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

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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.

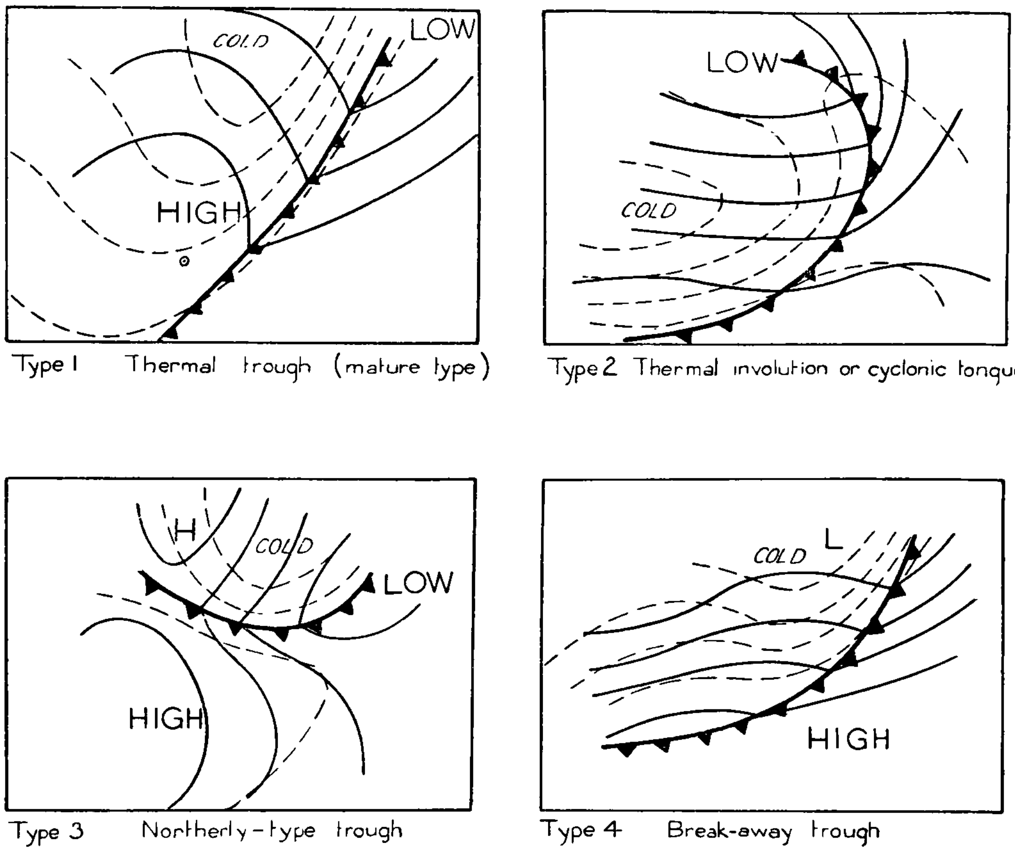


FIG. 1—MAIN TYPES OF THERMAL TROUGH OCCURRING OVER THE ATLANTIC OCEAN AND THE BRITISH ISLES

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.

