M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 974, AUGUST 1953

REVIEW OF METHODS OF LONG-RANGE FORECASTING WITH PARTICULAR REFERENCE TO THE BRITISH ISLES

By J. M. STAGG, D.Sc.

This paper is a critical summary of the principal processes that have been explored or proposed for forecasting for periods longer than can be dealt with by extending the normal synoptic methods used in short-period forecasting.

It is an abridgement of a *Meteorological Research Paper*. The only important change from the original paper consists in the omission of suggestions for future research prepared for the consideration of the Meteorological Research Committee; all the essential technical information has been retained.

Each principal process suggested for long-range forecasting will be considered in turn.

Regression equations.—Statistical relations in the form of multiple correlations or regression equations between present- or past-weather elements and later events in the same or other regions have been used in various parts of the world, particularly where large-scale processes dominate the weather over a wide area. In India regression procedures have proved of value in assessing whether temperature and rainfall are likely to be substantially above or below normal during the monsoon season.

Because few of the relationships among meteorological events are simple or direct, especially when separated in time as they have to be for application to forecasting, the correlations are liable to be unstable, and therefore the regression equations require to be modified from time to time so that new or improved correlations may replace those whose validity has deteriorated. And even though the physical processes behind the regression equation may be broadly understood the relationships are purely statistical, so that the forecaster can exercise only such judgement as the transformation of the arithmetic of his result into the words of his forecast allows him.

The search for correlations among meteorological elements in different parts of the world can improve understanding of the functioning of the atmosphere, and the use of regression equations may be helpful in conjunction with other methods. But forecasting by this means alone cannot lead far, especially in a meteorologically complex area like the British Isles, even if the correlations were elaborated and extended to take account of the more recently available upper air information.

Pressure waves.—Analysis of selected barograms of surface pressure from selected stations in middle and high latitudes has shown that apparently regular wavelike oscillations are set up in the atmosphere from time to time: the principal periods are approximately 72 and 48 days and their submultiples. If one or more of these oscillations can be diagnosed early enough, they may be used to estimate the future pressure pattern over a network of stations. A similar procedure has been applied to pressure-height contours at 500 mb. and higher levels. Pressure waves have been extensively investigated and applied to long-range forecasting in Germany where other important properties have been attributed to particular waves. For example the 72- and 36-day waves are believed to extend into the stratosphere and exercise control over the direction of travel of the 6-day wave and the movements of the centres of the 24-hr. isallobaric pattern; the amplitude of the 24-day wave on the other hand decreases rapidly with height and is conspicuous only in high latitudes. Pressure waves have also been investigated in the Meteorological Office.

It has been shown that a single- or double-layered model atmosphere, having prescribed kinds of temperature structure, can oscillate in a number of periods ranging from 6 to 72 days, and also that the oscillations are propagated from west to east in middle and high latitudes. But there is no unanimity about their origin; they have been variously attributed to unstable gravitational waves between troposphere and stratosphere induced by extension upwards of instability waves on the polar front, to roughly periodic outbreaks of cold air from the polar calotte or the breaking away of cold pools, to waves dependent upon the temperature differences between the main land and sea masses around zones of the earth, and even to precession movements in the wind circulation zones around the earth set up by unsymmetrical pressure fields tilting the wind belts out of their appropriate latitude. No one of these explanations is physically satisfactory or complete.

But even without a satisfactory physical basis the existence of regular trains of periodic oscillations might be of value in forecasting if they were sufficiently regular, of big enough amplitude and sustained over long enough intervals. Unfortunately these requirements are seldom, if ever, all met. The wavelengths of the dominant waves vary over a considerable range and a sequence of oscillations seldom continues for more than three or four cycles; the use of the word wave (in the sense of a sustained and regular recurrence pattern) in connexion with the tendency of the atmosphere to oscillate is misleading.

It has to be concluded that wavelike oscillations of the atmosphere probably do exist, and that further study may well be valuable in giving further information about the structure and behaviour of the atmosphere; but pressure waves are too transient and irregular, and perhaps too localized and variable from season to season and year to year to be of real assistance in forecasting.

Symmetry patterns.—From time to time the sinusoidal pattern formed by the larger surges of pressure in particular areas over an interval of a month or more from a particular date is roughly a direct, or less frequently an inverted, mirror image of the pattern before that date; and the pattern as a whole appears to be translated into other areas as if it were embedded in the circulation. Only a very few patterns are recognizable without detailed analysis, and they are found only a few times a year, mainly in winter. But if a pattern of this kind can be recognized before, or by the time of, the central date as likely to be a symmetry pattern, harmonic or other analysis can be employed to extend it into the future over a grid of stations, and so allow it to be applied to forecasting the surface pressure distribution.

The chief components in a symmetry pattern are found to be the same as in pressure waves, namely 72 days and its submultiples, and its formation is therefore explained by the simultaneous existence of pressure waves phased so that the extreme minimum or maximum values coincide at the point of symmetry. If this is the only physical explanation of symmetry patterns—and it fits the facts—then the value of their application to forecasting is as precarious as is the use of pressure waves. There are however some further aspects. The 24-day wave is one of the most prominent constituents of every symmetry pattern, and this has been attributed to major outbursts of polar air from the arctic basin; if there is a tendency for these outbursts to occur at about 24-day intervals, the occurrence of a roughly symmetrical pattern a few times each year may express little more than the tendency for one prolonged weather type (e.g. south-westerly, with its series of depressions each having its particular family characteristics) to be interrupted by a polar-air outburst. This leaves open the questions whether the polar-air surges do have a 24-day rhythm, even if only for two or three cycles, and whether, if there is an approximate rhythm, it is inherent in the build-up and break-down of pressure over the polar cap, or whether it is started by a smaller and less spectacular tendency for the atmosphere to oscillate naturally at about 24-day intervals. There is so much doubt about the answers to these questions, and indeed about any system which depends on the analysis of an element like pressure having intrinsic coherence in its day-to-day variation, that some authorities have concluded that symmetry patterns are the result of fortuitous circumstances in the pressure field.

To be of value in forecasting the existence of a pattern and the symmetry date must be known as soon as possible after the central point of symmetry has been reached, and its main features must be reproducible by a few of the harmonic components. But there is no known method of forecasting the symmetry date, and even if there were, the lack of persistence in the pattern and uncertainty about its form and amplitude after the central date would make the information of very doubtful value. Methods have been devised and applied both in Germany and in Great Britain by which the pressure field over a whole region can be analysed in means of one to three or more days, but such statistical devices do not compensate for the inherent weaknesses of the method both in physical interpretation and practical application.

Climatic singularities.—In probably every region of the world there is a tendency for particular types of weather, or abrupt changes in its annual course, to recur round about the same calendar dates each year. These singularities (as the German meteorologists who have studied them most have called them) include large-scale phenomena like the beginning of the Indian monsoon, or, at the other extreme, discontinuities in trend of mean temperature through the year such as were first discussed by Mossman and Buchan for south-east Scotland. Lamb has recently shown that many of the singularities listed by German meteorologists appear also in the weather of the British Isles.

When the singularities are restricted to a few well marked events each with a genuine physical basis there can be little doubt of their value in forecasting;

the reality and value of many singularities become more questionable when their number is increased so that six or eight are expected each month. It is admittedly dangerous to discount a phenomenon because it has no obvious explanation, and until more is known of the mechanism which leads to the major changes in the zonal tropospheric circulation in middle latitudes the explanation of the high incidence of particular pressure distributions over an area on days linked with the calendar must be lacking. But the reality of individual singularities can be accepted and used as an auxiliary factor in forecasting only when their frequency of occurrence over a long series of years is substantially higher than random, and when some explanation, at least proximate, can be offered when they fail to occur or are much displaced from their position in the calendar.

Up to now the only explanation of singularities is in terms of pressure waves, particularly the 72-day wave and its submultiples. According to this, the wave processes determine the pattern of surface pressure distribution and through it the major changes from zonal to meridional circulation; on this theory the absence or displacement of singularities is to be taken as a warning that another system of waves has been established or the phase altered, and this in itself is a tool in the experienced forecaster's hand.

In current synoptic language many of the more important singularities are probably associated with greater or lesser degrees of "blocking" of the zonal westerlies, and an intensive study of this phenomenon might therefore throw light on the cause of authentic singularities. Alternatively the study of real singularities, critically segregated from the merely fortuitous, might well be extended to the middle and higher troposphere and lower stratosphere; even though it might not lead to conclusions directly applicable to long-range forecasting, a study of this kind would be one method of obtaining further experience of the three-dimensional behaviour of the atmosphere which could hardly fail to have applications to forecasting practice.

Pressure trends and other trend phenomena.—As the amount of detailed information in synoptic charts is apt to conceal the slow, though widespread, changes that may be in progress, charts representing the deviation of the mean surface-pressure distribution over a number of days from the long-term normal distribution have been used to bring these slower trends into prominence. In this way centres of abnormally high or low pressure are identified, and their movements studied with the object of extrapolating their trajectories. But the results of at least one experiment on these lines conducted by C. E. P. Brooks using 6-, 12- and 24-day mean charts were not encouraging.

A similar kind of procedure forms part of other systems of forecasting. For example trends of index figures representing the strength of the zonal circulation have been applied to help in assessing the future circulation pattern; surface-pressure profiles at a network of stations are similarly used as a clue to the general trend of pressure over an area.

In these and other applications trend procedures are quite empirical, and for want of knowledge of the causes of the trend the bias in extrapolation must always be toward normal. It is therefore not surprising that the contribution of trend methods to long-range forecasting has not been found helpful; at best they can be only auxiliary aids.

Long waves in the zonal westerly circulation of middle latitudes.—The working hypotheses which allow long-wave ideas to be applied to forecasting are, first, that the waves are more slowly variable and their immediate behaviour is a little more amenable to forecasting than the surface-pressure field, and secondly, that the main features of, and changes in, the surface field are related to the pattern of the upper tropospheric circulation. Unfortunately these hypotheses are not conspicuously reliable beyond the second or third day. The only approximately realistic theory of long waves so far developed rests on assumptions, both as regards the physical characteristics of the medium and the nature of the undulations, which seldom hold in the actual atmosphere, so that substantial empirical and subjective factors have to be superposed when the theory is applied in practice. Even then inferences can be made about speed and wave-length only of waves that already exist; little help can be given about the time and place of formation of new waves or about the intensification or decay and disappearance of old ones. For these aspects of the long-wave pattern the forecaster must use the second hypothesis in reverse, and assess the changes in the pattern of tropospheric circulation that are likely to be brought about by the development and movement of surface features. And reliance on this interaction is impaired in that its extent depends among other things on the scale and intensity of the surface developments. Small and shallow depressions and high-pressure cells are steered by the circulation pattern without altering it substantially, but the larger and more vigorous features of the pressure field impress their effects on the circulation.

Notwithstanding these weaknesses, techniques based on circulation theory and experience have contributed to the preparation of 5- and 30-day forecasts in the United States of America, and of 10-day forecasts in Germany. In the United States 5- and 30-day mean configurations of the surface and upper air circulation patterns are dealt with as units, using step-by-step daily practice for the first 2 or 3 days as a check in the preparation of the 5-day forecast. In Germany the technique adopted is understood to be a grafting of an extension of daily synoptic practice for the first five days on to a forecast derived from a combination of other methods for the second half of each 10-day period.

Apart from the uncertainties inherent in the use of circulation ideas, application of the wave theory to 5-or-more-day mean patterns introduces further doubts. It may be contended that mean circulation charts for even as many as 5 days can have little physical significance and that the equations of circulation theory cannot be satisfied by mean values of meteorological elements which do not correspond with any actual state. On the other hand those who use them claim that 5- and even 30-day mean circulation charts and their surface field counterparts have real physical individuality, and that only mean charts can disclose the centres of action which regulate the longer-period trends in weather; they claim that the results of long-wave theory can be applied to mean charts with only a little more empirical modification than is already necessary for daily charts, and, further, that the broad features of weather, e.g. departure of temperature and rainfall from normal, can be inferred from the mean surface charts deduced from the mean charts of circulation.

