorological time series. *Met. Res. Pap., London*, No. 1051, 1957.
11. CRADDOCK, J. M.; An analysis of the slower temperature variations at Kew Observatory by means of mutually exclusive band pass filters. *J. R. statist. Soc., London*, Series A, **120**, p. 387.

WORLD METEOROLOGICAL ORGANIZATION

Second Session of the Commission for Synoptic Meteorology

Five years after its opening session in Washington, the World Meteorological Organization Commission for Synoptic Meteorology met for the second time on 21 January 1958. The conference was held at New Delhi and lasted for four weeks, with a total of over 70 representatives from 36 countries. The United Kingdom delegation consisted of Messrs. Boyden, Harding and Ockenden from the Meteorological Office and Instr. Capt. Burnett from the Naval Weather Service.

All meetings took place at Vigyan Bhavan, a spacious building designed for such gatherings and lavishly equipped for the purpose. The Minister of Transport and Communications welcomed the delegates on behalf of the Government of India and the conference then settled down to its work under the presidency of Dr. W. Bleeker. Dr. S. Basu, the Director of the Indian Meteorological Service, was elected his deputy for the duration of the session.

As at the 1953 session, three committees were established. One was concerned with codes, another with telecommunications and the third with matters falling under neither of these headings. A number of items were inevitably considered by more than one committee.

The approach to code problems was somewhat circumspect, and many meteorologists will be relieved to know that the conference was opposed from the start to any major changes. Machine-handling of data for climatological purposes is already so far advanced that discontinuities in coding procedure should not lightly be introduced. There was, moreover, the background thought that increased mechanization in forecasting might ultimately call for fundamental changes in the form of the transmitted message, and for this reason piecemeal changes at the present time were best avoided. With such considerations in mind the Commission decided to establish a working group on codes which is to report to the Third Session, but it was made clear that the working group should not attempt to justify its existence by the number of changes it recommended. By way of light relief from more serious cogitations, the suggestion was made that the working group might begin by clarifying $C_s = 6$ in Code 15, whereby the International Analysis Code makes provision for the cloud system defined as "Depression with misty tail".

Some minor changes in codes were made to bring Volume B of World Meteorological Organization Publication No. 9, the handbook on which national coding manuals are based, into line with the 1956 edition of the *International Cloud Atlas* (which covers more elements than its title suggests). There was some extension of the International Analysis Code and of the flight forecast codes, primarily to allow for the inclusion of more information in the region of maximum winds, and the conference endorsed the code for the nature of the tropopause which had been proposed by the Commission for Aerology.

A code was adopted for the transmission of supplementary reports by ocean weather ships and broad criteria were set out for the making of such reports. This introduces little or no change from present procedures by British ships. The messages will be preceded by the word SPESH, since neither MMMMM nor BBBBB is appropriate to a report which is of synoptic rather than purely aviation significance. An alternative proposal was made for 1½-hourly reports, giving 16 equally spaced observations a day, but this received little support.

The 100-millibar surface was added to the list of "mandatory levels" transmitted in upper air messages, and preferred levels were decided upon for the high atmosphere. With increasing heights being attained by radiosondes there is a need for standardization in the levels for which charts are drawn, and the Commission recommended that countries should concentrate on 150, 70, 50, 30, 20 and 10 millibars. With 100 millibars these levels give a roughly uniform height distribution up to over 30 kilometres.

An attempt was made to resolve the differences in reporting visibility. In preference to the recognized "minimum visibility" of the international code a number of countries at present report some form of average visibility, which of course differs from the minimum whenever visibility varies with direction. Both forms of report are firmly established procedures and in the hope of eventually removing the anomaly it was proposed that work be undertaken to obtain further information on the directional differences of visibility that exist at a number of aerodromes.

There was an interesting discussion on what was the best time to release radiosonde balloons so that the readings should most nearly synchronize with surface synoptic observations. The compromise adopted was that the balloon should be near the 500-millibar level when the corresponding surface synoptic observation was made, and therefore was best released within the half-hour preceding that observation. A latitude of 15 minutes at either end of this period was agreed upon, one object being to permit release by observers who have just made and transmitted a surface observation at the synoptic hour.

The telecommunications committee spent most of its time considering the Final Report of the Commission for Synoptic Meteorology Working Group on Telecommunications which met in Paris in October of last year, under the chairmanship of Mr. Ockenden. Further impetus was given to the replacement of wireless telegraphy transmission by radio-teleprinter and facsimile, and a satisfactory measure of agreement was reached on the standardization of equipment and procedures. An outstanding recommendation which was adopted after detailed study by a working group was that a scheme should be introduced for the rapid exchanges of observations around the hemisphere. This would be obtained by means of a chain of five stations around the globe which would be connected by land-line or radio-teleprinter, each being responsible for the transmission of surface and upper air reports from an extensive area and for the dissemination within that area of reports collected by the other four stations. The aim of the scheme is to make available quickly and regularly enough material for the construction of circumpolar charts for the Northern Hemisphere.

Towards the end of the session Mr. P. H. Kutschenreuter, the leader of the United States delegation, was elected as the new President of the Commission, with Dr. S. N. Sen, of India, as Vice-President.

Everyone was impressed with the organization of the conference and the efficiency with which the thousands of documents were circulated as the session progressed. There was much appreciation, too, of the personal assistance given by the staff of the Indian Meteorological Department and the way in which they ensured that delegates made the most profitable use of their very limited free time. Such highlights as the celebrations of Independence Day, the visit to the Taj Mahal and attendance at a Presidential garden party were unforgettable events. A visit was also made to the New Delhi Meteorological Office, where among other things the delegates saw the complete manufacture of radiosondes, and in the last week the Minister of Civil Aviation entertained the delegates to a farewell dinner, which took place in an atmosphere appropriate to the occasion.

REVIEW

Artificial stimulation of rain. Proceedings of the first Conference on the physics of cloud and precipitation particles, held at Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 7–10 September 1955. Edited by H. Weickmann and W. Smith, 10 in. × 7½ in., pp. xvi + 428, *illus.*, Pergamon Press, 4 and 5 Fitzroy Square, London, W.1. 1957. Price: £5 5*s*.

The first and perhaps the most important comment to pass on this book is that its main title of *Artificial stimulation of rain*, which is the only one to appear on the cover, is grossly misleading. Out of forty-nine papers and discussions only two have any connexion with the artificial stimulation of rain and neither of these gives an account of new work: both in fact provide summaries and discussions of aspects of work that have been written up in greater detail elsewhere—a comment applicable to many of the other papers as well. The first gives an account by Fournier d'Albe of the cloud-seeding trials in Pakistan using common salt, and the second by Braham and Sievers describes the overseeding of cumulus clouds with dry ice. There are no papers on seeding with silver iodide of either cumulus clouds or layer clouds, whether by aircraft or by generators on the ground; such papers are certainly to be expected in a book with the present title since most attempts at commercial or economically valuable rain-making in middle latitudes make use of silver iodide.

The book is divided into six parts covering respectively:

(i) Aerosols: their origin, distribution and measurement (13 papers).

(ii) Condensation and coagulation; measurement of cloud- and raindrop size; rain from water clouds (13 papers).

(iii) Melting and freezing; studies of snow and ice in the generation of precipitation (12 papers).

(iv) Crystal growth and nucleation; laboratory and field studies (9 papers).

(v) Thunderstorm electricity (1 paper).

(vi) International terminology (1 paper).

The first part has one paper on meteoritic dust by Schaefer and another by Junge; these offer no support for the well known theory of E. G. Bowen. The second part is interesting in that it shows how the realization of the importance of collision processes in the formation of rain has grown in recent years. The third and fourth parts contain interesting and beautiful photographs illustrating the freezing of droplets and crystal growth.

The general impression produced by the book, as with most published conference proceedings, is of patchiness and incompleteness. Many papers describe aspects of work dealt with more fully elsewhere, and others describe work in an incomplete form. In view of this, the lavish and glossy production by the Pergamon Press and the very high price of five guineas seem to the reviewer to be quite unjustified; a much cheaper reproduction of typescript would have sufficed.

R. P. WALDO LEWIS

HONOUR

Award of the International Meteorological Organization Prize to Mr. Ernest Gold

At its tenth session in Geneva this year, the Executive Committee of the World Meteorological Organization awarded the International Meteorological Prize for 1958 to Mr. Ernest Gold, formerly Deputy Director of the Meteorological Office. The previous awards were made to Dr. M. Hesselberg (1956) and to the late Professor Rossby (1957).

The I.M.O. Prize was created by the Second Congress of W.M.O. in 1955. The Prize consists of a gold medal, a substantial sum of money and a certificate giving the citation of the award, bearing the signature of the President of W.M.O. and the official seal of the Organization. The award is made annually by the Executive Committee by selection from names proposed by Member countries and it is laid down that "in the selection of the recipient, both scientific eminence and the record of work done in the field of international meteorological organizations should be taken into consideration". The inscription on the medal "Societas Gentium Meteorologica. Pro singulari erga scientiam meteorologicam merito" expresses this thought most concisely.

Those who know Mr. Gold's long and distinguished career in meteorology will readily agree that no one could be better qualified to receive this award. He was the first to explain the existence of the stratosphere by mathematical analysis and his memoir on "Barometric gradient and wind force" is among the classics of meteorology. Equally famous among professional meteorologists is his work for the organization of forecasting, and the Gold Slide and the Gold Visibility Meter bear witness to his skill as a designer of instruments. In international meteorology his record is outstanding. He was President of the Commission for Synoptic Weather Information of the I.M.O. from 1919 until he retired from the Meteorological Office in 1947, and he was also President of the Meteorological Subcommission of the International Commission for Air Navigation (the forerunner of the present International Civil Aviation Organization) from 1922 to 1946. During this period he did much to formulate the present international meteorological codes.

Mr. Gold is well known to the staff of the Meteorological Office, both as a member of the Meteorological Research Committee and as a frequent attender at the "Monday Discussions". His long experience and vast range of knowledge make his contributions unique, and his wit is as incisive as ever. His many friends, both in the Meteorological Office and the wider circle of international meteorology, will rejoice that a life-long service to the science of the atmosphere has been recognized in so fitting a manner.

O.G.S.

BOOK RECEIVED

Radiosondages du gradient de potentiel et de la conductibilité électrique de l'air. By J. Lugeon and M. Bohnenblust. (Reprinted from *Annales de la Station centrale suisse de Météorologie*, 1956). 12 in. × 8½ in., pp. 14, *illus.*

WEATHER OF APRIL 1958

Northern Hemisphere

In most regions of the Northern Hemisphere the mean-pressure chart closely resembled the normal for the month, although from the point of view of synoptic types the month was more than usually heterogeneous.

The Icelandic low was near its usual position and slightly deeper than usual. Mean pressures were below normal over Greenland and Iceland but the anomalies did not exceed 5 millibars. The Azores high was also centred near its normal position. It was slightly more intense than normal and had a well-marked north-eastward extension towards the British Isles. This feature, in conjunction with a westward displacement of the Siberian anticyclone to a position over the Urals, gave positive pressure anomalies everywhere in Europe, the maximum values being +7 millibars over Ireland and +6 millibars over northern Scandinavia.

Neither the polar anticyclone nor the North Pacific high showed any significant departure from normal. The Aleutian low, however, was about 8 millibars deeper than usual and an associated area of negative pressure anomaly with a central value of −10 millibars occurred in the extreme north of the Pacific.

A larger easterly component than usual in the mean surface flow resulted in surface temperatures below normal over all Europe except in western and northern districts of the British Isles and in southern Spain. Anomalies of −3°C. were reported at a number of stations in Italy, eastern Germany and Poland, but elsewhere temperatures were within 2°C. of normal. Temperatures were also below normal in Northern Siberia and the Canadian Arctic, anomalies reaching −5°C. in both these regions. Positive temperature anomalies of +3°C. occurred in Spitsbergen, Alaska, Ontario, the Sudan, Iraq and Pakistan.

The rainfall distribution over Europe was very irregular, amounts being generally below normal in Britian, the Low Countries and Spain, but up to twice the normal in the Balkans, Italy, and parts of Norway. In northern Russia, precipitation amounts reached four times the normal in places, although totals were only of the order of 40 millimetres. There were some unusually large totals for April in eastern coastal districts of the United States of America due largely to one or two particularly vigorous depressions which moved north-east from the Caribbean. Some stations in north Florida had over four times the average rainfall for the month.

WEATHER OF MAY 1958

Great Britain and Northern Ireland

May was a cool and very unsettled month during which an almost uninterrupted sequence of depressions from the Atlantic passed over or near the British Isles. On most days a front lay over some part of the country, and rainfall during the month was above average practically everywhere.

The month opened with sunny warm weather, an anticyclone being centred over the North Sea; there was over 12 hours' sunshine at most places on the 1st and afternoon temperatures exceeded 70°F. over much of southern and central England. The following day was warmer still over the greater part of England and Wales—80°F. was reached at Farnham—but over Scotland and Northern Ireland temperatures fell about 10°F. during the day with the onset of cool northerly winds. A frontal zone became established roughly east–west across the country, with cold air to the north and warm air to the south, and persisted for about a week. The periods 5th–10th, 14th–15th, 18th–19th and 22nd–29th were rather wet and marked by fairly vigorous cyclonic activity. During the first period small depressions moved north-eastward across the British Isles on a progressively more southerly track giving widespread rain, the largest amounts falling in Wales, northern England and western Scotland; Stornoway had over 1½ inches on the 7th. The night of the 7th–8th was unusually mild especially in south-eastern England, where temperatures were in the upper fifties. After a few days of fairer weather, active depressions moved across southern England on both the 14th and 15th bringing gale force winds and heavy rain locally; many places in south-east England recorded more than ½ inch of rain in 12 hours on the 15th. A depression, which developed in mid-Atlantic, deepened as it moved north-east toward the British Isles skirting the coast of Scotland during the night of the 18th–19th and bringing considerable rain to Northern Ireland and western Scotland; associated warm air lifted temperatures in southern England, which had been below average for more than a week, into the middle sixties. There were showers and bright periods in the mainly westerly winds during the next few days. On the night of the 22nd–23rd a depression deepened off the mouth of the Bristol Channel subsequently moving northward; it was situated over the Irish Sea for most of the 23rd and reached north-west Scotland about noon on the 25th; its passage was accompanied by substantial rainfall with outbreaks of thunder over western districts of England and Wales and over much of Scotland. From the 25th to the end of the month weather over the British Isles was weakly cyclonic and rather cool with rain or showers and scattered thunderstorms. Small thundery depressions moved northwards across south-east England on the 29th giving prolonged rain in places.

The month was persistently cool apart from the first two days though there was little air frost in England and Wales. Sunshine was about average. Apart from May 1955 it was the wettest May for 16 years over England and Wales where there was 133 per cent of the 1916–50 average rainfall. Scotland and Northern Ireland had 127 and 111 per cent of the average respectively. Less than the average occurred over the greater part of the Thames Valley, Somerset, the west and north Midlands of England, in Peebleshire, the Lothians, in south-west Scotland and in Antrim, Northern Ireland. More than twice the average was recorded in the Forest of Bowland and in Ross and Cromarty.

Generally the weather of May has been kind to most farmers and growers. Apart from some reports of gale damage to early potatoes and fruit blossom about mid-month in the south-west, most areas state that vegetables are growing steadily and seeds germinating well. Strawberries and apples show good prospects but plum and pear sets are thin in several districts.

WEATHER OF JUNE 1958

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 ...	78	33	—1·1	200	+6	70
Scotland	78	28	—0·2	103	—1	76
Northern Ireland ...	69	38	—0·9	195	+5	67

* 1916-1950 † 1921-1950

RAINFALL OF JUNE 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	5·11	281	*Carm.*	Pontcrynfe	3·87	123
Kent	Dover	3·59	223	*Pemb.*	Maenclochog, Dolwen Br.	5·14	149
,,	Edenbridge, Falconhurst	4·88	271	*Radnor*	Llandrindod Wells ...	3·67	153
Sussex	Compton, Compton Ho.	3·37	164	*Mont.*	Lake Vyrnwy	4·53	124
,,	Worthing, Beach Ho. Pk.	2·78	182	*Mer.*	Blaenau Festiniog ...	6·73	74
Hants	St. Catherine's L'thouse	3·38	245	,,	Aberdovey	4·92	161
,,	Southampton, East Pk.	3·44	198	*Carn.*	Llandudno	3·77	211
,,	South Farnborough ...	2·98	183	*Angl.*	Llanerchymedd ...	5·08	212
Herts.	Harpenden, Rothamsted	4·57	267	*I. Man*	Douglas, Borough Cem.	3·83	137
Bucks.	Slough, Upton ...	4·16	254	*Wigtown*	Newtown Stewart ...	3·80	143
Oxford	Oxford, Radcliffe ...	3·31	196	*Dumf.*	Dumfries, Crichton R.I.	3·68	139
N'hants.	Wellingboro' Swanspool	5·87	365	,,	Eskdalemuir Obsy. ...	3·73	94
Essex	Southend W.W. ...	5·07	387	*Roxb.*	Crailing...	2·73	139
Suffolk	Ipswich, Belstead Hall	4·78	308	*Peebles*	Stobo Castle	3·92	163
,,	Lowestoft Sec. School	3·21	201	*Berwick*	Marchmont House ...	3·94	195
,,	Bury St. Ed., Westley H.	4·08	240	*E. Loth.*	N. Berwick	2·51	129
Norfolk	Sandringham Ho. Gdns.	2·54	129	*Midl'n.*	Edinburgh, Blackf'd H.	3·30	176
Dorset	Creech Grange... ...	2·95	160	*Lanark*	Hamilton W.W., T'nhill	3·18	135
,,	Beaminster, East St. ...	3·79	192	*Ayr*	Prestwick	2·68	117
Devon	Teignmouth, Den Gdns.	2·96	177	,,	Glen Afton, Ayr. San ...	3·76	120
,,	Ilfracombe	3·21	167	*Renfrew*	Greenock, Prospect Hill	3·49	104
,,	Princetown	6·27	138	*Bute*	Rothesay, Ardencraig...	...	...
Cornwall	Bude	3·82	213	*Argyll*	Morven, Drimnin ...	...	...
,,	Penzance	3·75	191	,,	Ardrishaig, Canal Office	3·22	79
,,	St. Austell	4·48	193	,,	Inveraray Castle ...	2·81	54
,,	Scilly, St. Mary ...	2·89	166	,,	Islay, Eallabus ...	3·41	114
Somerset	Bath	5·76	325	,,	Tiree	3·29	117
,,	Taunton	2·96	177	*Kinross*	Lock Leven Sluice ...	3·48	149
Glos.	Cirencester	3·90	187	*Fife*	Leuchars Airfield ...	2·37	139
Salop	Church Stretton ...	4·42	203	*Perth*	Loch Dhu	3·89	92
,,	Shrewsbury, Monkmore	4·58	265	,,	Crieff, Strathearn Hyd.	3·90	153
Worcs.	Worcester, Red Hill ...	3·53	235	,,	Pitlochry, Fincastle	2·84	177
Warwick	Birmingham, Edgbaston	4·23	223	*Angus*	Montrose Hospital ...	1·57	87
Leics.	Thornton Reservoir ...	3·43	190	*Aberd.*	Braemar	3·15	168
Lincs.	Cranwell Airfield ...	4·33	272	,,	Dyce, Craibstone ...	1·55	76
,,	Skegness, Marine Gdns.	2·56	168	,,	New Deer School House	1·48	66
Notts.	Mansfield, Carr Bank...	5·03	305	*Moray*	Gordon Castle	2·07	92
Derby	Buxton, Terrace Slopes	7·01	221	*Inverness*	Loch Ness, Garthbeg ...	1·50	60
Ches.	Bidston Observatory ...	4·69	237	,,	Fort William	2·11	46
,,	Manchester, Airport ...	5·41	231	,,	Skye, Duntulm... ...	1·63	49
Lancs.	Stonyhurst College ...	4·61	151	,,	Benbecula	2·25	77
,,	Squires Gate	3·53	160	R. & C.	Fearn, Geanies ...	1·87	104
Yorks.	Wakefield, Clarence Pk.	3·75	230	,,	Inverbroom, Glackour...	2·09	63
,,	Hull, Pearson Park ...	3·78	220	,,	Loch Duich, Ratagan...	2·37	49
,,	Felixkirk, Mt. St. John...	2·79	132	,,	Achnashellach	2·64	53
,,	York Museum	3·24	175	*Suth.*	Stornoway	1·53	60
,,	Scarborough	3·69	217	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough... ...	3·01	171	,,	Wick Airfield	·91	45
,,	Baldersdale, Hury Res.	3·56	173	*Shetland*	Lerwick Observatory ...	·66	31
Nor'l'd	Newcastle, Leazes Pk....	2·58	130	*Ferm.*	Belleek	4·91	144
,,	Bellingham, High Green	3·07	140	*Armagh*	Armagh Observatory ...	5·41	224
,,	Lilburn Tower Gdns ...	3·05	153	*Down*	Seaforde	7·28	290
Cumb.	Geltsdale	2·45	91	*Antrim*	Aldergrove Airfield ...	4·65	207
,,	Keswick, High Hill ...	3·98	120	,,	Ballymena, Harryville...	3·54	125
,,	Ravenglass, The Grove	4·70	171	*L'derry*	Garvagh, Moneydig ...	4·28	157
Mon.	A'gavenney, Plâs Derwen	3·33	157	,,	Londonderry, Creggan	5·89	181
Glam.	Cardiff, Penylan ...	3·12	137	*Tyrone*	Omagh, Edenfel ...	4·90	176

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,035, SEPTEMBER 1958

EXTREME WIND SPEEDS OVER GREAT BRITAIN AND NORTHERN IRELAND

By H. C. SHELLARD, B.Sc.

Introduction.—Requests are frequently received from design or consulting engineers for information on the maximum wind velocities which are to be expected in various parts of the country. This information is needed in order to calculate the greatest wind pressures which may effect a given structure so that this structure (which may be a tall building, a chimney stack, a tower, a bridge, etc.) can be designed to withstand such pressure. Thus the engineer requires from the climatologist estimates of the probable maximum velocity for a specified interval and the probable maximum gust at a given place and height above the ground.

The climatologist has at his disposal the anemograph records from a network of stations which may cover the country more or less adequately, although there may be important gaps. In the past the usual procedure has been to examine the wind records from the station, or stations, nearest to the site and to take out the highest speeds so far recorded. These have then been adjusted, using the appropriate velocity–height relations,[1, 2] so as to be representative of the desired height above the ground (which may be several hundreds of feet), and an approximate allowance made for difference in exposure. The anemograph will normally be on a fairly open and level site while the proposed structure may be sheltered by other buildings, etc. or may be on a hill-top.

Objections to the procedure outlined above are, first, that the absolute extreme value tends to increase as the length of record increases, whereas the periods over which wind records in this country are available vary from less than 10 years to a little over 40 years; and second, that it is statistically unsound to try to estimate the largest possible value without regard to the frequency with which very high values are likely to occur. What is really required is an estimate of the probability of occurrence of extreme values based not on one extreme alone but on all the values available. This should enable the engineer to design his structure economically on the basis of a calculated risk, that is, that it would fail within a specified time interval, say 100 years. The requirement can be met by applying to the data the statistical theory of extreme values, as developed by Gumbel[3] and others.

TABLE I—ANNUAL MAXIMUM WIND SPEEDS (GUSTS) AT CARDINGTON, 1932–54

Rank m	Highest gust x m.p.h.	Year	Plotting position $p = \frac{m}{n+1}$	Reduced variate $y = -\log_e(-\log_e p)$
1	55	1953	0·042	−1·16
2	59	1950	0·083	−0·91
3	60	1941	0·125	−0·73
4	61	1951	0·167	−0·58
5	62	1952	0·208	−0·45
6	63	1937	0·250	−0·33
7	63	1939	0·292	−0·21
8	64	1942	0·333	−0·09
9	65	1933	0·375	0·02
10	67	1949	0·417	0·13
11	68	1948	0·458	0·25
12	69	1945	0·500	0·37
13	71	1940	0·542	0·49
14	72	1934	0·583	0·62
15	72	1944	0·625	0·75
16	76	1954	0·667	0·90
17	78	1943	0·708	1·06
18	78	1946	0·750	1·25
19	81	1932	0·792	1·46
20	82	1936	0·833	1·70
21	86	1938	0·875	2·01
22	88	1935	0·917	2·44
23	93	1947	0·958	3·15

Application of extreme probability theory to annual extreme wind speeds.—Table I lists the highest gust speeds in miles per hour recorded at Cardington in the years 1932–1954 inclusive, arranged in order of size from the smallest to the largest. The fourth column gives the corresponding values of $\frac{m}{n+1}$ where m is the rank and n the number of observations, in this case 23; they provide plotting positions for use on extreme probability graph paper and may be regarded as representing the frequencies with which the corresponding values of x (highest gust) are not exceeded. Extreme value probability graph paper has a uniform scale along one axis, usually the vertical. This is used for the observed values. The horizontal axis is the probability scale and it is marked according to the formula $y = -\log_e(-\log_e p)$. On this scale the limiting values $p = 0$ and $p = 1$ are never reached but if $p = \cdot 01$ were taken as $y = 0$ then $p = \cdot 05$ would be 2·034 units, $p = \cdot 09$ would be 6·963 units and $p = \cdot 9999$ would be 10·877 units to the right of the origin. If a set of extreme values conforms to Gumbel's theory, then when those values are plotted again $p = \frac{m}{n+1}$ on extreme value probability paper the points obtained will lie along a straight line. If extreme value probability paper is not available then values of $y = -\log_e(-\log_e p)$ can either be computed or taken from published tables.[4] The extremes can then be plotted against y on ordinary graph paper. Values of y for the set of highest gust data from Cardington are given in the last column of Table I and Figure 1 shows the plotted data for both the highest gusts and the highest mean hourly speeds recorded at that station during the years 1932–1954 inclusive. Both the p and y scales are shown and also that of T, the return period in years, which is equal to $\frac{1}{1-p}$. This is the average time interval between recurrences of an event and is useful

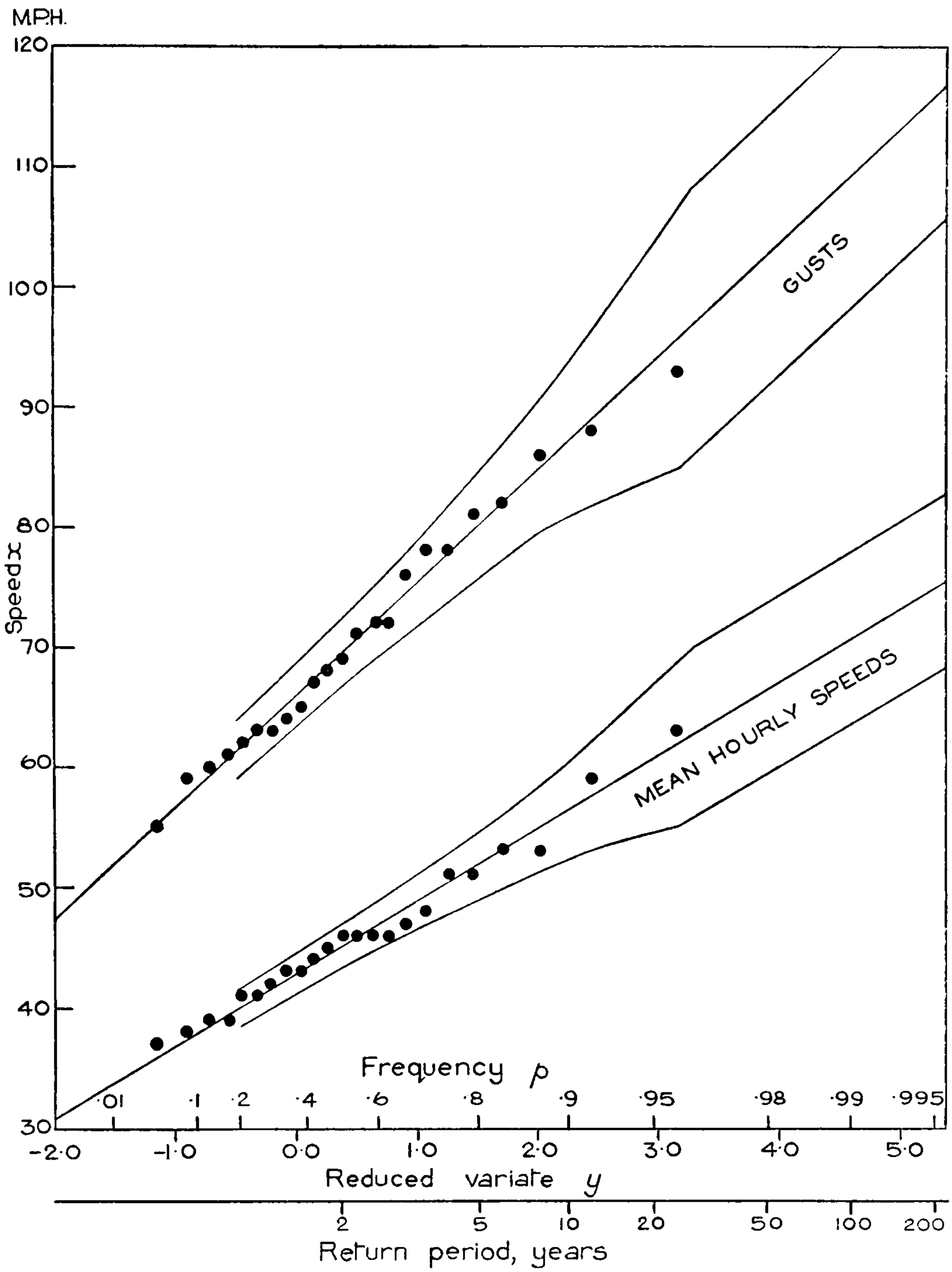


FIGURE 1—ANNUAL MAXIMUM WIND SPEEDS, CARDINGTON, 1932–54

because it allows the annual maximum value which may be expected to be exceeded on the average only once in any desired number of years to be read off directly from the graph.

It can be seen from Figure 1 that the Cardington wind data fit the theory quite well and the fitted straight lines have been computed and drawn in. The lines on either side are called control curves and they indicate the limits

TABLE II—MAXIMUM MEAN HOURLY WIND SPEEDS IN MILES PER HOUR AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years: 10	20	50	100	Highest on record	Mean annual maximum
Lerwick... ...	24	1931–54	67	70	75	79	73	57·7
Kirkwall ...	14	1930–43	58	61	65	69	59	50·1
Stornoway ...	18	1937–54	67	71	77	81	73	56·5
Aberdeen ...	15	1933–47	44	47	52	55	44	35·5
Balmakewan ...	21	1915–35	45	48	53	56	51	36·8
Bell Rock ...	25	1930–54	57	60	63	66	59	49·3
Edinburgh ...	38	1915–33 1936–54	56	59	63	65	59	49·5
Tiree	28	1927–54	62	67	73	77	64	51·5
Paisley	41	1914–54	41	43	46	48	43	36·2
Prestwick ...	11	1944–54	52	55	58	61	48	45·2
Eskdalemuir ...	32	1914–45	54	57	60	63	56	47·1
Point of Ayre ...	19	1936–54	59	63	67	71	63	49·9
Durham ...	17	1938–54	48	51	55	57	50	41·2
South Shields ...	21	1934–54	56	60	66	71	61	44·7
Catterick ...	10	1933–42	51	56	62	67	49	38·8
Spurn Head ...	29	1922–46 1948–50, 54	56	59	62	65	59	50·1
Cranwell	23	1928–42, 44 1947–48, 50–54	47	50	54	57	49	38·7
Gorleston ...	36	1913–31, 34–39 1941–46, 48, 51–54	50	53	57	59	55	43·8
Felixstowe ...	17	1931–35, 37–38 1944–52, 54	45	48	51	54	45	39·1
Mildenhall ...	17	1938–54	48	52	57	61	56	37·7
Cardington ...	23	1932–54	44	48	52	56	49	36·2
Shoeburyness ...	29	1926–54	46	49	52	55	48	39·7
Leicester ...	10	1938–40, 43–45 1947–50	45	50	56	61	42	33·0
Birmingham ...	31	1924–54	38	40	43	46	38	31·7
London (Kingsway) ...	11	1944–54	37	40	43	46	34	29·7
Croydon ...	23	1928–39 1944–54	41	44	47	50	45	34·8
Kew Observatory	24	1931–54	33	34	36	38	34	28·9
Dover	21	1924–39 1948–50, 53–54	44	45	48	50	46	39·1
Lympne ...	27	1923–29, 31–43 1945–51	48	50	54	56	52	42·0
Manston ...	12	1943–54	46	48	51	54	45	39·6
Thorney Island	12	1943–54	43	46	50	53	45	36·2
Calshot	24	1920, 22–41 1950–52	51	54	58	61	50	43·0
S. Farnborough	10	1945–54	50	55	62	68	49	36·8
Boscombe Down	22	1933–54	48	51	54	57	49	41·4
Larkhill... ...	24	1931–54	46	48	51	53	46	40·6

between which each extreme value should lie with a probability of ·68, the theory being accepted if all the observations lie between them. By extrapolating the fitted straight line it is possible to predict the return period corresponding to any desired speed or the speed which has any desired return period. With only 20 to 30 years of record available it would probably be unwise to carry the extrapolation very far, certainly not beyond 100 years. Thus from Figure 1 it may be inferred that the speeds which are likely to be exceeded only once in 50 years are 103 miles per hour in a gust and 66 miles per hour averaged over one hour. These speeds relate to the effective height of the Cardington anemograph, that is, 135 feet above the ground.

TABLE II—MAXIMUM MEAN HOURLY WIND SPEEDS IN MILES PER HOUR AT 33 FEET ABOVE THE GROUND (CONT.)

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years 10	20	50	100	Highest on record	Mean annual maximum
Fleetwood ...	29	1924–43, 1946–54	61	65	70	73	62	52·5
Manchester Airport ...	10	1942–50, 1954	54	58	63	67	54	44·3
Southport ...	42	1913–54	60	63	68	71	65	51·0
Bidston	25	1929–44, 1946–54	57	60	65	68	62	48·3
Sealand... ...	19	1928–41, 1943–47	49	52	56	59	53	41·4
Holyhead ...	19	1933–51	61	64	69	73	64	51·7
Aberporth ...	10	1945–54	56	60	66	70	56	45·4
St. Ann's Head	14	1935–46, 1948–49	69	75	83	89	70	54·9
Plymouth ...	30	1921–43, 1947–48, 50–54	53	57	61	64	58	45·4
The Lizard ...	17	1935–42, 45–47, 1949–54	63	66	70	74	67	54·8
Pendennis Castle	20	1929–38, 1941–50	65	68	72	75	67	58·2
Scilly	28	1927–54	62	66	71	75	67	53·1
Aldergrove ...	25	1928–46, 1949–54	45	48	51	54	48	38·9

TABLE III—MAXIMUM GUST SPEEDS IN MILES PER HOUR AT 33 FEET ABOVE THE GROUND

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years 10	20	50	100	Highest on record	Mean annual maximum
Lerwick... ...	24	1931–54	98	102	108	112	101	87·0
Kirkwall ...	14	1930–43	92	97	102	106	100	82·3
Stornoway ...	18	1937–54	103	110	119	126	107	85·7
Aberdeen ...	15	1933–47	78	83	89	93	83	67·8
Balmakewan ...	21	1915–35	76	82	89	94	87	62·8
Bell Rock ...	25	1930–54	90	95	101	106	91	77·2
Edinburgh ...	38	1915–33, 1936–54	86	90	96	99	87	76·7
Tiree	28	1927–54	96	102	111	118	106	79·7
Paisley	41	1914–54	87	93	99	105	104	74·7
Prestwick ...	11	1944–54	87	92	98	103	85	74·9
Eskdalemuir ...	32	1914–45	88	93	100	105	91	75·3
Point of Ayre ...	19	1936–54	88	93	99	104	90	75·9
Durham ...	17	1938–54	90	96	102	107	95	78·1
South Shields ...	21	1934–54	84	90	97	103	86	70·8
Catterick ...	10	1933–42	86	92	99	105	88	71·1
Spurn Head ...	29	1922–46, 1948–50, 54	85	90	96	101	91	73·7
Cranwell ...	24	1928–44, 1947–48, 50–54	88	96	106	113	108	68·7
Gorleston ...	36	1914–31, 34–39, 1941–48, 51–54	76	80	86	90	82	66·2
Felixstowe ...	17	1931–35, 37–38, 1944–52, 54	81	87	95	101	85	66·3
Mildenhall ...	17	1938–54	88	94	103	110	94	71·3

TABLE III—MAXIMUM GUST SPEEDS IN MILES PER HOUR AT 33 FEET ABOVE THE GROUND (CONT.)

Station	No. of years of record	Period of record used	Speeds likely to be exceeded only once in stated no. of years 10	20	50	100	Highest on record	Mean annual maximum
Cardington ...	23	1932–54	78	84	91	97	83	63·1
Shoeburyness ...	29	1926–54	75	79	85	90	79	64·2
Leicester ...	10	1938–40 1943–45, 47–50	83	91	101	108	84	65·2
Birmingham ...	31	1924–54	75	80	87	92	79	63·3
London (Kingsway) ...	11	1944–54	79	86	95	102	77	61·3
Croydon ...	23	1928–39 1944–54	76	80	86	90	77	64·8
Kew Observatory	24	1931–54	71	74	79	83	71	61·9
Dover	21	1924–39 1948–50, 53–54	74	78	84	88	85	63·5
Lympne ...	27	1923–29, 31–43 1945–51	80	84	89	93	84	69·8
Manston ...	12	1943–54	78	82	87	91	80	68·1
Thorney Island	12	1943–54	79	83	89	94	81	68·3
Calshot	24	1920, 22–41 1950–52	80	85	92	98	86	67·2
S. Farnborough	10	1945–54	78	82	89	93	79	66·0
Boscombe Down	22	1933–54	79	84	89	94	86	68·7
Larkhill... ...	24	1931–54	78	82	86	90	80	70·2
Fleetwood ...	29	1924–43 1946–54	88	93	100	106	91	75·4
Manchester Airport ...	10	1942–50 1954	91	97	105	111	90	75·7
Southport ...	42	1913–54	89	94	101	106	93	76·5
Bidston	25	1929–44 1946–54	95	100	107	112	100	82·3
Sealand... ...	18	1928–41 1944–47	82	87	93	97	86	70·7
Holyhead ...	19	1933–51	94	100	107	113	107	79·1
Aberporth ...	10	1945–54	93	100	110	117	92	75·2
St. Ann's Head	13	1935–45 1948–49	105	112	122	128	>107	88·3
Plymouth ...	30	1921–43 1947–48, 50–54	80	85	92	97	91	67·2
The Lizard ...	17	1935–42 1945–47, 49–54	93	97	101	105	94	84·7
Pendennis Castle	20	1929–38 1941–50	100	106	114	120	102	85·2
Scilly	28	1927–54	98	104	111	116	107	84·8
Aldergrove ...	25	1928–46 1949–54	83	88	94	99	87	71·5

Results.—The wind data from 49 anemograph stations have been analysed in this way and the results are set out in Table II, which refers to mean hourly speeds and Table III, which refers to gust speeds. In every case the values refer to a height of 10 metres (33 feet) above the ground and have been reduced to that level using the formulae

$$v_{10} = v_h \left[\frac{10}{h}\right]^{0.17} \text{ for mean speeds[5] and}$$

$$v_{10} = v_h \left[\frac{10}{h}\right]^{0.085} \text{ for gusts,[6]}$$

where h is the effective height of the anemograph. The highest speeds on record, up to December 1954, the mean annual maxima and the number of years of the record are also given.

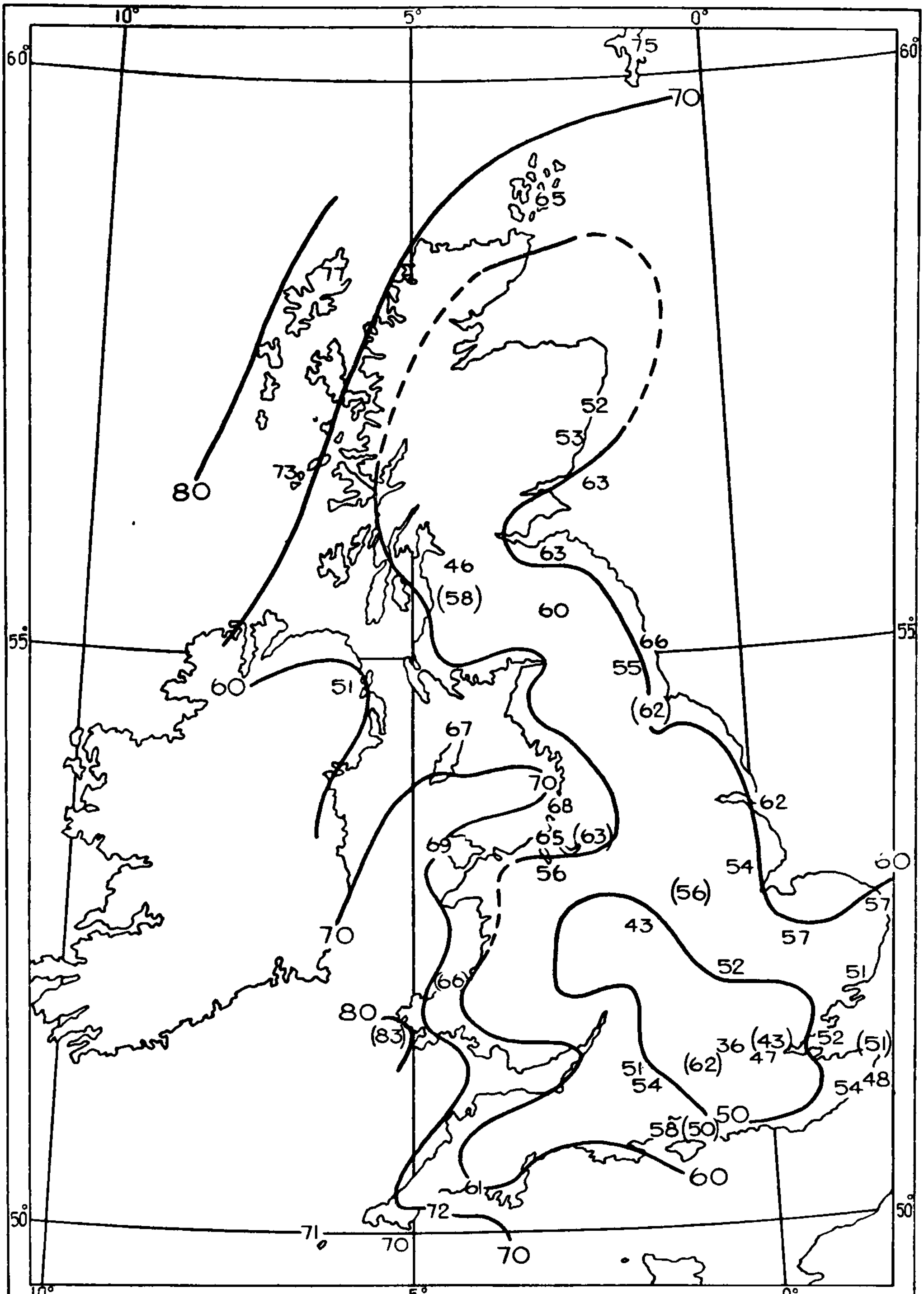


FIGURE 2—HIGHEST MEAN HOURLY WIND SPEED (MILES PER HOUR) AT 33 FEET, LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS

(values based on less than 15 years of record bracketed)

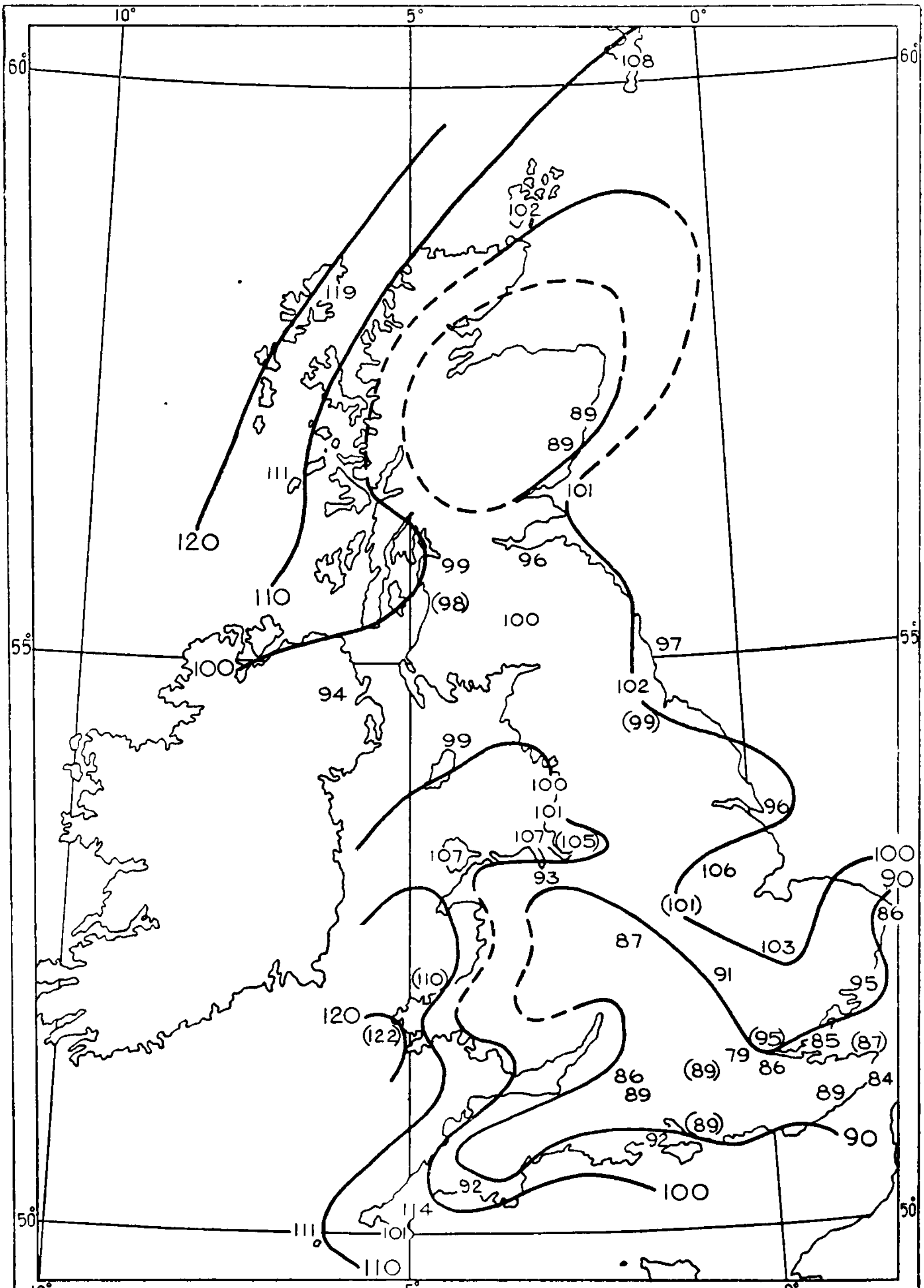


FIGURE 3—HIGHEST GUST SPEED (MILES PER HOUR) AT 33 FEET, LIKELY TO BE EXCEEDED ONLY ONCE IN 50 YEARS

(values based on less than 15 years of record bracketed)

The highest mean hourly speeds at 10 metres (33 feet) likely to be exceeded only once in 50 years are plotted in Figure 2 on a map of the British Isles on which tentative isopleths at intervals of 10 miles per hour have been drawn in to show the general distribution. Figure 3 has been drawn similarly to show the general distribution of gust speeds likely to be exceeded only once in 50 years. It must be emphasized that extreme wind speeds are greatly dependent on local topography and that these maps only represent a broad picture based on wind observations which, generally speaking, relate to open and level sites. Such maps must therefore be used with great caution, as values interpolated from them may need considerable adjustment in the light of a study of the actual exposure of any specified location. Nevertheless the author considers that Figure 3 is more satisfactory than a map which is simply based on the highest recorded gusts such as the one in the "Climatological atlas of the British Isles".[7]

It should be pointed out that the current Code of Practice concerned with the calculation of wind pressures on buildings[8] requires the use of the highest expected mean wind speed over one minute. The records from standard anemographs have too close a time scale for means to be measured over such a short period, however, and the available statistics are limited to means over one hour, together with details of the highest gusts. The highest mean over one minute will clearly lie somewhere between the highest hourly mean and the highest gust – the duration of a gust being of the order of 10 seconds. An examination by G. A. Bull (unpublished) of special anemograph records, obtained at Cardington, which had a much more open time scale, has shown that the highest one-minute mean lies much nearer to the highest hourly mean than it does to the highest gust and that it can be taken approximately as the highest hourly mean plus 10 miles per hour.

REFERENCES

1. London, Meteorological Office; Observer's Handbook, London, 1952, p. 72.
2. BILHAM, E. G.; Notes on extreme gusts recorded in the British Isles. Unpublished.
3. GUMBEL, E. J.; Statistical theory of extreme values and some practical applications. *Appl. Math. Ser. U.S. Bur. Stand., Washington, D.C.*, No. 33, 1954.
4. Washington, D.C., United States Bureau of Standards; Probability tables for the analysis of extreme value data. *Appl. Math. Ser., U.S. Bur. Stand., Washington, D.C.*, No. 33, 1954.
5. CARRUTHERS, N.; Variations in wind velocity near the ground. *Quart. J. R. met. Soc., London*, **69**, 1943, p. 293.
6. DEACON, E. L.; Gust variation with height up to 150 m. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 562.
7. London, Meteorological Office; Climatological atlas of the British Isles. London, 1952, p. 20.
8. London, British Standards Institution; British Standard code of practice. CP3—Ch. V (1952). Code of functional requirements of buildings. Ch. V., Loading, p. 22.

THE ESTIMATION OF MAXIMUM DAY TEMPERATURE FROM THE TEPHIGRAM

By D. W. JOHNSTON, B.Sc.

In his paper on this subject, E. Gold[1] gave assessments of monthly values of the thickness of a surface layer, expressed in millibars, (Δp in the present note) which could be changed from an isothermal state at dawn to a state of dry adiabatic lapse rate in mid-afternoon as a result of solar radiation. His values are given overleaf.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Δp mb.	60	80	95	110	120	125	120	110	100	85	60	50

It is suggested by the present writer that this way of expressing the facts is more useful than the more familiar reference to squares on the T-Φgram, and leads to a simple graphical method of determining the day maximum temperature.

Dealing first with the case in which convection cloud is not expected to develop, the method is as follows. Since radio-sonde observations are now made at midnight instead of near dawn, it is first necessary to modify the lowest part of the T-Φgram selected as representative of the place for which the forecast is to be made by using reported values of the dawn screen temperature.

Next, the isobars p_0 (surface pressure), AB, and $p_0 - \Delta p$, CD, should be drawn on the T-Φgram (Figures 1 and 2). Then a point, P, on the $p_0 - \Delta p$ isobar should be selected such that the isothermal, PE, and the dry adiabatic, PF, through that point enclose with the p_0 isobar and the modified temperature curve, equal positive and negative areas. This construction is facilitated by having a piece of perspex with two lines at right angles scribed on it, the point of intersection being slid along the $p_0 - \Delta p$ isobar until the positive and negative areas become equal. The point, F, where the dry adiabatic intersects the p_0 isobar represents the day maximum temperature.

The case in which convection cloud is expected to develop is naturally rather more difficult, but a similar sort of method can be used.

As before, the p_0, AB, and $p_0 - \Delta p$, CD, isobars should be drawn (Figure 3). A point, P, should then be selected on CD such that the isothermal PE, the dry adiabatic FPS up to the saturation level, and the saturated adiabatic SG from the saturation level upwards, enclose with the modified temperature curve and the p_0 isobar equal positive and negative areas. The point, F, where the dry adiabatic intersects the p_0 isobar represents an upper limit for the afternoon temperature—an upper limit because the convection cloud which develops will prevent a portion of the solar radiation being used to raise the temperature of the surface layers.

The technique of matching an area on the T-Φgram with a triangle was used by Jefferson[2] to determine the temperature rise occasioned by the addition of a specific amount of solar energy. A set of values of Δp could be worked out for this purpose also.

The method outlined above has the advantage of balancing out small areas on the T-Φgram instead of estimating a relatively large area. Also, no separate measuring scale is necessary, the millibar scale over the T-Φgram itself being the only one required. However the operation can be facilitated by the use of a piece of perspex with lines at right angles ruled on it. The method is independent of the scale of the T-Φgram and of the temperature units used. It could be adapted for use with any aerological diagram in which equal areas represent equal amounts of energy.

REFERENCES

1. GOLD, E.; Maximum day temperatures and the Tephigram. *Prof. Notes. Met. Off., London.* No. 63, 1933.
2. JEFFERSON, G. J.; Temperature rise on clear mornings. *Met. Mag., London.* **79**, 1950.