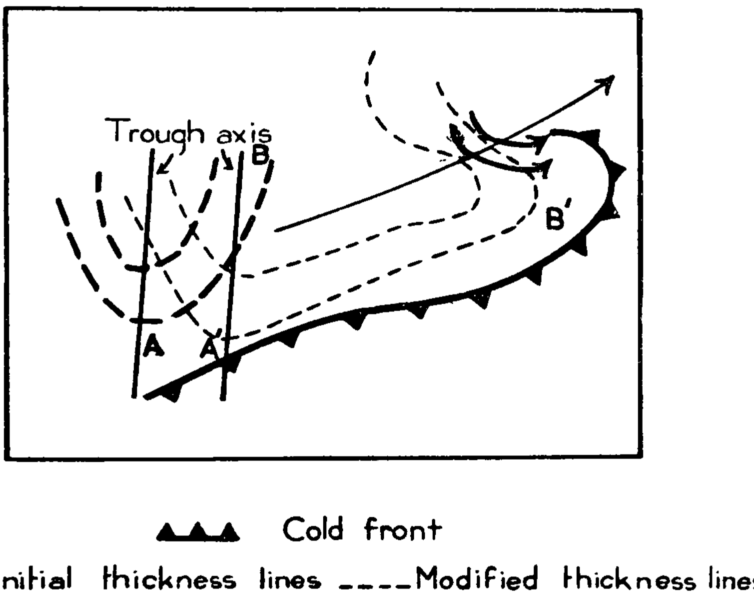


FIG. 2—DISTORTION OF TYPE-1 TROUGH BY CYCLONIC DEVELOPMENT

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).

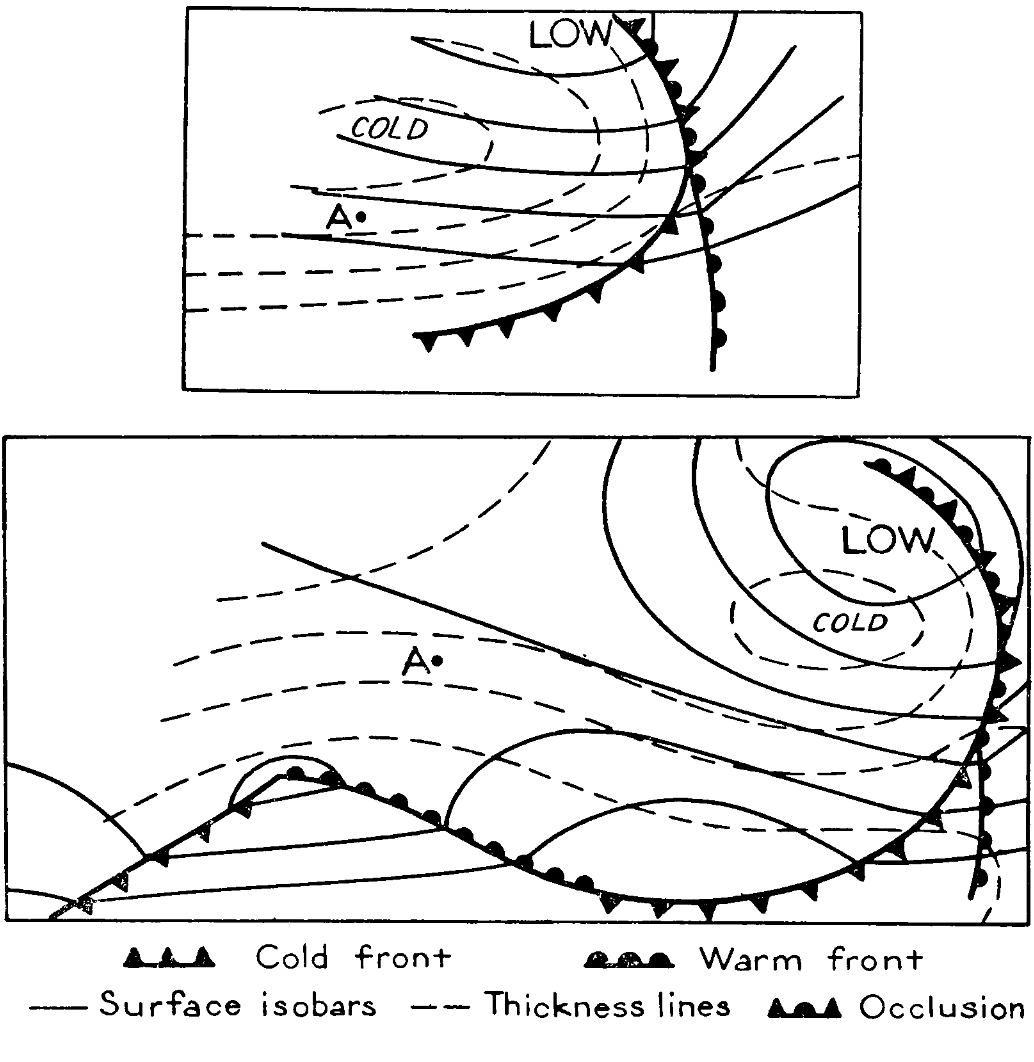


FIG. 3—TWO STAGES IN THE CUTTING OFF OF A COLD POOL AT THE TIP OF A CYCLONIC THERMAL TONGUE

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.