But whatever value these methods may have for large continental regions, they are unlikely to give much useful guidance for areas of the size and meteorological situation of the British Isles, where quite small displacements of the main features of the circulation have such important effects on the weather.

Kinematics of air flow and trajectories of pressure cells.—With their weather dominated for much of the year by anticyclones and their vast plains providing a natural laboratory for the study of air-mass and pressure-cell movements, it is not surprising that Russian meteorologists should have been led to base their system of forecasting on trajectories of high-pressure cells. Though analogues and rhythms and dynamical reasoning also play an important part in the system begun by Multanovski and elaborated by Pagava, the movements of anticyclonic cells and the pressure fields associated with them form the "natural" basis of their "natural" processes within "natural" regions.

According to the Multanovski-Pagava school the anticyclonic nuclei that invade Russian territory come predominantly either from the Azores, from Greenland, or from the arctic basin by way of the Taimyr peninsula. They have preferred axes along which they move, and the frequency of invasion from each of the main centres and the orientation of their trajectories depend on the time of year and on the kind of season. In some years, for example those characterized by unusually mild autumns, the frequency and the orientation of the tracks followed are consistently abnormal. Once a high-pressure cell has started to migrate its future track is approximately known, and by reference to charts which have been constructed to show the positions of the other high- and low-pressure cells relative to similar tracks followed about the same time in other years, the general form of the surface pressure distribution linked with a particular anticyclonic axis can be forecast. As the likely orientation of the trajectory of a high-pressure cell can be determined within 2 or 3 days after the nucleus of the cell has appeared and as the average life of a cell is 10–12 days, it is possible by the Multanovski-Pagava system to forecast 7 or 8 days ahead.

This period of 7–8 days can be extended by other considerations. At a time varying from 30 to 35 days before the start of a high-pressure cell process, there are recognizable premonitory symptoms in the surface field, and in the interval between the appearance of these warnings and the start of the process there are several recognizable phases of 6 to 15 days each characteristic of a stage leading to the formation of the anticyclone. In addition the Russian long-range forecasting school has discovered that there is a tendency to rhythms with still longer periods in the behaviour of the atmosphere. The principal rhythms are of 3 and 5 months' duration and are related to major outbreaks of air south or south-westwards from the Taimyr area.

It is difficult to form an appreciation of the Multanovski-Pagava system of forecasting, and even if it were proved to be successful in Russia it does not follow that it could be successfully applied to any other area, because Russia's extent (east–west and into the arctic basin) and surface topography relative to the general circulation are unique. But the Russian emphasis on dynamic climatology, on natural periods and natural regions, and on the genesis, development, migration and decay of high-pressure cells are aspects of the system which might well repay further study in other countries.

Analogues.—In forecasting for short periods, frequent observations, good communications and simple extrapolation go a long way to fill blanks in the forecaster's knowledge of the physical processes, and so the use of mechanical means of aiding his memory is unnecessary and is even to be deprecated. Physical reasoning should replace memory. But if it be accepted that a preliminary to starting any system of forecasting for periods more than 2 or 3 days ahead must be an intensive study (with a broader perspective than short-period forecasting requires) of the modes of evolution of particular types of weather and of the corresponding thermal and flow pattern in the middle and higher troposphere and lower stratosphere then the information derived from the study must be systematized. The best way to systematize it is to devise a theory which takes account of the dynamics and thermodynamics of the whole field of interaction. But it is unlikely that that will be available for many years. So, unless each member of the forecasting team makes his own study so as to build up his own background of case histories, an adequate analogue system for comparing and grouping situations of like evolution may be useful so long as it is kept in mind that any analogue system is only an auxiliary and interim measure, to be discarded as fast as physical knowledge of the underlying processes replaces empiricism. But there are at least as strong reasons for avoiding the use of any analogue system, even though the development of an equally successful, but scientifically sounder, procedure for forecasting may take longer.

Solar phenomena.—As regular seasonal changes in solar radiation so obviously affect the general temperature in each hemisphere and the tempo and intensity of weather changes, it is contended that the irregular changes in the sun's output of radiation which are assumed to vary in parallel with particular indices of its surface activity should also affect weather. Much work has been done in many countries to discover relationships; mean annual, monthly and daily values of sunspot numbers, and of measures of the solar constant, numbers of faculae and other indices have been correlated with a great range of climatic and weather parameters. The results, though of interest for the light they shed here and there (or fail to shed) on indirect relationships between solar activity and terrestrial weather, are of no value for forecasting; the only reliable and persistent correlation so far found is between sunspots and temperature in the more cloudy regions of the tropics, and this (negative) correlation shows up only in the mean annual values. More must be known about the relationships between measures of solar activity and the output of radiation from the sun in various spectral regions, particularly in the ultra-violet, and about the possible effects of corpuscular radiation, before solar phenomena can be of use in forecasting; and even then it is not clear that it will be any easier to forecast behaviour on the sun than the behaviour of our own atmosphere, except perhaps in a general way for the 11- (or 22-) year cycle.

Ozone.—Although much is now known about the life history of atmospheric ozone, its distribution over the globe, its seasonal changes and its relation to the pattern of the surface pressure field especially in moderate and high latitudes, measurements of ozone are so far of value to the forecaster only as pointers to the nature of the upper air processes that accompany the birth, growth and decay of low- and high-pressure cells in the lower troposphere. Even if the redistribution of ozone by some extra-terrestrial influence preceded rather than accompanied the changes in the higher circulation pattern and surface field it would still be necessary to forecast the behaviour of the mechanism which effects the irregular changes in the amount and distribution of the ozone.

Conclusion.—There is no ready-made procedure or combination of procedures suitable for long-range forecasting in the British Isles. The objections to the methods that have been tried or proposed are that most of them are primarily applicable to large continental areas, that they rely too much on empirical and impermanent relations, that they are too dependent on personal judgement, and that too few of them are founded on lines which will allow organic development into sound physical methods as knowledge of the atmosphere grows. A worth-while system of long-range forecasting, like any modern system of day-to-day synoptic forecasting, requires the gradual building up of an elaborate procedure and the accumulation of experience in its use. To avoid waste of effort it is therefore necessary to see that any new system should start on sound physical lines, and should be sufficiently elastic to permit modification for absorbing new ideas without wholesale abandonment of technique and experience.

Much research has still to be done on the maintenance of the zonal westerly circulation, its role in the interchanges of heat and momentum with adjacent zones and its interactions with the great land and ocean surfaces below and with events in the stratosphere above; and it may be that deeper insight into these processes will shift the emphasis to some more fundamental mechanism. But the circulation is likely to continue to be regarded as the main link between the still imperfectly understood primary causes and the changes in the field of flow near the earth's surface which have weather as their end product. While the basic research proceeds, it is therefore inevitable that the study of the modes of behaviour of the westerly zonal circulation corresponding with the main weather types and spells, and of the modes of transition from one weather type to another must be the starting point for any modern system of longer-range forecasting.

BIBLIOGRAPHY

All the important papers which have been consulted in the preparation of this review are given in the comprehensive "Selective annotated bibliography on general and extended forecasting" compiled by C. E. P. Brooks in *Meteorological abstracts and bibliography*, *American Meteorological Society*, *Boston Mass.*, **2,** 1951, p. 42 and p. 124. The only important omissions are the unpublished reports by Dr. C. E. P. Brooks and his colleagues and by Mr. J. Wadsworth on British experiments in forecasting by pressure waves.

FORECASTING MOUNTAIN AND LEE WAVES

By R. S. SCORER, Ph.D.

It is a complicated matter to calculate wave amplitudes and lengths even in a simple hypothetical case, but some indication as to whether waves will be good or not can be fairly simply given. The best lee waves are produced by hills with smooth, fairly steep lee slopes if they lie across the wind, but the air current must also be of the right kind. Waves are more likely if the wind direction does not vary much with height and is across a mountain ridge. It has also been shown[1] that waves over the mountains and to their lee only become noticeable when the quantity l^2 decreases with height and the purpose of this note is to indicate how this quantity can be fairly quickly estimated. By definition:

$$l^2 = g\beta/U^2 - U''/U$$

where g is gravity, β is the static stability and equal to θ'/θ, θ being the potential temperature, U is the wind across the mountain and a prime denotes a differentiation with respect to height. Because it is only important in shallow layers and cannot be computed with much accuracy the second term is best ignored in the present state of the subject in forecasting problems. It is actually more convenient to calculate l^{-1} and the following procedure has been adopted:

(i) Obtain an estimate of the wind and temperature profiles of the air current, and plot them on a tephigram up to 400 mb. at least.

(ii) For each 100-mb. layer obtain the thickness Δz in feet and the difference in potential temperature between the top and the bottom of the layer in degrees Fahrenheit. These can be read directly from the tephigram.

(iii) From Fig. 1 read off the value of $(Ul)^{-1}$; multiply this by U, the average wind speed in the layer in knots, and obtain l^{-1} in miles.

If l^{-1} increases substantially with height waves are more likely than if it does not. The best conditions are when there is a layer at least 200 mb. thick near the ground in which l^{-1} is considerably less than in a layer higher up at least 300 mb. thick. Sharp inversions and changes of wind with height are best smoothed out in these calculations. The formula is not accurate in these regions if the inversion is a fairly thin layer or if the velocity profile is very curved, but it is adequate over most of the heights dealt with here.

If l^{-1} is very large near the ground a thicker layer above in which it is small (with another layer in which it is large above that) is required for waves.

If l^{-1} does not change much in the lowest 500 mb. it may be necessary to continue the calculation up to 300 or 200 mb.

Very roughly the lee waves have a maximum amplitude at the top of the layer in which l^{-1} is small, i.e. at the level where l^{-1} begins to increase substantially with height.

The wave-length of lee waves will be less than $2\pi l^{-1}$ as measured in the upper layers and more than $2\pi l^{-1}$ as measured in the lower layers; and it will be in miles if l^{-1} is calculated as just described. If the ridge is well defined and fairly narrow the first lee wave is only three-quarters of a wave-length from the ridge crest. If during the day, because of a decrease in lapse rate in the lower layers, l^{-1} increases, the wave-length also increases; but as it cannot exceed $2\pi l^{-1}$ as measured in the upper layers waves may become impossible, only to return again in the evening with a slowly shortening wave-length.

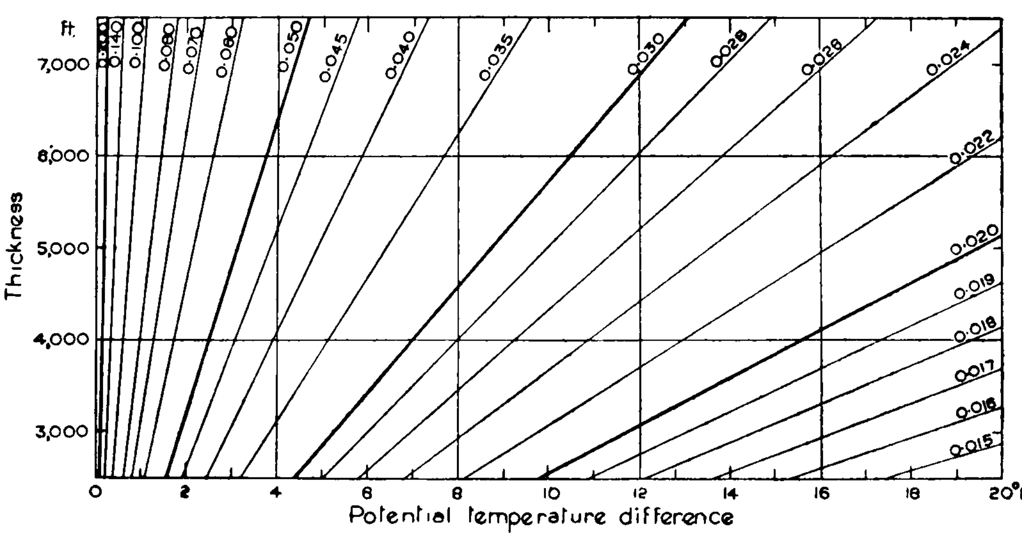

FIG. 1—ISOPLETHS OF $1/Ul$ TO GIVE $1/l$ IN MILES WHEN U IS IN KNOTS

Generally, when conditions are favourable for lee waves they also favour large-amplitude disturbances over the hills themselves. If mountains have great extent in the direction of the wind the disturbance may not be proportional to the height. In such cases there may not be much observable vertical motion unless the mountains have a fairly steep lee slope.