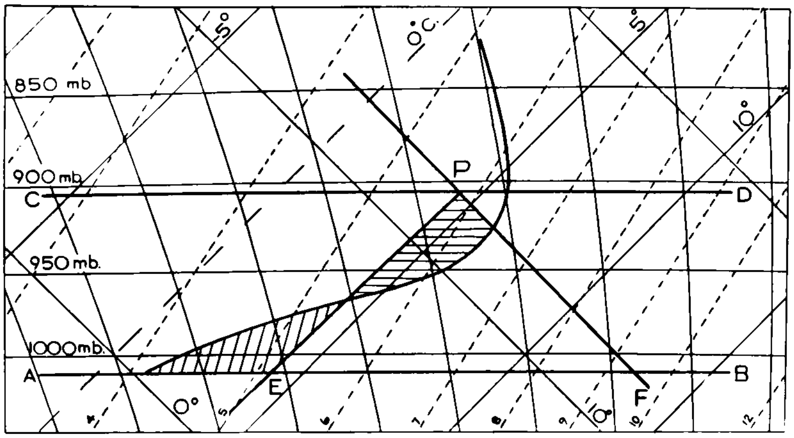


FIGURE 1—ESTIMATION OF MAXIMUM DAY TEMPERATURES
Convection cloud not expected

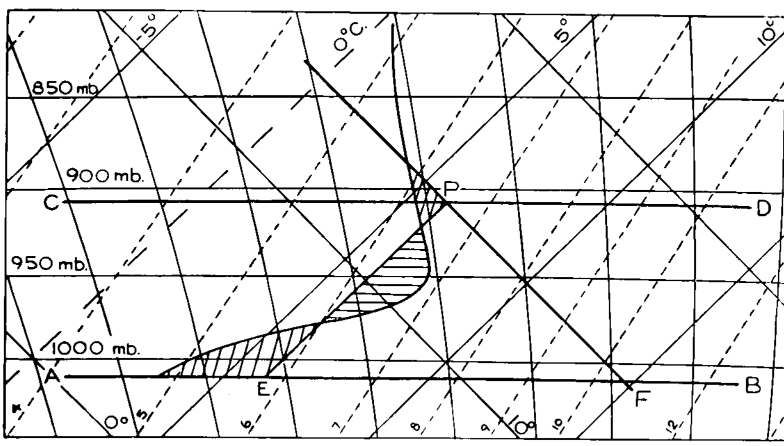


FIGURE 2—ESTIMATION OF MAXIMUM DAY TEMPERATURES
Convection cloud not expected

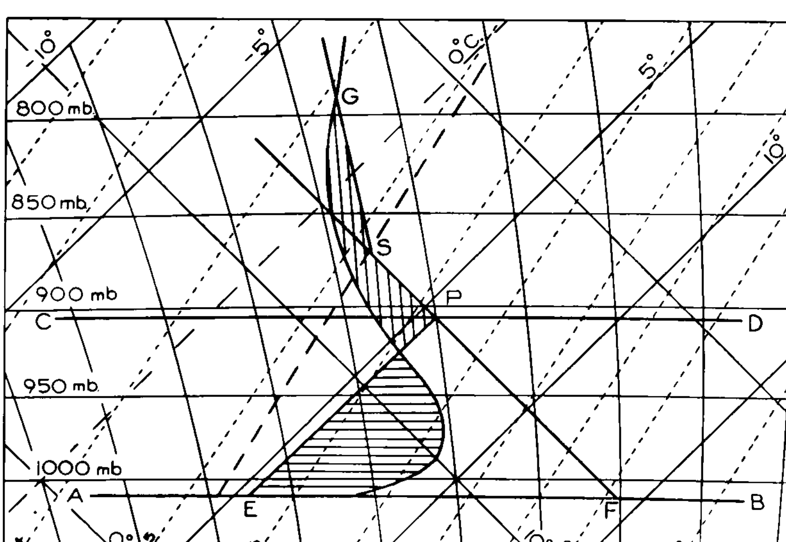


FIGURE 3—ESTIMATION OF MAXIMUM DAY TEMPERATURES
Convection cloud expected to develop

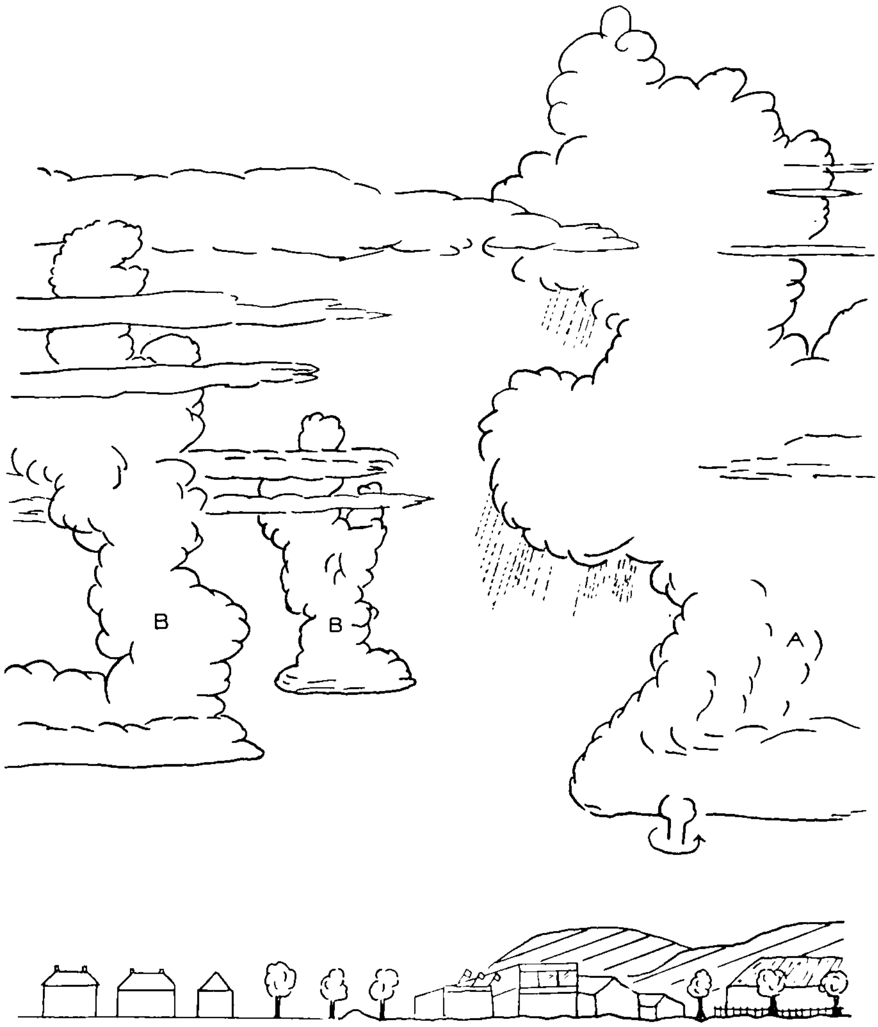


FIGURE 1—CUMULONIMBUS DEVELOPMENT AT RENFREW 1645 G.M.T. 28 APRIL 1957
View from Meteorological Office looking north-west

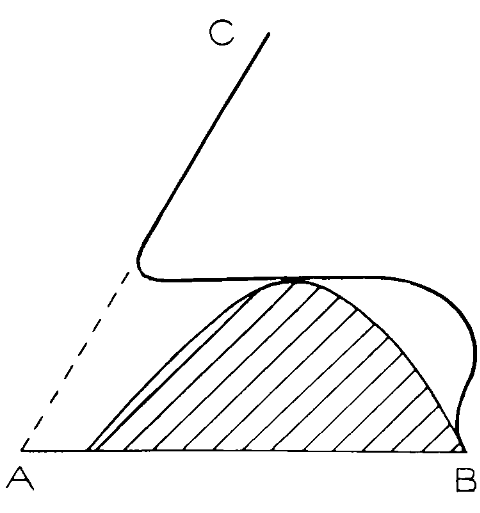


FIGURE 2—A VERTICAL CROSS-SECTION SHOWING THE DISTORTION OF A COLD FRONTAL SURFACE OVER THE GRAMPIANS (HEIGHT 3,000–4,000 FEET)

BC is the frontal surface. The unretarded frontal surface extended meets the ground at A. B is the surface position of the retarded front.

RAPID DEVELOPMENT OF CUMULONIMBUS CLOUD BEHIND A WEAK COLD FRONT AT RENFREW

By A. McEWAN

At 1500 G.M.T. on Sunday 28 April 1957, a weak occlusion from the Isle of Man to North Berwick was moving slowly south-east. Behind this occlusion and parallel to it was a weak cold front from Aldergrove to just north of Renfrew to Lossiemouth. To the rear of the occlusion the weather was cloudy with a little light rain, gradually clearing, and by mid-afternoon the temperature was 57°F., about 6°F. higher than the general temperature in mid-Scotland. Cumulus cloud developed slowly to about half-cover with no showers and the tops were 5,000 to 6,000 feet.

The weak cold front passed through Renfrew at 1630 G.M.T. and the only significant changes in weather were a veer in wind from 210° 8 knots to 330° 5 knots and a slight drop in dew point. Immediately behind the cold front, however, three cumulus clouds began to develop rapidly.

At 1635 G.M.T. the observing assistant noticed a funnel cloud protruding from the base of the cumulus cloud immediately above the airfield. From the Meteorological Office, looking north-west, the funnel was clearly visible and although much of this cloud was overhead (base 1,800 feet), the funnel was silhouetted against blue sky and was approximately 2,500 feet away (horizontally). The funnel was clearly seen to be revolving in an anticlockwise direction at one revolution in 4 seconds, the timing being taken from the ragged edges which, in one part of the funnel circumference, hung further down than the rest of it.

Precipitation began to fall from the over-hang of this cumulus cloud, which had now become very dark underneath, but did not reach the ground. Two neighbouring clouds, (B) in Figure 1, had also developed rapidly and had penetrated thin layers of altocumulus at about 10,000–12,000 feet. By 1645 G.M.T. from observations of smoke from factory chimneys there was a 10–15 knot easterly wind to the north-west of the airfield and a similar speed but westerly to the south-east. Other observations in different directions more or less confirmed that a circulation had been set up at ground level corresponding to the direction of rotation of the funnel.

The funnel slowly disappeared at 1650 G.M.T. and almost immediately the rain area from cloud (A) spread rapidly towards (B). The space between the three clouds filled up very quickly into what looked like very turbulent convection cloud and the precipitation reached the ground. It started as a slight shower at Renfrew at 1700 G.M.T. but soon turned to hail and heavy rain. A total of 9·6 millimetres of rain fell by 1800 G.M.T., most of it in 25 minutes. Almost as soon as the precipitation ceased a thunderstorm commenced to the east and south-east of the airfield.

No other showers were reported in the cold air over west and north-west Scotland and two aircraft, inbound to Renfrew from Dublin and London, reported that this was the only cloud of significant development over their respective routes. Both aircraft found other cumulus tops to be 6,000 feet with stratocumulus to the north of Renfrew and unlimited visibility in this direction. The pilot of one of the aircraft found no turbulence until he was about 4 miles from this developing cloud. From this point onwards the turbulence increased progressively and became so severe within the rain area associated with the cloud that avoiding action had to be taken.

The timing of cold fronts approaching Renfrew from the north is complicated by the high ground of the Grampians which acts as a barrier to the first 3,000–4,000 feet of the frontal surface. Although the reasons may be more complex, the following gives a forecaster a rough method of forecasting the true clearance of the front and, in this case, explains the isolated thunderstorm.

Figure 2 is a schematic diagram showing a vertical cross-section through the high ground to the north of Renfrew and the suggested configuration of the frontal surface. A temporary clearance is usually found when point A reaches Renfrew and in many cases the front appears to be through. However, the surface position of the front at B may be several hours later in reaching Renfrew and a deterioration to pre-frontal conditions occurs. After the surface position B moves south the cold air has now attained considerable depth due to the distortion of the frontal surface by the high ground.

On this occasion the front was so weak that there was no weather associated with it (at B) and the cold air behind it overran the valley in which Renfrew lies. The relatively warmer air in the valley rose rapidly into the cold air thus causing the exceptional instability and the phenomena as described.

FITNESS FIGURE STATISTICS AS AN AID IN LOCAL FORECASTING

By J. E. ATKINS

Summary.—A comparison of airfield weather fitness figures at Stradishall for south-easterly winds, with those for winds of other directions, shows a marked tendency for poor flying conditions with the south-easterly winds during the winter months. Reasons for this tendency are discussed, and similar figures for Waterbeach show the extent to which this is a purely local characteristic.

Local topography (Figure 1).—Although the East Anglian ridge is only some 400 feet above mean sea level in Suffolk, forecasters appreciate it as a significant local factor in weather. Stradishall is situated near the crest of the ridge and slightly on the south-eastern side, at a height of 385 feet above mean sea level and with up-sloping ground from the south-east. Waterbeach lies north-west of the ridge, about 16 nautical miles from Stradishall and at a height of only 23 feet above mean sea level.

An example of poor conditions in south-easterlies.—In general one would expect lower cloud bases at Stradishall than at Waterbeach, solely on account of the difference in heights. However, it has been noticed that flying conditions tend to be particularly bad at Stradishall in south-easterly surface wind situations—to an extent not accounted for merely by the height above sea level.

For example, on 8 November 1955, the 0600 G.M.T. chart (Figure 2) shows widespread fog or low stratus over East Anglia. There was a fairly rapid clearance during the morning to the north-west of the East Anglian ridge, and at 1000 hours a pilot flying north-westward from Stradishall reported a sudden break in the low cloud and fog, commencing at Newmarket. By 1200 hours (Figure 3) most of the airfields north-west of the ridge show visibilities of about

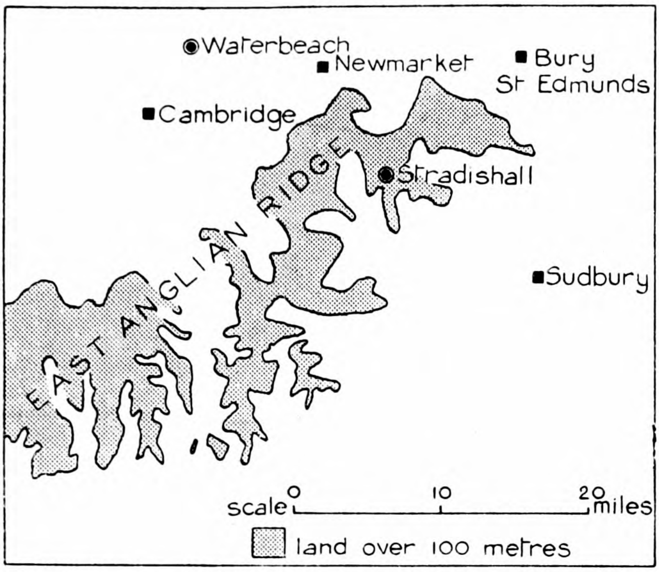


FIGURE I—TOPOGRAPHY OF THE STRADISHALL AREA

4 nautical miles, and only well broken stratus at 600–1,000 feet. On the south-east slope of the ridge, however, there was no substantial improvement, the cloud only lifting to 200–300 feet and soon after, falling to the surface again. The up-slope on the south-east side of the ridge appears to have been a significant factor affecting the persistence of fog and stratus.

Fitness figure analysis.—Appendix IV of the "Observer's Handbook"[1] contains a description of the airfield weather fitness number and its computation. The following is an extract:

"Fitness numbers give a measure of the fitness of an airfield for the landing of aircraft; they take account of the meteorological elements which affect such landings, i.e. visibility, height of cloud base, amount of cloud, precipitation, wind.

"The scale of fitness numbers is 0–9, figure '0' referring to the worst conditions, and figure '9' to the best conditions."

As the poor conditions discussed here are frequently due to a combination of low cloud, poor visibility, and sometimes a drizzly type of precipitation, the airfield fitness figure provides a convenient and simple index. The following analysis (Table I) was made in the hope that the available records held at Stradishall (some seven years) could show the extent to which the situation described above is a recurring feature. No regular observations were available for the night period, the records normally being from 0600 to 1800 G.M.T. In the day-time during summer the up-slope effect is probably masked by surface heating, but with the small degree of day-time heating during winter, the up-slope effect consequently becomes more significant. This investigation was therefore limited to the months of November to February. The choice of limits for the south-easterly direction was rather arbitrary and was made from personal experience of these situations. The figures in Table I confirm the definite bias towards bad flying conditions with south-easterly surface winds during the winter months.

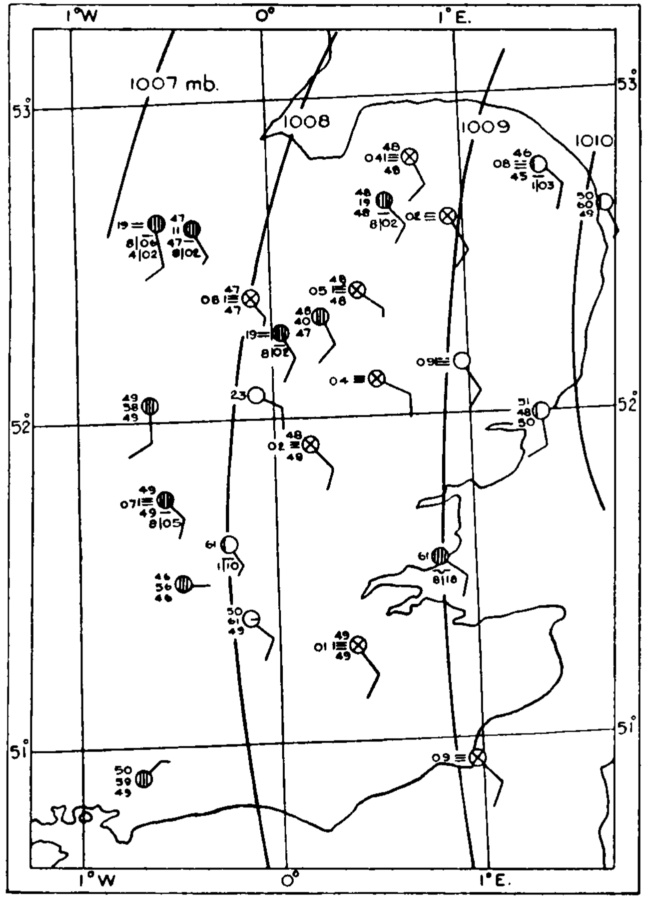


FIGURE 2—SYNOPTIC CHART FOR 0600 G.M.T., 8 NOVEMBER 1955

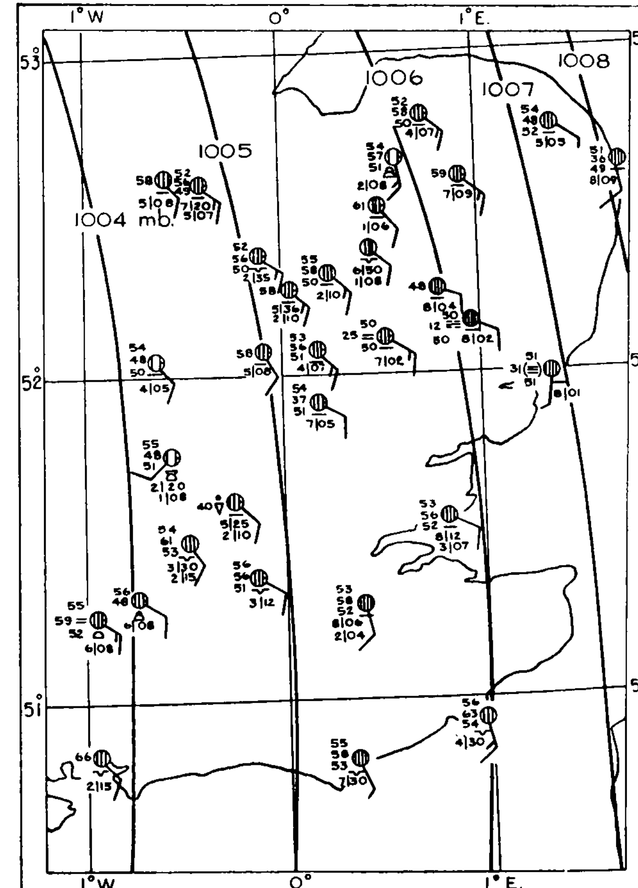


FIGURE 3—SYNOPTIC CHART FOR 1200 G.M.T.

TABLE I—PERCENTAGE FREQUENCIES FOR EACH AIRFIELD WEATHER FITNESS FIGURE: STRADISHALL 0600 TO 1800 G.M.T. SEVEN WINTERS (NOVEMBER TO FEBRUARY), 1949 TO 1956

Surface wind	Fitness figures 0	1	2	3	4	5	6	7	8	9	Total no. of hourly obs.
	per cent										
120°—160°	19·1	9·4	11·7	8·2	10·0	10·9	13·0	10·1	7·1	0·5	814
Other directions and calm	7·3	3·8	7·9	5·6	7·6	11·5	15·6	18·5	16·6	5·6	7495

A further analysis (Table II) of the Stradishall fitness figure frequencies according to time of day shows that even in the midday period the prevalence of poor flying conditions with south-easterlies persists.

TABLE II—PERCENTAGE FREQUENCIES OF DIFFERENT RANGES OF FITNESS

Time	Fitness figures 0, 1 and 2	3, 4 and 5	6, 7, 8 and 9
G.M.T.	*per cent*		
0600	43·7 (22·6)	25·0 (23·4)	31·3 (54·0)
0700, 0800 and 0900	48·2 (20·4)	28·5 (27·2)	23·3 (52·4)
1000, 1100 and 1200	35·5 (18·1)	31·7 (25·2)	32·8 (56·7)
1300, 1400 and 1500	34·8 (16·8)	29·2 (21·2)	36·0 (62·0)
1600, 1700 and 1800	40·4 (19·9)	28·4 (25·0)	31·6 (55·1)

The percentage frequencies for wind directions other than south-easterly are given in brackets

Another feature of these situations is the frequency of fog with relatively strong winds. Over the same seven winter periods the following fog frequencies were recorded with surface wind 120°—160°:

Wind range	Observations below 1,100 yd.	Total no. of obs.
kt.	%	
10–14	19·9	271
15–18	15·7	140

A single observation of fog with a wind of 20 knots was recorded. On only two of the above observations was the deterioration in visibility caused by snow.

Fitness figures for the same seven winters, 0600 to 1800 hours, were also analysed for Waterbeach; the results are in Table III. They reveal a slight

TABLE III—PERCENTAGE FREQUENCIES FOR EACH AIRFIELD WEATHER FITNESS FIGURE: WATERBEACH

Surface wind	Fitness figures 0	1	2	3	4	5	6	7	8	9	Total no. of hourly obs.
	per cent										
120°–160°	3·3	3·8	10·6	7·7	8·7	19·2	20·1	17·1	9·1	0·4	548
Other directions and calm	3·6	2·1	8·2	7·7	7·1	14·2	16·1	22·0	14·7	4·3	6574

tendency for poorer landing conditions with south-easterly winds. However, the outstanding comparison is that for the south-easterlies between the two stations, and this shows the importance of the local orographic factor.

The fitness figures quoted in this article include an element for the component of wind across the direction of the main runway (060° to 240° at Stradishall) which is, strictly speaking, irrelevant to the purpose of this inquiry. The correction for wind across the runway is zero for all winds of less than 17 knots, and for winds of less than 33 knots from within 20° of the runway (see *Observer's Handbook*[1], p.187). In the extreme case of a wind of 34 to 40 knots from a direction between 60° and 90° of the runway it is 5. Usually the correction is zero. The same correction is included in the figures for Waterbeach where the runway is in almost the same direction (040° to 220°) and so does not affect the comparison.

The difference between the Stradishall and Waterbeach figures emphasizes that the poor weather in south-easterly winds at Stradishall is not due solely or even mainly to low cloud and drizzle before eastward-moving warm fronts and occlusions.

Conclusions.—In the case of Stradishall, the figures only confirm a tendency which is probably well known by forecasters with a few years' experience of the area. However, they are considered to be of some value as a substitute for experience to the newly arrived forecaster. Although this is a rather crude analysis, taking no account of synoptic situation, the figures are fairly forceful, particularly in view of the fact that only one forecast parameter (the surface wind direction) is involved. In effect it would make the forecaster very wary of forecasting good conditions with south-easterlies in winter, unless some clearly overriding factor, for example, the advection of dry continental air, were evident.

There is a possibility that even relatively slight up-slope motion may be a significant local factor affecting the persistence of winter fog throughout the day.

REFERENCE

1. London Meteorological Office; Observer's Handbook. London. 1956, p. 182.

MEASUREMENTS OF RADIATION INSIDE A STEVENSON SCREEN ABOVE A SNOW SURFACE

By R. A. HAMILTON, M.A.

The main problem in designing a screen for use in polar regions is, as pointed out by Stewart,[1] to maintain proper ventilation of the thermometers and yet prevent the fine drift snow from entering the screen and settling on the instruments. There is another difficulty that must not be overlooked, the adequate screening of the instruments from solar radiation diffusely reflected from the snow surface.

During the summer at "Northice" (78°N.,38°W., 2341 metres) the station on the Greenland ice sheet established by the British North Greenland Expedition, I noticed that the readings of two dry-bulb thermometers, in the normal positions for the dry- and wet-bulb thermometers in the large Meteorological Office Stevenson screen, differed at times by as much as 0·5°F., the one on the right being the higher even if the thermometers were interchanged. In this position the thermometer was comparatively close to the black case of the hygrograph, and if this was removed from the screen the thermometer readings agreed. It appears that sufficient radiation entered the screen to raise the temperature of the hygrograph and of the nearby thermometer appreciably above air temperature.

In order to obtain some measurement of the amount of radiation entering the screen I mounted a Weston exposure meter by means of a wire frame so that it stood on the floor of the screen. The sensitive side was vertical and faced the south side of the screen, and the dial faced the opening. When the opening was gradually closed the meter reading would fall to a value which changed little after the opening was half closed. The meter was read just before the screen opening was finally closed: this was taken as a measure of the radiation entering the closed screen.

Readings taken at noon in the period 19 July to 2 August 1953 when the sun's elevation was about 31°, varied from about 130 units for a sky clear or with only small amounts of high cloud, to about 30 for an overcast sky. When the sun was approximately east or west, at an altitude of about 19°, the readings varied from 50 for a clear sky to 20 for an overcast sky.

In order to compare these readings with those in a screen under normal conditions, I made similar measurements with a different exposure meter by the same manufacturer in the screen at Prestwick (56°N.,05°W.) standing on a grass plot. The readings varied from 3 to 5 with a clear sky and the sun at an elevation of 30° to 40°.

Solar radiation is very strong in the summer in the polar regions and the amount which enters a normal Stevenson screen standing on snow is of the order of 20 times that entering a normal screen in the British Isles. It is clear that screens for use over snow surfaces must be designed to exclude diffusely reflected solar radiation.

I wish to thank Chief Officer E. O. Jones, who took all but the first few readings.

REFERENCE

1. STEWART, R. H. A.; Trans-Antarctic Expedition, 1955-58. *Met. Mag., London,* **85**, 1956, p. 78.

WORLD METEOROLOGICAL ORGANIZATION

The Tenth Session of the Executive Committee

By the Director-General

The Executive Committee held the final regular session of the present financial period in Geneva from 29 April to 17 May. There was a full attendance of members and in addition, Dr. Bleeker, the former President of the Commission for Synoptic Meteorology and Mr. Mezin, the former President of the Commission for Bibliography and Publications, were present to explain the work of their Commissions. A particularly memorable visitor to a special meeting of the Executive Committee was Mr. Dag Hammarskjöld, the Secretary-General of the United Nations.

The session was a busy one, as usual, but particularly so this year because of preparation for the Third Congress, which will be held in Geneva from 1–29 April 1959. Among other things, the Executive Committee examined the Secretary-General's estimates of expenditure for the Third Financial Period (1960–63). It is inevitable that these show a considerable increase on the maximum expenditure approved by Second Congress for the present financial period, and it remains to be seen whether the next Congress will accept the estimates or will insist on substantial modifications. The Executive Committee also dealt with certain administrative matters relating to its own rules of procedure and the internal staff rules of the Secretariat.

In technical matters, the Committee gave a long and detailed examination to the meteorological problems which will arise when jet aircraft are introduced for civil aviation on a global basis. At its Ninth Session in 1957 the Executive Committee heard from Mr. de Azcarraga about the findings of the Jet Operations Requirements Panel (J.O.R.P.) of the International Civil Aviation Organization, and it appointed a Panel of Experts to examine the matter. As a result of the work of this Panel, the Executive Committee decided to invite Members who have some experience in high-level forecasting to collaborate in the preparation of a Technical Note devoted to descriptions of the methods they use for analysis and forecasting at high levels, the texts being sufficiently detailed to permit the practical use of these methods for routine forecasting. Such a Technical Note should be of the greatest interest to meteorologists everywhere, and is a good illustration of the kind of work which W.M.O alone can do.

The Technical Note will be considered by a Panel of Experts, who will attempt to define as clearly as possible any special problems related to the improvement of high-level analysis and forecasting with a view to meeting the J.O.R.P. requirements, which are very exacting. Certain special problems, notably the forecasting of hail, turbulence, icing and dense cirrostratus cloud and the density of networks required for improving high-level wind and temperature forecasts were referred to C.S.M.; the Commission for Aerology was asked to study the potentialities of numerical prediction for high-level forecasts. It was also decided to explore the desirability of arranging international symposia on the problems of the atmosphere at the levels at which jet airliners operate.

The Executive Committee also gave considerable attention to the proposal that W.M.O. should extend its activities in hydrology. The general feeling was in favour of an initial approach on a broad front and it was finally agreed to recommend to Third Congress that the future policy of the Organization should be to accept responsibilities in all aspects of hydrology which involve meteorological considerations. It was also generally agreed to support the view that a Commission for Hydrology should be established by Congress, but there was little enthusiasm for a change in the name of the Organization at this early stage, and no recommendations for amending the Convention to include hydrology more specifically have been made.

The I.G.Y. was very much in evidence during the discussions, but the Executive Committee felt that it could not support a proposal to make the Data Centre a permanent feature of international meteorology now, although it recognized that in the future such a centre might be desirable for the collection of data in aerology, ozone and radiation.

Two events, of a non-technical nature, made this session memorable. One was the laying of the corner stone of the new W.M.O. building by the President, who placed in a cavity a sealed box containing certain documents.

The other event, which has given great pleasure to meteorologists in the United Kingdom and elsewhere, was the award of the I.M.O. Prize for 1958 to Mr. Ernest Gold, F.R.S., formerly Deputy-Director of the Meteorological Office.

It is evident that Third Congress will have a lengthy programme to consider and its decisions may well be critical for the future of W.M.O. By careful management, the Organization has weathered a period of world-wide financial instability, and in the opinion of the writer is now well established as an essential factor in the development of our science. The attainment of this position is to be attributed to two factors: the whole-hearted voluntary co-operation of the national services in the work of the Technical Commissions, Regional Associations and the many working groups and panels of experts, and the skilled and devoted services of the Secretariat under the able direction of the Secretary-General.

LETTERS TO THE EDITOR

Atmospheric chemistry and chemical aeronomy

The April issue of the *Meteorological Magazine* includes a report[1] of the Meteorological Office Discussion held on December 16 1957, devoted to Atmospheric Chemistry. This very interesting report is a welcome sign of the growing interest among meteorologists in the chemistry as well as in the physics of the atmosphere. This interest was certainly much stimulated by that great meteorologist, the late Dr. C.-G. Rossby, whose influence furthered the inclusion of atmospheric chemistry in the meteorological programme of the International Geophysical Year. The results of this work will be eagerly awaited by oceanographers, chemists and aeronomers as well as by meteorologists.

This note is written to draw attention to the existence of problems of atmospheric chemistry that were left wholly unmentioned in the report of the discussion. The standpoint there adopted is indicated in one of the last reported sentences in the excellent review by Mr. Oddie, who opened the discussion: "The behaviour of the simple inorganic salts in the air is still, however, the central problem of atmospheric chemistry." If the words "one branch of" were inserted before the last two words of this sentence, all might agree on its truth. As stated, however, the sentence expresses a subjective view, and others might locate the central problem elsewhere.[2]

Among these may be the highly skilled and respected meteorologists who specialize in the study of atmospheric ozone, a branch of atmospheric chemistry that has much association with important weather changes, and perhaps with the general circulation of the atmosphere.

Consideration in 1929 of the chemical aspects of ozone formation and destruction in the atmosphere[2] opened a new chapter in the chemical exploration of the upper atmosphere, far above the "weather" region. It led to the recognition that the chemical state of the atmosphere at heights above about 60 miles differs greatly from that of the lower atmosphere. In particular, the oxygen of the air above 60 miles is mainly in the atomic form, although molecular oxygen is still present in a minor degree up to heights of many hundred kilometers. Nitrogen also is partly dissociated into the atomic form, though far less so than oxygen.

Atomic oxygen is highly reactive; in conjunction with molecular oxygen and molecular and atomic nitrogen it forms ozone and oxides of nitrogen in the upper atmosphere.

Watei vapour at high levels—of order 50 miles—is dissociated by sunlight[3] into atomic hydrogen and hydroxyl (OH). The latter reveals its presence strongly in the airglow—the intrinsic luminosity of the high atmosphere, whose observation in many regions of the earth is an important part of the programme of the International Geophysical Year. Atomic oxygen is another notable contributor to the airglow. Atomic sodium also reveals its presence in the upper atmosphere by emitting the light nowadays made familiar to the public by the use of sodium vapour lamps. There must be molecular sodium and also sodium oxide in the upper air. Twilight emission of light by ionized calcium atoms in the upper atmosphere has also been observed, following notable meteor showers.[4]

This branch of atmospheric chemistry impinges on the sphere of interest of workaday meteorologists mainly because of the part played by ozone. But a much wider group of scientists are interested in it. Already the literature of the subject has attained considerable dimensions. One token of this is a recent volume[5] on chemical aeronomy—a report of a conference on the subject, held in 1956, and attended by many American, British and other workers in that field. The word aeronomy signifies the science of those regions of the upper atmosphere where dissociation and ionization are important. Aeronomy has numerous branches, static, dynamic, electromagnetic, etc., and *chemical* aeronomy is a part of the wider subject of atmospheric chemistry. It is now an experimental as well as an observational science. Following a suggestion made by Prof. D. R. Bates in 1950, atomic sodium has been injected into the air at high levels by means of rockets[5, 6] and has produced artificial luminosity by consequent chemical reactions there. More recently nitric oxide[5] and ethylene[5] have similarly been injected, with very interesting results.

S. CHAPMAN

Geophysical Institute, College, Alaska; and High Altitude Observatory, Boulder, Colorado.*

REFERENCES

1. ODDIE, B. C. V.; Atmospheric Chemistry. *Met. Mag. London*, **87**, 1958, p. 108.
2. *Compendium of Meteorology*, Amer. Met. Soc., Boston, Mass. 1951; articles by H. Cauer and S. Chapman.
3. BATES, D. R., and NICOLET, M.; The photochemistry of atmospheric water vapor, *J. Geophys. Res.*, Baltimore, **55**, 1950, p. 301.
4. JONES, A. VALLANCE; Ca II emission lines in the twilight spectrum. *Nature, London*, **178**, 1956, p. 276.
5. The Threshold of Space. London, 1957; edited by M. Zelikoff.
6. COOPER, C. DEWEY, MANRING, E. R., and BEDINGER J. F.; 3303 A Emission from sodium ejected into the upper atmosphere. *J. Geophys. Res.*, Baltimore, **63**, 1958, p. 369.
7. ZELIKOFF, M., MARMO, F. F., PRESSMAN, J., MANRING, E. R., ASCHENBRAND, L. S. and JURSA, A. S.; An attempt to measure atomic nitrogen by rocket release of ethylene at 105 and 143 km. *J. Geophys. Res.*, Baltimore, **63**, 1958, p. 31.

* Professor Chapman is engaged in a joint programme of research supported by the National Bureau of Standards and the Air Force Cambridge Research Center.

Reply by B. C. V. Oddie

It would no doubt have been better to give the Meteorological Office discussion the title "The chemistry of the lower atmosphere". But the use of the term "atmospheric chemistry", in this sense, is to some extent sanctioned by custom. It has, after all, hardly been used except by workers of the Swedish school inspired by Rossby and Egner, and has naturally come to connote the kind of activity in which they specialized. Not that the Swedish workers intended the term to be exclusive: but it is a fact that chemical aeronomers have never rallied to the cry of atmospheric chemistry. For example, chemical aeronomy has scarcely figured at all in the annual Conferences on Atmospheric Chemistry held in Stockholm since 1954. I do not know why this is, but it can of course be very reasonably argued that chemical aeronomy deals with such a very different class of problems, and uses such very different tools, that it is best treated as a subject separate from the chemistry of the lower atmosphere. But of course the two are closely related, and some way of keeping them in touch is very desirable.

I agree, however, with Professor Chapman that the term "atmospheric chemistry" ought not to apply exclusively to the lower layers. We need a new name—"tropospheric chemistry", perhaps.

A green sun after sunset

On 10 April 1958, after an almost cloudless day, the sun set (as seen from our house at Upper Duntuilm, Skye) behind the Sound of Harris.

At 1925, about two minutes after the sun had gone, a perfect "sun" appeared low on the horizon where it had vanished. The disc of this "sun" was pale green and what was surprising was that there was no mistiness or faintness in its outline. Thinking my eyes might have deceived me through watching the actual sun I went into the house, but when I came out at the door, I had my second view of the "sun".

I then called to my wife and when she came out we agreed that the disc of this "sun" had now changed in colour to pale pink.

It gradually faded as we watched.

Any "mock sun" that I have seen has had a misty outline but this had the edges extremely clear and distinct, although faint. It was something quite new to me.

Upper Duntuilm, Isle of Skye. SETON GORDON, C.B.E.
12 *May* 1958.

[The phenomenon reported by Mr. Seton Gordon was probably due to a change in the refractive properties of the atmosphere beyond the normal horizon of such a kind that the rays from the sun to the observer there became more concave with respect to the earth. Such a change in curvature would cause an apparent elevation of the sun. The necessary meteorological condition is that the air should be markedly warmer than the sea. This is supported by the way in which the sun faded away and perhaps by the colour effects, though the latter might be due to retinal fatigue. An even more remarkable occurrence of the same type is that of the S.S. *Theliconus* off Gibraltar[1] when five successive images of the sun reappeared.

Temporary reappearances of the sun have frequently been observed in the polar regions at the beginning of the polar night. The phenomenon is very rare in temperate latitudes.

It is interesting to note that an almost identical observation has since been reported to the Marine Branch. The details are: *S.S. Arabia.* 11 June 1958 in lat. 55°46′N., long. 32°56′W. (North Atlantic). As the upper limb of the sun set below the horizon there was a distinct green flash lasting about half a second. The upper limb of the sun then reappeared for about six seconds and set again with a further distinct green flash.—Ed. *M.M.*]

REFERENCE

1. Abnormal refraction. *Mar. Obs., London,* **22,** 1952, p. 125.

Observation of optical phenomena at Sirah Island, Aden, 7 October 1957

At 1915 hours local time a very pale green glow was observed in the southern sky, over the Indian Ocean. The glow was marked by a very faint ill-defined boundary about 25 degrees above the southern horizon lowering to about 20 degrees on the south-western horizon. It was impossible to see the southern horizon as vision was obscured by rocks rising to about 600 feet high. The phenomena lasted from approximately 1915 (when it was first observed) to 2130 hours when it faded completely. About 2125 hours a russet-coloured band of light was observed low down on the southern horizon just before the glow faded completely. Throughout the whole period there were occasional rays of light mostly orange in colour at infrequent intervals. These never rose to above 3 degrees above the southern horizon. Stars in the sky at about 15 degrees above the horizon were seen to be changing colour quite frequently (mostly red and green). At times the colour of the stars was observed to be particularly bright, predominantly green. The glow was at its brightest between 1915 and 1930 hours but after 1930 hours the glow was observed to brighten occasionally for periods not exceeding five minutes. The weather at the time was fine. There was a bright moon almost overhead. There was no cloud, a light wind and the sea was practically calm. A sketch is attached (see Figure 1).

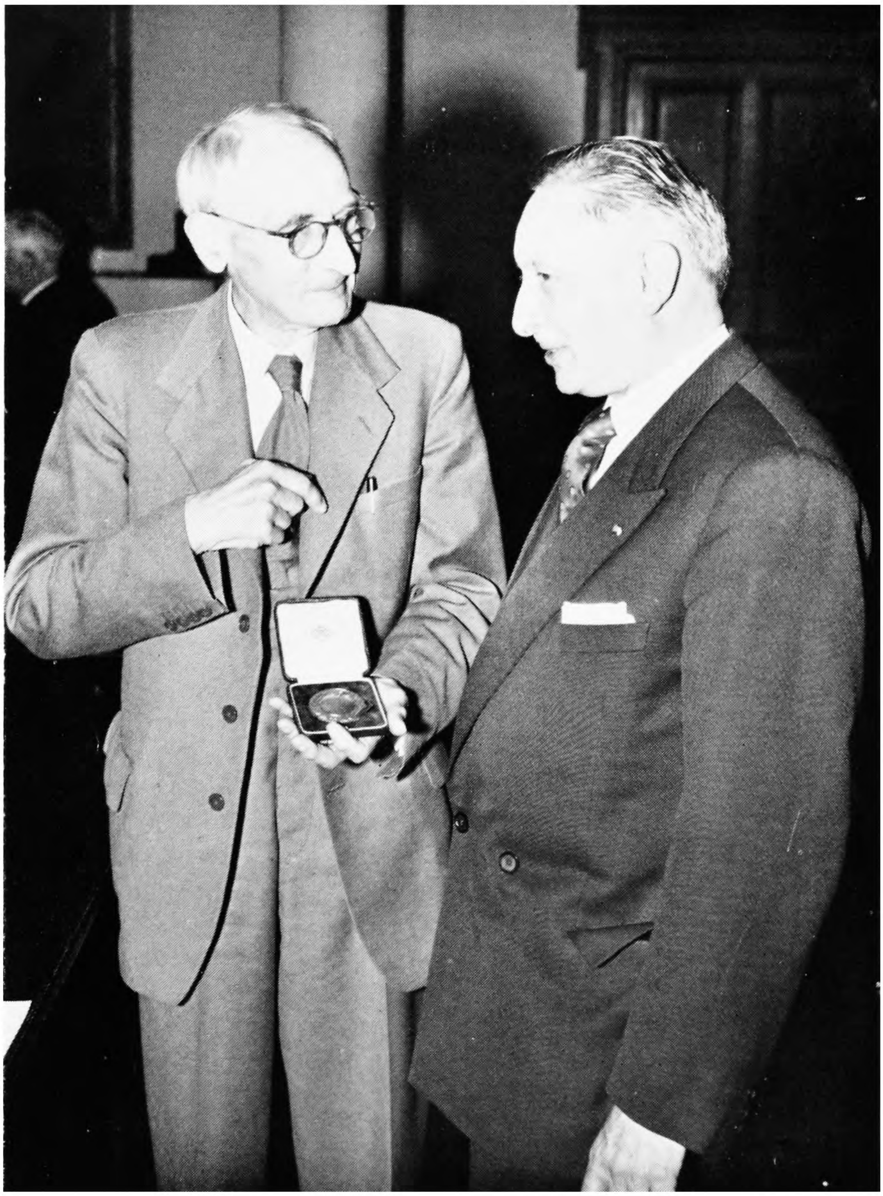
Royal Air Force, Khormaksar, Arabian Peninsula. N. F. HIRST
26 *November* 1957.

[At Aden (latitude 12°46′N.) on 7 October sunset was at 1746 local mean time and civil, nautical and astronomical twilight 1808, 1833 and 1858 respectively. No reports of aurora have been received at the Balfour Stewart Auroral Laboratory, Edinburgh University, and Mr. McInnes of that laboratory states that 7 October 1957 was a very quiet day magnetically. Mr. McInnes suggests it may have been air-glow or moonlight reflected from dust layers.—Ed., *M.M.*]

PRESENTATION OF THE INTERNATIONAL METEOROLOGICAL ORGANIZATION PRIZE TO MR. E. GOLD, F.R.S., BY M. ANDRÉ VIAUT, PRESIDENT OF THE WORLD METEOROLOGICAL ORGANIZATION 30 JUNE 1958.

MR. GOLD SHOWS THE MEDAL AND DIPLOMA TO OTHER METEOROLOGISTS.

To face p. 279]



Crown copyright

MR. GOLD DISCUSSES THE MEDAL WITH M. VIAUT (see previous page).

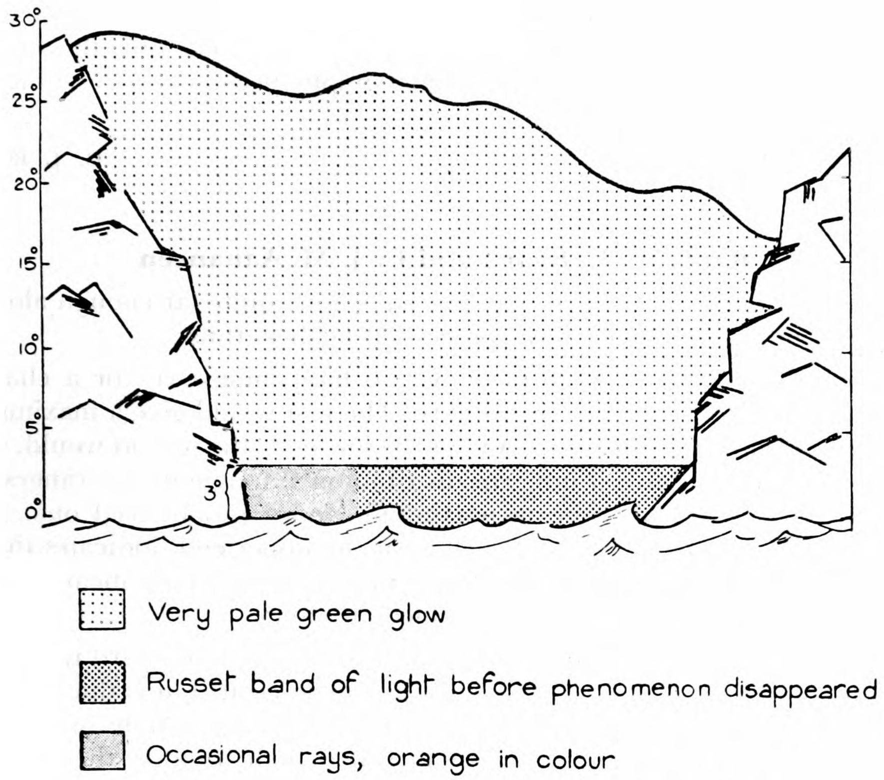


FIGURE I—A SKETCH OF THE OBSERVED PHENOMENA

The left-hand scale shows the angular elevation from the point of observation.

Deterioration of visibility in radiation fog

A recent note entitled "Deterioration of visibility in radiation fog"[1] claims to give some support for the belief that visibility in fog decreases comparatively rapidly through the intermediate ranges. It is not at all clear, however, that the statistics given provide any information about the changes in an individual fog.

Table I gave frequencies of visibilities on radiation nights within consecutive 200-yard ranges. Now there are two happenings which contribute to a low frequency in a particular range, such as appears for 600–800 yards. One is a rapidly changing visibility passing quickly through this range. The other is a visibility which throughout the night remains higher than the upper limit of the range. This second factor would have raised the frequencies in the upper ranges and it is therefore probable that the percentage frequencies in fogs which became thick would have been lower for higher visibilities than the figures given in Table I. Moreover, this adjustment might well remove the minimum shown for a visibility of 600–800 yards.

Table II seems to be open to a similar criticism. If I understand it correctly, it deals with 154 fogs, of which more than half cleared within three hours. Most frequency figures in the table are compounded of some visibilities that had become worse, some that had improved and some that remained in the same range. The high frequency in the 800–1,000-yards range is presumably due to the fogs that were at their thickest and were about to clear. The only figures which it seems might be relevant to the behaviour of an individual fog are the higher frequencies after the fourth hour in the 200–400-yards range, though these may indicate no more than that on the average the longer the fog lasts the thicker it is likely to get. As the writers point out, the high frequencies in the 0–200-yards range occur simply because the visibility can fall no further.

Central Forecasting Office. C. J. BOYDEN
24 *March* 1958.

Reply by E. Evans and C. J. M. Aanansen

It would seem that Mr. Boyden may not have gone quite far enough along his line of reasoning, but should have proceeded farther, thus:

In Table I, each figure is formed by two happenings: (i) for a changing visibility and (ii) for a stationary visibility. The first would give a maximum at the high and a tapering to a minimum at the low end; the second would, unless biassed at any range, give a uniform distribution throughout the ranges. The fact that the combination gives a maximum, and a pronounced one, at the lower end of the visibility range as well as at the upper end, indicates that the second factor is biassed towards the lower ranges. This simply means that the visibility does not often stop in the intermediate ranges.

In Table II, similarly, the high frequency in the 800–1,000-yard range is not due to fogs that were at their thickest and about to clear, but is due to all fogs passing through this range. The relevant feature is the maximum in the lowest range coupled with the rapidity with which it is built up after the first hour, whereas the 400–600-yard range, for example, shows little change with time indicating comparatively little halting of the visibility in this range: in other words, the visibility tends to pass through this range quickly.

It is not correct to deduce from Table II that 84 (154—70) fogs cleared within three hours. As stated, the nightly period examined ended with the last hour before sunrise. (A number of the 84 fogs continued into daylight, some with marked thickening.) Each hour is a self-contained analysis and, as stated above, the intermediate ranges show no significant change from hour to hour.

Mr. Boyden's second sentence is, of course, strictly correct. But does one expect statistics to say what any individual fog will do, or give an indication of the general behaviour?

REFERENCE

1. EVANS, E., AANANSEN, C. J. M. and WILLIAMS, T. E.; Deterioration of visibility in radiation fog. *Met. Mag., London,* **87,** 1958, p. 33.

NOTES AND NEWS

Meteorological Office Awards to Captains and Navigators of Civil Aircraft

The Meteorological Office Awards for 1958 to captains and navigators of civil aircraft for long and meritorious service in the provision of weather reports were presented on 15 July 1958 by Dr. J. M. Stagg, Director of Services. The presentation was made at the Royal Aero Club in a small ceremony held under the auspices of The Guild of Air Pilots and Navigators with the Master of the Guild, Sir Frederick Tymms, in the chair.

Dr. Stagg, before making the presentations, spoke of the mutual understanding which existed between meteorologists and pilots and navigators. He emphasized the great value of the reports, in providing information from the wide spaces between upper air reporting stations and in increasing knowledge of the atmosphere, especially at the greater heights at which aircraft were now beginning to fly. He assured all aircrew that all these reports were used and that more were needed. He then presented brief-cases to Captain R. H. Rose, D.S.O. of British European Airways and to Captain W. J. Wakelin, D.F.C. of the same Corporation.

Awards of suitably inscribed books will be sent later to the following officers:—

Captain G. M. Allcock	B.O.A.C.	Navigating Officer A. P. Hossack	B.O.A.C.
Navigating Officer G. F. Andrews	B.O.A.C.	Captain G. P. Neil	B.O.A.C.
Navigating Officer J. S. Blair	B.O.A.C.	Captain R. H. Payne	B.E.A.
Navigating Officer E. A. Brownjohn	B.O.A.C.	Navigating Officer A. A. Payton	B.O.A.C.
Captain L. H. Carey	B.O.A.C.	Navigating Officer V. R. Pitcher	B.O.A.C.
Navigating Officer W. L. Chander	B.O.A.C.	Captain D. F. Redrup	B.O.A.C.
Navigating Officer W. F. A. Haines	B.O.A.C.	Navigating Officer M. B. Richards	B.O.A.C.
Captain J. R. Turner	B.E.A.		

Mr. J. S. Sawyer—Special Merit Promotion to Deputy Chief Scientific Officer

The many colleagues and friends of Mr. Sawyer, Assistant Director of Dynamical Research in the Meteorological Office, will have been delighted to learn of his promotion to Deputy Chief Scientific Officer on "Special Merit" and it is a task particularly congenial to me, as one who has been closely associated with him in the past 10 years of his remarkably productive research career, to express, on behalf of the Director-General and the staff, our heartiest congratulations to Mr. Sawyer on the well-earned award and our gratitude to him for the distinction which the award, recommended by the Interdepartmental Scientific Panel, brings to the Office.

It is inevitable that in the Government service, as indeed in most public bodies including the Universities, the number of higher posts should be determined by requirements and that promotion should depend on the occurrence of vacancies created for the most part by retirements on superannuation. In filling the normal vacancies considerations of individual merit are always in the forefront and the need for special machinery in a scientific service arises, not only because the exceptional man may be held back by lack of a suitable vacancy, although this must arise from time to time, but even more because, at the higher levels, normal promotion means new duties, wider administrative responsibilities, with less opportunity for personal scientific work. The enlightened provision for exceptional promotion by "Special Merit", independent of establishment vacancies, permits the advancement of the outstanding research worker while avoiding interruption in his work. It is a relief to know that Mr. Sawyer will be able to continue in his present post and to lead his group in dynamical research on the promising lines which he personally has done much to pioneer.

Mr. Sawyer's contributions to the scientific literature include some 50 papers which evidence not only an exceptionally wide knowledge of the atmosphere as it is observed to behave but also a remarkable equipment of basic skills in cartographical, statistical and dynamical analysis. There would be inspiration to others in a survey of his original work but to do justice to it would call for a longer essay than is perhaps appropriate here. Suffice it then to remark that the major preoccupation of his group at the present time is the development of numerical forecasting, starting from the differential equations which express the hydrodynamics and thermodynamics of the atmosphere. With the electronic computer shortly to be provided at Dunstable it will be possible to accelerate the quantitative exploration of the mathematical-physical ideas which Mr. Sawyer and his group are elaborating. This line of research is without any doubt the most exciting thing in the science of weather forecasting since the concept of fronts emerged in Norway 40 years ago. The practicability of numerically integrating certain approximations to the basic equations in a time acceptable for use in daily forecasting was first recognized and tested in America where the modern electronic calculating machine first became available. But Mr. Sawyer was quick to realize the potentialities and the Sawyer-Bushby model of 1953 has been the basis of much later work on the baroclinic atmosphere. Military authorities do not, if they are wise, change the commander when the campaign is going well although he may gain promotion. It is good that in scientific research we should from time to time have evidence of comparable administrative wisdom.

R.C.S.

Dust in the stratosphere over western Britain on 3 and 4 April 1956

An article of the above title[1] published in the October 1956 number of the *Meteorological Magazine* presented evidence that dust from an eruption in Kamchatka on 30 March 1956 travelled across the Arctic basin and Greenland to Great Britain by 3 April.

The computed trajectory is supported by the statement in an article in the January 1958 number of the Russian periodical *Priroda* (Nature)[2] that the dust trail from the eruption was to the north-east. The eruption is described in the article as an explosion comparable with those of Krakatoa (1883), Katmai (1912) and Pelee (1902). The article states further that the explosion produced a rise of pressure of 23·5 millibars at a point 45 kilometres from the volcano and one millibar at a point in north-east Siberia 1,100 kilometres away while the pressure wave was traced on sensitive barographs for $1\frac{1}{2}$ circulations of the globe.

G. A. BULL

REFERENCES

1. BULL, G. A., and JAMES, D. G.; Dust in the stratosphere over Western Britain on April 3 and 4, 1956. *Met. Mag., London*, **85**, p. 293.
2. GORSHKOV, G. S.; Unusual eruptions in Kamchatka. *Priroda, Leningrad*, No. 1, 1958, p. 61.

OFFICIAL PUBLICATION

PROFESSIONAL NOTES

No. 123—*Forecasting cirrus cloud over the British Isles.* By D. G. James, Ph.D.

Some synoptic features are presented which are known to be associated with four oktas or more cirrus cloud over the British Isles. A combination of 13 of these features is suggested for use in forecasting the occurrence of cirrus cloud up to 9 hours ahead, the features being evaluated from the current synoptic charts. For forecasts of up to 24–36 hours ahead, a combination of six of the features is suggested, the evaluations in this case being made from forecast charts.

OBITUARY

Sir Ernest Maclagan Wedderburn, O.B.E., D.L., M.A., LL.D., D.Sc., F.R.S.E.

When Sir Ernest Maclagan Wedderburn died in Edinburgh on 3 June 1958, the country, and Scotland in particular, lost a loyal and able servant.

Sir Ernest was indeed a "man o' pairts", and the range of his interests and talents was so great that it would be impossible in a brief note to attempt even an outline of his activities and attainments. In fact he was so unassuming and unobtrusive in his work that a complete list of his public services may never be put on record. It must suffice to say that his status in the legal profession was such that he resigned the Chair of Conveyancing at the University of Edinburgh to become Deputy Keeper of the Signet in 1935. He was in turn Chairman of the Joint Committee of Legal Societies in Scotland, Chairman of the General Council of Solicitors and Chairman of the Law Society of Scotland—in short the leader and guiding mind of the legal profession in Scotland.

In scientific circles he was probably best known for his work on the movement of water in large lakes. After studying the barometric *seiche* under Professor Crystal, he tackled the problem of temperature oscillations, a problem which gave full scope to his mathematical ability, physical insight and powers of painstaking analysis. For this work he was awarded, in addition to a D.Sc., the Makdougall-Brisbane prize of the Royal Society of Edinburgh, and he later became the Treasurer and then Vice-President of that Society.

His association with meteorology can be dated from 1908, when he became a member of the Scottish Meteorological Society. He was Joint Honorary Secretary and then Honorary Secretary of the Society in the troubled years which followed; he was, in fact, destined to be the last to hold that position, as he played a leading part in the negotiations at the end of the First World War which led to the Meteorological Office taking over the organizational functions of the Society, and the amalgamation of the Scottish Society with the Royal Meteorological Society. It was particularly fitting that Sir Ernest also played a leading part in the formation of the Scottish Branch of the Royal Meteorological Society at the end of the Second World War. He was Vice-President for Scotland during the period 1950–52 and again in 1955–56, the latter period covering the Centenary of the old Scottish Meteorological Society.

In the meantime, however, Sir Ernest's meteorological activities had ranged far afield. He volunteered for service in 1914 and was placed in charge of the meteorological unit with G.H.Q., Mediterranean Expeditionary Force. During this period he was twice mentioned in dispatches, and was later awarded the O.B.E. (Military Division). It was also during this period that he produced the work best known to meteorologists, although his name is seldom associated with it. In the course of his duties he evolved the concept of "equivalent constant wind" in applying ballistic corrections to artillery fire, a revolutionary idea at the time which has since become an accepted part of the standard practice of gunnery.

After the First World War Sir Ernest returned to the legal profession, but he continued his association with meteorology in an advisory role. He represented the Royal Society of Edinburgh on the Meteorological Committee for a number of years and served on the Advisory Committee on Meteorology for Scotland from its inception in 1921 until he retired in 1952, representing in turn the Royal Meteorological Society, the University of Edinburgh and the Royal Society of Edinburgh.

Those who had the pleasure of attending the Centenary Dinner of the Scottish Meteorological Society in 1955 will have a clear picture of Sir Ernest as his friends remember him. He presided with genial informality and infectious good humour, starting the conversational ball rolling with tales of his own discomfiture as a forecaster during the Gallipoli Campaign and afterwards. He was always approachable and always helpful, with the deceptive air of having the leisure to devote his attention to any problem put to him, however trivial. He will be greatly missed.

R. CRANNA

METEOROLOGICAL OFFICE NEWS

Retirement.—*Mr. J. S. Smith,* Senior Experimental Officer, retired on 8 July 1958. He joined the Office as a Technical Assistant in February, 1920, after service in the Meteorological Section of the Royal Engineers from February 1917 until November 1919. His 38 years' service has been spent at aviation outstations including tours of duty in the Middle East from 1935–38 and 1946–53. From 1954 until his retirement he served at Wyton.

Mr. W. J. Hotten, Senior Assistant (Scientific), retired on 18 June 1958. He joined the Office from the Air Ministry in September 1923. Nearly all his service has been spent at Headquarters in the Forecast Division. From 1949 until his retirement he was engaged on administrative duties at the Central Forecasting Office at Dunstable.