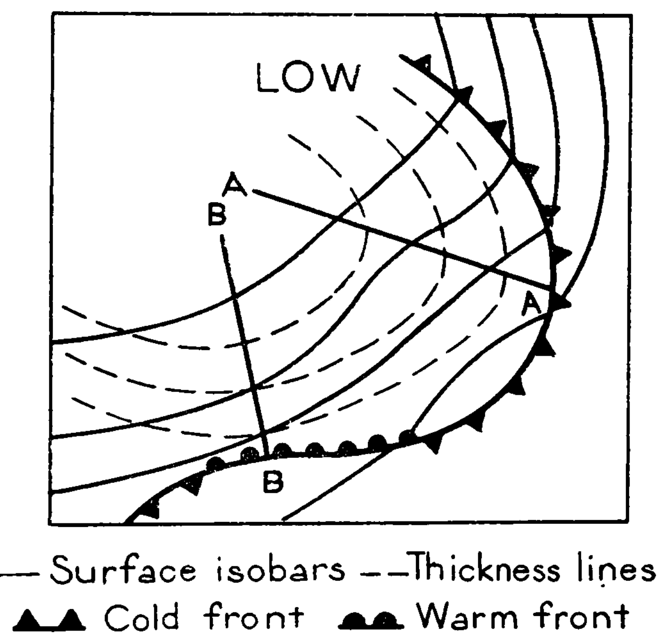
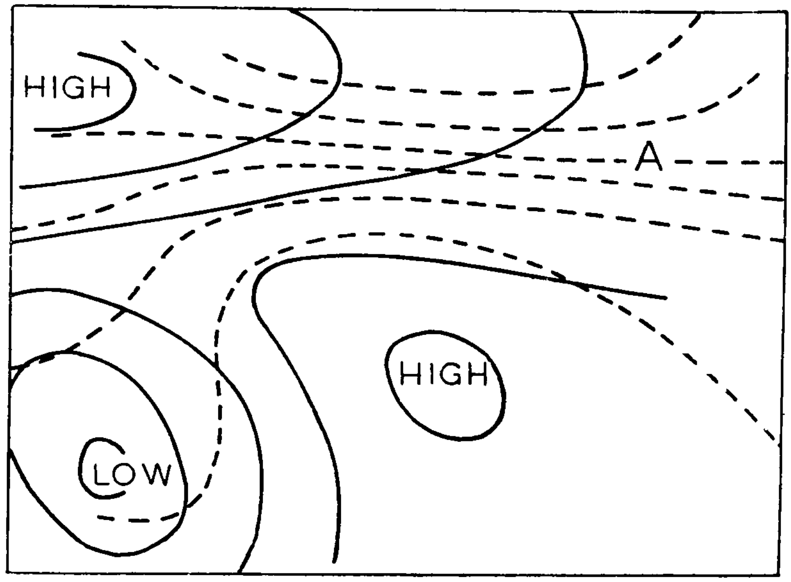