It is impossible to be more precise than this without also becoming much more involved. It seems best that this simple calculation should be tested for its adequacy first.

REFERENCE

1. SCORER, R. S.; Theory of airflow over mountains, II—The flow over a ridge. *Quart. J.R. met. Soc., London,* **79**, 1953, p. 70.

HELM-WIND EFFECT AT RONALDSWAY, ISLE OF MAN

By F. W. WARD

With straight isobars from a direction between 340° and 360°, the surface wind at Ronaldsway has been noticed to be subject to unexpected deviation from that which had been forecast. Sometimes the wind was considerably stronger than expected whilst the direction has been observed to change by as much as 180° in a few seconds. On July 28, 1952, the wind which had been blowing steadily NW. with a strength of about 10 kt. suddenly became SSW. 13 kt.

Frequent observations of the wind velocity were made in an attempt to trace the origin of this strange behaviour. Eventually a marked difference between the wind at the Control Tower and that at a wind-sock some 800 yd. due east of the Control Tower was noticed. A selection of the observations is given in Table I.

TABLE I—WIND OBSERVATIONS AT CONTROL TOWER AND AT WIND-SOCK

G.M.T.	Tower Direction	Tower Speed	Wind-sock Direction	Wind-sock Speed
		kt.		kt.
0700	S.	15	..	..
0716	calm	..	..	..
0728	360° cycle	8	..	..
0731	SE.	14	N.	14
0736	N.	10	SW.	9
0741	SW.	6	N.	14
0748	ENE.	14	N.	5
0752	calm	..	N.	14
0754	W.	10	N.	9
0802	SW.	10	N.	14
0808	E.	6	NW.	9
0824	calm	..	NW.	9

From 0830 G.M.T. onwards the wind both at the Control Tower and at the wind-sock behaved normally averaging NNW. 10–15 kt.

Other Observations.—Cloud conditions varied between 2 and 4 oktas stratocumulus or cumulus with the base at 1,700 ft. (estimated) and tops at 3,000 ft. (estimated). The cloud was in four cylindrically shaped bands, each aligned approximately south-west to north-east. The northernmost band was about six to eight miles long, and lay just above the crest of the mountain range to the north and west. The second was about 4 miles south of the first and about half a mile north of the Control Tower. The third was situated about 2½ miles south of the second and was much shorter. The fourth band, about 2½ miles further south, was thinner, less well defined and shorter than any of the others. Cloud motion round the second and third bands was noticed to be in the form of a circular whirl, moving from a northerly direction at the base of the cloud and then ascending almost vertically round the southern boundary of the roll. There was no cloud between the first and second, and between the second and third rolls (see Fig. 1). No upper lenticular cloud was observed.

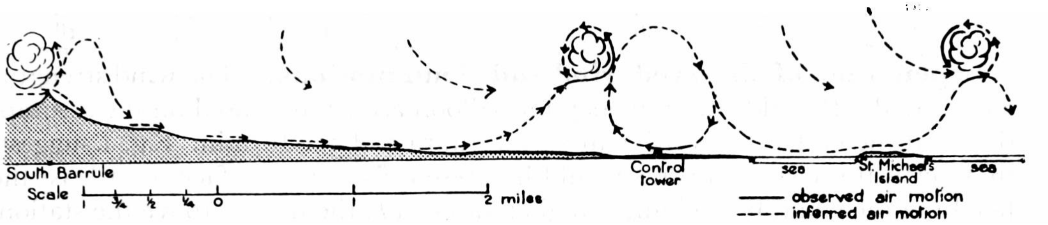

FIG. 1—VERTICAL CROSS-SECTION SHOWING OBSERVED AND INFERRED AIR MOTION

After 0826 G.M.T. when the wind variations were no longer apparent, the cloud formation ceased to be of the band form described above, and became the more normal detached cumulus or broken stratocumulus type.

The dry-bulb temperature rose from 54°F. at 0700 to 55°F. at 0800 and to 56·5°F. at 0900 G.M.T.

The routine tailless pilot balloon ascent made at 0800 G.M.T. at Ronaldsway gave the results shown in Table II.

TABLE II—0800 G.M.T. PILOT BALLOON ASCENT AT RONALDSWAY

Height	Wind Direction	Wind Speed	Height	Wind Direction	Wind Speed
ft.	°true	kt.	ft.	°true	kt.
4,000	330	16	1,000	360	6
3,000	360	5	Surface	calm	..
2,000	330	21			

People resident on the airport about 1,000 yd. north-north-east of the Control Tower remarked on the strong wind during the night and early morning. The wind strength at the Control Tower during the same period did not exceed 13 kt.

Topography.—A range of hills aligned approximately south-west to north-east forms the rocky backbone of the Isle of Man, and runs practically throughout the whole length of the island. The hills reach a height of over 1,400 ft. in several places, the highest point in the southern portion of the range being South Barrule (1,585 ft.) 4½ miles north by west of the airport at Ronaldsway. Between the summit of South Barrule and the sea at Derby Haven the ground falls 1,000 ft. in the first mile and then the slope becomes more gentle (see Fig. 2).

Synoptic situation.—At 0600 G.M.T. on July 28 an anticyclone was centred about 50°N.25°W. and a depression was situated over Denmark. The British Isles lay under the influence of a cold northerly air stream. The 0300 G.M.T. ascent from Aldergrove showed a marked inversion at about 3,000 ft. with dry air aloft. The winds at Aldergrove at 0900 G.M.T. are given in Table III. The gradient wind measured over the Isle of Man on the 0600 G.M.T. chart was 350° 20–25 kt.

TABLE III—0900 G.M.T. ASCENT FROM ALDERGROVE

Height	Wind Direction	Wind Speed	Height	Wind Direction	Wind Speed
ft.	°true	kt.	ft.	°true	kt.
24,000	10	36	5,000	350	28
14,000	10	33	4,000	350	28
10,000	355	25	3,000	350	27
8,000	350	25	2,000	350	25
6,000	350	26	1,000	350	18

Explanation of observed wind and cloud motions.—The wind strengths found by the Ronaldsway tailless pilot balloon ascent are based on the assumption that the balloon was rising at a uniform rate of 500 ft./min. Fig. 1 suggests that vertical upward currents would be present from the surface to at least the height of the cloud base giving a higher value of h, the height above the station, than was used in the computation. This would result in too low a value of the horizontal wind speed. The speed found at the assumed height of 2,000 ft. would similarly be high if the balloon were affected by down-currents. The low value of the wind at the assumed height of 3,000 ft. is more difficult to explain, but it is possible that the balloon was near the third of the cloud rolls and was under the influence of another upward current, or it may have been

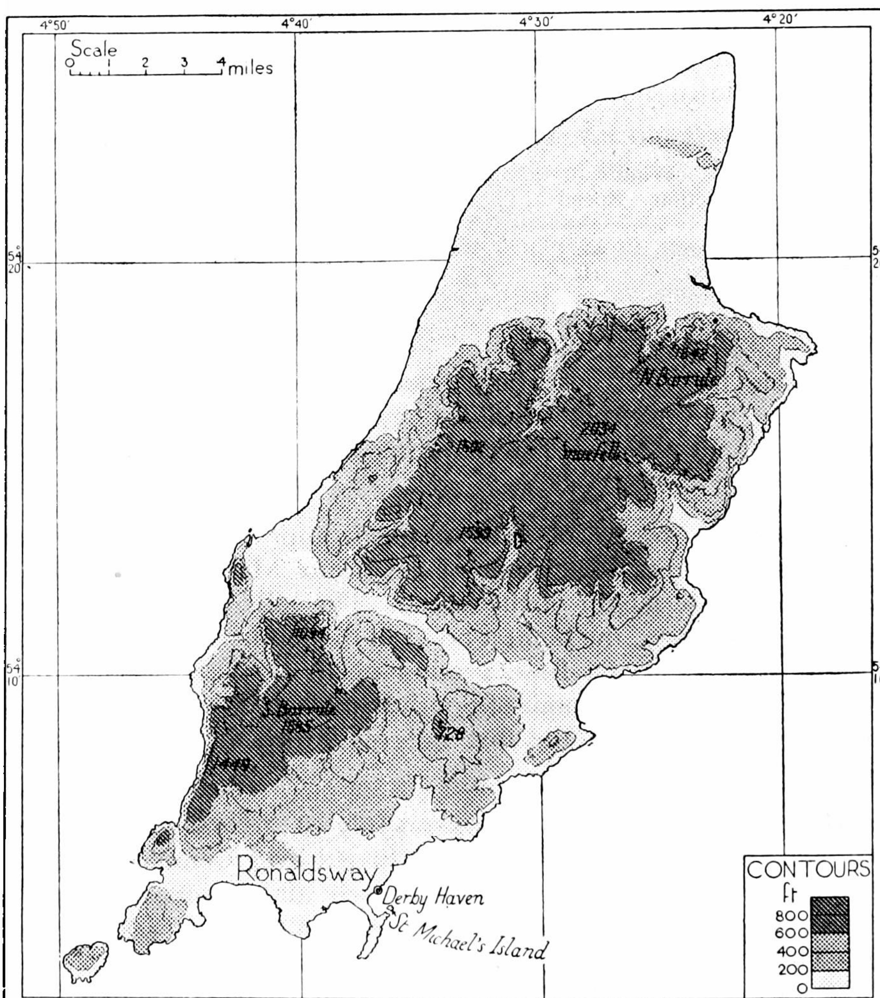

FIG. 2—ISLE OF MAN

caught in the southerly drift near the upper edge of the third roll resulting in a small northerly component averaged over the whole minute. The higher value of the wind at 4,000 ft. (assumed) could be explained by similar reasoning to that at 2,000 ft.

The irregularities in the wind speeds found by the ascent from Ronaldsway and the cloud motions observed point strongly to the existence of eddy currents caused by the mountainous ridge of South Barrule. This is also supported by the peculiar roll-form cloud indicating at least four standing waves in the lee of the mountainous ridge.

There seems little doubt that the effect is very similar to that investigated by Manley* in the Crossfell district of the northern Pennines, and that the whole phenomenon is of the three-bar type described in Manley's paper. The wind at the wind-sock was obviously much less affected than that at the Tower, but some rapid fluctuations did take place.

Break-down of the helm wind and bars.—The 1400 G.M.T. ascent from Aldergrove shows only a small increase (about 10 mb.) in the depth of cold air since 0200, and the decrease in the wind strength over the period of the helm wind was imperceptible. The only element to show any significant change was the dry-bulb temperature which rose from 54·0°F. at 0700 to 56·5°F. at 0900 G.M.T. From the ascent from Aldergrove for 0200 G.M.T. the formation of small cumulus, base 2,000 ft. tops 3,000 ft., would be expected when the surface temperature reached 54·5°F. The detached type of cumulus did not, in fact, form until the surface temperature reached 56°F., and it is in this that a possible explanation of the break-down of the helm wind and bars can be found.