Award.—While on detached duty at Stansted, Mr. J. S. Barnes, Assistant (Scientific) was awarded a Flying Scholarship by the Air Training Corps. He trained at Cambridge Airport and has qualified for his private pilot's licence.

Sports activities.—The Air Ministry Annual Sports were held at the White City Stadium on 11 June 1958. The Office regained the Bishop Shield (awarded to the department gaining the highest number of points in all the Air Ministry sports competitions held during the year) which they had failed to retain last year after eight consecutive years. The Office also won the Tug-of-War Shield and the Jones Aggregate Cup. Miss M. Boucher and Mrs. A. Brown shared the Victrix Ludorum Cup. Mr. C. E. Fairbrother won the Men's High Jump at 6 ft. 5 in., a new Air Ministry record (previously 5 ft. 6 in.). Mr. Fairbrother is the present holder of the Scottish High Jump Championship and he was nominated for the Empire Games at Cardiff.

The annual Sports Meeting organized by the Harrow Social and Sports Committee was held on the evening of 5 June at the Headstone Manor Ground. Events were open to all members of the Meteorological Office and there were many entries. Five new records were established for these Sports. They were:—

100 yd. Men (Meteorological Office Championship) 10·6 sec. by P. H. Anderson (Kew Observatory).

Half-mile Men (Meteorological Office Championship) 2 min. 3·7 sec. by R. Stratton (Harrow).

One mile Men (Meteorological Office Championship) 4 min. 42·5 sec. by R. Stratton (Harrow).

Men's High Jump. 5ft. 0¾ in. by S. Spurrier (Harrow).

Men's Long Jump. 18 ft. 1 in. by C. Kensett (London Airport).

The fourth Meteorological Office Championship, the Ladies 100 yds. was won by Mrs. A. Brown (Harrow).

The weather was ideal and many visitors came from Dunstable, London Airport, Kew Observatory and Victory House as well as from Harrow to enjoy a pleasant evening's sporting entertainment. The prizes were presented by Mrs. A. G. Forsdyke.

LATE RAINFALL REPORTS—1958

Great Britain and Northern Ireland

Month	County	Station	Inches	Per Cent Average
January	*Caith*	Lairg, Crask	5·82	101
March	*E. Loth.*	N. Berwick	2·61	162
March	*Argyll*	Morven, Drimmin	2·48	69
March	*Argyll*	Poltalloch	0·83	23

Correction to Rainfall Table—1958

April	*Notts.*	Mansfield, Carr Bank	0·77	39

WEATHER OF MAY 1958

Northern Hemisphere

The most striking feature of the mean pressure chart for the month was a well-marked ridge of high pressure extending northwards from the Azores anticyclone at about 40°W. and linking with the polar anticyclone. Pressure anomalies were positive over Greenland, Iceland and the Atlantic north of 30°N. (excluding coastal waters of the British Isles) and reached +10 millibars off Cape Farewell. The centres of both the Azores and polar anticyclones were near normal in position and intensity. The Icelandic low was not present in its usual form, but low pressure areas were centred over Sandinavia and eastern Canada (Quebec) the lowest pressure being 1009 millibars in each case. Associated areas of small negative pressure anomalies extended over the British Isles, Scandinavia and north-west Russia, and over the Hudson Bay region and the Canadian Arctic. Over the Pacific, the Aleutian low was near its normal position but was some 3 millibars deeper than usual, giving small negative pressure anomalies between Kamchatka and the Aleutians. A slight westward displacement of the North Pacific high produced small negative anomalies off the west coast of the U.S.A. and small positive anomalies further west.

The largest temperature anomalies in the hemisphere occurred in western areas of the U.S.A. and Canada, reaching +5°C. at stations in Alberta and Montana. This abnormal warmth was apparently due to a combination of more anticyclonic conditions than usual and reduced northerly advection. Unusually strong southerly advection resulting from the higher pressures than normal over the Atlantic gave mean temperatures 3° or 4°C. above average in Newfoundland, Labrador and Baffin Island. Temperatures were also above average over all Europe apart from the north-west, and over the Mediterranean and north-west Africa. Anomalies of +4°C. occurred in Czechoslovakia and Hungary, where the usual north-easterly advection was absent. All the negative temperature anomalies in the Northern Hemisphere were small, although they extended over wide areas including most of the Atlantic and Arctic oceans and Siberia.

Rainfall totals for the month were near or above the average in northern and central Europe, but below average over the Mediterranean and the Balkans. An excess of rainfall was reported in north-east Canada and also in the Caribbean area, while the month was unusally dry in districts just east of the Rockies between 40°N. and 50°N. Amounts of rainfall were well above normal in southern India, suggesting an earlier onset of the monsoon than usual.

WEATHER OF JUNE 1958

Great Britain and Northern Ireland

During the first week pressure remained low to the south-west of the British Isles and thundery rain belts moved northwards across the country. About the middle of the month high pressure from the Azores extended north-eastwards and weather became drier for several days, but from the 19th a succession of Atlantic depressions brought a return of unsettled conditions which lasted until the end of the month.

The month began with widespread thunderstorms over England and Wales followed by a night of extensive fog. On the 2nd exceptionally heavy rain occurred over a broad area from Wales to Kent associated with a depression over the Midlands—some places recorded more than 2 inches—but in Scotland it was relatively dry and sunny. Apart from heavy local rain in North Devon and Somerset on the 3rd, which resulted in severe flooding in the Boscastle area, weather in general was warm and sunny and relatively dry from the 3rd to the 5th; on the 5th temperature exceeded 70°F. at many places and parts of East Anglia had more than 15 hours sunshine. Renewed outbreaks of heavy rain occurred on the 6th and 7th, particularly in Devon and Cornwall, the southern part of the Pennines and locally in Northern Ireland, and also on the 9th and 10th in south-east England. Over the country as a whole weather was mostly cool from the 6th to the 12th with rain at times, sunny periods and occasional thunderstorms.

On the 13th an anticyclone from the Azores became centred over Southern England and for the first time since the beginning of the month there was no appreciable frontal activity over the country and weather became relatively dry for several days. On the 15th and 16th temperature reached the middle seventies in parts of England, but cooler air from the Atlantic was spreading slowly south-east and temperature in London on the afternoon of the 17th only reached 60°F., 17°F. lower than the previous day's maximum temperature. Slight ground frost was recorded locally in the west midlands that night.

Weather became unsettled with widespread rain on the 19th as a complex depression from the Atlantic extended eastward across the country and thereafter cool cloudy conditions persisted for several days with an increasing tendency for thunder. Heavy thunderstorms occurred in Lancashire and Yorkshire on the 22nd and thunderstorms were widespread over England during the next two days.

During the 25th, a depression approaching from the south-west moved up the Irish Sea bringing gales and heavy rain to many districts; $4\frac{1}{4}$ inches fell in the Mourne Mountains (Fofanny Reservoir), County Down in 24 hours. Another depression moved northward from France to give heavy rain in south-east England during the night of the 26th–27th.

Fine warm weather was experienced over much of the country on the 29th with temperatures well into the seventies, but it was cool on some eastern coasts where fog persisted all day. On the 30th temperature reached 74°F. at Lerwick, the highest temperature ever recorded there this century.

The month as a whole was generally cool and dull especially in north-east England where day temperatures were 2–3°F. below the average and sunshine in places 70–80 hours below the normal. It was the wettest June in England and Wales since 1912 and in Northern Ireland since records began in 1920. Less than average rainfall occurred over the greater part of Scotland north of a line from the Firth of Clyde to Montrose, but over three times the average fell in the Mendip hills, over the east midlands and the southern part of East Anglia. Four times the average fell locally in the Royston area.

After a period of very promising early growth the wind and heavy rain spoiled prospects of heavy harvests of grass, cereals and soft fruit. Large quantities of hay went to waste and many farmers turned to silage to cut losses. There was serious laying of corn crops and strawberries suffered severely. Blight affected early varieties of potatoes in many areas and at the end of the month was spreading to main crops some three or four weeks earlier than usual.

WEATHER OF JULY 1958

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 ...	85	32	−0·7	117	+2	97
Scotland	85	29	0·0	121	0	115
Northern Ireland ...	76	36	+0·2	128	+1	112

*1916-1950 †1921-1950

RAINFALL OF JULY 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	2·29	95	*Carm.*	Pontcrynfe	5·58	128
Kent	Dover	3·20	136	*Pemb.*	Maenclochog, Ddolwen B.	6·43	125
,,	Edenbridge, Falconhurst	1·69	63	*Radnor*	Llandrindod Wells ...	4·87	154
Sussex	Compton, Compton Ho.	2·09	69	*Mont.*	Lake Vyrnwy	5·21	118
,,	Worthing, Beach Ho. Pk.	2·23	104	*Mer.*	Blaenau Festiniog ...	8·93	96
Hants.	St. Catherine's L'thouse	1·25	58	,,	Aberdovey	6·10	158
,,	Southampton, East Pk.	1·78	74	*Carn.*	Llandudno	3·26	157
,,	South Farnborough ...	1·45	57	*Angl.*	Llanerchymedd ...	3·51	121
Herts.	Harpenden, Rothamsted	1·88	70	*I. Man*	Douglas, Borough Cem.	4·73	154
Bucks.	Slough, Upton ...	3·12	133	*Wigtown*	Newton Stewart ...	4·05	113
Oxford	Oxford, Radcliffe ...	2·50	105	*Dumf.*	Dumfries, Crichton R.I.	4·70	122
N'hants.	Wellingboro' Swanspool	2·51	112	,,	Eskdalemuir Obsy. ...	6·69	134
Essex	Southend W.W. ...	2·38	118	*Roxb.*	Crailing...	5·18	179
Suffolk	Ipswich, Belstead Hall	2·52	117	*Peebles*	Stobo Castle	6·02	194
,,	Lowestoft Sec. School	2·08	90	*Berwick*	Marchmont House ...	4·41	150
,,	Bury St. Ed., Westley H.	2·80	99	*E. Loth.*	N. Berwick	5·25	196
Norfolk	Sandringham Ho. Gdns.	3·29	121	*Midl'n.*	Edinburgh, Blackf'd H.	6·47	214
Dorset	Creech Grange... ...	2·42	91	*Lanark*	Hamilton W.W., T'nhill	5·25	180
,,	Beaminster, East St. ...	2·62	86	*Ayr*	Prestwick	4·67	158
Devon	Teignmouth, Den Gdns.	2·27	104	,,	Glen Afton, Ayr San. ...	4·41	109
,,	Ilfracombe	2·12	71	*Renfrew*	Greenock, Prospect Hill	6·30	155
,,	Princetown	6·74	102	*Bute*	Rothesay, Ardencraig...	5·27	123
Cornwall	Bude	2·85	106	*Argyll*	Morven, Drimnin ...	3·50	83
,,	Penzance	3·29	120	,,	Ardrishaig, Canal Office	5·26	111
,,	St. Austell	4·30	127	,,	Inveraray Castle ...	4·76	80
,,	Scilly, St. Mary ...	2·09	94	,,	Islay, Eallabus ...	3·40	88
Somerset	Bath	3·51	127	,,	Tiree	1·82	54
,,	Taunton	1·90	85	*Kinross*	Lock Leven Sluice ...	5·33	142
Glos.	Cirencester	3·07	108	*Fife*	Leuchars Airfield ...	5·17	182
Salop	Church Stretton ...	4·06	137	*Perth*	Loch Dhu	5·90	113
,,	Shrewsbury, Monkmore	4·18	174	,,	Crieff, Strathearn Hyd.	4·32	126
Worcs.	Worcester, Red Hill ...	2·33	104	,,	Pitlochry, Fincastle ...	4·06	120
Warwick	Birmingham, Edgbaston	3·41	119	*Angus*	Montrose Hospital ...	5·61	191
Leics.	Thornton Reservoir ...	4·34	159	*Aberd.*	Braemar	3·53	118
Lincs.	Cranwell Airfield ...	4·56	181	,,	Dyce, Craibstone ...	5·89	177
,,	Skegness, Marine Gdns.	4·82	217	,,	New Deer School House	5·25	162
Notts.	Mansfield, Carr Bank...	4·87	182	*Moray*	Gordon Castle	6·63	215
Derby	Buxton, Terrace Slopes	6·02	154	*Inverness*	Loch Ness, Garthbeg ...	3·48	100
Ches.	Bidston Observatory ...	3·35	121	,,	Fort William	3·27	61
,,	Manchester, Ringway...	4·30	139	,,	Skye, Duntulm... ...	1·75	46
Lancs.	Stonyhurst College ...	4·61	114	,,	Benbecula	0·92	25
,,	Squires Gate	2·18	96	R. & C.	Fearn, Geanies ...	1·88	70
Yorks.	Wakefield, Clarence Pk.	4·32	170	,,	Inverbroom, Glackour...	2·13	57
,,	Hull, Pearson Park ...	3·24	134	,,	Loch Duich, Ratagan...	2·87	48
,,	Felixkirk, Mt. St. John...	2·65	90	,,	Achnashellach	2·61	45
,,	York Museum	2·87	116	*Suth.*	Stornoway	1·44	47
,,	Scarborough	2·55	103	*Caith.*	Lairg, Crask	0·00	000
,,	Middlesbrough... ...	2·23	82	,,	Wick Airfield	2·14	83
,,	Baldersdale, Hury Res.	3·02	98	*Shetland*	Lerwick Observatory ...	3·65	144
Nor'l'd	Newcastle, Leazes Pk....	3·49	122	*Ferm.*	Belleek	4·92	114
,,	Bellingham, High Green	5·80	177	*Armagh*	Armagh Observatory ...	5·44	165
,,	Lilburn Tower Gdns. ...	4·00	134	*Down*	Seaforde	4·53	124
Cumb.	Geltsdale	4·23	108	*Antrim*	Aldergrove Airfield ...	3·92	129
,,	Keswick, High Hill ...	3·26	74	,,	Ballymena, Harryville...	4·75	118
,,	Ravenglass, The Grove	3·83	98	*L'derry*	Garvagh, Moneydig ...	5·26	135
Mon.	A'gavenney, Plâs Derwen	3·68	121	,,	Londonderry, Creggan	4·55	108
Glam.	Cardiff, Penylan ...	3·42	100	*Tyrone*	Omagh, Edenfel ...	4·37	110

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,036, OCTOBER 1958

SOME NOTES ON OPTICAL PHENOMENA IN ANTARCTICA

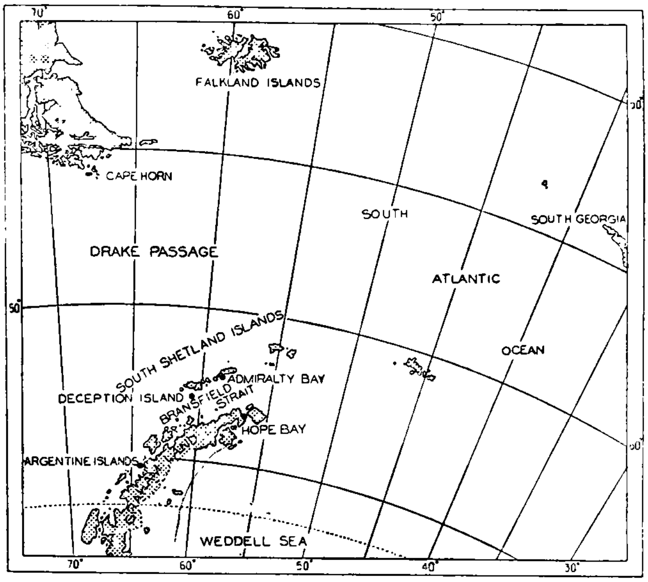
By D. J. GEORGE, F.R.G.S.

Introduction.—The following notes were made while serving with the Falkland Islands Dependencies Survey at bases in the South Shetland Islands, to the west and north-west of the Grahamland peninsula. In the Antarctic, meteorologists are ideally situated for observing meteorological optical effects, which are in many cases rare and present an inspiring spectacle to those lucky enough to see them. The region is a natural laboratory for observing examples of the optical laws, owing to the favourable conditions which prevail—the low temperatures experienced and the frequent occurrence of ice crystals near the ground, the lack of industrial pollution and the consequent clarity of the atmosphere, the large temperature differences between air and land and sea surfaces, and careful observers to observe and record the phenomena.

Most of the phenomena were observed at Deception Island (62° 59′S. 60° 34′W.) and Admiralty Bay (62° 03′S. 58° 24′W.) some 80–90 miles from the tip of the Grahamland peninsula, but some were observed when travelling down the west coast of Grahamland as far as 65°S. on the R.R.S. *John Biscoe.*

For most of the year the area is under the influence of the depressions which pass in a general south-west to north-east direction along the Drake Passage, but the more extreme continental weather prevails from May or June to November, when the adjacent seas freeze over. The majority of the ice crystal phenomena were observed during those months. The air temperature varies between approximately +45°F. and −30°F. in the South Shetlands, whilst the sea temperature varies by a few degrees around 30°F. Topography and the occurrence of orographic cloud favoured the observation of some phenomena and, in the case of Deception Island, the volcanic nature of the island contributed to the formation of local effects.

Methods of observation.—At the base a pilot balloon theodolite was available for accurate measurement of angular distances, but for quick routine use a measuring stick was made, consisting of a T-shaped piece of 2 × 2 centimetre wood, with the leg 57·3 centimetres long. The crossbar had marks made and panel pins inserted at centimetre intervals so that, when one end was held to the eye, each centimetre on the crosspiece represented one degree.



FALKLAND ISLANDS AND GRAHAMLAND.

For rough measurement in the field, the distance between the thumb and little finger of an outstretched hand was assumed to subtend an angle of 22 degrees. Angular distances were marked on an outstretched ski stick or ice axe haft in pencil, for later checking by theodolite at the base.

For photographing phenomena, a panchromatic film (Ilford F.P.3. or Pan -F in good lighting, and H.P.3. in poor light or for night photography) was used, with a 5X orange filter for solar phenomena. Polaroid spectacles of the type used to eliminate snow glare were very useful for observing bright effects.

Rainbows, ulloa's rings (fogbows), and brocken spectre.—In summer and early winter, when the precipitation was often wholly liquid, rainbows and secondary bows were seen.

In the winter of 1953 at Deception Island, it was possible for an observer, on the Mount Pond ridge (1,200 ft.), to stand with his back to the sun and see an enlarged shadow of himself, with a corona round the shadow of his head, thrown on a bank of orographic stratus a few hundred feet thick which often formed on the island.

During the winters of 1953 and 1954, after the sea ice had formed, banks of cloud which were classed as stratus or stratocumulus in accordance with the F.I.D.S. practice of classifying clouds by appearance, would cause the formation of fogbows centred at 180 degrees to the sun. (Previous observers on earlier expeditions have classified such clouds as "Cirrus at low heights", "Ice crystal fog", and "Ice needle fog".) These clouds appeared to be composed of a mixture of water droplets and ice crystals, the evidence for this being that in the cloud soft rime would form, and precipitated crystals would drift in the light air from the cloud bank causing haloes and fogbows to appear simultaneously. These fogbows were usually white, but on one occasion at Deception Island on a cloud bank about 200 yards away from an observer, a fogbow was visible with faint red, orange and yellow coloration, the elevation of the centre of the arch being 34 degrees.

At Admiralty Bay in August 1954, during a period of anticyclonic weather, fogbows were observed throughout the day for several days, the elevation of the centres of the arches varying between 28 and 38 degrees. The true radii of the bows would be larger than this as the theodolite was levelled at the height of the observer's eye, whereas the centre of the bow would be in line with the observer's eye and the sun, the sun being at an approximate elevation of 12 degrees at midday at that time of year.

Broadbear[1] mentions that the 38-degree radius bows observed at the Argentine Islands were presumably caused by refraction through ice crystals. If these bows were formed in cloud composed of a mixture of ice crystals and water droplets, as is possible at temperatures considerably below 32°F.[2,3] and indicated in actual cases by the formation of soft rime and the occurrence of haloes, then the bows could be caused by refraction and reflection of the light ray in the water droplets, similar to a rainbow, rather than by reflection in ice crystals. The size of the droplets and the elevation of the sun may account for the varying radii of the bows observed.

Mirages.—At Deception Island two types of mirage were observed, one of the inferior type and one of the superior type.

During the summer the snow-line receded to about 100 feet above sea level, exposing a coastal belt composed of black volcanic ash of a low albedo. During a calm fine day the surface would be heated by the sun, resulting in an abnormal lapse rate near the ground. Objects at the opposite side of the island could be seen shimmering and occasionally disappearing, apparently obscured by a smooth water surface. Similar mirages at Admiralty Bay were caused by air of a temperature ten or fifteen degrees below freezing overlying air warmed by the sea at a temperature of about 30 degrees. Icebergs could be seen drifting in the Bransfield Strait apparently elevated above the horizon by half a degree.

A superior mirage was observed from the Mount Pond ridge at Deception Island in midwinter, 1953. The plateau of Grahamland, 4,000–5,000 feet high and about 90 miles away, would normally in good visibility be visible quite low on the horizon. When suitable conditions prevailed the plateau would loom above the horizon and when viewed through binoculars would have an unnatural appearance due to refraction. The mirage was probably caused by cold air from the snow-covered land and growing pack ice cover being overlain with warmer air from the sea areas to the north.

Surveyors have found difficulty in using optical instruments in conditions of abnormal refraction. Sir Douglas Mawson in his report on meteorological optics on the British Antarctic Expedition of 1907–1909[4] mentions that it was impossible to make theodolite observations between 1 a.m. and 6 a.m. on the summer journey to the South Magnetic Pole, owing to extreme refraction caused by the katabatic flow of cold air from the plateau mingling with the warmer air over the sea ice.

It is of interest to note here that normally in conditions of unlimited visibility the coast of Grahamland would appear white or slightly yellowish from Deception Island, but on several occasions where air had travelled round an anticyclone from over the southern half of South America and southwards over the Drake Passage, the plateau appeared brownish through the polluted air although the visibility would still be classed as excellent for statistical purposes.

Dust would probably be collected over the dry Patagonian steppe, some 1,400 miles to the north, and industrial pollution over the northern half of Argentina, some 1,800 miles away.

Coronae.—Lunar coronae caused by diffraction through cloud droplets were observed on many nights because of the high frequency of occurrence of orographic cloud. The radii of the coronae varied between 2½ and 10 degrees, depending on the height of the cloud and the size of the cloud droplets. Sometimes two coronae would been seen, formed in two layers of thin cloud. Often the range of colours would be repeated. A yellowish aureole was sometimes visible round the moon although no cloud could be discerned. Some observers used the evidence of an aureole as confirming the presence of thin cirrus, but the aureole may have been formed in mother of pearl cloud. Solar coronae were occasionally observed.

Iridescent clouds.—Irisation of high stratocumulus, altocumulus and cirrus edges was often seen, usually within 25 to 30 degrees of the sun and less frequently within a few degrees of a full moon. The coloration was delicate, following the contours of the cloud.

A good example of iridescence over a wide area of cloud occurred at Admiralty Bay on 3 July 1954. The coloration was first observed at 1135 Zone time within 45 degrees of the sun and was of a moderate to bright red, green and light blue shade persisting till sunset. At 1430 Zone time a patch of coloration appeared opposite the sun. Measurements were made at 1500 Zone time—the coloration round the sun extended from 268 to 050 degrees (true) in an arch form between elevation 17 and 25 degrees. Opposite the sun the patch extended from 099 to 117 degrees between elevation 18 and 20 degrees. The cloud over the period was 6/8 Ci., Cs. and Cc. estimated to be at 17,000 feet with 2/8–3/8 Sc. at 1,500 feet. A nephoscope observation at 1100 Zone time gave the wind at the cirrus height as 240 degrees 20 radians per hour. The cloud was orientated in polar bands from 240 to 060 degrees. A small depression had passed in the morning, the barometer rising and cloud breaking in the rear of a cold front just before 1100 Zone time.

Haloes, parhelic circles, arcs of contact, parhelia and paraselenae, sun and moon pillars.—These refraction and reflection phenomena were observed in cirrostratus sheets ahead of depressions but the more spectacular types occurred in winter when ice crystals formed near the surface. Various combinations were observed, depending on the shape of the crystal and its orientation in relation to the light source.

At Deception Island in July and August 1953 brilliant haloes of 22½ degrees, arcs of contact, parhelia and crosses (sun pillar above and below the sun with part of the parhelic circle) were observed in microscopic crystals (sometimes called "diamond dust"), which appeared to be precipitated from a bank of stratus-like cloud which formed at a few hundred feet over the island. A 46-degree lunar halo was observed twice in such conditions, the halo appearing between the observer and the hillside.

On several occasions in an apparently clear sky with a light north-west air, brilliant haloes, parhelia, upper arcs of contact and sun pillars were formed by microscopic crystals which drifted from the north-west and which could only be seen when viewed against the sun, when they glittered. It is believed that in this case the crystals originated from the steam which rose from patches of open water near the shores (similar to Arctic sea-smoke). In the sunken crater of the volcano which formed the harbour at Deception Island were warm areas, which heated the water near the beaches sufficiently to remain ice free all the winter, whilst the rest of the harbour was covered in bay ice. (The steaming beaches were warmed to 90–140° F., whilst the sea water was around 28°F. and the air temperature −7°F.) The temperature difference was probably sufficient to cause the formation of microscopic crystals from the vapour.

At Admiralty Bay between 10 and 14 August, and again on 24–26 August 1954, an anticyclone was centred over the north-west of the Weddell Sea, giving pressures of 1000–1012 millibars at the base, temperatures between −15°F. and −26°F. and clear skies. Haloes and associated phenomena were of daily occurrence over this period, caused by crystals precipitated from thin banks of stratified cloud on the sea ice or on the 2,000 foot plateau.

A fine sun pillar was observed at 1125 Zone time on 25 August from the summit of Flagstaff (1,000 feet) in ice crystals which drifted from a bank of cloud on the plateau, the visibility in the crystals being reduced to 700 yards at times. An analysis of the snow crystals, using the International Snow Classification, showed them to be 60 per cent stellar crystals, 0·5 millimetres in diameter, with equal percentages of the remainder being irregular microscopic particles and small hexagonal plates, some of which were double and connected by short columns.

The photograph, Plate I, was taken at 1125 Zone time and shows part of the glittering white pillar which extended from 5 degrees above to over 46 degrees below the sun. A faint 22½ degree halo was visible. The pillar was of a brilliant whiteness and had a bright spot (possibly the lower arc of contact of the 46 degree halo) at 46 degrees below the sun. The individual crystals forming the pillar could be seen glittering and appear in the lower part of the pillar in the photograph as bright streaks. The bright spot can be seen as a circular bright area probably due to halation effects. Simultaneously at the base near sea level a fogbow, 22½ degree halo, sun pillar, partial parhelic circle and a circumzenithal arc were visible. The circumzenithal arc, which showed very pure red, orange, yellow-green and blue colours, was convex to the sun and 48 degrees above it. The ends extended from bearing 351 degrees to 059 degrees from true north.

A circumzenithal arc, formed with a bright 22½ degree halo and parhelia, was observed in crystals drifting from a bank of cloud at 1,800 feet at 1330 Zone time on 7 September 1954 at Admiralty Bay. The arc was bright and showed red, orange, green and blue coloration, being at an elevation of 45 degrees above the sun which was 20 degrees above the horizon. The arc was about a third of a circle.

Plate III shows a typical 22½ degree halo, parhelic circle, sun pillar and parhelia observed from Hope Bay, Grahamland, during the 1954 winter and photographed by Dr. W. Turner. The crystals causing the phenomenon probably drifted from the bank of low stratified cloud over the sea ice in the background.

Sun and moon pillars are often reported with beams of light above the luminary, but less frequently with the beam below. Murray[5] reported that on the British Antarctic Expedition of 1907–09, pillars were observed above the sun only. This may be due to the low elevation of the sun or to the particular type of crystal causing the reflection. Flat plates and stellar crystals were observed in 1953 and 1954 with rime-like growths on one side. If this type of crystal were falling in still air with its principal axis vertical, the reflection from the upper side would be broken up by the rime-like growths resulting in the upper pillar only being visible.

Sunrise and sunset coloration.—Coloration of the sky in clear conditions with unlimited visibility was observed frequently during the winter of 1954. As the sun was setting an arch appeared in the eastern sky, which grew darker as the sun lowered. The colours slate blue, purple, red, pink, orange and greenish blue were noted upwards from the eastern horizon, merging into one another. The arch grew in elevation to about 40 degrees before darkness commenced. Similar coloration was observed at sunrise in the western sky.

Alpine glow.—This phenomenon was observed during the 1953 and 1954 winters but the best examples were seen in latitude 65°S., from on board the R.R.S. *John Biscoe* when lying off the Argentine Islands in March 1954. The 4,000–5,000 foot plateau of Grahamland lay north to south about ten miles to the east and, long after the observer at sea level was in shadow at sunset, the glaciers and snow fields of Grahamland would be illuminated a deepening rose colour. The only cloud at the time was a small amount of high cloud from the edge of a depression far to the north.

Conclusion.—Standards of observing varied greatly between individuals, stations and from year to year, thus making a comparable frequency analysis of optical phenomena over the period impracticable. Descriptions of the snow crystal types were commenced at the F.I.D.S. bases in 1953 and with long-term records it may be possible to correlate optical effect with snow crystal type, cloud structure and synoptic situation.

Acknowledgment.—I am grateful to the Falkland Islands Dependencies Survey and Scientific Bureau for permission to publish this article and for the loan of Plates II and III.

REFERENCES

1. BROADBEAR, N. R.; Notes on observing at Argentine Islands, Grahamland in 1950 and 1951. Appendix IV to Meteorology of the Falkland Islands and Dependencies, 1944–50 by J. Pepper, London, 1954.
2. DOBSON, G. M. B.; Ice in the atmosphere. *Quart. J. R. met. Soc., London,* **75,** 1949, p. 117.
3. LUDLAM, F. H.; The forms of ice clouds. *Quart. J. R. met. Soc., London,* **74**, 1948, p.39.
4. MAWSON, D.; Meteorological optics. Appendix to "The heart of the Antarctic", by E. H. Shackleton, London, 1909.
5. MURRAY, J.; Additional notes on meteorological optics. Appendix to "The heart of the Antarctic", by E. H. Shackleton, London, 1909.

VARIATION OF PRESSURE AT GIBRALTAR

By G. W. HURST, B.Sc.

Introduction.—Pressure records exist for many years at Gibraltar and analysis has been made of both seasonal changes and diurnal variation. Several interesting points emerged.

Seasonal change in average pressure.—There are observations for over a century until 1929 for South Bastion (50 feet), 1930–36 for Alameda Gardens (90 feet), 1937–46 for Windmill Hill Flats (400 feet) and 1947 onwards for North Front (10 feet). Examination of the older records showed that there was a marked change in corrections applied after September 1912 (in consequence of an inspection of the station, observations at which were performed by R.A.M.C. personnel). The error had been about 2 millibars and earlier records have therefore been held to be unreliable particularly as times of reading were varied at frequent intervals. The period from 1913 has however been taken as homogeneous, as all stations were within 1½ miles of South Bastion and none was higher than 400 feet above mean sea level; in fact, apart from the ten years 1937–46, the stations were within 1½ miles of each other and less than 100 feet above mean sea level. Average monthly values have been taken for the period 1913–56 (converting from inches to millibars before 1936) and a comparison has been made of these with corresponding North Front figures for the 10 years 1947–56. This is shown in Table I.

TABLE I.—AVERAGE MONTHLY AND SEASONAL PRESSURE READINGS (IN MILLIBARS) AT GIBRALTAR 1913–56

Period	All stations (1913–56) Mean	Standard Deviation	50% range of mean	North Front (1947–56) Mean	Standard Deviation	50% range of mean
Jan.	1020·91	3·62	1020·54–21·28	1019·8	1·70	1019·4–20·2
Feb.	1019·29	3·70	1018·91–19·67	1018·5	4·49	1017·5–19·5
Mar.	1017·23	3·30	1016·89–17·57	1017·2	3·67	1016·4–18·0
Apr.	1016·03	2·01	1015·83–16·23	1016·6	2·53	1016·1–17·1
May	1016·10	1·62	1015·94–16·26	1016·0	1·62	1015·7–16·3
June	1016·78	1·23	1016·66–16·90	1016·8	1·24	1016·5–17·1
July	1016·29	·88	1016·20–16·38	1016·0	·77	1015·8–16·2
Aug.	1015·66	1·28	1015·53–15·79	1015·2	·91	1015·0–15·4
Sept.	1016·69	1·02	1016·59–16·79	1016·9	·81	1016·7–17·1
Oct.	1017·07	1·83	1016·88–17·26	1018·0	1·69	1017·6–18·4
Nov.	1017·82	2·69	1017·55–18·09	1018·9	2·09	1018·5–19·3
Dec.	1020·19	2·84	1019·90–20·48	1020·2	2·13	1019·7–20·7
Winter	1020·13	2·15	1019·91–20·35	1019·5	1·59	1019·2–19·8
Spring	1016·46	1·45	1016·31–16·61	1016·6	·87	1016·4–16·8
Summer	1016·25	·78	1016·17–16·33	1016·0	·50	1015·9–16·1
Autumn	1017·19	·82	1017·11–17·27	1017·9	1·25	1017·6–18·2
Year	1017·51	·82	1017·43–17·59	1017·51	·65	1017·4–17·6

Data for all stations have been taken to two places of decimals but the shorter period for North Front does not justify this. Average figures for both sets are shown in Figure 1, together with lines indicating values which will contain 90 per cent of the mean monthly pressures. It is immediately evident that the mean North Front values in nearly all cases fall within the 90 per cent range, and only in October is the North Front average appreciably different from that over the longer period. The difference is still such however as to suggest no significant departure for the month. It is clear therefore that North Front is fairly representative of the Rock as a whole, though it does happen that pressure in autumn 1947–56 was rather above average and that in winter correspondingly rather below.

Three points stand out from Figure 1: the considerably higher average pressure in winter than summer, the much greater variability of average monthly pressure in winter and the secondary maximum pressure in June. Average pressure would be expected to be lower in summer, as a feature of the Gibraltar summer is the slack pressure gradient in the area: more or less col conditions, with low pressure over the heated land masses of Iberia to the north and Morocco and the Sahara to the south. No depressions as such are effective in this part of the year and variation of pressure is therefore restricted. In winter, there is little or no thermal heating effect and pressure tends to build up slightly

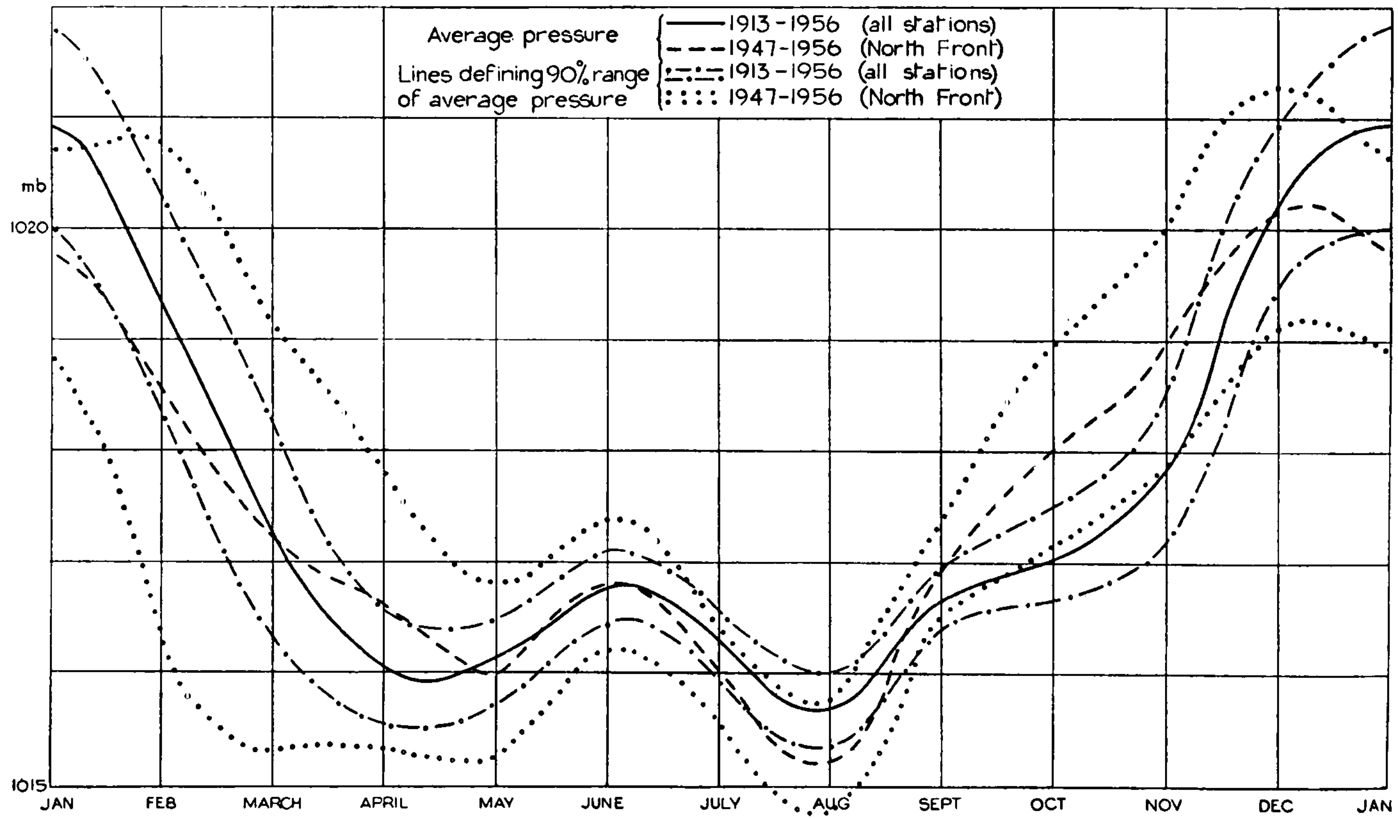


FIGURE I—ANNUAL VARIATION OF PRESSURE AT GIBRALTAR

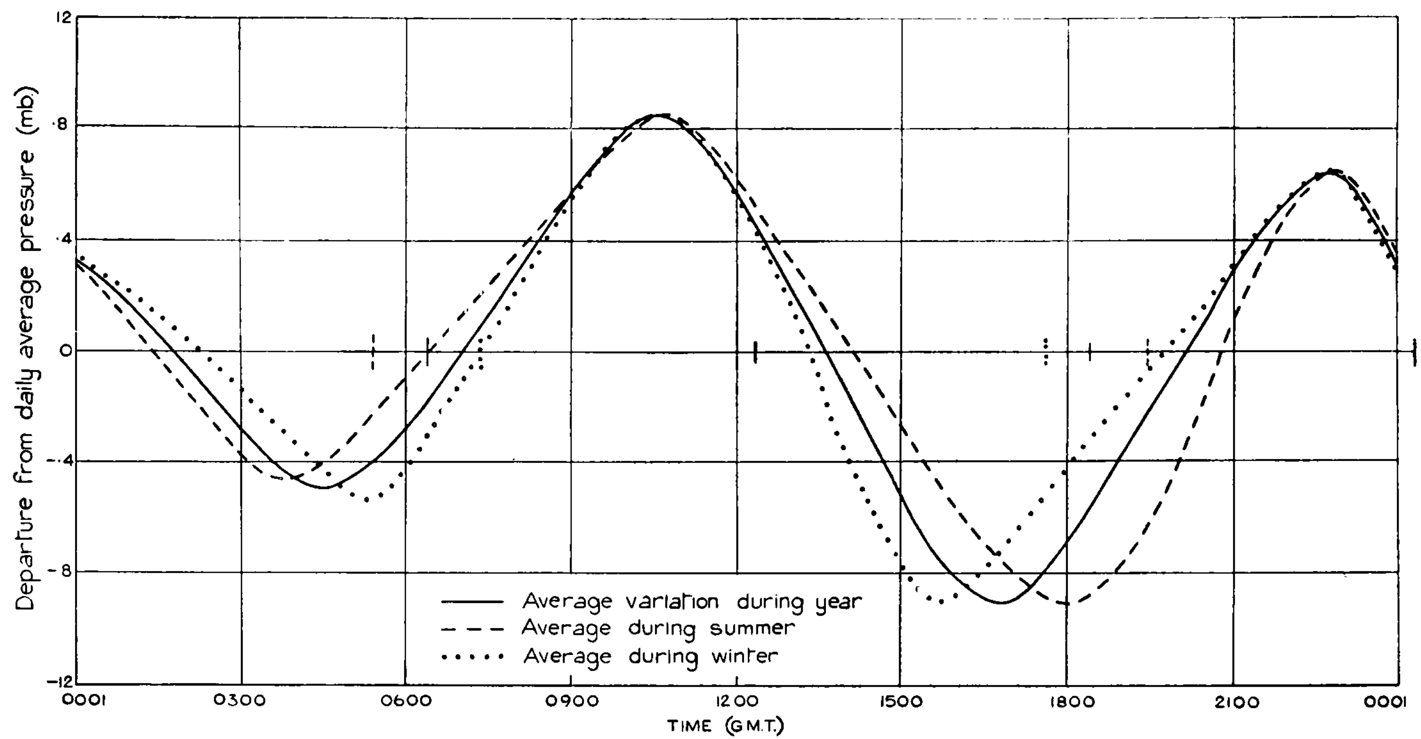


FIGURE 2—DIURNAL VARIATION OF PRESSURE AT GIBRALTAR (NORTH FRONT) 1952–56.

Local times of sunrise, sunset, midday and midnight are shown.

to the north or more frequently to the south. Occasional active depressions move across the Straits (usually from west to east) so that variation in pressure must be far higher. The secondary maximum in June is rather interesting. This is the time of the start of the levanter season at Gibraltar, with really high temperatures occurring in the north Africa area. This is not thought to be the main factor in this change, however. Gibraltar, at 36°N. 5°W., lies in the subtropical summer high pressure zone and with no interference due to the land heating effects discussed, the average pressure would show a maximum in summer. Pressures for two typical Azores stations[1] from March to September are given in Table II.

TABLE II.—AVERAGE PRESSURE (IN MILLIBARS) AT AZORES STATIONS DURING SUMMER HALF OF YEAR

Station	March	April	May	June	July	August	September
Horta (25 year period)	1021	1021	1021	1024	1025	1023	1022
Ponta Delgada (45 year period)	1020	1021	1021	1023	1024	1023	1021

The subtropical high obviously gains in intensity between May and June and, taking this as a common tendency for the latitude, the increase of pressure in June is readily explained, as the increase due to the anticyclonic build-up is rather greater than the seasonal fall due to continental heating. The fall of pressure at Gibraltar is continued in July and August, when the anticyclone is no longer intensifying appreciably. This effect of a secondary summer maximum is reflected in other stations in south-west Spain and north-west Africa in similar latitudes. It is interesting to note that pressure in summer at Gibraltar is almost 10 millibars lower than over ocean areas at the same latitudes.

Seasonal changes—extreme values.—Monthly and seasonal data have been examined for variation in extreme pressures during the period 1947–56 for North Front. Analysis of seasonal and annual values is given in Table III.

TABLE III.—EXTREME SEASONAL PRESSURES (IN MILLIBARS) AT NORTH FRONT 1947–56

Period	Average	Standard Deviation	Extreme Recorded	Values expected to be exceeded once in 10 years	Values expected to be exceeded once in 100 years
		(a) Highest values			
Winter	1033·3	2·41	1037·4	1036·4	1038·9
Spring	1029·3	3·67	1036·0	1034·0	1037·8
Summer	1023·2	·85	1024·9	1024·3	1025·2
Autumn	1028·2	2·42	1032·6	1031·3	1033·8
Year	1033·7	2·43	1037·4	1036·8	1039·4
		(b) Lowest values			
Winter	996·8	3·84	990·6	992·8	987·9
Spring	1002·1	3·73	993·3	996·3	993·4
Summer	1008·7	2·06	1003·9	1006·1	1003·9
Autumn	1003·1	7·17	986·4	993·9	986·4
Year	995·5	4·27	986·4	990·0	985·6

The range of possible pressure extremes is naturally far higher in winter than in summer: the range for a typical winter is 36·5 millibars and in summer 14·5 millibars; extremes over 10 years would differ by at least 47·3 and 19·3 millibars respectively. The only slight anomalies in Table III are the high values of the standard deviation for the autumn minimum, due to an exceptionally low pressure recorded on 30 November 1947 and the lowness of the absolute minima for all seasons except winter. Most of the anomalously low values arising in spring and autumn occur as isolated values within a few days of the winter season; those of summer occur mostly at the begining and end.

Considering the settled season as the conventional summer, but omitting unduly high or low readings in the first four days of June and the last four of August, readings corresponding to entries in Table III would be:

Settled season.

(a) Highest values.
Average 1023·0 millibars, standard deviation 0·76 millibars.
Highest recorded 1024·1 millibars.
Value expected to be exceeded once in 10 years 1024·0 millibars.
Value expected to be exceeded once in 100 years 1024·8 millibars.

(b) Lowest values.
Average 1009·7 millibars, standard deviation 1·31 millibars.
Lowest recorded 1007·8 millibars.
Value expected to be exceeded once in 10 years 1008·0 millibars.
Value expected to be exceeded once in 100 years 1006·7 millibars.

The unsettled season consists of the conventional winter together with about half November and March, and includes all extremes in the 10 years 1947–56 except 994·9 millibars on 10 November 1951 (1·6 millibars lower than the February reading) and 1035·0 millibars on 5 April 1947 (2·4 millibars higher than the December pressure).

It is therefore seen that in high summer pressure values outside the range 1006/1025 occur only about once a century, whereas in winter limits are 985/1039, giving a range in the settled season of 19 millibars and in the unsettled 54 millibars. Agreement is fairly close with data for South Bastion and Windmill Hill,[1] where the actual summer range over the 17 year period 1922–38 was 1006/1026 and that of winter 990/1038. The rather higher summer value of 1026 millibars (1025·7 millibars on 10 June 1923) appeared very exceptional as no other reading in the period exceeded 1024·1 millibars. Most of the higher pressure readings occur during surface easterlies, with ridge conditions over southern Spain.

Diurnal variation of pressure.—Diurnal variation can be observed on barograms throughout the year with ease, even at 36°N., and is the main feature in summer. Data for North Front were extracted on a three-hourly basis for the period 1952–56, backed by hourly data for two typical months in summer and winter. Data were also extracted for the period 1947–52 for minor synoptic hours only (a period when tabulated data for the other hours were not readily available), and also for similar hours for Windmill Hill observations (reduced to sea level); both confirmed that there was no important error in considering the shorter period only as representative. The diurnal variation from the average pressure is shown in Figure 2 for the seasons winter and summer and for the year as a whole. Also are marked local times of sunrise and set, and midday and midnight.

The maxima occur rather under two hours before midday and midnight (local time), but an interesting feature is that there is virtually no variation throughout the year in amplitude, which is +·85 at 1015 and +·65 at 2220 local time. This compares, for example, with a morning maximum variation between ·60 millibars in summer and 1·05 millibars in winter at the Cape of Good Hope (almost symmetrically placed to Gibraltar in the southern hemisphere at 34°S. 18°E.) and almost one millibar difference at Calcutta at 22°N. The average morning maximum at Good Hope of ·83 millibars is almost identical with Gibraltar. The evening maximum pressure is only ·50 millibars at Good Hope and the average summer maximum at this time is ·30 millibars higher than that in winter. (Data from Shaw.[2])

Minima at Gibraltar are more or less typical, with the greater in the evening, —·90 millibars through the year. There is a slight yearly difference in the morning minimum (average —·52 millibars), though much less than at Good Hope. The average annual diurnal range is 1·75 millibars compared with 1·55 millibars at Good Hope, and the mean amplitudes are ·73 and ·67 millibars respectively. This amplitude of ·73 millibars is rather higher than the figure of ·66 millibars which would be expected for the latitude (Simpson[3]). A final point is that the winter minima occur about 2 hours before sunrise and set, but the period is only about 1½ hours in summer; the average over the year is about 1¾ hours.

A natural deduction from the three hourly departures from normal is an assessment of the contributions to the tendency at the various synoptic hours. These are shown in Table IV.

TABLE IV.—MEAN CONTRIBUTION OF DIURNAL VARIATION TO BAROMETRIC TENDENCIES (IN MILLIBARS) AT GIBRALTAR

Time G.M.T.

Period	00–03	03–06	06–09	09–12	12–15	15–18	18–21	21–00
Winter	—·4	—·3	+1·0		—1·3	+·3	+·7	
Spring	—·8		+·8		—1·0	—·2	+1·1	
Summer	—·7	+·3	+·7	+·1	—·9	—·6	+1·0	+·2
Autumn	—·6		+1·1	—·2	—1·2	+·1	+·9	—·1

The effect of diurnal variation is almost negligible for charts at the major synoptic hours, except possibly in summer at 1800 G.M.T. with an average value of —·6 millibars (as high as —·7 millibars in July); at no other time or season is it greater than ·3 millibars. Characteristics tend to be of the rising then falling type at 0001 and 1200 G.M.T., and vice versa at 0600 and 1800 G.M.T. Diurnal variation contribution to intermediate tendencies, however, is mainly of the order of a millibar except at 0300 G.M.T., when the range is —·4 to —·8 millibars. Table IV can be used with little error for any low level coastal station in the vicinity (for example Port Lyautey, Tangier, etc.), but tendencies resulting from diurnal changes inland over heated Spain and Morocco are of course much more irregular and variable and, in particular, values well over a millibar can occur inland during the period 0900/1800 G.M.T.

REFERENCES

1. London, Meteorological Office; Weather in home waters and the north-eastern Atlantic. Vol. II, Part 1, The Atlantic from the Azores to the African coast with an appendix on Gibraltar, London, 2nd edition, 1944, pp. 148, 150, 230.
2. SHAW, SIR NAPIER; Manual of Meteorology. Vol. II. London, 1928, pp. 224–229.
3. SIMPSON, SIR GEORGE; The twelve-hourly barometer oscillation. *Quart. J. R. met. Soc., London,* **44**, 1918, p.9.

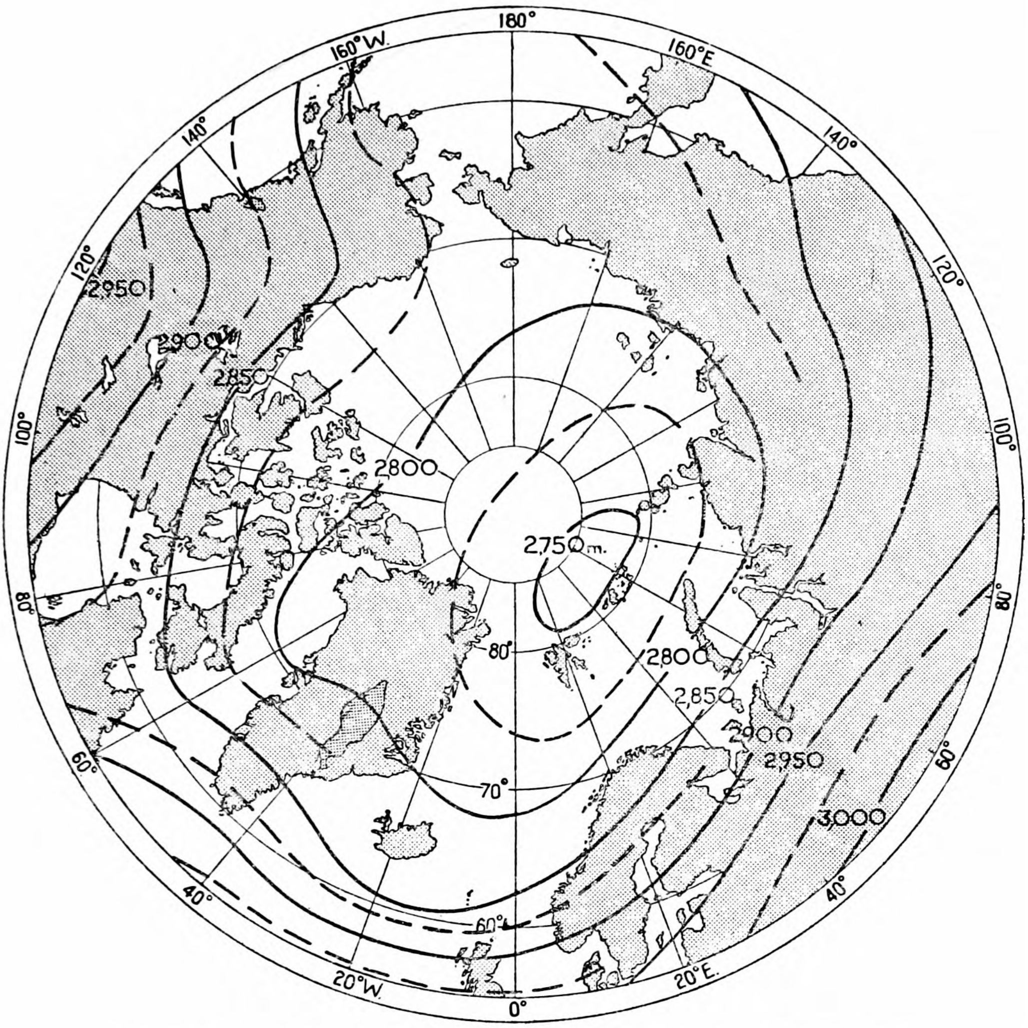


FIGURE 1—AVERAGE 700-MB. CONTOURS FOR APRIL 1949–53

AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE NORTH POLAR REGIONS IN APRIL AND OCTOBER

By H. HEASTIE, M.Sc.

Introduction.—The revision of *Geophysical Memoirs No.* 85—*Upper winds over the world*—has been started by constructing circumpolar charts of the height of the standard isobaric surfaces, as explained in a previous article.[1] In that article some of the charts for January were shown and a further article[2] showed some of the corresponding charts for July. This part of the revision of the memoir has been completed by the construction of circumpolar charts for April and October[3] and this article presents, with a brief description, some of these charts.