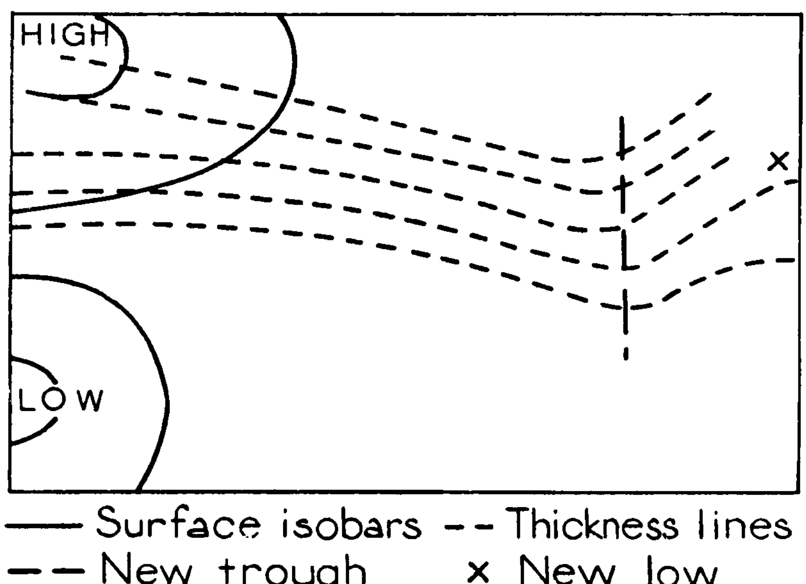
FIG. 4—DOUBLE AXIS IN A CYCLONIC TONGUE

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



(*a*)



(*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.

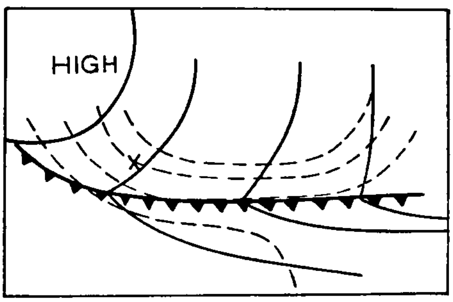


FIG. 6—BROAD COLD TROUGH ASSOCIATED WITH AN ANAFRONT OCTOBER 25–27, 1955

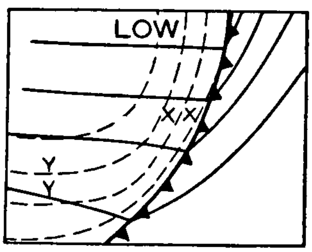


FIG. 7—PATTERN LEADING TO DRY AIR ALOFT IN FRONTAL ZONE X—X

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.

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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