The four roll-shaped bands of cloud were undoubtedly caused by the ascent of the air over the mountainous ridge which initiated a train of standing waves in its lee. When the surface temperature reached 54·5°F., weak vertical convection currents would be produced in the cloud-free spaces between the rolls. The air flow of the standing-wave system in the cloud-free spaces would oppose the convection currents, and cloud would not form. When however the dry-bulb temperature reached 56°F., the convection currents must have been stronger than the descending currents in the standing-wave system. The whole wave system would be disturbed with the subsequent break-down of the roll-form cloud and the development of the usual detached cumulus type of cloud.

Manley* also has noticed that the helm wind of Crossfell is checked by increased convectional activity.

Comparison with the helm wind of Crossfell.—The main point of interest in the "helm" wind produced by South Barrule is that the effect can be initiated by a range of hills as low as 1,500 ft. The long narrow backbone shape of the southern range of hills in the Isle of Man is similar to that of Crossfell, and the slope from the summit is unbroken by obstacles.

The variability of the surface wind at Ronaldsway would appear to be greater than that found near Crossfell. It is possible that the slightly greater steepness of slope (1 : 5 compared with 1 : 6) may be the reason for this.

It is interesting to note that the ratio of the depth of cold air to the height of ridge is similar to the critical conditions found near Crossfell (3,000 : 1,585 compared with 6,000 : 2,930 near Crossfell) and is approximately 2 in both cases.

* MANLEY, G.; The helm wind of Crossfell, 1937–1939. *Quart. J.R. met. Soc., London,* **71**, 1945, p. 197.

INFLUENCE OF THE ETESIAN WINDS ON THE SUMMER TEMPERATURE IN ATHENS

By L. N. CARAPIPERIS

During the summer, along the shores and the coastal plains of the eastern Mediterranean and especially over the Aegean Sea, calm conditions seldom prevail, because either the etesian winds or sea breezes constantly blow. These winds control the climate of the above places and they are of great importance to human comfort.

This paper is concerned with the influence of the etesian winds on the summer temperature in the Athens area, where they blow from a direction between NE. and NW.

Athens is situated at a distance of about 5 Km. from the Gulf of Saronikos and 55 Km. from the east coast of Euboea. The etesian winds, as previously shown[1,2], appear, though with little strength and stability, in the above area from the beginning of May and maintain this character till the end of June. From the beginning of July their frequency increases, and from the middle of this month until the middle of September they have their greatest strength and stability. After this their frequency decreases and they become infrequent by about the middle of October.

Etesian winds and the fluctuations of summer temperature.—A comparison between the mean summer temperature for each year of the period 1901–50 and the corresponding number of etesian days* makes the influence of these winds upon the summer temperature in the Athens area obvious. The deviations of the summer temperature from the average, have the same sign as the corresponding deviations of the number of etesian days from their average for 42 of the 50 years of the above period. Specifically from the 26 years which present a summer temperature higher than the average, 22 of them have deviations of the same sign as the corresponding deviations of etesian days. From the remaining 24 years which represent a summer temperature lower than the average, 20 of them have deviations which are also of the same sign as the deviations of the etesian days.

The highest mean summer temperature during the period 1901–50, 28·04°C., occurred in the year 1946 in which there was also observed the greatest number of etesian days, and the lowest summer temperature, 24·33°C., occurred in the year 1913 in which was noted the least number of etesian days. But the correlation between the above winds and the summer temperature in Athens, is more clearly seen in Fig. 1, in which the continuous line shows the mean temperature of the summer for each year of the period 1901–50 and the dotted one the number of etesian days, both curves having been smoothed by using the formula $\frac{1}{4}(a+2b+c)$. The principal maxima and minima of summer temperature coincide with the maxima and minima of the number of etesian days, in almost all cases. If the small irregularities which appear in the first ten years are excepted, in the remaining part of the period both lines are nearly parallel.

The coefficient of correlation between the frequency of etesian days and the summer temperature amounts to 0·68 for the period 1901–50 and to 0·82 for the period 1910–50.

* Only those days throughout which a wind having the special characteristics of the etesian wind are considered as etesian days. This was made possible by the use of charts from a Meteorological Office pressure-tube anemograph and a Richard's "anémo-cinémograph" and from the general meteorological records.

From all the above it is concluded that stronger etesian winds and higher summer temperature occur together in the Athens area.

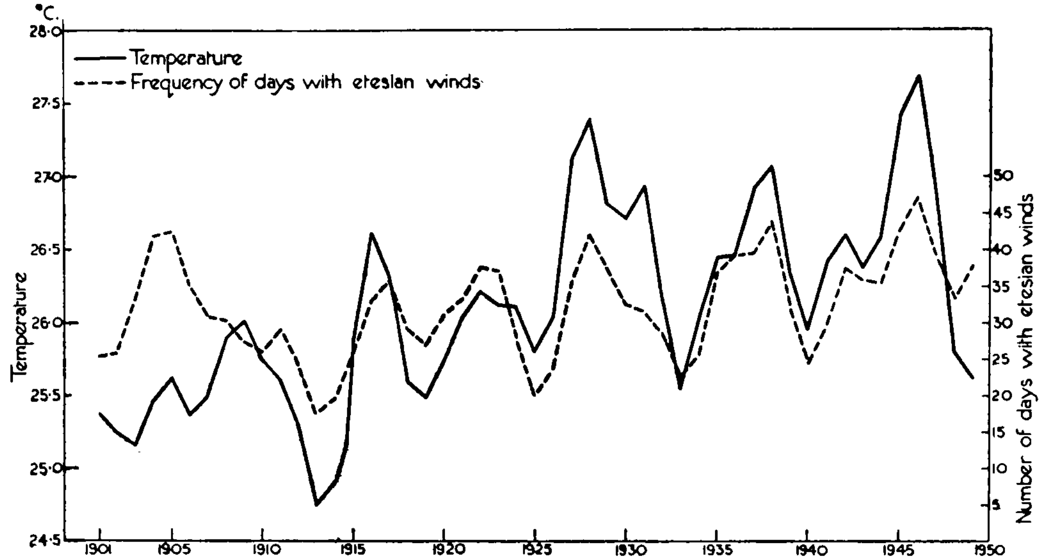

FIG. I—MEAN SUMMER TEMPERATURE AND THE FREQUENCY OF ETESIAN DAYS IN ATHENS, 1901–50

However, since the sea breeze increases the relative and absolute humidity of the air, especially in the afternoon[3], and the evaporation during the days of sea breeze is less than during the etesian days, the cooling power is greater in the latter. That is why, especially in the afternoon[4–6], the etesian winds in the Athens area often seem fresher than the sea breeze.

REFERENCES

1. CARAPIPERIS, L. N.; *Prakt. Akad., Athens*, No. 20, 1945, p. 126.
2. CARAPIPERIS, L. N.; On the periodicity of the etesians in Athens. *Weather, London*, **6**, 1951, p. 378.
3. KARAPIPERIS, P.; The diurnal march of vapour pressure on sea-breeze days at Athens, Greece. *Quart. J.R. met. Soc., London*, **78**, 1952, p. 82.
4. EGINITIS, D.; The climate of Greece. *s.l.*, 1907
5. MARIOLOPOULOS, E. G.; The climate of Greece. Athens, 1938.
6. PARASKÉVOPOULOS, J. S.; The etesiens. *Mon. Weath. Rev. Washington*, **50**, 1922, p. 417.

STATISTICAL ANALYSIS OF GEOPHYSICAL TIME SERIES

By R. P. WALDO LEWIS, M.Sc. and D. H. McINTOSH, M.A., B.Sc.

This note concerns some methods which have been found useful in the statistical analysis of geophysical data.

Reduction of standard deviation by removal of linear trend.—Geophysical series frequently have a secular trend arising from a definite (and usually known) physical agency. Failure to allow for such trends leads to an over-estimation of the variability resulting from random influences and may thus lead to a failure to recognize a significant result. The effect of the trend on the standard deviation is here obtained as an approximate correction to be applied to the standard deviation of the original series; tedious removal of the trend from the original observations may be avoided in suitable cases by applying this correction.

In a series x_i of n terms let $x_i = x_i' + (i - 1)\,\delta$ where x_i' is random and δ the trend per unit interval (assumed regular).

Then $$\bar{x}_i = \bar{x}_i' + \frac{\Delta}{2}$$

where Δ is the total trend and is $(n - 1)\,\delta$. If x_i has standard deviation σ and x_i' standard deviation σ'

$$\sigma^2 = \Sigma\frac{x_i^2}{n} - \bar{x}_i^2$$

$$= \Sigma\frac{x_i'^2}{n} - \bar{x}_i'^2 + \left(\frac{2\delta}{n}\right)\Sigma\,(i - 1)\,x_i' + \left(\frac{\delta^2}{n}\right)\Sigma\,(i - 1)^2 - 2\bar{x}_i'\frac{\Delta}{2} - \frac{\Delta^2}{4}.$$

Since $$\Sigma\,(i - 1)\,x_i' \simeq \bar{x}_i'\,\Sigma\,(i - 1) = \bar{x}_i\frac{n}{2}(n - 1)\,,$$

and $$\Sigma\,(i - 1)^2 = \frac{n}{6}(n - 1)\,(2n - 1)\,,$$

then $$\sigma^2 = \sigma'^2 + \frac{\delta^2}{12}(n^2 - 1)\,.$$

Thus $$\sigma'^2 = \sigma^2 - \frac{\Delta^2\,(n + 1)}{12\,(n - 1)} \simeq \sigma^2 - \frac{\Delta^2}{12}$$

for large n.

The correction to σ obtained above may be applied only in those cases where the data are spaced at fairly regular time intervals and where the trend is approximately linear, as, for example, in the analysis of geomagnetic data subject to secular change and of ionospheric data subject to solar-cycle variation. Analogous trends to these are not evident in meteorological data which in general show only periodic variations of period length, a day or a year. The application of the correction to meteorological data is justified only in the analysis of a small sample not covering times of maximum or minimum, e.g. a series of daily values for months near an equinox.

Effect of linear trends on a correlation coefficient.—In the correlation of two time series, each with a secular trend and with fluctuations about the trend, it may be necessary to know the contributions to the correlation coefficient made by the two trends on the one hand and by the two sets of fluctuations on the other. A method for easy calculation of these separate influences is given below.

Let the two series be given by x_i and y_i, with standard deviations σ_x and σ_y,

$$x_i = x_i' + (i - 1)\,\delta$$
$$y_i = y_i' + (i - 1)\,\varepsilon$$

where x_i' and y_i' are random with zero mean and standard deviations σ_x', σ_y' and δ and ε are the trends per unit interval (assumed regular)

$$\Sigma x_i y_i = \Sigma\{x_i'y_i' + \delta\,(i - 1)\,y_i' + \varepsilon\,(i - 1)\,x_i' + (i - 1)^2\,\delta\varepsilon\}$$

[*To face p. 240*

Reproduced by courtesy of R. Biddulph

LENTICULAR CLOUDS BETWEEN PENRITH AND KESWICK, JULY 16, 1937

Reproduced from the Cave Collection by courtesy of the Royal Meteorological Society

LENTICULAR ALTOCUMULUS

Reproduced from the Clarke Collection by courtesy of the Royal Meteorological Society

LENTICULAR ALTOCUMULUS

Reproduced by courtesy of J. W. Wilkins

WAVELIKE IRIDESCENT CLOUDS, DUNKELD, SCOTLAND, MAY 25, 1953
(see p. 249)

$$\Sigma (i - 1) y_i' \doteq \Sigma (i - 1) x_i' \doteq 0.$$

Therefore
$$\Sigma x_i y_i = \Sigma x_i' y_i' + \frac{\delta \varepsilon n}{6} (n - 1)(2n - 1)$$

and
$$\Sigma \frac{x_i y_i}{n} - \bar{x}_i \bar{y}_i = \Sigma \frac{x_i' y_i'}{n} + \frac{\delta \varepsilon}{6}(n - 1)(2n - 1) - \frac{\delta \varepsilon}{4}(n - 1)^2$$
$$= \Sigma \frac{x_i' y_i'}{n} + \Delta E \frac{(n + 1)}{12 (n - 1)}$$

in terms of the total trends Δ and E.

