M.O. 174.

THE

LIFE HISTORY OF SURFACE AIR CURRENTS.

A STUDY OF

THE SURFACE TRAJECTORIES OF MOVING AIR.

BY

W. N. SHAW, Sc.D., F.R.S.
(Director of the Meteorological Office),

AND

R. G. K. LEMPFERT, M.A.

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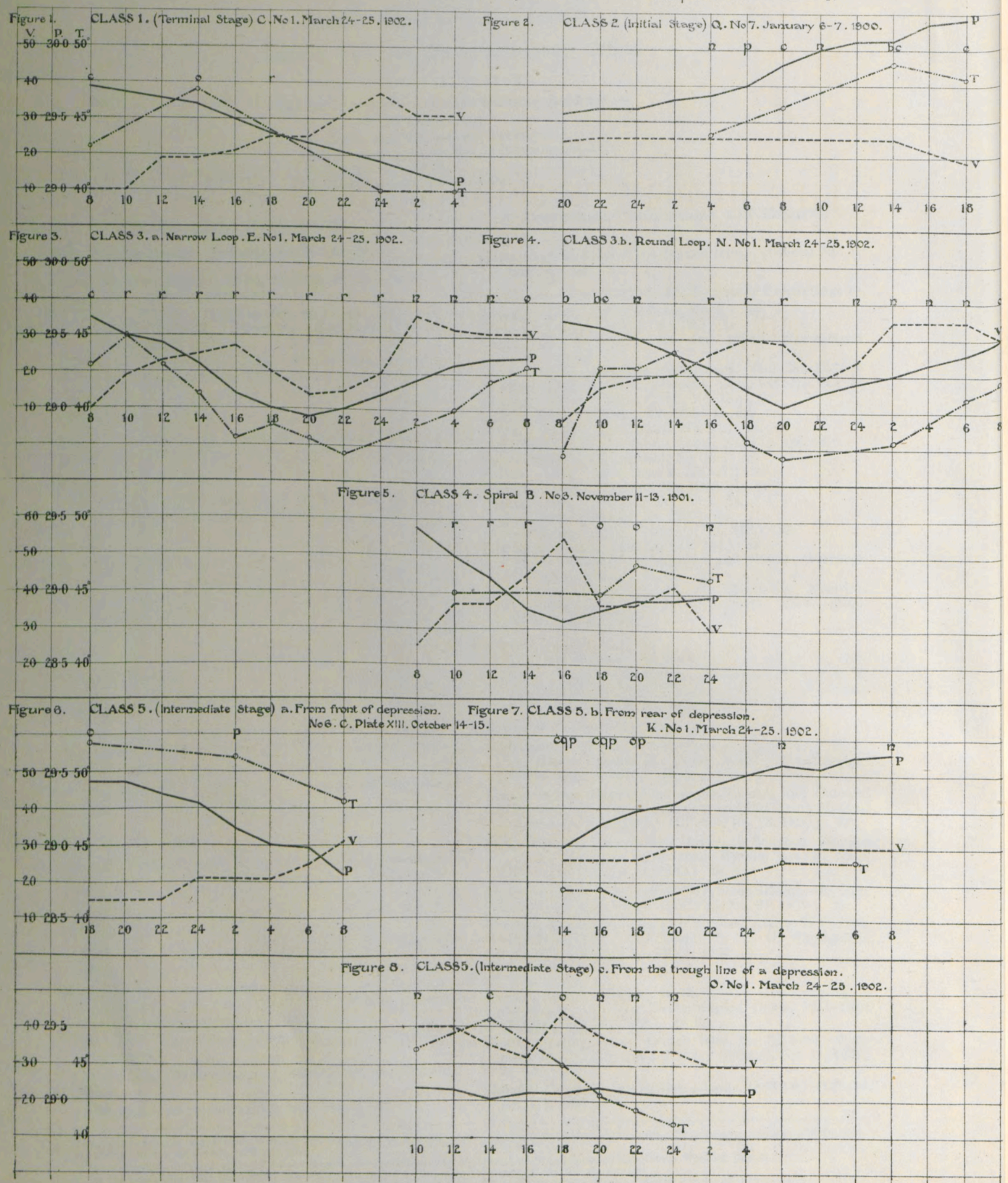
Surface Trajectories of Air. Typical Curves of Change in Pressure, Wind Velocity and Temperature.

Curves for Pressure ——— P. for Velocity - - - - - V. for Temperature o—o T.



Note. In all cases the figures marking the successive vertical lines represent hours measured from 2 to 24.

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THE LIFE HISTORY OF SURFACE AIR CURRENTS: A STUDY OF THE SURFACE TRAJECTORIES OF MOVING AIR.

The investigation of which the results are presented here arose from a consideration of the supply of air to the storms or deep barometic depressions on the Eastern border of the North Atlantic Ocean. Guided by the generalisation that the surface currents of air blow spirally out of anticyclonic areas and converge spirally towards cyclonic centres or barometrical minima, the synoptic charts of the Atlantic for the year 1882–3 prepared in the Meteorological Office, were carefully scrutinised to find typical illustrations of spiral curves connecting areas of high and low pressure and thus indicating the lines along which the air was travelling between those areas. The idea which prompted the search was that differences in the shape or position of the spirals leading up to a depression might perhaps exhibit some connection with the special meteorological characteristics and the behaviour of the depression. Admitting the principle that at any moment the flow of air is spirally outwards from the periphery of a high pressure area and spirally inwards towards that of a low pressure area, it seemed possible that the north-westerly wind, for example, in a depression over the British Isles in winter might be comparatively warm if a short double spiral curve connected it with an anticyclone over the Atlantic but comparatively cold if the spiral were elongated and the feeding anti-cyclone lay over Finland.

A fine example of spirals of wind direction connecting anticyclonic and cyclonic areas was found in the chart for November 15, 1882 (*See* Plate XXVI.), and the charts for the following day were examined to see whether the expected meteorological results could be traced. But it was obvious that in the twenty-four hours the situation with regard to the spirals was entirely changed. Although not nearly enough time had elapsed for the air to reach the cyclonic areas from the anticyclones the spirals indicating the direction of motion had altered beyond recognition. The high pressure and the low pressure areas were no longer in the same positions and it became apparent that although the spirals showed the direction of instantaneous motion of the air at any of the points in their length they would not represent the paths which the air actually followed unless the high and the low pressure areas remained stationary for some days, a combination of circumstances which practically never happens. It is indeed evident, on consideration, that the curve on a synoptic chart which shows the wind direction at any point of its length is a hydrodynamical *line of flow* and does not show the *path* which a particle of air actually follows from day to day or from hour to hour unless the motion is steady and unchangeable, and that is notoriously not the case with the cyclonic depressions of the Northern Atlantic.

It is perhaps unnecessary to labour a point so obvious but an illustration may be useful for those to whom the distinction between the two kinds of curve is unfamiliar. If a captain set his course to keep a vessel in sight always on his port beam he would describe a circle round the vessel, if it were anchored. But if the vessel were moving the captain's course and his distance from the vessel would depend upon the speed and direction of its motion and if he kept to the circle his position would have no known relation whatever to that of the moving vessel. The actual curve described by one vessel following the movement of another in the way indicated can be drawn by the apparatus described in Part IV., p. 98. The problem is to a certain extent similar to the mathematical problems known as *curves of pursuit*. Thus a dog seeing his master on the opposite side of the road runs after him, but although he always makes straight for his object he does not go in a straight line because the object is itself moving. The actual curve described obviously depends upon the rate at which man or dog severally progresses.

It follows from what has been said that when we are considering the motion of air with reference to a moving barometric minimum the spirals which can be drawn to represent the instantaneous motion on a synoptic chart do not represent the paths which air actually follows. If we wish to know whether air between a cyclonic and an anti-cyclonic centre is coming from the anticyclone we must consider where the anticyclone was yesterday, and, on the other hand, if we wish to know whether the air is approaching the centre of a depression we must consider where that centre will be to-morrow. Yet the source from which the air is ultimately derived and the destination which it ultimately reaches are items of information of obvious meteorological importance, and the present investigation is devoted to such questions. We propose to call the actual path described by an isolated portion of air moving along the surface a *surface trajectory of air* and to draw attention to some examples of surface trajectories.

Theoretical Computation of Surface Trajectories.

There are two ways of approaching the problem of finding the surface trajectory or actual path described by air associated with a cyclonic or anticyclonic area under given circumstances. One is to make some conventional representation of the distribution of motion of air in the anticyclone or cyclone, to assign some speed and direction to the motion of its centre and thence compute mathematically the actual paths of the air. Some examples of this method of dealing with the subject will be given hereafter in a section upon looped trajectories (Part IV., A., pp. 97 to 101).

This mode of procedure is both interesting and valuable, but there are objections to dealing with the subject exclusively in this manner. The distribution of motion in the cyclone as adopted for computation must be based upon some hypothesis as to the formation or nature of a cyclonic depression and as to its motion. In adopting any hypothesis of that kind we may be making assumptions which are not justifiable in all cases. We may, for example, take the average characteristics of a number of cyclonic depressions as applicable to individual examples and thereby overlook the differences in character in such phenomena which undoubtedly exist. Moreover, in computations of this kind it is usual to construct a hydrodynamical system with a suitable spiral motion and then endow all its parts with a common motion of translation. This presupposes the travel of a whole train of conditions, whereas in actual practice we must allow that the motion of the centre may be merely a circumstance in the process of formation. The apparent progress of the centre may be the result of constant development of a fresh system, more or less similar to the existing one, out of new materials in the front and a corresponding decay in the rear.

Practical Construction of Surface Trajectories.

The other method of dealing with the subject is to determine the surface trajectories from actual observations of the direction and speed of motion of the air. If we take the synoptic chart for any epoch, we know to a moderate degree of approximation the speed and direction of the wind at any point. The wind observations give us the information for certain points, and the known relation between wind and barometric gradient helps us to interpolate for points on the chart for which no actual wind observations exist. The continuous records of anemographs show in detail what the nature of the changes were for particular localities.

A knowledge of the direction and speed of the wind at any point enables us to draw a step in the surface trajectory which passes through the point if we can assume the

average movement of the air to have remained constant for a sufficient interval. Thus, for example, if an observation gives the wind direction at a station as South-West, and its speed the equivalent of 20 miles per hour, we may suppose that within the half-hour preceding the observation the air travelled 10 miles from the South-West, and in the succeeding half-hour it travelled 10 miles further towards the North-East. For longer periods a proportionately longer step must be drawn. The anemometer records will show for certain points whether the motion is sufficiently uniform to carry over the interval between two consecutive charts ; and for other points a comparison of the isobars of successive maps gives a means of determining the path of the air during the interval.

In the eight examples which are here described in detail (pp. 29 to 67, Plates I.—XXIII.) charts of isobars over the British Isles and the immediate neighbourhood have been prepared for every hour, or every two hours, and from them a series of surface trajectories has been constructed in the manner indicated, by marking in succession the steps for the intervals between successive maps. The charts and accompanying descriptions will be referred to as illustrating the subject here treated. So long as the motion of the air is of considerable magnitude and remains persistent for a considerable time, there is little difficulty in drawing the steps with sufficient confidence ; but when we have to deal with a region of light airs, as in the outlying area of an approaching depression, or when the changes are rapid, as in the region of the centre of a depression, the drawing of the trajectory is an uncertain process.

The latter case requires special notice. It is illustrated by the trajectories D and E of Plate II. and H, K, and L of Plate V., which are continued as looped curves, in contrast with others, such as A in Plate II., A and B in Plate V., C, D, E of Plate VIII., C, F, G, and others of Plate XX., which are carried close up to the position of minimum pressure and there allowed to end. In the cases where looped curves have been drawn, it is easy to trace the air up to the immediate neighbourhood of the minimum, and equally easy to trace the part of the curve leaving the central portion of the depression after the minimum is passed. The rapidity of the succession of events and the shape of the isobars lead one to join up the two portions and complete the loop, but the connection is very uncertain. There is some evidence, as will be seen, in favour of regarding the two portions, namely the approaching portion and the receding portion, as composed of different air, and probably the approaching portions of D, E of Plate II. and H, K, L of Plate V. should be classed with the trajectories which terminate near the minimum, and the receding portions should be considered as fresh trajectories, which start from within the central area, and are fed by a supply of air coming to the surface there. It must, however, be noticed that the transition from the trajectories with narrow loops to those with wider loops, such as M and N on Plate II., is gradual, and in these latter there are also sometimes indications of a change in the character of the air from that in the front moving from the South and that of the same trajectory moving from the North in the rear of the storm.

This point, however, of the change in the air supply for different parts of the same trajectory is more fully dealt with in the detailed descriptions given below. We are at present concerned with it only in connection with cases of uncertainty in the application of the method of constructing surface trajectories from synoptic isobaric charts.

The Life History of Surface Air Currents.

It will be seen that, if we had a sufficient number of observations and for a sufficient area, the course of a surface air current could be traced completely, and the full trajectory would show the progress of the air, either round the globe upon the surface or from its descent in some part of the globe to its ascent in another. Beyond those limits, in the latter case, surface observations can tell us nothing, but from what happens within them we can acquire a large amount of useful information. Besides the actual path of the air, the surface observations tell us the pressure, the temperature, and the humidity of the moving air, and we can therefore trace the changes in those elements along the path of the air. We also know the state of the sky overhead and the amount of rain which falls from it. These last two items may be connected with the motion of air on the surface, for, where air is descending, the dynamical warming produced by the compression as the air approaches the surface, and is therefore subject to increased pressure, dissipates any cloud it may carry, and a place of descending air will be a place of dry air and clear sky unless there is some upper layer in which there is an independent cause of cloud formation. On the other hand, where air is rising from the surface, cloud will generally form, in consequence of the dynamical cooling due to rarefaction, and the persistent supply of surface air to feed a persistent column of rising air, whether stationary or moving, will probably be associated with continuous formation of cloud, and possibly with continuous rain.

Hence, if our observations were sufficiently extensive and sufficiently accurate, by working out the details of a trajectory from its origin in a descending current to its termination in an ascending current, we could find its relation to the weather of the descending current, trace the changes in its pressure, its temperature, its humidity, and the weather along its path over sea or land, and finally look for the rainfall which may be expected when it leaves the surface and forms part of an ascending current.

It would be necessary to be on our guard against an exchange of air during the passage alongs a trajectory, but any exchange, except with the upper air, is, from the nature of the case, excluded if there are sufficient observations. The meteorological conditions for vertical exchange can hardly be regarded as indefinite, and any evidence of vertical exchange in circumstances when such exchange is not expected would be of itself a meteorological contribution of some importance.

The whole course of events attending the passage of a surface air current from the place where it reaches the surface to where it leaves it again may be referred to appropriately as its life history, borrowing the phraseology of biological study. We know of no other words that express so concisely the objects which this investigation has in view, and we have therefore used it in the title of this work, with apologies for our inability to find a word in the meteorological vocabulary that expresses equally well the same ideas.

Scope of the Investigation.

The method of surface trajectories has been applied to a number of typical meteorological conditions over the British Isles, which are represented in Plates I.—XXIII., and are discussed in pp. 29—67. For these, hourly or two-hourly maps have been constructed from all available material, including (1) many barograms, anemograms, and rain records lent by private persons from various parts of the British Isles, and (2) the eye observations at all available stations at home and abroad.* Whenever possible, the area of the charts has been extended by including observations from the Continent as well as from Iceland and the Faroes.

The conditions represented in the selected cases are :—

Nos. 1 and 2. Two examples of fast travelling circular storms, March, 1902, and September, 1903.

No. 3. One example of a slow travelling storm, November, 1901.

Nos. 4 and 5. Two examples of the formation of circular storms over the British Isles, October, 1903, and December, 1900.

No. 6. One example of a circular storm, which changed the direction of the motion of its centre from N.E. to S.E. after reaching the North of Scotland, October, 1903.

No. 7. One example of the progress of a V-shaped depression, January, 1900.

No. 8. An example of a sudden decrease of wind velocity with accompanying meteorological changes, February, 1903.

* *See* Appendix, p. 103.

The storm of February 27th–28th, 1903, has been dealt with already in the Quarterly Journal of the Royal Meteorological Society, Vol. XXIX., p. 233.

The trajectories constructed to represent the progress of the air in the surface currents of the examples referred to are given in the Plates II., V., VIII., X., XI., XIII., XIV., XVII., XVIII., XX., XXIII., while selected specimens of the hourly or two-hourly maps from which they were derived are given in Plates I., IV., VII., IX., XII., XIII., XV., XVI., XVIII., XIX., XXII. The changes in wind velocity, pressure, temperature, and weather experienced by the air during its passage along the trajectories are given in tables printed on the several plates. The evidence for the ascent of air and its relation to the accompanying rainfall is given in the text relating to each case.

Motion of Air with Reference to the Position of Minimum Pressure and the Relative Distribution of Cloud and Rainfall.

The diagrams of trajectories, constructed in the manner already described, give the paths of the air over the surface represented by the map. It has already been mentioned that, in dealing theoretically with the phenomena of travelling storms, it is usual to regard the cyclonic disturbance as a set of meteorological conditions carried along bodily by a current of air, which is equivalent to superposing upon each portion of an original cyclonic system a motion equal and parallel to that of the centre. It is clear that in such a case the actual motion of any portion would be the resultant of its motion *in the cyclonic system* with reference to the centre, compounded with the motion of the centre itself. The motion in the system can therefore be obtained by subtracting (in the geometrical sense) from the motion of every portion the motion of the centre, or, what amounts to the same thing, by compounding with the observed or actual motion a motion equal and opposite to that of the centre. The motion of the centre can be obtained from the maps, and hence the elimination of the motion of the centre, and the determination of the residual motion relative to the centre, is an easy geometrical process. It has been carried out for four cases—Plates III. and VI., Fig. 1, for the two fast travelling storms, Plate VI., Fig. 2, for the slow travelling storm, and Plate XX. for the V-shaped depression, in which the motion is referred to the line of the trough. On these diagrams the points of origin or termination of the trajectories have been marked, as well as the weather in all positions relative to the centre, and the area of rain has been shaded. We have thus an instructive representation of the distribution of conditions relative to the centre. For the two cases of fast travelling storms they show motion along somewhat similar curves, which are different in shape from those obtained for the slow travelling depression, but only a few exhibit any suggestion of general circular or spiral motion, and none indicate the path as a spiral round the minimum of pressure as centre. The relative motion in the V-shaped depression (No. 7) is shown by a series of nearly straight lines inclined to or from the line of trough.

Mr. G. T. Bennett, of Emmanuel College, has shown (*see* Part IV., p. 97) that in a circular storm of uniform wind without incurvature the motion of the air may be analysed into a planetary motion about the centre of isobars, and a uniform motion equal and parallel to that of the centre. The planetary motion is elliptic, parabolic, or hyperbolic, according as the wind velocity is greater than, equal to, or less than that of the centre. The corresponding curves have been drawn on the diagrams referred to, in order to show how far the actual storm conformed to the conditions specified.

Trajectories over the Atlantic.

Reference to the details of the cases discussed in Part II. will show that the "life history" of the surface air currents represented in the examples dealt with by means of the hourly and two-hourly synoptic charts is incomplete in nearly all cases. Many examples can be given of the termination of a surface trajectory, presumably in an ascending current—for example, A and B of No. 1, A and B of No. 2, C, D, E of No. 3, F, G, H, and others of No. 7—and some can also be given of the origin of a trajectory within the region represented—for example, S, U, and V in No. 3, M and L in No. 4, and a considerable number in the diagram for No. 7, the V-shaped depression. Such cases are indicated by the trajectory being drawn from a small circle, but it is only in a few of the last named example that the whole course of the trajectory from its descent to its ascent is included in the area for which the synoptic charts are drawn. The life history of the currents is accordingly fragmentary, and, as the selected examples deal mainly with the motion of minima, it is the final portion of the life history that is most frequently represented. The origin of the trajectories is generally in some region for which no observations are available in the particular case.

In order to follow up the idea over larger areas, reference has been made to the charts of the Atlantic for the 13 months August, 1882, to September, 1883, already mentioned. In drawing trajectories from these maps, we are on much less secure ground. We have to assume a permanence of conditions for the 24 hours' interval between consecutive maps, instead of for an hour or for two hours, and the wind velocities are much more uncertain. Mr. Lempfert,* however, in discussing, in conjunction with Dr. Mill, the falls of red dust in February, 1903, found by the method of trajectories with isobaric charts of the North Atlantic satisfactory evidence that the current carrying the dust came from the North-West of Africa, round an anticyclone over Spain, which remained persistent for many days together; and in a similar way examples can be selected in which it is possible to trace the course of the air over the Atlantic.

An endeavour was made to select examples for periods near the winter and summer solstices and the autumnal and vernal equinoxes respectively, and these are represented by the diagrams of trajectories for December 23rd–30th (Plate XXIV.), June 13th–20th (Plate XXV., Figs. 1 and 2), September 22nd–28th (Plate XXV., Fig. 3), and March 22nd–28th (Plate XXVI., Fig. 4) respectively, which are reproduced. Trajectories for the period November 13th–17th (Plate XXVI., Fig. 2) were also drawn, in order to exhibit the contrast between the spirals representing the instantaneous motion connecting high-pressure areas and low-pressure areas on the map for November 15th and the trajectories which probably represent the actual paths of the air under the given meteorological conditions of that period. Furthermore, the trajectories were drawn for the period December 12th–17th (Plate XXVI., Fig. 3), as exhibiting some points of special interest.

Reference must be made to the plates and text of Part III. for details of this part of the investigation. The results obtained are very striking. On some occasions the air is found to travel over long distances and in various directions. The following are conspicuous examples:—

December 23rd–30th ...	From	West Africa to Northern Russia.
	„	Florida to the British Isles.
	„	Mount Washington round the Azores to the British Isles.
	„	the North-East of Greenland round the Azores to the sea off the N.W. of Ireland.
June 13th–20th ...	„	Arctic Ocean to the N.E. Trade.
September 22nd–30th ...	„	Labrador to the N.E. Trade.
November 13th–17th ...	„	Hudson's Bay to the Adriatic.
December 12th–17th ...	„	North-East Greenland to Nova Scotia.
	„	Nova Scotia to North Scotland.
March 22nd–28th ...	„	White Sea to Newfoundland.

* Quarterly Journal of the Royal Meteorological Society, Vol. XXX., p. 57.

But the changes in the meteorological conditions over the Atlantic during the periods are so kaleidoscopic that it is difficult to present the results by means of charts in such a way that the relation of the moving air to the various areas of high and low pressure can be easily followed. For the period December 23rd–30th four isobaric charts have been reproduced, showing the meteorological conditions on alternate days, and the trajectories, drawn for the whole period, have been superposed upon each chart in red. On each map the portions appropriate to the particular day have been thickened. The result is, unfortunately, not so conspicuously successful that the course of events can be followed without close attention, but it is hoped the charts will be sufficient to give an indication of the way in which the trajectories have been drawn. For the June period two maps have been reproduced with the trajectories superposed, and for the others the diagram of trajectories alone has been printed, with references to the positions of high and low pressure centres.

Results of the Investigation.

We now pass on to consider the information with regard to the life history of the surface currents which has been obtained from a study of the trajectories exhibited in Parts II. and III. These results may be presented most effectively by grouping our remarks according to the various meteorological elements, wind velocity, pressure, temperature, state of the sky, or rainfall, which indicate the physical conditions of the air, and are subject to changes as the air moves. The changes in the wind velocity at different parts of a trajectory are necessary for its construction, and must be estimated for every step, and the corresponding pressure changes, as taken from isobaric charts, are almost equally part of the data of construction. Observations of weather are not as numerous as could be wished, but the general character of the weather may sometimes be inferred from observations at neighbouring stations or at subsequent times. For example, if no rain is registered at a station for the 24 hours ending at any time, we are entitled to say that at any one of those hours it was not raining, and there are conditions under which, if fine weather is recorded at neighbouring stations, it is reasonable to infer fine weather at one for which there is no actual observation. The changes of temperature are also not unfrequently uncertain. All data obtained by inference have been indicated in the tables by being enclosed in brackets, although they have only been adopted when there was really good ground for them.

The results will be considered under the headings "A. Changes in Wind Velocity, Pressure, and Temperature" and "B. Air Supply, State of the Sky, and Rainfall."

A. Changes in Wind Velocity, Pressure, and Temperature.

Classification of Trajectories.

An inspection of the trajectories represented in the charts for the eight selected examples of pressure distribution over the British Isles (Plates I.—XXIII.) shows that of the curves which have been drawn some, starting from a wind of definite direction and considerable force, have been traced *forward*, and ultimately lost in a region of indeterminate air movement near the centre or trough-line of a depression. These may be supposed, in general, to represent the *final stages of surface air currents* which feed an upward flow of air. There are a number of examples, particularly in No. 8, in which the trajectory representing a Southerly or South-Westerly wind is brought to a conclusion by meeting a wind from a more Westerly point crossing its path, under conditions which indicate an upward flow over the coming wind. Others have been traced *backwards*, and find their *origin* in a place of calm or indeterminate air movement, and these may be supposed to represent the *initial stages of surface currents* fed from above. Others, again, only show the passage between points of definite air motion, and exhibit changes, more or less pronounced, in the direction and speed of the wind during their course. These last might all be regarded as representing an *intermediate stage* in the life history of an air current, as they show neither its origin nor its termination, but the curves representing them are of different shapes, and they therefore admit of further classification. The most easily identified type of this third series is the looped curve of the fast travelling storms, in which the trajectory, in its later stages, crosses its own path. These looped trajectories, which form the subject of a special section (p. 97), generally cross the track of the storm centre twice, once in the front and again in the rear of the barometric minimum, and there is a gradation by insensible steps between rounded loops embracing a considerable area on the map, and exhibiting a striking continuity of curvature throughout, and narrow loops that pass through a region of somewhat indefinite conditions, emerging with a sudden change of direction, and sometimes of speed also. It seems not improbable that these last are in reality a combination of two trajectories of the first two classes. The point of rapid change in the narrow loop may represent, in fact, the termination of a trajectory of the first type and the origin of another of the second type. These have accordingly been classed separately.