Data.—Data for the same period, 1949–53, were used; sources are listed elsewhere.[4]

Method of constructing the charts.—The method used was similar to that described previously.[1] Again the data from Siberia were very sparse

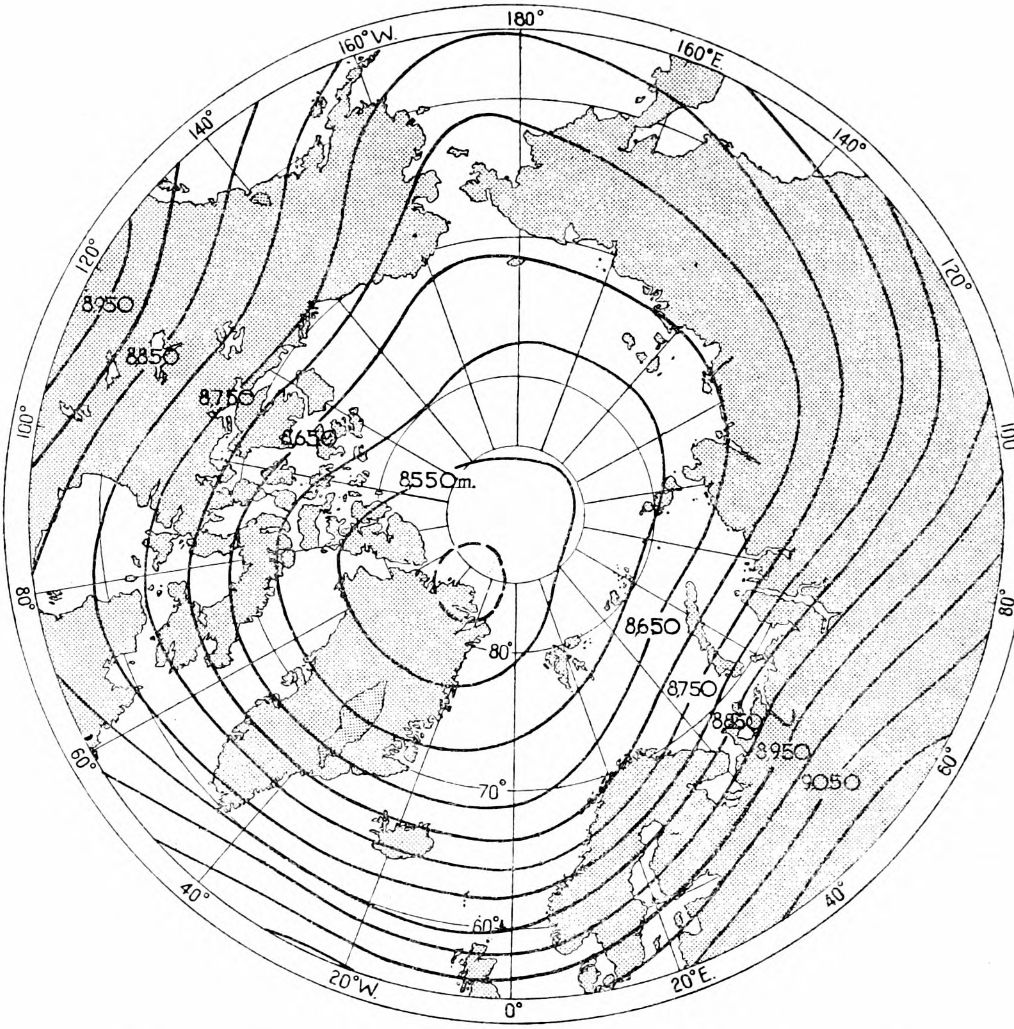


FIGURE 2—AVERAGE 300-MB. CONTOURS FOR APRIL 1949–53

both in April and October and the charts were drawn up to the 300-millibar level by means of the correlation method described in an earlier article.[2]

It was not possible to use data from night-time ascents only and the effect of solar radiation could not be eliminated entirely. 0300 G.M.T. data were used generally, but 1500 G.M.T. data were available from the Aleutian and Alaskan stations and were used when the 0300 G.M.T. ascents were made in daylight. At 0300 G.M.T., daylight covers most of the U.S.S.R. in April and all of Siberia in October, and no Russian data for 1500 G.M.T. were available. Guterman[5] discusses the radiation correction of the comb radiosonde used in the U.S.S.R. and suggests that for solar elevations below 15° the error is negligible. For solar elevations of 50°–60° he quotes figures which would imply errors of 3–4 metres in the 500–300-millibar thickness and 30–35 metres in the 300–100-millibar thickness. However, no Russian data above 300 millibars were available and use was made of the temperature lapses from a memoir on upper air temperature.[6] In the preparation of this memoir data at both 0300 G.M.T. and 1500 G.M.T. were used

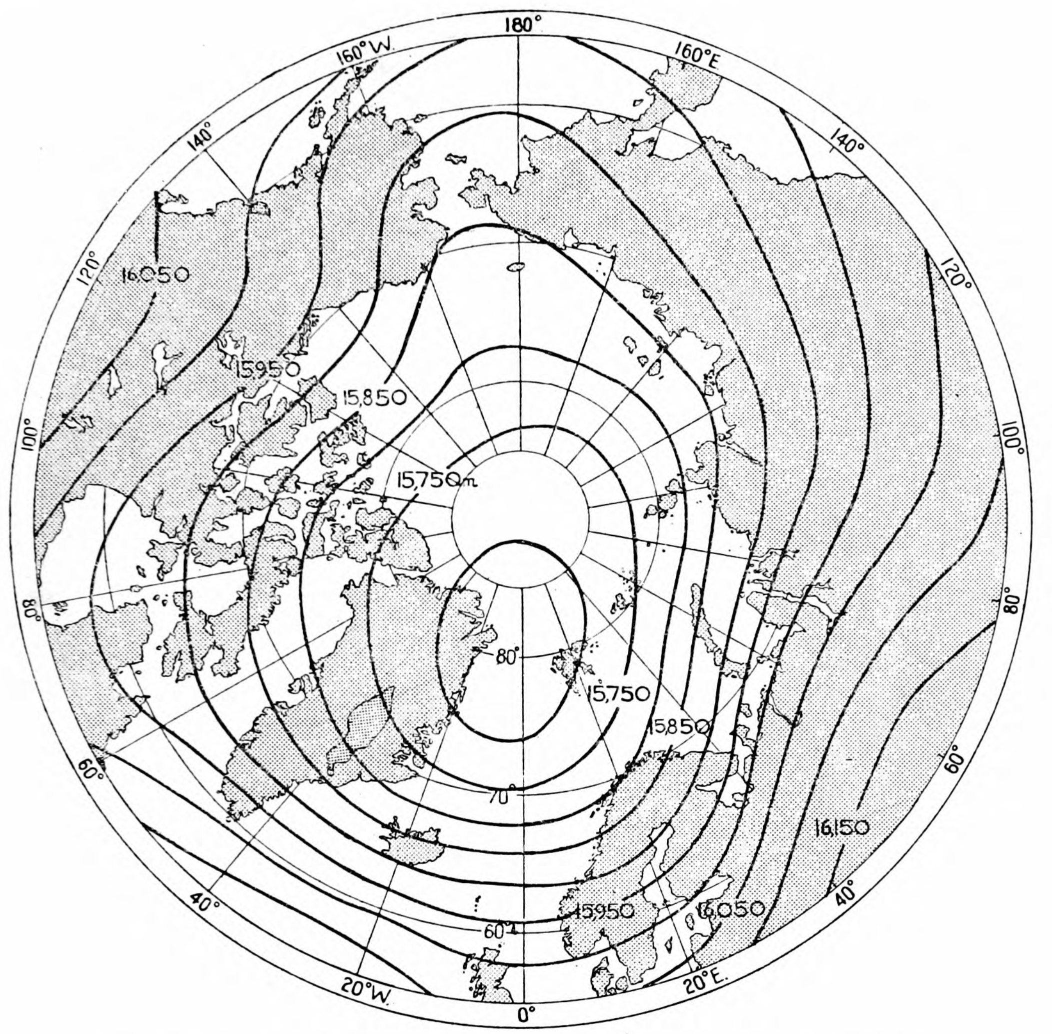


FIGURE 3—AVERAGE 100-MB. CONTOURS FOR APRIL 1949–53

and, it is reasonable to suppose, any error due to radiation halved in consequence. Further, the maximum elevation of the sun for the area and period considered is 10° or more below that to which the radiation corrections quoted are applicable. It was assumed, therefore, that the maximum error due to radiation was less than 20 metres at 100 millibars. As, however, the variation of radiation correction with solar elevation was unknown, no attempt was made to assess the actual error.

The charts.—The April charts show two interesting differences from those for the other mid-season months. The first concerns the centre of the main circulation. In January, July and October, at all levels above 700 millibars, this centre lies between 75° and 90°W. and 67° and 87°N. i.e. within a relatively narrow sector of northern Canada and the Canadian Arctic. In April, at 700 millibars (Figure 1), it lies to the north of Franz Josef Land at 84°N., 50°E. At 300 millibars (Figure 2) it lies to the north of Greenland (84°N., 35°W.) and, at 100 millibars (Figure 3) between Greenland and Spitsbergen (82°N., 10°W.). It is possible to attribute the centre at 700 millibars to the persistence of a

FIGURE 4—AVERAGE 200–100-MB. THICKNESS FOR APRIL 1949–53

secondary centre at about 80°N., 70°E. on the 700 millibar chart for January.[4] Changes from a winter to a summer régime take place very rapidly in the spring and not necessarily at the same time in different regions of the chart (though detailed evidence from the Russian Arctic is lacking) and it is doubtful whether the April or any other monthly chart represents a true "mid-season" circulation pattern. The second peculiarity of the April charts is a departure from the normal association between features of the tropopause pressure and stratospheric thickness patterns shown generally on the charts for the other three months. This occurs at about 20°E. where the tropopause pressure chart[6] shows a marked ridge which is almost immediately below troughs in the thickness charts 300–200 millibars and 200–100 millibars (Figure 4) i.e. relatively low stratospheric temperature above a relatively low tropopause. These thickness patterns are consistent with the patterns shown on the relevant average temperature charts.[6] In this area fairly adequate data were available and this peculiarity is believed to be real.

Both the April and October charts show a westerly circulation at all levels with main troughs at 60–80°W., and 160–180°N., though there appears to be a

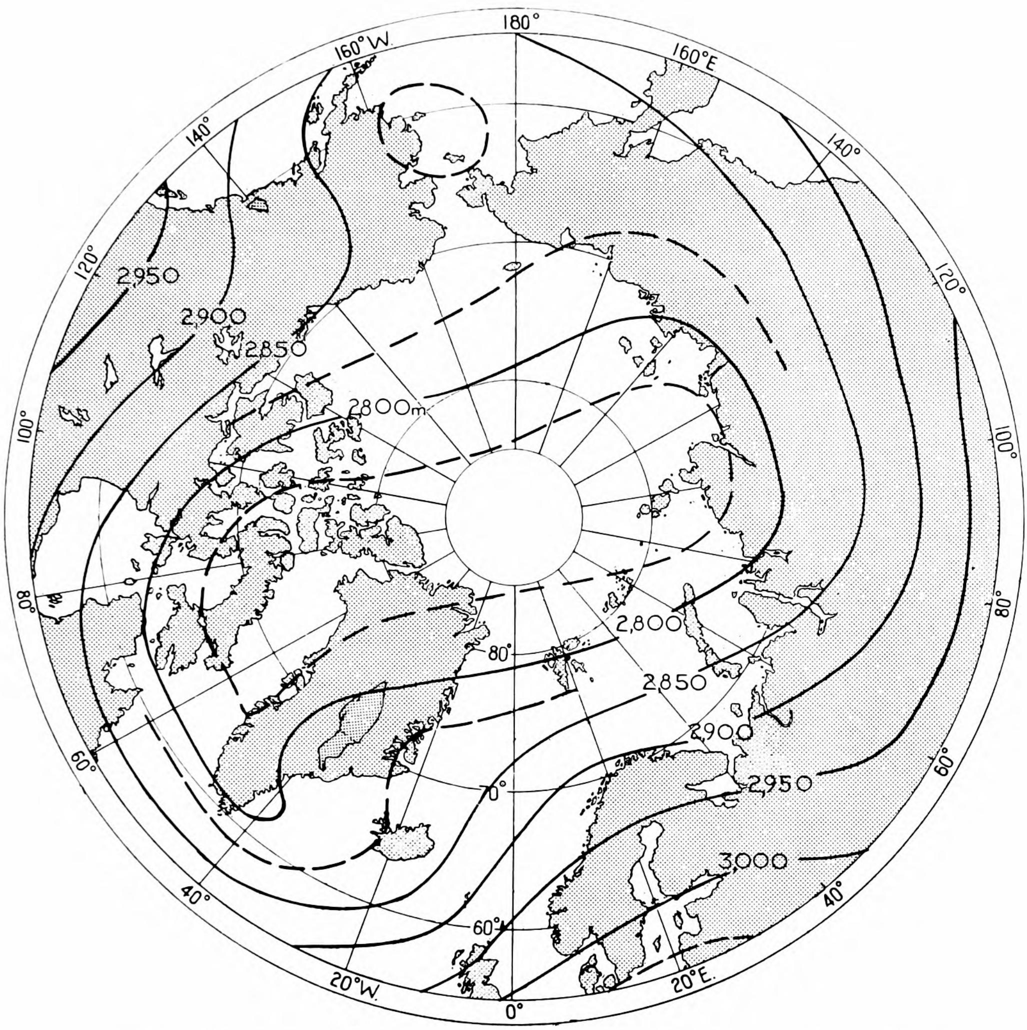


FIGURE 5—AVERAGE 700-MB. CONTOURS FOR OCTOBER 1949–53

Falkland Islands Dependencies Survey *Photograph by D. J. George*

PLATE I—SUN PILLAR AT ADMIRALTY BAY, ANTARCTICA, ON 25 AUGUST 1954

(see p. 293)

Falkland Islands Dependencies Survey *Photograph by G. Brookfield*

PLATE II—PARHELIA AT HOPE BAY, GRAHAMLAND, 1954

(see p. 293)

To face p. 305]

Falkland Islands Dependencies Survey

Photograph by Dr. W. Turner

PLATE III—PARTIAL 22½ DEGREE HALO, PARHELIA AND CROSS AT HOPE BAY, GRAHAMLAND, 1954

(see p. 293)

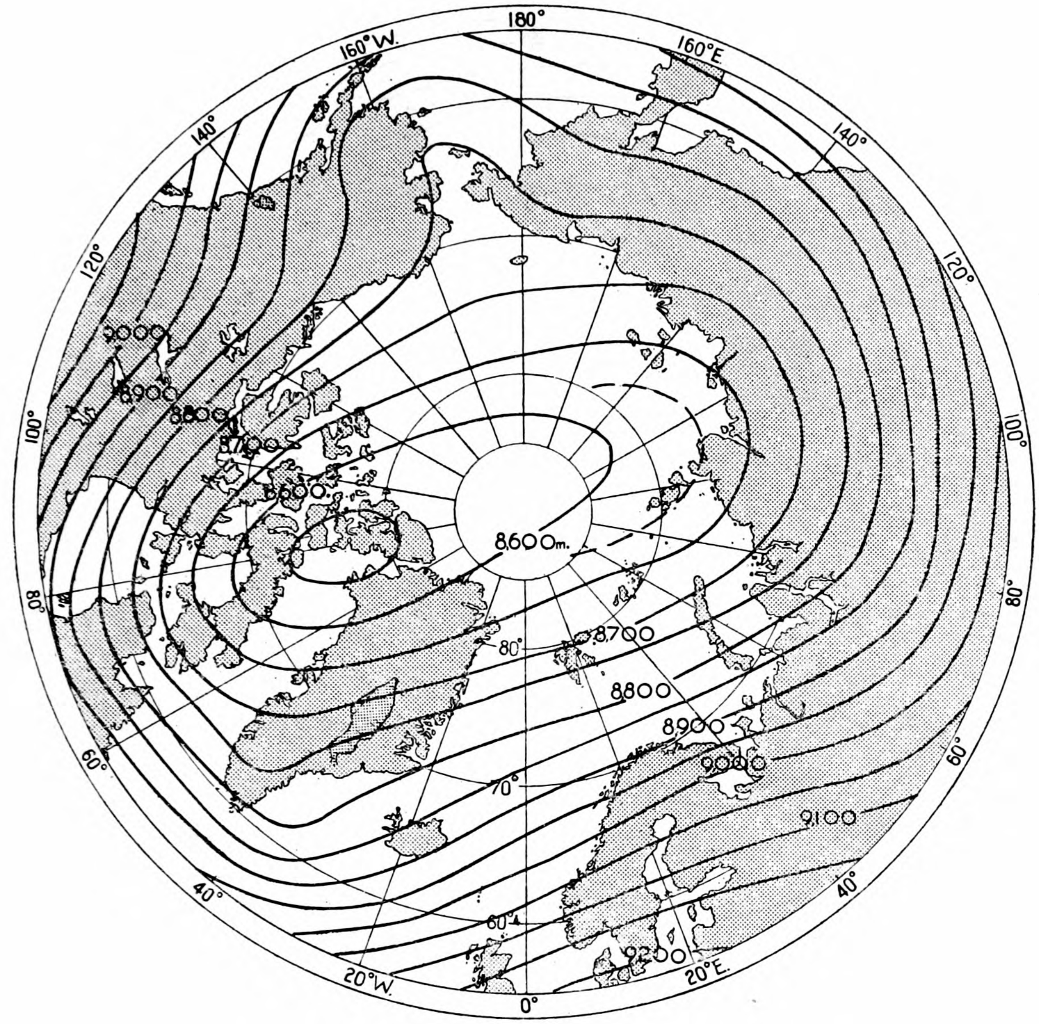


FIGURE 6—AVERAGE 300-MB. CONTOURS FOR OCTOBER 1949–53

weak secondary circulation at 700 millibars in the Bering Sea in October (Figure 5). The main centre of the circulation lies between Franz Josef Land and north-east Greenland in April (Figures 1, 2, 3) and over Ellesmere Island in October (Figures 5, 6, 7). The April charts show a further main trough about 0°W. and a rather indeterminate trough over Siberia, while in October there are troughs between Iceland and Greenland and over western Siberia.

The stratospheric thickness charts for both months are extremely flat and the pattern rather nondescript. This might be expected from the corresponding charts for January and July. In January the 200–150-millibar and the 150–100-millibar thickness charts[4] both show a mainly cyclonic circulation centred near the pole while in July the 200–100-millibar thickness chart[2] shows an anticyclonic circulation centred on the pole. For the two shown here (Figures 4, 8) the corresponding thermal wind is everywhere less than 10 knots and in large areas less than 5 knots. Relatively high values of thickness are shown over Siberia and northern Canada corresponding to the two main centres of low tropopause.[6] In April the thickness values are, on average, some 50 metres greater than in

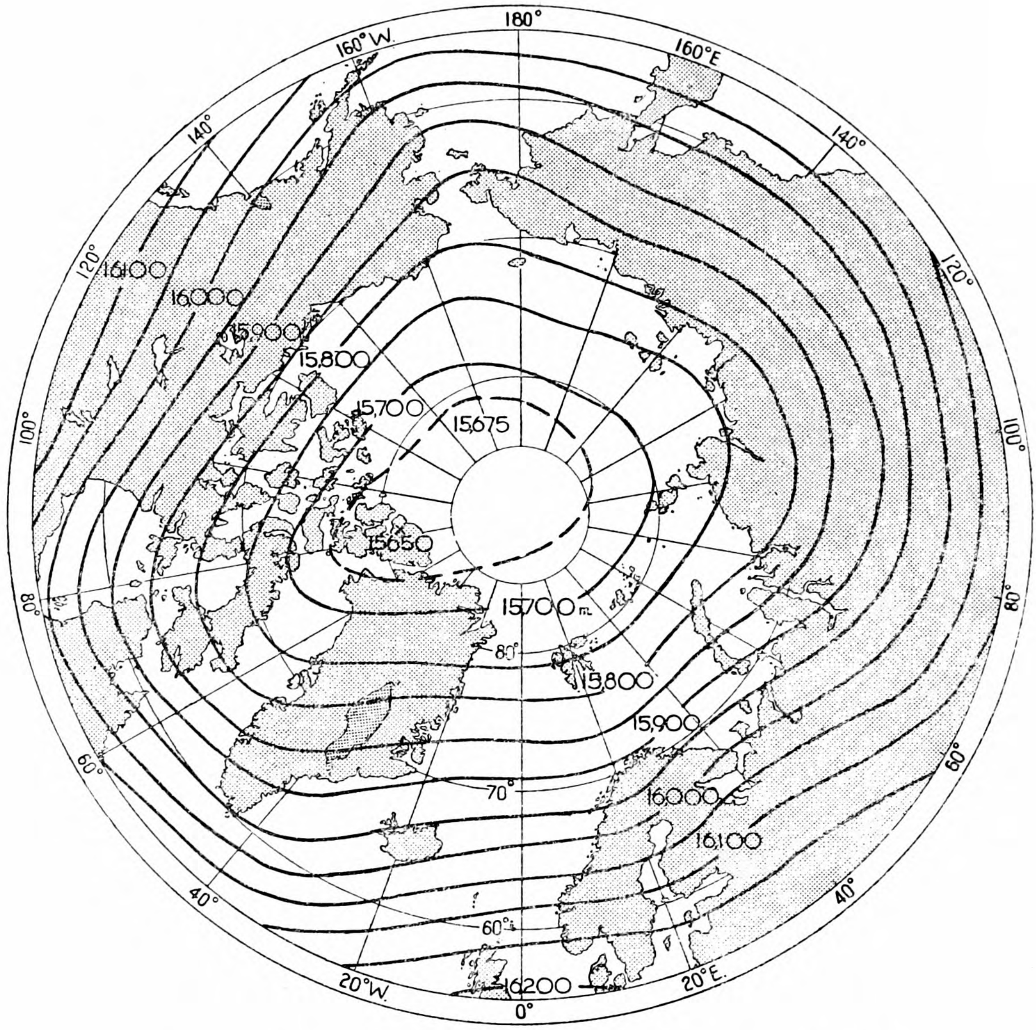


FIGURE 7—AVERAGE 100-MB. CONTOURS FOR OCTOBER 1949–53

October. This implies that the layer 200–100 millibars in the stratosphere is approximately 2·5°C. warmer in April than in October and is in good agreement with the tropopause pressure charts,[6] which show the pressure at the tropopause to be, on average, about 20 millibars higher in April than in October. In the central North Atlantic the thickness and the tropopause pressure are approximately the same in both months.

REFERENCES

1. HEASTIE, H.; Average height of the standard isobaric surfaces over the North Polar regions in January. *Met. Mag., London,* **85,** 1956, p. 368.
2. HEASTIE, H.; Average height of the standard isobaric surfaces over the North Polar regions in July. *Met. Mag., London,* **86,** 1957, p. 198.
3. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in April and October. *Met. Res. Pap., London,* No. 1020, 1956.
4. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January. *Met. Res. Pap., London,* No. 918, 1955.
5. GUTERMAN, I. G.; Radiation error of the comb radiosonde. *Met. Hydr., Leningrad,* No. 5, 1955, p. 49.
6. GOLDIE, N., MOORE, J. G., and AUSTIN, E. E.; Upper air temperature over the world. *Geophys. Mem., London,* No. 101, 1958.

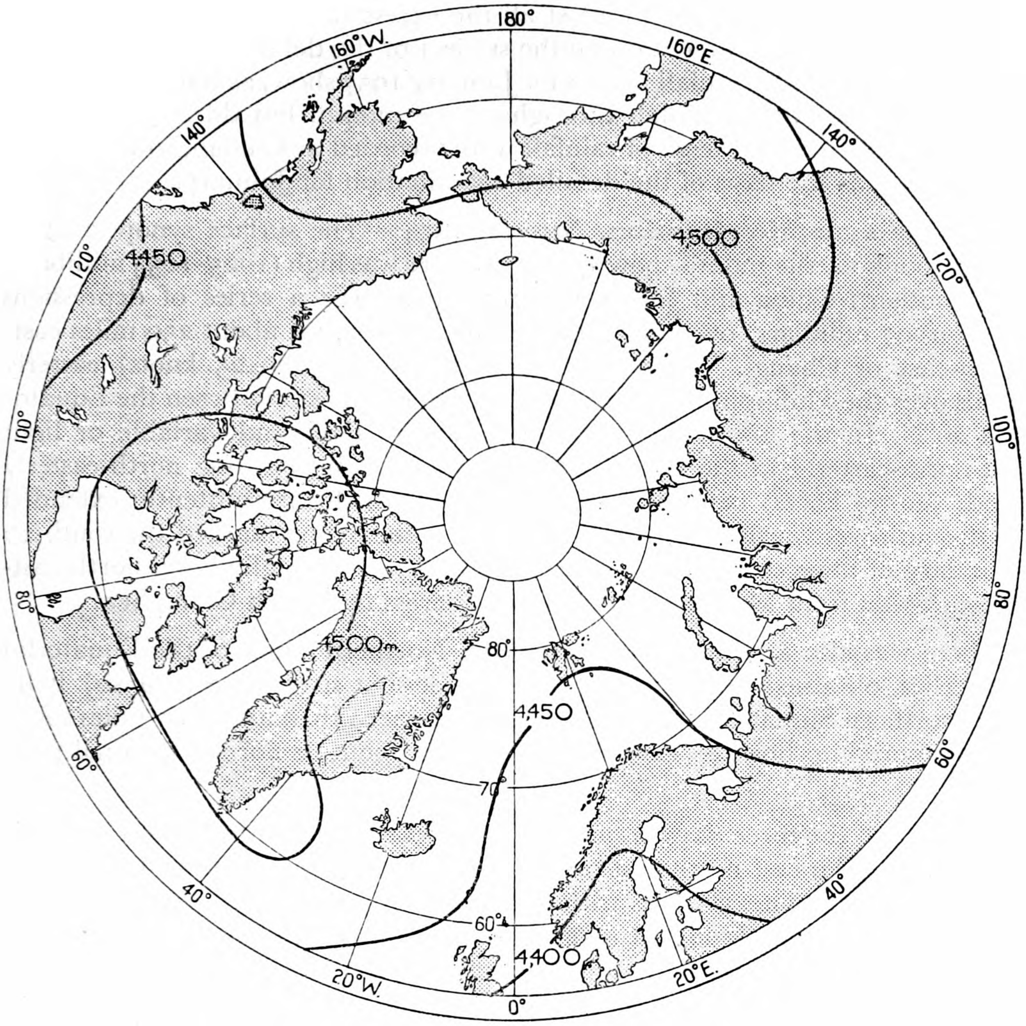


FIGURE 8—AVERAGE 200–100-MB. THICKNESS FOR OCTOBER 1949–53

COMPARISON OF MONTHS GIVING EXTREMES OF RAINFALL DURING NORTH-EAST MONSOON AT CHANGI, SINGAPORE ISLAND

By K. BRYANT

December 1954 was an extremely wet month at Changi[1], Singapore Island, the recorded rainfall of 35·91 inches being three and a half times the 54-year mean for December (10·22 inches). January 1957 on the other hand was very dry, the recorded rainfall at Changi being 1·93 inches, approximately one fifth of the 54-year January mean (10·61 inches).

Singapore is covered by the North-east Monsoon in December and January, and it was thought that examination and comparison of these two very different months in the same monsoonal flow might indicate the synoptic situations associated with such extremes of rainfall in this area.

A review of the daily rainfall figures for December 1954 shows that there were three extremely wet days namely the 9th (12·66 inches), the 13th (3·85 inches) and the 16th (6·69 inches) and that these three days accounted for two thirds of the month's rainfall (this was almost all the excess rainfall). It was considered reasonable that these three days be the subject of the detailed examination for December. The daily rainfall figures for January 1957 show, as is to be expected, only small amounts of rainfall throughout the month, but during the period 19th–28th only odd "traces" of rainfall were recorded at Changi, so this period was selected as the basis of the detailed examination for January.

Surface synoptic situation. *December* 1954.—The surface synoptic situation throughout the month showed that pressure was high (1025–1035 millibars) over southern China and Japan and that there was a series of depressions (1006–1007 millibars) over the South China Sea centred about 250 miles east-north-east of Changi. There were unusually strong (20–25 knots) easterly winds over the Philippines and the western Pacific Ocean between the Equator and 20°N. In the South China Sea winds were light and variable or light east-north-easterly in the south but there was a belt of strong north-easterly winds (20–30 knots) between 5°N. and 12°N. which intermittently extended south-south-westwards to southern Malaya. A shear line marked the southern boundary of these strong north-east winds and was generally lying north-east to south-west from Mersing to 8°N. 110°E. across the South China Sea.

There was also a convergence zone (the Northern Limit of the Equatorial Westerlies, obtained from the 1,000 and 3,000-foot streamline analysis) lying from northern Sumatra along the Straits of Malacca then about 25 miles south of Singapore into Borneo (see Figure 1): this is about its normal seasonal position.

On each of the three days in question it appears that the depression approximately 250 miles east-north-east of Changi deepened during the 12 hours prior to the moderate to heavy rains with the stronger north-easterly winds from the north of the South China Sea surging south-south-westwards. The shear line became more intense and moved southwards merging with the convergence zone at a "triple point" (described as the meeting point of two or more convergence zones) shown at A in Figure 1. The depression then filled slowly and appeared to move away north-eastwards, the shear line becoming weaker and withdrawing northwards. There was an extensive surface trough from central Australia across Java to Burma containing several small depressions.

Throughout the remainder of the month there was either a shear line or convergence zone (obtained from the 1,000 and 3,000-foot streamline analysis) within 50 miles of Singapore and minor fluctuations in these features gave nearly the normal rainfall for the remainder of the month. The mean pressure for December 1954 at Changi was 0·5–1·0 millibars below the 9-year mean for Changi at all hours, but this is within the standard deviation of 1·6 millibars.

January 1957.—During the period 19–28 January 1957 there was no shear line or convergence zone (obtained from the 1,000 and 3,000-foot streamline analysis) within 90 miles of Singapore Island on any of the days. The pressure distribution over Malaya and the South China Sea was flat with a tendency towards slight ridging from the north. A depression near the Cocos Islands on the 19th gradually deepened to become a tropical storm (990 millibars) centred at 11°S. 96°E. by the 28th (see Figure 3). The mean pressure for January 1957 at Changi was within 0·1 millibars of the 9-year Changi mean at all hours.

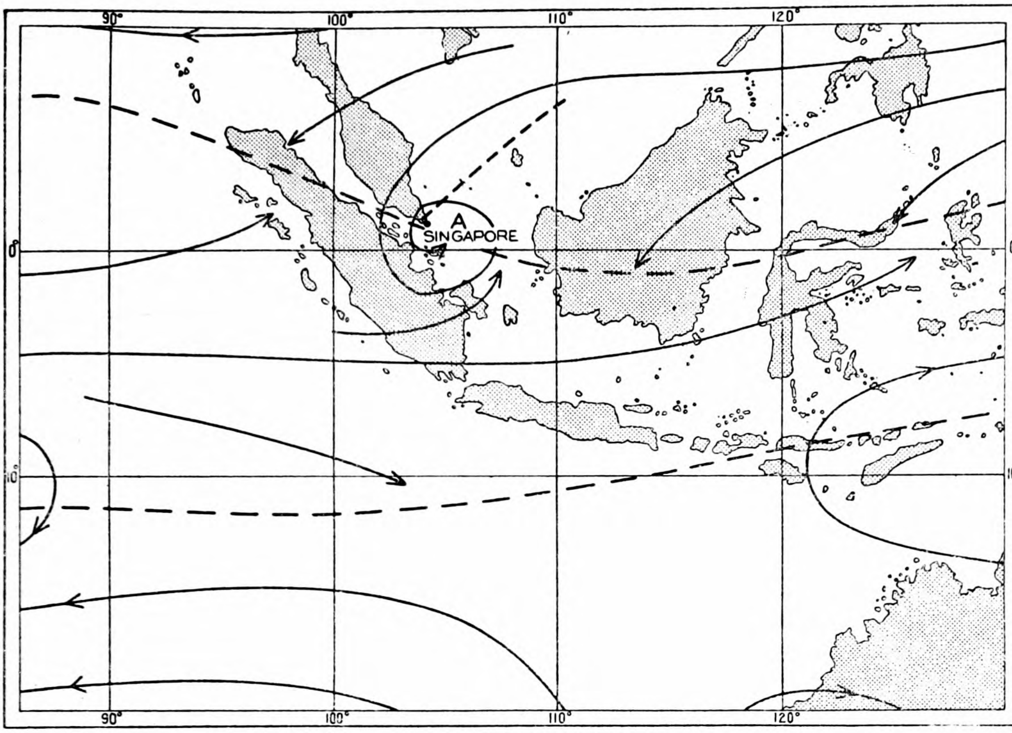


FIGURE 1—3,000-FOOT STREAMLINES FOR 1200 G.M.T., 9 DECEMBER 1954
— — — Northern and Southern Limit of the Equatorial Westerlies
- - - - - - Shear line

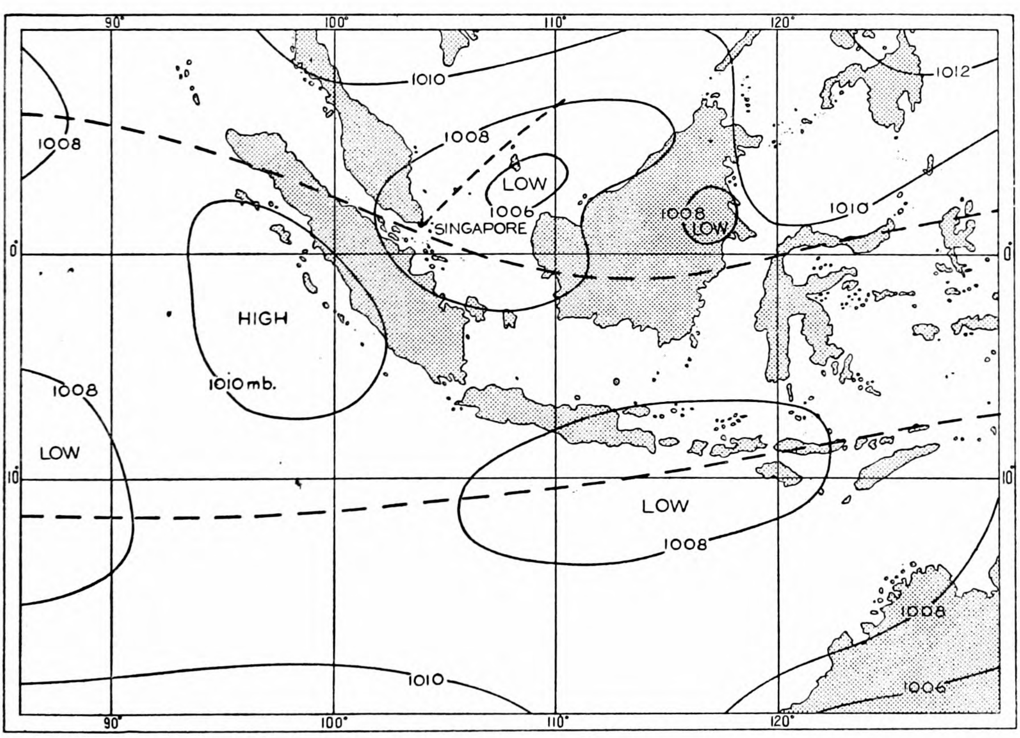


FIGURE 2—MEAN SEA LEVEL PRESSURE FOR 1200 G.M.T., 9 DECEMBER 1954
— — — Northern and Southern Limit of the Equatorial Westerlies
- - - - - - Shear line

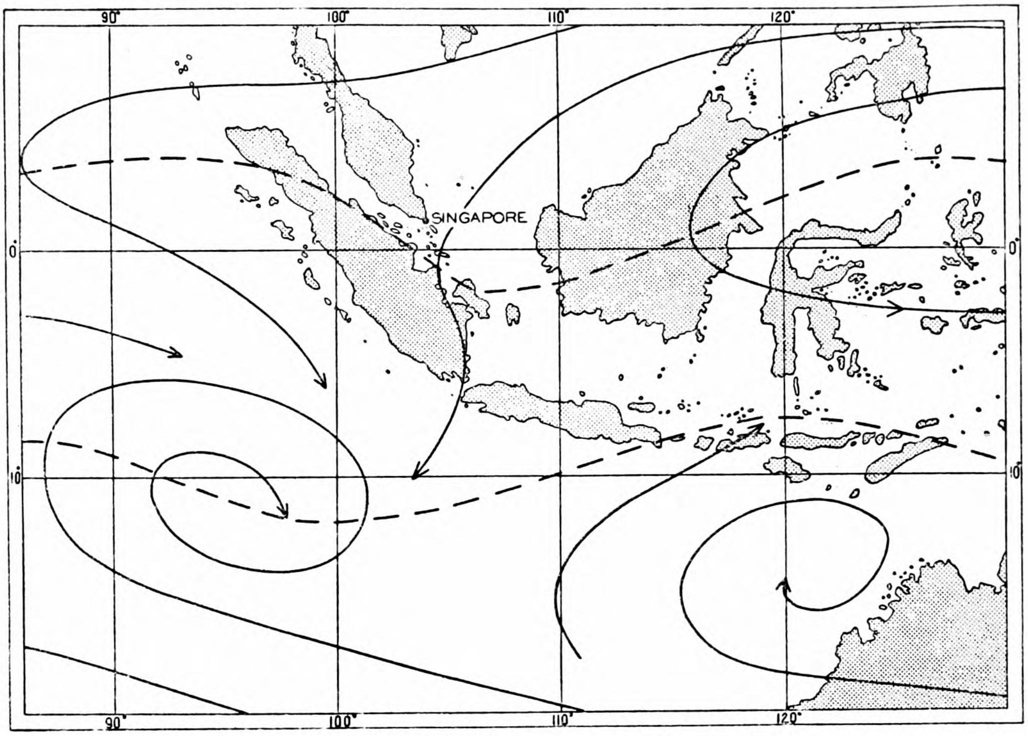


FIGURE 3—3,000-FOOT STREAMLINES FOR 0001 G.M.T., 27 JANUARY 1957
— — — Northern and Southern Limit of the Equatorial Westerlies

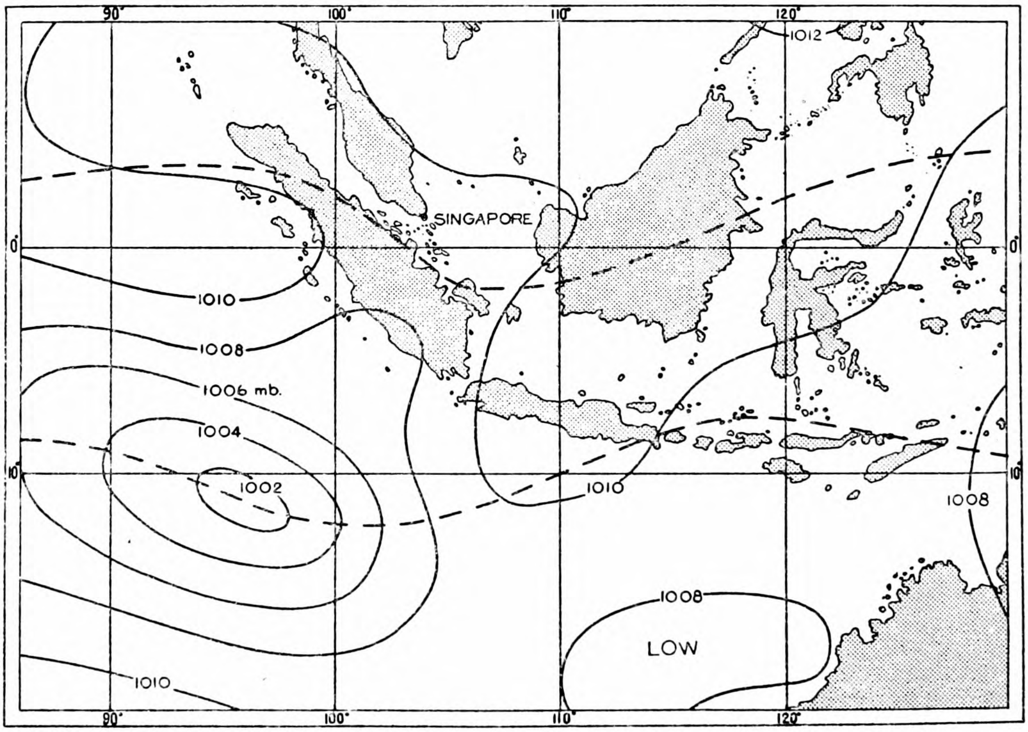


FIGURE 4—MEAN SEA LEVEL PRESSURE FOR 0001 G.M.T., 27 JANUARY 1957
— — — Northern and Southern Limit of the Equatorial Westerlies

Streamline analysis.—Streamline analysis for the three very wet days in December was treated subjectively owing to the lack of wind observations in South Malaya due to rain and low cloud and also to the fact that the radar wind-finding equipment was unserviceable. It appears that the depression over the South China Sea together with the high pressure over China and Japan strengthened the north-easterly flow at 1,000 and 3,000 feet over the northern part of the South China Sea and along the east coast of Malaya. The shear line became more marked and moved slowly southwards, as the depression gradually deepened, eventually merging with the convergence zone. The steady 10–15 knot north-easterlies or easterlies from 3,000 –10,000 feet over the South China Sea showed little change throughout the days in question, but there was convergence at all levels within 25 miles of Singapore.

In January 1957 with full wind information available it was apparent that the 10–15 knot north-easterly flow at 1,000 and 3,000 feet was sweeping straight across Singapore Island and that low level convergence was taking place about 100–150 miles south of Singapore Island. The upper level charts to 10,000 feet showed very variable north-east to east winds with indefinite shear over Malaya but they did not show consistent convergence to all levels for any position in the area.

Divergence charts.—Divergence charts ($\partial u/\partial x + \partial v/\partial y$), after Forsdyke[2], at 3,000 feet were drawn for 8 and 9 December 1954 and for 24 January 1957. The charts for 8 December showed an area of divergence over the South China Sea and a very rapid change over southern Malaya to a centre of convergence over eastern central Sumatra and the Straits of Malacca. Wind data for 9 December was sparse (as previously explained) but the charts treated subjectively gave indication of an eastward movement of this centre of convergence.

The chart for 24 January showed an extensive area of divergence over Thailand, Viet Nam and most of the South China Sea and an area of convergence near to the Cocos Islands but no marked change or centre of convergence near to Malaya.

Conclusions.—It is suggested that the essential factors in the development of the "rain area" over Singapore Island in December 1954 were:-

(*a*) The high pressure over South China and the development of the depressions in the south of the South China Sea (possibly lee depressions created by the stronger than normal easterly flow over Borneo) which helped increase the speed shear to the north-east of Malaya.

(*b*) The shape of the east coast of Malaya (with associated hill ranges) south of Trengganu, which may increase cyclonic curvature of the strong north-easterly flow towards the Equator.

(*c*) The extensive trough from Burma to Australia possibly assisting the development of depressions in the South China Sea.

(*d*) The merging of the shear line and convergence zone at the "triple point" over the east of Singapore Island. This feature is in many respects similar to the conditions which some authors[3] consider to be the start of typhoons. In this instance the position was too near the Equator for the rotary circulation of a tropical storm to develop, but the weather with heavy cloud and rain was similar to that of a typhoon. It is interesting to note that with such active convergence taking place no reports of lightning or thunder were made on

Singapore Island during the three wet days in December; this also is in line with the more stable conditions found in mature typhoons.

In January 1957 the deepening depression near the Cocos Islands was a major factor in drawing the "Northern Limit" south of its seasonal position and this led to the straight north-easterly monsoonal flow across Singapore, with little or no rain in the east and only scattered slight showers over the west of the island, but with no active convergence in the area.

Thus although the two months being considered were in the same monsoonal season, it is suggested that external pressure systems can materially affect the seasonal position of convergence zones and lead to totally different weather in the north-easterly monsoon season from year to year at Singapore.

REFERENCES

1. BOTHWELL, F.; Heavy rainfall at Changi, Singapore. *Met. Mag., London,* **84,** 1955, p.156.
2. FORSDYKE, A. G.; Weather Forecasts in Tropical Regions, *Geophys. Mem., London,* No. 82, 1949.
3. Report of Tropical Cyclone Conference, Brisbane, Australia, 1955, pp.18, 105, 106.

METEOROLOGICAL RESEARCH COMMITTEE

The meeting held on 28 November 1957 was devoted mainly to consideration of the progress reports from the three Subcommittees for the period March to August 1957. It was noted that the entire field of technique for upper air sounding by radio-sonde and radar procedure was under review. Among other items of interest were the results obtained in the application of numerical prediction (machine computation) to a small deepening depression, the promising nature of an analogue method for forecasting the general character of weather a month ahead (based on mean monthly temperature anomaly pattern in the preceeding month), and significant results on the composition of fogs obtained by optical investigations.

Instrument Subcommittee

At the meeting held on 4 December 1957, the Subcommittee reviewed the progress reported on items of instrument development for the period March to August 1957. Mention was made of the progress with a frost point hygrometer —using polarized light—for indicating values of frost point down to −100°C.; the development of an automatic frequency recorder system for use in conjunction with the standard radio-sonde; and the results of further comparisons between the height of cloud base as indicated by the modulated beam searchlight and the standard cloud searchlight.

Three papers dealing with aircraft measurements of meteorological elements were considered. It was gratifying to note from M.R.P. 1043 that flight tests by the Meteorological Research Flight of a conical-head thermometer (made according to the specification of M.R.P. 960) had shown the speed correction coefficient of the instrument to be sensibly constant with height up to 40,000 feet. The next paper, M.R.P. 1070, presented information on the accuracy of determination of the wind velocity by the use of a Marconi radio navigational system (Doppler principle) installed in a jet aircraft of the Meteorological Research Flight. This technique is likely to have important meteorological applications. The diagram, described in M.R.P. 1071, for obtaining the true air temperature from the temperature indicated by an aircraft thermometer removes the need to use more or less complicated tables for this purpose, and might form the basis of an instrument for the purpose.

ABSTRACTS

HINKEL, C. H.; Report on flight tests of a prototype conical-head aircraft thermometer. *Met. Res. Pap., London.* No. 1043, 1957.

Flight test results are given for an aircraft thermometer in the shape of a cone of 10° semi-angle. The recovery factor of the thermometer is shown to be sensibly constant. An increase in the scatter of the data at high altitudes is noted and discussed with reference to similar data for a standard flat-plate thermometer mounted on the same aircraft. It is suggested that this increased scatter is caused by inaccuracies in the measurement of altitude and airspeed and not by the thermometer.

MURGATROYD, R. J., and HELLIWELL, N. C.; The measurement of wind at altitude by airborne instruments. *Met. Res. Pap., London,* No. 1070, 1957.

A Marconi Doppler navigational equipment has been installed in a Canberra aircraft of the Meteorological Research Flight. It can be used for the instantaneous measurements of wind in flight by comparison of the vectors of groundspeed and airspeed. Tests were made to investigate the accuracy of winds obtained by this method by flying different geometrical patterns and also by direct comparison with wind measurements obtained from the Crawley radiosonde-radarwind ascents. It was concluded that, providing suitable corrections can be made for any slight misalignment of the aerial system of the navigational equipment and for errors in the airspeed found from the aircraft's airspeed indicator, the wind can be measured in flight with an accuracy of ± 5 knots. If special attention is not paid to these possible sources of error, the wind error may be 10 knots or more.

DURBIN, W. G.; A diagram for obtaining true air temperatures from indicated air temperatures for aircraft resistance thermometers. *Met. Res. Pap., London,* No. 1071, 1957.

Air temperatures measured by aircraft thermometers must be corrected for kinetic heating effects. A graphical method is presented which enables these corrections to be derived readily from readings of indicated temperature, height and airspeed at any given value of the thermometer recovery factor. Compressibility effects are taken into account, but any instrumental corrections must be made before using the diagram. It is claimed that by its use, corrections can be obtained very rapidly and conveniently with about the same accuracy as calculations using a slide rule.

Physical Subcommittee

The five papers discussed at the meeting on 12 December 1957 are typical of the range of investigations with which this Subcommittee is concerned. M.R.P. 1062 was noted as a valuable contribution to the intricate problem of estimating the spectrum of atmospheric turbulence from series of fine-scale simultaneous measurements of fluctuations of wind and temperature, with special reference to the effect of the length or duration of the series. Discussion on the further study of convection-diffusion processes below a stable layer presented in M.R.P. 1073 (a sequel to M.R.P. 1048 considered at the meeting on 9 May 1957) suggested that the formal results obtained by the theoretical treatment of idealized models indicated the need for more detailed study of the physical mechanisms operating and could therefore influence the nature and interpretation of field experiments. For several years it has been fairly generally believed that widespread (often densely packed) radar echoes, not associated with precipitation, are due to meteorological causes, for example intense localized gradients of air temperature and humidity. M.R.P. 1068, however, advances evidence that at least on many occasions these echoes ("angels") are caused by flocks of birds in migratory or similar flight. The Subcommittee accepted this conclusion as applying to the occasions cited in the paper, but did not exclude the possibility of the occurrence of angel echoes as a result of back scatter from the ground in certain atmospheric structures. It was noted that M.R.P. 1068 would be of much interest to ornithologists. Consideration of the data reported in M.R.P. 1069 on the vertical variation of the concentration of condensation nuclei, as determined by a Pollak photo-electric condensation nucleus counter installed in an aircraft of the Meteorological Research Flight, pointed to the desirability of obtaining similar information in maritime air masses well away from sources of pollution. The Subcommittee welcomed the highly interesting paper M.R.P. 1074 which describes early significant results obtained by optical methods (light-scattering and infra-red transmission) of determining the composition of fogs at Kew Observatory. It is proposed to examine whether at places less subject to pollution the contribution made by very small droplets to the opacity of thick fog is as important as at Kew.

ABSTRACTS

CHARNOCK, H. and ROBINSON, G. D.; Spectral estimates from subdivided meteorological series. *Met. Res. Pap., London*, No. 1062, 1957.

The relation $\frac{1}{2} \frac{\partial^2}{\partial s^2} \left\{ s^2 \, \Phi(s) \right\} = 1 - R_+(s)$ between $\Phi(s)$, the average fraction of the coverance contained in a subseries of s terms and $R_+(s)$, the even part of the correlogram, is simply derived. Its use and practical limitations are illustrated by the analysis of an artificial series.

The form $\Phi(s) = s/(a+s)$ appears to be a suitable approximation for certain observed series involving vertical wind near the surface, and at heights up to 2,000 feet. The corresponding spectrum is discussed; it is asymptotic to the inverse square of frequency.

SMITH, F. B.; Convection-diffusion processes below a stable layer. Part II. *Met. Res. Pap., London*, No. 1073, 1957.

M.R.P. 1073 (an extension of M.R.P. 1048) deals with the dual effect of convection and normal turbulent diffusion on the dispersal of an emittant from a ground level crosswind line source into an atmosphere of finite depth. In the mathematical analysis, the diffusion coefficient $K(z) = kz^{-\alpha}$ represents the turbulent diffusion (cf. $K = k(H-z)$ in M.R.P. 1048). Approximate solutions for general $K(z)$ are indicated.

Free convection is represented directly. Entrainment into ascending convective motions is linked to the velocity of the compensating environmental subsidence, empirically defined as $v = \lambda z$. Uniformity of concentration throughout the layer, being hastened by convection, is achieved at distances downstream dependent on k, α and λ.

HARPER, W. G.; The origin of radar "angels". *Met. Res. Pap., London,* No. 1068, 1957.

The remarkable nature and intensity of bird migration is shown to be adequate in explaining radar "angels", which, as output powers have been increased, have come to present a hazard to airfield-control and military-type radars. With a telescope mounted on the aerial of a target-tracking radar large numbers of birds have been seen when the radar was tracking angels, and it was clear that the radar was following their flight. It would seem unnecessary to invoke any other mechanism to explain these phenomena and it is suggested that there is little prospect of entirely eliminating their effects from airfield control radars.

DAY, G. J.; Some airborne observations of condensation nucleus concentration. I. Variation in the vertical. *Met. Res. Pap., London,* No. 1069, 1957. Abstract not yet available.

STEWART, K. H.; Some observations on the composition of fogs. *Met. Res. Pap., London,* No. 1074, 1957.

Observations on the number and size of water drops in a fog were made with a cascade impactor and by two specially devised optical methods, one based on the measurement of the scattering of light at small forward angles, the other on the measurement of attenuation at different wavelengths, up to 10 microns.

Approximate size distributions are given for many fogs at Kew Observatory. The most striking feature is the preponderance of very small drops; drops of less than 3 microns diameter contribute at least half the opacity in all fogs and over 90 per cent of the opacity in fogs with visibility above 100 yards.

REVIEW

Climatology. By W. G. Kendrew. $5\frac{1}{2}$ in. × $8\frac{3}{4}$ in., pp. xv + 400, *illus.* Clarendon Press. Oxford University Press, London. 2nd edition, 1957, Price: 42*s.* net.

Kendrew's "Climate" first appeared in 1930 and became a classic. After running through two editions and being reprinted, the work was largely rewritten, appearing under the new title "Climatology" in 1949. This new edition includes further revisions of parts of the text and some additions, notably paragraphs on ozone in the upper atmosphere, jet streams and the upper westerlies, zonal index, blocking anticyclones, the Antarctic and microclimates near the soil. There is also a brief appraisal of the probable role of numerical forecasting in the meteorological service. An index of place names has been added.

The efforts to keep the work up to date have been praiseworthy. It is still one of the best and most readable descriptive works for students, laymen and inquirers. A real merit is the quotation of graphic descriptions, sometimes by travellers, of characteristic weather experiences in different parts of the world—a West Indian hurricane, a cold front in the Sahara, a hailstorm in Tibet (and many others). The photographic illustrations are well-chosen and beautiful.

The book begins with a nice summary of the fundamentals of the radiation and heat budget, which represent the energy supply of the atmospheric circulation. From that point on, however, the development is more disappointing for anyone who wants to understand the broad essentials of atmospheric movement which is the mechanics of climate. What actually follows is a very good text book on regional and descriptive climatology with some useful reference data, but the upper atmosphere is introduced (as explained in the preface) rather incidentally, for its relevance to air navigation and its "repercussions" on surface weather.

The new diagrams dealing with the jet stream, blocking anticyclones etc. are good, but the text tries to say too much in too short a space, sometimes producing a distorted view.

A number of the old diagrams (e.g. many pressure maps and figure 10 showing surface temperatures around Oxford on a radiation night) are marred by an oddly erratic isopleth interval. In the case of the pressure maps, this defect is more apparent than real, being the result of the dubious (but doubtless economically dictated) expedient of renumbering to the nearest whole millibar isobars which had been drawn to 1/10 inch for an earlier edition. These difficulties will be with us until the metrical system is fully and finally adopted.

The reader is made aware the "climate is always changing" but the discussion in terms of cycles is out of date. Suprisingly, in view of the admission of climatic change, the book treats it as needless to specify even approximately the datum periods of the tables and maps. This criticism, though logical, may be a little unfair, since we still await the day when specification of a consistent datum period is regarded as an essential standard practice in climatology. Yet, the distributions of different phenomena described may be inexplicable in physical terms unless they are all related to the same epoch with its characterstic patterns and intensity of atmospheric and ocean circulation.

In the Arctic and at the fringe of the arid zone in the tropics climatic figures are liable to be meaningless, unless the years in question are specified. This also applies to the table of frequencies of tropical cyclones on p.131, since the West Indian hurricanes have stepped up their frequency from 6 a year in the first decades of the century to a yearly average of 9 since 1933.

The short, carefully selected bibliography should surely have included a longer list of the excellent climatological atlases of different countries coming out in recent years—e.g. for China, Rumania and most of the German Länder. This represents an important current activity in climatology and more countries will be covered as time goes on. In the reviewer's opinion, Brooks's "The English climate" and "Climate in everyday life" should have been mentioned too.

The book is arranged in six parts: (1) insolation and temperature; (2) atmospheric pressure and winds, dealing with distributions and such implications as physiological effects of reduction of pressure with height and a world map of sailing ships tracks; (3) vapour in the atmosphere and its condensation, rain, cloud, sunshine and visibility, touching also upon atmospheric pollution; (4) mountain and plateau climates; (5) weather of the westerlies, anticyclones, depressions, frontal weather and spells; (6) a few specific types of climate. It can be recommended as one of the most useful, standard works in the field.

H. H. LAMB

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. S. P. Peters, C.B.E.*, Deputy Chief Scientific Officer, retired on 1 July 1958. He joined the Office as a Junior Professional Assistant in July 1923 and was posted to Cranwell. Early in 1925 he was transferred to the Airships Division at Headquarters and after some three months he was posted to Cardington. In 1932 he was transferred to Worthy Down and for a period in 1935 and 1936 he was in charge of the Meteorological Office School at South Kensington. From 1937 to 1946 he served successively at Foynes, Gloucester and Prestwick. In 1946 he was transferred to Headquarters to be Head of the Coastal Command Branch. From 1948 until his retirement he has been located at Dunstable, first in the Forecast Division and since 1953 as Deputy Director Forecasting and Central Services respectively. Mr. Peters served in the Meteorological Section of the Royal Engineers from 1918 to 1919. He was appointed a Commander of the Order of the British Empire in the Birthday Honours List of 1956. Mr. Peters has accepted a temporary appointment in the Meteorological Office.

Mr. J. Wadsworth, Senior Scientific Officer, retired on 18 July 1958. After service in the Meteorological Section of the Royal Engineers from 1917 to 1919 he joined the Office as a Junior Professional Assistant in the Forecast Division. In 1922 he was transferred to Malta and on his return in 1925 served in the Climatology and Forecast Divisions at Headquarters. In 1927 he was posted to the Middle East and after a period of one year he was transferred to Larkhill. In 1930 he left the Office to take up the post of Director of Apia Observatory, Western Samoa where he remained for eight years. He rejoined the Office in 1938 and has since served at Headquarters in the Climatology and Forecast Divisions and from 1948 until his retirement in the Special Investigations Division.

Miss D. G. Lee, Senior Experimental Officer, retired on 31 July 1958. She joined the Office in August 1918 as a Clerk Assistant in the Forecast Division where she remained until 1937 when she was transferred to the Climatology Division. From 1940 until her retirement she has served in the Administrative Division.

WEATHER OF JUNE 1958

Northern Hemisphere

As in May 1958, the depression track across the North Atlantic was unusually far south for the time of year. Mean pressures for the month were below normal over north-east Canada, much of the North Atlantic and Europe, excluding Scandinavia, and coastal regions of the Mediterranean. The greatest anomalies, of −5 millibars, occurred a little west of Ireland where a small area of low pressure was present on the mean chart. The polar anticyclone was centred near its normal position and was more extensive than usual, with a strong ridge over Siberia and another north of the British Isles.

The North Pacific high was a smaller feature than usual and the centre was displaced northwards. The most important departure from normal in the Pacific sector was the presence of a well marked Aleutian low, an unusual feature for June. Both the low pressure areas of Asia were deeper than normal and a belt of small negative anomalies extended from the eastern Mediterranean to central China.