If the correlation coefficient between x_i and y_i is r, and between x_i' and y_i' is r',

$$r = \frac{\Sigma \frac{x_i y_i}{n} - \bar{x}_i \bar{y}_i}{\sigma_x \sigma_y}$$
$$= \frac{\Sigma \frac{x_i' y_i'}{n} + \frac{\Delta E (n + 1)}{12 (n - 1)}}{\sigma_x \sigma_y}$$
$$= \left(\frac{\sigma_x' \sigma_y'}{\sigma_x \sigma_y}\right) r' + \frac{\Delta E}{12 \sigma_x \sigma_y} \left(\frac{n + 1}{n - 1}\right),$$

and
$$r' = \left(\frac{\sigma_x \sigma_y}{\sigma_x' \sigma_y'}\right) r - \frac{\Delta E}{12 \sigma_x' \sigma_y'} \left(\frac{n + 1}{n - 1}\right),$$

where σ_x', σ_y' can be calculated by the method of the preceding section. If Δ and E are small and n is large, the formula may be written approximately as

$$r' = r - \frac{\Delta E}{12 \sigma_x \sigma_y}.$$

Effect of periodic trends on σ and r.—The influence on σ and r of such systematic periodic trends as are common in meteorological elements was given by W. H. Dines in the "Computer's handbook". Putting these results in the form obtained for the effects of linear trends

$$\sigma'^2 = \sigma^2 - \frac{\Delta^2}{8}$$
$$r' = \left(\frac{\sigma_x \sigma_y}{\sigma_x' \sigma_y'}\right) r - \frac{\Delta E}{8 \sigma_x' \sigma_y'} \cos (\phi - \chi),$$

where Δ and E are the respective total trends (i.e. twice amplitude of oscillation) of the two series and ϕ and χ the respective phase angles.

Comparison shows that the effects of periodic and linear trends of equal magnitude are in the ratio 12 : 8. This results from the fact that the average departure from mean is greater for the periodic than for the linear trend values because of the flattening of the periodic trend curve near times of maximum and minimum.

Significant tests in coherent series.—A common test for significance in statistical investigations is the consideration of the difference of two sample means of an element in terms of the general variability of the element. Thus the standard error of the difference between two means of n terms of standard deviation σ is usually taken as $\sqrt{2}\sigma/\sqrt{n}$, and significance is not attached to such a difference unless it exceeds $\sqrt{2}\sigma/\sqrt{n}$ by more than about three times. This value for the standard error of a difference is obtained on the assumption of complete independence between the two sample means. The case where each of the means is calculated from n values which are not independent has received a good deal of attention. The effect in such a case is, briefly, that the standard error of the means themselves and of their difference is increased so that a difference between the means greater than $3\sqrt{2}\sigma/\sqrt{n}$ is required for significance. Here the case is considered where, although each mean is calculated from n independent values, the means are yet not independent because they are adjacent, or near-adjacent, terms in a coherent time series. It is apparent that two such means have a greater-than-random probability of being identical, and thus a difference between them smaller than $3\sqrt{2}\sigma/\sqrt{n}$ must suffice for significance.

Let the means to be considered be $\bar{x}_i$ and $\bar{x}_{i+j}$. These are produced by summing vertically over n examples of a coherent series, each example being of course written horizontally; the two means are separated by an interval j. If the standard deviations of the individual x_i's and x_{i+j}'s are both σ the standard errors of the means are $\sigma/\sqrt{n}$, assuming vertical independence. While, in practice, it is easy to achieve vertical independence by choice of appropriate data, horizontal coherence, the effects of which are being considered here, must remain.

The standard deviation of the difference $(x_i - x_{i+j})$ (s, say) is given by:—

$$s^2 = \frac{1}{n}\Sigma(x_i - x_{i+j})^2 - (\bar{x}_i - \bar{x}_{i+j})^2$$

$$= \frac{1}{n}\Sigma x_i^2 + \frac{1}{n}\Sigma x_{i+j}^2 - \bar{x}_i^2 - \bar{x}_{i+j}^2$$

$$- \frac{2}{n}\Sigma x_i x_{i+j} + 2\bar{x}_i\bar{x}_{i+j}$$

$$= 2\sigma^2 - 2\sigma^2 r_j$$

where r_j is the correlation coefficient between terms separated by j intervals; r_j calculated from the means is the average of the values of r_j calculated from the individual rows.

Thus, since the differences are independent vertically, the standard error of the mean difference $\bar{x}_i - \bar{x}_{i+j}$ is given by

$$\frac{\sqrt{2}\sigma}{\sqrt{n}}\sqrt{(1 - r_j)}$$

The case $r_j = 0$ is that of independence between the two means; this is approximately true in most geophysical series of successive daily values for $j > 5$.

Two cases may be quoted in which it would be necessary to take account of a positive value of r_j : (i) in a test of the significance of apparent discontinuities in a mean variation, e.g. two closely separated maxima in an otherwise smooth curve; (ii) in an assessment of the accuracy of apparent time of maximum in a mean curve by comparison of the differences between the maximum value and those on either side with the standard deviation $\sqrt{2}\sigma\sqrt{(1 - r_j)}/\sqrt{n}$. These examples of the way in which the coherence of time series can lead to some relaxation in the stringency of the tests to be applied for significance contrast with the more familiar case of lack of independence requiring increased stringency of tests.

OFFICIAL PUBLICATION

The following publication has recently been issued:

Condensation trails. Notes for the use of pilots.

Simple physical explanations are given in this pamphlet of the two main types of condensation trails which may be formed by the passage of aircraft through the air. These types are exhaust trails which are formed by condensation of water vapour from the engine exhaust, and trails of aerodynamic origin, sometimes called adiabatic trails. The former type is by far the more common and important of the two and can only occur at low temperatures. Immunity temperatures, i.e. temperatures above which exhaust trails are very unlikely to form, are given for various heights for the Spitfire and Canberra aircraft as typifying propeller and jet-engined aircraft respectively. A complete discussion of the physical theory of condensation trails is given in "Condensation trails from aircraft".*

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Royal Meteorological Society held on March 18, 1953, the President, Sir Charles Normand in the chair, the following papers were read:—

Mason, B. J.—The growth of ice crystals in a supercooled water cloud†

Mr. Mason described the production of the crystals in a chamber 10 ft. high containing a supercooled cloud of water drops and their growth as they fell through the cloud. The experiments were carried out at different temperatures, and he found that in the ranges of temperature shown below the following crystals formed:—

0 to −5°C. Hexagonal plates.
−5 to −10°C. Hexagonal prisms.
−10 to −25°C. Plates and star-shaped crystals.
below −25°C. Hexagonal prisms.

There was a marked change from plates to prisms at about −5°C., but in the ranges of temperature below that indicated above, the corresponding types of crystals were predominant but were sometimes mixed with crystals of the other types.

Wexler, R.—Theory of the radar upper band‡

Dr. Wexler's paper, which was read for him, dealt with the theory of the upper bright radar band above the main bright band of the radar echo produced by melting snow at the freezing level. The upper band was first reported by Bowen in Australia though it has also been noticed in Great Britain and North America. The band is observed to form and then move downwards to coalesce with the main bright band. At intervals a new upper band will form and move down. Wexler's theory is briefly that the upper band is caused by reflection from graupel particles (ice crystals with frozen water droplets attached). The graupel particles are believed by Wexler to form at the level at which more liquid water is condensed in the up-draught than can be used up in the growth of ice

---

* London, Meteorological Office. Condensation trails from aircraft. 2nd edn, London, 1952.
† *Quart. J.R. met. Soc., London,* **79**, 1953, p. 104.
‡ *Quart. J.R. met. Soc., London,* **78**, 1952, p. 372.

crystals by diffusion from the water droplets. The rate of growth of graupel increases rapidly with their size and fall. In falling they remove much of the liquid water above the freezing layer. The theory is given mathematically in the published paper.

*Browne, I. C.—Precipitation streaks as a cause of radar upper bands**

Mr. Browne gave a different explanation of the radar upper band. In his view it is produced by reflection from precipitation streaks which form in small volumes in the upper part of the cloud, and in which owing to the increase of wind with height the drops trail up wind as they fall. As a precipitation streak moves across the beam of a radar set directed vertically upwards the particles in the streak enter the beam at continually lower heights and so produce the falling echo. A mathematical theory gave values of the rate of fall of the echo calculated from the terminal velocity of the particles, wind speed and wind shear, which agreed well with those observed.

The principal contributor to the discussion on these two last papers was Mr. Jones of the Meteorological Office radar station at East Hill. Mr. Jones showed photographs of upper bands produced by falling streaks seen as such in a height-range presentation and also of horizontal bands. Mr. B. J. Mason said falling streak echoes had also been observed in Canada and the United States.

At the meeting of the Society held on April 29, 1953, the President, Sir Charles Normand in the Chair, the Symons Memorial Lecture was delivered by Dr. T. W. Wormell, Lecturer in Meteorological Physics in the University of Cambridge, on the subject of "Lightning".

The first part of Dr. Wormell's lecture was a historical survey of the development of the investigation of the structure of lightning, from Franklin's demonstration that lightning was an electric spark to C. T. R. Wilson's measurements, with earthed spheres and plates, of the sudden changes in the vertical electric field near the ground associated with lightning and the discovery of the stepped leader and return stroke mechanism by B. F. J. Schonland with the Boys rotating lens camera. These investigations gave much information also on the approximate distribution and magnitude of the electric charges in the cloud, showing that the positive and negative charges were of magnitude 20 to 30 coulomb with voltage difference of 10^8 to 10^9 volts between the main charge centres.

The second part of the lecture was devoted to recent work by Dr. Wormell and his colleagues at the Cavendish Laboratory on the detailed structure of the electric disturbance produced both by close and by distant lightning discharges. The intensities of the electromagnetic radiation in atmospherics from distant sources are being recorded on an oscillograph and their variation with time from the initial impulse examined. It is found that the atmospherics received at night from sources to the south and east at distances up to 2,000 Km. produce a sharply peaked oscillation with peaks decreasing in amplitude with time. The peaks of the oscillation are produced by waves reflected an increasing number of times from the ionosphere. With this type of atmospheric it is possible for a single station to determine both azimuth and distance of the source. Measurements of distance obtained in this way agree with those found by the

* *Quart. J.R. met. Soc., London,* **78**, 1952, p. 590.

Meteorological Office "sferic" method. This situation, however, does not hold for sources at over 1,500 Km. over the Atlantic, which produce a smooth quasi-sinusoidal variation which does not fit the reflection theory and which cannot be used for finding the distance of the lightning flash. By day almost all atmospherics produce smooth oscillations.

The publication of Dr. Wormell's lecture in the *Quarterly Journal of the Royal Meteorological Society* will be awaited with much interest.

ROYAL SOCIETY

At a meeting of the Royal Society on Thursday, April 23, 1953, Dr. T. V. Davies read a paper of meteorological interest.

The paper, entitled "Forced flow of a rotating viscous liquid which is heated from below", described experimental and theoretical work similar to the now familiar Chicago dish-pan experiment of Dr. Fultz. Using a cylindrical vessel, with a heating element attached to its base near its outer edge, containing water and rotating about its axis of symmetry, Dr. Davies produced two distinct régimes of fluid flow. Below a critical angular velocity he obtained a low rotation régime in which lines of flow spiralled inwards towards the centre; above the critical angular velocity a high rotation régime, with a long-wave pattern similar to that found in the atmosphere was obtained. The wave pattern progressed relatively to the cylinder, and with different angular velocities the number of waves and their amplitude varied.

When the Rossby numbers (inertia terms/coriolis terms) for the experiment and for mean conditions in the atmosphere were calculated, they were found to be in good agreement. From similarity arguments, Dr. Davies suggested that the experiment may be expected to produce effects which occur in the atmosphere.