There are also a number of trajectories of the intermediate stage represented in Nos. 3, 4, 5 (Plates VIII., X., XI.), whose shape may be regarded as approximating to a spiral form with reference to the barometric minimum. The curves come round mostly from the North or East, and seem to "hug" the centre of the depression, although their history terminates without their destination being declared. These are classed as *spiral trajectories*.

Finally, there are trajectories representing intermediate portions of the life history of air currents without any conspicuous incidents. These may be called *intermediate-stage trajectories* without any qualification, but they are of three different kinds, representing the motion of air starting originally (1) from the front of the trough-line, (2) from the rear of that line, or (3) from the trough-line itself.

Having regard, therefore, to the life history of the currents, the trajectories represented in the maps may be grouped into the following classes :—

Class 1. *Final stage trajectories*, terminating, generally speaking, near the centre or trough-line of a depression, but in some cases elsewhere (*see* No. 8).

Class 2. *Initial stage trajectories*, showing the origin of an air current in a region of calms or light airs within the map. These are of two kinds, according as the origin is within the central region of a depression or in the calm area outside.

Class 3 (*a*). *Narrow looped trajectories*, which may perhaps be regarded as a combination of trajectories of Classes 1 and 2.

Class 3 (*b*). *Round looped trajectories* of continuous curvature, which cross their own path.

Class 4. *Spiral trajectories*, which have definite relation with a moving minimum, but do not form loops.

Class 5 (*a*). *Intermediate stage trajectories from a point in front of trough.*

Class 5 (*b*). „ „ „ *from a point in rear of trough.*

Class 5 (*c*). „ „ „ *on line of trough.*

The 162 trajectories mapped in the Plates I.—XXIII. can be distributed among these classes as follows :—

—	Class 1.	Class 2.	Class 3. a.	Class 3. b.	Class 4.	Class 5. a.	Class 5. b.	Class 5. c.
Example No. 1 (Plate II.)	3	—	2	6	—	—	2	3
„ No. 2 („ V.)	2	—	2	6	—	2	2	—
„ No. 3 („ VIII.) ...	10	4	—	—	6	—	—	—
„ No. 4 („ X.)	2	2	—	—	6	—	3	1
„ No. 5 („ XI.)	4	2	—	—	5	2	—	—
„ No. 6 („ XIII., XIV., XVII.,XVIII.)	6	2	—	—	—	3	27	22
„ No. 7 („ XX.)	5	13	—	—	—	—	2	—
„ No. 8 („ XXIII.) ...	7	—	—	—	—	—	—	5
	39	23	4	12	17	7	36	31

Two of the trajectories, W of Example 3, Plate VIII., and G of Example 8, Plate XXIII., are exceptional, and cannot be included in the classification. Five are included both in Class 1 and Class 2, because both the initial and terminal stages are represented in the same curve.

The propriety of grouping together all the trajectories comprised under Class 2 is very doubtful. The principle of classification is that the curve includes the representation of the origin of a surface current in a region of calms or light airs. There are two kinds of such regions—one representing the central portion of a depression with variable airs, the other the calm regions, sometimes of fine weather, outside the depression altogether. The course of events for these two kinds of trajectories is quite different. In the latter case (represented by the trajectories of Class 2 of Nos. 3, 4, and eight examples of No. 7) the air finds its way towards the minimum with diminishing pressure, and the weather becomes rainy. In this respect its course is strictly analogous to that of the trajectories of Class 1 or Class 5 (*a*), while in the former, when the origin is near the minimum of pressure (as in the case of the two trajectories of Class 2 of No. 5 and five of those of No. 7) the order of changes is precisely the reverse. As the study here presented had special relation to moving minima, the trajectory with its origin near the barometric centre or trough has been taken as typical, and the trajectories of the reversed kind ought perhaps to be classed rather with those of Class 1 or Class 5 (*a*), but as they do comprise a representation of the origin of a surface current, it has been considered preferable to include them with Class 2 and add this explanation.

Changes in the Meteorological Elements along Trajectories.

The changes of pressure, wind velocity, and temperature which take place in the course of the motion of the air along the trajectories of the several classes will be most easily understood from the eight diagrams representing the changes in cases which have been chosen as being typical of the several classes (Figs. 1–8, frontispiece), though reference should be made to the tables in, or the plates of, Part II. for details of other cases. The corresponding changes in the weather, so far as they are known, are indicated by the letters of the Beaufort notation along the top line of each diagram. The notation has been supplemented by the addition of the letter "n" to mean that it was known that no rain was falling, but that there was no information as to the state of the sky.

In all cases the paucity of observations makes the tracing of the temperature changes uncertain, and as the changes in that element during the passage of a barometric minimum are more or less obscured by ordinary diurnal changes, or by changes due to the passage of the air over stretches of sea, the conclusions drawn must be stated with a certain amount of reserve. In spite of that fact, an examination of all the cases presented seems to justify, in a general way, the suggestions here put forward.

Class 1.

In the trajectories of Class 1 the air travels with continually diminishing pressure, and with velocity increasing in a somewhat irregular manner until the region of uncertain air motion on the trough-line (Nos. 1, 2, 6, and 7), or on the line of motion of the minimum (Nos. 3, 4, 5) is reached, or until the air meets another current crossing its path at a finite angle (No. 8); then the velocity falls off, and the trajectory ends. The weather becomes increasingly cloudy along the path, and the trajectory runs into a region of steady rain. It is thus fair to conclude that the air is a part of that which feeds a rising current from which the rain descends. It is remarkable that all the trajectories representing this class lead from almost due South, and show very little curvature. The currents, as a rule, seem to flow directly to the points where the air ascends. The temperature falls as the pressure diminishes, and the rate of fall approximates roughly to a degree Fahrenheit for every tenth of an inch fall of pressure. This fall is greater than the adiabatic change, and the larger change of temperature may be accounted for in various ways. As it is generally associated with steady rain, the cooling of the surface air by the rain is a possible explanation, and, on the other hand, as the motion of the air is also generally towards the North, change of temperature of the surface with latitude may contribute to it. Into these details we do not wish to enter at present.

Class 2.

The trajectories of Class 2, which originate near the minimum pressure, show a series of changes (Fig. 2), with certain exceptions, the reverse of those of Class 1. The pressure *continually increases*, the temperature rises at approximately the same rate as that at which it fell during the fall of pressure, and the weather improves in the sense that the rain ceases, and sometimes a region of clear sky or detached clouds is approached. This rise of pressure in the moving air is remarkable. The investigation was commenced with the idea that the flow of air, spirally outward from anticyclonic regions and spirally inward in regions of barometric depression, was a general representation of a universal flow of air along the surface towards regions of diminishing pressure. But so many cases are shown in the trajectories of air-pressure increasing as the air pursues its path along the surface that it is impossible to attribute the increase of pressure to mistakes in constructing the trajectories, and we are obliged to conclude that there are many cases in which air flows along the surface to regions of increased pressure. The change in the velocity of the air during the barometric rise is very irregular. In the case illustrated the velocity is shown to remain practically constant, but a considerable increase of velocity in the earlier stages is sometimes shown. It follows naturally from this fact that the actual trajectory of air is a three dimensional curve, and that descending air within the region of the depression must not be excluded from the possibilities of the situation.

Class 3.

Two figures are drawn to represent the changes in pressure, wind velocity, and temperature in trajectories of Class 3 (looped curves), namely, Fig. 3 for class 3*a* or narrow loops, and Fig. 4 for class 3*b* or round loops, but the sequence of changes as shown in the curves is not essentially different. The figures indeed may be regarded as a combination of the figures for Class 1 (Figure 1), and Class 2 (Figure 2), taken in succession. The increase of wind velocity as the pressure diminishes, followed

by a lull near the minimum, is represented in the two Figures 3 and 4 as in Class 1, and in these two figures there is a conspicuous increase of wind for some time after the minimum of pressure has been passed. In this connexion some interesting features are represented in the numbers for trajectory H of Plate V., which shows wind continually increasing through the minimum of pressure and an increase up to 60 miles after a secondary maximum of pressure.

The temperature changes in Class 3 are likewise generally similar to the combination of changes in Class 1 and Class 2, taken in succession—a diminution of temperature as the pressure diminishes, of the same character as before (subject to changes due to diurnal range or change of path from land to sea and *vice versâ*), and an increase of temperature under increasing pressure.

Class 4.

The changes attending the course of the spiral trajectories, Class 4, are represented in Fig. 5. They do not differ in character from those of Class 3 as regards pressure and wind velocity, though in this particular case the increase of wind velocity up to the minimum is very marked, but the temperature changes are quite irregular. On reference to the charts, it will be seen that these trajectories represent the course of a cold current from the North or East, which turns round the barometric minimum and displaces the Southerly current from the Southern region of the depression, and there is no regular temperature change. There is again a recovery of pressure in the later stages of the trajectories, although, particularly in the case of the one represented in the figure, the air seems to be still making its way towards a position on the line of motion of the centre of the depression. The recovery is, however, much less than the fall, and seems to be associated with the filling up of the depression. Other examples (Plate VIII., trajectories A, G, and H) of this kind of trajectory, pursued further, indicate that the pressure after reaching a maximum passes into another stage of decrease, and the air reaches a second region of cloud or rain.

Class 5.

Of the three figures of Class 5 (5*a*, Fig. 6; 5*b*, Fig. 7; 5*c*, Fig. 8), the first two are so like those of Class 1 and Class 2, as regards pressure, temperature, and velocity, that further description seems to be superfluous, but attention should be called to the third, which is of a very special type. It is representative of a very large number of trajectories, which start from a position in the line of trough of a travelling depression. Its most remarkable feature is that there is hardly any change of pressure, and such changes as are recorded in the tables are very irregular. The wind velocity is considerable, and its changes are irregular. The temperature changes are also irregular, more so, as a rule, than in the particular case represented. The weather in that case is also of an indefinite character, being overcast or cloudy, but without rain.

In other examples, however, of similar trajectories taken from No. 6 (Plate XIV., A, B, C, D, E, F, G, H) the weather letters *chq*, *cpq*, *cp*, *cptq*, *cql*, will be found representing a squally type of weather.

These trajectories seem to represent the course of a steady and extensive current of air, chiefly from the west, on the margin of which the depressions are formed. It is in ordinary experience a region of occasional showers belonging to the type of convective rainfall with bright intervals.

Atlantic Trajectories.

For a description of the phenomena attending the course of the several trajectories, the reader must be referred to the plates, tables, and text of the individual cases. The general course of an air current originating in a region external to a depression is evidently towards a region of reduced pressure, and, generally speaking, of cloud and rain. The air may then either pass round the centre of lowest pressure and emerge, or it may disappear as an ascending current. In the latter case, it may be replaced by a descending current. There are only a few examples in which the air can be traced from its descent on the outskirts of a depression to its ascent in the central region. Cases are, however, afforded by the trajectories C, F, G, H of No. 7, Plate XX., and possibly also by the trajectory L of Plates XIII. and XIV.

A question naturally arises as to the origin of those trajectories which commence as winds of moderate strength outside the region of a depression, and as to the further course of the trajectories which are receding from barometric minima, and show increasing pressure. Some light is thrown upon these questions by the curves which appear in the plates representing the selected cases (1–8) of pressure distribution over the British Isles. Trajectories H and K, for example (Plate V.), show that the air of the looped trajectories which leave the area of lowest pressure bends round again and after crossing a stretch of sea—perhaps because it crosses the sea—approaches the line of minima again. A similar experience attends the spiral trajectories of cases 3, 4, and 5. We have no case of a trajectory leaving the area of minimum pressure a second time, perhaps only because the necessary maps are not available.

In order to obtain further information as to the ultimate origin of air currents for which the selected examples referring to the British Isles are inadequate, the surface trajectories of air over the Atlantic (Part III.) should be referred to. In that part of the investigation the whole scale is coarser. On that account no attempt can be made to trace the trajectories through a cyclonic depression; when they come within a region definitely under the influence of such a depression the air must be regarded as lost.

It will be seen that in the case of the trajectories of air over the Atlantic the course run is sometimes the short distance between the region of an anticyclone and a cyclonic depression not far distant, but not infrequently the air describes a course not far short of a quarter of the circumference of the globe, and the course may run from North (Plate XXV., Figs. 1 and 2, Trajectory C), East (Plate XXVI., Fig. 4, Trajectory A), or West (Plate XXVI., Fig. 2, Trajectory A). *Trajectories of southerly winds are generally short.* The occasions on which a trajectory can be traced back to the central region of an anticyclone are very few. The source of the air which feeds the cyclonic areas shown on the charts is generally speaking in the "col" or shoulder of an anticyclone or the region of comparatively low pressure that separates two anticyclonic areas and two cyclonic areas, and this inference is justified by the position of local air supply identified in the maps for the British Isles (*see* p. 56).

As regards temperature the trajectories over the Atlantic are most instructive. A special example will afford the best illustration. The trajectory D of Plate XXIV. is to be traced almost certainly to a strong cold upper current over Mount Washington above a secondary depression. After leaving the land the temperature rapidly approaches that of the sea water, and, thereafter, the temperature of the air adjusts itself to that of the sea. Numerous instances of corresponding adjustment of air temperature to sea temperature may be quoted, and it is not too much to say that the temperature of the air in the trajectories over the Atlantic is determined by that of the sea water. For the course of events thus suggested there is some justification from a consideration of the physical processes which are concerned. Warm air passing over cold sea gets reduced in temperature generally at once, with the formation of fog (*see* trajectories A and B, Plate XXV., Figs. 1 and 2, and table, p. 74), the cold air remains on the surface, and conditions are favourable for a continuation of the process. In the case of cold air passing over warm sea the explanation of the near approach to equality of temperature is less easy because one would expect the air to become gradually warmer and to ascend from the surface and perhaps cause rain and possibly thunder, but the practical evidence for that approach is quite definite. This is in marked contrast with what takes place over land, where, as is well known, a change of wind may spread a thaw over the whole of

the British Isles in twenty-four hours. It is perhaps exaggerating the case to say that over the sea the air takes its temperature from the water, whereas over the land the surface takes its temperature from the air, but the exaggeration is not a gross one, and the concise statement conveys so near a representation of the actual facts that it is perhaps not undesirable to put it in that form.

B. Air Supply, State of the Sky, and Rainfall.

We have now to deal more particularly with the phenomena to be inferred from the trajectories of air with reference to the position of currents ascending from the surface in the regions where trajectories terminate and descending where they originate. Phenomena of both kinds are intended to be included in the heading of this section, and it may be explained at once that in this connection, for the sake of brevity, air supply must be understood in either the positive or negative sense, that is to say, it may refer to the feeding of the surface current by air from above where trajectories originate or diverge, or the supply of air from the surface to an ascending current where trajectories terminate or converge.

In order to make the subject clear, we may here recapitulate once more certain well known facts in connection with dynamical meteorology. Diminution of the pressure of air without any compensating supply of heat causes a reduction of temperature and ultimately the formation of cloud. If continued on the natural scale the rarefaction would result in rainfall. Such a continual diminution of pressure occurs when air is continually rising. Cooling is thus produced in the rising column, which results first in cloud and ultimately in rainfall from the cloud. On the other hand when air descends the increased pressure due to the greater weight of superincumbent air produces a rise of temperature which causes the evaporation of the drops of water carried down by the descending air, and thus dissipates any cloud which the air may have originally contained. These phenomena of the condensation of water in an ascending column, and the consequent formation of cloud and rain on the one hand, and of the evaporation of water and consequent dissipation of cloud in a descending column on the other hand, are now well established meteorological events, and, when, for example, we find a trajectory starting in a region of blue sky and terminating in a region of rainfall, we may fairly infer, as we have already mentioned, that it originated in a descending current and was lost in an ascending one.

We may, indeed, go further and, adopting the view to which all meteorologists have gradually come, and which is strongly supported by the work of von Bezold,* regard an ascending current of air as *necessary* for the formation of measurable rainfall on the ground that the alternative method of producing cloud, namely, the mixing of air currents of different temperatures without ascension could not deposit enough moisture to form rain.

We shall, therefore, now regard the trajectories from the point of view of the evidence they afford of currents ascending from the surface or descending thereto. It must be allowed that it is not always necessary that the ascending current which produces rainfall should make itself felt at the surface, nor is it necessary that the effect of a descending current should always be visible from the surface. It must also be remembered that the ascending current may be very oblique, and the rise take place comparatively slowly, and further that descending air may come from above the air of an ascending current and reach the surface at some distance from the region where its descent commences. Still there are meteorological situations in which fine weather may be definitely regarded as associated with the descent of air to the surface and rainfall with its ascent therefrom, and the examination of the evidence for ascent and descent of air within the region traversed by the trajectories is an investigation of some interest and importance.

* Zur Thermodynamik der Atmosphäre, III., Mitteilung: Luftmischung. Sitzungsberichte der Berliner Akad., XIX., 1890, p. 355. *See also* Hann, Lehrbuch der Meteorologie, p. 243.

The representation of the motion of air in the neighbourhood of a barometric minimum as a general convergence of air along spiral curves would lead to the conclusions (1) that the whole region of the depression should be a region of more or less uniform ascent of air, and therefore of more or less uniform rainfall, (2) that no descent of air takes place within the area of the depression. Yet the general character of the depressions that pass over the British Isles does not suggest uniformity in the distribution of rainfall. As a general rule there is a region of steady rainfall in the front part of the depression and in the region to the North of the path of the centre, while in the region of Westerly and North-westerly winds in the rear of the depression there are often showers with bright intervals, which are probably associated with local ascent and descent of air. For the three travelling depressions, represented by Cases 1, 2, 3 (pp. 30 to 44), the instantaneous distribution of rainfall with reference to the centre is represented on charts, Plates III. and VI., and it differs widely from uniformity over the region of the depression. An endeavour has been made to determine how far the distribution there shown can be explained by the motion of the air along the trajectories.

Convergence and Divergence of Trajectories.

In order to trace the connection between the motion of air over the surface and the ascending or descending currents, it is desirable to give some account of the methods of defining the position of ascent and descent of air, since generally speaking there can be no direct observations, still less any direct measurement of ascending and descending currents.

A position of ascent is indicated by the trajectories where there is a convergence of the lines and a position of descent where there is divergence. These terms must be

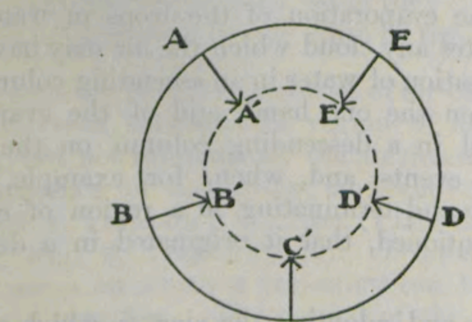

Fig. 9.

understood in a generalised or mathematical sense. As the most obvious example of convergence we may take the case in which the winds from all points of a closed curve blow inwards. If for example we draw a circle A B C D E, Fig. 9, and the winds at the points named are all directed inwards, there will be obvious convergence and the extent of the convergence will be indicated by the diminuation of area from A B C D E to A′ B′ C′ D′ E′. An example of convergence approximating to this type is shewn in Case 3, Plate VIII., Fig. 4.

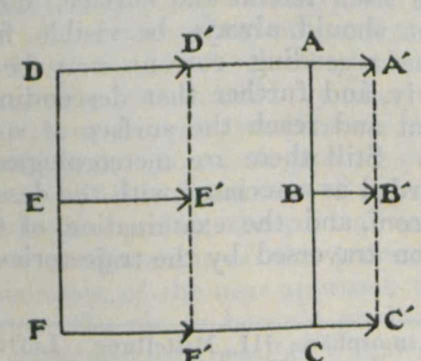

Fig. 10

As another example we may take a case in which the air from one portion of an area is apparently overtaking the air in front of it, both moving in the same direction. Fig. 10 will illustrate this. Suppose the air in front represented by A B C moves in a certain interval to the points A′ B′ C′, while the air behind it at D E F, moving faster, reaches the points D′ E′ F′, in the same interval. Again there is "convergence" indicated by diminution of area from ABCFED to A′B′C′F′E′D′. Examples of this kind of convergence are given in pp. 37, 50.

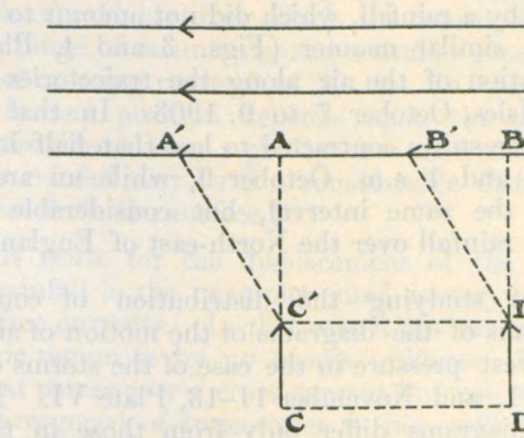

Fig. 11.

Thirdly, suppose the air at one position approaches a persistent cross-wind. This case is illustrated by Fig. 11, in which the air particles C D are represented as moving directly towards the common line of motion of the two particles A B. Again there is a shrinkage of area from A B D C to A′ B′ D′ C′. There are numerous examples of the convergence by the approach of one current to a cross-current passing under the first, in Cases 6 and 8.

In each of the three cases cited, if the directions of all winds were reversed the process could be reversed and increase of area or dilatation would be represented.

The three Figs., 9, 10, 11, represent three typical cases for which few specific examples can be given from weather maps. As a rule the wind changes its direction as well as its speed, and a real case represents a composite result in which the effects of all three types may be combined.

Another indication upon the charts of the locality of the ascent or descent of air is found when air is traced forward or backward to an area of calm, or, what is the same thing, a region of uniform pressure. Again, if trajectories are drawn from a series of points on the boundary of a definite area and steps are taken along the trajectories for equal intervals, the variation of the area defined by the series of points can be measured and a region where the area so enclosed is diminishing is a region of convergence and indicates a locality of rising air, whereas an expanding area is characteristic of a region of dilatation and indicates a locality of descending air.

Application to Determine the Position of Ascending Currents and Rainfall.

The methods thus indicated have been applied in two ways. In the first place selected points on the diagrams of trajectories have been chosen and lines drawn to join adjacent points and so form closed areas. The alteration in these areas as the points move along the trajectories for equal intervals has been measured. The most conspicuous example of a great diminution of area, or convergence of trajectories, is that represented in Fig. 4, Plate VIII., for the slow-travelling storm of November 11–13, 1901. It appears from that diagram that points which at 7 a.m. on November 12 were at the extreme boundaries of the area of observation, approached each other to such an extent that the area enclosed by them at 9 a.m. on November 13 had been reduced to one-twelfth part of its original size. This great contraction was associated with very heavy rainfall over the North of England and the Irish Sea, amounting to upwards of two inches over a considerable area. With this may be compared the changes of area which took place in the case of the fast travelling storm of March 24–25, 1902. In this case an area in the front of the storm centre contracted by about one-half in the interval from 7 a.m. to 5 p.m. (*see* p. 32), while in the rear the contraction was only in the ratio of 8 to 11 in the interval from 9 p.m. to 9 a.m. The much smaller contraction in this case was represented by a rainfall, which did not amount to an inch at any station. Diagrams constructed in a similar manner (Figs. 3 and 4, Plate X.) represent the changes of area due to motion of the air along the trajectories for the storm which originated over the British Isles, October 7 to 9, 1903. In that case it is shown that an area near the centre of the storm contracted to less than half its original dimensions between 5 p.m. October 8 and 1 a.m. October 9, while an area in the rear showed very slight contraction in the same interval, but considerable contraction later on. In this case there was heavy rainfall over the North-east of England.

The second method of studying the distribution of convergence in different parts of the storm is by means of the diagrams of the motion of air with reference to the position of the centre of lowest pressure in the case of the storms of March 24–25, 1902, Plate III., September 10–11, and November 11–13, Plate VI. The lines representing the motion of air in these diagrams differ only from those in the diagrams of actual trajectories by being compounded with a displacement of each point through a distance equal and opposite to that through which the centre has moved. Thus no change is introduced in the *alterations of area* obtained by moving a series of points for equal intervals along the lines of motion, but the changes of area are much more easily traced. This method of determining the changes of area in different positions with reference to the storm centre is explained in the text, p. 34, and the results obtained show, in the case of March 24–25, a great contraction in an area in front of the centre and quite close thereto but very little change of area in other parts except to the north of the line of motion, where a considerable *increase of area* is shown. These results agree well with the weather experienced in the regions indicated.

For the case of September 10–11 very similar results were obtained. Considerable contraction of area took place in the front of the centre a little to the South of the region where the recorded rainfall was heaviest, and appreciable dilatation was found in the rear of the storm where the weather was recorded as fine.

The third case, November 11–13, is a fine example of the contraction due to a Southerly current approaching an Easterly one. An area in the region of the crossing currents contracted to half its size in two hours and the rainfall just to the North of that position was very heavy. In the Southerly current, before the Easterly current was approached, no change occurred, and there was only slight contraction in the Northerly current at the rear of the storm.

Convergence of the surface air associated with rainfall is excellently represented on the diagram of the motion of air with reference to the trough line of a V-shaped depression (Fig. 4, Plate XX.), where the lines of relative motion show that the two currents approached one another obliquely and the region where the Southern trajectories terminated and the Northern trajectories originated was precisely the region of rainfall.

Different Meteorological Conditions for Rainfall.