Mean temperatures for the month were close to the average everywhere in Europe, there being slight negative anomalies in central and eastern Europe and slight positive ones elsewhere. Negative temperature anomalies were reported in the area east of the Rockies between 40°N. and 60° N., associated with a stronger northerly advection than usual there. Positive anomalies occurred in Alaska as a result of warm air advection from the south around the Aleutian low; further positive anomalies of +3°C. occurred west of the Rockies.

In central and western Europe rainfall totals were above normal; more than twice the usual amount was recorded at a number of stations in the British Isles and France. Precipitation totals were up to twice the normal over north-east Asia, but were near or below normal in other parts of that continent. The rainfall pattern over North America was very irregular.

WEATHER OF JULY 1958

Great Britain and Northern Ireland

After four days of cyclonic weather with pressure low to the south of the British Isles, the situation became weakly anticyclonic until the 13th of the month when a depression moved north-east across the country accompanied by widespread rain. Subsequently pressure distribution over the country was somewhat featureless though weakly cyclonic for some days, but from the 21st until the end of the month a sequence of depressions brought changeable weather to most of the country.

From the 1st–3rd a shallow depression was centred over the western English Channel and thundery rain belts moved slowly northwards across England and Wales, although over most of Scotland weather was sunny and warm; on the night of the 1st/2nd 1·3 inches and 1·7 inches of rain fell in 12 hours at Cardington and Shawbury respectively; in Scotland on the 3rd the exceptional temperature of 80°F. was recorded at Benbecula and on the 4th Renfrew reported 82°F. From the 6th–8th a ridge of high pressure moved across the country and weather was generally fine and warm during the day, but fog was fairly widespread at night; extensive fog over the Irish Sea and English Channel kept the adjacent coastal temperatures about 20°F. lower than at places further inland where, on the 8th, 80°F. was exceeded in many eastern districts and 83°F. was reached at places as far apart as Cardington, Finningley and Dyce. Although a weak cold front gave a little rain as it crossed the country on the 9th, the mainly dry weather continued for several days until rain, associated with a deep depression on the Atlantic, reached Cornwall and north-west England during the evening of the 11th, subsequently spreading to most areas except the extreme north of Scotland. The depression moved north-east across the Irish Sea during the early hours of the 13th reaching the northern North Sea by the evening and was accompanied by heavy falls of rain and strong winds. Except in northern Scotland and south-east England, most districts from 11th to 13th had a daily fall of ½ inch of rain or more and daily falls exceeded 1 inch in Northern Ireland and west Wales. Wind rose in gusts to 50 knots and more along the south coast.

From the 14th to 19th wind was rather light and variable over the British Isles and weather showery, with good sunny periods, and a steadily rising temperature; thunderstorms were reported from many places particularly from eastern districts on the 16th and 20th.

A succession of depressions approached the British Isles from the west and south-west during the last ten days of the month bringing generally unsettled weather. The first of these moved over the country on the 21st and the next skirted the south coast two days later. Another depression moved across Ireland and southern Scotland to the North Sea on the 25th and 26th, while the fourth and final depression of the series moved north-eastward from Southern Ireland to the northern North Sea about two days later. During this time there was heavy rain over most western districts, and in southern and eastern Scotland rainfall was heavy and prolonged and in places falls exceeded 2 inches in 24 hours. Flooding was reported from Glasgow and Perth. In parts of Scotland more than half the average rainfall for July was recorded in 12 hours on the 28th.

The month ended with three days of showery weather, heavy thunderstorms occurred locally particularly in southern Scotland; although there were good sunny periods. At Eskdalemuir 1·3 inches of rain fell in 12 hours on the 30th.

Rainfall was 112 per cent of the 1921–50 average in England and Wales, 126 per cent in Scotland and 121 per cent in Northern Ireland, where it was the wettest July since 1947. The combined rainfall for May, June and July over England and Wales was the highest recorded since 1924. Less than half the July average was recorded in the Hebrides and the extreme north-west of the Scottish mainland. Twice the average was exceeded in parts of Lincolnshire, Morayshire, around Edinburgh and in East Lothian. Thunderstorms occurred over the British Isles on the 1st–5th and 20th–23rd inclusive and on seven other days. July was a cool month generally with average temperatures generally near or a little below the normal. At Aberdeen two temperature records were broken; air temperature reached 83°F. on the 8th and fell to 35°F. on the 25th which were respectively the highest and lowest values recorded there since records began in 1925. Sunshine amounts were about normal at most inland stations but coastal stations showed a deficit.

The heavy rains during the month, besides causing severe floods in eastern districts, continued to interfere seriously with farm work. Crops were badly beaten down locally and the harvest in consequence will almost certainly be retarded and yields possibly low. Potato blight continued to be spread rapidly in the worst year of the century for this disease. The rain also reduced the promised bumper strawberry crop and cherries were affected to a lesser extent. The pea crop was reduced but most summer vegetables were in plentiful supply and prospects for winter vegetables were considered to be good.

WEATHER OF AUGUST 1958

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	35	−0·1	123	+6	74
Scotland	77	34	+0·3	112	+2	89
Northern Ireland ...	70	39	+0·1	123	+3	80

*1916–1950 †1921–1950

RAINFALL OF AUGUST 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	3·92	170	*Carm.*	Pontcrynfe	3·52	72
Kent	Dover	3·11	139	*Pemb.*	Maenclochog, Ddolwen B.	6·67	132
„	Edenbridge, Falconhurst	3·66	125	*Radnor*	Llandrindod Wells	2·97	94
Sussex	Compton, Compton Ho.	5·51	179	*Mont.*	Lake Vyrnwy	3·66	72
„	Worthing, Beach Ho. Pk.	4·80	211	*Mer.*	Blaenau Festiniog	8·01	75
Hants.	St. Catherine's L'thouse	4·39	205	„	Aberdovey	4·12	98
„	Southampton, East Pk.	4·37	168	*Carn.*	Llandudno	1·80	71
„	South Farnborough	4·25	188	*Angl.*	Llanerchymedd	2·65	77
Herts.	Harpenden, Rothamsted	3·35	146	*I. Man*	Douglas, Borough Cem.	5·41	139
Bucks.	Slough, Upton	3·61	165	*Wigtown*	Newton Stewart	4·95	122
Oxford	Oxford, Radcliffe	2·65	117	*Dumf.*	Dumfries, Crichton R.I.	3·75	94
N'hants.	Wellingboro' Swanspool	2·67	116	„	Eskdalemuir Obsy.	6·05	110
Essex	Southend W.W.	3·71	190	*Roxb.*	Crailing	2·19	67
Suffolk	Ipswich, Belstead Hall	3·54	171	*Peebles*	Stobo Castle	3·68	104
„	Lowestoft Sec. School	2·32	108	*Berwick*	Marchmont House	4·10	125
„	Bury St. Ed., Westley H.	2·63	107	*E. Loth.*	N. Berwick	2·37	77
Norfolk	Sandringham Ho. Gdns.	2·39	99	*Midl'n.*	Edinburgh, Blackf'd H.	3·11	99
Dorset	Creech Grange	3·83	132	*Lanark*	Hamilton W.W., T'nhill	5·81	159
„	Beaminster, East St.	2·76	88	*Ayr*	Prestwick	4·00	131
Devon	Teignmouth, Den Gdns.	2·95	120	„	Glen Afton, Ayr San.	6·33	148
„	Ilfracombe	4·54	144	*Renfrew*	Greenock, Prospect Hill	5·07	110
„	Princetown	11·49	171	*Bute*	Rothesay, Ardencraig	...	...
Cornwall	Bude	6·65	236	*Argyll*	Morven, Drimnin	6·39	127
„	Penzance	5·78	196	„	Ardrishaig, Canal Office	7·79	142
„	St. Austell	7·58	211	„	Inveraray Castle	8·50	122
„	Scilly, St. Mary	4·61	183	„	Islay, Eallabus	4·41	104
Somerset	Bath	2·41	85	„	Tiree	3·12	86
„	Taunton	2·22	96	*Kinross*	Lock Leven Sluice	3·46	95
Glos.	Cirencester	2·81	91	*Fife*	Leuchars Airfield	2·59	97
Salop	Church Stretton	4·96	155	*Perth*	Loch Dhu	7·36	119
„	Shrewsbury, Monkmore	3·36	134	„	Crieff, Strathearn Hyd.	3·84	98
Worcs.	Worcester, Red Hill	2·47	112	„	Pitlochry, Fincastle	5·37	160
Warwick	Birmingham, Edgbaston	2·72	99	*Angus*	Montrose Hospital	4·76	170
Leics.	Thornton Reservoir	2·80	107	*Aberd.*	Braemar	3·20	104
Lincs.	Cranwell Airfield	2·11	97	„	Dyce, Craibstone	2·75	92
„	Skegness, Marine Gdns.	1·75	82	„	New Deer School House	3·70	120
Notts.	Mansfield, Carr Bank	2·56	102	*Moray*	Gordon Castle	4·26	137
Derby	Buxton, Terrace Slopes	3·37	81	*Inverness*	Loch Ness, Garthbeg	4·08	120
Ches.	Bidston Observatory	4·47	143	„	Fort William	5·39	90
„	Manchester, Ringway	5·09	160	„	Skye, Duntulm	3·62	82
Lancs.	Stonyhurst College	5·02	102	„	Benbecula	4·33	114
„	Squires Gate	3·98	114	R. & C.	Fearn, Geanies	3·33	134
Yorks.	Wakefield, Clarence Pk.	2·58	98	„	Inverbroom, Glackour	5·25	119
„	Hull, Pearson Park	2·20	85	„	Loch Duich, Ratagan	4·92	79
„	Felixkirk, Mt. St. John	3·88	128	„	Achnashellach	4·17	64
„	York Museum	2·33	91	*Suth.*	Stornoway	3·26	97
„	Scarborough	2·40	92	*Caith.*	Lairg, Crask	...	...
„	Middlesbrough	3·02	110	„	Wick Airfield	3·19	121
„	Baldersdale, Hury Res.	4·18	124	*Shetland*	Lerwick Observatory	3·45	125
Nor'l'd	Newcastle, Leazes Pk.	2·54	82	*Ferm.*	Belleek	5·14	108
„	Bellingham, High Green	3·32	97	*Armagh*	Armagh Observatory	3·89	115
„	Lilburn Tower Gdns.	3·29	104	*Down*	Seaforde	5·57	151
Cumb.	Geltsdale	4·26	100	*Antrim*	Aldergrove Airfield	2·79	85
„	Keswick, High Hill	6·73	133	„	Ballymena, Harryville	4·45	109
„	Ravenglass, The Grove	3·89	96	*L'derry*	Garvagh, Moneydig	4·96	124
Mon.	A'gavenney, Plâs Derwen	3·09	92	„	Londonderry, Creggan	4·53	105
Glam.	Cardiff, Penylan	5·69	147	*Tyrone*	Omagh, Edenfel	4·58	115

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,037, NOVEMBER 1958

A DECADE OF RESEARCH

By R. C. SUTCLIFFE, F.R.S., Director of Research, Meteorological Office

The history of any organization such as the Meteorological Office is punctuated by what are called "reorganizations" demanded by changing commitments, by changing views on policy within the organization, and by the changing climate of public policy affecting organizations of a similar kind. Not in all cases does a reorganization, dear though it may be to the authorities who conceive and impose it, seem to those who play a humbler role to be more than a re-deal of the same cards, the game to proceed as before, but in 1948 there was a change of quite major consequence to my present topic in that of three deputy directorates then created in the Office, one was entitled Research.

It would be an interesting exercise to trace the history of research work through the lifetime, more than a century, of our Office, but not an easy one, for the word research was not fashionable in earlier days as it is now and organization tables would give little indication. Certainly from the beginning of the present century when Napier Shaw, as the new Director, began to collect a team of scientists around him, work of high scientific quality has always been in hand. Later, under Sir George Simpson, himself one of the most fertile research scientists in our record, the emphasis was by pressure of events so much on an expanding forecasting service for aviation that research might seem to have been side-tracked, but we must not overlook the steady stream of reports, memoirs and learned society papers from members of the staff, many of whom gained enviable research records and in a few cases scientific eminence of the first rank, largely by work before the Second World War. It was no stagnation period in the Office, as the names Brooks, Brunt, Douglas, Durst, Gold, Goldie, Scrase, Simpson, Stagg, Sutton and Whipple will remind us.

But the pressure of expansion did have an effect which in the long run became very serious scientifically. Instead of the newly recruited staff being assigned to some branch of work calling for organizing skill and research ability, they became a new kind of meteorologist, the general practitioner in forecasting, busy with routine and special daily inquiries, often on roster duties round the clock, with little or no opportunity for the continuous and undisturbed thinking which research has always demanded. So it was that a generation of scientific staff potentially as able as their predecessors gave rise to few names of scientific eminence and, what was much worse, there was no provision for attacking the host of problems which synoptic forecasting was throwing up. The position was, in the view of the forecasters themselves, rapidly becoming intolerable.

No one was more aware of the urgent need for research than Sir Nelson Johnson who, shortly after taking over the directorship, gained the objective which those who knew him were aware was very near to his heart. He put research unequivocally on the map when, for the first time, in 1939, the word appeared in the designation of a senior post. Post-war reorganizations, again under Johnson in 1948 and later under our present Director-General, have all tended towards its greater prominence until today we have a Director of Research side by side with a Director of Services and it may fairly be said that the dual function of the Office, to serve the community and to advance the science, is as fully recognized as it can ever be.

In this trend over many years to a position which is best regarded as the end of a transition period we have been carried along as much by the "changing climate of public policy" as by the convictions of our directors. Scientific research in this mid-twentieth century is widely respected for a glory of intellectual achievement comparing creditably with the creative arts or the scholarship of letters, while those who are uncertain of these values and are happier with practical economics see it as a worthwhile investment. The fight for greater research recognition in our own Office has been carried on as a skirmish in a sweeping tide of successful battle. By looking back over the last ten years since the creation of a deputy directorate of research, a reasonable period over which to review a research enterprise, I wish to show evidence of worthwhile achievement, justification for the policy, proof that in our corner of science we have exploited our opportunities with credit.

The point should not be difficult to make, indeed the task might be thought superfluous, for during the decade the published output of new work is contained in some hundreds of *Meteorological Research Papers*, 22 *Geophysical Memoirs*, 33 *Professional Notes* and 20 *Meteorological Reports* as well as a very large number of papers in the scientific journals. The difficulty lies in summarizing such a wealth of material, avoiding an invidious selection of names where so many have taken part and avoiding also a disjointed cataloguing of contributions. I shall therefore be content to pick out what seem to me to be the highlights of our achievement in the different branches of the science, mentioning in the narrative the names only of those who have been undisputed leaders and originators. Where I begin is arbitrary and perhaps the choice of the oldest branch of meteorology, climatology, is as appropriate as any.

In world climatology the highlight is obvious and bright: the monumental work on upper winds and temperatures over the world. The task was set, with Dr. Goldie's effective backing, so to collect and digest all accessible aerological data as to present the outline of a world climatology of the upper atmosphere. With the late C. E. P. Brooks as the leading author, the first edition of *Upper winds over the world* appeared in 1950[1] giving mean monthly contours and winds (including wind variability) at levels up to 130 millibars for the four seasons. The publication has been in demand ever since, for the aviation interest in upper winds has grown with every extension of air routes and every increase in cruising height. It is now out of print but a new and much improved edition, extending the analysis to greater heights, is well on the way as the outcome of a continuous effort of critical compilation over the intervening years. In addition, temperature is treated in a *Geophysical Memoir* recently published[2]. This incorporates previously published world charts of the average temperature and pressure of the tropopause for the four mid-season months[3]. With J. K. Bannon as the leading contributor there have been many supplementary studies on the upper air including turbulence in clear air at higher altitudes[4], an unexpected trouble for fast high-flying aircraft not yet satisfactorily explained. The world interest is further illustrated by A. G. Forsdyke's surveys of tropical meteorology[5] and H. H. Lamb's studies of polar regions[6], two fields still rich in problems.

British climatology by contrast has been studied for so many years and with such copious data that strikingly new results are unlikely to appear very often. A considerable effort in applied climatology, in relating rainfall and evaporation to hydrology and in analysing agricultural problems has however been fully productive. A specialist from outside the Office remarked on one occasion that if the work of the agricultural branch of the Office had led to nothing more than the arrangements for warnings of conditions conducive to outbreaks of potato blight, the branch would have justified its existence for a generation. Applications of modern theories to the calculation of irrigation needs in different parts of the country have also aroused much interest, while the continued studies of *British Rainfall*, published mainly in the annual volume with that title, have made J. Glasspoole's name a household word amongst water engineers, gracefully recognized by his election as Honorary Member of their Institution. And here also it is most suitable to mention the important textbook by Brooks and Carruthers[7], *Handbook of statistical methods in meteorology*, incorporating amongst other things material which the senior author had accumulated over many years.

In the Marine Division of the Office many contributions have been made both to pure and applied science, and more than twenty significant papers have been published although, since the work has not I think led to major discoveries, I shall shirk the task of picking out names and references. The regular production of the *Marine Observer* under the able editorship of Commander C. E. N. Frankcom has provided a continuous stream of scientific guidance much valued by mariners everywhere and the publication of meteorological and current charts of the oceans is a national service of major importance.

The transition from climatology to synoptic meteorology and forecasting is a natural one and the decade is perhaps most noteworthy in that "forecasting research" was in 1948 at last accepted as a field to be deliberately attacked, so recognizing the urgent need to which I made earlier reference. The new Forecasting Research division had a clear field and with the post-war elaboration of radiosonde and radar wind stations three-dimensional analysis naturally received the major attention. A paper of 1947[8] had presented for the first time a dynamical basis for the discussion of the forecasting problem in terms of divergence and vorticity as inferred from contour and thickness charts. A further paper of 1950[9] discussed the theory and use of thickness charts more fully and as the result of many papers, basic training and routine application, it may justifiably be said that dynamical thinking has permeated the minds of forecasters everywhere. At the same time the basic ideas were found to be remarkably well adapted to the concept of prediction by numerical calculation, a dream of Richardson in 1926 which had become a realistic prospect in America with the invention of the electronic calculating machine. Sawyer and Bushby[10], quickly recognizing the potentialities, presented in 1953 a set of differential equations suited to numerical predictions for a baroclinic atmosphere, using a two-parameter model, and in this way began a programme of research which will be pursued for years to come. By this initiative the Meteorological Office is second only to the United States in its contributions to this revolutionary approach to forecasting. Already one can foresee teleprinted data from observing stations being fed into a calculating machine to be objectively analysed, stored and processed to produce forecast charts taking into account, with some verisimilitude, the baroclinic field, non-geostrophic motion, effects of friction, topography and non-adiabatic processes. The outcome in terms of forecasting guidance will surely be valuable, how precise and accurate may ultimately depend more on the unpredictability inherent in the unstable atmosphere than on the ingenuity of the research workers or the versatility of machines.

At the same time research on more conventional synoptic lines has not been neglected and from many I can mention only three contributions. The first is the study of the structure of fronts and jet streams[11] under Sawyer's leadership revealing, with the supplementary aid of many special frontal sorties performed by the Meteorological Research Flight, not only the instantaneous structure of the jet-stream—frontal complex but also the striking effects of upward motion with the cloud-laden air following a slope steeper than that of the frontal surfaces and separating from them, within the warmer air mass, above heights of about 700 millibars; and revealing also tongues of extreme dryness, the effects of subsidence, extending downwards from the upper troposphere along or near the frontal surfaces themselves. (By frontal surfaces I here imply the two surfaces of first order discontinuity in temperature bounding the sloping zone of hyperbaroclinity, which analysis has established as the most common frontal structure.) The analyses led Sawyer[12] to develop a dynamical theory of frontogenesis which goes a considerable way towards explaining what is observed, while escaping from the limitations imposed by the unsatisfactory classical model of simple upsliding of one air mass over another.

Next I select, also from Sawyer's papers, the series of contributions,[13] empirical and statistical, on the rainfall from various types of depression and finally some practical studies of the forecasting of fog by Saunders[14] as an illustration of what can still be done by the keen operational forecaster—for Saunders was not in a research post and yet he found time to pursue an independent line of research and produce a method of forecasting whose merit is widely recognized.

A special paragraph must be accorded to work by C. S. Durst[15] on the statistical handling of vector winds leading to studies of the forecasting of upper winds by purely statistical methods. This entirely original approach has many possible applications especially when conventional methods of forecasting are difficult to apply.

Forecasting for an extended period of time beyond the 36 hours, more or less, which is regularly attempted has received much attention and lengthy research experiments have led to the introduction of a technique of hemisphere chart analysis and prediction, which at Dunstable is proving useful in the preparation of outlooks for two or three days ahead. In this connection Sumner's[16] studies of blocking have been valuable, but otherwise it can hardly be said that specific new discoveries have been made although the behaviour of the atmosphere on the hemisphere scale has been much described. There is more originality in a recent attack by Craddock[17] on the truly long-range problem of prediction for a month ahead. Started as a study of variability in weather over periods of a few weeks with temperature over a large part of the hemisphere as the parameter chosen for first attention, the work has led to a method of obtaining normal charts by harmonic analysis, to power-spectrum analysis demonstrating the large contribution to variance provided by fluctuations of time-scale some 30–50 days, to the demonstration of the large and persistent features, geographically speaking, of temperature anomalies, and so to the trial of prediction primarily on the basis of analogues (assuming that the behaviour in the forthcoming month would be similar to that in previous years which had showed similar anomaly patterns). Tests have shown success certainly better than chance but whether so much better as to render the forecasts of significant value to anyone remains to be established. But clearly there has been some progress and there is work for a long time ahead in studying, explaining, and perhaps predicting the departures from average expectations which go to make our summers sunny or depressingly wet, our winters mild or arctic as the case may be. One feels that a new break-through has appeared in an old and tantalizingly difficult problem.

Before passing to what, for want of a better term, we call physical meteorology (as though all meteorology were not physics in its wider sense), reference must be made to important studies of wave-motion, on the scale of a few miles, set up in the free atmosphere up to great heights, by orography. The basic theory was developed outside the Office by R. S. Scorer but the studies, particularly by Corby,[18] have done much to advance the subject and to show how synoptic forecasters may apply the theory in daily practice when the demand arises. Ten years ago the phenomena were hardly known and what was known was a theoretical mystery.

We come now to our most valuable tool, other than sondes, for the exploration of the troposphere and lower stratosphere, the Meteorological Research Flight. With three, formerly four, aircraft at the disposal of the Office, a large number of basic data have been collected. The most remarkable discovery of all, perhaps, is the dryness of the lower stratospheric air as established by measurements with the Dobson-Brewer frost-point hygrometer.[19] Recent measurements from the tropics to the arctic indicate little variability about a frost-point of −84°C. and although the result was quite unexpected there seems no reason seriously to doubt the observations. The implications of these results, coupled with other evidence, for example on atmospheric ozone which the Flight has also measured, are far-reaching in the theory of the general circulation of the stratosphere, by no means only an academic issue in these days of nuclear weapons trials.

Outstanding also has been the large amount of work in measuring and counting nuclei of condensation and of freezing, droplets and ice crystals in clouds and drops of precipitation. In this field of basic observing the ingenuity lies in designing and suitably exposing the instruments and a paper by Murgatroyd[20] gives an impression of what has been achieved in this way. On more theoretical aspects of droplets in the atmosphere, A. C. Best[21] contributed a long series of research papers, a few of which are included in the bibliography. In this context the special research with centimetric radar at East Hill, under R. F. Jones[22] and later Harper, is suitably introduced. A great deal has been learnt from the radar echoes from precipitation, about the bright-band due to the melting of falling snow, about the initiation of precipitation by freezing and by coalescence, about the development, travel and decay of rain areas, encouraging the use of weather radar for short-period forecasting and establishing a useful forecasting rule relating travel with wind at 700 millibars, about the association of thunderstorm echoes with severe turbulence, so justifying the use of airborne radar for the avoidance of severe flying conditions. An unexpected outcome was Harper's[23] convincing evidence that many echoes from clear skies, so-called angels, were reflections from flocks of birds, and his work has caused much excitement amongst ornithologists who have seized upon the tool for the study of migration and roosting habits. The provision of a new eye for the bird-watcher is not expected of a meteorologist but his services will still be demanded in relating flight habits to the accompanying conditions of wind and weather.

A service for which the synoptic meteorologists have special reason to be grateful to the M.R.F. has already been mentioned: the provision of data from many flights through fronts and clouds combining visual observations with readings of temperature and humidity on quick-response instruments at intervals of a minute or less. Other flights with recording equipment have provided unique data on the fine structure of the atmosphere.

What of rain-making, the exciting and much-publicized prospect for cloud physicists? In mountainous regions of other countries some success, small but probably real and even economically valuable, has been claimed but similar conditions are not found in these Islands and very careful studies of available knowledge yielded no grounds for optimism. Nevertheless trials of seeding with ground generators of silver iodide particles have been run for three years, thanks to the co-operation of the Chemical Defence Experimental Establishment at Porton. If the results so far are negative they at least confirm the expectations of most specialists and have stimulated other work on large-scale diffusion which is referred to later.

Under the leadership of Robinson,[24] the observing of radiation, solar and terrestrial, and of illumination, has been put on a firm and acceptable basis with new or improved instruments. A ventilated heat-flux plate now serves as an efficient radiation balance meter. Solarimeters have been mounted in ocean weather ships and also on aircraft to provide measures of absorption in cloud and of the albedo of cloud and the earth's surface. Robinson's scheme of observations was the same as that eventually adopted internationally for the I.G.Y. It may truly be said that radiation in the atmosphere is no longer exclusively the concern of specialists but is gradually becoming recognized as a regular climatological factor and one which the synoptic and dynamical meteorologist may hope to take into account quantitatively. This has indeed already been done in making up the heat budgets of stratocumulus cloud[25] and fog,[26] both of which are shown to be in a dynamical condition of near-balance rather than static phenomena. Kew Observatory has been prominent also in the study of exchange by eddy diffusion near the earth's surface, the work having been co-ordinated with that of the research unit attached to the School of Agriculture, Cambridge University. The "aerodynamic method" of estimating evaporation as explored by Rider[27] has indicated large differences in evaporation from cultivated land dependent in part upon the nature of the crop.

Diffusion and turbulence generally were, historically, a pioneer interest of the Meteorological Office and particularly of our present Director-General. Sir Graham Sutton's textbook on micrometeorology[28] appeared in 1953 and if its compilation cannot be claimed as Office work it owed so much to earlier research that it is justifiably recorded in this account. Early in the decade important papers by Calder[29] and by Deacon[30] confirmed the logarithmic profile for neutral conditions and provided generalizations applicable to an unstable atmosphere, while recently mathematical papers have treated convective (buoyancy) transport.[31] Also, in recent years, the problem of larger scale diffusion has been attacked under Pasquill's[32] leadership and led to extensive experimental work with trace substances sampled by aircraft and by instruments mounted on the cables of captive ballons. By combining empiricism with theory, one may now hazard practical estimates of concentrations, at distances up to 100 miles or more, of an airborne contaminant released either at the surface or at an elevated source, in terms of ordinary observables, wind speed, direction and gustiness near the surface, variation of wind with height, the degree of vertical stability or instability and the occurrence of inversions. Realistic problems of this kind occur in considering such diverse questions as pollution from smoke stacks, seeding of cloud by silver iodide smokes, and the improbable but possible dangers due to the accidental release of radioactive matter from Atomic Energy Establishments, as well as to the problems which are the particular field of the Ministry of Supply's Chemical Defence Experimental Establishment where most of the meteorological work has been carried out, and whose invaluable resources for instrument design, air sampling and field experiments have been freely available and are here gratefully acknowledged. Elsewhere mention has been made of the experiments conducted by C.D.E.E. on the release of silver iodide smokes in connexion with rainfall modification.

Finally, I must not forget the efforts of those concerned with the development of instruments, to improve upon standard observations, to yield new data demanded by the service and to assist the research worker, although naturally research physicists must often design and produce their own special tools. A reference to the Assistant Director now in charge provided me with a list of 32 items which might find a place in the ten-year record and my choice for this account is my own. First, under Dr. Scrase's[33] guidance the production of an *Instrument Manual* Part I and, recently finished by Scrase himself, Part II, provides the guidance long awaited to instrument users everywhere, both for surface and upper air observations: this is a major work. A modulated beam cloud searchlight for use in daylight, mainly due to Bibby, and a pulsed-light system due to Almond,[34] both became serviceable although neither fully meets operational needs. Recently a high altitude searchlight, also designed by Bibby and intended to study air density up to heights of 60 kilometres has undergone preliminary trials. A recording transmissometer of Office design has been in use for some years at London Airport. Upper air instruments, radiosonde and wind radar, have been under continuous attention resulting in many minor improvements with gain in accuracy, stability and reliability but radical re-design has been in abeyance pending the outcome of a protracted commercial development of a radarsonde using an airborne transponder (secondary radar). Recently further development on these lines was abandoned owing to high cost and design difficulties and now the Instrument Development division is concentrating its attention once more on the well-tried combination of radiosonde and radar wind with heights of 120,000 feet as the new operational ceiling.

This account has done injustice to many by omission of important successes in special lines and the injustice will be aggravated by the attempt I now make, and for which I freely apologise, to summarize the major items.

In turbulence and diffusion preliminary solutions, useful in practice, to problems of downwind concentrations at all distances from a source to a range of order 100 miles have been made available. Atmospheric radiation, solar and terrestrial in origin, has been developed with theoretical appreciations to the stage of becoming a synoptic and climatological factor, well instrumented with a network of stations. Basic data on cloud physics and atmospheric nuclei have been accumulated by aircraft and radar; the reality of precipitation initiation by coalescence has been established and the water content of clouds is becoming known. The physics of stratocumulus cloud and of fog has been considerably clarified and practical, if empirical, methods of forecasting fog have been improved. The structure of fronts has become much better documented and the vertical motions with the accompanying cloud structure and dry tongues have been incorporated and in part explained by basic dynamics. Rainfall in association with depressions has been statistically analysed and related with the dynamics. Three-dimensional dynamical studies have led to the assimilation of this mode of thinking into routine forecasting practice with a technique of contour and thickness analysis and prediction which is suited to the ideas. With the assistance of electronic computing, hydrodynamical methods, in principle "exact" although in application approximate, have opened up what promises to be the new era of numerical weather prediction. The study of wave motion initiated by topography has been brought to a stage where it can be applied in day-to-day synoptic work. Studies at high levels have revealed the remarkable dryness of the lower stratosphere and so put the general circulation in a new light. The tropopause has been analysed synoptically and climatologically and the world atmosphere up to the lower stratosphere has been mapped in terms of pressure-contours, winds with isotachs, temperatures and in part humidity, so that upper air world climatology is now beyond the early conjectural stage and is a well-developed part of our science. Naturally, ideas and results from British work outside the Office and from other countries have been borrowed with the freedom essential in science but in all the ways mentioned the Office can justly claim to have made major contributions. It is, I feel, a 10-year record in which we may take pride.

The reader, conceding as I hope this claim of achievement, will naturally ask the question: what may we expect from the next decade? But I shall not attempt to conjecture. There are, if we care to examine the record, glaring gaps in progress both on problems of immediate concern to operational meteorologists and on those of scientific meteorology having deep interest if less obvious utility, and future success will depend on planning wisdom, which may or may not fail us, and on the inspiration of British scientists which surely will not.

REFERENCES

1. BROOKS, C. E. P. et alii; Upper winds over the world. *Geophys. Mem., London,* **10,** No. 85, 1950.
2. GOLDIE, N. et alii; Upper air temperature over the world. *Geophys. Mem., London,* **13,** No. 101, 1958.
3. MOORE, J. G.; Average pressure and temperature of the tropopause. *Met. Res. Pap., London,* No. 874, 1954.
4.(a) BANNON, J. K.; Meteorological aspects of turbulence affecting aircraft at high altitude. *Prof. Notes met. Off., London,* **7,** No. 104, 1951, reprinted 1953.
(b) BANNON, J. K.; Shear frequencies in the upper troposphere and lower stratosphere over England. *Met. Mag., London,* **79,** 1950, p. 161.
5.(a) FORSDYKE, A. G.; Weather forecasting in tropical regions. *Geophys. Mem., London,* **10,** No. 82, 1949.
(b) FORSDYKE, A. G.; Research requirements in tropical meteorology–Report of a survey made by the author 1956–57. Unpublished.
6.(a) LAMB, H. H.; Meteorological results of the Balaena Expedition, 1946–47. *Geophys. Mem., London,* **12,** No. 94, 1956.
(b) LAMB, H. H.; Topography and weather in the Antarctic. *Geogr. J., London,* **111,** No. 1, 1948.
(c) LAMB, H. H.; Meteorological situations over the South Polar Regions and alimentation of the Antarctic Ice-Cap. *Int. Un. Geod., Ass. Hydrol., Louvain,* Publ. **32,** 1952, p. 172.
(d) LAMB. H. H.; The southern circumpolar westerlies: broad characteristics and apparent associations. *Met. Res. Pap., London,* No. 1065, 1957.
7. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953.
8. SUTCLIFFE, R. C.; A contribution to the problem of development. *Quart. J. R. met. Soc. London,* **73,** 1947, p. 370.
9. SUTCLIFFE, R. C. and FORSDYKE, A. G.; Theory and use of thickness patterns in forecasting. *Quart. J. R. met. Soc., London,* **76,** 1950, p. 189.
10. SAWYER, J. S. and BUSHBY, F. H.; A baroclinic model atmosphere suitable for numerical integration. *J. Met., Lancaster, Pa.,* **10,** No. 1, 1953, p. 54.
11.(a) MATTHEWMAN, A. G.; A study of warm fronts. *Prof. Notes met. Off., London,* **7,** No. 114, 1955.
(b) SAWYER, J. S.; The free atmosphere in the vicinity of fronts. *Geophys. Mem., London,* **12,** No. 96, 1955.
(c) SAWYER, J. S. and DINSDALE, F. E.; Cloud in relation to active warm fronts near Bircham Newton. *Prof. Notes met. Off., London,* **7,** No. 115, 1955.
(d) MURRAY, R. and JOHNSON, D. H.; Structure of the upper westerlies: a study of the wind field in the eastern Atlantic and western Europe in September 1950. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 186.
(e) MURRAY, R.; Some features of jet streams as shown by aircraft observations. *Geophys. Mem., London,* **12,** No. 97, 1956.
(f) MURRAY, R. and DANIELS, S. M.; Transverse flow at entrance and exit to jet streams. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 236.
(g) JOHNSON, D. H. and DANIELS, S. M.; Rainfall in relation to the jet stream. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 212.
12. SAWYER, J. S.; The vertical circulation at meteorological fronts and its relation to frontogenesis. *Proc. roy. Soc. A, London,* **234,** 1956, p. 346.
13.(a) SAWYER, J. S.; A study of the rainfall of two synoptic situations. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 231.
(b) SAWYER, J. S.; Rainfall of depressions which pass eastward over or near the British Isles. *Prof. Notes met. Off., London,* **7,** No. 118, 1956.
(c) WALLINGTON, C. E.; A comparative study of the rainfall of two warm fronts. *Met. Res. Pap., London,* No. 1082, 1957.
14.(a) SAUNDERS, W. E.; Night cooling under clear skies. *Quart. J. R. met. Soc., London,* **75,** 1949, p. 154.
(b) SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 603.
(c) SAUNDERS, W. E.; Method of forecasting the temperature of fog formation. *Met. Mag., London,* **79,** 1950, p. 213.
15. DURST, C. S., and JOHNSON, D. H.; The preparation of statistical wind forecasts and an assessment of their accuracy in comparison with forecasts made by synoptic techniques. *Prof. Notes met. Off., London,* **8,** No. 124. (To be published shortly.)

16. SUMNER, E. J.; A study of blocking in the Atlantic-European sector of the northern hemisphere. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 402.

17.(a) CRADDOCK, J. M.; An analysis of the slower temperature variations at Kew Observatory by means of mutually exclusive band filters. *J. R. statist. Soc., A, London,* **120,** Pt. IV, 1957, p. 16.

(b) CRADDOCK, J. M.; Meteorological Office discussion—research in the Meteorological Office concerned with long-range forecasting. *Met. Mag., London,* **87,** 1958, p. 239.

18.(a) CORBY, G. A.; The air flow over mountains: a review of the state of current knowledge. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 491.

(b) CORBY, G. A.; Air flow over mountains; notes for forecasters and pilots. *Met. Rep., London,* **3,** No. 18, 1957.

(c) CORBY, G. A.; A preliminary study of atmospheric waves using radiosonde data. *Quart. J. R. met. Soc., London,* **83,** 1957, p. 49.

(d) WALLINGTON, C. E., and PORTNALL, J.; A numerical study of the wavelength and amplitude of lee waves. *Met. Res. Pap., London,* No. 1025, 1957.

19.(a) MURGATROYD, R. J. et alii; Some recent measurements of humidity from aircraft up to heights of about 50,000 ft. over southern England. *Quart. J. R. met. Soc., London,* **81,** 1955, p. 533.

(b) HELLIWELL, N. C. et alii; Some further observations from aircraft of frost point and temperature up to 50,000 ft. *Quart. J. R. met. Soc., London,* **83,** 1957, p. 257.

(c) TUCKER, G. B.; An analysis of humidity measurements in the upper troposphere and lower stratosphere over southern England. *Met. Res. Pap., London,* No. 1052, 1957.

(d) JAMES, D. G.; Observations from aircraft of temperatures and humidities near stratocumulus cloud. *Met. Res. Pap., London,* No. 1055, 1957.

20. MURGATROYD, R. J.; The Research Flight of the British Meteorological Office. Miscelânea geofisica publicada pelo Serviço Meteorológico de Angola em comemoraçao do X aniversário do Servico Meteorologico Nacional, Loanda, 1956, p. 229.

21.(a) BEST. A. C.; Empirical formulae for the terminal velocity of water drops falling through the atmosphere. *Quart. J. R. met. Soc., London,* **76,** 1950, p. 302.

(b) BEST. A. C.; The size distribution of raindrops. *Quart. J. R. met. Soc., London,* **76,** 1950, p. 16.

(c) BEST, A. C.; The size of cloud droplets in layer-type cloud. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 241.

(d) BEST. A. C.; Drop-size distribution in cloud and fog. *Quart. J. R. met. Soc., London,* **77,** 1951, p. 418.

(e) BEST, A. C.; Effect of turbulence and condensation on drop-size distribution in cloud. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 28.

(f) BEST, A. C.; The evaporation of raindrops. *Quart. J. R. met. Soc., London,* **78,** 1952, p. 200.

22.(a) JONES, R. F.; Radar echoes from and turbulence within cumulus and cumulonimbus clouds. *Prof. Notes met. Off., London,* **7,** No. 109, 1954.

(b) JONES, R. F.; The temperatures at the tops of radar echoes associated with various cloud systems. *Quart J. R. met. Soc., London,* **76,** 1950, p. 312.

(c) JONES, R. F.; Five flights through a thunderstorm belt. *Quart. J. R. met. Soc., London,* **80,** 1954, p. 377.

23.(a) HARPER, W. G.; The origin of radar "angels". *Met. Res. Pap., London,* No. 1068, 1957.

(b) HARPER, W. G.; "Angels" on centimetric radar caused by birds. *Nature, London,* **180,** 1957, p. 847.

24.(a) ROBINSON, G. D.; The use of surface observations to estimate the local energy balance of the atmosphere. *Proc. roy. Soc. A, London,* **236,** 1956, p. 160.

(b) ROACH, W. T.; Measurements of atmospheric radiation and heat balance at the ground at Kew, May 1953—May 1954. *Met. Res. Pap., London,* No. 936, 1955.

(c) POWELL, D. B. B.; On the development of an improved daylight illumination recorder. *Met. Res. Pap., London,* No. 988, 1956.

25. JAMES, D. G.; Nocturnal dissipation of stratocumulus cloud. *Met. Mag., London,* **85,** 1956, p. 202.

26. STEWART, K. H.; Radiation fog investigations at Cardington 1951–54. *Met. Res. Pap., London,* No. 912, 1955.

27.(a) RIDER, N. E.; Water losses from various land surfaces. *Quart. J. R. met. Soc., London,* **83,** 1957, p. 181.

(b) RIDER, N. E.; An account of the development of the aerodynamic method for the evaluation of the natural evaporation conducted in Great Britain from 1947–1953. *Assembl. gen. Un geod. geophys. int. Rome* 1954, *Louvain,* **3,** 1955, p. 135. (Ass. int. Hydrol, Sc. Publ., No. 38).

28. SUTTON, O. G.; Micrometeorology. London, 1953.

29. CALDER, K. L.; The criterion of turbulence in a fluid of variable density, with particular reference to conditions in the atmosphere. *Quart. J. R. met. Soc., London,* **75,** 1949, p. 71.

30. DEACON, E. L.; Vertical profiles of mean wind in the surface layers of the atmosphere. *Geophys. Mem., London,* **11,** No. 91, 1953.

31.(a) MEADE, P. J.; Convection from a small, continuous source of heat in a calm, neutral atmosphere. *Met. Res. Pap., London,* No. 952, 1955.

(b) SMITH, F. B.; The diffusion of smoke from a continuous elevated point-source into a turbulent atmosphere. *J. Fluid Mech., London,* **2,** 1956, p. 49.
(c) SMITH, F. B.; Convection-diffusion processes below a stable layer. Parts I, II. *Met. Res. Pap., London,* Nos. 1048, 1073, 1957.
(d) BEST, A. C.; Maximum concentration at ground level of gas from a heated elevated source. *Met. Mag., London,* **84,** 1955, p. 297.
32.(a) PASQUILL, F.; Meteorological research at Porton. *Nature, London,* **177,** 1956, p. 1148.
(b) PASQUILL, F.; Preliminary studies of the distribution of particles at medium range from a ground-level point source. *Quart. J. R. met. Soc., London,* **81,** 1955, p. 636.
33. London, Meteorological Office. Handbook of meteorological instruments. Part I, London, 1956. (Part II to be published.)
34. ALMOND, R. An experimental pulsed-light cloud-base meter. *Met. Res. Pap., London,* No. 941, 1955.

A NEW OCEAN WEATHER SHIP

By C. E. N. FRANKCOM.

On 16 May 1958 the former "Castle" class frigate H.M.S. *Oakham Castle* was renamed O.W.S. *Weather Reporter* by Lord Hurcomb, chairman of the Meteorological Committee, thus marking the beginning of her career as an ocean weather ship.

Weather Reporter replaces *Weather Explorer,* which is the first of the earlier British weather ships to be withdrawn from service. *Weather Explorer* and her three sister ships—*Observer, Recorder* and *Watcher*—have done over eleven years strenuous service as ocean weather ships in the Atlantic. Prior to that all these ships did a very good job on the exacting duty of convoy escort vessels and it is scarcely surprising that they are now "showing their age", and need replacing by somewhat newer vessels.

It is right to mention that the choice of these ships as ocean weather ships has been amply justified. They have been economical to operate, they have been excellent sea boats and have carried out their duties very effectively. But the "Flower" class corvettes are rather small and their accommodation is inevitably cramped. The "Castle" class frigates being somewhat larger in size (length about 230 feet, compared with 205 feet) can provide much more comfortable accommodation than their predecessors. They also have the advantage of greater fuel capacity, which enables them to operate at either of the ocean stations A, I, J or K without the necessity of refuelling.

Oakham Castle was built at Glasgow by Messrs. A. J. Inglis and launched in July 1944. Her conversion to an ocean weather ship, which involved quite extensive work over about nine months, was carried out by Messrs. James Lamont & Co. at Glasgow.

The renaming ceremony was carried out at Princes Pier in Greenock. About 150 guests were present including the Provost of Greenock and other prominent local citizens, representations of foreign Governments which are signatories of the North Atlantic Ocean Station Agreement, and representatives of British and foreign airlines operating across the Atlantic. Wives of the ship's company of *Weather Reporter* and representatives from other weather ships and from the weather ship base, were also present. Fortunately the weather was fine with a fresh northerly breeze. The ship's white hull and bright yellow upper works, in contrast to the black hull of the earlier ships, gave her a gay and cheerful appearance. At her foremast flew the flags of the other countries which operate weather ships in the North Atlantic—a tribute to her international work.

During the forenoon, Lord Hurcomb had made an unofficial inspection of the ship. Before officially renaming the ship he inspected the ship's company, totalling 57, who were lined up on the pier in front of the ship and he had a few words to say to each man. In his address to the assembled company, Lord Hurcomb emphasized the good work which had been done by the original weather ships since the first North Atlantic Ocean Station Agreement was signed in 1947; he referred to the international nature of the work of these ships for peaceful ends and for the benefit of humanity and pointed out that the observations provided by the weather ships give a regular series of observations at the surface and in the upper atmosphere from fixed points in the Atlantic, which supplement the surface observations provided voluntarily by observers aboard a large number of merchant ships. Lord Hurcomb stressed the good job which had been done by the men serving aboard the weather ships during these eleven years, in carrying out these important duties in all weather in the notoriously stormy North Atlantic Ocean; he drew particular attention to the fact that the meteorologists and some of the radio and radar staff aboard these ships are not professional seamen but have nevertheless stood up to the job admirably. He referred to the difficulties of launching a meteorological balloon in a storm and tracking the balloon by radar in such circumstances, and preparing hot meals in heavy weather—tasks which were regularly carried out no matter what the weather was. Finally Lord Hurcomb expressed a hope that the crew would be happy in their new ship and that she would prove even more successful than her predecessor.

Lord Hurcomb then went aboard the ship, accompanied by the Master, and officially renamed her by releasing a canvas cover which exposed her name painted on the bow and said "I rename this ship *Weather Reporter*—may good fortune attend all those who sail in her".

A meteorological balloon carrying a radiosonde and target was then released for the benefit of the guests; visitors were then invited aboard the ship to inspect her. An exhibition of air/sea rescue equipment—such as inflatable life rafts, immersion suits, first aid equipment, portable radio sets for use in boats and rescue belts—was displayed on the quay alongside the ship.

An inspection of the ship showed that her accommodation was considerably more spacious and better fitted out than that of her predecessors, which were converted soon after the war when almost everything was in short supply. Every officer and petty officer has a well appointed cabin to himself, whereas the ratings are accommodated in 3-berth cabins. The messes and smoke rooms for officers, ratings and petty officers are lined with comfortable cushioned settees and they are attractively furnished generally.

The meteorological office is situated on the upper deck aft, immediately forward of the balloon shelter. It is a bright and cheerful room lighted with four 21-inch portholes. The equipment includes two radiosonde receivers, a plotting table for upper winds, three mercurial barometers and a "precision aneroid", a distant-reading thermograph from the engine room intake, a distant-reading psychrometer from screens on each side of the bridge and a distant-reading anemometer and wind direction dials, the instruments being mounted on a yard each side of the mainmast. For radiosonde reception a special aerial is mounted on top of the balloon shelter. A wave recorder connected to instruments located in the engine room, and a recording potentiometer which records total radiation and net flux of radiation from instruments mounted near the bridge, are also included.

Hydrogen stowage is provided on deck each side of the balloon shelter but for use in very heavy weather a few cylinders are carried inside the shelter. The balloon shelter is provided with a special ventilation system to obviate any risk of a hydrogen explosion and there are no electrical fittings of any kind inside it. Wiring has been installed between the meteorological office and various points in the ship where experimental meteorological equipment may need to be installed, such as the bridge, masts and bow of the ship, so that special investigations can be carried out as necessary. The masts are provided with reasonably spacious platforms from which it will be possible to carry out experimental work aloft more easily.

The radio equipment, which is of a more modern type than that installed in the earlier weather ships, includes HF and MF W/T and R/T, VHF and UHF R/T, a non-directional MF beacon, MF and VHF DF, and "walkie-talkie" sets for use in the lifeboats. A 10-centimetre naval type radar similar to that installed in the earlier ships is provided for radar wind observations and for giving navigational "fixes" to aircraft in flight, as well as a "Decca" radar for navigational purposes. The navigational equipment includes a gyro compass, an echo sounder, Loran and a "clear view" screen.

Weather Reporter is under the command of Captain A. W. Ford, who has served aboard the weather ships since they first came into service in 1947; he was formerly in command of *Weather Recorder.*

A COMPARISON OF RADIOSONDE AND METEOROLOGICAL RESEARCH FLIGHT HUMIDITY MEASUREMENTS

By C. H. HINKEL, B.Sc. and G. B. TUCKER, Ph.D.

Introduction.—Aircraft of the Meteorological Research Flight have measured temperature and humidity (frost-point) in the upper air over southern England since 1943. By the end of 1955, 399 soundings had been made. A preliminary analysis of the data[1] suggested serious discrepancies between the seasonal values of humidity mixing ratio obtained from these ascents and those obtained from radiosonde soundings. The three possible sources of discrepancy were due to differences of sampling, processing the data, and instrumentation. The differences in sampling exist because the results of the preliminary analysis were compared with seasonal averages for Larkhill for the period 1946–50[2] which are based on four radiosonde ascents per day. The M.R.F. seasonal values of humidity mixing ratio were computed from the average of frost-point measurements; this method of processing the data will not give the same answer as that obtained by first converting each frost-point into a humidity mixing ratio and then taking the seasonal average. Instrumentation may be a source of discrepancy because the radiosonde and M.R.F. instruments are different and measure different parameters. The humidity recording instrument on the radiosonde is a gold-beater's skin hygrometer which measures relative humidity—subsequently converted into dew-point by referring to the temperature reading of the bi-metallic thermometer. On the M.R.F. aircraft a frost-point hygrometer was used.

It was decided to analyse the M.R.F. data in more detail and, by eliminating errors due to sampling and processing of data, to attempt a comparison of the humidity measurements obtained from the frost-point hygrometer with those from a radiosonde.

Procedure.—Data were analysed for the 700-millibar and 500-millibar levels. The seasonal classification used was winter (January, February, March), spring (April, May, June), summer (July, August, September), autumn (October, November, December). This conforms to the classification in previous papers on this topic.[1, 3]

Each M.R.F. ascent was paired with a radiosonde sounding made as near as possible in time and place. The frost-point and humidity mixing ratio were computed from both instruments, and mean values at 700 millibars and 500 millibars were computed for each season and the year. There are more observations at 500 millibars than at 700 millibars because before 1950 M.R.F. aircraft made no readings at the lower level.

Results.—Values of the mean seasonal humidity mixing ratio are given in Table I. In all seasons for both the 700-millibar and 500-millibar levels the radiosonde value is much higher than the M.R.F. value, the difference between the two in many cases is more than 50 per cent of the M.R.F. value. The frost-point hygrometer can be regarded as the more accurate instrument, therefore the mean radiosonde humidity mixing ratio is probably a substantial overestimate. Seasonal values of humidity mixing ratio for Larkhill between 1946 and 1950[2] are included in Table I, these are based on four ascents per day. The agreement between these and the radiosonde values suggests that the sampling error of the M.R.F. aircraft ascents is relatively small. The seasonal values of humidity mixing ratio obtained from routine radiosonde soundings (at least over Larkhill) must therefore be regarded as substantially in excess of the true values.

TABLE I—MEAN HUMIDITY MIXING RATIO (H.M.R.) IN GRAMMES/KILOGRAMME

	Winter		Spring		Summer		Autumn		Year	
	H.m.r.	No. of obs.	H.m.r.	No. of obs.	H.m.r.	No. of obs.	H.m.r.	No. of obs.	H.m.r.	No. of obs.
					700 *mb.*					
(i)	0·83	45	1·64	42	2·12	42	1·36	51	1·47	180
(ii)	1·31	45	2·03	42	2·87	42	2·14	51	2·08	180
(iii)	1·46		1·81		2·98		2·27		2·13	
(iv)	+0·48		+0·39		+0·75		+0·78		+0·61	
					500 *mb.*					
(i)	0·28	68	0·48	98	0·66	79	0·47	58	0·48	303
(ii)	0·43	68	0·77	98	1·05	79	0·70	58	0·75	303
(iii)	0·48		0·60		1·01		0·78		0·72	
(iv)	+0·15		+0·28		+0·39		+0·23		+0·27	

(i) Meteorological Research Flight. (ii) Radiosonde. (iii) Averages for Larkhill 1946–50. (iv) Difference (ii)–(i).

Values of the mean seasonal frost-point are given in Table II. The radiosonde frost-points are between 4°C. and 8°C. warmer than the M.R.F. frost-points. Individual pairs of frost-point observations were plotted on scatter diagrams (Figure 1), radiosonde value plotted against M.R.F. value. All points would lie on the diagonal line if paired values were identical. Most of the points (nearly 80 per cent of the total) lie on the top-left of the line, that is, the radiosonde systematically gives higher frost-points.

TABLE II—MEAN FROST-POINT (F.P.) IN °C.

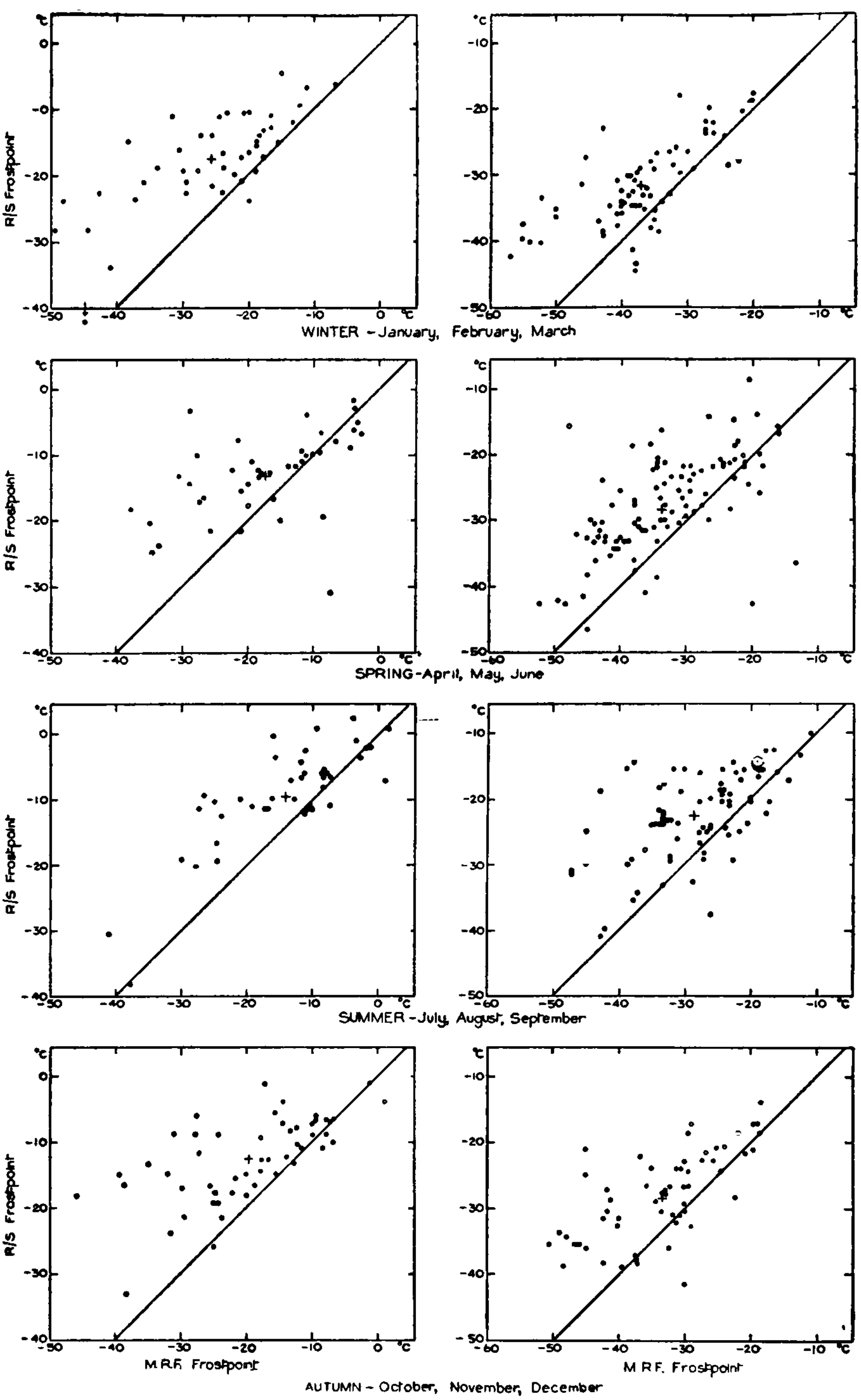
	Winter		Spring		Summer		Autumn		Year	
	F.P.	No. of obs.	F.P.	No. of obs.	F.P.	No. of obs.	F.P.	No. of obs.	F.P.	No. of obs.
700 *mb.*										
(i)	−25·7	45	−17·3	42	−14·3	42	−19·8	51	−19·4	180
(ii)	−18·1	45	−13·0	42	− 9·4	42	−12·7	51	−13·3	180
(iii)	+ 7·6		+ 4·3		+ 4·9		+ 7·1		+ 6·1	
500 *mb.*										
(i)	−38·2	68	−33·5	98	−29·6	79	−33·3	58	−33·6	303
(ii)	−33·0	68	−28·0	98	−23·9	79	−28·1	58	−28·1	303
(iii)	+ 5·2		+ 5·5		+ 5·7		+ 5·2		+ 5·5	

(i) Meteorological Research Flight. (ii) Radiosonde. (iii) Difference (ii)−(i).