Dr. Davies then described the results of his theoretical work. He solved the equations of motion, including the viscous terms, for the low rotation régime of the experiment and obtained the horizontal and vertical velocity fields. For simplicity he initially ignored the non-linear terms in the equations, and found for the meridional flow that the fluid should rise at the outer edge, move inwards along the upper surface, descend at the centre and move outwards along the bottom of the cylinder. The effect of the non-linear terms would be to cause the fluid to descend at an intermediate radius as well as at the centre. For zonal motion he found that there should be a region of maximum velocity in the direction of rotation on the upper surface and elsewhere a varying velocity field in the direction of rotation. When he included the non-linear terms he found that a region of velocity should exist in the opposite direction in the lower levels at the outer edge of the cylinder.

Apart from finding a region of maximum velocity on the surface at an intermediate radius, Dr. Davies found no further experimental evidence to support the theoretical results—the technical difficulties have proved, to date, to be unsurmountable.

In conclusion Dr. Davies pointed out the striking resemblance between his theoretical results for the low-rotation régime and the actual conditions found in the atmosphere, e.g. he identified the region of counter-rotation velocities with the low-level equatorial easterlies.

LETTERS TO THE EDITOR

Unusual temperatures recorded during fog

When I read the thermometers in the screen this morning, March 3, 1953, I could hardly believe my eyes. There was dense fog, visibility about 20 yd.; there was dew on the lawn; the bare ground was not frozen; there was no hoar-frost or rime; and the dry bulb read $28\frac{1}{2}$°F., the wet bulb $29\frac{3}{4}$°F.

I felt so incredulous that I examined the lawn and confirmed that it was dew and the bare ground where it was damp to confirm that it was not frozen. It was quite soft; the dry knobs were powdery. I began to doubt the thermometer so I put an inspector's thermometer in the screen, at 8.45 a.m. About 20 min. later this thermometer was a degree below its lowest graduation, 30°F. My dry bulb was vindicated.

I then, seeking for ice, found clear transparent frozen droplets on the twigs of a *Cornus Mas* shrub on the edge of the lawn; and a little further away, similar frozen dewdrops on the horizontal wires of a framework supporting young cordon apple trees. I emphasize the transparency and globular form of the drops because in so dense a fog at a temperature so much below freezing point I should have expected rime, and not glazed frost.

I can think of no convincing explanation of this or of the temperature at screen level in nearly calm, radiation conditions with no frost on the ground; a superadiabatic lapse between the ground and 4 ft. in a dense fog seems unusual. The phenomenon was not an isolated occurrence. The following morning, March 4, with a fog not quite so thick (visibility about 50 yd.) the temperatures in the screen were both 31°F. at 9.15 a.m. and the lawn was again covered with dew. The temperature just afterwards on the short grass was 35·7°F., but $1\frac{1}{2}$ in. above it was only 33·1°F. By this time, 9.20 a.m., the sun was just visible through the fog. On bare soil immediately afterwards the temperature was 36°F. On March 10, at 7.30 a.m., with visibility about 60 yd. the temperatures in the screen were both 29°F. and again the lawn was covered with dew and the ground was not frozen. The temperature on the grass just afterwards was 30·7°F. and on bare soil 30·4°F. On both days there were clear ice globules on the *Cornus Mas*, many on March 4, but only one or two on March 10.

On the other hand, on March 5, between 7.10 and 7.20 a.m. with clear sky and no fog there was hoar-frost on the lawn, the temperature in the screen was 31°F., on the grass 29°F. and 2 in. above the grass $31\frac{1}{2}$°F.

On all these days I verified that the temperature at about screen level in the open air was nearly the same as in the screen, i.e. the lag in the screen temperature was small.

E. GOLD

8 Hurst Close, London, N.W. 11, March 14, 1953.

[London Airport had a screen minimum of 26° and a grass minimum of 28°F. for the period ending 0900 on March 3. The dry- and wet-bulb temperatures were identical from 0400 to 1000: 29·4° at 0400, 28·0° at 0600, 26·4° at 0800, 26·8° at 0900 and 27·8°F. at 1000. There was thick wet fog with visibility 40 to 110 yd. The observer realized the unusual relation of the minima and an independent check was made.

At Kew Observatory, Northolt, Hampstead, Camden Square, Kensington Palace, and Regents Park, on March 3, the screen minimum was higher than the grass minimum. The grass minimum at Northolt was 15° and at Kew 23°F.

Mr. A. G. Howard reports that at Woodcock Hill, Kenton, Middlesex, early on March 3 there was frost on hedge tops but the ground was not frozen, and Mr. Pilsbury that at Rayners Lane, Pinner, Middlesex, there was ice on tall trees but dry ground. Mr. W. E. Saunders writes that at Chivenor, near Barnstaple Devon, the screen and grass minima were 30° and 31°F. respectively on the 4th and 26° and 30°F. on the 5th. There was fog at Chivenor throughout both nights and rime was observed on hedges and dew on the grass.

The *Daily Weather Report* shows grass minima higher than screen minima at Bristol on the 3rd (22–23°), 4th (25–27°) and 5th (29–30°) at Manchester (31–33°) on the 3rd, and Lympne (27–28°), Mildenhall (27–28°) and Ross-on-Wye (25–28°) on the 4th. All these stations had fog. At Prestwick on the 4th the same applied (34–35°) but there was stratus, 8 oktas, at 700 ft. without fog.

Sunrise was at 0743 in London on March 3.

These observations show that a surface temperature some 3° above screen temperature is quite possible during fog.

The development of a lapse of temperature in fog is described in papers on the temperature-gradient observations at Leafield[1] and Ismailia[2], and explained on the basis of excess upward radiation in the upper part of the fog[3], but temperatures below screen level were not observed.

Mr. A. C. Best suggests the phenomenon is not unusual. There may be an adjustment between cooling by radiation at the top of the fog and the upward flow of heat through the soil such that ground temperature remains above 32°F. while air temperature falls below 32°F. Such a state can only occur when there is shallow dense fog and a ground temperature slightly above freezing. With regard to the lapse rate between ground and screen Mr. Best asks if there is any evidence that the superadiabatic lapse rate extended up to 4 ft. or if it was confined to the lowest one or two inches.

Dr. G. D. Robinson states it is not safe to infer a ground temperature above freezing point from the presence of dew as he has several times seen copious water and no detectable ice on grass whose surface temperature was undoubtedly below 32°F. On one such occasion the surface temperature measured by thermometer and radiometer was as low as 24·5°F.

The 0300 Larkhill radio-sonde observations on March 3 were:—

Height	Dry bulb	Dew point
ft.	°F.	°F.
5,350	43	−60
3,810	48	−60
2,300	52	20
950	37	29
Surface 440	24	24

Mr. Corby suggests that if, as seems certain, the fog was several hundred feet thick, then radiation from the top of the fog is unlikely to have affected the lapse rate in the lowest few feet of the atmosphere.—Ed., *M.M.*]

REFERENCES

1. JOHNSON, N. K. and HEYWOOD, G. S. P.; An investigation of the lapse rate of temperature in the lowest hundred metres of the atmosphere. *Geophys. Mem., London,* **9,** No. 77, 1938.
2. FLOWER, W. D.; An investigation into the variation of the lapse rate of temperature in the atmosphere near the ground at Ismailia, Egypt. *Geophys., Mem., London,* **8,** No. 71, 1937.
3. HEYWOOD, G. S. P.; Some observations on fogs and the accompanying temperature gradients. *Quart. J. R. met. Soc., London,* **57,** 1931, p. 97.

Iridescent wavelike clouds

On Thursday, February 19, 1953, between 1630 and 1700 G.M.T. the following interesting cloud formation was observed from the meteorological office at London Airport. To the westward a series of short parallel bands of alto-cumulus cloud orientated east–west attracted attention through their unusually marked iridescent colouring. Closer observation revealed that the bands were in fact forming at the crests of successive waves, the first one forming on a bearing of 250°. The crests were most clearly marked by cloud at the southern end of the series and gradually faded away northwards; at one time sixteen such crests were counted.

IRIDESCENT WAVELIKE CLOUDS, HARROW, FEBRUARY 19, 1953

The wave motion was very clearly marked on the first two crests with streamers of cloud even being carried down into the trough between them. An elevation of 15° was measured with the searchlight alidade, and, assuming a height of 3½ miles (18,000 ft. approximately), the clouds were forming at a point 13 miles away. From measurements taken, the width across a crest was of the order of 700 yd. and the depth from crest to trough approximately 1,500 ft.

Readings taken with the nephoscope indicated a wind of 165° 27 kt. at the height of the cloud. The 500-mb. chart for 1500 drawn at London Airport showed a small low centred over the Welsh border area, and such a wind seems probable. Radar winds reported at Larkhill were 16,000 ft., 222° 38 kt.; 18,000 ft., 228° 44 kt.; 20,000 ft., 224° 67 kt.; and at Liverpool 16,000 ft., 69° 11 kt.; 18,000 ft., 50° 15 kt.; and 20,000 ft., 29° 13 kt.

It is wondered whether the feature responsible for producing this series of waves could possibly be either the Hog's Back (height 505 ft.) or Leith Hill, just south-east of Guildford (height 965 ft.).

Other clouds to the west at the time of observation were a sheet of strato-cumulus low in the sky cutting off the sun from direct view and also a band of cirrus at about 80° elevation stretching north–south and marking the rear edge of the cloud associated with a surface trough which went through London Airport just before 1500.

C. R. BARRINGTON

London Airport, February 21, 1953

While on holiday in Scotland recently I was fortunate enough to observe a similar phenomenon to that reported by Mr. C. R. Barrington and observed by Mr. J. L. Monteith and myself.*

*This account of the February clouds is to be published in a future issue of *Weather*.

The wavelike clouds were seen from Dunkeld, at 2030 G.M.T. on Monday, May 25, 1953, after the passage of a vigorous cold front. On this occasion there were two parallel sets of clouds—one to the westward, the other to the eastward, both with the same characteristics. The westward series shown in the photograph facing p.240 were better illuminated by the setting sun, and several of the clouds exhibited iridescence. Unfortunately the uneven nature of the countryside in the area did not permit the clouds to maintain their wavelike structure for long and the leading members were breaking up quite rapidly.

Their estimated height was 18,000 ft., and using that assumption they were calculated to be 10 miles distant, with a distance of ½ mile between the crests. Both sets of clouds were moving down wind but their actual velocity was difficult to gauge.

Topography may be suggested as the cause, but as the present-day theory does not take into account the subsequent movement of topographic clouds, caution is certainly needed when nominating their source of origin. Under the circumstances it appears that they are most likely to occur within a post-frontal subsiding air mass and possibly in the lee of hills. Further reports of the occurrence and circumstances of such clouds are required for analysis before any definite theory as to their origin may be forthcoming.

J. W. WILKINS

21 Sheen Park, Richmond, Surrey, June 20, 1953

Medium-level instability

I should like to point out an interesting development of instability at medium levels which occurred here recently. This was shown by the sequence of cloud forms noted during Thursday, February 26, 1953.

At approximately 1100 G.M.T., patches of fine altocumulus lenticularis, resembling cirrocumulus, rapidly developed on the spot until about 6 oktas coverage of altocumulus densus was produced, which, by 1200, locally showed signs of vertical development. After 1300, altocumulus floccus appeared, first on the edges of the sheet, but later within the sheet itself, as shown by obvious tufts of virga below the cloud base, and the percentage of this type steadily increased throughout the afternoon and evening, being locally of considerable vertical extent (estimated at 5,000 ft.) by 1900. Two other interesting points were:—

(i) At about 1330 an aircraft, having flown horizontally through the cloud sheet, left a contrail in the form of a thickening of the cloud into a dark roll, which, within half an hour, had developed a prominent fringe of virga, extending for probably at least five miles across the sky. This contrail was continuous with a distrail formed only at the edge of the cloud sheet, the whole extending over about 140° azimuth.