It has been noticed (p. 14) with regard to the trajectories of air over the British Isles that those which pass directly to the line of motion of the minimum pressure come mostly from the South, and with regard to those over the Atlantic that trajectories of air which have taken a Northward direction are very short lived (p. 16). These observations suggest that the rainfall in the cases here represented is due to a Southerly current passing upward, in the fast travelling storms in consequence of the general convergence which takes place principally in front of the storm; in the slow travelling storm and in the two cases of developing storms by the passage of the moisture-laden Southerly

current over a crossing Easterly current. In the latter case a good deal of rain falls through the surface Easterly current, which may on occasions be a dry current.* The rain is deposited to the Northward of the places where great surface convergence of the trajectories can be identified, but this dislocation of the position of rainfall does not prevent our attributing the rain to the rising of the Southerly air from the surface. In this respect the cyclonic rainfall is somewhat analogous to the orographic rainfall of Mr. G. E. Curtis's classification.† The current of Easterly air for example in No. 3 (Plate VIII.) forms practically a bank of cold air over which the warm Southerly current gradually rises as it would over a range of mountains, and a similar course of events is indicated by the rainfall in the case of crossing currents of No. 8. In the case of orographic rainfall the amount measured in any position depends upon the slope of the ground; with a gentle slope the fall is distributed over a greater area than with a steep slope, and in the former case the heaviest rainfall may be at a considerable distance from the place where the air commences to rise from the surface.‡

When allowance is made for the displacement of the position of rainfall in the manner indicated, the rainfall in the examples cited is very fairly accounted for by the convergence of the surface currents. In that case it is clear that the distribution of convergence over a cyclonic region is by no means uniform. There is great convergence where a southerly current passes over a cross-current but not much convergence elsewhere. The evidence of the divergence of trajectories is not sufficiently clear to demonstrate beyond doubt that there is descent of air in cyclonic depressions as well as ascent, but in the case of the fast travelling storms (Nos. 1 and 2) and in the V-shaped depression (No. 7) there is very strong presumption in favour of the replacement of surface air by air descending from near the minimum of pressure.

GENERAL CONCLUSIONS.

Before stating the general conclusions which we have drawn from the consideration of the life history of surface air currents as detailed in this account of our investigation it will be well to notice an objection which is almost certain to be raised. It may be said that observations of the meteorological elements, especially of wind direction and velocity, are for various reasons too inaccurate and too local in their application to warrant the deduction of any conclusions which conflict with a general theory of cyclonic depressions and their motions or of anti-cyclones and their origin.

It cannot be denied that there is much force in the objection, yet for reasons given below we feel that it will be for the advantage of the study of meteorology that we should give such conclusions as may be drawn from the observations without reference to their agreement or disagreement with meteorological theory.

In the first place the observations are the best material available for the determination of actual meteorological facts in the localities to which they refer and a study of the direct results of observation is of interest and importance apart from any specific dynamical theory.

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* A conspicuous example of this occurred in London during June, 1905. From the 5th to the 9th of the month a low pressure system lay over the North of France, and the wind in the South of England was persistently Easterly or North-easterly. Rain fell almost continuously throughout the whole period with only a few short intervals, and the humidity as shown by a self-recording hair hygrometer remained steady at about 90 per cent. During a rather long cessation of rainfall, which occurred on the afternoon of the 8th, the humidity sank rapidly to as low as 35 per cent., showing that the air of the Easterly current was exceedingly dry when not moistened by rain falling through it.

† "Analysis of the Causes of Rainfall," American Meteorological Journal, Vol. 10, p. 274.

‡ It may be noticed in passing that the focus of heavy rainfall near the highest point of the Lake District of England may be accounted for by the fact that the average slope of the ground from that centre to the sea is nearly the same in all directions between South and North-west. This range includes the chief rainy winds. Thus the orographic effect is the same for most of the rain-bearing winds, whereas if the distribution of orographic features had been linear instead of central the orographic effect upon rainfall would have had a maximum for the direction transverse to the line and have gradually diminished for other directions from that maximum.

Secondly, no theory of cyclonic depressions and their motion is sufficiently applicable to individual cases for it to be used to supply corrections for local observations.

Thirdly, the relation of wind direction and force, which are surface phenomena to the barometic gradient which is the resultant of the distribution of pressure throughout the whole thickness of the atmosphere, in accordance with Buys Ballot's law, shows that the observations are of more than local significance.

In this respect the British Isles are perhaps exceptional. In the course of the daily weather work of the Meteorological Office, Buys Ballot's law is hardly ever lost sight of even when the depressions are of the shallowest or the distributions of pressure the most complicated. Even faint indications of the existence of low pressure centres in the barometric distribution have their counterpart in the circulation of the winds.

Buys Ballot's law is the only theoretical principle which has been used in the preparation of the trajectories and the conclusions are drawn, for what they are worth, from the observations themselves.

We are not unconscious of the limitations of the method. Considering how small a number of instances have been investigated the conclusions are stated with less qualification and fewer provisos than are really required and these may be understood to be postulated here once for all. We could wish that those who do us the honour of criticising our results may point out, not merely the uncertainties of the method and the various ways in which we may have been led to erroneous conclusions, of many of these we are fully conscious, but what other conclusions are within the limits of the ascertained facts.

Cyclonic depressions have been the subject of close study for many years and yet their origin and the laws which govern their movement are at most imperfectly understood. To improve our position with regard to this important subject it is urged that the observations must be extended on the one hand by enlarging the area and on the other by including measurements made in the upper air. Both these contentions may be true and yet it is equally true that the mere inspection of additional data whether from a wider area or a greater height will not dispense with the necessity for close investigation of surface observations and their relations. We must define the questions for which we wish to obtain answers from the new observations, for it is almost certain that the mere extension of observations will not be, in itself, a solution of the problems which confront us. A closer examination of surface observations for a limited area, especially of such a region as that of the British Isles, on the East of the North Atlantic, intersected by sea channels of various widths, helps us to define with greater precision our requirements with regard to additional observations that will throw light on unsolved questions. It is on that ground that in this investigation, the combination and examination of surface observations for the area covered by our maps has been carried, as we believe, somewhat further than heretofore.

Our investigation has been confined to what will probably be recognised as typical cases and one of the first reflexions that suggests itself is how seldom in actual practice typical cases occur. Well defined fast travelling circular storms, as represented by cases 1 and 2, are certainly typical but very rare in our area. The slower travelling storms such as that represented by case 3 are more common but a satisfactory typical instance is not of frequent occurrence. Cases 4, 5, 6, and 7 illustrate definite typical occurrences but such cases are also rare. In numbers 6 and 8 we deal more directly with the phenomena exhibited in the various modifications of the great Westerly current which forms the Southern boundary of the persistent low pressure area of the North-eastern Atlantic, and the results point to the necessity of studying the variations of that great wind system as a whole, encroaching from time to time in some places, receding in others, rather than regarding portions of it as detached and independent cyclonic systems. Such encroachments and recessions are a very general representation of the variations of conditions over the Western and Northern districts of the British Isles in particular, and the special examples of detached circular storms which we have examined appear to be rare and exceptional developments of the variations which, in less developed form, are of common occurrence. Some aspects of the relation of the great low pressure area to the general circulation of the atmosphere are given in a paper in the Proceedings of the Royal Society,* but more detailed investigation has yet to be undertaken.

With these remarks, we put forward the following as the general conclusions to be drawn from our investigation :—

1. In travelling storms, while in the front portion there is motion of the air from higher pressure to lower pressure, associated with falling temperature and with the gradual development of cloud and rainfall, there is also in the rear, sometimes from points quite near to the centre, motion of air from lower pressure to higher pressure and higher temperature with improving weather, and again there are instances of motion with practically no change of pressure, temperature or weather.

Over the Atlantic, air moves generally from higher pressure to lower pressure, but sometimes from lower pressure to higher pressure. There are also instances of air moving for long distances with little or no change of pressure.

2. An essential difference must be drawn between fast travelling storms (as estimated by the ratio of the velocity of the centre to the speed of the wind) and slow travelling storms. The former take all their air for the part which is represented by circular isobars from the region on the right hand or Southern side of the path in the front of the storm and throw out an approximately equivalent amount on the same side in the rear. A slow travelling storm makes use of air from both sides of its path. That from the right hand or Southern side flows directly towards the central portion, while that from the Northern side curls round the rear of the storm.

This difference in the characteristics of the two types cannot be accounted for by regarding all approximately circular storms as revolving vortices of air carried along by currents of different velocities.

The distributions of pressure and of rainfall with reference to the centre of lowest pressure are not conspicuously dissimilar in the two cases, though differences in detail are noticeable in the cases examined.

3. In travelling storms the veering of wind is not generally a uniform sequence. Winds from some of the directions are relatively transient; on the other hand, winds from other directions are relatively persistent during the passage of the storm, even at considerable distances from the centre; the transition from the one persistent direction to the other is comparatively sudden.

In fast travelling storms the directions of the more persistent winds are S. or S.W. and N.W., while in the case of slow travelling storms the more persistent winds are E. to N.E. and S.W. to S.

4. On the Eastern side of the Atlantic, surface air currents from the South are generally short lived, and soon disappear in the central portions of cyclonic depressions. Only in fast travelling storms do Southerly currents continue beyond the path of the centre and describe loops round the centre, and even in those cases the air which describes the part of the loop leaving the storm centre may be different from that which described the earlier part of the loop approaching the centre.

5. Air currents from other directions than the South are much longer lived. They persist until either (1) they reach the trade winds, or (2) turn round the rear of a depression and approach the centre from the Southward, or (3) join a depression over the Western Atlantic.

* The general circulation of the Atmosphere in middle and higher latitudes. Proceedings of the Royal Society, vol. 74, p. 20, 1904. Monthly Weather Review, vol. 32, p. 264, 1904.

6. The flow of air along the Southern side of the great Atlantic area of low pressure which is associated with a series of approximately parallel isobars may consist of a combination or alternation of currents of different direction, force and temperature, with marked meteorological changes attending the sudden transition from one current to another.

In such cases the local variations of wind direction and force shown on a synoptic chart correspond with real phenomena associated with the two sets of currents.

7. The rainfall incidental to travelling storms can be, generally speaking, related to the ascent of air from the surface, as indicated by the convergence of the air, deduced from its motion, in a region not far distant from the locality of the rainfall, generally to the South or South-east of it. There are, however, some cases of rainfall unaccounted for by the method of surface convergence.*

8. In the case of air moving over the sea, the temperature of the water governs that of the air, which rapidly assimilates itself to that of the water. The passage of warm air over cold water can generally be definitely associated with the formation of mist or fog on the surface, but a corresponding effect arising from the motion of cold air over warmer water is not so easily traced in the instances which have come under notice.

9. We have failed to identify the central areas of *well-marked anticyclones* as regions of origin of surface air currents. The areas of descending air seem to be (*a*) the shoulders or protuberances of anticyclones, in particular the regions of comparatively high pressure between two consecutive cyclonic depressions, and therefore also between two anticyclones, or the extension of an anticyclone, between a depression and its secondary; (*b*) the trough lines of travelling V-shaped depressions, and parts of the central area of travelling circular storms. The latter have not been identified sufficiently well for them to be specified in a precise manner, but there is too much evidence in favour of the descent of air within the region of approximately circular isobars for the exchange of air between the surface and the upper layers in these regions to be disregarded.

10. The regions of high pressure that intervene between depressions and travel with them may be called anticyclones when we are dealing with a chart for a restricted area, but they are to be distinguished from the well-defined anticyclones which are persistent for days together. These latter are for the most part inert and comparatively isolated masses of air, taking little part in the circulation which goes on around them.

11. The motion of air with reference to the moving centre of a cyclonic depression is not, as a rule, properly described as circular motion round the position of minimum pressure, modified by incurvature, and thus transformed into spiral motion about a moving centre. The description would apply to the motion of air in the case of certain currents commencing on the Northern side of a slow travelling storm, but the following cases of motion also occur:—(*a*) in approximately straight lines leading towards the minimum or a point on its path in front, or on the trough line of a V-shaped depression, (*b*) round the minimum in curves, to which the minimum stands rather in the relation of the focus of a conic than that of the centre of a circle.

12. We are as yet unable to identify in the surface observations the conditions which determine the direction or speed of the motion of a barometric minimum. It should, however, be remarked that case 5 shows the development of a circular depression from a secondary in the South-east part of the primary twice successively, and from a single map per day the result would appear as the travel of a minimum from the North-west of

* The relation between the convergence of air and the incidence of rainfall is sufficiently close to justify the investigation of such a question as the effect of the retardation of the surface layers of air by friction in producing rainfall in a steady current, which could be dealt with by an extension of observations to the velocity of lower clouds and of wind at different levels.

Ireland to the Gulf of Genoa. We are not yet in a position to say whether this is a special modification of a normal process of travel by the continuous development of secondaries.

The Relation of Surface Air Currents to Cyclonic Depressions and Anti-cyclonic Areas.

The conclusions which have been enumerated throw some light upon the question from which the investigation started, viz., the relation of surface air currents to cyclonic depressions and anticyclonic areas.

It is sometimes supposed, and indeed it may be said without injustice, that the commonly accepted view with regard to surface air currents is that they represent the passage of air from anticyclonic areas, where they are supposed to originate, to cyclonic depressions, where they become ascending currents. It is a natural consequence of this view that the currents should be regarded as due to the difference of pressure between the anticyclone from which they proceed and the cyclonic area towards which they tend. The energy of their motion should therefore be regarded as representing the exhaustion of the potential energy of the pressure difference, which must be supposed to have originated in some manner, although at present we do not understand precisely how it is produced or maintained.

We propose, therefore, to consider the conclusions we have drawn from the study of the surface trajectories of air as affecting these views of the nature and origin of surface air currents.

In order to make our meaning clear we may refer to another case of motion which will enable us to illustrate some important points of difference between the conditions under which bodies move whether they be composed of air or of solid material. Consider a plumb bob suspended by a long string from a point and hanging over a table. If the bob be pulled aside and let go it will move towards its original position of rest with increasing speed. After it has arrived there it will go forward and oscillate like a pendulum. Its motion towards the centre is rightly attributed to the force tending to restore it to its original position, its energy of motion to the potential energy of the displaced bob. But if after drawing it aside, instead of simply allowing it to move as it will, we project it judiciously, it will describe a circle about its original position which only diminishes in radius very slowly as the velocity gets worn away. In the second case the motion of the bob cannot be said to be derived from its potential energy, though that energy is necessary to keep it in its circular path. Its motion is derived from the impulse which projected it.

The motion directly towards the centre on the one hand and the motion in a circle without any appreciable approach to the centre in a single revolution on the other hand are two limiting cases which indicate motion under essentially different conditions. In one the kinetic energy of the bob is the equivalent of potential energy sacrificed in the motion, in the other it is due to some separate action starting the motion and the potential energy of the bob only guides it. The question we now ask is to which of these two kinds of motion should we assign that of surface air currents? Does their energy represent the exhaustion of the potential energy of the pressure-difference between anti-cyclones and cyclonic depressions, just as the increasing motion of an oscillating pendulum represents the exhaustion of the potential energy of its bob, or are surface air urrents like the bob moving in a circle needing only to be guided by the distribution of pressure?

Any actual case of motion may be in reality a combination of the two kinds just as the motion of the bob would be if it were not projected with exactly the velocity necessary to describe a circle, but we may consider whether the actual motion inclines more to the one type than the other.

The results of our investigation seem to show that surface air currents belong rather to the type of circular motion controlled in direction by pressure difference than to the type of motion derived from the exhaustion of the potential energy of pressure difference. The close agreement of the direction of the motion with the direction of the isobar at right angles to the pressure gradient—the direction of the force—is in itself a strong point of analogy ; and there are other conclusions in its favour. We have seen that the well-marked anticycionic areas are not conspicuous as the sources of surface air currents. We have called them inert and comparatively isolated masses of air, taking little part in the circulation that goes on around them. The identification of currents of air moving from lower pressure to higher pressure, of which there are many examples, supports this view. Such currents do not terminate in anticyclones, they skirt them and pass on. There are many instances of this in the trajectories represented in the charts, and particular attention may be directed to Plate XXV., Figs. 1 and 2, in which a high pressure area in the North Atlantic is skirted by trajectories on all sides, and to Plate XXV., Fig. 3, in which the position of an anticyclone is shown to progress day by day with the current so that the highest pressure is always kept on the right hand side of the moving air.

Further evidence in favour of regarding anticyclones as masses of air which for some reason is not taking part in the circulation going on around it may be derived from the study of anticyclones themselves. They are not of single meteorological character. Local changes of many kinds may take place within them, and almost any kind of weather, except those which represent violent atmospheric changes, may be associated with their central regions.

If these views be correct, in such cases as those referred to, the moving currents may be regarded as maintaining the anticyclone quite as truly as being maintained by it, and this aspect of affairs gives to the moving current a more important place in the scheme than it has if we regard it simply as an incidental circumstance in the equalisation of pressure differences arising from some unassigned but independent causes.

In a similar way the relation of moving air to cyclonic depressions is much less close than the idea of surface currents as air in direct transit from anticyclone to cyclone would lead us to suppose. It is true that, as a rule, moving air can be shown to disappear ultimately in the central region of a cyclonic depression. There is, doubtless, a motion *on the average* across isobars from high pressure to low pressure, and the motion is not one of pure analogy with the description of the circle by the plumb bob, *but the transverse motion is not the chief component.* In some cases a number of depressions may be safely passed before the air becomes involved in the rotatory system. Hence it follows again that the flowing air current is, on the whole, a more stable and persistent feature than the depression, and it would not be difficult to cite instances in which cyclonic whirls appear as comparatively local phenomena on the Northern margin of a vast current, originating at a great distance in the West and flowing to the Eastward or North-eastward over the Northern Atlantic.* The fact that the fast moving cyclonic depressions draw all their air from the Southern side affords a strong confirmation of this view. The air which describes the looped trajectories in such storms is diverted from the main current, and it, or its equivalent, rejoins the current again after the centre has passed.

We are thus led to regard the main atmospheric currents of middle latitudes as being analogous to the circular motion of the bob of the pendulum, not depending for their energy upon local pressure differences which guide but do not necessarily produce them.

It was for these reasons that, in the paper on the general circulation of air in middle and upper latitudes, already referred to on page 23, the main Westerly currents were considered from the point of view of a general circulation round the poles. It was there

* See especially *Charts illustrating the Weather of the North Atlantic Ocean in the winter of 1898–99* (Meteorological Office Publication No. 142).

pointed out that the average circulation of the upper air in January, as shown by M. Teisserenc de Bort, is a general Westerly flow circulating round the poles from the S.W. over the oceans and from the N.W. over the continents ; that, if it were not for the modifications introduced by the alignment of the great continents, there would be *on the surface* in the higher latitudes a circulation in the opposite direction on account of the distribution of pressure following that of temperature.

It was moreover pointed out that such phenomena would probably be exhibited with greater clearness in the Southern hemisphere where the disturbing influence of land is hardly appreciable in middle latitudes because there is so little land, and in higher latitudes because the distribution of land or ice round the pole is comparatively symmetrical.

All the evidence that has been derived from the Antarctic Expeditions tends to confirm this view, if we except some observations of surface winds on the sledge journeys of the *Discovery*. The average direction of surface winds at the winter quarters of the *Southern Cross*, the *Discovery*, and the *Gauss* is Easterly ; and, on the other hand, the smoke of Erebus, at a height of 13,000 feet, was seen to move almost invariably from the West.

These conclusions seem to show that in the Southern hemisphere the Easterly surface circulation and the Westerly one above it are comparatively steady, whereas the effects of the irregular distribution of land in the Northern hemisphere make the circulations in that hemisphere irregular and broken. Still, they remain important factors for consideration, and with them we must probably associate those currents which are the main features of our meteorological conditions, and which may, as we have seen, be looked upon to some extent as the causes of the cyclones and anticyclones of the Northern Atlantic.

We have put forward no dynamical or kinematical theory of the nature and motion of cyclonic depressions. From the examination of the details of certain typical cases actually observed, we have determined the motion relative to the centre, and have compared it with the corresponding motion computed for the case of a storm of uniform winds travelling with constant speed. We do not wish to be understood as regarding the circular storms of North-west Europe as storms of uniform wind, or a storm of that character as the most appropriate basis for a dynamical theory. The computed curves are simply used in the same way as squared paper is used to examine the relations of quantities of which the law of connection is unknown. Anyone who examines the diagrams must judge for himself whether he regards the comparison between the curves for the actual storm and these computed for reference, as sufficiently satisfactory to justify his considering the former as an index of the existence of the dynamical conditions required to account for the latter.

PART II.

TRAJECTORIES OF AIR

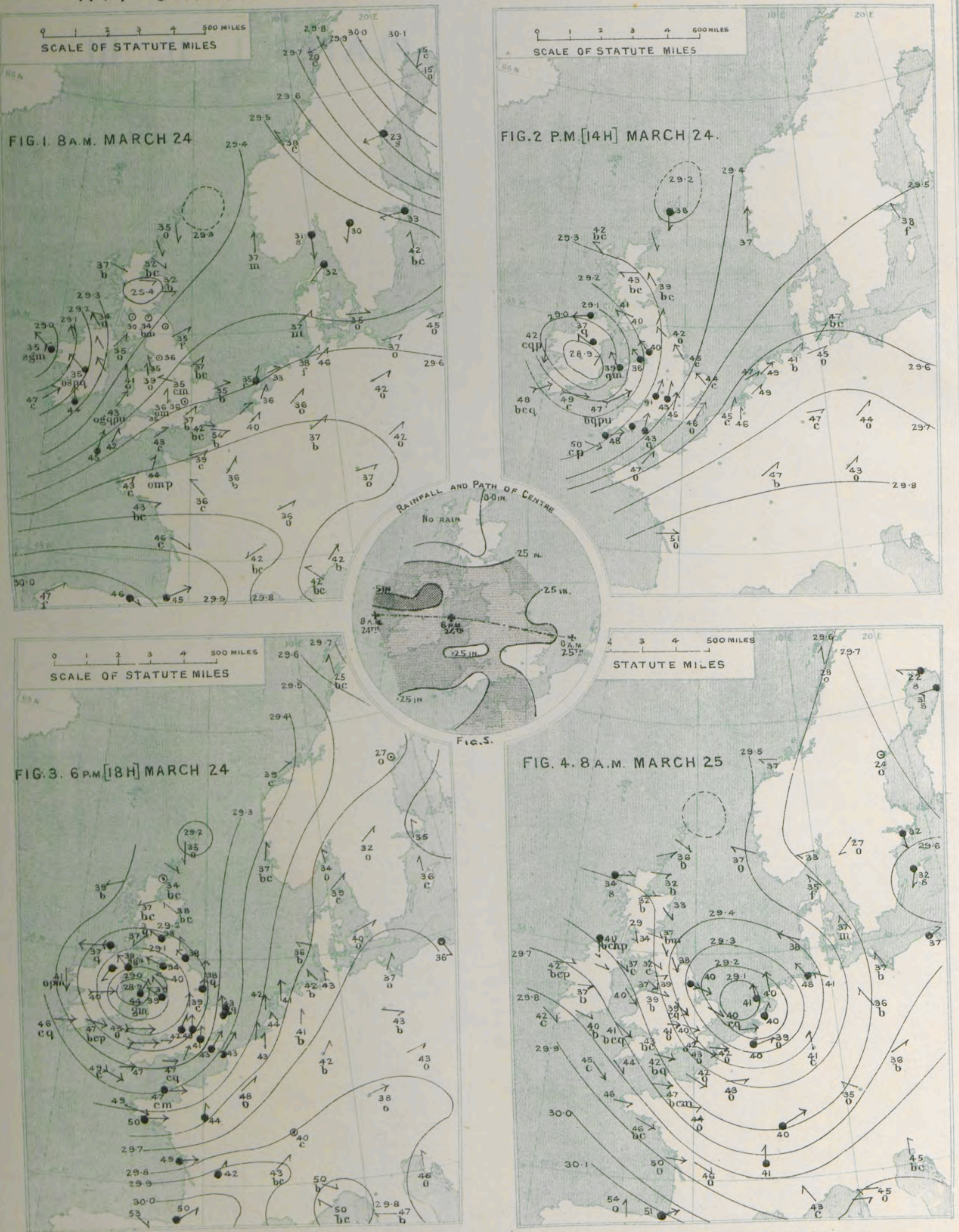
IN

TRAVELLING STORMS.

CHARTS AND DIAGRAMS OF SELECTED CASES, WITH DESCRIPTIVE TEXT.

PLATES I, II., III.

No. 1 CIRCULAR STORM OF MARCH 24–25 1902.



ISOBARS, WINDS, TEMPERATURE AND WEATHER

The mark ● shows that rain was falling at the hour of observation

TRAJECTORIES OF AIR, MARCH 24–25, 1902.

Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D V	D P 20+	D T	D W	Hours.
8	30	9·15	47	c	19	9·57	42	n	10	9·73	43	c	25	9·43	43	op	8
10	32	9·07			21	9·40		(r)	10				25	9·30		(r)	10
12	34	**8·95**			26	9·30		(r)	19				30	9·15		(r)	12
14					36	9·14			19	9·60	(47)	o	30	8·95		(r)	14
16					25	**9·05**		r	21					**8·90**		(r)	16
18									25	9·40		(r)	21	8·95			18
20									25				31	9·08		n	20
22									31				31	9·18		(n)	22
24									37	9·20	(40)		35	9·28			24
2									31				34	9·30		n	2
4									31	**9·05**	(40)		35	9·35		n	4
6													35	9·40		(o)	6
8													30	9·43			8

Hours.	E V	E P 20+	E T	E W	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	H V	H P 20+	H T	H W	Hours.
8	10	9·63	43	c	17	9·54	35	b	7	9·44	35	f	19	9·27	34	o	8
10	19	9·50	(45)	(r)	12				10				19	**9·10**			10
12	23	9·45	(43)	(r)	12				14				29				12
14	25	9·30	(41)	(r)	12				12				30				14
16	27	9·10	(38)	(r)	15				12				25				16
18	20	9·00	(39)	(r)	16				12				19				18
20	14	**8·96**	38	r	20				14	**9·23**			25				20
22	15	9·00	(37)	(r)	20				14	9·23			25	9·55	39	(n)	22
24	20	9·10		(n)	20				14	9·28			25	9·60			24
2	36	9·20		(n)	20				28	9·35		(n)	25	9·70			2
4	32	9·30	(40)	(n)	20	9·18			31	9·38		(n)	25	9·73			4
6	31	9·35	(42)	(n)	26	9·24			31	9·45	(37)	(n)	25	9·80			6
8	31	9·36	43	o	35	9·24	40	rq	31	9·55	39	b	20	9·85	45	c	8

FIG. 1. TRAJECTORIES A TO K

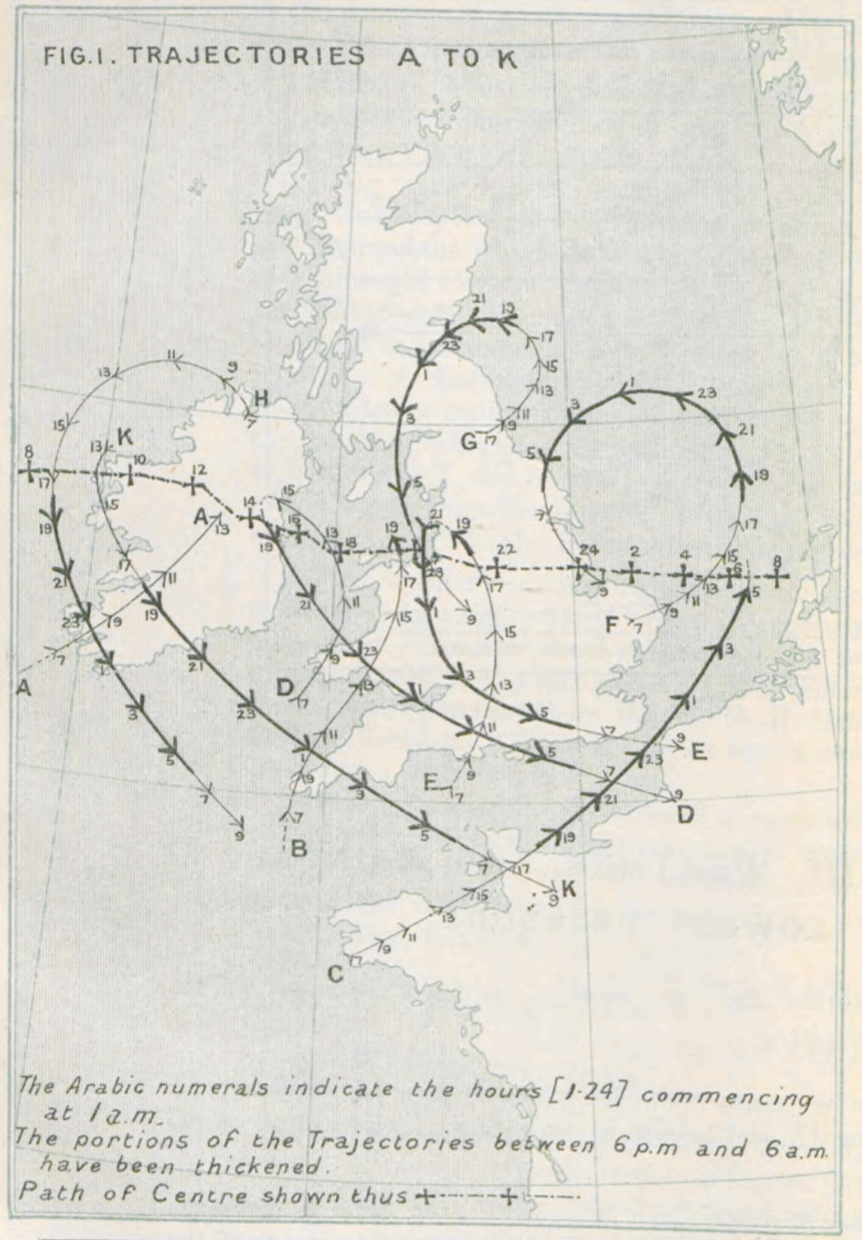
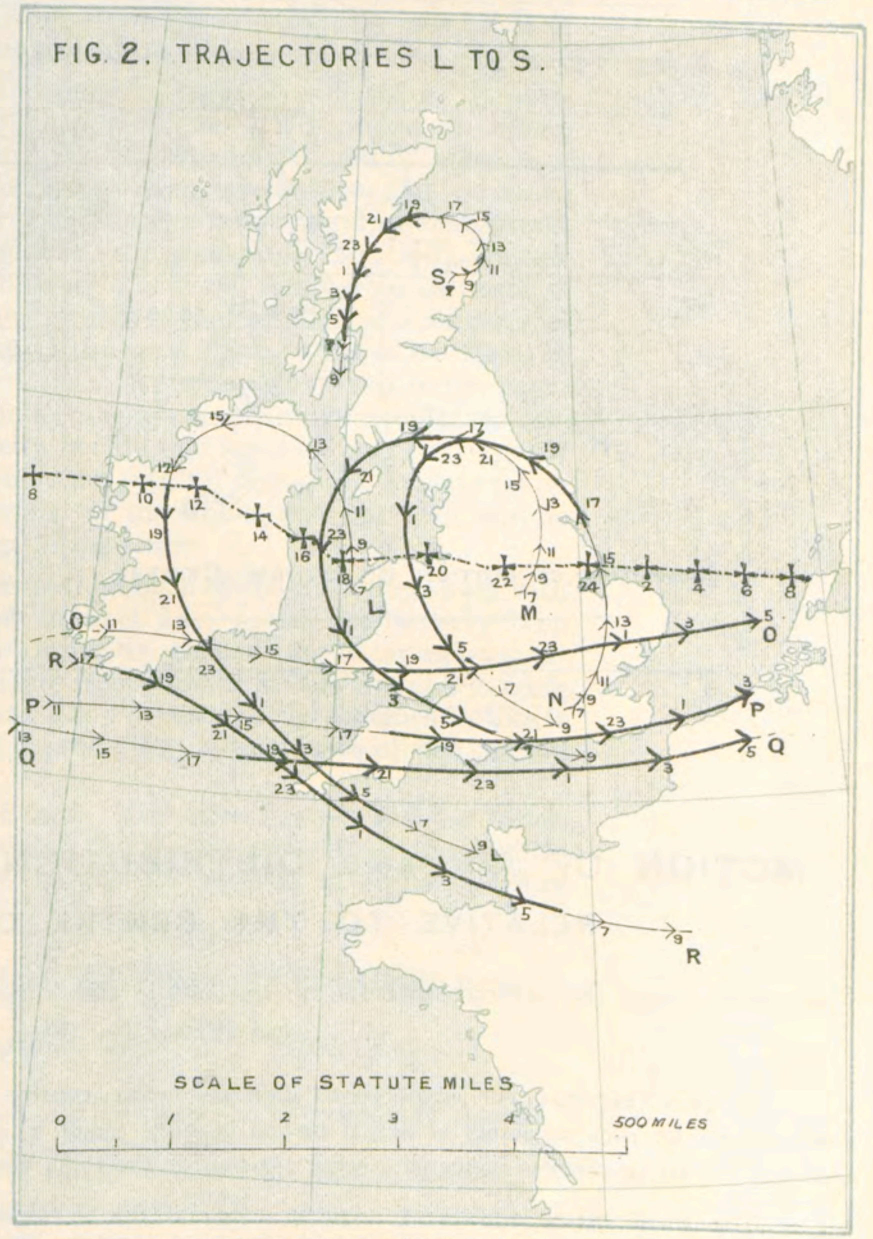


FIG. 2. TRAJECTORIES L TO S.

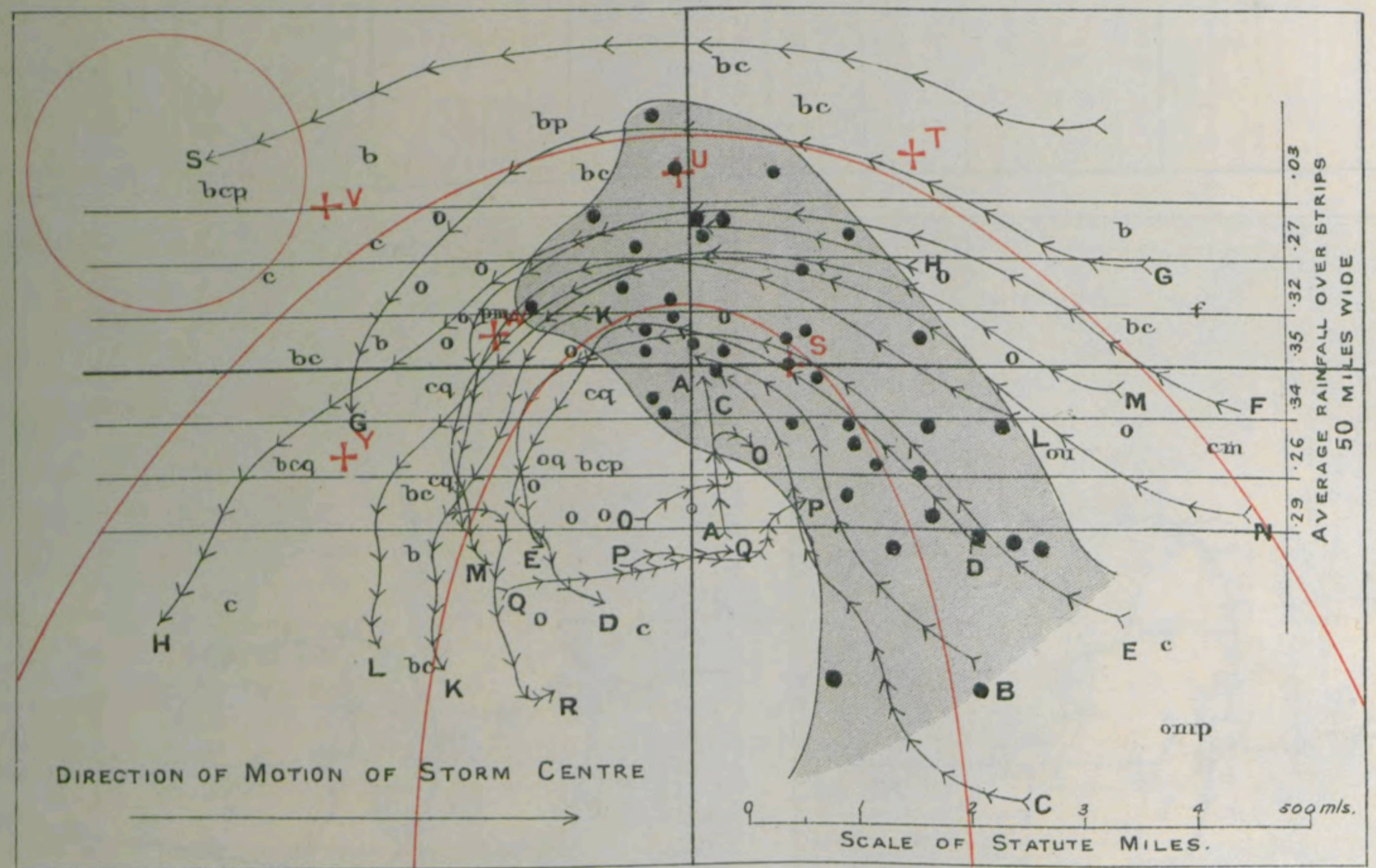


Hours.	K V	K P 20+	K T	K W	L V	L P 20+	L T	L W	M V	M P 20+	M T	M W	N V	N P 20+	N T	N W	Hours.
8					16	9·41	41	ou	7	9·48	36	c	8	9·62	37	b	8
10					22	9·28			12	9·45	38	c	17	9·58	(43)	(bc)	10
12					26	9·09		(r)	15	9·42		n	19	9·50	(43)	n	12
14	26	8·99	42	cqp	39	**8·95**	(38)	r	19	9·33	(41)	(n)	20	9·40	(44)		14
16	26	9·15	42	cqp	36	9·05			24	9·20			26	9·30		(r)	16
18	26	9·23	(41)	(op)	26	9·15	(38)	(n)	25	**9·06**	(34)	r	30	9·15	(38)	r	18
20	30	9·28			30	9·27	38	op	31	9·10			29	**9·04**	(37)	r	20
22	30	9·42			31	9·46		(n)	35	9·17	(38)	(n)	19	9·14			22
24	30	9·50			31	9·50		n	38	9·28		(n)	24	9·20		(n)	24
2	30	9·57	(44)	(n)	31	9·55		n	38	9·38		(n)	35	9·25	(38)	n	2
4	30	9·55			31	9·60	43	n	35	9·40	(40)	(n)	35	9·33		(n)	4
6	30	9·63	44		31	9·65		n	32	9·43	(42)	(n)	35	9·40	(41)	n	6
8	30	9·65		(n)	25	9·70	47	bcm	30	9·49	43	c	30	9·50	42	o	8

Hours.	O V	O P 20+	O T	O W	P V	P P 20+	P T	P W	Q V	Q P 20+	Q T	Q W	R V	R P 20+	R T	R W	Hours.
8																	8
10	40	9·10	46	n													10
12	40	9·08			40	9.25	(47)	n									12
14	35	9·02	(48)	(c)	40	9·23	48	(bc)	40								14
16	32	9·06			40	9·21			40				35	9·35	47	n	16
18	45	9·06	45	o	45	9·20	(45)	n	40	9.30			35	9·31	(47)	(cp)	18
20	38	9·10	(43)	n	37	9·18			40	9.25	46	c	35	9·30			20
22	34	9·06	42	n	33	9·22	45	op	40	9·21	(46)		35	9·40			22
24	34	9·05	41	n	33	9·10			40	9·23			35	9·49	45	n	24
2	30	9·06			33	9·20			37	9·25			35	9·52			2
4	30	9·06							37	9·15			35	9·55			4
6													35	9·65			6
8													27	9·65	(44)	(o)	8

The Trajectories are referred to by letters A, B, to R. The Tables give the Wind Velocity (V), the Pressure (P), the Temperature (T), and the Weather (W) at the points of the Trajectories corresponding with the hours named in the margin. Figures in brackets are conjectural. The symbol n indicates the absence of rainfall as shown by self-recording rain gauges.

CIRCULAR STORM OF MARCH 24–25, 1902.



MOTION OF AIR AND DISTRIBUTION OF WEATHER AND RAINFALL RELATIVE TO THE CENTRE OF LOWEST PRESSURE.

Computed from the actual motion of air along the trajectories and the motion of the centre as shown on Plate II., Figs. 1 and 2.

NOTE.—The lines with arrow heads show the motion relative to the storm centre for successive two hour intervals. A line is drawn for each trajectory of actual motion in Figs. 1 and 2, Plate II., and lettered correspondingly. The position of the centre of lowest pressure is indicated by the crossing of the thick lines.

The small letters indicate the weather noted at the corresponding distances from the centre. The mark ● represents rain, the shaded area indicates the region of continuous rainfall. The figures in the right-hand margin show the average of the falls of rain at stations in successive strips 50 miles wide to right and left of the path of the centre.

The red lines show the paths of air with reference to the centre for a perfectly circular storm of uniform wind, the centre of which moves with a velocity equal to 0·91 × Velocity of wind.

For the reference to the points marked T.U.V.W. see p. 34.

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TRAJECTORIES OF AIR IN TRAVELLING STORMS.

The following series of trajectories form a continuation of the inquiry of which the first results were given in the paper on the Meteorological Aspects of the Storm of February 27th, 1903, read before the Royal Meteorological Society. (Q.J., Vol. XXIX. p. 233.) It was there pointed out that a circular storm at the surface, travelling at the same speed as the component winds, would draw all its air from one quadrant and throw out winds in the adjacent quadrant on the same side of the line of motion of the centre.

Further, it was suggested that the trajectories representing the paths of air in such storms, showed convergence at certain parts of the storm area, and divergence at others. This suggestion indicated a means of inferring the position of the rainfall area in a travelling storm and the extent of the rainfall for storms of specified shape, and it seemed important to follow it up in order to account for the difference between rainy depressions, and depressions which show a circulation of wind, but little or no rain. Mr. G. T. Bennett of Emmanuel College, Cambridge, suggested a number of ways of forming an estimate of the convergence of air for various areas, by measurements of the direction and velocity of the wind at a number of points in the boundaries of the areas; and, at the same time, he pointed out that a storm which conformed strictly to the type represented in the paper referred to, or indeed any type represented by uniform winds tangential to circular isobars, the centre of which moves with any given velocity, would not produce any convergence or divergence.* Such alteration of surface area could not result if there were no incurvature of the winds from the isobars, no want of uniformity of the winds over the area, and no change of shape of the isobars during the passage of the storm.

Mr. Bennett's geometrical solution of the general problem of the travelling storm with uniform tangential winds, which is reproduced in Part IV., p. 97, has already been mentioned. An analytical solution of the problem for the general case of air moving at uniform speed and at any given angle of incurvature from circular isobars round a moving centre, was contributed by Mr. W. H. H. Hudson, late Professor of Mathematics at King's College, London. From his paper two figures, representing special cases of motion, are reproduced in Part IV.

The following is a list of the cases which have been investigated, and for which hourly or two-hourly maps have been constructed, by making use of all the regular official information, and, in addition, a large number of records of self-registering instruments kindly lent for the purpose:—

†1. Fast travelling circular storm.
8 a.m. March 24 to 8 a.m. March 25, 1902. (Two-hourly maps.)

†2. Fast travelling circular storm.
8 a.m. Sept. 10 to 8 a.m. Sept. 11, 1903. (Hourly maps.)

†3. Slow travelling storm.
6 p.m. Nov. 11 to 6 p.m. Nov. 13, 1901. (Two-hourly maps.)

†4. Formation of a slow travelling storm over the British Isles.
6 p.m. Oct. 7 to 6 p.m. Oct. 9, 1903. (Two-hourly maps.)

5. Formation of a circular storm from a secondary over the South-west of England.
8 a.m. Dec. 30 to 8 a.m. Dec. 31, 1900. (Hourly maps.)

6. Circular storm in which the direction of motion of the path changed from N.E. to S.E.
6 p.m. Oct. 14 to 6 p.m. Oct. 17, 1903. (Two-hourly maps.)

7. A "V" shaped disturbance.
6 p.m. Jan. 5 to 6 p.m Jan. 7, 1900. (Two-hourly maps.)

8. Sudden decrease of wind velocity, accompanied by veering of wind. (Hourly maps.)
Feb. 24th, 1903.

* *See* Part IV., B. II., p. 102.

† The terms "fast travelling" and "slow travelling" must be understood to be defined by the ratio of the velocity of the wind in the storm area to the velocity of the storm centre.

In an inquiry extending over a long period of time it is difficult to secure uniformity in the conventions adopted. Improvements suggest themselves in later stages, which cannot always be introduced into work already completed. So far as possible, the following rules have been adhered to in the maps and diagrams included in this volume:—

(1.) Hours have been numbered from 1 to 24, commencing with 1 a.m.

(2.) The Beaufort notation has been used to indicate the weather at the hour of observation. On the charts a black dot has been substituted for the letter *r* to indicate "raining," and in the tables the letter *n* has been used to indicate "not raining."

(3.) The rainfall maps summarize the total falls for the 24 hours ending at 8 a.m. or 9 a.m. on the dates of the maps.

---

1. Fast Travelling Circular Storm (Plates I.–III.).

8 a.m. March 24 to 8 a.m. March 25, 1902.

The main features of this disturbance are shown in the selection from the two-hourly charts reproduced on Plate I. The storm centre crossed the British Islands in a West to East direction. At 8 a.m. on the 24th it lay to the West of Blacksod Point, and at the corresponding hour on the 25th it is shown off the Helder. The distance between these two positions is 630 miles, so that the average rate of travel was 26 miles per hour. The wind forces shown on the maps within the area of the storm are for the most part between 6 and 8 on the Beaufort scale; force 9 was quoted as the extreme by many observers, and at some light-ships in the Bristol Channel force 10 was reached. The highest velocity recorded by an anemometer was 42 miles in the hour (factor 2·2) at 2 p.m. at Valencia. We may, therefore, assume 30 and 45 miles per hour as the average and the extreme hourly wind velocities respectively in the storm area. The ratio of the average wind velocity to that of the storm centre was thus about 1·1, while the corresponding ratio for the strongest winds was about 1·7. Judged by this standard, the storm must be looked upon as a fast traveller, though its actual speed was not very great.

With the help of the two-hourly maps the trajectories reproduced on Plate II. have been constructed, commencing, generally speaking, at 7 a.m. on March 24 and continued till 9 a.m. on March 25; in the cases of A, B, C, K, and O to R, a portion only of this period could be included. They show that the air involved in the storm consisted, in so far as it was derived from the surface, of air which lay within the region passed over by the storm, say to within 120 miles on either side of the path, and of air drawn in from the South-west and West. No air was supplied from other directions, unless that represented by the trajectory S be regarded as indicating a supply from the North in the extreme rear of the storm. The Tables on Plate II. give for each trajectory the velocities in miles per hour used in drawing each step, the pressure and temperature of the moving air, and the weather as noted at stations lying on the trajectories. The pressures quoted refer to the middle points of each step, and have been read off from the isobars of the maps; temperature and weather are taken from the observations at stations over which the trajectories pass; in cases in which these elements are not specially recorded, but are inferred from the records from stations lying near the trajectories, the values quoted have been enclosed in brackets. The symbol *n* has been used when it could be safely inferred that rain was not falling.

The trajectories may be divided into three classes:—(1) Those which flow to the calm region in the centre of the storm and there end: A, B, C. (2) Those which form loops, usually crossing the path of the storm twice: D, E, F, G, H, L, M, N, S. (3) Trajectories running in a West to East direction on the Southern side of the storm path, and parallel to it: O, P, Q, and perhaps also R.

The trajectories A, B, C, ending near the storm centre, and the first portions of those which form loops, D to N, present the following characteristics. The direction of motion of the air was from the South (S.W. to S.E.), the pressure decreased continuously, while the velocity increased rapidly. The weather at the starting point was fair in the case of those trajectories which commence in the East of England; in the case of those which start further West it was cloudy or overcast, but as we trace the curves Northward, we sooner or later reach a region in which steady rain was falling in all cases. The temperature changes were comparatively small. A slight increase is shown during the first few steps by many of the curves; in the cases of M and N this amounted to a change from 36° and 37° to 41° and 44° respectively; the low temperatures at the starting points may be attributed to nocturnal radiation, so that the initial rise was probably due to insolation; subsequently a decided fall is shown in most cases. This change was associated with the setting in of rain, a fact which is more clearly brought out if we consider the records from a single station. Thus at Berkhamsted rain set in at 12.15 p.m. and the temperature fell suddenly from 44° to 39° at the same hour. The station was, at the time, within the Southerly air current represented by the first portions of the trajectories, and there can be no question of a change of air supply to account for the change of temperature shown by the thermograph.

Up to their most Northerly points, almost due North of the storm centre, where the air has an East to West motion, the trajectories which form loops present similar characteristics to those which end near the centre. Subsequently the pressure increases again and the velocity is much more nearly constant, the values being in general somewhat greater than those found in the region of diminishing pressure. The last few steps of the trajectories generally show a decrease of velocity.

Shortly after passing the point of minimum pressure rain ceased, but the exact time of stoppage cannot be fixed for lack of observations. Throughout the remainder of their course these trajectories pass through a region of casual rainfall; no precipitation was registered by any of the self-recording rain-gauges, but it is probable that isolated showers occurred. The weather was generally noted as dull or cloudy at stations in the rear of the storm; it did not become fine until some considerable time after the storm centre had passed. Very few temperature records are available for this part of the trajectories. We find, however, that the readings during the last few steps are in all cases several degrees higher than those met with near the minimum of pressure, so that we must assume that a slow rise was taking place. The final steps of L lie over the Western part of the Channel, and here we find the temperature increasing from about 43° near Falmouth at 4 a.m. to 47° at Jersey at 8 a.m.

In the case of trajectories such as L, M, and N, which form large loops, there is no reason for supposing that we are not dealing with substantially the same air throughout, though doubtless some loss, due to ascent, occurred in the early stages and most probably some gain from descending air in the later ones. But in the case of D and E this is not so; the steps 15–17 in D and 19–21 in E (shown dotted in the diagrams) lie within the region of light and variable breezes near the centre of the storm, and it is probable that the apparent continuity shown in the diagrams had no real existence. The portions 7–15 and 7–19 of these trajectories are of the type to which A, B, and C belong. They end in the storm centre, *i.e.*, the air composing them rises from the surface of the earth.

The parts 17–9 and 21–9 represent different air. This point will be more fully discussed in dealing with the storm of September 10th, 1903 (p. 39).

The trajectories of the third type, O, P, Q, represent a steady flow of air on the Southern side of the storm centre and parallel to its path in a West to East direction. The greatest wind forces experienced during the storm occurred in this Westerly current. The velocities remained nearly constant at about 40 to 45 miles per hour during the early stages, and decreased somewhat towards morning. We may regard the pressure as remaining approximately constant, as the values for this element, quoted in the Tables, only show small and irregular fluctuations. The highest tempertures, 45° to 48°, experienced in the storm are to be found along these trajectories, the course of which lay, for the most part, over the Ocean. O passed over the Midland Counties during the very early hours of the morning, and here we find the temperature of the air falling to 41° or 42°. The weather seems to have been fair ; rain was not recorded at any station possessing a self-recording rain-gauge.