Instrumental considerations. *General.*—The discrepancies between the values of the humidity mixing ratio and frost-points determined by the two methods are caused in the first instance by the over-all accuracy of the instruments and in the second by the conditions under which each set of measurements is made.

The radiosonde and frost-point hygrometer are used under very different conditions. The sonde is ascending at a comparatively slow rate (about 1200 feet per minute) and in general is traversing regions in which there is a hydrolapse. It is therefore to be expected that lag errors will occur. The actual measurement is performed by an observer working in comparative comfort upon the ground. The frost-point hygrometer is mounted inside an aircraft travelling horizontally at 200 knots or more, an observation takes at least half a minute and the aircraft will have travelled over a mile and a half during this time. Lag effects will be relatively unimportant. The instrument requires considerable manipulative skill to operate it in the laboratory and the cramped conditions inside modern military aircraft do not make matters easier.

The two instruments use fundamentally different principles for the measurement of humidity. In the sonde, the detector is a piece of gold-beater's skin[4] which expands or contracts with changing relative humidity. The change of length is converted by means of a suitable transducer into a change of frequency which is transmitted to the ground and after measurement is converted by means of a calibration graph into a relative humidity. In order to obtain either the humidity mixing ratio or the frost-point the temperature of the ambient air must also be known. The frost-point hygrometer[5] measures the temperature at which a deposit of frost forms on a cooled surface (or thimble as it is usually called) as air flows over it, the formation of the deposit being observed by the human eye. The method is thus an absolute determination of the frost-point.



700 mb. 500 mb.

FIGURE 1—SCATTER DIAGRAMS SHOWING THE RELATIONSHIP BETWEEN THE FROST-POINT OVER SOUTHERN ENGLAND AS SAMPLED BY RADIOSONDE AND METEOROLOGICAL RESEARCH FLIGHT INSTRUMENTS

Ushaw College, Durham.

FUNNEL CLOUD AT USHAW COLLEGE, DURHAM

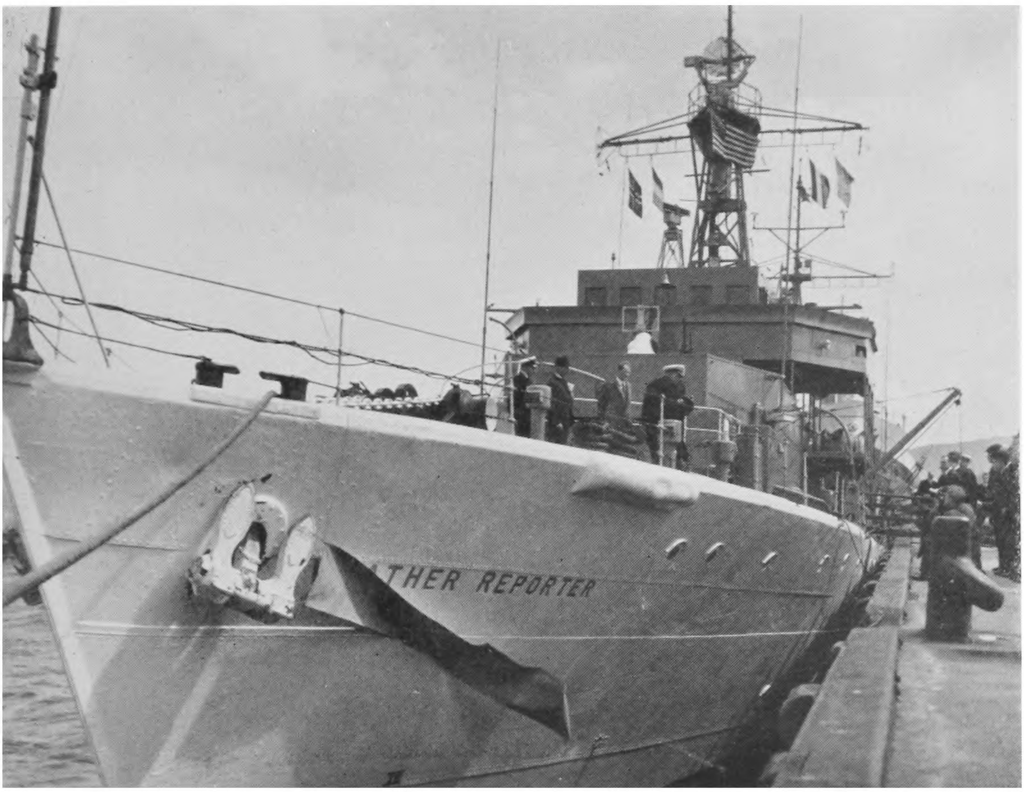
We are indebted to the Rev. A. Pickering, Chief Observer at Ushaw College, Durham, for this photograph of a cloud funnel. The photograph was taken from the College building by one of the students at 0854 G.M.T., 24 June 1958. The cloud funnel did not reach the ground.

On 24 June northern England was in a shallow low pressure area extending from Scandinavia to the Atlantic. A heavy shower fell at Ushaw College at 1100 G.M.T.

Crown copyright

O.W.S. WEATHER REPORTER

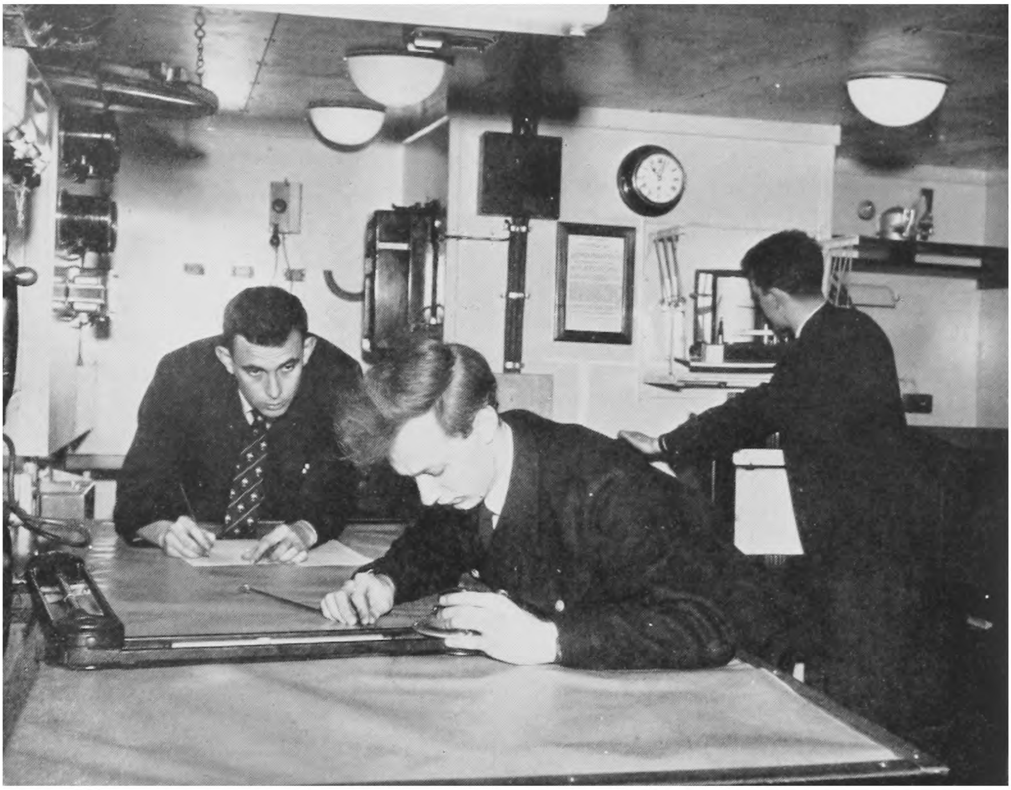
(see p. 331)



Crown copyright

H.M.S. OAKHAM CASTLE IS RENAMED O.W.S. WEATHER REPORTER BY LORD HURCOMB ON 16 MAY 1958

(see p. 331)



Crown copyright

PLOTTING RADAR WINDS IN THE METEOROLOGICAL OFFICE

Crown copyright

O.W.S. WEATHER REPORTER'S METEOROLOGISTS IN THE PETTY OFFICERS' SMOKEROOM
Left to right: G. Wind, H. J. Matthews (in front), D. W. Griffiths, R. E. Clement, M. Parkin, J. A. Graham, A. B. Smith

(see p. 331)

Errors.—The errors of each instrument will now be considered in greater detail:

(i) *The radiosonde humidity element:*—Each sonde is calibrated in the Instrument Division of the Meteorological Office before issue to the outstations who carry out a spot check at one point only on the calibration curve immediately before flight to test for drift. It is assumed that any drift found to occur has caused no change in the slope of the calibration curve. Gluckauf[6] has shown that the skin extension with humidity exhibits a hysteresis effect when the relative humidity is reduced below 70 per cent. He also states that provided relative humidity with respect to water is plotted against skin extension, the calibration curve is unaffected by temperature, but recent experiments carried out in the Instrument Division point to a variation of the extension of the skin with temperature at a given relative humidity. Another source of error is that the lag is not a constant but increases rapidly with decreasing temperature and is of the order 30 seconds between 700 and 500 millibars. A hydrolapse will cause the sonde to give humidity values that are too large and a humidity inversion will have the opposite effect. The magnitude of the errors from these sources depends upon the conditions at the time of flight and is impossible to assess them accurately. The total effect may be large on one day and small on another, but there is good reason to believe that on average their combined effect gives rise to a reading of the relative humidity that is too high by about 10 per cent or about 2°C. if the frost-point is used as the measure of humidity.

The temperature element is affected by radiation from the sun which causes it to give a higher temperature reading than the true air temperature. Prior to February 1956 no allowance was made for this heating which may amount to about 1·0–1·5°C. at the heights concerned. The measurements discussed above were all made before this time. It is equivalent to a reading of the dew-point that is too high by a similar amount.

(ii) *The frost-point hygrometer:*—The platinum resistance wire thermometer wound round the body of the thimble is connected to a Wheatstone bridge which is calibrated directly in temperature units. The bridge and thimble are calibrated as a single unit before issue. Their combined errors are thus known and the calibration drift of these instruments is very small. A recent check of one particular instrument after five years' use showed that the calibration drift did not exceed 0·75°C. at any part of the scale. A small temperature gradient exists between the thimble surface and that part of the body on which the platinum wire is wound. It is at most 1–2°C. at temperatures above −40°C. and causes the instrument to read low. A loose winding may also contribute a further error whose magnitude cannot easily be assessed but might in extreme cases amount to several degrees. However, in all cases it tends to make the instrument read low.

The frost-point hygrometer has the advantage of giving an absolute measure of the humidity but tends to give values of the frost-point which are about 2°C. too low at temperatures down to −40°C. The sonde element on the other hand does not give an absolute measure of humidity, its range is limited to ambient temperature above −40°C., it is subject to a hysteresis drift and has a considerable lag at sub-zero temperatures. It is extremely difficult to assess all these factors, but it is possible that they cause values of frost-point measurement by the radiosonde to be 3–4°C. high at temperatures down to −40°C. On individual flights the errors may vary considerably on either side of these limits.

Conclusion.—The inaccuracy of the humidity element in the radiosonde is well known to most meteorologists, but there appears to be little quantitative information published concerning the magnitude of the errors involved.

The above discussion of the accuracies of the radiosonde humidity element and the frost-point hygrometer show that the error of each instrument is of opposite sign, their difference therefore could be 5–6°C. The average differences of 4·3–7·6°C. obtained are not therefore surprising. About two-thirds of the discrepancy probably arises from the positive error of the radiosonde and one-third from the negative error of the frost-point hygrometer.

The results of this analysis show that the gold-beater's skin hygrometer of the radiosonde systematically overestimates the humidity. The above allocation of errors implies that the mean humidity mixing ratios at 700 millibars and 500 millibars computed from routine radiosonde soundings are probably 15 to 35 per cent too high.

REFERENCES

1. TUCKER, G. B.; An analysis of humidity measurements in the upper troposphere and lower stratosphere over Southern England. *Met. Res. Pap., London*, No. 1052, 1957.
2. London, Meteorological Office; Upper air data 1946–50. Part I. Larkhill. London, 1952.
3. BANNON, J. K., FRITH, R., and SHELLARD, H. C.; Humidity of the upper troposphere and lower stratosphere over Southern England. *Geophys. Mem., London*, **11**, No. 88, 1952.
4. DYMOND, E. G.; The Kew radiosonde. *Proc. phys. Soc., (A), London*, **59**, 1947, p. 645.
5. DOBSON, G. M. B., BREWER, A. W., and CWILONG, B.; Measurement of atmosphere humidity in aircraft by dew point hygrometer. *Met. Res. Pap., London*, No. 126, 1943.
6. GLUCKAUF, E.; Investigations on absorption hygrometers at low temperatures. *Proc. phys. Soc. (A), London*, **59**, 1947, p. 344.

ANALYSIS OF WIND AT 300 AND 200 MILLIBARS OVER HONG KONG

By D. S. GILL

Observations and yearly analysis.—Daily radiosonde ascents are made in Hong Kong by the Royal Observatory staff at about 0001 G.M.T. and radar winds form a part of these ascents. The results of the ascents are published by the Royal Observatory[1]. An analysis of these radar winds for the years 1950 and 1951 has already been published[2] and the present work is an extension of this analysis to cover the years 1952, 1953, and 1954.

The observations at 300 millibars (approximately 32,000 geopotential feet) and 200 millibars (approximately 41,000 geopotential feet) have been analysed separately for each month and each year. The mean components V_N and V_E for the months were calculated and from these the vector mean wind $\mathbf{V}_R$ was obtained. The scalar mean wind speed V_S was calculated and from this the constancy q defined as $100 V_R/V_S$ was obtained.

Standard deviations of the northerly and easterly components σ_N and σ_E were calculated from the sum of the squares of the differences and a standard vector deviation was obtained from the square root of the sum of the squares of σ_N and σ_E. Computed values of $\mathbf{V}_R$, q, σ_N, σ_E, and standard vector deviations (S.V.D.) are given in Table I.

Effect of missing observations.—Large numbers of observations are missing in some months, a large proportion probably being due to strong winds carrying the sonde balloon beyond radar range. A rough test was made of the skewness of the January observations at 300 and 200 millibars by calculating

TABLE I.—STATISTICS OF MONTHLY MEAN WINDS AT 300 MILLIBARS AND 200 MILLIBARS OVER HONG KONG AT 0001 G.M.T.

		300 mb.						200 mb.					
Month	Year	No. of obs.	$\mathbf{V}_R$ deg/kt	q %	σ_N kt.	σ_E kt.	SVD kt.	No. of obs.	$\mathbf{V}_R$ deg/kt	q %	σ_N kt.	σ_E kt.	SVD kt.
Jan.	1952	22	265/70	99	9·4	21·5	23·4	9	257/69	98	17·0	11·1	20·3
	1953	6	265/72	97	15·3	8·7	17·6	4	250/78	97	20·3	13·6	24·4
	1954	19	261/60	95	19·9	11·4	22·3	9	258/61	92	26·4	11·4	28·6
	1952–54	47	264/65	97	15·6	16·0	22·3	22	256/67	95	22·3	13·6	26·1
Feb.	1952	18	257/56	97	13·9	11·5	18·0	10	258/56	96	14·4	7·8	16·4
	1953	5	248/64	98	14·9	16·9	22·5	NIL					
	1954	16	266/64	99	10·3	18·1	20·8	6	256/52	99	7·8	15·9	17·7
	1952–54	39	260/61	98	15·3	16·3	22·3	16	257/55	98	11·6	13·3	17·6
March	1952	19	256/60	96	15·7	9·0	18·1	12	254/68	98	12·1	8·7	14·9
	1953	15	265/64	97	16·5	11·6	20·1	7	264/61	99	12·2	18·1	20·3
	1954	21	258/58	98	10·1	9·3	14·4	13	255/65	98	12·7	11·7	17·2
	1952–54	55	259/60	97	14·8	10·6	18·3	32	257/65	98	13·4	13·5	19·0
April	1952	20	270/52	95	13·8	14·4	15·8	15	276/60	95	19·6	15·3	25·0
	1953	22	270/51	98	12·1	11·3	16·6	16	266/60	98	12·0	11·1	16·3
	1954	17	266/38	87	18·7	16·6	25·0	14	277/47	90	18·3	19·2	26·6
	1952–54	59	270/47	94	15·2	15·6	21·8	45	272/56	95	17·2	16·9	24·1
May	1952	22	265/17	89	7·5	9·4	12·0	20	301/18	82	10·4	11·4	15·4
	1953	23	265/28	92	8·4	16·6	18·6	22	260/32	87	11·4	23·4	26·0
	1954	24	284/09	63	5·4	13·7	14·7	19	319/13	62	7·8	16·5	18·3
	1952–54	69	273/18	81	7·3	15·5	17·2	61	293/21	74	10·2	20·4	22·8
June	1952	18	345/05	36	9·8	13·9	17·0	15	360/10	44	11·1	22·0	24·6
	1953	22	024/02	10	6·5	15·3	16·6	21	359/04	17	12·0	21·1	24·2
	1954	20	342/03	35	5·4	10·1	11·5	19	041/15	78	7·7	11·8	14·1
	1952–54	60	351/03	23	7·6	13·3	15·3	55	023/09	41	10·9	19·4	22·3
July	1952	26	092/13	75	9·1	10·8	14·1	25	079/22	87	9·5	17·5	19·9
	1953	26	079/21	93	8·3	7·6	11·2	26	077/39	97	9·1	12·4	15·4
	1954	27	079/16	94	6·4	6·7	9·2	18	062/34	97	7·9	14·8	16·8
	1952–54	79	082/17	87	8·2	9·2	12·3	69	073/31	94	10·1	16·4	19·2
Aug.	1952	16	077/13	73	11·3	11·7	16·3	12	056/17	73	13·3	12·7	18·4
	1953	25	090/14	79	6·9	11·8	13·7	24	093/23	88	11·3	11·4	16·1
	1954	22	109/05	33	12·4	10·7	16·4	18	067/12	71	12·6	11·7	17·2
	1952–54	63	089/10	63	10·6	11·8	15·9	54	078/18	79	13·2	13·0	18·6
Sept.	1952	16	068/08	53	10·2	9·2	13·6	8	063/11	51	6·5	20·1	21·1
	1953	18	041/03	29	6·8	10·2	12·3	17	039/07	34	12·5	16·7	20·9
	1954	24	083/09	64	9·6	9·0	13·1	18	090/11	57	13·2	12·6	18·1
	1952–54	58	072/07	50	9·0	9·9	13·4	43	068/09	44	11·3	17·0	20·4
Oct.	1952	21	314/09	59	8·2	11·9	14·4	19	311/13	61	11·9	15·9	19·9
	1953	25	285/12	69	7·0	14·3	15·9	25	281/14	68	8·4	15·6	17·7
	1954	25	287/18	62	9·0	25·4	27·0	23	292/20	59	14·6	26·2	30·0
	1952–54	71	291/13	62	8·2	18·8	20·5	67	293/15	60	12·2	20·1	23·5
Nov.	1952	22	242/15	70	9·9	18·7	21·2	20	244/18	80	9·5	20·2	22·9
	1953	19	241/25	93	7·8	12·7	14·9	16	247/31	88	12·9	15·7	20·3
	1954	25	270/30	83	12·9	26·5	29·5	20	250/29	84	14·0	23·5	27·7
	1952–54	66	255/23	80	11·6	21·2	24·2	56	246/26	86	12·5	20·9	24·4
Dec.	1952	11	267/59	97	15·1	14·6	21·0	8	242/61	99	10·5	10·6	15·0
	1953	20	249/55	97	15·0	17·3	22·9	13	242/60	97	13·5	20·8	24·8
	1954	23	251/44	97	10·7	15·5	18·9	17	240/45	94	15·0	14·5	20·9
	1952–54	54	253/51	97	14·8	17·4	22·8	38	241/54	97	13·5	17·3	21·9

$\sqrt{\beta_1}$ for these observations, $\sqrt{\beta_1}$ being defined as μ_3/σ^3 where μ_3 is the third moment of wind speed and σ is the standard deviation of wind speed[3]. January was chosen as a month with high constancy, high wind speeds and almost equal values of σ_N and σ_E.

The results were:

January 1952	300 mb.	−0·01;	200 mb.	+0·44.
January 1953	300 mb.	−0·50;	200 mb.	−0·08.
January 1954	300 mb.	−0·17;	200 mb.	−1·0.

These values show a tendency for skewness from normal distribution with a larger number of observations less than the true mean, except in the case of January 1952 at 200 millibars.

In view of this it seems that the mean values obtained for wind speed are lower, in most cases, than the true mean. It was found impossible to apply the corrections suggested by Graystone[4] owing to the lack of a full set of observations at a lower level, although Graystone's examples support the suggestion that the uncorrected mean will be too low.

Mean zonal and meridional components.—The mean zonal components (V_E) at 300 and 200 millibars are given in Table II. This table shows a change from a westerly to an easterly component between May and July and the reverse between September and October. The probable error ($\cdot 6745\sigma_E$) and the constancy q are also given and it will be seen that q reaches a minimum during the change-over periods.

The mean meridional component shows a change from southerly in winter to northerly in summer but its values are much lower than those of the zonal component especially in summer, when the northerly component is very small.

TABLE II.—MEAN MONTHLY ZONAL COMPONENT, PROBABLE ERROR, AND CONSTANCY

Month	300 mb. V_E	300 mb. P.E.	300 mb. q	200 mb. V_E	200 mb. P.E.	200 mb. q
January	−65·6	10·8	97	−65·4	9·2	95
February	−59·4	11·0	98	−53·1	9·0	98
March	−59·0	7·2	97	−63·3	9·1	98
April	−47·5	10·5	94	−55·8	11·4	95
May...	−17·8	10·5	81	−19·2	13·8	74
June...	− 0·5	9·0	23	+ 3·4	13·1	41
July	+16·5	6·2	87	+30·0	11·1	94
August	+10·4	8·0	63	+17·3	8·8	79
September ...	+ 6·3	16·7	50	+ 8·0	11·5	44
October	−12·2	12·7	62	−14·1	13·6	60
November	−22·2	14·3	80	−23·9	14·1	86
December	−48·5	11·7	97	−47·2	11·7	97

Constancy.—Possibly the most interesting feature of the analysis is the very high values obtained for q, the constancy, during the winter months. These values are as high as those obtained by Clarkson[5] at 50,000 feet over Singapore even at the 300-millibar level. They show a marked drop, as would be expected, in the transitional months of June and September.

Wind speeds.—Table III shows the wind speed which may be expected to be equalled or exceeded on 5 per cent of occasions. It is calculated from the formula[3]

$$V_p = V_R + \text{S.V.D.}\ \sqrt{\log_e (100/p)},\ \text{putting } p = 5 \text{ in this case.}$$

TABLE III.—WIND SPEED EQUALLED OR EXCEEDED ON 5 PER CENT OF OCCASIONS

Month	300 mb. Calculated	300 mb. Observed	300 mb. Maximum Observed	200 mb. Calculated	200 mb. Observed	200 mb. Maximum Observed
January	104	98	123	112	96	96
February	100	93	93	85		75
March	92	82	93	98		87
April	85	80	81	98	87	95
May...	48	44	47	60	66	68
June...	29	31	46	48	45	45
July...	38	34	46	64	61	69
August	38	40	48	60	49	52
September	30	27	29	46	33	26
October	48	50	57	56	52	62
November	65	70	75	68	65	74
December	90	86	88	92	86	115

TABLE IV.—FREQUENCIES OF WIND SPEED IN WINTER AND SUMMER

Speed kt.	0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–110	111–120	121–130
					Winter: December to February								
200 mb.			2	11	9	21	16	8	5	3		1	
300 mb.		3	2	16	19	28	31	22	14	4			1
					Summer: June to August								
200 mb.	23	37	66	23	18	6	4	1					
300 mb.	54	89	47	8	4								

TABLE V.—ACTUAL VALUES OF σ AND VALUES CALCULATED ASSUMING A NORMAL CIRCULAR DISTRIBUTION

Month	300 mb. Calculated	300 mb. Actual	200 mb. Calculated	200 mb. Actual
January	21	22	30	26
February	15	22	14	18
March	20	18	16	19
April	23	22	25	24
May	17	17	24	23
June	14	15	23	22
July	15	12	15	19
August	17	16	17	19
September	14	13	22	20
October	22	20	24	23
November	22	24	19	24
December	17	22	18	22

Where sufficient observations were available the observed wind exceeded on 5 per cent of occasions is given in the table together with the maximum observed wind. The strongest wind observed in the period was 123 knots at 300 millibars on 27 January 1952.

Table IV shows the distribution of wind speed in winter and summer. The most frequent range in winter is 51–60 knots at 200 millibars and 61–70 knots at 300 millibars. In summer the most frequent range is 21–30 knots at 200 millibars and 11–20 knots at 300 millibars.

Distribution of vectors.—For some months the standard deviations of the easterly and northerly components were found to be unequal and it was suggested by Clarkson[5] that this results in a non-circular distribution of winds about the vector mean.

Application of Mauchly's test[3] shows that at the 5 per cent level of significance the wind vectors are not circularly distributed about their mean for the following months:

March, May, June, October, and November at 300 millibars.

May, June, July, October, and November at 200 millibars.

It will be seen from Table I that in all these cases (except March at 300 millibars) the standard deviation of the easterly component is substantially greater, usually 50–100 per cent, than the standard deviation of the northerly component. This is similar to the result obtained by Clarkson for winds at 50,000 ft. in November over Singapore.

It may be noted, however, that the computed values of the standard vector deviation obtained from the approximate relation between q and σ/V_R for a normal circular distribution (given by Brooks and others[6]) are in good agreement with the actual values of the standard vector deviation (see Table V).

Conclusion.—The results obtained from this analysis are similar to those obtained by Hay[2] using more limited data. Strong westerly winds occur over Hong Kong during the winter season (November to April) at 200 and 300 millibars. There is a similar, less marked, tendency for easterlies in summer (June to September). Transition months for the change from west to east and vice versa are June and September-October respectively. The distribution of the winds is non-circular in some months.

REFERENCES

1. Royal Observatory, Hong Kong. Meteorological results, upper air observations 1947–55. Hong Kong, 1948–57.
2. HAY, R. F. M.; High level strong easterlies over Singapore and Hong Kong. *Weather, London*, **8**, 1953, p.206.
3. BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, pp. 55, 204, 233.
4. GRAYSTONE, P.; Estimation of mean winds and standard deviation at high levels. *Met. Mag., London*, **83**, 1954, p. 325.
5. CLARKSON, L. S.; Analysis of winds at 40,000 and 50,000 ft. over Singapore. *Met. Mag., London*, **85**, 1956, p.1.
6. BROOKS, C. E. P., DURST, C. S., CARRUTHERS, N., DEWAR, D., and SAWYER, J. S.; Upper winds over the world. *Geophys. Mem. London*, **10**, No. 85, 1950.

REVIEWS

The Planet Earth. Edited by D. R. Bates, F.R.S. $5\frac{1}{2}$ in. $\times 8\frac{3}{4}$ in., pp. vi+312, *illus.*, Pergamon Press, 4 and 5, Fitzroy Square, London. 1957. Price: 35*s.*

It is most appropriate that a book should be written with a background theme of the International Geophysical Year. *The Planet Earth* is a book with such a theme. The vast enterprise of international co-operation in scientific observation and investigation which is now in operation has aroused world-wide interest. This book has been written to meet this interest and to provide the general reader with some knowledge of the various geophysical sciences which make up the story of this world upon which we live. And a fascinating "truth is stranger than fiction" story it is too. It is told in 17 chapters ranging from the astronomical to the atomic scale. Almost every chapter is written by a specialist in his subject, but continuity of the story is readily maintained.

The meteorologist may find the chapters outside his own science a useful introduction to other fields; he will certainly find the chapters on meteorology a refreshing review. The latter are headed "Composition and Structure of the Atmosphere" by Bates, "Climate" and "The General Circulation of the Atmosphere and Oceans" both by Eady and "Meteorology" by Mason. There are also several chapters about the upper atmosphere.

The chapter on "Climate" is perhaps more an essay in methodology than of fact or theory, but the different approach does not make it less interesting. It might have been less confusing to confine Eady's second chapter to the atmospheric circulation. The oceanic circulation is well covered by Deacon earlier in the book. To couple ocean and atmosphere may be useful as an analogue but the general circulation of the atmosphere can be described in its own right.

Mason's chapter is twofold. The first half deals with weather forecasting and the second with the physics of rain clouds. The former is up-to-date but familiar, while the latter subject in the author's specialist field could perhaps have been expanded and given a chapter to itself. Figure 1 in Mason's chapter is not a good example of air-mass analysis. The moist tropical air identifies an easterly current which is blowing from the continent!

A. H. GORDON

Atmospheric electricity. By J. Alan Chalmers. $8\frac{3}{4}$ in. $\times$ $5\frac{1}{2}$ in., pp. viii + 327, *illus.*, Pergamon Press, 4 and 5 Fitzroy Square, London, W.1. 1957. Price: 63*s*.

Dr. Chalmers, who over the past twenty-five years or so has devoted his research interests primarily to atmospheric electricity and has initiated many students into its mysteries, is eminently qualified to have written a treatise on the subject. His latest book is, in effect, a greatly expanded and, of course, more up-to-date version of his earlier one (1949) with the same title and practically the same chapter headings. Almost all the chapters are much increased in length, the largest additions being to that on general principles and results and to the list of references. The latter now occupies thirty-one pages instead of six and must surely be one of the most comprehensive bibliographies on the subject ever published. Two other changes have been made; one is the adoption of the m.k.s. system of units in place of the c.g.s. electrostatic system and the other is the avoidance of the term "electric field" and the use of "potential gradient" instead because of the confusion between sign conventions for field in atmospheric electricity and ordinary electrostatics. There can be little objection to these two changes.

The book starts with a brief but interesting historical survey, followed by an outline of fundamental principles, methods and results. Then there are chapters on the usual subdivisions of the subject such as atmospheric ions, potential gradient, precipitation currents, thundercloud electricity and lightning discharges. The book ends with chapters on the separation of charge and on conclusions about the outstanding problems of atmospheric electricity and the possibilities of solving them. The numerous theories of charge separation are described and discussed and the author concludes that some of the questions which still remain unanswered would best be investigated by aircraft flights through storms, with instruments suitable for the measurement of electrical phenomena, air temperature and vertical currents. Perhaps the time is now ripe for a repetition of the "Thunderstorm Project" with more emphasis on the electrical aspects. Dr. Chalmers also suggests that many of the theoretical arguments used to explain atmospheric electrical phenomena assume that a quasi-static state exists, whereas it is often likely that steady conditions will not be reached and that more complex mathematical treatment is needed. Such a suggestion might well apply to a variety of meteorological problems.

The book is undoubtedly much more useful than its predecessor, as, indeed, it should be at the considerably higher price. It is well illustrated and the presentation, as in all of Dr. Chalmers' writings, is concise and lucid. He is, perhaps, more discursive than in his earlier book, devoting more space to assessing the relative merits of conflicting results and views and being more critical in discussions of controversial points. One or two aspects of the subject are dismissed rather too briefly. For example, one would expect to find included in the chapter on the lightning discharge more on atmospherics than a brief paragraph consisting mostly of references.

Probably it will be found that the best use of the book is as a source of reference, since there would appear to be very little published work on the subject which has not received at least a brief mention by the author. It should, therefore, appeal to the research worker who wishes to be relieved of the time-consuming task of searching the very wide field of literature over which the subject spreads. At the same time, the book should be useful to the student in providing him with a good introduction to the subject and a comprehensive review of the present state of knowledge of it. The cost of the book may seem somewhat high in comparison with that of the earlier book, which was about half the length but only one quarter of the price; increases in production costs over the past eight years, however, probably account for the difference.

F. J. SCRASE

The Physics of Clouds. By B. J. Mason. (Oxford monographs on meteorology. Editor P. A. Sheppard) 9½ in. × 6 in., pp. xi + 481, *illus.*, Clarendon Press: Oxford University Press, Amen House, Warwick Square, London, E.C.4. 1957. Price: 70*s*. net.

The discovery by Schaefer and Langmuir, eleven years ago, that super-cooled clouds could in favourable circumstances be precipitated by means of a cooling agent, was one of the most exciting events in the history of meteorology. It seemed that we were no longer to be mere spectators, but actors—we were offered a magic wand which we had only to learn to wave, and the heavens would deliver their floods to order. Alas! when the wand was waved, the deluge which descended consisted of paper. As Dr. Mason says in his preface, "This rapid development" (of research into cloud physics) "along a broad front has produced a large and diverse literature, the growth of which has made life increasingly difficult for the research worker and impossible for the student".

This last is hardly an overstatement: for the literature is not merely large and diverse—is it extraordinarily confused and contradictory. Clouds have not proved an easy subject for study: they are inaccessible and enormously variable. Then, too, the experimenter is driven to the use of aeroplanes, probably the most infuriating working platform any scientist ever had to occupy. In an aeroplane one needs a huge, expensive, temperamental, electronic apparatus even to measure such basic things as one's geographical position or the wind speed: and the accurate measurement of even so simple a quantity as temperature in cloud still defies us. Perhaps some of the trouble was that at first everyone was in too much of a hurry. Success—that is, success in controlling rainfall—was only just round the corner. It seemed better to use the tools that were lying handy than to spend years developing special ones, and, perhaps, be too late.

Whatever the cause, the results of research in cloud physics are extremely discordant and inconclusive. Time and again one finds the same point investigated by half a dozen different investigators, who obtain as many different results. There is remarkably little agreement even on fundamentals. For example, every raindrop that falls on the earth is believed to start either as an ice crystal or by the coalescence of cloud droplets. Yet hitherto a student who wanted to learn what happens when two cloud droplets meet, or in what circumstances ice crystals form, would have found that there was no generally accepted answer, nor even a satisfactory summary of the attempts which have been made to find one. He would have been driven to study the original papers —perhaps a hundred of them in half a dozen languages—and at the end would have been no wiser than when he started. Thus a concise and orderly account of the work that has been done in the past ten years was most urgently needed, both to give the unfortunate student a fighting chance and in order that future research might be intelligently and economically directed. This is the principal object of Dr. Mason's book, the appearance of which will be greeted with a sigh of relief by all workers in this field. He has confined himself to the microphysics of cloud, leaving the large-scale phenomena to a later volume, and, within these limits, has given a notably lucid and comprehensive account of the subject.

He begins with a chapter on the condensation of water vapour in a nucleus-free atmosphere. Like a good deal of the theory in this field, it has no actual contact with cloud physics, but it makes a nice background to the scene. He then deals successively with condensation nuclei, the growth of droplets, ice forming nuclei, the formation of snow crystals, and precipitation processes. These five chapters are the backbone of the work; they are followed by three more dealing with the artificial stimulation of rain, radar studies, and the electrification of clouds, and by two long appendices dealing with the physical behaviour of falling drops. An introduction by Mr. F. H. Ludlam on the large-scale physics of clouds looks like an afterthought: it runs to only seven pages, and is too compressed to be very useful.

Although this is a textbook, and deals comprehensively with each subject, the principal interest, as already noted, lies in the study of the recent literature. All this is hand-picked, set in good order before us, and its results clearly stated and appraised. There is hardly any plot to the story—no grand discoveries, no sweeping progress—almost everything is inconclusive, every chapter asks more questions than it answers. The result might well have been both dull and irritating, and yet is neither. Dr. Mason obviously finds the problems which surround him immensely stimulating and entertaining, and has no difficulty in persuading the reader to share his feelings. This quality, combined with the simplicity and clarity of the language, make the book unusually easy and enjoyable reading.

As a textbook, it has some faults. The author seems too eager to get down to his analysis of recent work, and sometimes hurries over the fundamentals. In particular the mathematical sections (there are very few of them) have a breathless air, and in some cases are condensed to the point of being misleading. Certainly anybody who tries to understand or apply Smoluchowski's equation (for the rate of coalescence of small particles) from the account given here on pp. 68–70, will discover that condensation nuclei can generate more than one kind of fog.

An immense number of papers are digested here: the bibliography contains over six hundred references, and it is apparent that these are by no means all that have been consulted. So far as can be judged, the bibliography is fairly comprehensive up to the year 1955—there are only a few items from 1956. But the flood of research rolls on, and already there are a number of points at which one feels a need for, at least, a footnote. Where so much material has to be considered, some selection is necessary, and probably no two people would agree precisely on this matter. It is a little surprising that there is apparently no reference to Bowen's theory of meteoritic dust as a source of freezing nuclei—which, even if one disbelieves it, has created too much of a stir to be ignored. Some consideration of the general principles of observation and measurement as applied to the study of clouds would likewise have been of great interest, for lack of system in observation is undoubtedly the principal cause of waste and confusion in this field.

The book is excellently printed and bound, in the usual style of the Clarendon Press. It is generously illustrated with twenty-nine photographic plates and a very large number of clear line drawings. Misprints seem to be few. At 70*s.* it is, by modern standards, remarkably good value, and certainly nobody concerned with cloud physics can afford to be without it. B. C. V. ODDIE

Physikalisch-Statistische Regeln als Grundlagen für Wetter- und Witterungsvorhersagen. Band I. By F. Baur. 10¾ in. × 7¾ in., pp. x + 138 *illus.*, Akademische Verlagsgesellschaft. Frankfurt am Main, 1956.

The name of Franz Baur will probably live, like that of Sir Gilbert Walker, as one of the pioneers in the application of statistics to the understanding of the general circulation of the atmosphere and early techniques of medium- and long-range forecasting. Great interest therefore attaches to the publication of a book to record Baur's methods, discoveries and working material.

Baur states the aims of his work in the preface: firstly, to prove the possibility of medium- and long-range forecasting; secondly, to show that, guided by physical considerations, rules can be found regarding connexions between successive weather phenomena or between weather patterns and solar phenomena; and thirdly to provide a better basis than the present universally adopted synoptic analogy methods for short-range forecasting also. The position as regards this last is considerably overstated. Baur's own record of medium- and long-range forecasting may perhaps be regarded as sufficient proof of the first point and demands a thorough study of his "rules" and methods. One gathers, however, that the enormous labour of such approaches as that incorporated in Table 2 (pp. 10–23)—from which the sign of the pressure change at Potsdam during the next 24 hours may be deduced, given the pressure change in the previous 24 hours at the Azores, Brest, Stykkisholm and Heligoland and knowledge of the trend of sky conditions at Potsdam—may result in but a single hard-won step forward: this table which only applies in high summer may be expected to give the right sign of the pressure change with 90 per cent certainty in only about one seventh of the cases arising—the majority of sets of circumstances would suggest no confident forecast. From this point the search goes on for further rules and further criteria to cover other contingencies. Undoubtedly many of Baur's rules work, but each one only covers a minority of special circumstances and for practical application the problem of indexing alone must be formidable.

This volume contains a further selection of rules relating to the forecasting of dry and wet spells of up to five days duration in middle latitudes. Later sections are concerned with defining large-scale circulation types and presenting data of their occurrence and of various measures of circulation intensity over the Northern Hemisphere. Relationships are explored between these data and the 11-year solar cycle.

The second volume is to deal with Baur's derived rules of behaviour of the general circulation affecting long-range forecasting. This reviewer is left with the impression that the work contains material of value both for long-range forecasting and for further research with this aim in view, but that future workers in this field will bend their efforts to clarifying the physical understanding and evolving simpler procedures than those represented by a mass of heterogeneous rules.

The book contains an introductory chapter which is a good four-page philosophical essay on the respective places of experimental and statistical approaches to research in physical science, showing the need for statistical treatment of masses of data in meteorology to be judged in the light of significance tests. In reality, this may be a necessary, but certainly not a sufficient, condition. The aptness and limitations of the concept of numerical measures of significance in solving the practical problems of meteorology may be illustrated by reference to two specific cases. Changes of climate may be defined in terms of the figures (for example, of temperature) alone: the averages and variances in two epochs show differences which have, say, a 5 per cent probability of occurring by chance. This is a useful, but not a high, significance level; yet we may find that the synoptic regimes and effects on living requirements of plants, disease organisms etc. differed notably. Or an association between certain meteorological events and previous conditions elsewhere may attain a higher significance level and clearly demand research, yet still provide an insufficient basis for confident forecasting until further study has revealed a good deal of the physical mechanism and its controls.

It may be that Baur has been successful as a forecaster just in so far as he has gained a real physical insight. His methods seem to point towards a use of statistical approaches at two points in long-range forecasting: first to identify physical mechanisms and secondly in the manner of stating a forecast—for example, that in cases similar to the given circumstances, *A* resulted in, say, 85 per cent of the cases, *B* in, say 9 per cent. of the cases, the remainder being more various. With considerable financial stakes involved for some recipients of the forecast, a presentation along these lines is perhaps the only wise and fair one. Baur's own contribution has been so much on the statistical side, however, that he possibly understates the need to know the physical links in the chains of association. H. H. LAMB

Untersuchungen über die Abhängigkeit der Winterroggenreife von der Witterung. (Veröffentlichungen des Instituts für Agrarmeteorologie der Karl-Marx

Universitat Leipzig, Band 1, Heft 3). By Kurt Müller. 6 in.×9 in., iv+53, *illus.*, Akademische Verlagsgesellschaft Geest und Portig K.-G., Leipzig, 1957. Price: *D.M.* 4.60.

This work uses phenological and climatological observations in an attempt to find a relationship between the weather and the ripening period of winter rye. The data are mainly from Germany for the years 1936 and 1937, and the ripening period is defined as the period between the beginning of blossom and crop harvest. Charts of mean daily sunshine in June and July and those for ripening period demonstrate a general inverse relationship between these elements in 1936 and 1937. Long-period means for 28 European stations lead to the regression:

$$R = 87{\cdot}7 - 5{\cdot}32h,$$

where R is mean ripening period and h the mean daily sunshine during this period. When rainfall is considered, the regression for Geisenheim becomes:

$$R = 95{\cdot}6 + 0{\cdot}114N - 8{\cdot}12h,$$

where N is the March–June rainfall (millimetres). The rainfall term is not strictly linear and a graphical adjustment is given for this.

A map of the mean number of hours of sunshine over Europe during ripening period shows a decrease from south to north, which suggests that day-length may also be important in determining ripening period.

The material presented in this paper has no obvious practical value and the author states that it is not possible to use past sunshine to forecast the date of end of harvest.

W. H. HOGG

Combination of observations. By W. M. Smart. $5\frac{1}{2}$ in.× 6 in., pp. xi + 253, *illus.* Cambridge University Press, London. 1958. Price: 35*s.*

The meteorologist as well as the astronomer and other scientists will find much useful information in this book, which is primarily concerned with methods of obtaining the best result from a given series of observations and of estimating the degree of precision of this result. It is not essentially a book on statistics though general statistical theory is discussed in the first introductory chapter and one chapter is devoted to theoretical frequency distributions including Pearson's curves. The main emphasis is on applications of the principle of least squares and the normal law of errors. Thus Chapters 2–6 are:- Errors of observation and the principle of least squares; probability and the normal law; measures of precision; measures of precision for weighted observations; equations of condition in several unknowns.

There are also chapters on the correction of statistics and correlation; normal errors of vectors are discussed briefly. Worked examples of some of the more important techniques are given. There are tables of the error function in an Appendix.

The book is clearly written and forms an excellent introduction to the subject as well as a useful and practical book of reference. Proofs are given of the underlying theory and this will enhance the value of the book to most readers, especially the student preparing for examinations.

It is perhaps strange that there is no mention of the book of the same name by Sir David Brunt, the last edition of which appeared in 1931. The scope of the two books is similar except that the earlier includes a long discussion of harmonic and periodgram analysis (now out of fashion), while Professor Smart dismisses the subject in a few pages. Professor Smart's new book is a worthy successor to the old which served many generations of students well. It is excellently printed (the reviewer found only one misprint) and the price is reasonable by present standards. J. K. BANNON

RAINFALL REPORTS

No readings of rainfall for Lairg, Crask have been received since April 1958.

METEOROLOGICAL OFFICE NEWS

Obituary.—*Mr. Thomas Leslie Hosker.* It is with deep regret that we learn of the death on 22 August of Mr. T. L. Hosker, Assistant (Scientific), at the age of 34 after a long illness. Mr. Hosker joined the Office in December 1941 as a Meteorological Assistant and all his service was spent at aviation outstations. Since 1952 he has served at Squires Gate.

He is survived by a widow, three sons and a daughter to whom the sympathy of all who knew him is extended.

Retirement.—*Mr. A. Stevens,* Senior Assistant (Scientific) retired on 22 August 1958. After service with the Royal Fusiliers in the First World War he was employed in the Ministry of Pensions. In 1926 he entered the Air Ministry and was transferred to the Meteorological Office in March, 1929. All his service in the Office has been at Headquarters in the General Services and Overseas Branches and, from 1955 until his retirement, in the overseas section of the Assistant Directorate Military Services.

WEATHER OF JULY 1958

Northern Hemisphere

For the third consecutive month the sub-polar trough in the Atlantic sector, although of normal intensity, was displaced south of its usual latitude. This displacement amounted to about 10° of latitude, the depression tracks lying across the British Isles instead of further north between Iceland and the Faeroes. Negative pressure anomalies of up to −5 millibars occurred over the Atlantic between approximately 30°N. and 55°N. and over Scandinavia.

The polar anticyclone was about 4 millibars more intense than usual and positive pressure anomalies occurred over Greenland reaching + 8 millibars on the south-east coast. Smaller positive anomalies occurred over most parts of Canada. The Azores high was centred near its normal position but was about 2 millibars weaker than normal. There was more cyclonic activity than usual in the Bering Sea area, giving small negative pressure anomalies there with a maximum value of −5 millibars over the Aleutians. Like the Azores high, the North Pacific high was a little weaker than usual. The Asian monsoon low was slightly deeper than normal and small negative pressure anomalies occurred in India and over the high ground in central and southern Asia.

Mean temperatures over western Europe were very close to the normal. They were 1° or 2°C. below normal over Scandinavia, whilst over eastern Europe and the Balkans the month was slightly warmer than average. Negative temperature anomalies predominated in European Russia, the largest being

−3°C. near the Caspian Sea. Over central regions of the North American continent temperatures were below average, anomalies of −3°C. occurring at some stations. These anomalies resulted from a southward displacement of the polar front and a number of particularly cold northerly outbreaks during the month. Temperature anomalies in Alaska and to the west of the Rockies in Canada and the United States were positive. They reached 3°C. at some stations but were generally about 2°C.

Rainfall totals for the month were above normal in most parts of western Europe. Over central and eastern Europe amounts were generally near normal and in the Balkans and Turkey the month was drier than usual. In all parts of the United States except the south-west, totals were above average. The southward displacement of the polar front gave very changeable weather especially in north-eastern states where many heavy storms and floods were reported. Canada, however, had a dry month, the total rainfall being between 40 per cent and 80 per cent of normal at most places.

WEATHER OF AUGUST 1958

Great Britain and Northern Ireland

The disturbed cyclonic weather of late July continued throughout August. At no time during the month did an anticyclone become established over the British Isles though around the 17th and 26th weather was dominated by ridges of high pressure.

A depression moved eastwards across Scotland on the 1st and thunderstorms were rather widespread over the British Isles on that and the following day. Slight rain or drizzle occurred at most places on the 3rd, but during the next two days there was moderate to heavy rain in many places and strong to gale force winds in the Orkneys and Shetlands associated with a vigorous depression which passed north-eastwards between Scotland and Iceland. Small secondary depressions moving east along the English Channel brought heavy rain with scattered thunderstorms to central and southern districts on the 7th.

On the 8th–10th a deep and slow-moving depression was situated in the eastern Atlantic and warmer air, accompanied by rain and drizzle, gradually spread northward over the British Isles. By the 10th, which was the warmest day of the month, a southerly airstream covered the country and temperature rose into the eighties locally in south-east England and reached 83°F. at London Airport. Thunderstorms broke out at many places during the afternoon and were fairly widespread also on the 11th and 12th. During the next three days there was a good deal of fog in the English Channel and vigorous depressions moving eastward across Scotland gave widespread rain on the 13th and 15th, much of which was heavy.

A break in the wet weather occurred on the 16th when a ridge of high pressure moved slowly eastwards across the country; the following day was also fairly dry and Dishforth recorded over 13 hours of sunshine.

Heavy thunderstorms became widespread on the 19th–22nd as a depression moved slowly from our south-west approaches to Western Europe. Flooding occurred in many areas, particularly in Devon, Cornwall and Yorkshire. On the 19th the village of Coombe Martin, north Devon, was badly damaged by floods and on the same day 1¼ inches of rain fell in an hour at Truro, Cornwall. There were widespread floods in the Manchester area on the 22nd where one inch of rain fell in an hour, while at Golder's Green, London, Col. Gold, late of the Meteorological Office, recorded 1½ inches in 46 minutes. A vigorous depression from the Atlantic brought gales to our south-west coasts and prolonged and often heavy rain to many districts on the 24th, as it moved eastward to the North Sea.

On the 26th a ridge of high pressure, associated with a weak anticyclone over France, brought a second break in the generally unsettled weather as it moved eastward across the country and on the following day, although troughs gave rain in the west, the eastern part of the country was dry with over 12 hours of sunshine at many places. During the last two days of the month, a quasi-stationary front in western districts and thundery troughs over France resulted in outbreaks of rain in the west and south-east while central districts had mainly dry weather.

Temperatures were a little below average generally, especially in central and southern districts of England; in Lancashire they were somewhat above average. Sunshine was below average in nearly all parts of the country; at Plymouth and Boscombe Down it was the dullest August since records began in 1921 and 1933 respectively. Most parts of the country had more than average rainfall, the excess being greatest in parts of Sussex, the Isle of Wight and Cornwall where more than twice the average was recorded.

The corn harvest has been seriously delayed by the absence of sun and the heavy rainfall; yields are fully expected to be reduced. The land was too wet to take heavy machinery and in areas where some harvesting was possible the more old-fashioned binder often had to be used in place of the heavier combine-harvester. Potato and sugar-beet crops are also threatened by the continued wet weather. Orchard work has been badly curtailed but yields promise to be good, especially the apple crop, provided that picking can proceed normally.

WEATHER OF SEPTEMBER 1958

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 ...	82	31	+2·2	158	+1	94
Scotland	78	27	+3·5	92	−5	107
Northern Ireland ...	72	40	+3·2	105	−1	86

*1916-1950 †1921-1950

RAINFALL OF SEPTEMBER 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square	3·64	167	*Carm.*	Pontcrynfe	11·07	248
Kent	Dover	2·29	101	*Pemb.*	Maenclochog, Dolwen Br.	10·57	197
,,	Edenbridge, Falconhurst	5·83	248	*Radnor*	Llandrindod Wells	6·71	214
Sussex	Compton, Compton Ho.	5·16	180	*Mont.*	Lake Vyrnwy	10·32	206
,,	Worthing, Beach Ho. Pk.	3·90	181	*Mer.*	Blaenau Festiniog	15·01	146
Hants	St. Catherine's L'thouse	3·75	158	,,	Aberdovey	8·41	202
,,	Southampton, East Pk.	4·87	192	*Carn.*	Llandudno	6·10	224
,,	South Farnborough	3·79	181	*Angl.*	Llanerchymedd	7·66	201
Herts.	Harpenden, Rothamsted	3·41	147	*I. Man*	Douglas, Borough Cem.	4·79	114
Bucks.	Slough, Upton	3·31	154	*Wigtown*	Newtown Stewart	6·28	146
Oxford	Oxford, Radcliffe	3·17	144	*Dumf.*	Dumfries, Crichton R.I.	5·56	149
N'hants.	Wellingboro' Swanspool	2·16	104	,,	Eskdalemuir Obsy.	6·11	115
Essex	Southend W.W.	3·48	217	*Roxb.*	Crailing	2·50	106
Suffolk	Ipswich, Belstead Hall	2·84	142	*Peebles*	Stobo Castle	3·91	118
,,	Lowestoft Sec. School	1·85	89	*Berwick*	Marchmont House	2·27	88
,,	Bury St. Ed., Westley H.	2·85	123	*E. Loth.*	N. Berwick	2·39	98
Norfolk	Sandringham Ho. Gdns.	2·96	124	*Midl'n.*	Edinburgh, Blackf'd H.	2·29	90
Dorset	Creech Grange	5·14	162	*Lanark*	Hamilton W.W., T'nhill	4·61	128
,,	Beaminster, East St.	6·11	190	*Ayr*	Prestwick	3·38	102
Devon	Teignmouth, Den Gdns.	3·86	151	,,	Glen Afton, Ayr. San	5·81	115
,,	Ilfracombe	6·36	190	*Renfrew*	Greenock, Prospect Hill	5·41	101
,,	Princetown	10·18	153	*Bute*	Rothesay, Ardencraig	2·87	57
Cornwall	Bude	5·98	202	*Argyll*	Morven, Drimnin	5·16	90
,,	Penzance	5·74	182	,,	Ardrishaig, Canal Office	6·11	96
,,	St. Austell	6·94	194	,,	Inveraray Castle	7·24	89
,,	Scilly, St. Mary	5·25	213	,,	Islay, Eallabus	3·03	61
Somerset	Bath	4·81	189	,,	Tiree	4·19	101
,,	Taunton	4·01	164	*Kinross*	Lock Leven Sluice	3·94	120
Glos.	Cirencester	5·36	190	*Fife*	Leuchars Airfield	1·87	77
Salop	Church Stretton	6·43	236	*Perth*	Loch Dhu	6·30	93
,,	Shrewsbury, Monkmore	6·82	319	,,	Crieff, Strathearn Hyd.	4·87	144
Worcs.	Worcester, Red Hill	5·67	278	,,	Pitlochry, Fincastle	4·66	153
Warwick	Birmingham, Edgbaston	3·92	157	*Angus*	Montrose Hospital	1·97	75
Leics.	Thornton Reservoir	2·68	116	*Aberd.*	Braemar	3·25	109
Lincs.	Cranwell Airfield	1·80	90	,,	Dyce, Craibstone	2·44	80
,,	Skegness, Marine Gdns.	2·63	132	,,	New Deer School House	2·69	79
Notts.	Mansfield, Carr Bank	2·51	117	*Moray*	Gordon Castle	2·70	89
Derby	Buxton, Terrace Slopes	5·92	150	*Inverness*	Loch Ness, Garthbeg	3·04	84
Ches.	Bidston Observatory	4·93	187	,,	Fort William	5·10	73
,,	Manchester, Airport	4·22	157	,,	Skye, Duntulm	4·33	86
Lancs.	Stonyhurst College	4·95	108	,,	Benbecula	4·58	109
,,	Squires Gate	3·23	98	R. & C.	Fearn, Geanies	2·08	92
Yorks.	Wakefield, Clarence Pk.	2·96	143	,,	Inverbroom, Glackour	2·41	48
,,	Hull, Pearson Park	2·27	112	,,	Loch Duich, Ratagan	3·87	53
,,	Felixkirk, Mt. St. John	3·16	132	,,	Achnashellach	38·6	54
,,	York Museum	2·41	116	*Suth.*	Stornoway	3·35	89
,,	Scarborough	1·50	72	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough	2·68	133	,,	Wick Airfield	0·84	29
,,	Baldersdale, Hury Res.	4·24	129	*Shetland*	Lerwick Observatory	4·46	119
Nor'l'd	Newcastle, Leazes Pk.	1·63	70	*Ferm.*	Belleek	3·64	80
,,	Bellingham, High Green	3·64	113	*Armagh*	Armagh Observatory	2·92	100
,,	Lilburn Tower Gdns	2·66	106	*Down*	Seaforde	7·31	202
Cumb.	Geltsdale	4·13	115	*Antrim*	Aldergrove Airfield	4·07	135
,,	Keswick, High Hill	6·44	115	,,	Ballymena, Harryville	3·90	100
,,	Ravenglass, The Grove	4·56	104	*L'derry*	Garvagh, Moneydig	3·57	96
Mon.	A'gavenney, Plâs Derwen	7·77	250	,,	Londonderry, Creggan	3·26	75
Glam.	Cardiff, Penylan	7·01	190	*Tyrone*	Omagh, Edenfel	3·99	104

* 1916–1950

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

Wt-18. K16.