(ii) At sunset, a mammatus structure was illuminated beneath many of the denser floccus patches.

By means of a balloon, the height of this cloud was observed at 1400 to be 15,000 ft., which agrees well with discontinuity levels marked on the 0200 and 1400 radio-sonde ascents by a sharp increase of humidity with height, and by a wind shear of about 120°. Although no temperature inversions were noted at this height, the wet-bulb potential temperature shows the discontinuity to be a diffuse frontal surface, separating a tropical air mass with about 50 per cent.

humidity from a much drier, subsided polar air mass, the two showing some degree of intermixing.

Convergence and turbulence are unlikely to be involved in the cloud formation. The former because the synoptic situation was definitely anticyclonic, and the latter because the resulting mixing with the dry polar air would tend to dissipate rather than form cloud. Frontal uplift is possible, especially when its wide extent, as shown by the numerous reports from southern England, is considered, but the transformation of a water-droplet cloud (altocumulus densus) to an ice-crystal cloud (altocumulus floccus) remains unexplained, since the air above 15,000 ft. was shown by the ascents to be not even latently unstable, assuming the 40-mb. uplift required for saturation (at 0200) to be possible.

Incidentally, two interesting points on the observation of clouds were well indicated on this day:—

(i) Thin altocumulus lenticularis may be easily confused with cirrocumulus even to the characteristic fine structure and rippling.

(ii) Altocumulus may be so dense and coarsely globular as to resemble stratocumulus with a base about 6,000 ft., even though the true base is 15,000 ft. This is borne out by the reported cloud heights from some stations in southern England at 1200 and 1800.

D. E. PEDGLEY

Larkhill, Wilts. March 11, 1953

NOTES AND NEWS

Exceptionally high mean pressure over the British Isles

In March 1953 mean pressure over the British Isles was exceptionally high. An examination of the values for all stations throughout the country for which the information is available since 1901 shows that the mean pressure in 1953 was

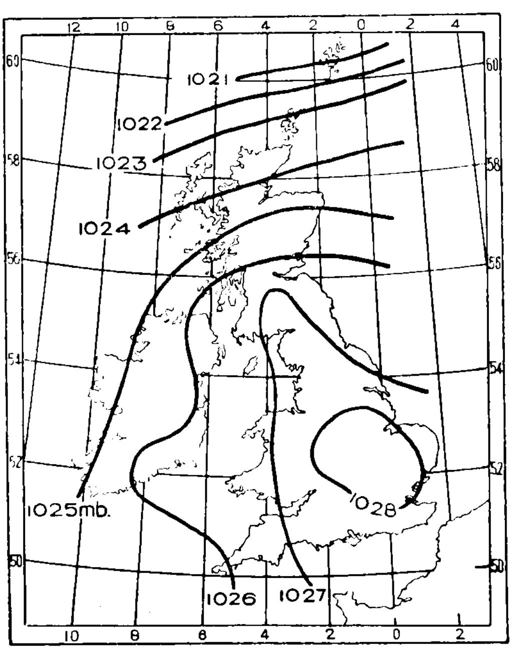

FIG. 1—MEAN PRESSURE, MARCH 1929, 0700 G.M.T.

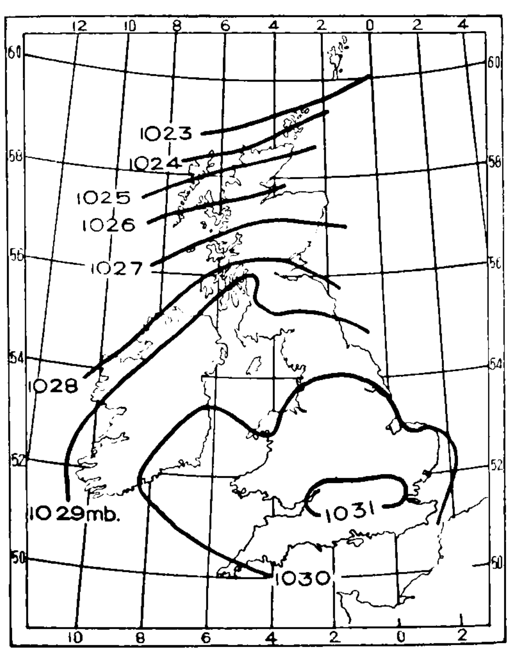

FIG. 2—MEAN PRESSURE, MARCH 1953, 0900 G.M.T.

everywhere the highest for March during this period. The March in which mean pressure most closely resembled that for 1953 over the country as a whole was that of 1929; in that month mean pressure ranged from more than 1028 mb. in the English Midlands to slightly less than 1021 mb. in the Shetland Islands compared with slightly more than 1031 mb. in an inland area in the south of England and somewhat less than 1023 mb. in the Shetlands in March 1953. The charts show the mean pressure at 0700 in March 1929 and at 0900 in March 1953. Observations have been taken at some stations for a much longer period, and from these records it appears that the pressure in March this year was the highest for a very much longer period than the present century. At Edinburgh in a record going back to 1769 the mean pressure for March 1953 has only once been exceeded, namely in 1840. At Southport, where local records have been kept since 1871, the value was higher than in any previous March, while at Oxford the pressure was the highest for March in a record going back to 1881 and has only once been exceeded in any month, that is in February 1891.

On March 10, 1953, pressure was exceptionally high in England and Wales; at Filton, Bristol and Abingdon the reading at 0900 was 1045·0 mb., the previous record for the month being 1044·5 mb. at Gorleston on March 13, 1929.

L. F. LEWIS

REVIEWS

Climate and growing of malting-barley in the Netherlands. By C. Kramer, J. J. Post and W. Wilton. *Meded. ned. met. Inst., De Bilt*, A, No. 57, 1952, pp. 152, *Illus.*, Staatsdrukkerij-en Uitgeverijbedrijf, 's-Gravenhage, 1952. Price: *fl.*2.25.

In this contribution to the ecology of spring barley the authors have examined the influence of climate on the yield and quality of the crops grown in three provinces of Holland where soil conditions and methods of husbandry are fairly similar. They have examined the available literature on the growth of barley, and point out that the ideal weather conditions for maximum yield or vegetative yield differ from those required for best malting quality.

Regression equations were computed for forecasting yield, but the correlation coefficients between weather data and yield or quality data seldom exceeded a value of 0·6. Nevertheless the results showed that cool dry weather in late spring favoured a high yield, and that dry sunny weather was needed in July for good quality.

Experimental work in the field showed that the rate of growth of the leaves was governed mainly by temperature; reduction of light by artificial shading decreased the rate. A close relation was shown to exist between average yield and the area below a curve of average total length of leaves plotted against time. During this work the importance of the relative incidence of diseases such as mildew and rust and the effect on yield and quality became evident; such incalculable factors often militate against a successful analysis of crop-yield data.

L. P. SMITH

Climate of the Canadian Arctic Archipelago. By R. W. Rae. 10·9 in × 8·2 in. pp. vi + 90, *Illus.*, *Canada Department of Transport, Toronto*, 1951. Price: $0.35.

This work is based on the observations of 20 stations between 60° and 80°N., 60° and 120°W.; the periods of observation are short but half of them cover

10 years. The stations are mainly coastal and not representative of the climate of the interior. With these limitations, a clear picture is given of general conditions by first discussing the climatic controls of latitude, distribution of land, water and ice, and the seasonal changes of pressure distribution, followed by a seasonal analysis of the observations of temperature, precipitation, winds, cloud, visibility and relative humidity. Tables give average monthly values of these elements and there are bi-monthly charts of the mean pressure distribution.

Special interest attaches to winter temperature conditions which may vary greatly from year to year, on account of the varying intensity of cyclonic activity in the area of the Davis Strait. Mean winter temperature is generally below 0°F. for six months and a minimum as low as −50°F. may be expected every year. Summer temperatures are more uniform because of the stabilizing influence of the ice-filled waters of the polar channels.

Snow may fall in any month but rain is limited to the short summer period—from the point of view of total annual precipitation, the Archipelago is a dry region, only 5–10 in. a year being recorded for stations between 75°N. and the Arctic Circle. The impossibility of accurate measurement of snowfall is emphasized.

In the extreme north, least cloud occurs in winter and most in summer, but generally the amount of winter cloud depends on the amount of open water near the station. An interesting analysis is given (for Resolute) of occasions when "fog" visibility is produced either by drifting snow, falling snow or radiation and sea fog.

Winds are discussed in relation to the pressure distribution; wind speeds are low in winter because of the stable stratification of the cold air.

J. PEPPER

Essentials of fluid dynamics with applications to hydraulics, aeronautics, meteorology and other subjects. By L. Prandtl. $8\frac{3}{4}$ in. × $6\frac{1}{4}$ in., pp. x + 452, *Illus.*, Blackie and Sons Ltd., London, 1952. Price: 35*s.* 0*d.*

This book is a translation of the 1949 edition of "Fuhrer durch die Stromungslehre". It covers a wide field, as may be seen from the five chapter headings which are as follows:—

I—Equilibrium of liquids and gases

II—Kinematics: dynamics of frictionless fluids

III—Motion of viscous fluids: turbulence: fluid resistance: practical applications

IV—Flow with appreciable volume changes (dynamics of gases)

V—Miscellaneous topics:—

(*a*) Combined effects of more than one state of matter

(*b*) Rotating body and rotating system of reference

(*c*) Flow in heavy stratified fluids

(*d*) Heat transfer in moving fluids.

Chapter V includes a discussion of a few special meteorological and oceanographical problems. There is an excellent bibliography, including references to post-war English and American work.

The author states in his Preface that the book is intended "to be a guide to the reader, to the beginner and the advanced student, as well as to the expert in an adjoining field of research", and he certainly should achieve his purpose. The condensation necessary to realize this completeness will make some sections difficult for the beginner (e.g. the paragraph on the stress tensor on p. 5 and the introduction to the use of conformal representation, p. 67), but it may be rightly said that such parts are unimportant at a first reading. For the most part, the book is delightfully easy to read, and if some item is not pursued far enough for a particular purpose the reader is told how or where to obtain more information.

The author also says that ". . . complex mathematics has been avoided as far as possible . . . the principal object being the awakening of clear, intuitive appreciation". Certainly the text is not overburdened with mathematics, but it is doubtful whether intuition is the ideal faculty with which to tackle such a complex subject as fluid dynamics. Mathematical formulation is but a shorthand method of writing down physical principles, and, so long as tedious manipulation of symbols to achieve limited ends is avoided, it is surely best to retain the mathematics rather than risk confusion and error by basing arguments on what seems intuitively reasonable. Needless to say, no false premises or arguments were discovered in Professor Prandtl's book, but intuition may be dangerous in others.

Though this reviewer would have sometimes preferred a more mathematical treatment he found the, to him, unusual approaches stimulating.

This book will be most valuable to meteorologists not for its description of a few particular problems, such as the general circulation on a rotating globe which may be found in more detail elsewhere, but as a general introduction or book of reference to other problems of fluid dynamics with which he may not be familiar, but which may concern him indirectly. Aerofoil theory, supersonic flow, shock waves, resistance of projectiles and many others are subjects on which the meteorologist may require guidance and they are all described.

The book is pleasantly printed on good paper, and is recommended as a general textbook and also as a first book of reference.

J. K. BANNON

ERRATUM

MAY 1953, PAGE 158, lines 4 and 5 from bottom of page; for "mean pressure at the Azores, 1011 mb., was 11 mb. below normal." read "mean pressure at the Azores, 1021 mb., was 1 mb. below normal."

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—Ocean weather ship *Weather Explorer*, on being relieved from station Juliett on June 6, proceeded to Plymouth where she refuelled and was painted before taking up anchorage off Ryde Pier (Isle of Wight) on the morning of June 14 to take her place in the Review of the Fleet at Spithead by Her Majesty the Queen. Some senior officers with their wives witnessed the Review aboard the ship where they also spent the night of the 15th–16th.