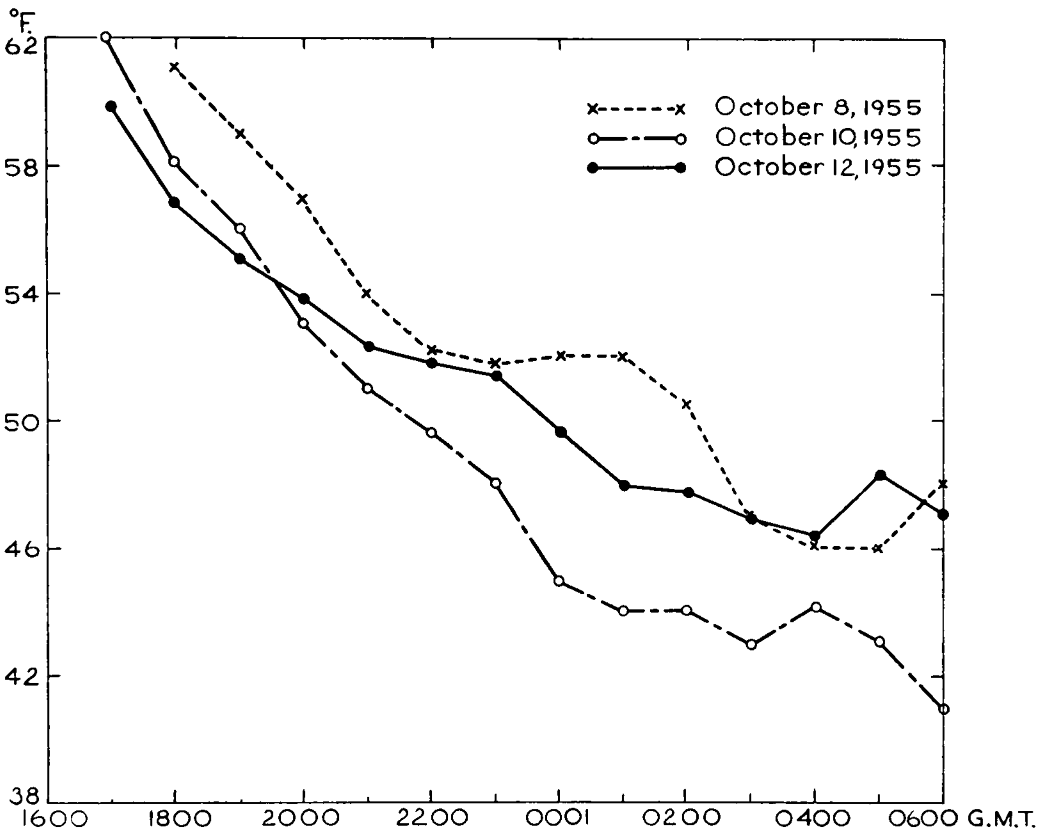


FIG. I—HOURLY TEMPERATURES ON THREE OCCASIONS OF CLEAR SKIES DURING EARLY OCTOBER 1955

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

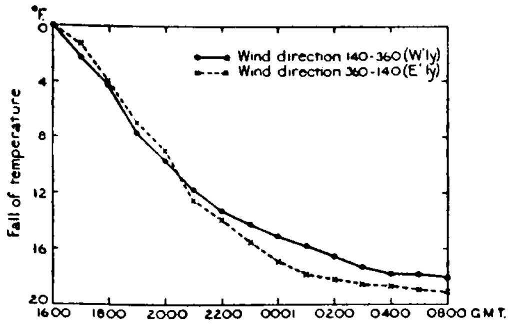
Application to forecasting.—The forecasting procedure is:—

(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.

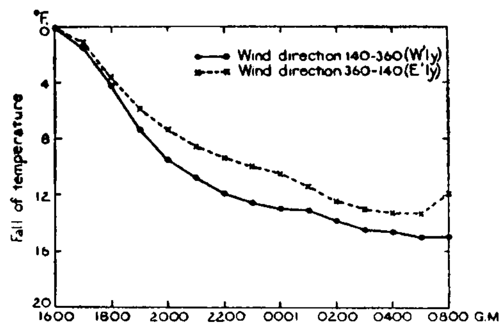
(ii) Calculate the night minimum temperature using the appropriate constant C for Wittering in McKenzie's formula,

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

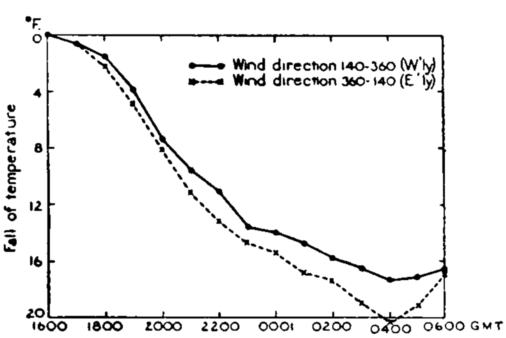
(iii) On the appropriate "typical" cooling curve plot the calculated night minimum temperature.



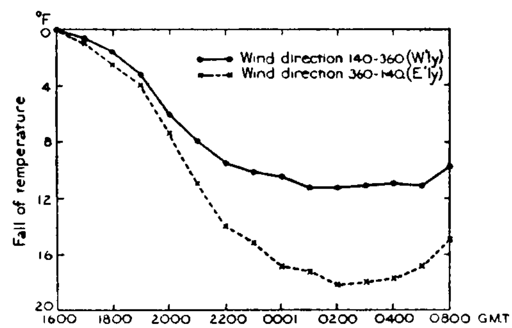
(a) Equinoctial months. Wind force 0–2.