The determination of the regions in which air is ascending or descending by the changes in size of areas included by lines joining synchronous points on the trajectories naturally presents some difficulties. Small differences in the direction and velocity of the winds used in constructing the trajectories, make very large differences in the areas, so that the results become untrustworthy. Using the trajectory values as drawn, Figs. 12 and 13, pp. 32, 35, are attempts to trace the changes which take place in two areas, one situated in front of the storm, the other in its rear. In order to avoid confusion, only the initial and final stages are shown in the diagrams ; the trajectories are indicated by means of dotted lines.

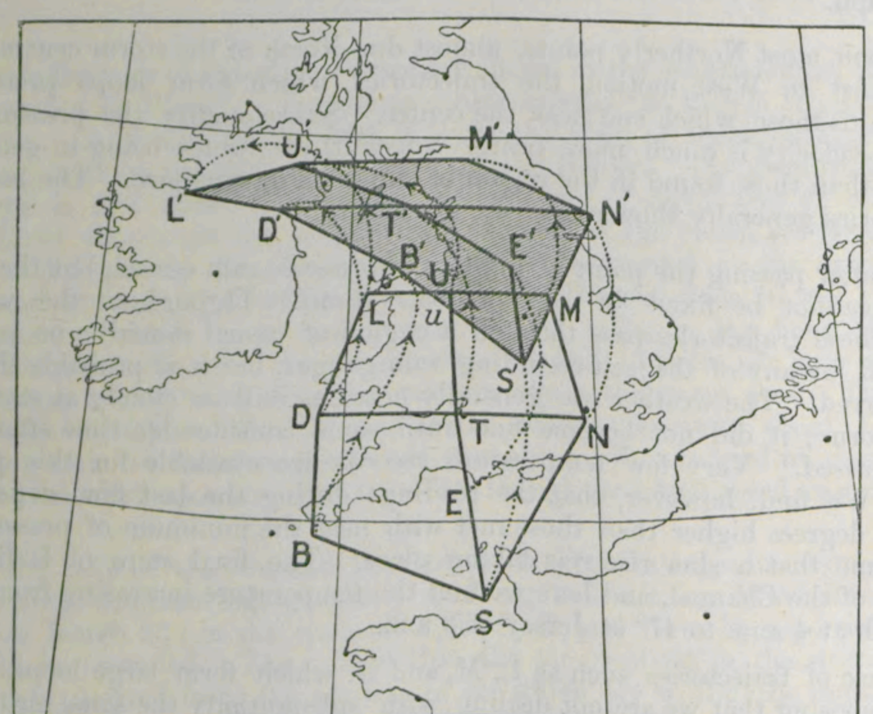


FIG. 12.—Changes of area in front of the storm of March 24–25, 1902.

The following Tables give the areas of these rectilinear figures at successive epochs as measured by a planimeter, and the ratios of corresponding areas for successive intervals.

AREAS OF RECTILINEAR FIGURES AT SUCCESSIVE EPOCHS, AND RATIOS OF CORRESPONDING AREAS FOR SUCCESSIVE INTERVALS.

(*See* Fig. 12, p. 32.)

Epoch.	T N S E.	Ratio.	U M N T.	Ratio.	D T E S B.	Ratio.	L U T D.	Ratio.	Total Area L M N S B D.	Ratio.
7 a.m. ...	2·58		2·72		4·50		2·63		12·43	
		1·01		1·00		0·93		0·64		0·90
11 a.m. ...	2·61		2·71		4·20		1·70		11·22	
		0·75		0·85		0·75		0·96		0·80
3 p.m. ...	1·96		2·27		3·16		1·64		8·99	
		0·99		0·80		0·72		0·84		0·82
5 p.m. ...	1·94		1·82		2·29		1·38		7·43	

(*See* Fig. 13, p. 35.)

Epoch.	L M N E D K.	Ratio.
9 p.m.	5·30	
		0·85
1 a.m.	4·52	
		0·85
5 a.m.	3·85	
		1·00
9 a.m.	3·88	

When dealing with so large an area as that covered by L M N S B D (Fig. 12), it may well happen that the conditions are not the same throughout. Thus, if we confine our attention to the more eastern polygons, T N S E and U M N T, we see from the above Table that their areas remained nearly constant during the interval from 7 a.m. to 11 a.m. Constancy of area corresponds to the case of no vertical motion of air, and hence we should expect fair weather, *i.e.*, an absence of rainfall within the region considered.

The synoptic chart for 8 a.m., March 24 (Plate I., Fig. 1) shows that though the sky was cloudy at the stations near the western edge of the polygons T N S E and U M N T the rainfall area lay considerably further to the Westward. Rain did not commence at Oxford, Berkhamsted, or Kew till after 11 a.m.

As a general rule we should expect to find a sky free of lower clouds as a forerunner of a cyclonic storm which forms one of a series of disturbances moving in approximately similar directions. In an area in front of such a storm we expect to find on its Eastern edge Westerly winds blowing towards a low pressure system in the East, while in the West the advancing depression has caused the wind to back to South or South-east ; a considerable increase in the size of the area considered must consequently be taking place, and this we know means descent of air to the surface from higher levels. If in the case before us we apply the expression for the dilatation given on p. 102, Part IV., B.

$$\frac{u}{p} + \frac{v}{q} + \frac{w}{r}$$

to the triangle Oxford, Yarmouth, Cape Gris Nez on the map for 8 a.m., March 24th, we find that the South wind at Oxford is approximately parallel to the line joining the other two stations, and hence u is zero ; the Westerly winds at Cape Gris Nez and West-south-westerly wind at Yarmouth give positive values for v and w, and hence the dilatation must have a decided positive value. The weather observations show a clear sky in the Eastern portion of the triangle.

Returning now to Fig. 12, the more Western polygons, D T E S B and L U T D during the same interval, 7 a.m. to 11 a.m., show a diminution of area which was very considerable in the case of L U T D. The corresponding weather records may be summarized as follows :—At 8 a.m. the sky was overcast throughout this region, and rain was falling at Scilly just outside it; by 9 a.m. rain was also falling at St. David's Head, and at 10 a.m. it had set in at Falmouth and Rousdon. There was no rain at Southport and Stonyhurst till after 2 p.m., in spite of the fact that these stations lie on the Eastern edge of the area L U T D in which the contraction was a maximum.

Between 11 a.m. and 3 p.m. and also between 3 p.m. and 5 p.m., there was a decrease of area in all parts of L M N S B D. The map for 2 p.m. shows rain at all stations then within the area, but not at Shields, Yarmouth, or London; by 6 p.m. it had become general throughout the North and East of England, and also in Ireland. During the 10 hours between 7 a.m. and 5 p.m. the whole area, L M N S B D, decreased from 12·4 to 7·4, or to almost one-half of its original size.

The regions of ascending or descending air, as indicated by the convergence or divergence of the trajectories, thus correspond in general to regions of rainy or fair weather respectively, in front of the storm, but in its rear the agreement is less satisfactory. Between 9 p.m. and 5 a.m. the area L M N E D K (Fig. 13), diminished in the ratio 0·7. At 9 p.m. the weather over it was generally dull, but the region of steady rain lay further to the East. None of the pluviographs near which the trajectories passed (Falmouth, Berkhamsted, Oxford, Rousdon, and London) registered any precipitation, and we must conclude that rainfall was at any rate discontinuous. During the last four hours, 5 a.m. to 9 a.m., the area remained constant; the state of the sky between 7 a.m. and 9 a.m. in the South-east of England and the adjoining parts of France was recorded either as completely overcast or as partially cloudy (o. and bc.)

For comparing the conditions of motion in this storm with those prevailing in the ideal case of winds of uniform velocity blowing tangentially to circular isobars, the actual motion has been resolved into two components, viz., the motion relative to the centre and that of the centre itself, as suggested on p. 9. The diagram on Plate III. represents the motion relative to the moving storm centre, *i.e.*, the motion as it might appear to an observer who travelled with the storm centre. The method of construction was as follows :—A sheet of tracing paper was placed over the trajectory diagrams shown in Figures 1 and 2, Plate II., and the positions of a set of isochronous points on the trajectories—those for 5 p.m. (marked 17)—were traced on it. To obtain the positions corresponding to any other epoch, the displacements of the air during the interval between 5 p.m. and the epoch in question were compounded with a displacement equal and opposite to that of the storm centre during the same interval. In practice this was done by shifting the tracing paper step by step, and then taking the corresponding points from the trajectory diagrams. Curves were then drawn through the points for successive epochs obtained from the different trajectories.

The distribution of observations of weather with reference to the centre is shown by the letters and symbols marked on the diagram. In order to refer the observations to their appropriate position with regard to the centre, the diagram was placed over the successive synoptic charts, in such a way that the centre coincided with the centre of the closed isobars for the particular chart, and the direction was properly adjusted. The observations entered on the map were then traced on to the diagrams. The observations of rainfall were, for the most part, found to lie within a well defined portion of the diagram, and to render this more obvious, a curve was drawn so as to include all observations of rainfall, and the enclosed area was shaded over. The occasional rainfall observations met with outside this region probably indicate passing showers.

For the ideal case described above, the curves of motion with reference to the centre would be conic sections of eccentricity equal to the ratio of the velocity of the storm centre to that of the winds. In the case most nearly corresponding to the present storm, the eccentricity of the conics would be ·91. For the purpose of comparison portions of two ellipses of this eccentricity have been drawn on Plate III.; they are in

close general agreement with the curves shown in the figure. The trajectories O, P, and Q of Fig. 2, Plate II., which represent the steady drift from West to East on the Southern side of the storm centre, have given rise to the curves similarly lettered on Plate III. In the ideal case the planetary velocities in this part of the diagram would be very small, and it is not surprising to find the curves obtained from the actual observations showing great irregularities. For the special case in which $e = 1$, *i.e.*, when the wind velocity is equal to that of the storm centre the conics become parabolas, and the curves corresponding to O, P, Q become points on the axis.

If we assume that the internal structure of the storm did not change, we may regard the curves of Plate III. as stream lines of air relative to the storm centre, and use them to examine the amount of convergence or divergence in different parts of the diagram. For this purpose a number of circles equal in area to the specimen shown in red were drawn in convenient positions on the diagram and traced back to the positions they would have occupied two hours earlier. This was accomplished by setting off along the curves, from all points where they cut the circles, distances equal to a step of two hours' duration, and then drawing a closed curve through the points so found.

The areas of the closed curves were measured with a planimeter and yielded the following results :—

Circle; Centre denoted by a cross and Red Letter.	Area of Circle.	Area of corresponding figure two hours earlier.	Nature of change during the Two Hours.	Ratio of areas.
S	12·6	14·6	Decrease.	0·86
T	12·6	10·0	Increase.	1·26
U	12·6	11·8	Very little change.	1·07
V	12·6	10·5	Increase.	1·20
W	12·6	12·3	Very little change.	1·02
Y	12·6	12·4	Very little change.	1·01

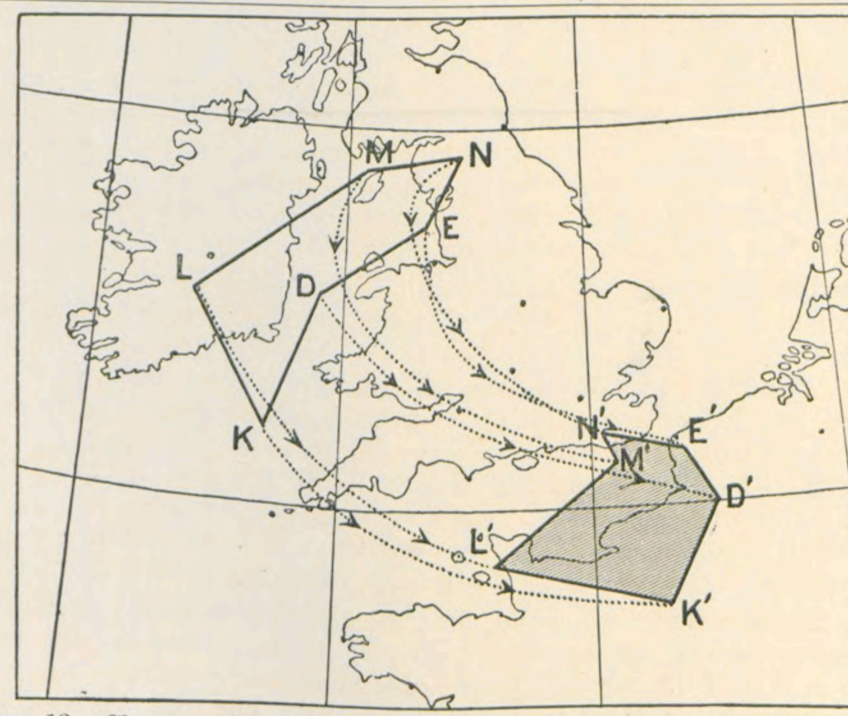
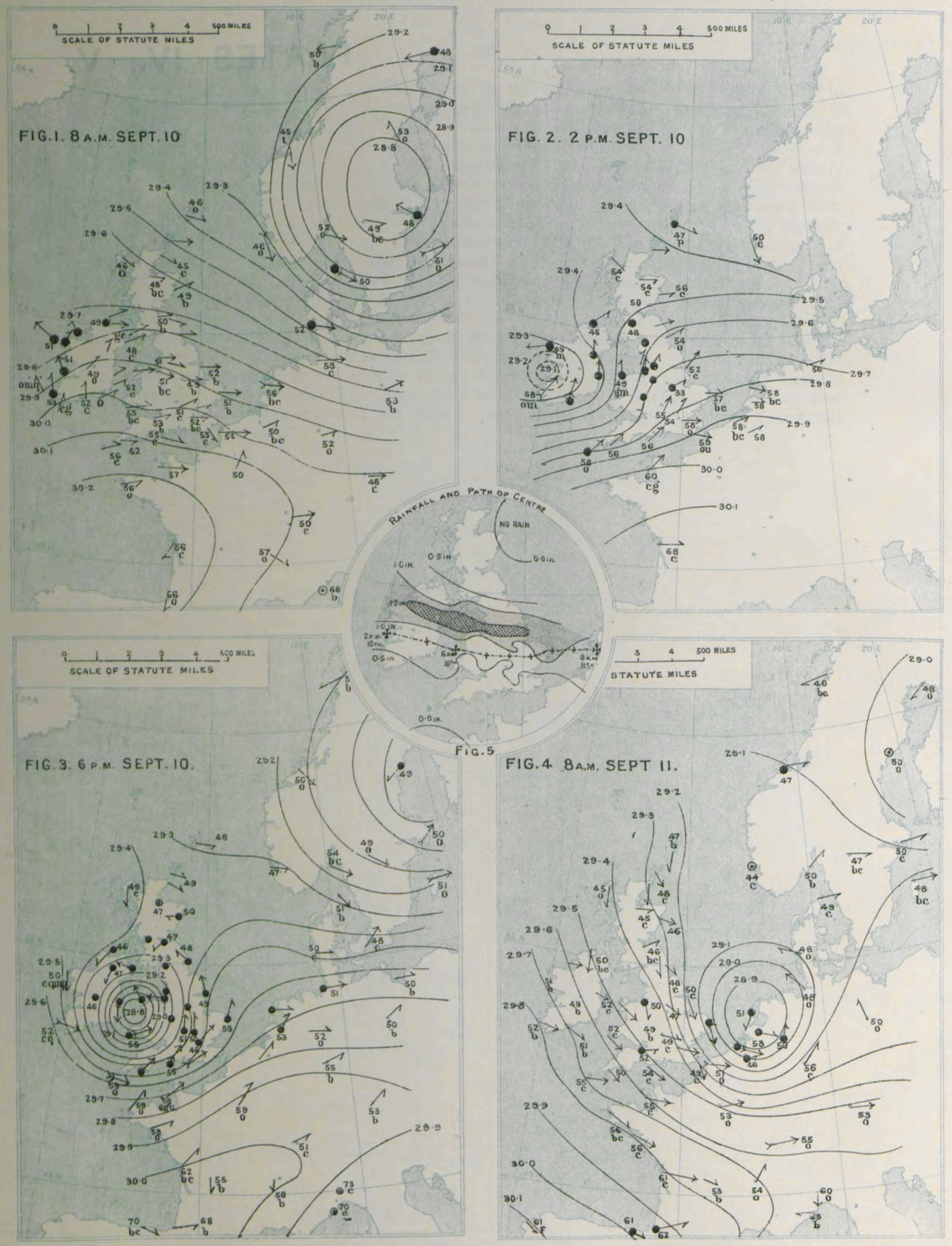


FIG. 13.—Changes of area in the rear of the storm of March 24–25, 1902.

These figures point to ascent of air in the region covered by the circle S, and to descent near T and V; over the remainder of the storm the resultant vertical motion is small. The general agreement between these results and the observations of weather may be pronounced satisfactory in that the circle S lies almost entirely within the region of continuous rainfall shaded over in the figure, while the circles T, V, W, Y lie mainly outside it, and the symbols b, bc are of frequent occurrence in them. The circle U, which lies mainly within the rainy region, appears to form an exception, but, as a matter of fact, the amount of rainfall over the greater part of its area was very small. For the purpose of comparison the average rainfall over a series of strips 50 miles wide on either side of the storm path has been calculated from the rainfall data, summarised in Fig. 5, Plate I., and the amounts so obtained have been entered along the vertical line on the right of Plate III. It will be seen that the heaviest rainfall occurred on the left-hand side of the storm path, though this fact is not as prominent in this case as in some others to be discussed below. We shall see in these that there is good reason for supposing that rain formed by the ascent of air on the southern side of the path is carried forward by the upper winds and subsequently drops to the surface through the lower air, which has no direct share in supplying the moisture. This may afford an explanation of the apparent contradiction between the increase of area of the circle U, and the fact that rain was falling throughout the greater part of it.

PLATES IV., V.

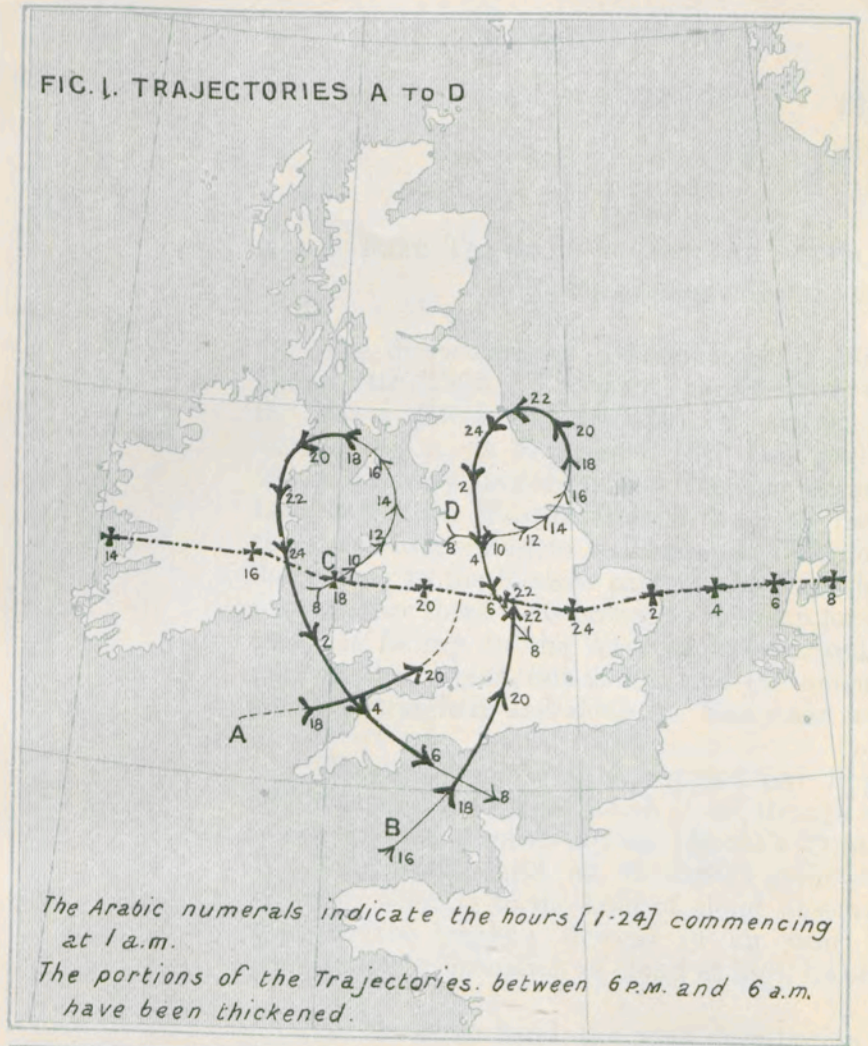
No. 2. CIRCULAR STORM OF SEPTEMBER 10–11, 1903.

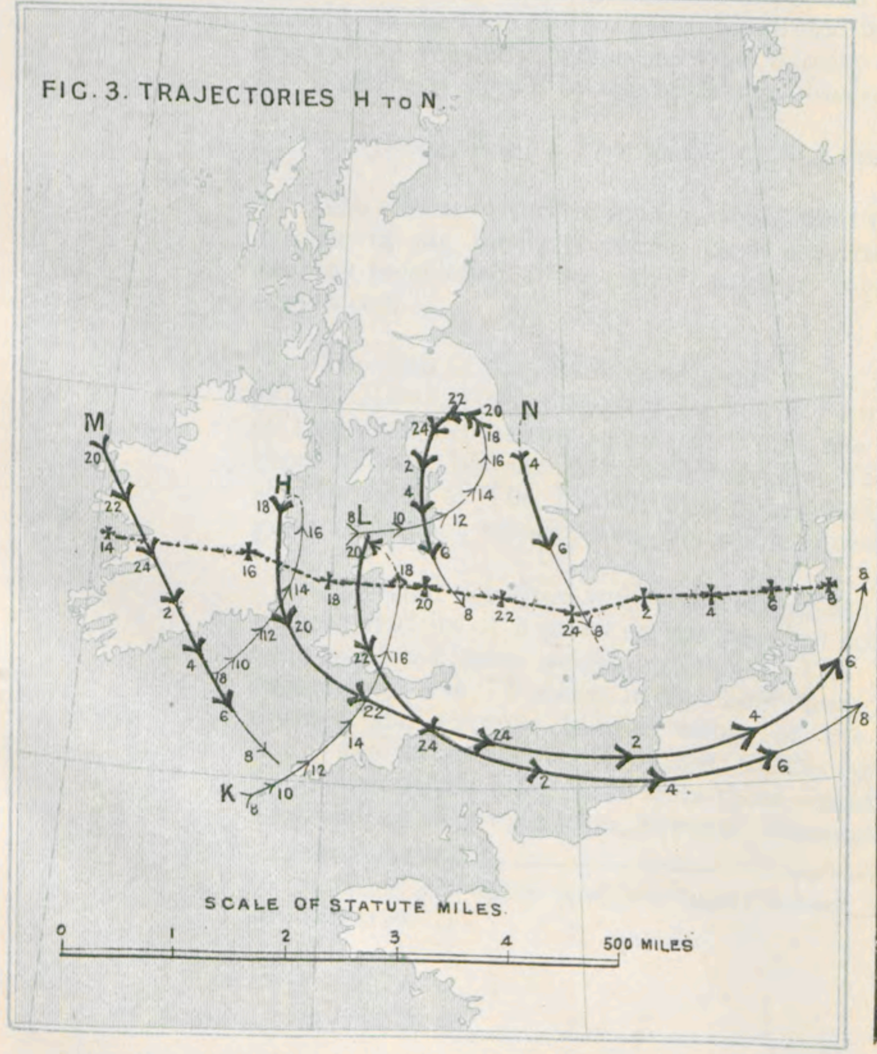


ISOBARS, WINDS, TEMPERATURE, AND WEATHER.

The mark ● shows that rain was falling at the hour of observation.

TRAJECTORIES OF AIR. SEPTEMBER 10–11, 1903.





Hours.	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	Hours.
	A				B				C				D				
8									14	9·91	(52)	(c)	20	9·90	52	bc	8
10									22	9·83			17	9·86			10
12									20	9·76		o	14	9·80			12
14									20	9·56	(49)	r	12	9·70			14
16					44	9·75	(59)	(o)	21	9·35		r	15	9·63			16
18	60	9·10	(55)	r	52	9·42	55	r	25	**9·26**	47	r	18	9·42	(49)	(r)	18
20	50	8·95		(n)	40	9·03	54	n	25	9·35		p	19	9·25			20
22						8·88	(50)	(r)	31	9·41		n	20	**9·19**			22
24									40	9·48			25	9·25		(r)	24
2									40	9·43			30	9·25	45	(n)	2
4									40	9·50	(49)		25	9·31			4
6									35	9·53		c	30	9·40			6
8									30	9·55		c	30	9·40	47	c	8
	E				F				G				H				
8	15	9·92	50	(r)	20	0·03	55	bc	14	0·09	55	c	15	0·04	(53)	(n)	8
10	20	9·70		(r)	20	9·98			16				15	9·87			10
12	20	9·52		(r)	20	9·90	(55)	(n)	19	0·02			19	9·72	(54)	r	12
14	30	**9·24**	49	r	25	9·72		(r)	25	9·88	(56)		21	9·45	(53)	r	14
16	45	9·45			25	9·55		r	25	9·67	55	n	25	9·01		r	16
18	40	9·50	(51)	(c)	25	9·15	47	r	25	9·51	(53)	r	50	**8·95**		r	18
20	40	9·56	·	(bcp)	35	**9·02**	(46)	r	25	9·15		(r)	50	9·22			20
22	40	9·60			50	9·18		(p)	28	**8·95**	(48)	r	52	**9·30**	(47)	p	22
24	40	9·66	(52)	(n)	50	9·29			35	9·05			60	9·15		c	24
2	40				50	9·31			35	9·03	(46)	r	60	9·15			2
4	40				40	9·35		c	40	**9·08**			45	9·02	(50)		4
6					30	9·38			45	9·05			40	8·92		(r)	6
8					20				35	9·04	46	r	25	8·85	52	r	8
	K				L				M				N				
8	10	0·15	56	c	22	9·93	52	c									8
10	18	0·07			20	9·82	53										10
12	22	9·97	56	n	18	9·75	(50)	(r)									12
14	30	9·75		r	18	9·64		(r)									14
16	35	9·35		r	18	9·50											16
18	35	**8·90**	56	r	12	9·35	48	r									18
20	50	9·08			7	9·30	44	r	25	9·55							20
22	50	**9·20**			13	**9·28**			25	9·58							22
24	50	9·20		c	19	9·34			25	9·61							24
2	50	9·18			21	9·33			25	9·61							2
4	50	9·15			20	9·37	48	n	25	9·61			31	9·18		r	4
6	41	9·05	(50)	(r)	25	9·41			25	9·65			38	9·18		(r)	6
8	31	9·04	(48)	r	25	9·46	49	b	25	9·68			38	9·20	48	(r)	8

The Trajectories are referred to by letters A to N. The Tables give the Wind Velocity (V), the Pressure (P), the Temperature (T), and the Weather (W) at the points on the Trajectories corresponding with the hours named in the margin. Figures in brackets are conjectural. The symbol n indicates the absence of rainfall as shown by self-recording rain gauges.