M.O. 641 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 87, No. 1,038, DECEMBER 1958

METEOROLOGICAL FACTORS IN THE CENTRAL DESERT OF ICELAND

By F. G. HANNELL, B.Sc., Ph.D. and I. Y. ASHWELL, M.A.

In August and September 1956 the members of the British Schools Exploring Society's eighteenth expedition spent six weeks in central Iceland, during which time various scientific tasks were undertaken. On this occasion certain meteorological projects received special attention, and these have already been outlined in general terms.[1]

The expedition's main meteorological station, at point A in Figure 1, was located near the south-eastern corner of Langjökull in latitude 64° 26′ N., longitude 20° 15′W. Immediately to the north lay the Jarlhettur, a range of very steep-sided tuff and lava hills, whose general alignment was continued south-westwards through Lambahraun, Porolfsfell and Hognhöfdi. Stretching for some miles to the east, west and south was a desert of volcanic and glacial debris whose surface, diversified by innumerable minor hillocks of irregular shape, varied from sand to rock pavement. There was virtually no vegetation except for isolated patches of turf-covered loess which were very sparsely distributed in the north but more numerous in the south-east. These were being rapidly destroyed by wind action. Much of the desert surface was covered by bare loess, from which most of the surface soils of Iceland's farming regions have been derived.[2] Mixed with the loess were large numbers of morainic stones and boulders of all sizes, which were left littering the surface as a result of the blowing away of the finer material.

During the first week of August, many dust-storms of two distinct types were observed in this desert area. Under the influence of strong winds the finer particles of surface material were raised as sheets of dust and carried away.[3] In calmer weather with strong sunshine, individual dust devils of a few feet in diameter developed, sometimes beneath small cumulus clouds.[4] These dust devils increased in number during the warmest hours and frequently coalesced into a widespread mass of dust which, however, was still clearly convective in character. Although on a few occasions dust devils moved in close proximity to the main meteorological station, most of the dust-storms of both types were restricted to the southern part of the desert near Sandfell, in spite of the fact that there was enough fine material on the surface to give rise to them almost anywhere. Since the deposition of this dust is of the utmost importance in building

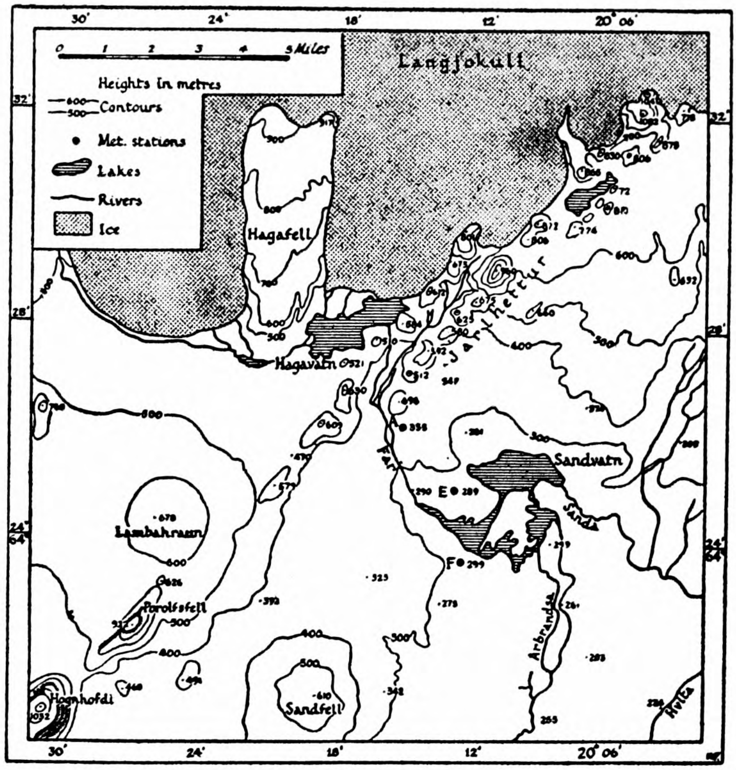


FIGURE 1.—POSITIONS OF STATIONS

up the cultivated soils of Iceland[5] it was decided to combine an examination of the factors influencing the development of dust-storms with an investigation of such changes in meteorological conditions as might occur with increasing distance from the ice-cap. Two subsidiary stations were therefore established at points E and F in Figure 1, and at each of these, as well as at station A, observations of all elements were made every hour, both by day and by night, from 2100 G.M.T. on 26 August to 0900 G.M.T. on 1 September.

Station A was sited reasonably clear of the Jarlhettur range and exposure in all directions other than due north was excellent. Here a large Stevenson screen housed a thermograph and a hygrograph, in addition to the maximum, minimum, wet-bulb and dry-bulb thermometers. A shipboard screen, containing wet- and dry-bulb thermometers, was also erected to provide readings strictly comparable with those taken at the subsidiary stations which were equipped with screens of this type. A cup counter anemometer was erected 9 feet above the surface and wind speed at the time of each observation was measured by noting the change of figures in a one-minute period and converting into knots at 33 feet from prepared tables. Wind direction was indicated by a vane comprising a stout aluminium arm mounted on the bearings of a bicycle wheel. This too was fixed 9 feet above the surface and proved to be well balanced and steady but very sensitive. Pressures were read from an aneroid barometer, which had been checked against a mercury barometer at Reykjavik, and a barograph, both of which were housed in a tent. A sunshine recorder was erected on a low hillock, with a good exposure in all directions except when the sun was very low in the west.

The subsidiary stations E and F were established at distances of 2 and 3½ miles respectively to the south-south-east of station A on surfaces which, as was general elsewhere, were covered with loess and heavily littered with rounded stones. At each site a cup counter anemometer, erected and read as at station A, and a wind-direction flag were placed at the summit of a small hillock, but the other instruments were set up well clear of it.

A shipboard screen was mounted on bamboo poles about 4 feet above the surface, and this housed wet- and dry-bulb thermometers. Bent-stem thermometers were placed at depths of 4 and 8 inches and in an effort to obtain some rough indication of surface temperature, the bulb of an ordinary thermometer laid on the ground was covered with a thin layer of soil. Owing to the fine nature of this soil it was difficult to keep the bulb covered and it is highly probable that radiation effects were considerable. A somewhat more reliable indication of air temperatures near the ground was obtained from the readings of an Assmann psychrometer held at a height of one inch above the surface, but it is likely that these were lower than the true values, particularly during the warmest hours, owing to a tendency for the instrument to draw down air from higher levels.[6]

The 6-day period during which the meteorological party was concerned with this particular project was characterised by two contrasting weather types; a calm type with mainly northerly winds and clear skies during the first three days, and a cloudy type with much stronger south-westerly winds during the last three. One day has been selected from each of these types to illustrate the prevailing conditions.

0800 G.M.T. 28 August to 0700 G.M.T. 29 August.—The synoptic situation at 0600 G.M.T. on 28 August is shown in Figure 2 (*a*) which is based upon all available data. At 0800 G.M.T., upper winds at Keflavik were slightly east of north up to 7000 feet at speeds of about 10 knots and then became west of north, increasing to 15 knots. Throughout the 24-hour period under review, Iceland lay on the north-east fringe of a large anticyclone.

At station A a continuous record of pressure was obtained by means of a barograph which was periodically checked against an aneroid barometer. Tendencies from an assumed zero at 0900 G.M.T. are represented in Figure 3(*a*). In view of the prevailing synoptic situation, the pressure at station A at 0900 G.M.T. is likely to have been only slightly higher than that at Reykjavik. Thereafter the pressure at both Reykjavik and Akureyri fell slightly until 1500 G.M.T., but at station A the decline was much more rapid and pronounced. There the lowest pressure was recorded at 1300 G.M.T. and its value was 2·5 millibars below that registered at 0900 G.M.T. The pressure at station A was maintained at this comparatively low level until 1800 G.M.T., but by 2100 G.M.T. it had risen by 2·5 millibars. Thereafter the tendency graph for station A runs roughly parallel with those for the coastal stations.

Throughout 28 August there was uninterrupted sunshine at station A from 0715 to 1940 G.M.T. and no cloud whatsoever was reported from A, E or F until after sunset. During the morning there was no measurable wind at A or E, and at F only very light breezes of uncertain direction were experienced (Figure 3(*b*)). However, between 0800 and 1200 G.M.T., when temperatures were increasing rapidly (Figure 3(*c*)), there were considerable fluctuations in the absolute humidity values (Figure 3(*d*)), and it is particularly worthy of note that each of

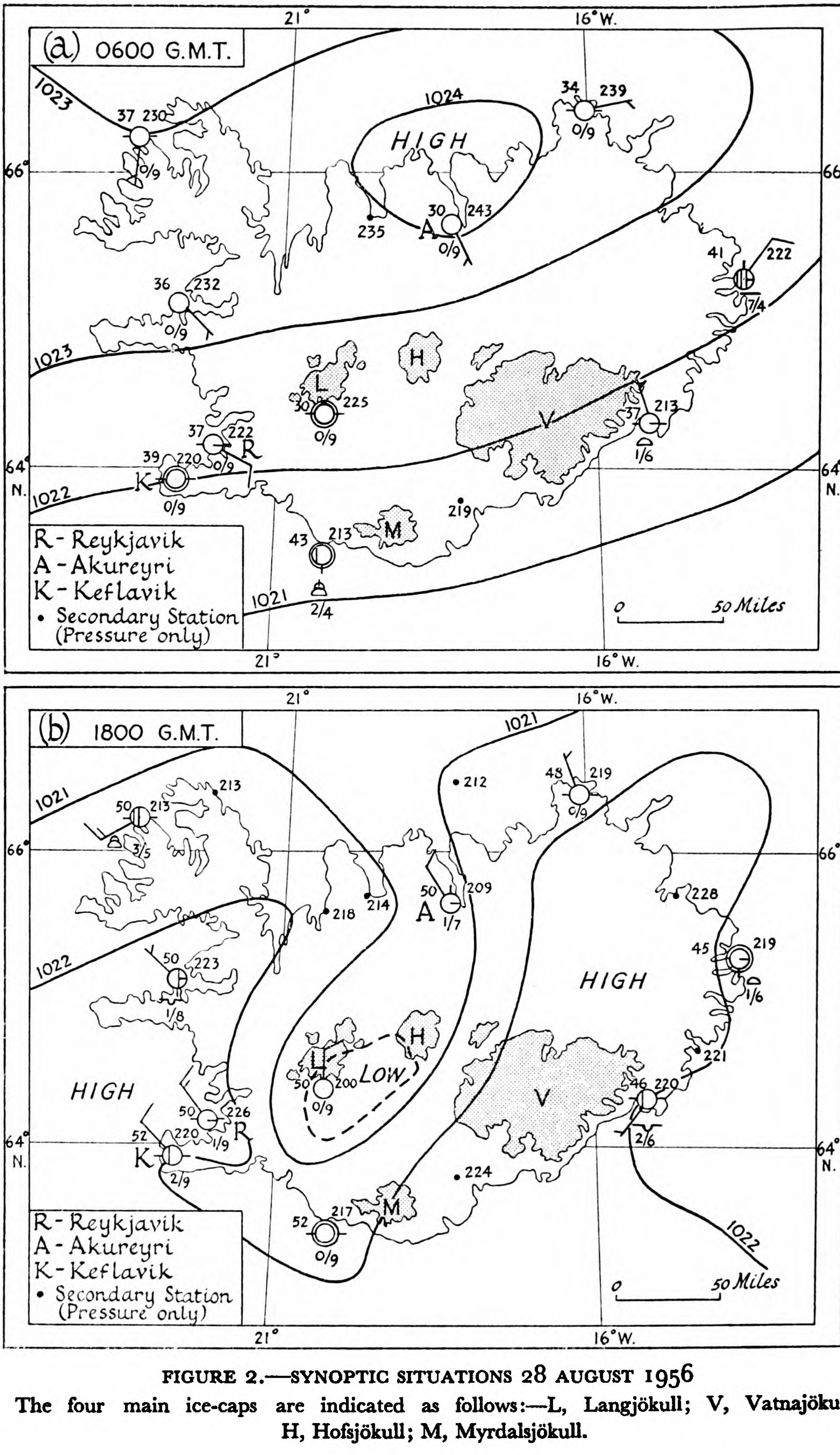


FIGURE 2.—SYNOPTIC SITUATIONS 28 AUGUST 1956

The four main ice-caps are indicated as follows:—L, Langjökull; V, Vatnajökull; H, Hofsjökull; M, Myrdalsjökull.

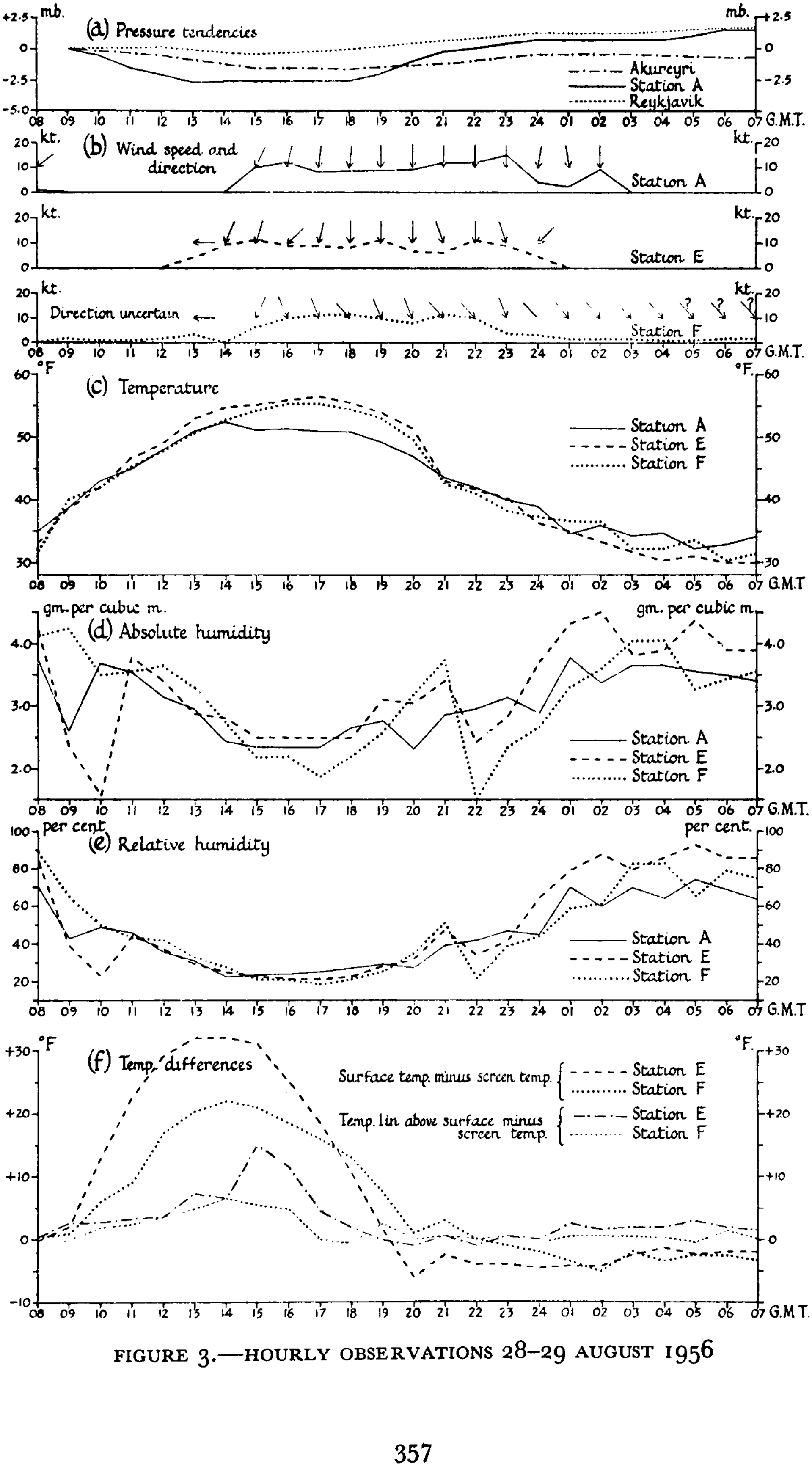


FIGURE 3.—HOURLY OBSERVATIONS 28–29 AUGUST 1956

these was first experienced at A, the station nearest to the ice-cap. Here the temperature reached a maximum for the day at 1400 G.M.T. In the succeeding hour the wind at station A rose from zero to a speed of 11 knots from the north-north-east, and this was accompanied by a fall in temperature which then remained virtually unchanged until 1800 G.M.T. Stations E and F also experienced this same wind, but at neither of these locations was there any decline in temperature. On the contrary, temperatures there rose to maxima at 1700 G.M.T., in spite of the fact that the winds at these stations, like that which produced the fall of temperature at station A, had undoubtedly come from the ice-cap. By 1800 G.M.T. absolute humidities at all stations were rising from the low values recorded during the warmest hours, but a temporary decline at station A at 2000 G.M.T. was followed two hours later by sharp falls at E and F. Thereafter absolute humidities rose but not without minor decreases, and that experienced at station A at 0200 G.M.T. coincided with a temporary increase in the strength of the northerly wind.

It would seem that these fluctuations in absolute humidity have a very close connection with a variation in the properties of winds blowing off the ice-cap. At each of the three stations the maximum wind was northerly and throughout the 24-hour period under review changes in absolute humidity values were first experienced at A, the station nearest to the ice-cap.

The relative humidity graphs (Figure 3(*e*)) are noteworthy for the low values attained in the middle and late afternoon, but the figure of 19 per cent recorded at station F at 1700 G.M.T. was by no means the only low figure obtained during the five-week period throughout which observations were continued at station A.

The fall in pressure at A during the late morning and early afternoon (Figure 3(*a*)) was also no isolated phenomenon. It was always most pronounced with clear skies and northerly winds, and may well indicate a general fall in pressure during the warmest hours over those extensive areas of bare sand and rock which lie between the main ice-caps.[7] It has previously been reported that these ice-caps, whose positions are indicated in Figures 2 and 4, set up a blocking action to northerly winds, and that small ridges of high pressure and troughs or even shallow cyclonic centres develop on their windward and leeward sides respectively.[8] Further evidence of this blocking action was provided by the members of a French expedition who, in the summer of 1954, made regular meteorological observations at Laugafell, some nine miles from the north-eastern edge of Hofsjökull. Their report states that on nearly 80 per cent of those 230 occasions when meteorological observations were made the wind blew due east or west; that is, in a direction parallel to the barrier provided by the northern slopes of Langjökull, Hofsjökull and Vatnajökull.[9]

An area of low pressure certainly developed on the leeward side of Langjökull during the late morning and afternoon of 28 August (Figure 2(*b*)), and this accounts for many of the fluctuations specified above. It would seem that the surface winds were blocked by Langjökull to the north, whilst over the desert intense insolation on the bare stony surface set up strong convection currents. Normally this large-scale raising of air would at once be compensated by surface currents, but since these were blocked an area of comparatively low pressure was established which increased in intensity with the surface temperature. The extent of this surface heating is indicated by the temperature differences shown in Figure 3 (*f*). As mentioned above, it is highly probable that the recorded values of surface temperature were strongly affected by radiation, but it is noteworthy that at each of the stations E and F the differences between the temperatures registered by an Assmann psychrometer at a height of 1 inch above the surface and those recorded in the shipboard screen show the same trend as the differences between the surface and screen values. It is particularly significant that at each of the two desert stations the maxima in these graphs of temperature differences occurred well before the time of the screen maximum. In fact, Figure 3 (*f*) indicates that the greatest turbulent activity on this particular day was between 1300 and 1500 G.M.T. It was at the beginning of this 2-hour period that the barograph at station A attained its maximum depression (Figure 3 (*a*)). At the same time mirages were seen over the desert to the south, and dust devils, which were observed over the southern part of the desert between 1200 and 1600 G.M.T., were reported to be particularly numerous in the neighbourhood of station F at 1345, 1400 and 1420 G.M.T. At 1300 G.M.T. very light breezes of uncertain direction were recorded at each of the two desert stations, but by 1500 G.M.T. all three stations were experiencing north-north-easterly winds which at A and E exceeded 10 knots.

In late July 1931, similar phenomena were observed near the north-west margin of Vatnajökull.[10] On that occasion thermometers were placed both above and below the surface, the temperature of which was then obtained by extrapolation. Results showed that over a period of five hot days the mean maximum temperature of the surface, very similar to that south of Langjökull, was 79°F., whereas that at a height of one metre was only 54°F. Thus the difference of 25°F. is one which is comparable with those shown in Figure 3 (*f*).On this earlier occasion mirages were seen in mid-morning, and dust devils, which attained a height of 400 metres above the surface, were also observed. As from that time, the north-east wind was replaced by a glacier wind from Vatnajökull which, without reaching any great strength, prevailed until a few hours before midnight.

Under the conditions prevailing on 28 August it seems probable that the lower pressure over the desert led to the establishment of a pressure gradient which eventually was sufficient to compensate for the blocking action of the ice-cap. Air which had passed over the ice-cap's summit was then drawn down as a Föhn wind, thus making good the loss by convection. The lower layers of this wind which had been in contact with the ice surface were cold and, in spite of adiabatic warming consequent upon their descent, their arrival soon after 1400 G.M.T. was marked by a fall in temperature at station A and a slight check in the temperature rise at station E. The upper layers of the Föhn wind, which had not been chilled by contact with the ice surface, were drawn down by turbulence over the central parts of the desert. There was thus no check in the rise of temperature at station F, but here the relative humidity at 1700 G.M.T. fell to 19 per cent. As convective activity decreased so did the descent of the Föhn wind's upper layers which it induced. The moister lower layers, which had been in contact with the melting surface of the ice-cap during the warmest hours of the day, now spread further southwards over the desert, thus causing a rapid increase in absolute humidity values at each of the three stations after 1700 G.M.T.

At 2100 G.M.T. there was a marked discontinuity in the rate of cooling at each of the three stations and this was followed throughout the night by minor fluctuations of temperature. These, together with the discontinuity and those more pronounced variations in absolute humidity which occurred throughout the night as well as in the late morning, were the consequence of meteorological events on the ice-cap. Such events were the subject of a separate study on other dates and the results obtained from this are to be reported in a later paper.

0800 G.M.T. 31 August to 0700 G.M.T. 1 September.—In the interval since the 24-hour period described above, an area of low pressure formed over the north-east coast of Greenland, and the anticyclone, which had induced northerly winds in the previous period, moved eastwards to a position almost due south of Iceland. The moist south-westerly winds associated with this change brought a remarkable reversal of conditions over the central desert.

At 0800 G.M.T. on 31 August the upper air ascent at Keflavik showed winds of average speed about 22 knots, which were south-westerly up to 3000 feet but almost westerly above 5000 feet. Moreover, between 4000 and 6000 feet there was a very marked layer of dry air. The synoptic situation at 0600 G.M.T. on this date is shown in Figure 4 (*a*), which is based upon all available information. It would seem that Langjökull, together with any weak anticyclonic circulation which may have been associated with it, was tending to divert air approaching from the south-west, whilst the wide but broken range of mountains, with highest points at about 1,100 metres, which runs south-westwards from Langjökull almost to the south coast had, together with the ice-cap, given rise to the formation of a ridge and trough on the windward and leeward sides respectively. On the western side of the trough, winds which were being diverted to the south of Langjökull had lost some of their moisture on the windward side of the mountains. However, on the eastern side of the trough, winds from the south coast were blowing parallel to the range of mountains without significant interruption. It would seem that the trough continued along the eastern side of Langjökull almost to the north coast, since the southerly winds at Akureyri, which would normally be attributed to the steering effects of local relief,[11] were also experienced by the expedition's long-march party, which was at this time half-way up the northern slope of Hofsjökull. At this latter location the southerly winds, which were estimated to exceed 20 knots, were accompanied by overcast skies.

Wind directions at each of the stations A, E and F fluctuated between west and south-south-west and there were periods duriug which the general wind speed of 10 knots increased to 20 knots (Figure 5 (*a*)). It is particularly noteworthy that whenever the wind veeredto a more westerly point, the absolute humidity values fell appreciably (Figure 5 (*b*)), whereas when it backed towards the south-south-west they increased. Moreover, the veering of the wind at stations E and F at 1100 G.M.T. and at all three stations at 1300 G.M.T., was accompanied not only by lower absolute humidity values but also by an increase in the rate of rise of temperature (Figure 5 (*c*)). In general, temperatures increased to maxima at 1500 G.M.T., and during the preceding hour station F experienced a very marked increase of temperature with an equally sharp decrease in absolute humidity. There was an extensive cloud cover of stratus throughout the 24-hour period, but following a veering of the wind slight breaks occurred, particularly between 1600 and 1800 G.M.T., (Figure 5 (*d*)), and these were accompanied by decreases in absolute humidity values. Furthermore, the sunshine recorder at station A showed a few isolated patches of sunshine

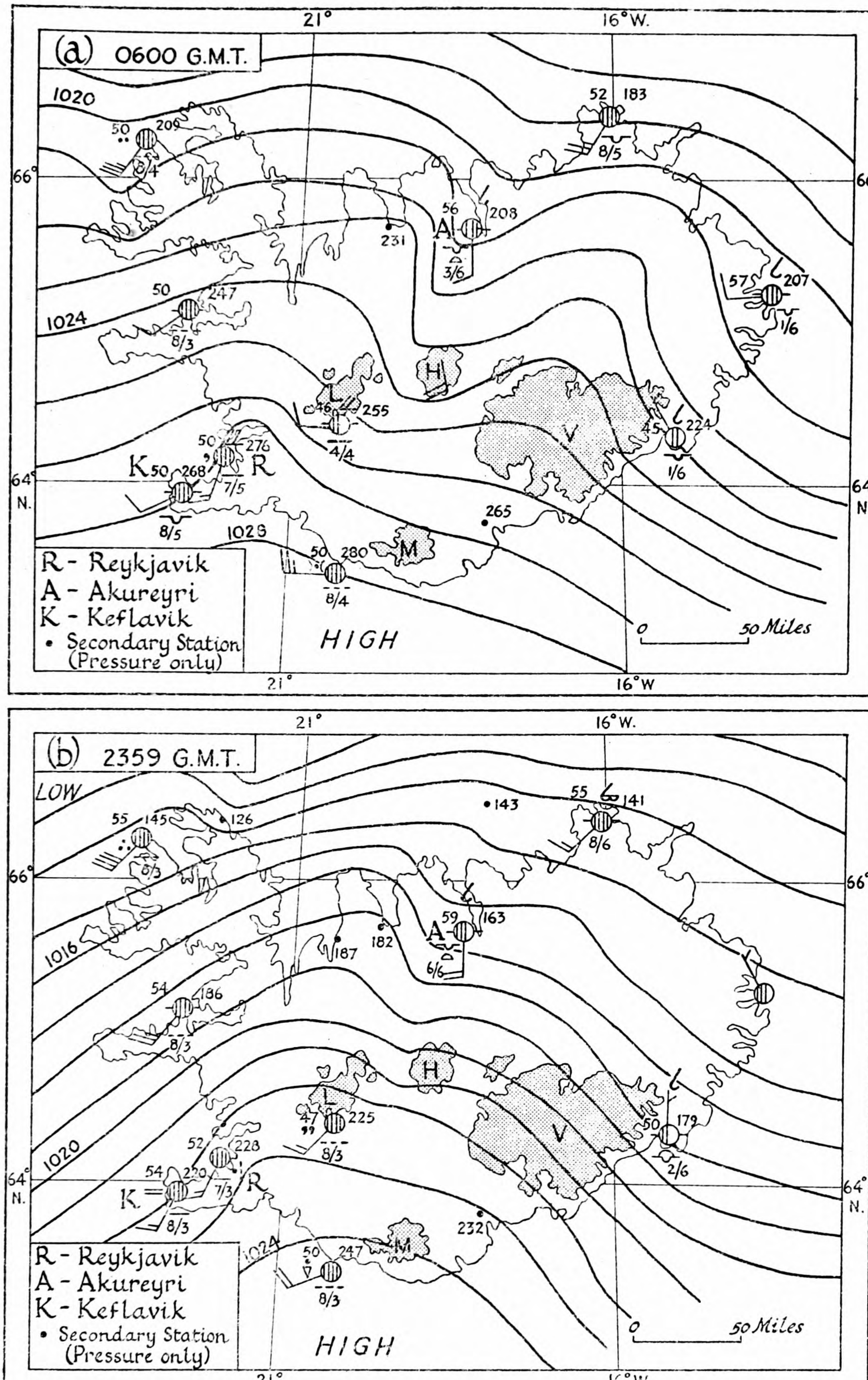


FIGURE 4.—SYNOPTIC SITUATIONS 31 AUGUST 1956

The four main ice-caps are indicated as follows:—L, Langjökull; V, Vatnajökull; H, Hofsjökull; M, Myrdalsjökull.

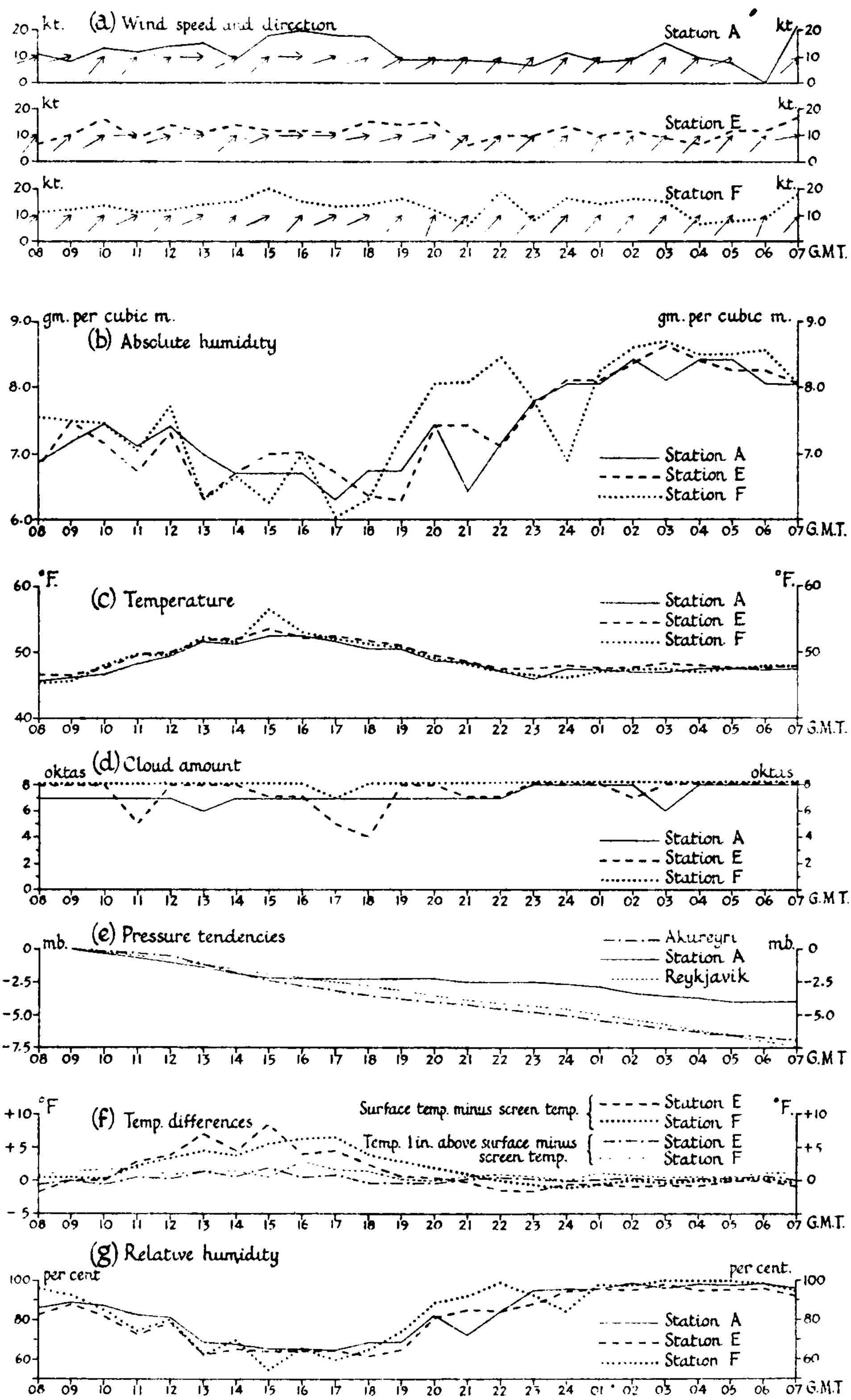


FIGURE 5.—HOURLY OBSERVATIONS 31 AUGUST–1 SEPTEMBER 1956

which coincided with the bursts of more westerly air. All these changes, which were initiated by a veering of the wind, are clearly indicative of Föhn conditions on the eastern side of the mountain range.

Although the three stations were affected by slight changes in the position of the local trough, this lay just to the east for much of the period between 1000 and 1900 G.M.T., and winds which were mainly from the more westerly points resulted in an over-all decrease in the absolute humidity values (Figure 5 (*b*)). However, by 1900 G.M.T. the winds at each of the three stations were beginning to back and thereafter absolute humidity values showed a general increase. The upper winds at Keflavik also showed this tendency, and by midnight a south-westerly airstream was established over the whole of south-west Iceland (Figure 4 (*b*)). Since the winds were now blowing parallel to the mountain range the cause of the local trough had disappeared, and in fact a ridge of relatively higher pressure was forming over the southern part of the central desert. It is significant that until 1500 G.M.T. pressure at station A decreased at the same rate as that at Reykjavik and Akureyri (Figure 5 (*e*)), but that thereafter it remained relatively static whilst that at the two coastal stations continued to decline.

Moreover, soon after the cessation of the Föhn effect, drizzle began to fall at each of the stations A, E and F. A meteorological observer with the expedition's long-march party reported conditions which suggested that the trough moved north from Hofsjökull during the late morning of 1 September.

The sharp falls in absolute humidity which occurred after 2100 G.M.T. and the slight increases of temperature which were recorded after 2200 G.M.T. appear to be connected, as on 28–29 August, with conditions on the ice-cap, since they are similar to those experienced with northerly winds. The fact that on this occasion the winds were south-westerly at 10 knots and that the most southerly station was the last to be affected constitutes a phenomenon of which a convincing explanation has yet to be found.

Under these conditions, with comparatively moist air, gusty winds and generally overcast skies, the temperature range (Figure 5 (*c*)) was very small compared with that of the previous period (Figure 3 (*c*)). Ground temperatures still showed a tendency to rise a few degrees above those recorded in the screen (Figure 5 (*f*)), but this effect was in no way comparable with that of the previous period (Figure 3 (*f*)). Dust-storms, however, were again very marked but there was now no sign of convective activity therein. On the contrary, whenever the wind speed exceeded 12 knots, dust was moved in dense sheets within a few feet of the ground, even though relative humidity was over 60 per cent throughout the period (Figure 5 (*g*)) and was over 80 per cent by 2000 G.M.T. when dust-storms were still being reported.

Conclusions.—Weather conditions typical of any particular air mass may be altered almost beyond recognition as a consequence of the effects produced by the ice-caps and the pronounced relief of Iceland. During the first of the above periods the weather was mainly influenced by the blocking action of Langjökull. Bright, dry conditions prevailed with very marked surface heating and convection, and a local area of low pressure was formed in the lee of the ice-cap. The ranges of air temperature (Figure 3 (*c*)) and relative humidity (Figure 3 (*e*)) were considerable and this probably had a marked effect on the weathering of rock on the desert surface.

Each of the three reporting stations was affected by winds which had passed over the ice-cap. However, those at station F, 6½ miles from the ice-cap, were Föhn winds, and true glacier winds were experienced only at station A, about 3 miles from its edge. During this period dust devils coalesced into large-scale convective dust-storms. These carried dust to great heights and this was deposited in other parts of Iceland or carried beyond its shores.

In the second period, however, the ice-cap played a much smaller part, although the trough formation was due very largely to its influence. Such troughs, which form as a result of the effects of relief upon air flow, may disappear entirely with a change in wind direction or possibly develop into fronts in the general circulation. Under the cloudy and windy conditions which now prevailed, the ranges of temperature and humidity were much smaller, but dust-storms still occurred on a large scale. These, however, were quite different to those which characterised the first period. When wind speeds exceeded 12 knots, dust was moved in dense sheets but only at a very restricted height, and it is probable that none of this material was carried far from its source.

REFERENCES

1. HANNELL, F. G. and ASHWELL, I. Y.; Meteorological studies in Iceland. *Weather, London,* **12,** 1957, p. 365.
2. EMILSSON, S.; Lossbildung auf Island. *Rit. Visind. Isl., Reykjavik,* **11,** 1931.
3. SPENCE, M. T.; Soil blowing in the Fens in 1956. *Met. Mag., London,* **86,** 1957, p. 21.
4. ROSS, J.; Dust devil observed at Coalburn, Lanarkshire. *Met. Mag., London,* **85,** 1956, p. 215.
5. THORARINSSON, S.; Tefrokronologiska studier pa Island. *Geogr. Ann., Stockholm,* **26,** 1944, Chapter 1.
6. NYBERG, A.; Temperature measurements in an air layer very close to a snow surface. *Geogr. Ann., Stockholm,* **20,** 1938, p. 234.
7. HANNELL, F. G., and STEWART, R. H. A.; Meteorological observations in central Iceland. *Met. Mag., London,* **81,** 1952, p. 257.
8. LAMB, H. H.; A visit to Iceland. *Quart. J. R. met. Soc., London,* **65,** 1939, p. 245.
9. BOUT, P., CORBEL, J., DERRUAU, M., GARAVEL, L. and PEGUY, CH. P.; Geomorphologie et glaciologie en Islande centrale. *Norois, Poitiers,* **2,** No. 8, 1955, p. 499.
10. SLANAR, H.; Klimabeobachtungen aus Zentral-Island. *Met. Z., Braunschweig,* **50,** 1933, p. 379.
11. KIMBLE, G. H. T.; Winds in Icelandic fjords. *Bull. Amer. met. Soc., Lancaster, Pa.,* **27,** 1946.

DIFFERENCES IN THE METEOROLOGY OF THE NORTHERN AND SOUTHERN POLAR REGIONS

By H. H. LAMB, M.A.

Read at the meeting of the International Association of Meteorology, International Union of Geodesy and Geophysics, Toronto, September 1957.

Summary.—Differences in the extent and arrangement of land, ocean and ice, and in the heat budget, introduce important differences of general atmospheric circulation as between Arctic and Antarctic. The southern upper westerlies are more powerful, more nearly circular in course and have less seasonal shift of latitude than their northern counterparts: in latitudes south of 40°S. the main trough and ridge are apparently positioned by thermal controls. At the surface the most striking difference is the penetration of deep, vigorous depressions in many sectors south of 67°S. in winter, so that little of Antarctica can be quite immune from the associated gales and blizzards. There should also be important differences between Northern and Southern Hemispheres in the response to small changes in the amount of incident radiation.

Introduction.—Meteorological differences arise of necessity from the very unlike geographical setting and the, partly consequential, differences of heat budget in north and south.

Shortage of observational data south of 40°S. has until recently compelled all workers on the synoptic weather analysis of the region to appeal to a greater or less extent to analogy with Northern Hemisphere experience. This has served well: for the differences are in the geographical framework and in the large-scale atmospheric flow patterns conditioned thereby, rather than in the meteorological processes observed.

Enough is now known of the prevailing mean-sea-level pressures and 500-millibar heights at the northern and southern flanks of the southern westerlies and from sample soundings within the westerlies to derive a useful first assessment of the strength and broad characteristics of the system. (The Pacific sector must unfortunately still be excluded from these remarks since data about the upper air circulation are still almost non-existent there.) From this it appears that the momentum of the southern circulation is so great that differences in the large-scale effects are by no means confined to the respective polar regions: in some ways the whole world is affected.

Geography.—The southern polar regions are occupied by the most elevated continent in the world whose area in relation to other great land masses is seen in Table 1. Antarctica's longest crossing, on the ninetieth meridian or from the coast of Queen Maud Land near Maudheim to the north coast of South Victoria Land, is about 2,400 nautical miles; from Little America across West Antarctica to the Weddell Sea is only about 1,200 miles.

TABLE I—AREAS OF MAIN LAND MASSES

	Millions of square (nautical) miles
Asia	13·0
Africa	8·7
North America	5·8
Central and South America	5·4
Antarctica	4·0 approx.
Europe	2·8
Australia	2·2
Greenland	0·6
Antarctica plus maximum extent of sea ice	10*

* Sir Napier Shaw's estimate[1] was 13·1 million square (nautical) miles. The new estimate of ten million is based on Mackintosh and Herdman's maps of the ice limits in the Southern Ocean.[2]

In spite of its general elevation of over 2,000 metres, Antarctica has regions which may be considered as fairly extensive lowland (for example, the Ross Ice Shelf—Rockefeller Plateau, the Filchner Ice Shelf south of the Weddell Sea, the Bellingshausen Sea ice and, probably, the hinterland of the eastern Wilkes Land coast). Unlike Greenland, Antarctica serves as the source of vast masses of deep cold air which are observed over the surrounding ocean.

The Southern Ocean rings the earth in 60°S., occupies most of the southern temperate zone and is generally 1,500–2,000 miles or more in width. It is invaded by no great meridional current of warm surface water to compare with the Gulf Stream (North Atlantic Drift) or the Kuro Shiwo (North Pacific Current). The more or less sharp water-current boundaries—the subtropical and Antarctic convergences—pursue a broadly zonal course, mostly near 40°S.

and 50–55°S.: only the Antarctic convergence, the boundary between Antarctic and intermediate water, has a decided north-eastward trend in one sector 80–35°W. between Drake Passage and a point north of South Georgia (that is, from about 62°S. to 48°S.).

By contrast, the central Arctic is a deep ocean with access to warm water of North Atlantic origin through the broad channel of the Norwegian Sea and Barents Sea. Nevertheless, the main ocean surface freezes in winter to form a continuous surface of ice and snow with the great continents which occupy most of the zone of westerlies 40–70°N.

The seasonal variation of extent of frozen surface is seen in Table II. Here the effect of Asia and North America in extending the frozen surface in winter and introducing a strongly heated surface to 70°N. in summer is clearly seen.

TABLE II—EXTENT OF SNOW AND ICE SURFACE

	Area in millions of square (nautical) miles	Equivalent latitude of limit
Antarctic		
Summer minimum (February–early March)	5·7	68°S.
Winter maximum (about September) ...	10 approx.	60°S.
Arctic		
Summer minimum (August–early September)	3·2 to 3·6	72–73°N.
Winter maximum (January–early February)	16 to 19	50°N.

Note:

1. Equivalent latitude of the limit is the position in which the boundary would lie if the frozen surface were circular and concentric with the Pole.
2. For the Antarctic, areas are measured from the normal limits of ice given by Mackintosh and Herdman.[2]
3. Arctic summer minimum areas are measured from charts published in the yearly volumes of *Isforholdene i de arktiske Have.*[3] The minimum area of northern ice, $3 \cdot 2 \times 10^6$ square nautical miles, refers to the optimum summers of the 1930's; the higher figure for the minimum occurred in the decade 1910–19 and probably also in more recent years.
4. Arctic winter maximum areas are measured from unpublished maps of the snow-and-ice limit. The northern winter ice- and snow-cover presents a non-circular form and the part south of 45°N. over the continents is generally impermanent, much of it thin snow easily removed by invading warm air, rain or sunshine. This leaves about 14×10^6 square nautical miles of well established snow- and ice-cover in January, corresponding to an equivalent latitude for the limit of 55°N.
5. A change of one degree of latitude in the mean position of the ice limit around the entire Southern Ocean at the time of the winter maximum would amount to about 8–10 per cent of the total extent of sea ice; a similar shift at the end of the melting season would amount to 30 per cent or more of the sea-ice belt, but would be less likely to occur because the present summer minimum normally eliminates the pack-ice belt in some eastern longitudes.

In midwinter part of the central Arctic about 75°N., 140°E.–140°W. partially isolated from the Pacific by high mountain chains* and beyond the limit of penetration of most Atlantic depressions following the favourite tracks towards the Barents and Kara Seas, is generally more remote from the main energy sources of cyclonic activity than anywhere in the Antarctic ever is. An exception to this statement may be represented by depressions deepening over the relatively warm open water in the one sector Denmark Strait–Barents Sea. Nowhere within 2,000 miles of the inner Arctic area specified do the gradient winds indicated by the mean 500-millibar pattern in winter exceed 20–25 knots; the region appears as an anticyclonic development area in relation to the nearest confluence in the 500-millibar flow over northern Canada: but at 60°S.

* The significance of mountain ranges, with extensive snow surfaces on the low ground beyond them, in blocking the advance of warm air was explored by the present author in an earlier paper.[5]

mean wind speeds over 40 knots are indicated, summer and winter, in most sectors. Upper winds observed over the South Pole International Geophysical Year station have been variable and at times quite strong, occasionally well over 100 knots at the maximum wind level, though more usually only 20 to 40 knots. (The maximum wind appears to be commonly at about 350 millibars.) The general run of depressions along the Antarctic fringe appear more vigorous in both summer and winter than in corresponding northern regions and gales are more frequent in the Antarctic than in the Arctic, whether we compare coastal or inland areas.

Radiation and heat budget.—The quantity of energy Q_s from solar radiation, which would fall on each square centimetre of horizontal surface *per diem* in the absence of the atmosphere, has its maximum value of about 1,150 gramme-calories at the South Pole about the December solstice. The corresponding value at the North Pole on 21 June is about 1,080 gramme-calories. There are secondary maxima at the solstices respectively of 1,060 near 48°S. and 1,000 near 48°N. At the equator the figure is between about 790 and 900 gramme-calories at all times of the year. (The figures are based on Milankovitch[6] but adjusted for reduction of the mean solar constant from 2 to 1·94 cal. cm.$^{-2}$ min.$^{-1}$. More recent estimates by Houghton[7] for the Northern Hemisphere based on the United States pyrheliometric measurements are in sufficient agreement.)

The over-all range of values of Q_s within each hemisphere is greatest at the equinoxes, but this over-all range is less important than the intensity of the zones of sharp gradient of net energy received, resulting from the modifying influence of such factors as cloudiness over the oceans and the high albedo of snow and ice.

Figure 1 is designed to show where, from radiation considerations, we should expect the main thermal gradients to be and where we actually find them in terms of 1000–500-millibar thickness. (The apparent discrepancies are no doubt mainly attributable to moisture effects—the density of water vapour and the redistribution of heat through liberation of latent heat of condensation—and to the effects of the circulation itself, but in the case of the Antarctic summer Simpson's radiation estimates here used seem to assume too low an albedo.)

Some fraction t of the incident solar energy actually reaches the earth's surface in the form of direct and diffuse radiation. This depends on the distance traversed through the atmosphere by the sun's rays and on the transmissivity of the atmosphere, affected by cloudiness, dust etc.

The balance of energy Q finally available for heating the earth's surface is given by

$$Q = t\,(1 - A)\,Q_s - Q_e$$

where A is the albedo of the surface and Q_e is the quantity of energy lost as outgoing terrestrial radiation. There are liable to be strong gradients of Q where A changes abruptly, for instance near the limit of the snow or ice surface.

Actually only a certain fraction b of Q is used in heating the surface, the remainder penetrating to some depth which is effectively very small on dry land but great in the oceans. Thus b changes abruptly at coastlines and produces further strong gradients of surface heating along the fringes of the continents.

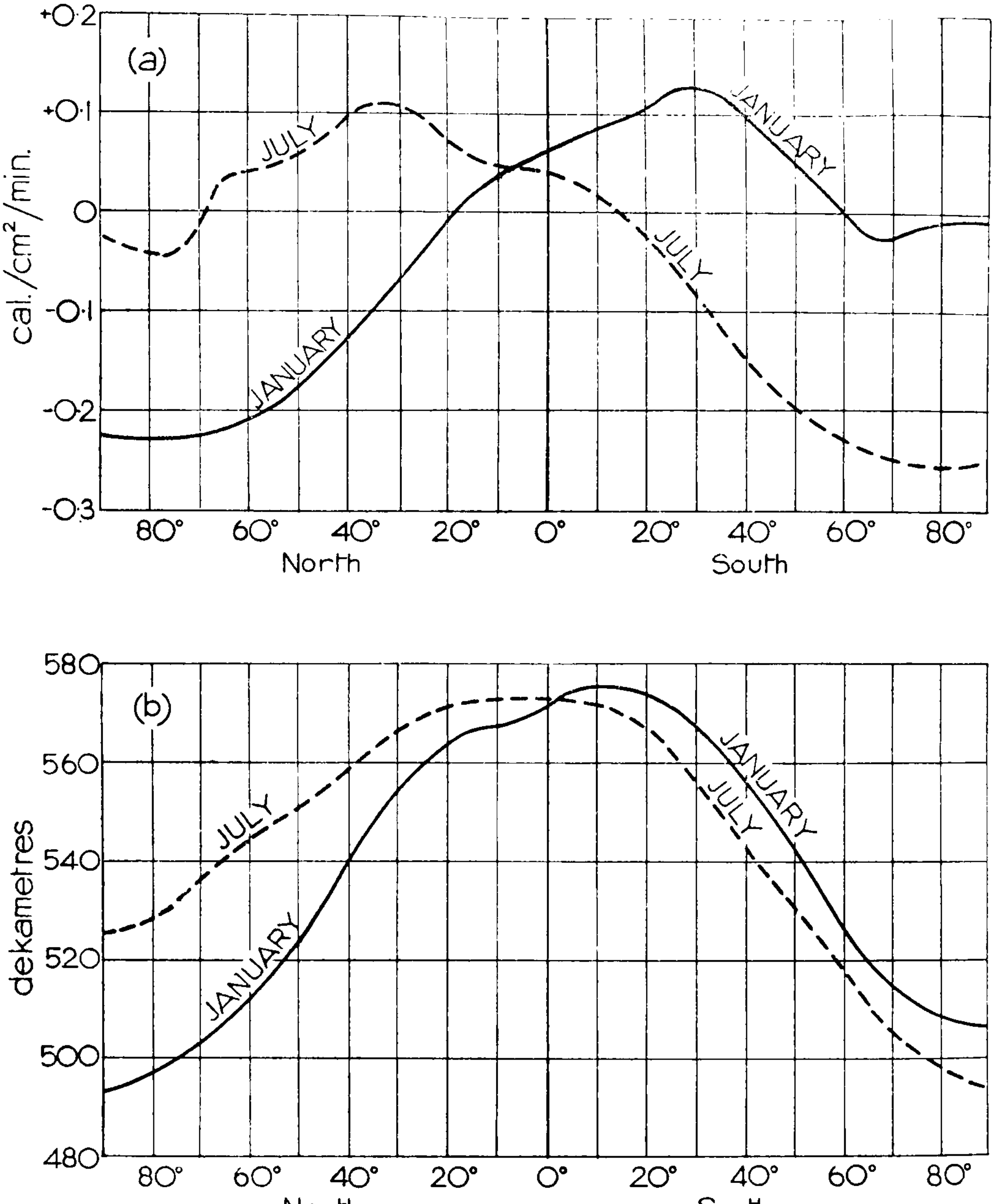


FIGURE 1.—LATITUDINAL DISTRIBUTION AND GRADIENT OF (*a*) INTENSITY OF NET RADIATION RECEIVED (AFTER SIMPSON) (*b*) 1000–500-MILLIBAR THICKNESS

Note: The main slope in middle latitudes is in each case slightly steeper in January than July. The thickness maxima are displaced towards the equatorial zone, also thickness values are high in relation to the net radiation receipt in the Southern Hemisphere in winter (moisture effects). The apparent discrepancy between the thickness and the radiation receipt in the Antarctic summer (January) is attributed to Simpson's underestimate of the albedo (0·65 for 0·8 to 0·9).

Photograph by F. G. Hannell

(*a*)

Photograph by F. G. Hannell

(*b*)

DUST-STORM ACTIVITY TO THE SOUTH OF STATION A ON 17 AUGUST 1956

(*a*) At 1530 G.M.T.: A single dust devil under cumulus cloud indicates the commencement of strong convective activity.

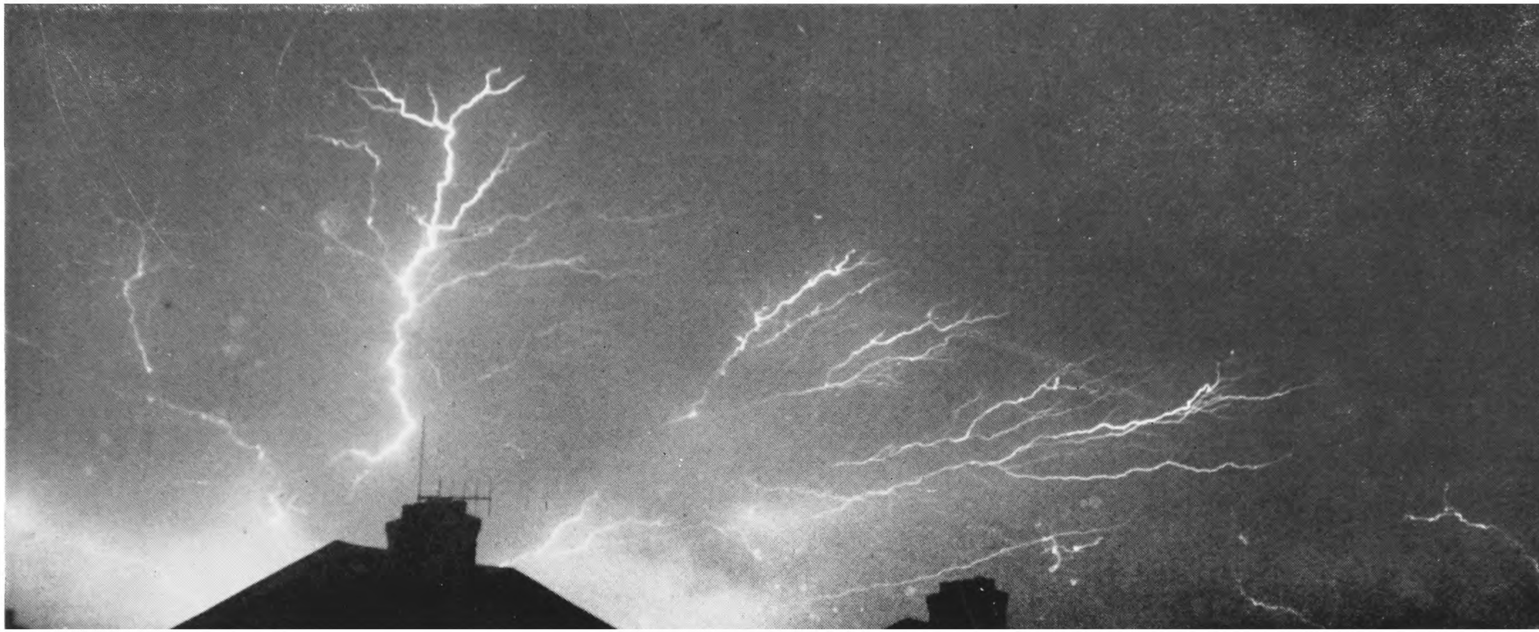
(*b*) At 1645 G.M.T.: Individual dust devils have coalesced into an area of general convection.

(see p. 353)

Photograph by T. Summers

LIGHTNING WITH UPWARD BRANCHING AT MILL HILL, LONDON, 5 SEPTEMBER 1958

(see p. 379)



Photograph by T. Summers

LIGHTNING WITH UPWARD BRANCHING AT MILL HILL, LONDON, 5 SEPTEMBER 1958

(see p. 379)

[To face p. 369

Photograph by D. W. Leddra

LIGHTNING FLASHES AT MOTTINGHAM, LONDON, 5 SEPTEMBER 1958
(see p. 379)

The albedo of the Antarctic snow surface appears to be between 0·8 and 0·9 at all times of the year,[8] and over the ice-cap the radiation balance is believed to be always negative.[9] By contrast, much of the Arctic snow and ice surfaces near sea level are modified by melting in summer; their albedo falls to between 0·64 and 0·7 at this season. At the extreme coast of Antarctica, and over a vastly greater proportion of the northern polar region, there are doubtless periods in summer of radiation gain. The average albedo for the whole earth is around 0·4.