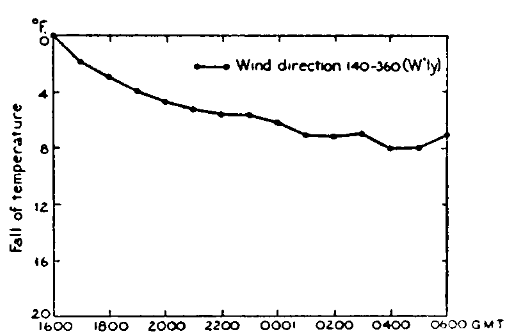
(b) Equinoctial months. Wind force 3–4.



(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.

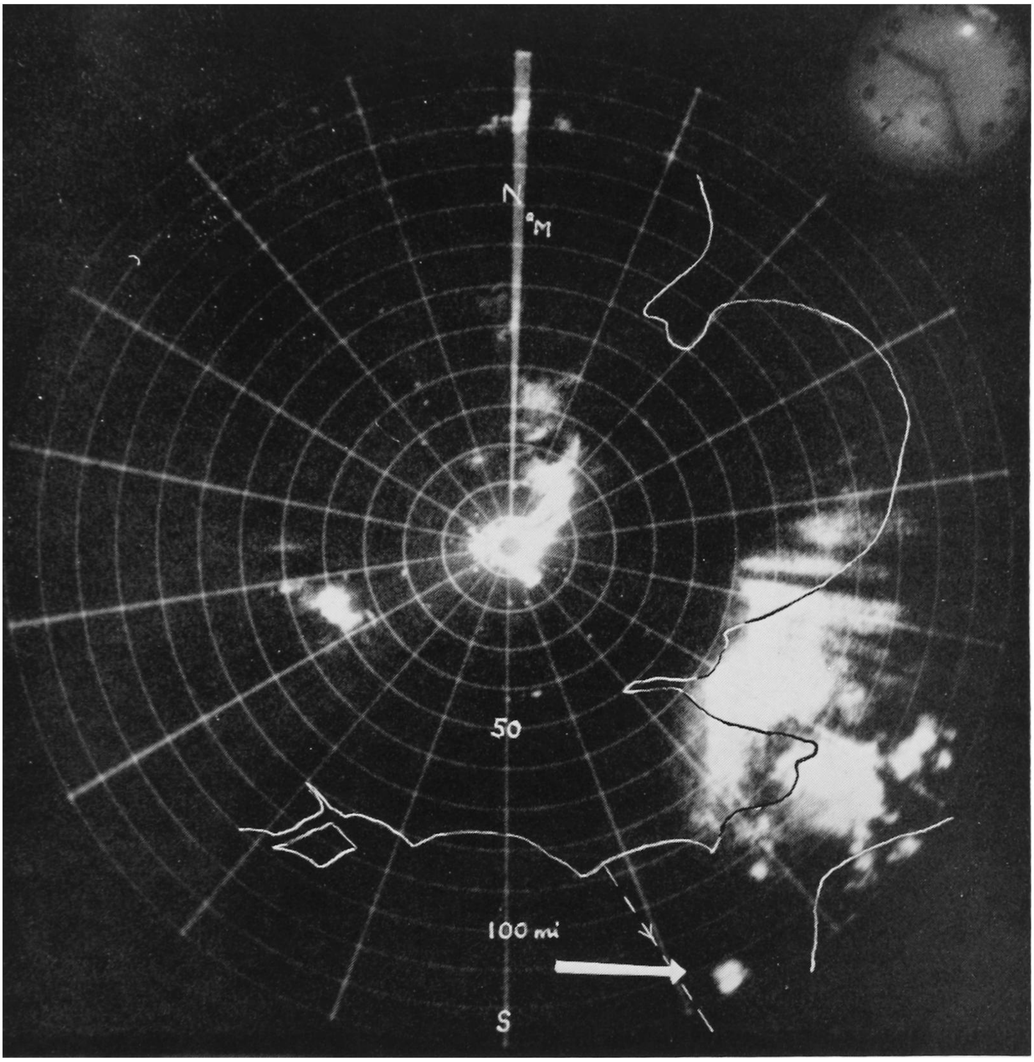
Appendix

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.