Staff suggestions.—Meteorological Office staff in common with all other Air Ministry staff are encouraged to submit suggestions "for improving efficiency and effecting economy" and cash prizes are offered for suggestions which are adopted or which are considered to have special merits.

Mr. A. Blackham, Senior Scientific Assistant, at the meteorological office, Cranwell, is believed to be the first member of the Office staff to receive an award under this scheme. He has prepared two tables which can be used to eliminate most of the labour of frequent divisions by 24 and 31 in the compilation of climatological tables. After a successful trial, copies of these tables have been sent to all offices responsible for climatological returns.

Sports and athletics.—The annual sports of the Air Ministry and Ministry of Civil Aviation were held at the White City on July 1 and marked the end of the year for the Bishop Shield competition. The Office won the Shield for the fifth successive year with a score of 123 points. Runners-up were the Ministry of Civil Aviation with 64 points. Successes in football, netball, swimming, lawn tennis, athletics, chess and bridge were the main contributions to the achievement, and these were due to the wholehearted co-operation of the staff.

The Jones Memorial Cup awarded for the highest number of points gained at the annual sports was won by the Office for the fourth consecutive year. The Office again won the Ladies' and Men's Relays and Miss C. Newman and Mr. R. Cohen ran well in the sprint events. A new cup, presented for the cross-country team race, has now been added to those held by the Office.

Lady Johnson presented the prizes at the termination of the sports meeting.

This year the sports meeting organized by the Harrow Meteorological Office Social and Sports Club was extended to include entrants from all meteorological offices in the London area and a very enjoyable evening was spent on the track at Headstone Manor Recreation Ground on Monday, June 22, 1953. Most events were well supported and an excellent innovation this year was an archery demonstration given by Dr. and Mrs. Frith. The evening ended with the presentation of medals and prizes by Mrs. Frankcom.

WEATHER OF JUNE 1953

Mean pressure was above normal over Scandinavia (as much as 9 mb. in the extreme north) and over the Atlantic between latitudes 40°N. and 50°N.; it was also above normal over much of the United States. Mean pressure was below normal over west and south Europe, generally between 2 and 4 mb. The mean pressure was highest over the Azores, 1027 mb. (2 mb. above normal), and it decreased northwards to 1006 mb. off south-east Greenland, where it was 4 mb. below normal. Another centre of high mean pressure, about 1021 mb., occurred to the north of Scandinavia.

Mean temperature was very high in Scandinavia, reaching 63°F. in many places, about 10°F. above normal. Over the rest of Europe, mean temperature was generally normal varying from 60°F. in the north to 70°F. in the south. The mean temperature in the east and south of the United States exceeded 70°F. and reached 85°F. in places and was generally 3°F. above normal.

In the British Isles the weather was dull, notably so in eastern and midland districts. Rainfall was variable owing to heavy local falls of thundery rain. The month was also unusually quiet, particularly in northern districts.

Early in the month pressure was high over the Atlantic and low over southern Scandinavia and the Low Countries giving cold, northerly winds and showery weather in the British isles, with widespread thunderstorms on the 1st and heavy rain locally in north-east England on the 2nd (2·69 in. at Uswayford, Northumberland). The 3rd was an exceptionally cold day; at Oxford, apart from June 4, 1909, it was the coldest June day on record. From the 5th to the 8th a belt of high pressure moved slowly east over the country maintaining dry weather, with varying amounts of bright sunshine; temperature rose in the west on the 6th but not until the 9th in the east and even then it was cool over much of East Anglia. On the 9th and 10th a trough of low pressure moved slowly east across the country giving rain in most parts. On the 11th a depression moved south-west from a position near Heligoland to the coast of East Anglia bringing rain to much of east England and the Midlands. This depression became stationary and filled slowly. On the 14th a depression moved into the British Isles from the Atlantic and was centred over Great Britain from the 15th to the 17th, maintaining a cool, unsettled type, with varying amounts of rain and local thunderstorms (3·50 in. in a thunderstorm at Brigflats, near Sedbergh, Yorkshire on the 16th). On the 18th and 19th a trough of low pressure moved east over the country giving further rain. Another depression moved east-south-east from south-west Ireland on the 21st–22nd causing heavy rain in the south-west (2·25 in. at Princetown, Dartmoor) and thunderstorms on the east coast from Kent to Norfolk during the following night. On the 23rd an anticyclone built up over Scandinavia and pressure became relatively low over France and central Europe. Low pressure persisted over France and central Europe for the remainder of the month, and winds over the British Isles were mainly from north or north-east; the weather became warm and close and low stratus cloud and fog were prevalent in the mornings in eastern and midland districts but it mostly cleared during the day except locally on the coast. Severe thunderstorms occurred at times from the 25th onwards, particularly in western and central districts from the 25th to 27th, when they were accompanied by heavy rain and hail causing floods and considerable damage. Among heavy falls in 24 hr. or less were 2·10 in. at Langham Waterworks, Essex, and 1·54 in. in 79 min. at Ruscombe, Gloucestershire on the 25th and 3·15 in. in 30 min. at Eskdalemuir, 2·09 in. in 39 min. at Langley, Cheshire, 1·72 in. in 15 min. at Nelson (all three very rare falls) and 2·15 in. in 90 min. at Ambleside on the 26th. Heavy rain fell locally in the south of England during thunderstorms on the 30th; at Ryde, Isle of Wight, 0·85 in. fell in 30 min. Temperature reached 80°F. locally on most days from the 23rd to the 30th and touched 83°F. at Prestwick on the 24th and at Poole and Weymouth on the 29th.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	83	30	−0·4	98	+2	74
Scotland	83	29	+1·4	87	−3	86
Northern Ireland ...	78	35	+0·3	77	0	103

RAINFALL OF JUNE 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·63	81	*Glam.*	Cardiff, Penylan ...	2·46	98
Kent	Dover	2·23	116	*Pemb.*	Tenby	1·92	80
„	Edenbridge, Falconhurst	1·69	77	*Radnor*	Tyrmynydd	2·14	65
Sussex	Compton, Compton Ho.	2·30	92	*Mont.*	Lake Vyrnwy	2·09	65
„	Worthing, Beach Ho. Pk.	1·86	106	*Mer.*	Blaenau Festiniog ...	4·46	69
Hants.	Ventnor Park	1·89	100	„	Aberdovey	2·56	94
„	Southampton (East Pk.)	2·70	134	*Carn.*	Llandudno	1·26	66
„	South Farnborough ...	1·35	70	*Angl.*	Llanerchymedd ...	1·80	76
Herts.	Royston, Therfield Rec.	1·70	76	*I. Man*	Douglas, Borough Cem.	1·63	67
Bucks.	Slough, Upton... ...	1·45	70	*Wigtown*	Newton Stewart ...	1·34	51
Oxford	Oxford, Radcliffe ...	1·59	71	*Dumf.*	Dumfries, Crichton R.I.	1·70	67
N'hants.	Wellingboro' Swanspool	1·81	86	„	Eskdalemuir Obsy. ...	5·50	175
Essex	Shoeburyness	2·06	117	*Roxb.*	Crailing...	1·47	67
„	Dovercourt	1·75	99	*Peebles*	Stobo Castle	3·62	155
Suffolk	Lowestoft Sec. School...	1·83	101	*Berwick*	Marchmont House ...	2·57	111
„	Bury St. Ed., Westley H.	3·48	166	*E. Loth.*	North Berwick Res. ...	1·27	77
Norfolk	Sandringham Ho. Gdns.	4·24	195	*Midl'n.*	Edinburgh, Blackf'd. H.	1·50	75
Wilts.	Aldbourne	2·26	97	*Lanark*	Hamilton W. W., T'nhill	1·10	50
Dorset	Creech Grange... ...	1·97	86	*Ayr*	Colmonell, Knockdolian	0·84	33
„	Beaminster, East St. ...	3·46	153	„	Glen Afton, Ayr San. ...	...	...
Devon	Teignmouth, Den Gdns.	1·77	92	*Renfrew.*	Greenock, Prospect Hill	1·24	40
„	Cullompton	2·68	126	*Bute*	Rothesay, Ardencraig...	1·51	49
„	Ilfracombe	1·72	79	*Argyll*	Morven (Drimnin) ...	2·41	78
„	Okehampton	1·68	61	„	Poltalloch	1·40	46
Cornwall	Bude, School House ...	1·13	56	„	Inveraray Castle ...	1·58	40
„	Penzance, Morrab Gdns.	1·93	87	„	Islay, Eallabus... ...	2·53	97
„	St. Austell	2·55	97	„	Tiree	1·46	57
„	Scilly, Tresco Abbey ...	1·85	107	*Kinross*	Loch Leven Sluice ...	2·13	97
Glos.	Cirencester	1·51	63	*Fife*	Leuchars Airfield ...	0·76	46
Salop	Church Stretton ...	1·97	78	*Perth*	Loch Dhu	2·59	62
„	Shrewsbury, Monkmore	2·30	111	„	Crieff, Strathearn Hyd.	3·47	131
Worcs.	Malvern, Free Library...	1·97	85	„	Pitlochry, Fincastle ...	2·91	139
Warwick	Birmingham, Edgbaston	1·93	83	*Angus*	Montrose, Sunnyside ...	1·66	100
Leics.	Thornton Reservoir ...	3·02	140	*Aberd.*	Braemar	3·19	163
Lincs.	Boston, Skirbeck ...	3·14	173	„	Dyce, Craibstone ...	2·52	135
„	Skegness, Marine Gdns.	3·38	188	„	New Deer School House	2·78	140
Notts.	Mansfield, Carr Bank...	2·01	89	*Moray*	Gordon Castle	3·05	150
Derby	Buxton, Terrace Slopes	3·52	109	*Nairn*	Nairn, Achareidh ...	2·55	144
Ches.	Bidston Observatory ...	1·56	71	*Inverness*	Loch Ness, Garthbeg ...	4·27	187
„	Manchester, Ringway...	2·37	98	„	Glenquoich	1·68	34
Lancs.	Stonyhurst College ...	1·70	55	„	Fort William, Teviot ...	1·09	31
„	Squires Gate	1·45	70	„	Skye, Duntuilm ...	2·10	81
Yorks.	Wakefield, Clarence Pk.	1·82	85	„	Skye, Broadford ...	1·65	42
„	Hull, Pearson Park ...	3·52	171	*R. & C.*	Tain, Mayfield... ...	2·50	135
„	Felixkirk, Mt. St. John...	4·13	189	„	Inverbroom, Glackour...	2·28	81
„	York Museum	1·24	60	„	Achnashellach	1·43	38
„	Scarborough	3·13	170	*Suth.*	Lochinver, Bank Ho. ...	1·69	79
„	Middlesbrough... ...	2·35	124	*Caith.*	Wick Airfield	1·64	91
„	Baldersdale, Hury Res.	2·31	105	*Shetland*	Lerwick Observatory ...	0·71	40
Norl'd.	Newcastle, Leazes Pk....	2·05	97	*Ferm.*	Crom Castle	0·79	29
„	Bellingham, High Green	1·58	69	*Armagh*	Armagh Observatory ...	2·33	93
„	Lilburn Tower Gdns. ...	2·97	143	*Down*	Seaforde	1·65	60
Cumb.	Geltsdale	2·25	83	*Antrim*	Aldergrove Airfield ...	2·21	92
„	Keswick, High Hill ...	1·57	54	„	Ballymena, Harryville...	2·93	101
„	Ravenglass, The Grove	1·10	42	*L'derry*	Garvagh, Moneydig ...	2·82	111
Mon.	A'gavenny, Plâs Derwen	2·28	85	„	Londonderry, Creggan	2·52	89
Glam.	Ystalyfera, Wern House	4·80	127	*Tyrone*	Omagh, Edenfel ...	1·23	44

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

Wt-34. K16.