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No. 2. Fast Travelling Circular Storm (Plates IV., V., and Fig. 1, Plate VI.)
8 a.m. September 10 to 8 a.m. September 11, 1903.

The disturbance of September 10th, 1903, was in many respects similar to that of March 24th, 1902. The main characteristics are shown in Figs. 1 to 4, Plate IV. Like the March gale it was preceded by another disturbance which, in this case, was a deep one; at 8 a.m. on September 10th this preliminary disturbance was over Scandinavia and a Westerly air current was blowing towards it over the greater part of the British Isles, but in the West of Ireland the wind had already backed to the South in front of the disturbance now to be discussed. We may therefore infer that air must have been descending in the Eastern part of the British Isles, and we should consequently expect fine weather there. Reference to the map for 8 a.m. September 10th (Fig. 1) shows that rain was falling in the West of Ireland, and that the sky was overcast over the greater part of that island, but in England the amount of cloud diminishes towards the East, till at Nottingham and along the East coast we find a cloudless sky.

The observations thus support our hypothesis in a general way, but it must be admitted that they show much cloud, though no rain, over the East of Ireland, an area in which the wind observations (Roche's Point, S.W., 1; Pembroke, W., 5; Holyhead, W., 5); would lead us to expect great descent of air. Unfortunately we possess no information as to the kind of cloud observed, so that we can form no estimate of its approximate height; descent of air near the surface is not incompatible with the persistence or formation of cloud at high levels.

On the other hand, the wind distribution over central England affords an excellent example of the type of divergence illustrated in Fig. 10 on p. 18. The wind direction was everywhere Westerly, while the wind velocity was distinctly greater in the East than in the West, as is shown by the following observations :—

Holyhead, W., 5; Pembroke, W., 5; Spurn Head, W., 7; Yarmouth, W., 6.

The effects of surface friction would tend to bring about the opposite result. Copious descent of air must, therefore, have occurred in the region lying between the four stations mentioned above; the "weather" observations show good agreement with this supposition.

The path of the disturbance about to be considered was very similar to that of the gale of March, 1902, though it lay slightly further South. The absolute rate of motion of the storm centre was rapid; at 2 p.m. the minimum lay off the West coast of Ireland, about midway between Blacksod Point and Valencia, while at 8 a.m. next morning it was slightly East of The Helder, thus it travelled a distance of 630 miles in 18 hours, which gives an average velocity over the whole course of 35 miles per hour.

The wind velocities were also very great; in the Southern and Western parts of the storm, velocities of 8 or 10 on the Beaufort scale were general and extremes of 11 or 12 were reported from several stations. The highest velocity recorded by a Robinson anemometer was 72 miles in the hour, from 7.30 to 8.30 p.m. at Scilly.* Assuming average and extreme hourly values of the wind velocity of 45 and 72 miles per hour, the ratios of these values to the velocity of the storm centre are 1·3 and 2·0, values which differ little from those already found for the gale of March 24th, 1902. The velocity of propagation, however, diminished considerably after 6 p.m. The distance

* Factor 3.0 which is approximately correct. The anemometer at this station is not of the standard type.

between the position of the storm centre off Holyhead at this epoch and its position at 8 a.m. next morning is 425 miles, which leads to a velocity of only 30 miles per hour. Using this value, the ratios of the velocity of wind to that of the centre become 1·5 and 2·3 respectively. The storm must consequently be looked upon as a relatively slower traveller than the one discussed above, in spite of the fact that its actual speed was considerably greater.

The trajectories of this gale, which have been drawn from hourly maps, are shown in Figs. 1, 2, 3, Plate V., and the corresponding changes of velocity, pressure, temperature and weather are given in the Tables accompanying them.

The main features of the flow of air which they reveal are very similar to those described in the case already dealt with, but some important differences are shown. In both cases air is taken in almost exclusively from the South and South-west, and only in the extreme rear of the storm do we find indications of a supply from the North (trajectories M and N, Fig. 3). As the trajectories of the gale now under discussion are commenced at a greater distance from the approaching centre than those of the March 1902 storm, their initial steps show a West to East motion over the Eastern part of our islands, but subsequently the advance of the depression causes the wind to back and the air takes a more Northerly direction.

Two of the three types of trajectory described above can be again identified. A and B (Fig. 1) are representatives of the type which ends in or near the storm centre, while the remaining trajectories bear a more or less close resemblance to the looped curves of Figs. 1 and 2, Plate II. Throughout the course of A and B, and until the most Northerly points on the looped trajectories are reached the changes in the meteorological elements (*See* Tables, Plate V.) are very similar to those already described for the corresponding trajectories in the March gale. Wind velocity increases while pressure and temperature decrease and sooner or later rain sets in in all cases.

The most Northerly points on the looped trajectories lie almost due North of the instantaneous positions of the storm centre. They are points of minimum pressure in all cases. After they have been passed the pressure of the air commences to increase briskly and a sudden and very considerable increase of velocity is shown in most cases. The latter feature was much less noticeable in the storm of March 24th, 1902. The subsequent changes of velocity are less regular, in fact it is probable that the variations in the numbers quoted in the tables on Plate V. are due as much to difficulties of correlating the wind estimations correctly as to actual meteorological changes.

There are unfortunately very few observations of weather available for the parts of the trajectories representing the flow of air towards the South, and we must have recourse to indirect evidence for information on this point. The trace of the self-recording rain gauge at Southport shows that heavy rain ceased at 10.15 p.m., when the centre of the disturbance was about 100 miles South-east of the station, though light rain continued till 3.30 a.m. A similar sequence of events seems to have occurred at Dublin, where the observer notes that light rain continued till 8.30 p.m. after heavy rain had ceased as early as 3.30 p.m. Occasional observations during the night are available from lighthouses, lightships, &c.; these generally give the weather in the rear of the storm as "cloudy" and showers are frequently mentioned. We may therefore infer that heavy rain continued for a short time after the air describing the trajectory had passed the point of minimum pressure, but that it soon became light and then ceased. From the maps for 8 a.m. and 9 a.m. on September 11th we can further infer that those trajectories which passed well in the rear of the storm, such as C, L, M, and the last few steps of D, entered a region of clear sky.

The most striking difference between the trajectories now under consideration and those of the gale of March 24th, 1902, is the absence of the Westerly current parallel to the path of the storm on its Southern side. The strong Westerly gales experienced in the English Channel during the night of Sept. 10th to 11th did not form part of a steady

flow parallel to the storm path (*see* trajectories O, P, Q, Fig. 2, Plate II.). When traced backwards they are found to take their origin in the Northerly gales which blew immediately in the rear of the storm centre (trajectories G, H and K), and when continued forward they approach the storm centre a second time. As this occurs the character of the changes of the meteorological elements along them alters. A point of maximum pressure, which appears also to be a point of maximum velocity, is reached to the South of the storm centre where the direction of motion is from the West; subsequently pressure and velocity both decrease, the motion becomes directed towards the North-east as the air gradually approaches the storm centre, and a second region in which rain is falling is entered. In the case of G there is no evidence to show that rain ceased during the transit, after once it had commenced in the first region of decreasing pressure.

The origin of the Northerly gale represented by steps 18-20 and 20-22 of trajectories H and K respectively, is an important and interesting question. Considerations of temperature indicate clearly that in trajectories such as these the air which approaches the centre from the South is different from that receding from it as a Northerly wind. There is no thermograph at Kingstown or Holyhead so that we cannot determine whether any sudden changes of temperature took place. The reading at Holyhead at 6 p.m. was 56°; if we regard this as typical of the portion of the trajectory K representing a flow towards the North (steps 8 to 20), it shows a marked contrast to the air in the flow from the North (steps 20 to 24) which was probably at a temperature of between 45° and 48°. The maps for 6 p.m. and 9 p.m. show that readings between these limits were general close in the rear of the storm. We are therefore forced to the conclusion that the air of the Northward flow of the trajectories H and K rises from the surface of the earth near the storm centre, and that it is not the same as that taking part in the flow towards the South represented by the later steps of the trajectories. The apparent continuity of the curves shown in the diagrams does not represent the motion of the same sample of air.

The records of the anemometers at Holyhead and Kingstown show the customary light and somewhat variable winds in the immediate neighbourhood of the storm centre, but shortly after the passage of the latter, a strong Northerly gale of velocity 50 miles an hour (factor 2·2) set in abruptly. There are two possible sources of this air; either it came as a descending current from the upper regions of the atmosphere or else there was great convergence of the surface air immediately behind the storm centre. Unfortunately we have not observations enough to enable us to draw trajectories with sufficient accuracy and sufficiently close together to decide the question, which is one of fundamental importance in dynamical meteorology, by the method of measuring the changes in size of a selected area. The fact that rain continued at Dublin for over two hours after the Northerly gale set in at the neighbouring station of Kingstown, speaks against the former view, but this evidence is not conclusive; cases will be given (pp. 51, 57, 62) in which there is good reason for supposing that rain formed in the upper regions of the atmosphere fell to the ground through a descending surface current, and, at the conclusion of this section, some further evidence will be put forward in favour of the view that descent of air occurred in the immediate rear of the storm centre.

Fig. 1, Plate VI., which represents the motion of the air relative to the moving storm centre has been constructed from the trajectories of Figs. 1, 2, and 3, Plate V., in the same manner as the corresponding diagram (Plate III.) for the gale of March 24th 1902. As the ratio of the average wind velocity to the speed of the storm centre during the interval from 6 p.m. September 10th to 8 a.m. September 11th was 1·5, the eccentricity of the ellipses of the corresponding ideal case would be ·67. Ellipses of that eccentricity are shown in red in the figure for comparison with the actual curves. The agreement between the two is even more striking in the present case than in the one discussed above, as the trajectories G, H and K which approach the storm centre a second time give rise to curves which, when taken in conjunction with those obtained from A and B, suggest closed curves of a general elliptical shape.

The convergence over the storm area, examined in a manner similar to that described above on page 34 has given the following results :—

Circle; Centre denoted by a cross and Red Letter.	Area of Circle.	Area of corresponding figure one hour earlier.	Nature of Change during the Two Hours.	Ratio.
P	7·1	10·8	Decrease.	·65
Q	7·1	8·3	Decrease.	·85
R	7·1	7·8	Very little change.	·91
S	7·1	7·5	Very little change.	·95
T	7·1	6·2	Increase.	1·1
V	7·1	6·3	Increase.	1·1

From these figures it is clear that the main ascent of air took place in the region covered by the circles P and Q ; or rather as the circles Q and R overlap to a large extent, and as the change in the area of R is only slight, we may say that the main region of ascent was confined to P and the Southern part of Q, *i.e.*, to the S.E. quadrant of the storm and to a limited region on the Northern side of the path.

It was pointed out by Dr. H. R. Mill, in a paper read before the British Association at Cambridge, in 1904, * that the region of heaviest rainfall usually lies on the left-hand side of the storm path, when travelling with the storm ; in this case we should, therefore, expect to find it on the North of the path and so it turns out to be. The distribution of rainfall measured on the morning of September 11th, is shown on Fig. 5, Plate V., and, from the data there summarised the average fall over strips 50 miles wide, running parallel to and on either side of the path, has been calculated as before. The results obtained have been entered along the right-hand margin of Fig. 1, Plate VI. From these it will be seen that the strip which experienced the heaviest rain is the one which extends from 50 to 100 miles on the Northern side of the path. To reconcile this fact with the convergence effects described above, we are driven to suppose that rain formed by the ascent of air in the South-eastern quadrant of the storm is carried forward by the ascending wind and subsequently drops to the ground through the surface layers of air considerably further to the Northward. The heaviest individual fall of which we have any record was 2·07 ins. at Lligwy, on the Northern coast of Anglesey. † This station lies about 40 miles on the Northern side of the path as drawn from the hourly maps ; the observer there adds a note to say that no less than ·82 inch of rain fell between 5 p.m. and 7 p.m., during which time the disturbance passed by on the Southern side of the station.

In the rear of the storm the circles T and V show an increase of area, *i.e.*, descent of air was occurring in these regions, a fact which is in general agreement with the weather observations entered on the diagram. It should be noticed that the area corresponding at the earlier epoch to the circle T, lay in the critical region immediately behind the storm centre and thus, so far as this evidence is concerned, it favours the view that this is a region of descending air.

* Symons' Meteorological Magazine, Vol. XXXIX., page 161.
† Symons' Meteorological Magazine, Vol. XXXVIII., page 159.

MOTION OF AIR AND DISTRIBUTION OF WEATHER AND RAINFALL RELATIVE TO CENTRE OF LOWEST PRESSURE.

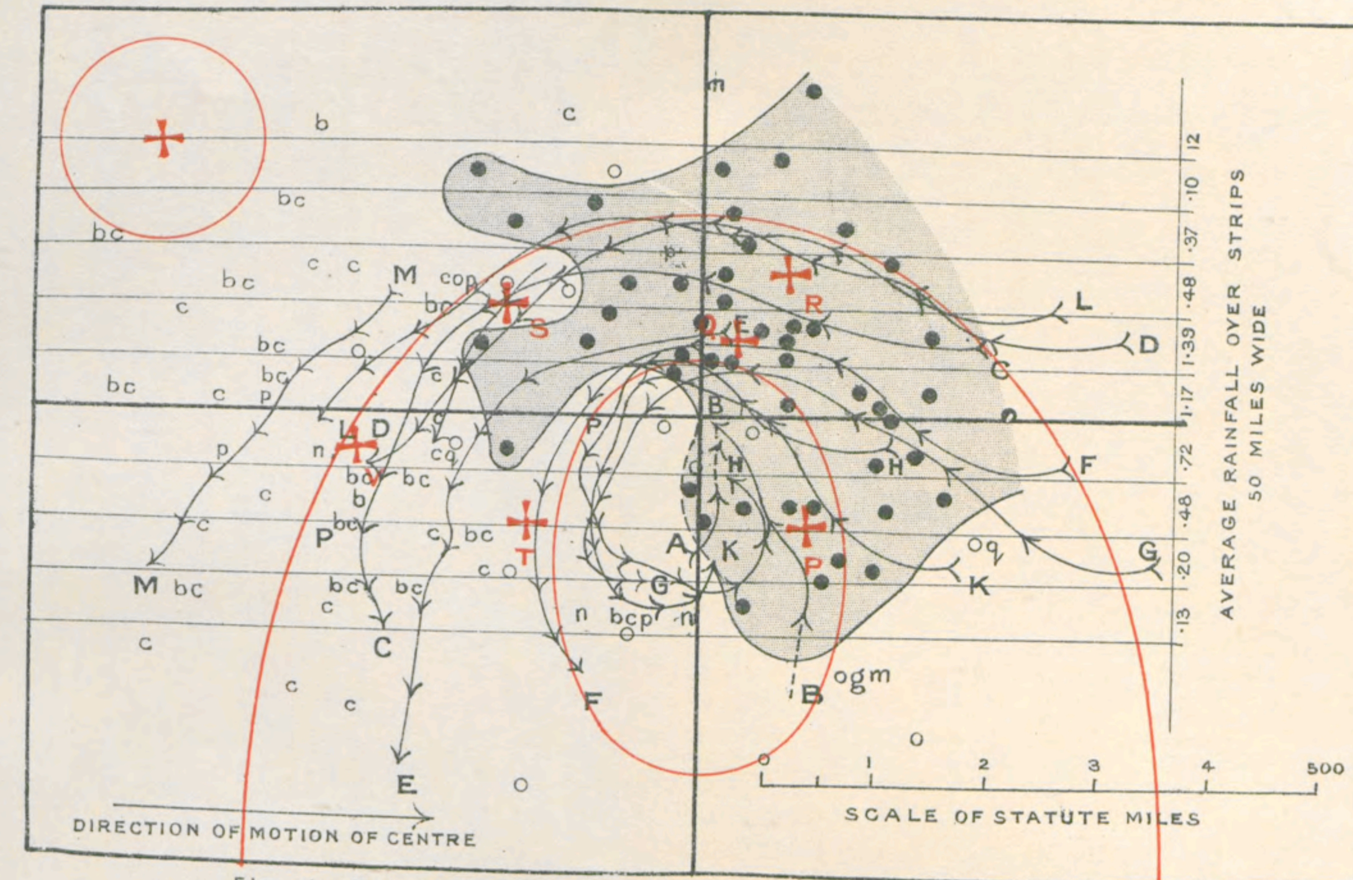

Fig. 1. No. 2. CIRCULAR STORM OF SEPTEMBER 10–11, 1903.
Constructed from Diagrams of Trajectories on Plate V.

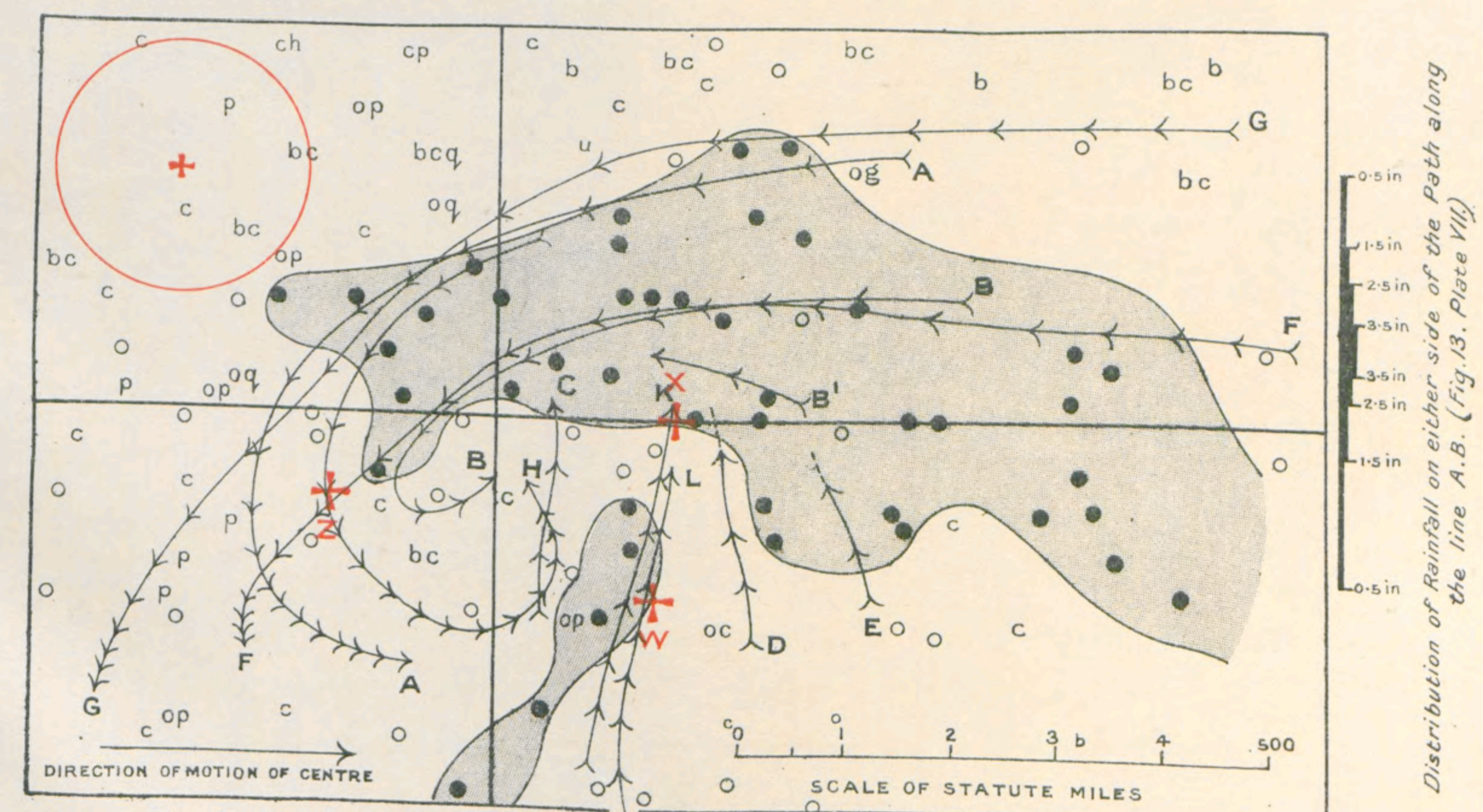

Fig. 2. No. 3. SLOW TRAVELLING DEPRESSION OF NOVEMBER 11–13, 1901.
Constructed from the Diagrams of Trajectories. Figs. 2 and 3 Plate VIII.

The red lines in Fig. 1 show the paths of air with reference to the centre for a perfectly circular storm of uniform wind, the centre of which moves with a velocity equal to 0·67 X velocity of wind.
For further explanations see notes on Plate III. and pp. 34, 40 and 44.

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PLATE VII.

No. 3. 6 p.m. NOVEMBER 11 to 6 p.m. NOVEMBER 13, 1901.

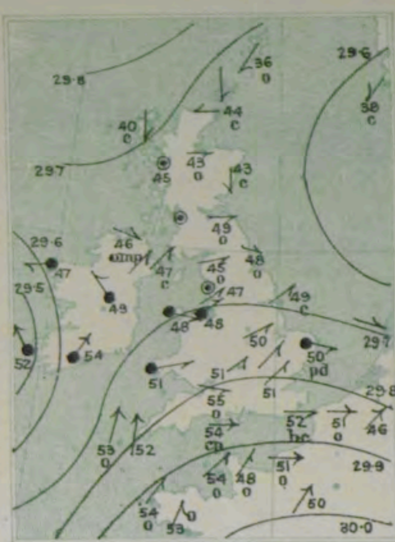
Fig. 1.—6 p.m. (18) November 11

Fig. 2.—9 p.m. (21) November 11.

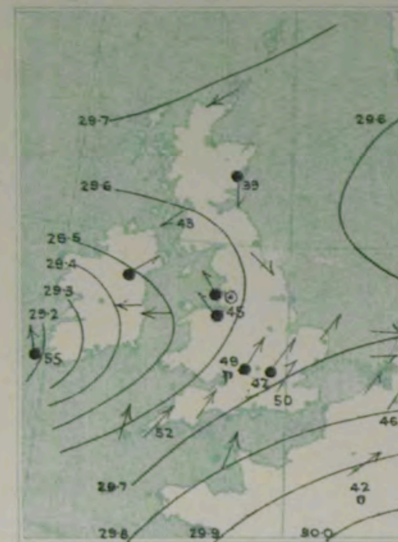
Fig. 3.—Midnight (24) November 11.

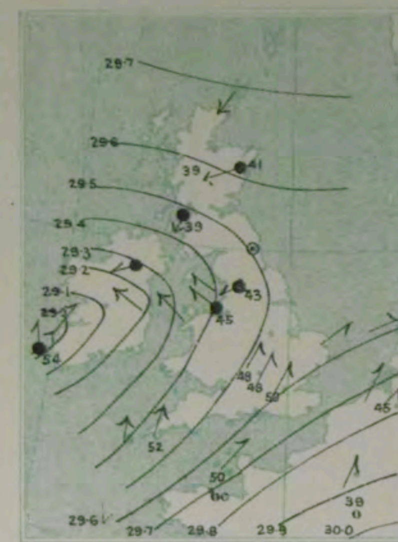
Fig. 4.—4 a.m. November 12.