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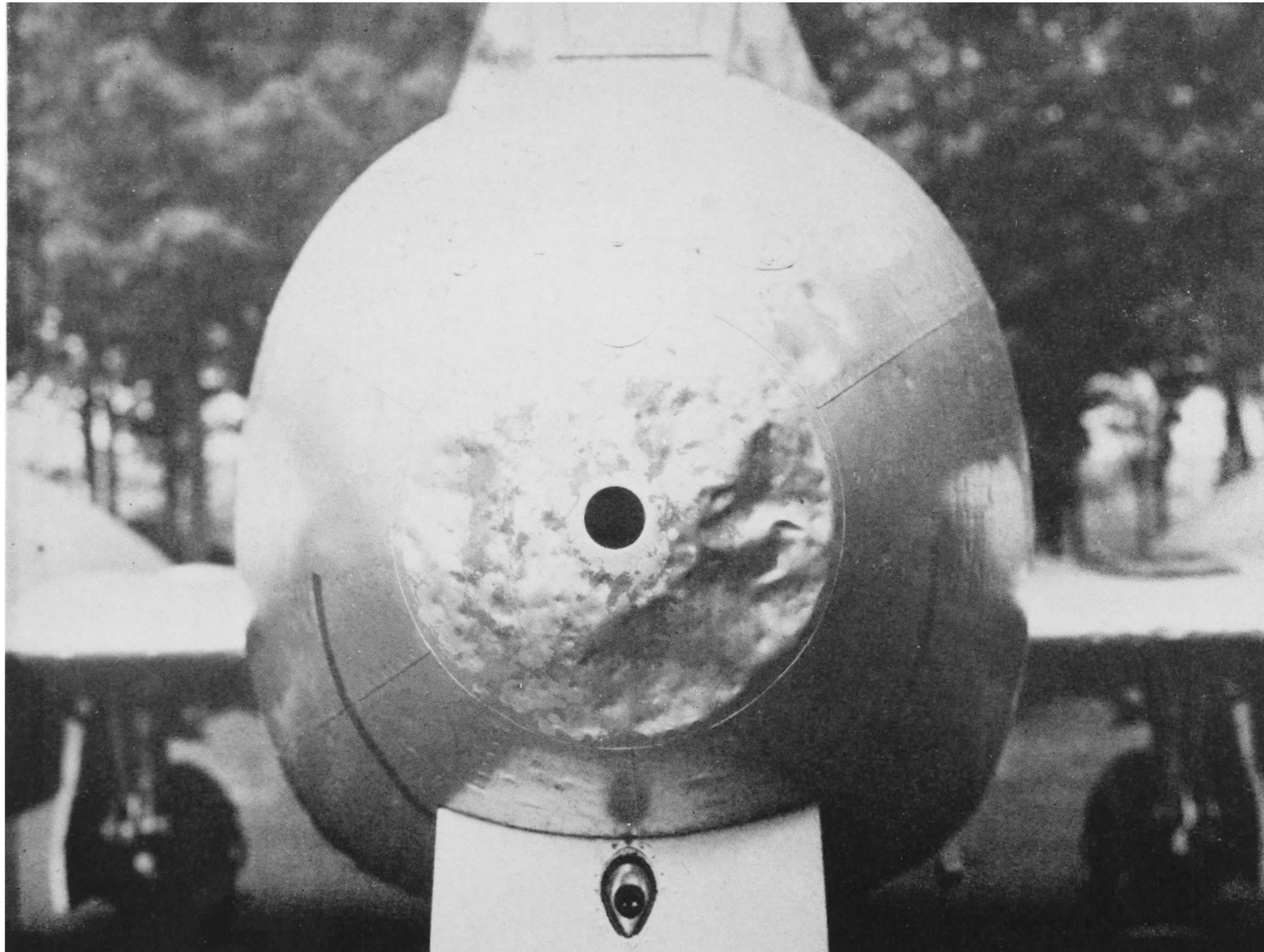
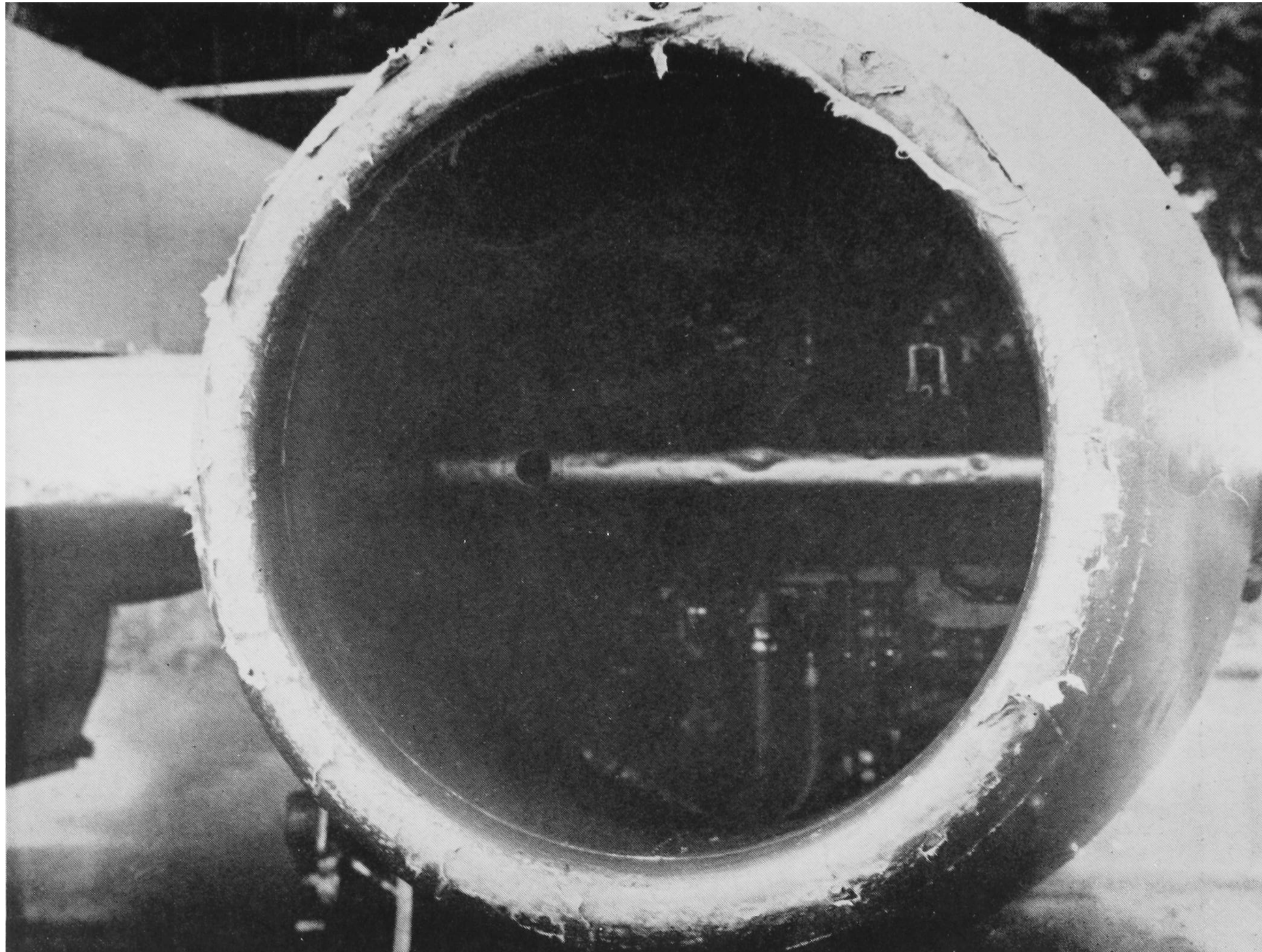
RADAR PICTURE AT 0924 G.M.T. ON JULY 3, 1957

(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 meso-meteorology 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	Percentage of average	No. of days difference from average	Percentage 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

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