Simpson[10] calculated realistic values of inward radiation received, $t(1 - A)Q_s$, for both clear sky and average cloudiness and also of Q_e and Q, to produce world maps. The curves (Figure 1) of difference between incoming and outgoing radiation averaged over each latitude, following Simpson, show the main gradient in middle latitudes; in the Northern Hemisphere this gradient is clearly steepest in winter, apart from the narrow zone of very steep summer gradient at about 70°N. corresponding to the heated land–Arctic ice boundary. In the Southern Hemisphere on balance there is not much difference between the summer and winter gradients of Q in middle latitudes: the strong gradient affects a broader range of latitudes in winter but between 45°S. and 60°S. near South America the gradient is decidedly strongest in summer. This gradient appears to be of the same order as that near the Atlantic coast of the Sahara and the Arctic coast of Asia or America in summer. In either hemisphere there is a latitude zone over which as a whole the gradient of Q is sharper in summer than in winter, respectively about 65–75°N. and 50–65°S. In both cases there is evidence of increased cyclonicity arising in or near the zone concerned in late summer–autumn, and over much of the zone 50–65°S. the mean tropospheric winds are probably rather stronger in late summer–autumn than in winter.[11]

Simpson's calculations suggest that the quantity of heat which must be made good per year by atmospheric and oceanic transport polewards across latitudes 30° to 40° is about 20 per cent, and across latitude 50° about 7 per cent, greater in the Southern than in the Northern Hemisphere. Oceanic transport contributes nothing south of 40°S., so Sverdrup estimated that the atmospheric contributions across the 40 and 50°S. parallels should be respectively 28–30 per cent and 7–8 per cent greater than those across the corresponding parallels in the Northern Hemisphere.[12] Since the steady meridional airstreams associated with stationary persistent blocking are rare in the Southern Hemisphere, it seems likely that the greater transport is mainly achieved by latent heat of condensation liberated in frontal processes over the Southern Ocean.

Meteorological consequences.

(*a*) *Upper air.*—1000–500-millibar thicknesses in summer and winter over the Arctic and Antarctic register the effects of the differing heat budgets.*

The Antarctic cold region is much more nearly circular than its northern counterpart, but it is centred somewhat away from the pole, in both summer and winter, near the true centre of the ice region at about 81–86°S., 50–70°E. In summer average 1000–500-millibar thicknesses are below 5,100 metres

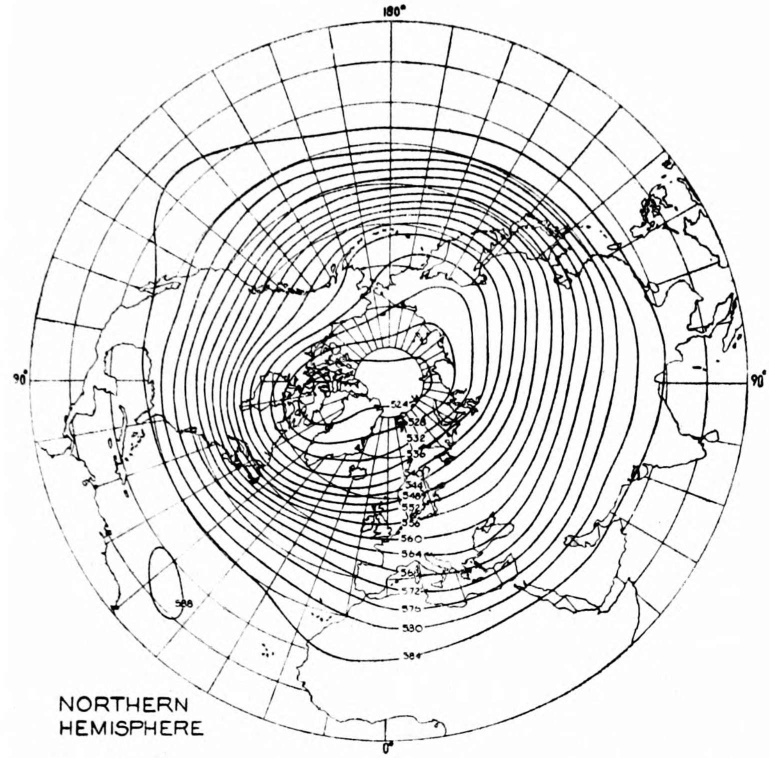
* Average upper air values and patterns over the far south referred to in this section have been derived from maps and data published in *Notos*,[13] except where otherwise stated. Corresponding Northern Hemisphere values are taken mostly from data computed in the Meteorological Office, London and partly published—an example is *Meteorological Reports* No. 13.[14] Earlier comparisons between the general circulation over the Northern and Southern Hemispheres by Gibbs[15] were based on much more restricted chart material.

over a roughly circular area 1,700–2,000 miles across, corresponding to maximum surface temperatures well below the freezing point all over the interior of Antarctica (−15°C. is the highest so far recorded on the South Polar Plateau—prior to the current International Geophysical Year expeditions. The highest reading at the South Pole in summer 1956–7 was −18°C.). Snow is the prevailing form of precipitation south of 60°S. even in summer, whereas rain is not uncommon near the North Pole between June and August[16] and actual minimum values of 1000–500-millibar thickness anywhere in the Arctic appear to be above 5,100 metres in July and August. By contrast, Antarctic winter values of 1000–500-millibar thickness appear to be slightly above the averages for the Canadian cold pole or north-east Siberia. At Maudheim (71°S., 11°W.)[17] observed temperatures at 500 millibars and below in the five late-winter months June–October were 1–3°C. higher, level for level, than in the corresponding months at Arctic Bay (73°N., 85°W.); but Maudheim was generally colder at all other levels and at all other times. The biggest disparity was in winter at 100 millibars and higher, where averages at Maudheim were in some cases below − 80°C. (at 50 millibars in July − 87°C.) and not below −58°C. at Arctic Bay. Summer temperatures above the 100-millibar level were closely alike in Arctic and Antarctic when latitude differences were allowed for.

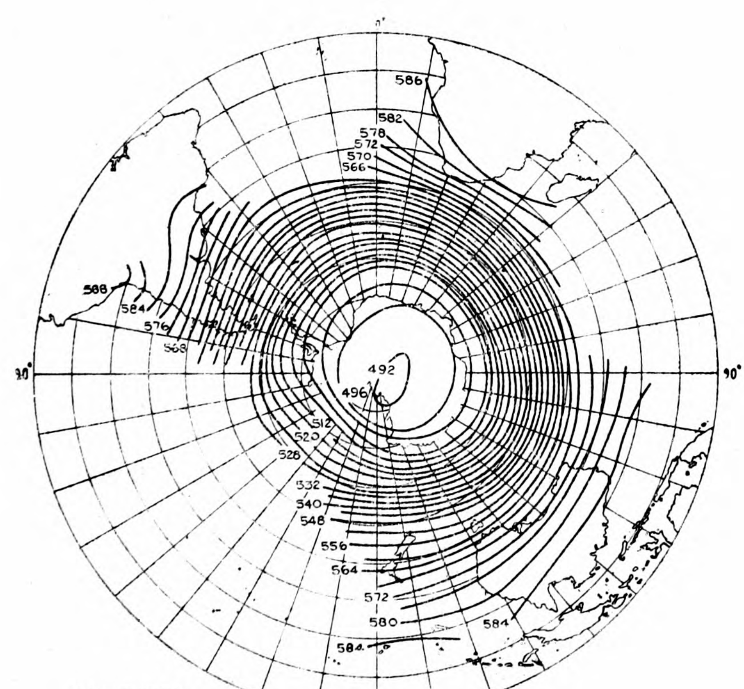
Surface temperatures probably fall below − 60°C. at times every winter over the inland ice of Antarctica at 67–90°S. (especially in the eastern sector between 50°E. and the Ross Ice Shelf, where owing to the general circulation near the surface the air habitually has had the longest run over the inland ice). The colder Antarctic stratosphere can reasonably be attributed to less upward radiation of heat from the ice surface and from clouds than takes place over the central Arctic pack-ice as suggested by Schumacher.[17] On the other hand the rather colder troposphere over the cold pole near 70°N. in winter probably means that the region concerned is more nearly immune from occasional advection of oceanic air than anywhere in the Antarctic.

Figure 2 shows the mean 500-millibar topography over the Northern and Southern Hemispheres. Unlike the northern pattern with its familiar troughs over north-east Canada and Asia, amounting almost to "twin" poles,† the southern circulation is nearly circular and the profiles along the 50°S. and 60°S. latitude circles shown in the subscript on Figure 2 are necessary to make clear where the mean troughs lie. In 50°S., and more clearly at 60°S., the main trough is in the Indian Ocean sector about 100–110°E., where it cannot be attributed to any orographic obstacle in the main flow. This trough appears most likely related to the quasi-permanent outflow of cold air from East Antarctica between 50°E. and 150°E. and possibly in the northern summer its amplitude may be increased by the Indian monsoon. The most noticeable warm ridge is about 150°E.–150°W. in the western Pacific, south of New Zealand. (A ridge pushing in from the north over Antarctica near the 140°W. meridian, east of the Ross Sea, has been reported by Rubin[18] to be a common feature of the first few months of daily charts at 500 millibars and higher levels

† Twin poles are very commonly present in the Arctic winter and may indeed be the usual condition. The minimum of 500-millibar height on the Asiatic side makes a less strong mark upon the average pattern at least partly because it is more variable in position than that on the Canadian side.



Average for the months January, April, July, October (1949–53).



Average for the year (1952–54 approx.).

FIGURE 2.—MEAN HEIGHT IN DEKAMETRES OF THE 500-MILLIBAR SURFACE

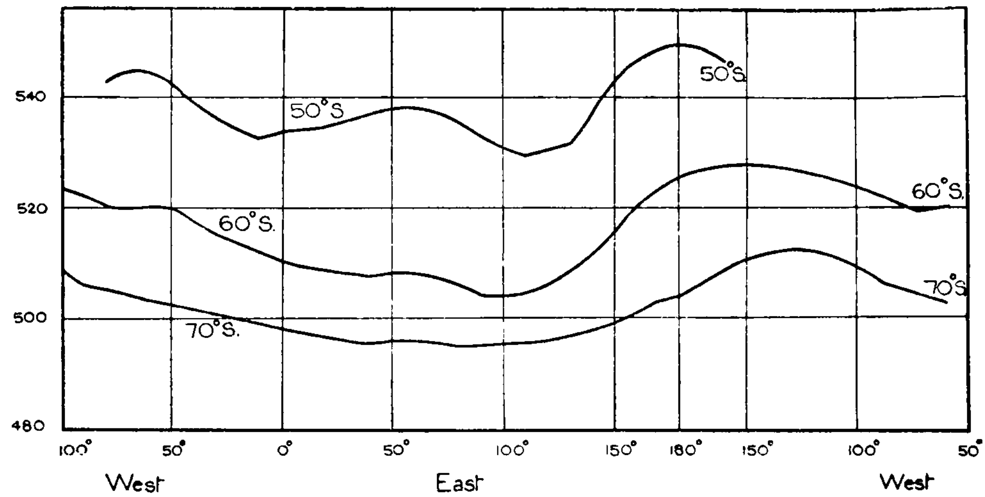
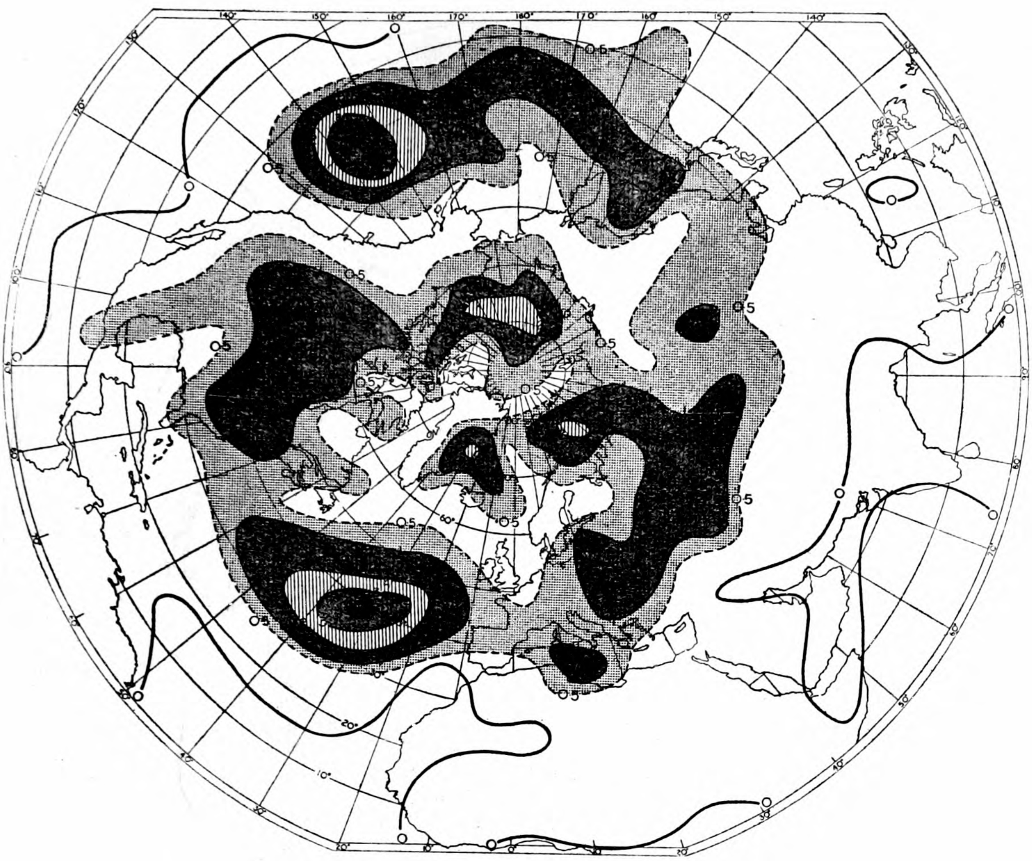


FIGURE 2.—MEAN HEIGHT IN DEKAMETRES OF THE 500-MILLIBAR SURFACE (*cont.*)
Yearly mean profiles in the Southern Hemisphere to show trough and ridge positions.

analyzed from International Geophysical Year Antarctic aerological observations.) The mean latitude of the strongest flow at 500 millibars shifts only a few degrees with the changing seasons, ranging for instance between about 50°S. and 58°S. at 70°E.[19] The position is about eight degrees north of the ice limit and the seasonal shift is identical with that of the ice limit, also eight degrees.

Calculation based upon the best available estimates of average upper winds indicates that the southern circumpolar westerlies carry much more momentum than any other wind system in the world. The overweight is primarily located in the lower troposphere from mean sea level to 500 millibars over the Southern Ocean in 40°–60°S. At levels up to 500 millibars the southern westerlies appear to be the most powerful wind system in the world at all seasons. Tentative integration of the westerly angular momentum between the 1000- and 100-millibar levels in either hemisphere between latitudes 0° and 70° suggests ratios of Southern to Northern Hemisphere of about 1·5 for the momentum of the westerlies over the year as a whole. In the northern summer the ratio is about 4; in the northern winter it drops to about 0·7. The ratios of linear westerly momentum are rather higher in each case and average nearly 2 over the year as a whole. (These estimates omit the Pacific sector between 170°E. and 70°W.)

(*b*) *Surface connexions.*—The unbroken ring of the Southern Ocean and the permanently strong thermal gradient from north to south over it make it almost impossible for even the biggest anticyclones and depressions to create a sufficiently distorted thermal pattern to maintain the system stationary over the ocean south of 40°S. Whole regions of the Southern Ocean, especially in the southern part of the broad Indian Ocean trough, are almost entirely avoided by the centres of anticyclones (Figure 3). Elsewhere blocking patterns do appear from time to time, but the systems are usually soon swept away by a renewal of the westerlies. Occasional linkages, when a ridge from the subtropical high pressure belt temporarily extends over a part of Antarctica, may be important in rejuvenating the polar anticyclones usually centred over East Antarctica near 80°S., 40°–90°E.; but there is no southern equivalent of either the persistent meridional airstreams associated with blocking anti-



(*a*) Northern Hemisphere, summer, 1952–54

FIGURE 3.—DISTRIBUTION OF ANTICYCLONE CENTRES

Unit: Percentage frequency of daily occurrencies per 100,000 square kilometres.

cyclones in 50°–70°N. or the persistent winter ridge of high pressure linking the anticyclones of the Azores region across Europe and central Asia with north-east Siberia and the Arctic ice north of Alaska.

The three regions most favourable for anticyclones over the ocean south of 40°S. are

(i) between Australia and 140–160°W. in association with the upper ridge already noted,

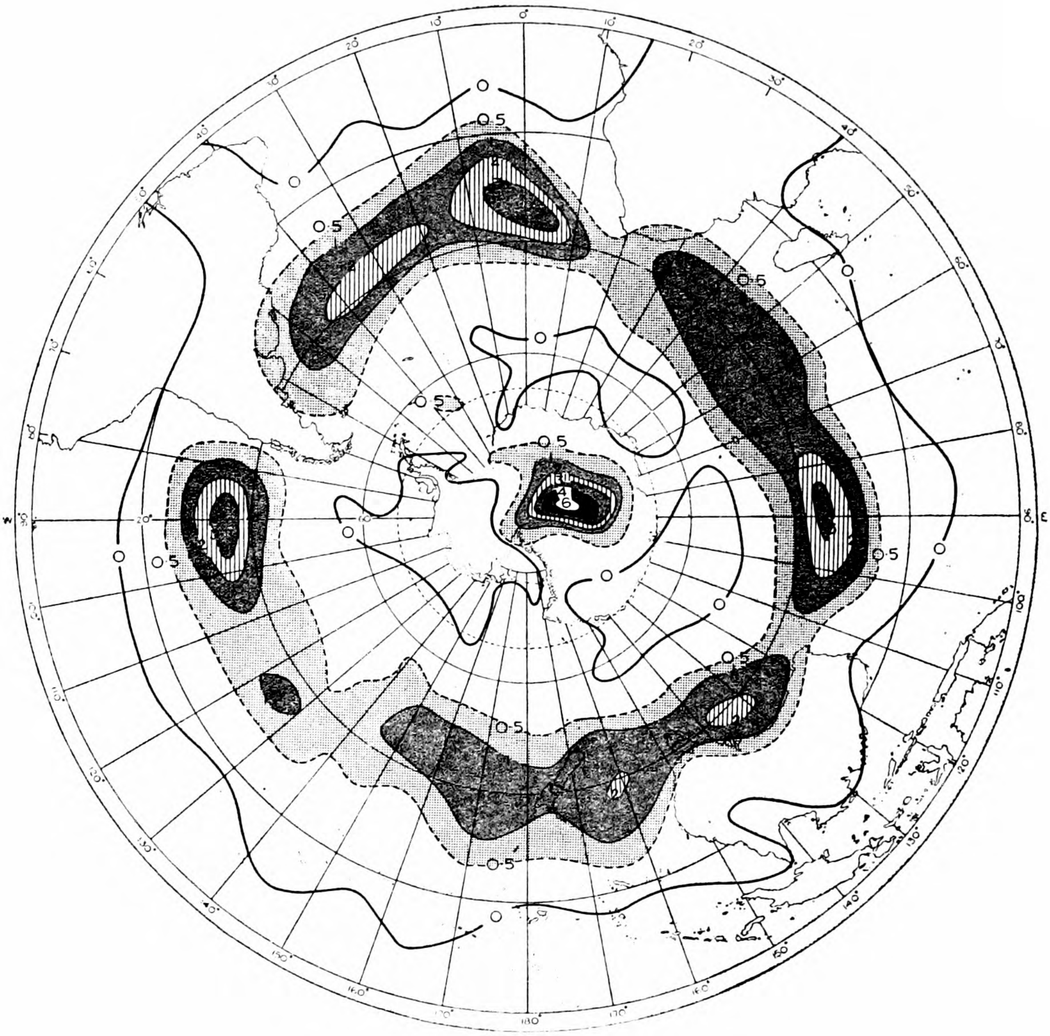
(ii) just east of South America, west of the trough in the South Atlantic,

(iii) between South Africa and about 60°E., west of the Indian Ocean trough.

These positions happen to be just east of each of the southern continents, not west as are the Alaskan and Scandinavian blocking anticyclones, but the relation to the thermal pattern is straightforward (that is, in keeping with Sutcliffe and Forsdyke[20]) in both hemispheres.

The large size* of the low pressure systems of the Antarctic fringe in the colder seasons produces outstandingly low mean pressures in late winter near the coast of Antarctica between about 50–90°E. and the Ross Ice Shelf

* More or less circular depressions attain a diameter of over 1,500 nautical miles several times a winter and depression complexes may be up to 3,000 miles or more across over the Southern Ocean.



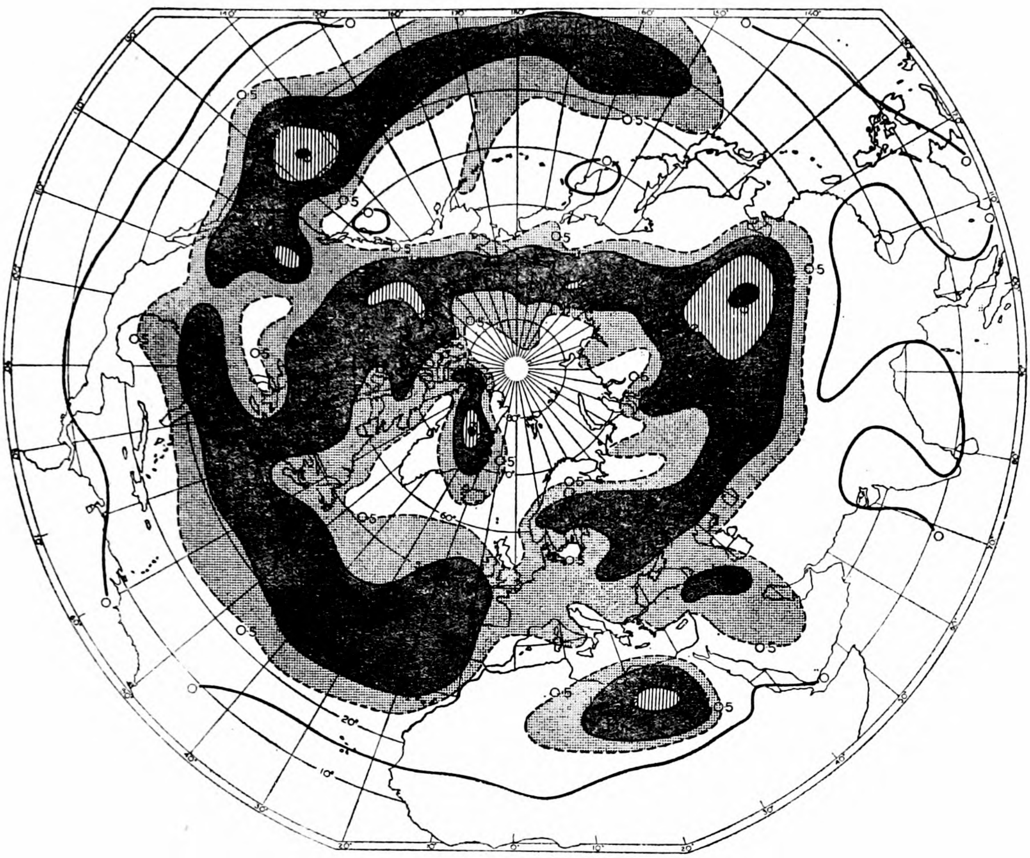
(*b*) Southern Hemisphere, summer, 1951–4

FIGURE 3.—DISTRIBUTION OF ANTICYCLONE CENTRES (*cont.*)

Unit: Percentage frequency of daily occurrencies per 100,000 square kilometres.

(160°E.–150°W.) and also incursions of some depression centres far over the Antarctic ice. The culminating phase is in August to October (October mean pressure, near 78°S., 166°W., from nine years' observations in the southern Ross Sea is 974 millibars, standard deviation 3 millibars; October mean pressure on the coast near 67°S., 90–95°E. is 980–982 millibars. Compare the lowest monthly mean pressures in the Icelandic depression—modal value 990 millibars, lowest known value in 85 years 977 millibars in 1890). The annual pressure trend in these eastern sectors of Antarctica appears "anti-monsoonal" (summer maximum and winter minimum); the only Arctic analogy is between South Greenland and Bear Island in the region most closely affected by the main Atlantic depressions.

Average mean-sea-level pressures south of about 45°S. are so much lower than in corresponding northern latitudes that there appears to be an over-all deficit of atmospheric mass in the Southern Hemisphere as compared with the Northern



(*c*) Northern Hemisphere, winter, 1952–55

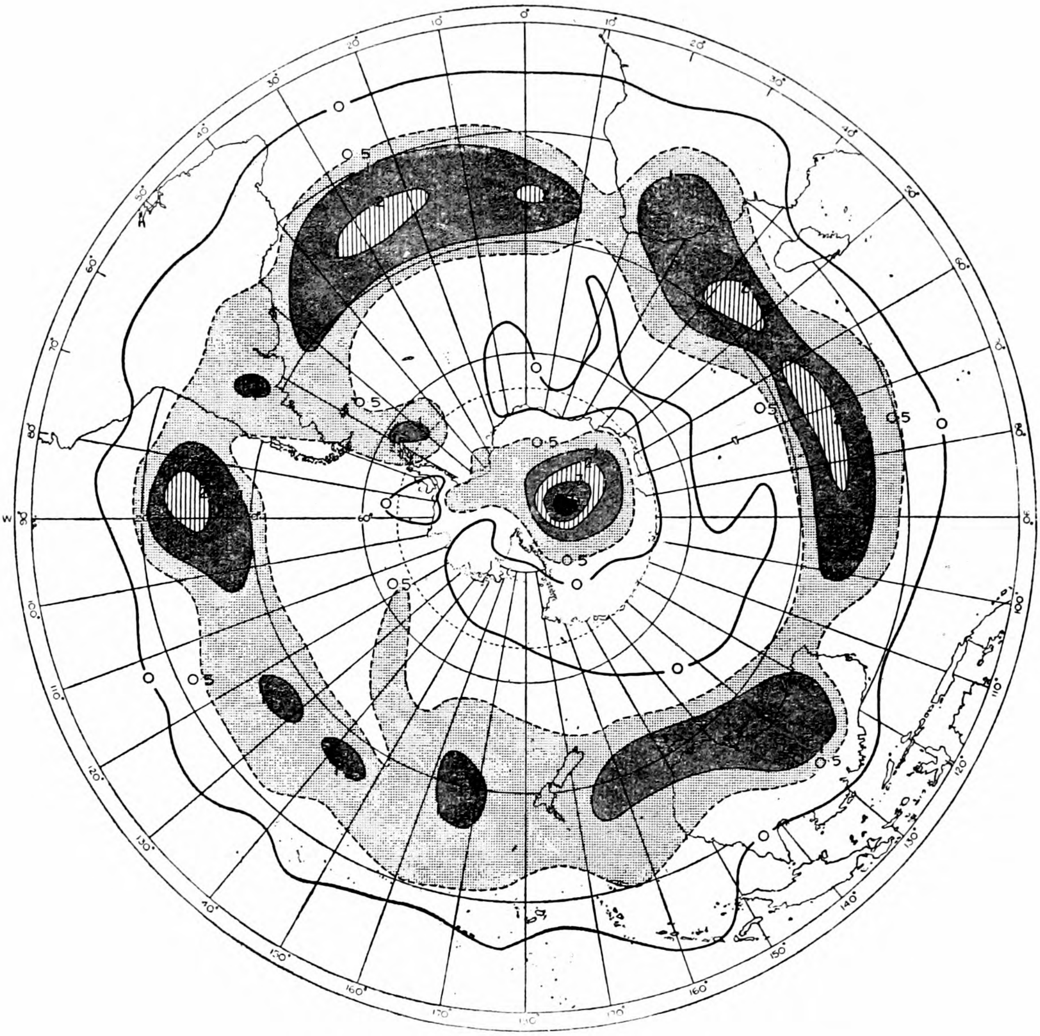
FIGURE 3.— DISTRIBUTION OF ANTICYCLONE CENTRES (*cont.*)

Unit: Percentage frequency of daily occurrencies per 100,000 square kilometres.

Hemisphere (Figure 4). In latitudes 60–70° the disparity amounts to 22–23 millibars.* The southern subtropical pressure maximum is about 5° latitude nearer the equator, summer for summer and winter for winter, than its northern counterpart.† These phenomena may be linked with the outstanding momentum of the southern westerlies, possibly through the Nullschicht effect,[19,23] which indicates on balance a more or less steady transference of mass towards the warm side of the strongest windstreams at altitudes near the maximum-wind level. (Meteorologists were first exercised by the problem of the very low atmospheric pressures in the Antarctic seen in the observations of Sir James Clark Ross in 1839 to 1842. As explanation, the centrifugal effect of the southern westerlies was put forward independently by Ferrel and by J. J. Murphy about 1856.)

* This disparity was to be seen in the figures for mean barometric pressure in latitude zones given by Teisserenc de Bort[21] in 1893 and was several times alluded to by Meinardus, but has so far hardly received notice in the text books, except in Hann's *Lehrbuch der Meteorologie.*[22]

† Another symptom of the displacement of the southern climatic zones into lower latitudes than their northern counterparts is to be observed in the latitude of glaciated features. The small mountainous island of Kerguelen (49°S., 70°E.) has many great glaciers some of which reach the sea. The northernmost glacier from the Patagonian ice-cap reaches the sea at 46° 40′S., 74°W. on the Chilean coast, ten degrees nearer the equator than any Alaskan glacier. Moreover the ice in 40–60°S. shows signs of advance rather than recession over the past century or so.



(*d*) Southern Hemisphere, winter, 1952–54

FIGURE 3.—DISTRIBUTION OF ANTICYCLONE CENTRES (*cont.*)
Unit: Percentage frequency of daily occurrencies per 100,000 square kilometres.

Table III gives comparative values of mean-sea-level pressure at the centres of the main subpolar and polar pressure systems on daily synoptic charts. In considering the lower pressures in the Antarctic and sub-Antarctic it must be remembered that the intensity of a particular system is related to the pressure departure from normal for the region. In the Antarctic winter there appear to be occasions, probably ranging from 10–50 per cent in different years (and over 50 per cent in occasional months) when there is no room for any anticyclone south of the depressions and jetstreams of the polar front. In the northern winter there is probably never a day when no polar anticyclone is present over some part of the extensive snow-cover, though there are days when relatively low pressure dominates most of the polar basin and the anticyclones are centred over the surrounding continents.

In summer, both in the Arctic and Antarctic, there is no polar anticyclone on a few days, probably varying from 0–10 per cent in different years.

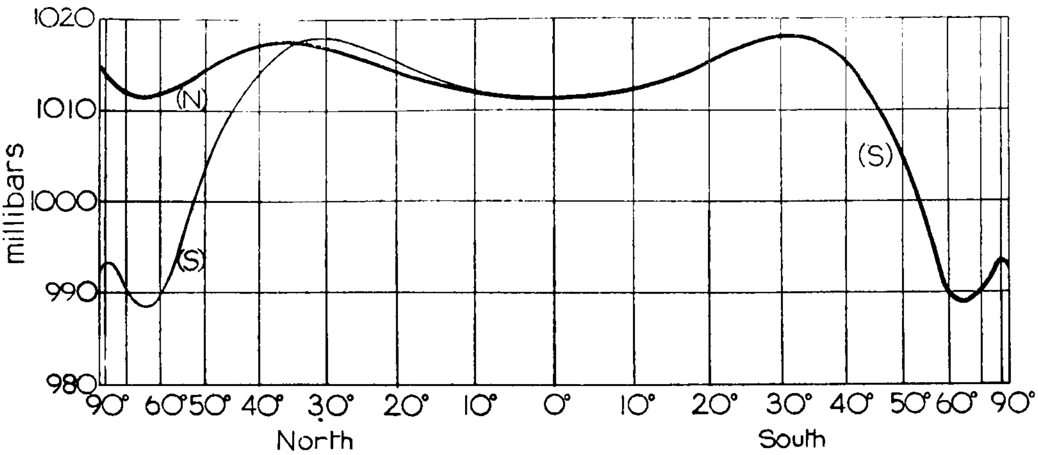


FIGURE 4.—MEAN PRESSURE OF THE ATMOSPHERE AT M.S.L. IN DIFFERENT LATITUDES—AVERAGE OF JANUARY AND JULY

The Southern Hemisphere curve is repeated as a thin line on the Northern Hemisphere side for comparison.

TABLE III—CENTRAL PRESSURE (IN MILLIBARS) OF MAIN SYSTEMS ON DAILY SYNOPTIC CHARTS

Period	Commonest range (mb.)	Approx. frequency (per cent)	Extremes likely about once a year (mb.)
	Sub-Antartic depressions		
Summer (Dec.–Feb.) ...	960–979	70–80	945
Winter (June–Sept.) ...	950–969	60–70	928
	Anticyclones over Antarctica		
Summer (Dec.–Feb.) ...	1000–1009	65	1018
Winter (June–Sept.) ...	1000–1009	60	1030
	North Atlantic depressions		
Summer (June–Aug.) ...	990–999	50–55	974
Winter (Dec.–Feb.) ...	970–979	30	947
	Northern polar anticyclones		
Summer (June–Aug.) ...	1020–1029	65	1038
Winter (Dec.–Feb.) ...	1030–1049	60–65	1065

Variations of the general circulation and climatic changes.—It appears that, owing to unlike geography, the responses of Northern and Southern Hemispheres (in temperate and polar latitudes) to any small changes in insolation should be fundamentally different.

Let us consider the likely effects of a reduction of a few per cent in the incoming radiation, such as may have been characteristic of the latter part of the nineteenth century, at least. There would be little, or only a very slow, effect upon the surface temperature of most oceans. Over the interiors of the temperate northern continents and Antarctica, however, summer and winter temperatures should fall by some degrees: this assumes insignificant changes of cloud amount over these regions, especially in Antarctica (where mean cloudiness is always low) and in the winter night. These changes might well suffice to stop all effective summer melting of the Antarctic ice-cap, reduce its plasticity and therefore reduce its rate of outflow. In consequence the sub-Antarctic belt of sea ice should contract, and places between 40°S. and the coast of Antarctica should become rather warmer. The southern westerlies should be displaced south by a degree or more. By contrast, over the Arctic Ocean the direct effects of insolation changes should be small on account of summer cloudiness, though the greater cooling of the temperate northern continents would contribute to greater production of sea ice and some equatorward expansion of the zone of maximum thermal gradient in the Northern Hemisphere.

These effects appear to act in the same sense as any world-wide adjustment to the strength and position of the southern westerlies.

If it is at bottom the overwhelming strength of the southern westerlies which maintains a generally low level of pressure over the Antarctic and climatic zones shifted towards the north, then either weakening or southward displacement of the southern westerlies might entail some southward adjustment of all the world's climatic zones. (On average over all longitudes secular fluctuations in recent centuries could only amount to 1 to 2° latitude, but for geographical reasons they might well be exaggerated in the North Atlantic sector.)

These propositions are in keeping with the occurrence of opposite climatic trends south of 40°S. and over most of the rest of the world, which appear to have been observed since the late nineteenth century, and imply that the trends observed up to about 1940–50 were such as might be expected with increasing radiation receipt.

REFERENCES

1. SHAW, W. N.; Manual of Meteorology. Cambridge, **2**, 1936, p. 9.
2. MACKINTOSH, N. A., and HERDMAN, H. F. P.; Distribution of the pack-ice in the Southern Ocean. *'Discovery' Rep., Cambridge,* **19**, 1940, pp. 285–296.
3. Copenhagen, Danish Meteorological Institute; *Isforhold. arkt. Have, København.*
4. MACKINTOSH, N. A.; The Antarctic convergence and the distribution of surface temperatures in Antarctic waters. *'Discovery' Rep., Cambridge,* **23**, 1946, pp. 177–212.
5. LAMB, H. H.; Two-way relationships between the snow or ice limit and 1000–500-mb. thicknesses in the overlying atmosphere. *Quart. J. R. met. Soc., London,* **81**, 1955, pp. 172–189.
6. MILANKOVITCH, M.; Die Bestrahlung der Erde durch die Sonne. Handbuch der Klimatologie (Köppen und Geiger) Band I, Teil A, Abschnitt I, Berlin, 1930.
7. HOUGHTON, H. G.; On the annual heat balance of the Northern Hemisphere. *J. Met., Boston, Mass,* **11**, 1954, pp. 1–9
8. LILJEQUIST, G. H.; Radiation, wind and temperature profiles over an Antarctic snow surface, Proceedings of the Toronto Meteorological Conference 1953. London and Boston, Mass., 1954, pp. 78–87.
9. LOEWE, F.; Etudes de glaciologie en Terre Adélie. *Expéd. Polaires Franç., Paris,* 1956.
10. SIMPSON, G. C.; The distribution of terrestrial radiation. *Mem. R. met. Soc., London,* No. 23, 1928.
11. MEINARDUS, W.; Die jährliche Periode der meridionalen Luftdruck-gradienten und der Windstärken auf der südlichen Halbkugel. *Met. Rdsch., Heidelberg,* **1**, 1947, pp. 134–137.
12. SVERDRUP, H. V.; The relationship between meteorology and oceanography. *J. Mar. Res., New Haven, Conn.,* **14**, No. 4. 1955, pp. 501–502.
13. Pretoria, South African Weather Bureau; *Notos, Pretoria,* **1–5**, 1952–56.
14. London, Meteorological Office; 1000–500-mb. thickness North America to Europe 1946–51. *Met. Rep., London,* No. 13, 1953.
15. GIBBS, W. J.; A comparison of hemispheric circulations with particular reference to the western Pacific. *Quart. J. R. met. Soc., London.,* **79**, 1953, pp. 121–136.
16. MEYER, H. K.; Das Wetter in der Nähe des Nordpols. *Met. Rdsch., Heidelberg,* **8**, 1955, pp. 35–39, 117–122.
17. SCHUMACHER, N. J.; Upper air temperatures over an Antarctic station. *Tellus, Stockholm,* **7**, 1955, pp. 87–95.
18. RUBIN, M. J.; Antarctica and the general circulation. Report of the proceedings of the International Association of Meteorology and Atmospheric Physics, XIth General Assembly of the International Union of Geodesy and Geophysics, Toronto, September 1957. London, 1958.
19. LAMB, H. H.; The southern circumpolar westerlies (unpublished).
20. SUTCLIFFE, R. C. and FORSDYKE, A. G.; The theory and use of upper air thickness patterns in forecasting. *Quart. J. R. met. Soc., London,* **76**, 1950, pp. 189–217.

21. TEISSERENC DE BORT, L.; Report on the present state of our knowledge respecting the general circulation of the atmosphere. Meteorological Congress at Chicago, August 1893. London (Stanford) 1893.
22. HANN, J.; Lehrbuch der Meteorologie. Leipzig, 1901.
23. FAUST, H.; Ubergradientische Winde in der Nullschicht und das Problem der Strahlströme. *Arch. Met., Wien,* **8,** Serie A, 1955. pp. 45–71.

NOTES AND NEWS

Loan of American meteorological aircraft and instrumentation

Arrangements have been made by the Director-General of the Meteorological Office with United States authorities for the loan of the U.2 Meteorological Research Aircraft to be flown from this country by Royal Air Force pilots under the technical control of the Meteorological Office.

Flights in the United States with this aircraft have produced very valuable meteorological data and it is hoped that equally valuable results will come from flights from the United Kingdom.

The meteorological instrumentation specially designed for this aircraft has also been obtained on loan from the United States Air Weather Service and the National Aeronautics and Space Administration but it is the intention also to adapt British equipment as far as possible.

Lightning with upward branching

We are indebted to Mr. Terry Summers, 12 Holmwood Grove, Mill Hill, N.W.7 for the two photographs of lightning in the centre of this magazine. They were taken during the thunderstorm of Friday, 5 September 1958 at about 2015 G.M.T. looking north-east. They are of special interest as showing flashes with the unusual upward branching which is believed to be associated with the unusual "upward leader" type of lightning stroke first observed in flashes striking the Empire State Building, New York. Mr. Summers reports that there are two tall spiky buildings in the direction of the flashes on the photograph.

Lightning flashes

We are indebted to Mr. D. W. Leddra, 3 Beaconsfield Road, Mottingham, London, S.E.9 for the photograph, facing page 369, showing three very close bright flashes apparently going to earth taken from his home with a 5-second exposure at 2000 G.M.T. on the evening of 5 September 1958. The branching of these flashes is the more usual downward one.

Extreme wind speeds over Great Britain and Northern Ireland

The following corrections should be made to this article in the September 1958 Meteorological Magazine:

P. 258, line 16; *for* "plotted again" *read* "plotted against".

P. 262, line 1; *for* "49 anemograph stations" *read* "48 anemograph stations".

P. 265, line 22; *for* "order of 10 seconds" *read* "order of a second".

METEOROLOGICAL OFFICE NEWS

Academic successes.—The following members of the staff have been successful in recent examinations. We offer them our congratulations.

B.Sc. (General): P. D. J. Rae.

General Certificate of Education (Advanced Level): R. J. Adams, J. Barker, G. P. Carruthers, B. Castle, F. Dalton, C. M. Draper, L. Gurney, Miss V. L. Gurr, R. N. Hardy, Miss M. Hoare, W. J. Hunter, C. Johnson, R. F. Johnson, J. Lack, J. G. Leslie, Miss M. J. Llewellyn, Miss B. A. Marsh, J. D. Randall, W. R. Sparks, J. A. Walke, E. J. Whitelam.

Higher National Certificate: G. A. Samuel.

Sports activities.—*Swimming.*—At the Air Ministry Swimming Gala held at Marshall Street Baths on 3 November, Miss R. M. Overton won the Ladies' Championship. The Office Ladies' Relay Team (Misses Overton, Lonnen and Leyland) won the Relay Championship.

Shooting.—Mr. P. S. Griffiths and Mr. K. Bruley have had a very successful year in the Civil Service Rifle Association Competition, obtaining three first prizes and one second. Mr. Griffiths also won a Bronze Medal at the National Rifle Association Imperial Meeting at Bisley. In addition they were two of the Bishops Stortford Rifle Club team of four that won the Youngsbury Cup.

Courses of training for climatological observers

Two Courses, each lasting four and a half days, were held in October 1958, at the Meteorological Office Training School, Stanmore. Fifty-two observers came, the largest number ever to attend. Instruction and discussion covered all aspects of weather observing and recording. Special attention was given to the new monthly return form (Form 3208) which is to be used at all co-operating climatological stations from November 1958 so that their data may be punched on Hollerith cards. Talks were given on the application of the data to climatological, agricultural and hydrological problems. Films and slides were shown. During visits to Harrow the general work of the Climatological Branch, the punching of data on to cards (which attracted special interest this year) and the testing of instruments were seen and discussed. The London Forecast Office was also visited. The courses are designed to help the observers with their specific work, to broaden their interest in meteorology, and to give them an insight into the ultimate value of the observations. It is hoped to arrange similar courses in October 1959.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 101—Upper air temperature over the world. By N. Goldie, B.SC., J. G. Moore, B.SC., and E. E. Austin, M.A.

From upper air soundings made chiefly between 1941 and 1952, maps and diagrams have been reproduced which show the distribution of average temperature in both space and time, as well as the variability of the daily values from which the averages have been computed. Isopleths of average temperature and standard deviation of temperature are shown on maps of the world (excluding the Antarctic) for the 700-, 500-, 300-, 200-, 150- and 100-millibar pressure levels in the four mid-season months.

Additional charts and diagrams have been included to enable interpolation between different pressure levels and also between the four different months. For the interpolation of temperature values between different pressure levels, curves showing the variation of average temperature with height in different latitudes, and charts showing the average pressure and temperature at the tropopause, for the four main months, have been included. For interpolation between the months, curves showing the variation of the average monthly values throughout the year over different parts of the world, for the six standard levels, and the tropopause, have been reproduced.

Comparison of conditions in different longitudes is made by temperature cross-sections extending from the North Pole to 50°S.

The estimation of extreme values of temperature at any given level from the average temperature and standard deviation of temperature is also discussed. Diagrams are included showing the extremes of temperature in January and July at the six standard pressure levels, for all longitudes of the Northern Hemisphere. Also reproduced is a chart showing the minimum temperature in the troposphere and lower stratosphere over the world.

A complete list of sources of data is given in the Appendices.

WEATHER OF AUGUST 1958

Northern Hemisphere

The southward displacement of the depression track and polar front over the North Atlantic which had persisted since May continued throughout August. On the mean pressure chart the subpolar trough over the North Atlantic was of normal depth but its southward displacement gave pressures as much as 7 millibars below normal between Ireland and Newfoundland. Associated negative pressure anomalies occurred over Europe west of approximately 10°E. and over eastern areas of the North American continent.

The polar anticyclone was more intense than usual and was situated over North Greenland, while a low pressure area was centred to the north of Siberia over Severnaya Zemlya. Maximum pressure anomalies in these two areas were + 8 millibars and − 9 millibars respectively. The pressure distribution over other parts of the hemisphere resembled normal in all respects, and anomalies did not exceed 3 millibars.

Much of Europe had mean temperatures slightly above average during the month. The two main exceptions were southern Scandinavia and the Iberian peninsula where negative anomalies of approximately 1°C. occurred, although some exceptionally high temperatures were recorded during a heat wave in both Spain and Portugal at the beginning of the month.

Over the U.S.A. and Mexico temperatures were higher than the average almost everywhere, the largest anomalies being + 4°C. along the west coast of the U.S.A. Similar anomalies occurred in the Canadian Arctic as a result of increased southerly flow into that region. In Labrador, Quebec, and districts near the south of Hudson Bay, where an easterly surface flow predominated, the month was 2°C. or 3°C. cooler than usual. The largest reported anomalies in Asia were − 3°C. in northern Siberia and + 3°C. further south near the Urals.

Rainfall totals for the month were above average in most parts of western Europe, reaching nearly three times the normal at some stations in France. Many violent storms occurred in France, Germany, Austria, and Switzerland during the month, giving floods in many areas. Over the North American continent rainfall amounts were variable, some places near the east coast having nearly twice the average while in central states of the U.S.A. totals were below average. The Asian monsoon gave more rain than usual in many parts of India but Pakistan had a drier August than usual.

WEATHER OF SEPTEMBER 1958

Great Britain and Northern Ireland

September was mild, and in England and Wales very wet with widespread thunderstorms, although in Scotland rainfall was below average. During the first half of the month pressure was persistently low to the south-west of the British Isles and for much of the third week the country was on the fringe of an extensive Atlantic depression. For the remainder of the month weather was alternately cyclonic and anticyclonic.

South-easterly winds maintained warm weather over the country during the first few days of the month and weak fronts moving slowly north-east brought occasional slight rain to most districts on the 2nd, 3rd and 4th, while associated cloud helped to keep night temperatures around 60°F. in many places. Afternoon temperatures became progressively higher during this period and reached 81°F. at Mildenhall, Herne Bay and Whitstable on the 5th. On the same day thunderstorms, probably associated with a shallow trough of low pressure moving north-eastwards from France, reached the Hampshire coast early in the afternoon and moved north-east over much of south-east England. Some of the heaviest rain fell in Kent and Essex where many stations had more than 2 inches in 24 hours, while at some the fall exceeded 3 inches in that time. Very rare falls included 2·73 inches at Chelmsford in 58 minutes, 2·18 inches at Wickford in 90 minutes and 1·59 inches at Tilbury in 120 minutes. A minor tornado was reported to have travelled from Sussex to Kent on the 5th giving a gust of 69 knots at Gatwick and, during a severe thunderstorm, hailstones 2½ inches in diameter fell at Horsham not far away. The following day thunderstorms developed over northern England and moved to Scotland, where some places reported torrential rain with almost continuous lightning lasting several hours.

Temperatures fell to near normal on the 7th as the depression, which had been in our south-west approaches since the beginning of the month, moved to Scotland, and the wind veered towards the west. Weather was showery on the 7th and 8th with a few scattered thunderstorms but there were good sunny periods. Apart from an outbreak of thunder in the south-west on the 12th, the weather from the 9th to the 13th was mostly sunny and dry after patchy early morning fog. On the night of the 14th–15th a small depression moved eastward along the English Channel accompanied by heavy thunderstorms: several places recorded over 2 inches of rain in 24 hours and 2·16 inches fell that night at Nantcwnlle, Cardiganshire in 1 hour 20 minutes. Fronts, associated with a deep depression off south-east Greenland, moved slowly across the British Isles on the 18th and 19th, giving generally cloudy weather with rain in all districts. Thundery showers were widespread over the country during the next three days as the depression moved slowly south-east towards Scotland, and filled. A deepening depression from mid-Atlantic moving north-east toward Scotland brought prolonged rain to the whole country on the 23rd; the rain was heavy in many places and in parts of Wales more than 3 inches fell in 24 hours, causing extensive flooding. As this depression skirted the north of Scotland the following day, it became very intense before turning south-eastwards into the North Sea. There were severe gales in coastal districts of Scotland and eastern England; gusts of more than 50 knots were recorded at a number of places and one of 73 knots was recorded at St. Abbs Head.

The stormy weather was followed by two or three mainly dry days with sunny periods in most places as a ridge of high pressure moved slowly eastwards across the British Isles. Pressure, however, began to fall again on the 27th, as a deep depression on the Atlantic moved steadily eastwards, and on the night of the 28th–29th a major rainbelt crossed the country which led to a renewal of flooding in many areas. There were good sunny periods on the last day of the month but also frequent showers with occasional thunder.

Temperatures were above normal for September over the whole country. In Scotland mean temperatures were generally 3°F. to 4°F. above the average, while in the southern half of England and Wales the average was exceeded by about 2°F. Sunshine was below average over much of Great Britain. In many parts of the Midlands and south-east England there was a deficit of as much as 20 hours during the month, but in Lancashire sunshine was above average in most places. Rainfall was 160 per cent of the average in England and Wales, whereas in Scotland and in Northern Ireland it did not differ greatly from the average. Less than half the average was recorded over much of northern Scotland while twice the average was exceeded in west Cornwall, in Kent and Essex and over much of mid and south Wales and the Severn Valley. More than three time the average occurred in Shropshire.

Thunderstorms, hail and local tornadoes caused serious, though localized, damage to crops and glasshouses, and there were reports of cattle being killed by lightning. Harvesting, though very difficult, was more or less completed, with yields and quality ranging from good to very poor. Autumn cultivations were badly delayed, and weeds became a serious problem in some areas. Winter vegetable crops, however, were generally above average, as were the yields of apples and pears.

WEATHER OF OCTOBER 1958

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 ...	69	28	+1·3	88	+1	95
Scotland	68	25	+2·1	81	−2	104
Northern Ireland ...	64	33	+1·8	73	−5	93

*1916-1950 †1921-1950

RAINFALL OF OCTOBER 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	2·87	121	*Carm.*	Pontcrynfe	5·31	84
Kent	Dover	4·70	141	*Pemb.*	Maenclochog, Dolwen Br.	4·73	67
"	Edenbridge, Falconhurst	3·36	101	*Radnor*	Llandrindod Wells ...	4·14	97
Sussex	Compton, Compton Ho.	2·96	76	*Mont.*	Lake Vyrnwy	4·22	59
"	Worthing, Beach Ho. Pk.	2·62	89	*Mer.*	Blaenau Festiniog ...	10·57	84
Hants	St. Catherine's L'thouse	2·68	79	"	Aberdovey	4·64	92
"	Southampton, East Pk.	3·20	97	*Carn.*	Llandudno	2·48	77
"	South Farnborough ...	2·41	93	*Angl.*	Llanerchymedd ...	3·44	75
Herts.	Harpenden, Rothamsted	2·44	93	*I. Man*	Douglas, Borough Cem.	3·70	73
Bucks.	Slough, Upton ...	2·36	94	*Wigtown*	Newtown Stewart ...	4·05	74
Oxford	Oxford, Radcliffe ...	2·85	114	*Dumf.*	Dumfries, Crichton R.I.	4·19	91
N'hants.	Wellingboro' Swanspool	2·21	96	"	Eskdalemuir Obsy. ...	4·69	72
Essex	Southend W.W. ...	2·60	117	*Roxb.*	Crailing...	1·30	47
Suffolk	Ipswich, Belstead Hall	2·54	107	*Peebles*	Stobo Castle	2·14	53
"	Lowestoft Sec. School	1·97	85	*Berwick*	Marchmont House ...	1·48	46
"	Bury St. Ed., Westley H.	2·13	88	*E. Loth.*	N. Berwick	·86	32
Norfolk	Sandringham Ho. Gdns.	2·08	81	*Midl'n.*	Edinburgh, Blackf'd H.	·93	33
Dorset	Creech Grange... ...	3·41	84	*Lanark*	Hamilton W.W., T'nhill	3·20	73
"	Beaminster, East St. ...	3·55	86	*Ayr*	Prestwick	...	...
Devon	Teignmouth, Den Gdns.	2·71	83	"	Glen Afton, Ayr. San ...	4·80	74
"	Ilfracombe	4·53	104	*Renfrew*	Greenock, Prospect Hill	6·37	86
"	Princetown	8·11	90	*Bute*	Rothesay, Ardencraig...	7·41	88
Cornwall	Bude	3·56	94	*Argyll*	Morven, Drimnin ...	9·30	125
"	Penzance	3·50	80	"	Ardrishaig, Canal Office	7·41	88
"	St. Austell	3·83	76	"	Inveraray Castle ...	8·50	80
"	Scilly, St. Mary ...	2·84	80	"	Islay, Eallabus ...	4·94	77
Somerset	Bath	2·22	68	"	Tiree	4·05	79
"	Taunton	1·66	54	*Kinross*	Loch Leven Sluice ...	2·36	74
Glos.	Cirencester	2·36	73	*Fife*	Leuchars Airfield ...	1·52	54
Salop	Church Stretton ...	3·71	107	*Perth*	Loch Dhu	8·18	87
"	Shrewsbury, Monkmore	2·07	78	"	Crieff, Strathearn Hyd.	3·61	82
Worcs.	Worcester, Red Hill ...	2·00	87	"	Pitlochry, Fincastle	2·92	72
Warwick	Birmingham, Edgbaston	2·49	86	*Angus*	Montrose Hospital ...	1·52	49
Leics.	Thornton Reservoir ...	2·40	90	*Aberd.*	Braemar	2·10	51
Lincs.	Cranwell Airfield ...	1·39	64	"	Dyce, Craibstone ...	1·61	45
"	Skegness, Marine Gdns.	1·41	71	"	New Deer School House	3·18	86
Notts.	Mansfield, Carr Bank...	2·31	87	*Moray*	Gordon Castle	1·51	48
Derby	Buxton, Terrace Slopes	5·04	101	*Inverness*	Loch Ness, Garthbeg ...	4·74	105
Ches.	Bidston Observatory ...	2·93	97	"	Fort William	10·39	113
"	Manchester, Airport ...	2·50	78	"	Skye, Duntulm... ...	6·35	106
Lancs.	Stonyhurst College ...	4·29	81	"	Benbecula	5·19	101
"	Squires Gate	3·12	85	R. & C.	Fearn, Geanies ...	2·78	107
Yorks.	Wakefield, Clarence Pk.	1·55	64	"	Inverbroom, Glackour...	7·76	124
"	Hull, Pearson Park ...	1·54	65	"	Loch Duich, Ratagan...	12·89	141
"	Felixkirk, Mt. St. John...	1·81	69	"	Achnashellach	12·72	139
"	York Museum	1·37	62	"	Stornoway	3·68	84
"	Scarborough	1·37	61	*Caith.*	Wick Airfield	3·48	112
"	Middlesbrough... ...	1·24	52	*Shetland*	Lerwick Observatory ...	...	...
"	Baldersdale, Hury Res.	2·54	66	*Ferm.*	Belleek	3·40	67
Nor'l'd	Newcastle, Leazes Pk....	1·25	48	*Armagh*	Armagh Observatory ...	3·91	117
"	Bellingham, High Green	2·21	64	*Down*	Seaforde	2·50	62
"	Lilburn Tower Gdns ...	1·72	54	*Antrim*	Aldergrove Airfield ...	2·05	57
Cumb.	Geltsdale	3·70	95	"	Ballymena, Harryville...	2·24	49
"	Keswick, High Hill ...	5·41	80	*L'derry*	Garvagh, Moneydig ...	2·95	66
"	Ravenglass, The Grove	4·54	95	"	Londonderry, Creggan	3·97	83
Mon.	A'gavenney, Plâs Derwen	5·05	113	*Tyrone*	Omagh, Edenfel ...	3·47	80
Glam.	Cardiff, Penylan ...	4·69	104				

* 1916–1950

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

Wt-18. K16.