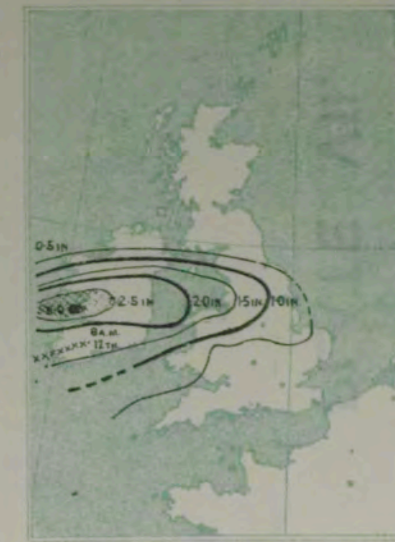
Fig. 5.—Rainfall November 12.*

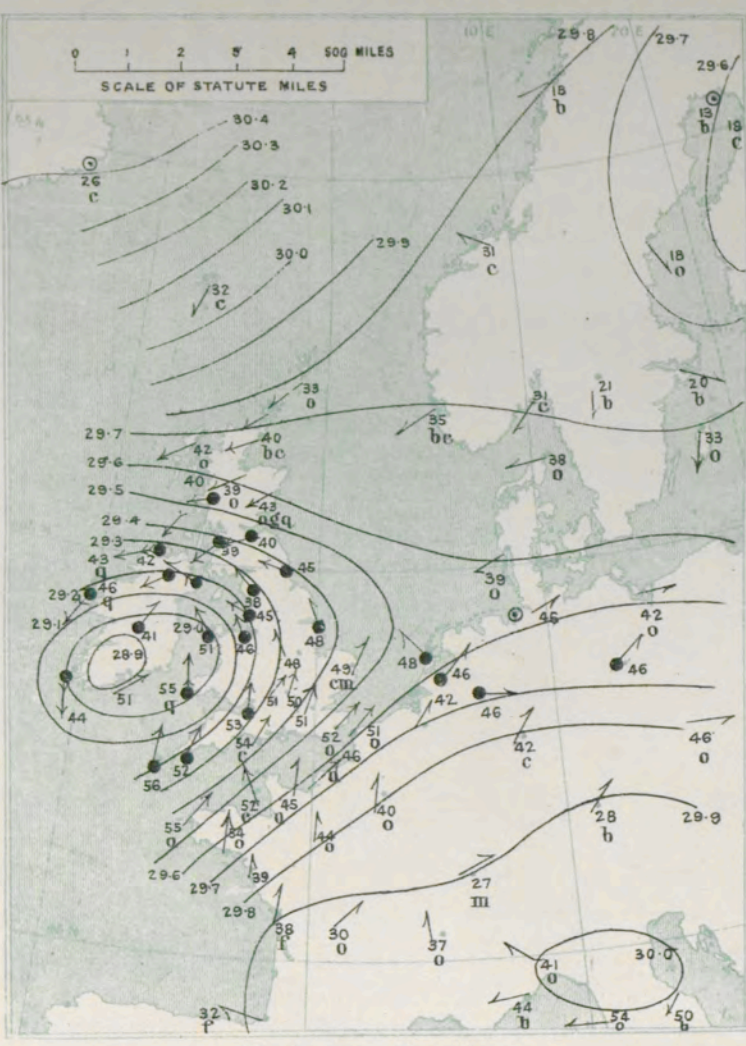

Fig. 6.—8 a.m. November 12.

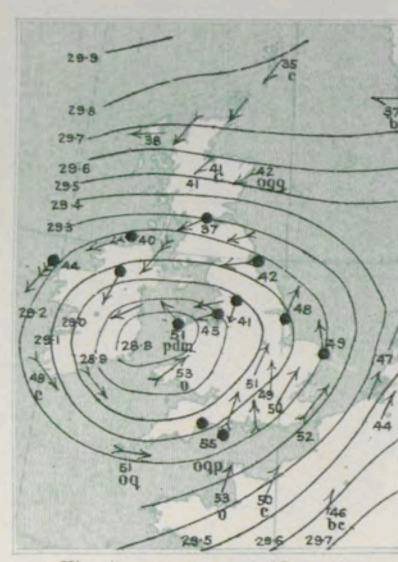
Fig. 7.—2 p.m. (14) November 12.

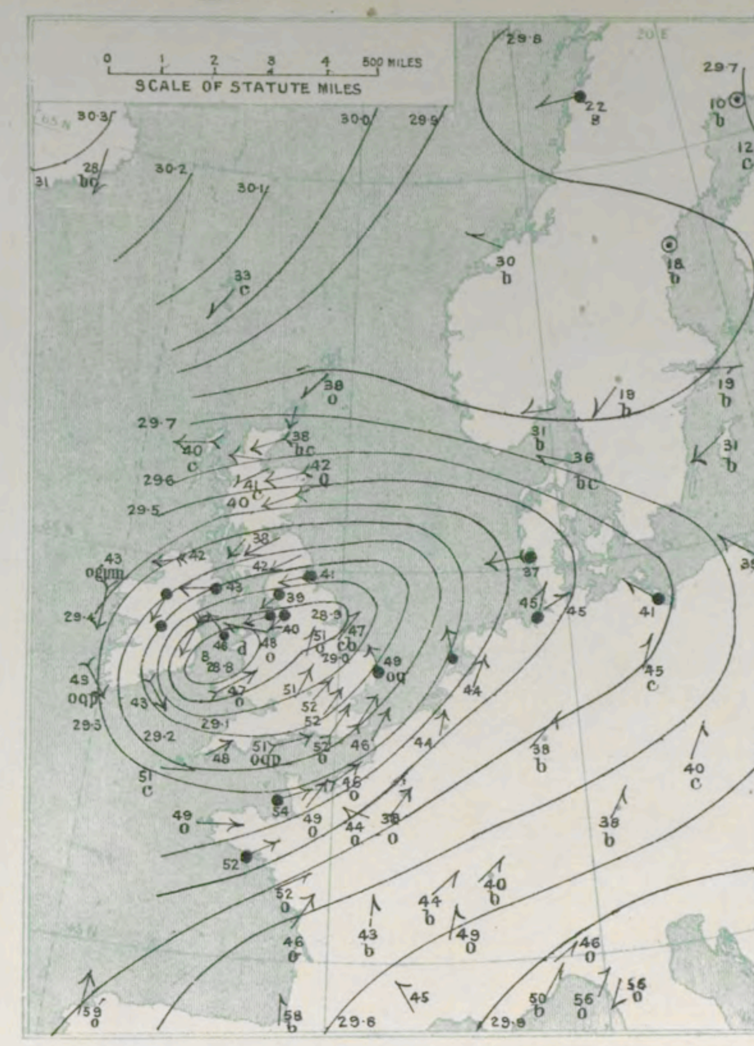

Fig. 8.—6 p.m. (18) November 12.

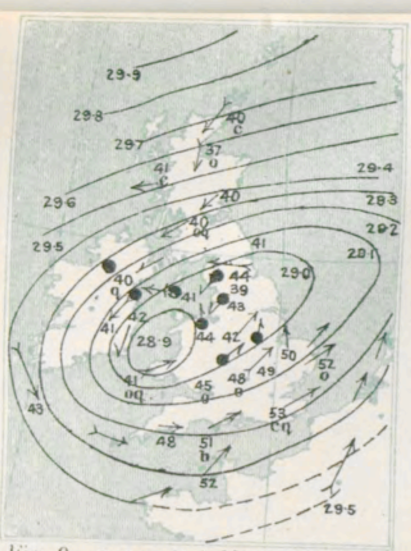
Fig. 9.—9 p.m. (21) November 12.

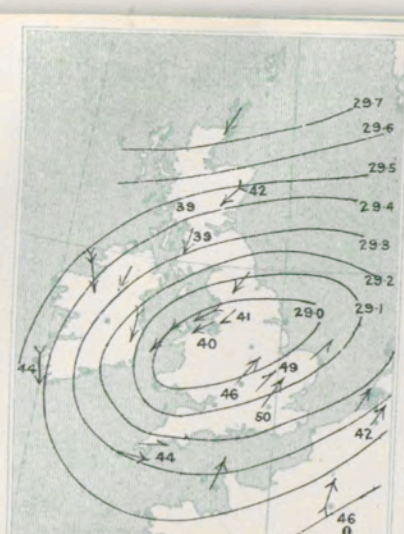
Fig. 10.—Midnight (24) November 12.

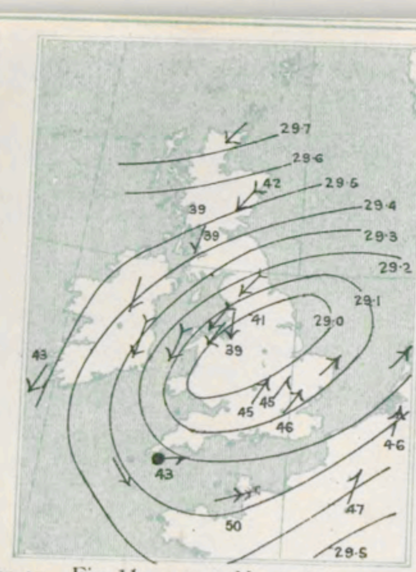
Fig. 11.—4 a.m. November 13.

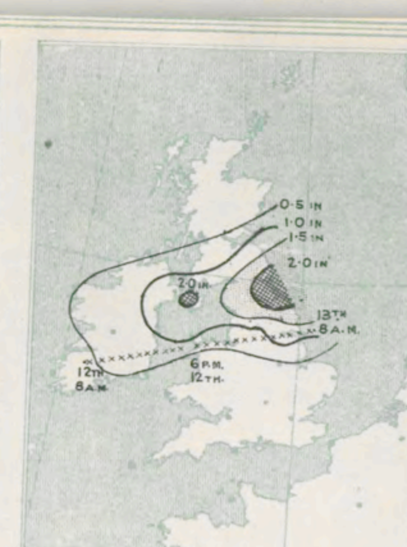
Fig. 12.—Rainfall November 13.*

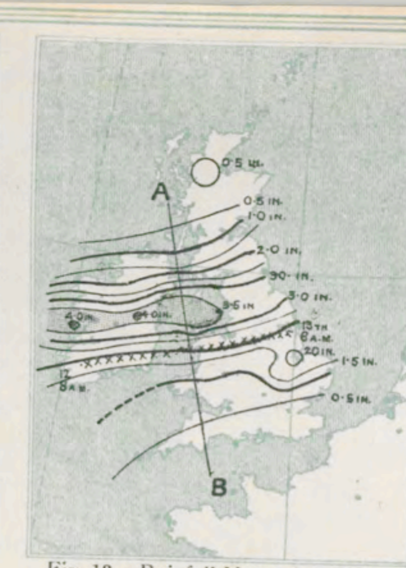

Fig. 13.—Rainfall November 11-13.*

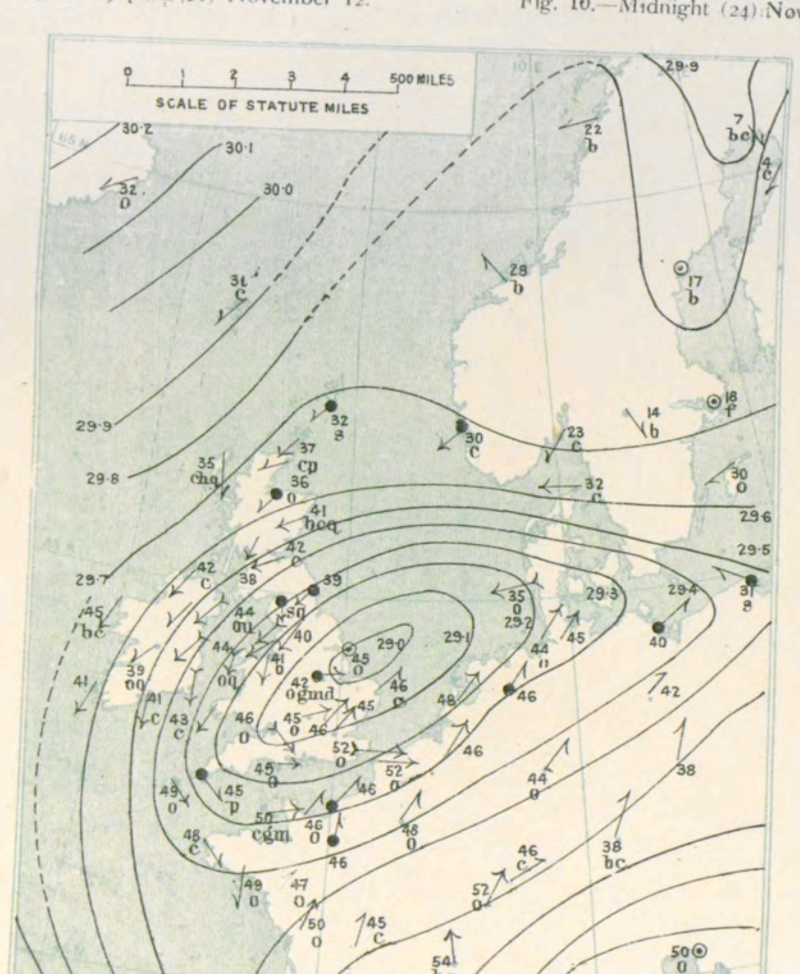

Fig. 14.—8 a.m. November 13.

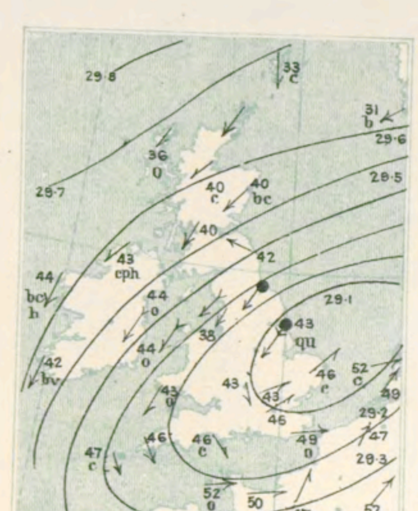
Fig. 15.—2 p.m. (14) November 13.

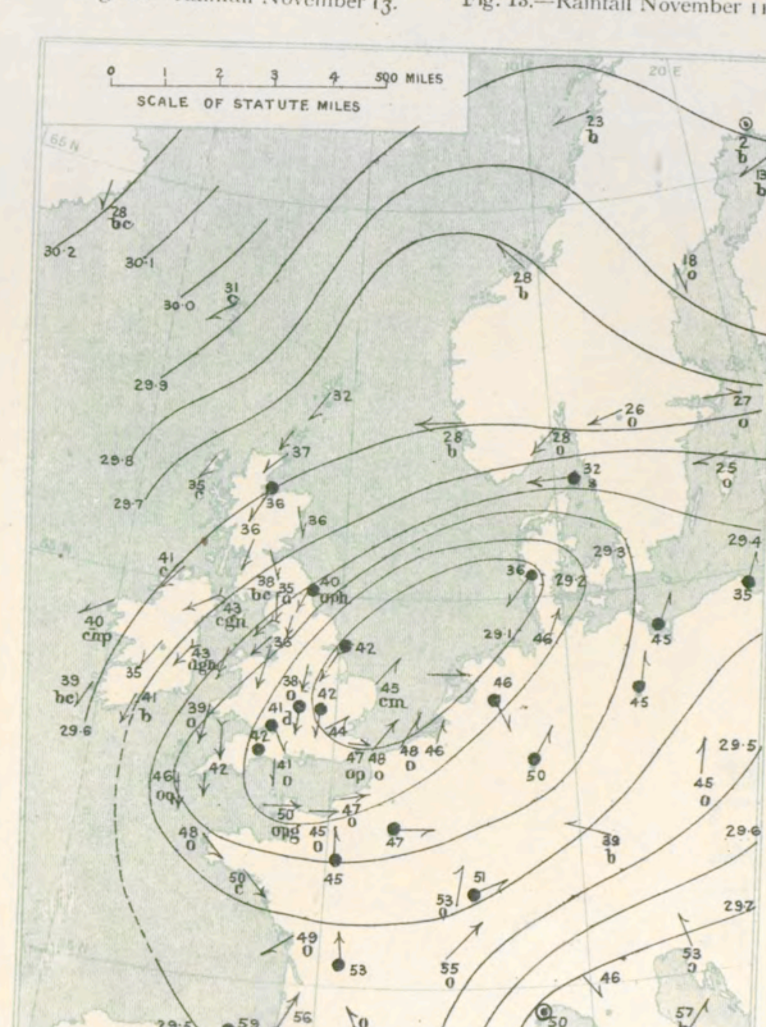

Fig. 16.—6 p.m. (18) November 13.

* *The rainfalls charted in Figs. 5, 12, and 13 are the amounts measured at 8 a.m. and 9 a.m. on the dates given. For reference to line* **A B** *Fig. 13, see Plate VI. Fig. 2.* ● *indicates that rain was falling at the hour of observation.*

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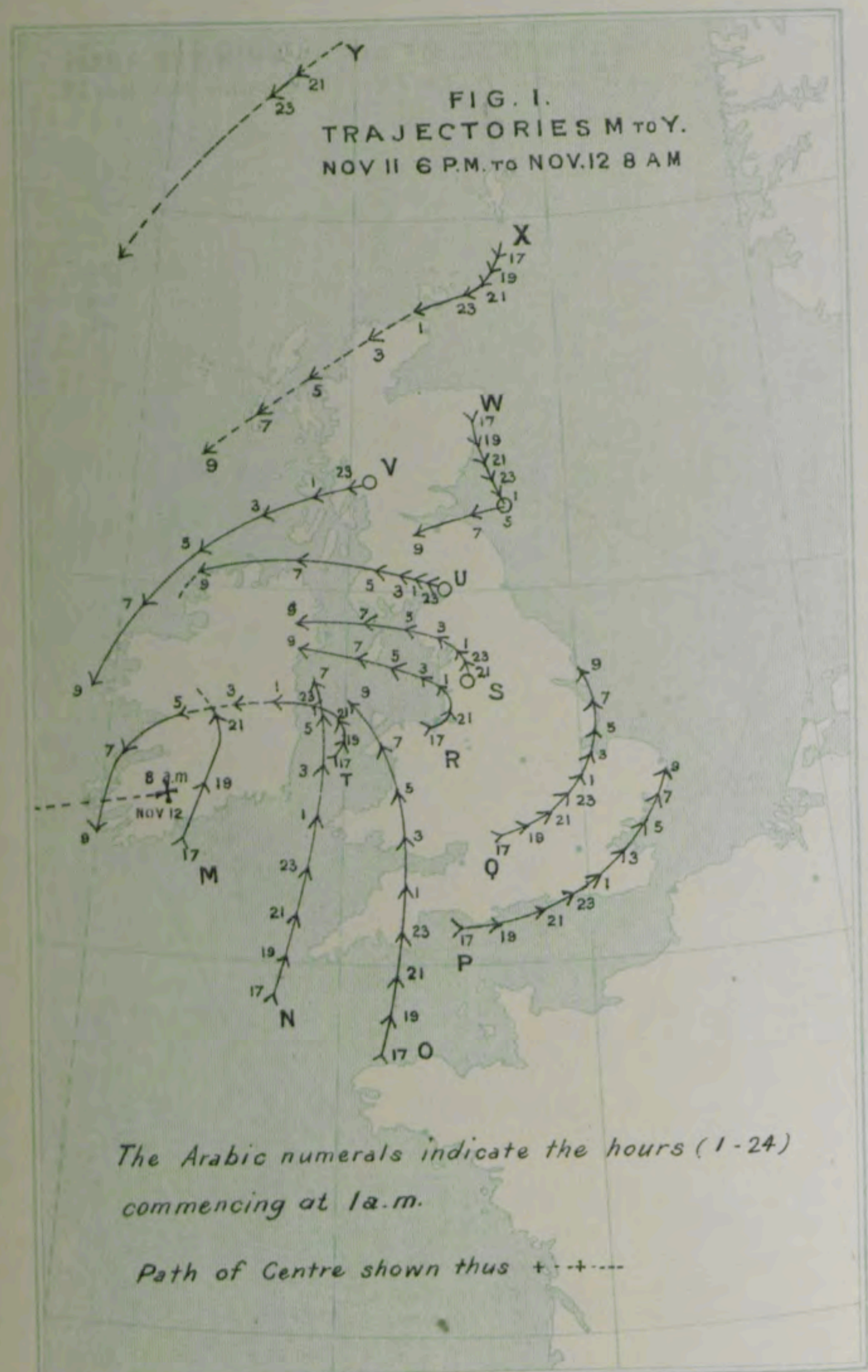
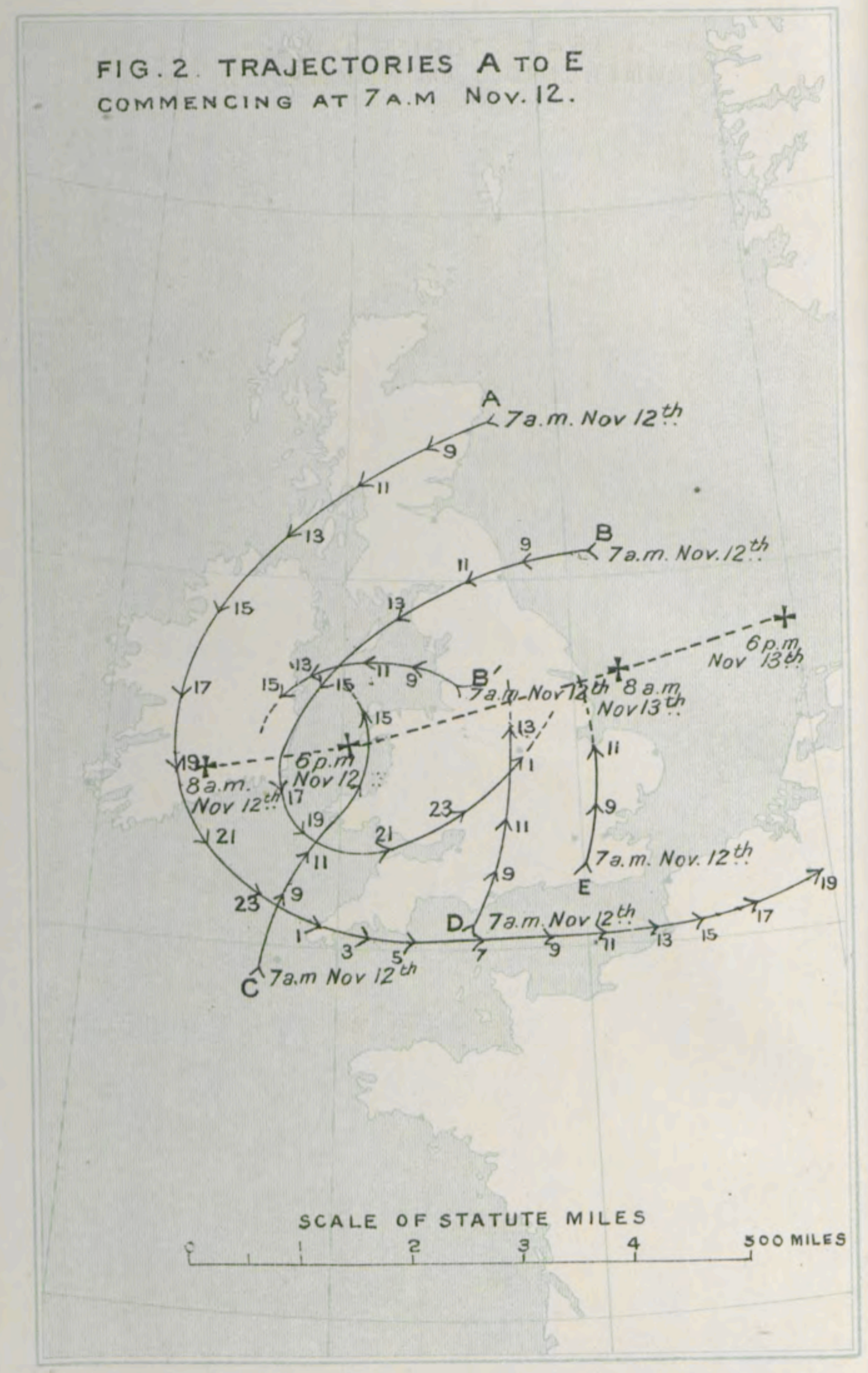
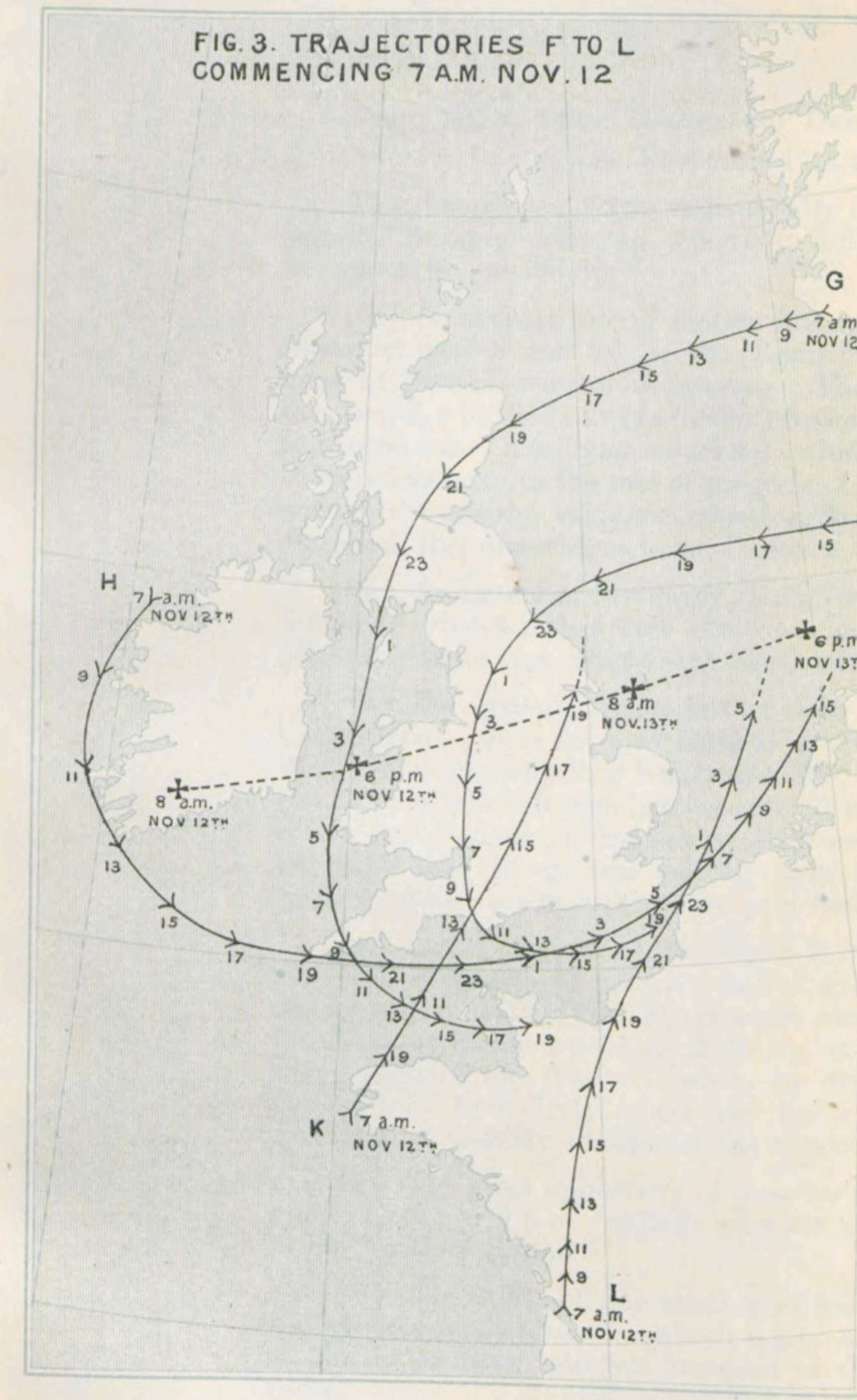
PLATE VIII.

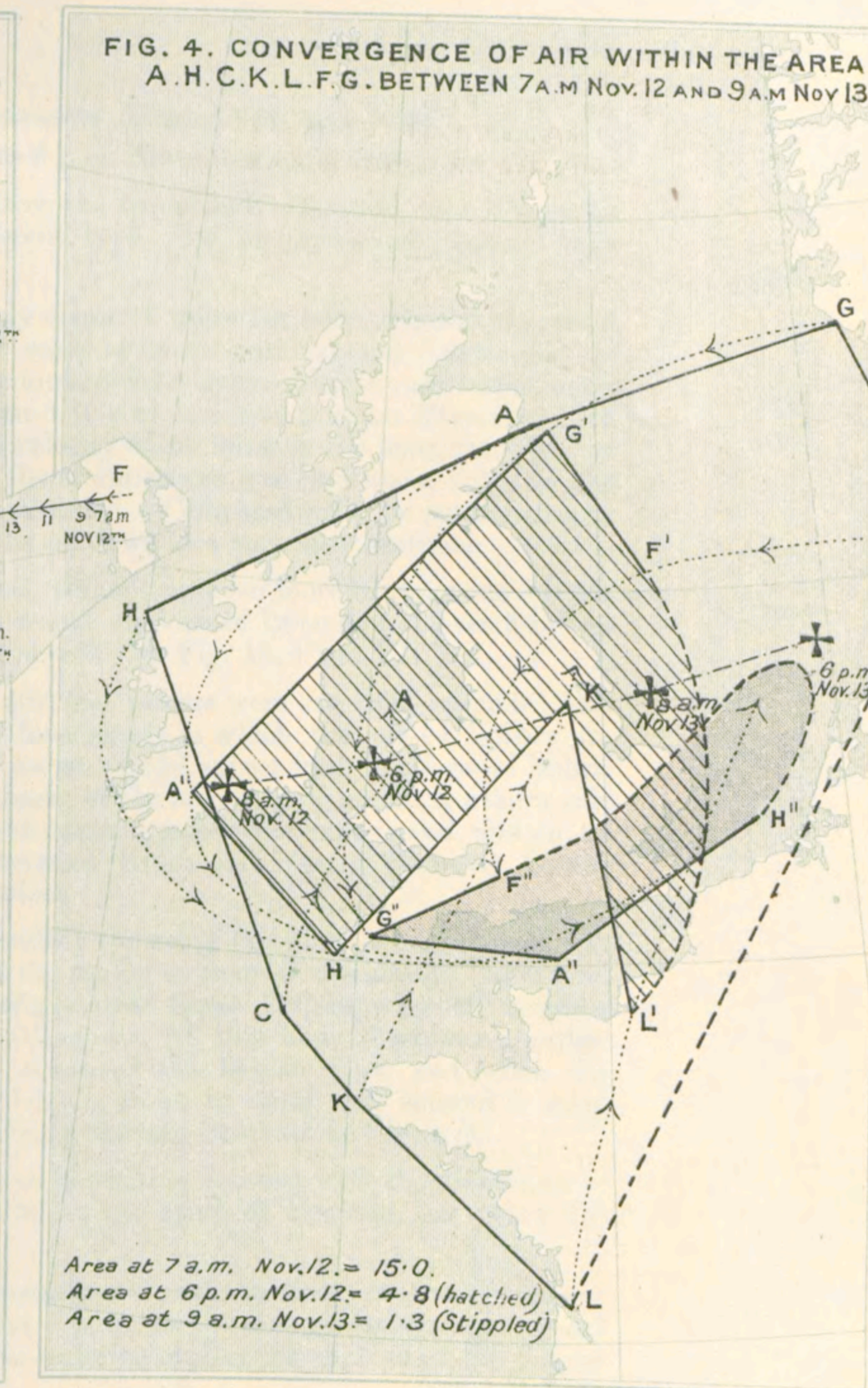
No. 3. TRAJECTORIES OF AIR. NOVEMBER 11-13, 1901.

TRAJECTORIES OF AIR AND CONVERGENCE DIAGRAM NOVEMBER 11-13, 1901.









Date.	Hours.	O V	O P 20+	O T	O W	P V	P P 20+	P T	P W	S V	S P 20+	S T	S W	V V	V P 20+	V T	V W	Hours.
11	**18**	15	9·89	(54)	(o)	19	9·83	54	p									**18**
	20	19	9·80	(53)	(n)	19	9·79			o	9·65	46	r					**20**
	22	19	9·75	(53)	(n)	15	9·78	50	(p)	5	9·65	45	r	o	9·65	41	r	**22**
	24	21	9·65		n	15	9·74	(50)	(n)	5	9·56	(45)	(r)	15	9·60			**24**
12	**2**	22	9·52			15	9·68	(49)	(p)	10	9·44		(r)	20	9·55			**2**
	4	22	9·40			15	9·61			15	9·39		(r)	30	9·45			**4**
	6	22	9·15			12	9·55		(n)	20	9·25		(r)	35	9·32			**6**
	8	24	8·97	51	r	12	9·45	49	c	30	9·18	44	r	45	9·18	48	r	**8**

Date.	Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D V	D P 20+	D T	D W	Hours.
12	**8**	25	9·61	43	op	25	9·45			31	9·18	55	r	31	9·39	54	o	**8**
	10	33	9·50	(40)	(n)	37	9·25	45	r	31	9·06			31	9·25	(50)	(r)	**10**
	12	36	9·40	(38)	(r)	37	9·11		r	37	8·91			35	**9·05**	(50)		**12**
	14	55	9·15	40	r	45	8·88		r	37	**8·78**	51	r					**14**
	16	50	**9·10**			55	**8·80**											**16**
	18	38	9·15	(44)	(n)	37	8·88	(45)	(o)									**18**
	20	38	9·20	(43)	(p)	37	8·95	(47)	(o)									**20**
	22	31	9·20			42	8·95											**22**
	24	31	9·25	(44)		30	8·98	46	n									**24**
13	**2**	25	9·26	43	p													
	4	30	9·25															
	6	32	9·27															
	8	31	9·15	(49)	(o)													
	10	22	9·14															
	12	22	9·18															
	14	20	9·20															
	16	25	9·20															
	18	15	9·20	(46)	(o)													

Date.	Hours.	B[1] V	B[1] P	B[1] T	B[1] W	E V	E P	E T	E W	Hours.
12	**8**	20	9·20	45	r	25	9·48	51	o	**8**
	10	21	8·95		r	32	**9·31**	50	n	**10**
	12	22	8·83							**12**
	14	22	8·71							**14**

Date.	Hours.	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	H V	H P 20+	H T	H W	K V	K P 20+	K T	K W	L V	L P 20+	L T	L W	Hours.
12	**8**	14	9·60	39	o	15	9·69	35	bc	42	9·18	48	r	31	9·49	55	o	14	9·91	38	f	**8**
	10	(14)				(16)				45	**9·05**			31	9·35			14				**10**
	12	(14)				(25)				36	9·10	47	n	37	9·20		(r)	19				**12**
	14	(21)				(25)				34				45	9·05	51	(n)	25	9·65	(45)	(n)	**14**
	16	(34)				(30)				32				35	8·96	(52)	(p)	25				**16**
	18	(40)				(37)				33	9·15	51	c	30	**8·90**	(50)	(o)	30	9·30	46	o	**18**
	20	(40)				40	9·49	42	n	32	9·12		(n)					30	9·30			**20**
	22	34				40	9·35	(40)		33	9·23		(n)					30	9·30			**22**
	24	32	9·05			40	9·28	(40)	(n)	30	9·22							30	9·25			**24**
13	**2**	20	8·97	(40)	(r)	47	9·15			30	9·15							30	**9·10**			**2**
	4	31	**8·95**			47	**9·12**			30	9·25							30	**9·10**			**4**
	6	31	9·00			32	9·20			25	9·15											**6**
	8	23	9·09	(46)	(o)	20	9·20	(45)	p	24	9·12											**8**
	10	19	9·15			20	9·23	(47)	(n)	21	9·15											**10**
	12	19	9·15			20	9·20			20	9·15											**12**
	14	19	9·15			19	9·22			16	9·10	(52)	(c)									**14**
	16	19	9·15			19	9·20															**16**
	18	19	9·15	47	(o)	19	9·18	(50)	(p)													**18**

Note.—For diagram exhibiting motion with reference to the centre of the storm see Plate VI.

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No. 3. Slow Travelling Depression (Plates VII. and VIII.).
6 p.m. November 11th to 6 p.m. November 13th, 1901.

This disturbance differs so materially from the two already discussed, that it must be regarded as representing an essentially different type. Its distinguishing features may be summarised as follows :—

(1.) Its average rate of motion was only about 17 miles per hour, whereas the wind forces reached 9 and 10 on the Beaufort scale at most stations, and "extremes" of force 11 were of common occurrence. The highest velocity recorded by an anemometer was 59 miles in the hour (factor 2·2) between 3.30 p.m. and 4.30 p.m. on November 12th at Kingstown. Assuming an average wind velocity of 50 miles in the hour, the ratio of the wind velocity to the rate of progress of the storm centre was thus about 3·0 ; for the strongest winds this value was considerably exceeded. Compared with the storms already discussed, this disturbance must, therefore, be set down as a very slow traveller.

(2.) An exceptionally heavy rainfall was, perhaps, an even more conspicuous feature. Totals of over 4 inches were recorded at several stations in Ireland, and over 3 inches fell over a large area lying to the North of the path (*see* Fig. 13, Plate VII.).

(3.) The synoptic charts further show that the isobars were far from circular ; this feature became more strongly marked in the later stages in which the closed isobars are elongated ovals extending N.E. and S.W. As we should expect from this form of isobar, South-easterly winds were almost entirely absent in the later maps ; on the Northern side of the lowest pressure Easterly or East-north-easterly gales were experienced, and on its Southern side the air was moving from between South and West. Wherever South-easterly winds occurred they were only transient.

(4.) Another characteristic, which is possibly typical of this class of disturbance, was the great uniformity of pressure shown over the region in front of the storm. At 9 p.m. on November 11th (Fig. 2), pressure readings over Great Britain were all between 29·80 ins. at Eastbourne, and 29·61 ins. at Glasgow. At this hour there was a rather steep gradient for Westerly winds to the South of the British Isles, and when the observations from Iceland and the Faröe Islands came to hand they showed a steep gradient for Easterly winds over the region lying between Scotland and Iceland.

(5.) The great uniformity of pressure was in striking contrast with the differences of temperature ; at 9 p.m. readings were above 50° in the South of England, but below 40° in the North of Scotland.

(6.) The region of fine weather so frequently met with in front of circular storms was conspicuously absent ; at both 6 p.m. and 9 p.m. the sky was generally overcast and at the latter hour rain was recorded at the majority of English stations of the second order.

The trajectories (Figs. 1, 2 and 3, Plate VIII.) are very different from those of the fast travelling storms. Whereas in the latter all the air entered from the South or South-west, in the present case two distinct sources of supply are shown feeding the storm from the South and from the North-east, respectively. As might be expected, the air from these two sources was at decidedly different temperatures, and the courses of these trajectories suggest that the processes going on in the depression consisted in the warm air from the South rising up over the top of the cold air from the North-east, while the latter flowed Southward along approximately semicircular paths to take its place. We are here, in fact, dealing with one of those cases referred to on p. 21 in which a bank of cold air acts like a mountain range placed across the path of a warm air current. Fig. 1, Plate VIII., represents the flow of air during the early stages of the storm from 5 p.m. November 11th to 9 a.m. November 12th ; the displacement of air which it depicts was associated with the rainfall summarised in Fig. 5, Plate VII. Figs. 2 and 3 cover the period from 7 a.m. November 12th to 6 p.m. November 13th; the corresponding rainfall is shown in Fig. 12, Plate VII. Fig. 13, Plate VII., gives the total precipitation associated with the passage of the disturbance.

Trajectories M, N, O, C, D, E, K, L, Figs. 1 to 3, Plate VIII., represent a Northward flow of warm air from the South. The initial steps of P and Q (Fig. 1) lie within the region of Westerly winds shown over the South of England on the earlier maps, but the motion of this air became directed towards the North in the course of the night, and the trajectories must be looked on as of the same type as those mentioned above. All these trajectories can be traced Northward to about the latitude of the storm-path, but reference to the appropriate maps will show that they here enter the region of minimum pressure, surrounded by the oval isobars. Past this they cannot be traced, for on the Northern side of this region we find Easterly winds at a much lower temperature which must have had a different origin. The fact that we cannot trace the Southerly winds further Northward indicates that the air composing them left the surface of the earth, and there can be but little doubt that it rose and continued its journey Northward over the top of the colder and denser air which formed the flow from the East. We shall see below that the distribution of precipitation confirms this hypothesis.

In the early stages of the storm the trajectories of the Easterly winds (R to V, Fig. 1) can be traced backward to the region of uniform pressure and calm or light variable breezes in front of the advancing storm. From T, U and V we see that this air was entrained ultimately in the cold Northerly gales which blew in the rear of the depression.

The observations show that a light Easterly breeze was blowing off the coast of Lancashire at 2 a.m., while at North Shields the air was calm till 7 a.m., and from this it follows that the commencement of motion towards the West gradually spread across the country from West to East, and we must imagine that the air acquired its momentum in consequence of some cause which we must seek in the West. The process seems to have borne some analogy to that of withdrawing water by means of a tap at the bottom and at one side of a large and rather shallow tank. Under such circumstances we should expect a certain amount of vertical motion to take place, but in the present case the observations contradict the hypothesis of any large descent of air from above, for over Northern England the weather was generally dull and rainy. It is of course possible that this cloud and rain was formed in the air above the calm layer at the surface, and that a limited amount of downward motion occurred in the latter.

The course of the trajectory W. is peculiar. At 6 p.m. the air on the East coast of Scotland was moving from the North in the rear of a low pressure system then shown over Southern Scandinavia; during the night this motion died away and from 1 a.m. to 5 a.m. (judging from the isobars) the air remained becalmed, but at the latter hour it was drawn into the circulation towards the West and its velocity rapidly increased.

In the later stages of the storm (Figs. 2 and 3) the air of the East winds (trajectories A, B, F, G) was derived from the region lying to the North-east of the British Isles, and when F and G are traced across the North Sea by computing approximately the wind directions and velocities from the isobars they are found to fall in very satisfactorily with the Easterly winds observed at Skudesnaes and Fanoe at 7 a.m. on November 12th. As was the case with T, U and V in Fig. 1, the current from the East becomes a North wind in the rear of the storm. It is interesting to note that during this part of its course the distance of the air from the centre of lowest pressure was increasing. Subsequently the motion of the air becomes directed towards the South-east and ultimately towards the East or North-east, and a second approach to the centre of the storm takes place.

Unfortunately we have no means of ascertaining from direct observation the direction of motion of the upper air in the region over which the Easterly surface wind flowed, as Ben Nevis, our only elevated station, lies too far North. Indirect evidence on this point can, however, be obtained from the distribution of rainfall. All three rainfall maps

(Figs. 5, 12 and 13, Plate VII.) show the heaviest precipitation on the Northern side of the path, *i.e.*, in the region of cold Easterly surface winds. It is, however, almost certain that the water was supplied by the warm moist air of the Southerly winds, and we must therefore suppose that the latter carried the droplets condensed from it during its ascent Northwards, and that these subsequently fell to the ground through the Easterly surface wind.

Though Ben Nevis lies too far North to give us any information about the subsequent history of the Southerly wind, the observations taken at the observatory confirm our supposition that the Easterly wind which swept round the rear of the disturbance was a surface current. Up to 4 a.m. on November 12th the wind at the summit was light in force and rather variable in direction; wind force 2 on the Ben Nevis scale, which has been estimated as corresponding to about 12 miles per hour, was not exceeded. From the distribution of pressure, as well as from the records of the anemometers at Deerness, Aberdeen, and Glasgow, it is probable that a North-easterly wind of this velocity set in several hours earlier at sea level, and that by 2 a.m. the wind velocity was considerably greater at the surface than on the summit. Shortly after 4 a.m. the North-easterly wind aloft increased in force, and after 10 a.m. we find the wind observations at the summit entered at from 3 to 8 on the Ben Nevis scale (estimated at 21 and 73 miles per hour respectively). Thus the Easterly wind appears to have commenced at the surface and to have gradually spread upward. The temperature observations give the following results. At 2 a.m. they show a difference of 14° between the base and the summit, which corresponds to a temperature gradient of 0°·3 F. per 100 feet, or 0°·57 C. per 100 meters. As the North-easterly current spread upward the temperature at the summit fell, and the difference of temperature was frequently greater than 20°, which gives a vertical temperature gradient of more than 0°·43 F. per 100 feet, or 0°·82 C. per 100 meters, a value which is only slightly less than the adiabatic gradient for dry air.

The Tables on Plate VIII., as before, give the changes in the various meteorological elements for each step of the trajectories. The winds from the South resemble the Southerly winds in fast moving storms in that they show decreasing pressures and increasing velocities. Rain set in some time before the region of Easterly wind was reached, thus indicating that a certain amount of convergence of the second type as described on p. 18 occurred within the Southerly current, but it is an interesting fact that the total rainfall over the South of England was comparatively small. The temperature of this Southerly air was generally above 50° (except in the case of L, of which the course lay over the continent of Europe); a distinct tendency for a fall of temperature (as before probably associated with the setting in of rain) can be traced.

In the Easterly winds pressure decreased briskly, while the velocity increased with extraordinary rapidity; minima of pressure and maxima of velocity, the latter frequently estimated at force 11, were reached as the wind assumed a Northerly direction in the rear of the storm. The subsequent recovery of pressure, as the wind direction became North-westerly and finally Westerly, was slow, but the velocity decreased rapidly. Trajectories A (Fig. 2) and H (Fig. 3), the latter being continuous with trajectory V of Fig. 1, show a second region of decreasing pressure as they approach the storm centre as Westerly and South-westerly winds.

The temperatures of these trajectories were, for the most part, between 40° and 45°, though a slight increase was generally shown during the day-time of November 13th; in H, of which the course lay over the English Channel, the temperature increased to over 50°.

Heavy rain fell during the early stages of the trajectories, but, as we have seen above, the main source of this was the warm Southerly wind which rose above the Easterly current. After the minimum of pressure was passed the continuous rain ceased, but the sky remained overcast.

To bring about such very rapid changes of the wind velocity as occurred in the cold air as it flowed towards the West and finally to the South a large supply of air is needed, and as it is improbable that any descent of air on a large scale took place in this part of the storm, this could only have been obtained, in the present case, from a great convergence of surface air. Fortunately we have evidence that this took place; the trajectories B and B′, Fig. 2, though differing greatly in place of origin, approach so closely together at 3 p.m. (15 hours) on November 12th that only one of them has been continued lest there should be confusion in the diagram. Indeed it is probable that the convergence exceeded that needed to supply the air for these strong gales and that some ascent of air occurred within the cold current. Attempts to determine the regions of ascent or descent in the different parts of the storm by the method of change of area described on p. 32 support this supposition, but the difficulties of applying the principle are so great that the results are not by any means free from uncertainty, and the diagrams have not been reproduced. Fig. 4, Plate VIII., illustrates the great shrinkage over the storm area as a whole, which gave rise to the rainfall shown in Fig. 12, Plate VII. If synchronous points on the trajectories F, G, A, H, C, K, L (Figs. 2 and 3) be joined so as to form a closed figure, the included area is found to diminish to about one-third of its original size during the interval from 7 a.m. to 6 p.m. on November 12th, while at 9 a.m. on November 13th the air represented by C, K, L had left the surface of the earth, and the points on the remaining trajectories all lay within the small shaded area over the South of England and the surrounding seas, which is less than one-tenth of the size of the original figure.

In Fig. 2 of Plate VI an attempt has been made to work out the motion of the air relative to the storm centre. Some difficulty attaches to the identification of the position of the latter, as a large region of uniform low pressure is shown near the centre of the storm on most of the maps. The method adopted was to ascertain the positions at 8 a.m. and 6 p.m. on November 12th and 8 a.m. on November 13th, with as much accuracy as possible and to join them by straight lines, which were then subdivided into two hourly intervals. With the points so obtained the diagram was constructed in a manner similar to that described above (*see* p. 34). The curves show not the slightest resemblance to any conic section having the centre as focus, a further proof of how completely this storm differed both from the fast travelling ones considered above and from the ideal case investigated by Mr. Bennett.

The ascent of the warm air currents entering the front of the storm transversely to the path, over the top of the colder air which flows in on the left-hand side of, and parallel to, the path, is clearly indicated and agrees well with the distribution of the rainfall area which lies mainly to the left of the path. A narrow band of rainfall on the right of the path and at right angles to it suggests that we have here a region in which the cold air, after flowing round the storm centre, forces its way under the main warm current.

Some interesting results obtained by considering the convergence effects in different parts of the storm are given below:—

Circle; Centre denoted by Cross and Letter Red.	Area of Circle.	Area of corresponding figure, two hours later.	Nature of Change in the Two Hours.	Ratio.
W	12·6	12·3	Little change	·98
X	12·6	6·2	Large decrease	·49
Z	12·6	11·3	Slight decrease	·90

The circle W lies entirely within the warm current blowing at right angles to the path, and in it we find hardly any shrinkage, which agrees well with the slight rainfall measured on the Southern side of the path (*see* Fig. 13, Plate VII.). X, on the other hand, has been drawn so as to include the line of separation between the two air supplies, and here we find very great shrinkage.

The results obtained from Z are of little value, as the conspicuous difference in character between the curves obtained from trajectories G and F and those from A, B and H show that the internal structure of the storm changed in this part of the storm area, and it is therefore not legitimate to regard the curves as simultaneous stream lines.

PLATE IX.

No. 4. FORMATION OF A DEPRESSION OCTOBER 7-9, 1903.

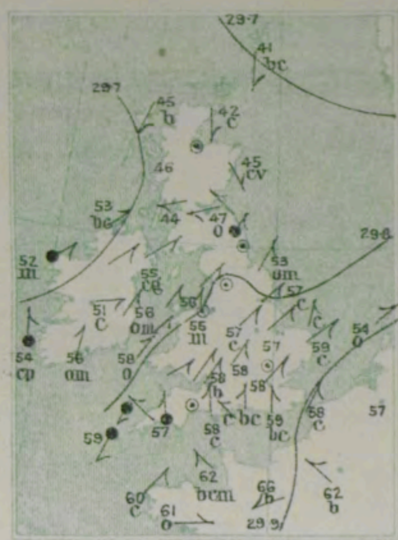
Fig. 1.—6 p.m. (18) October 7.

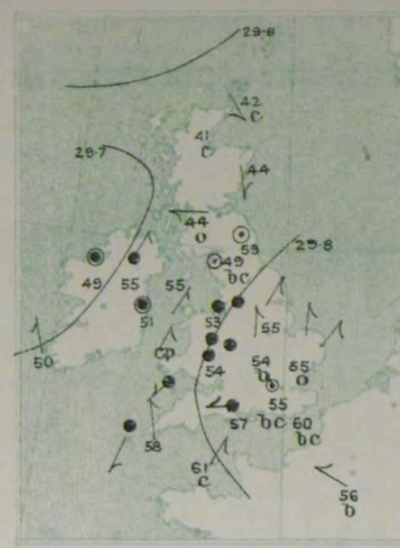
Fig. 2.—9 p.m. (21) October 7

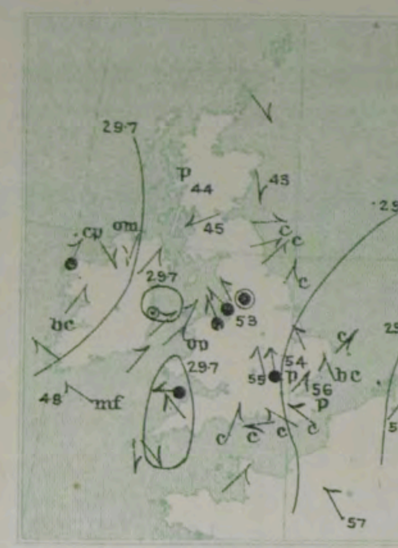
Fig. 3.—Midnight (24) October 7.

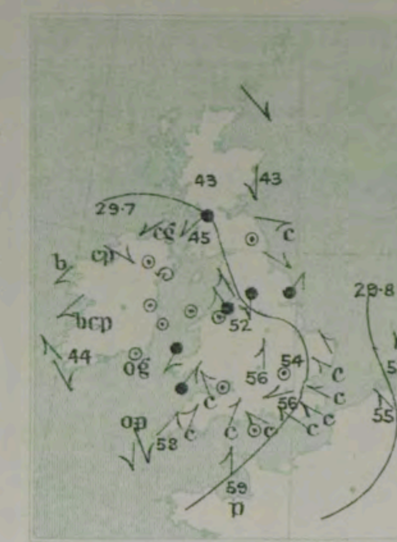
Fig. 4.—4 a.m. October 8.

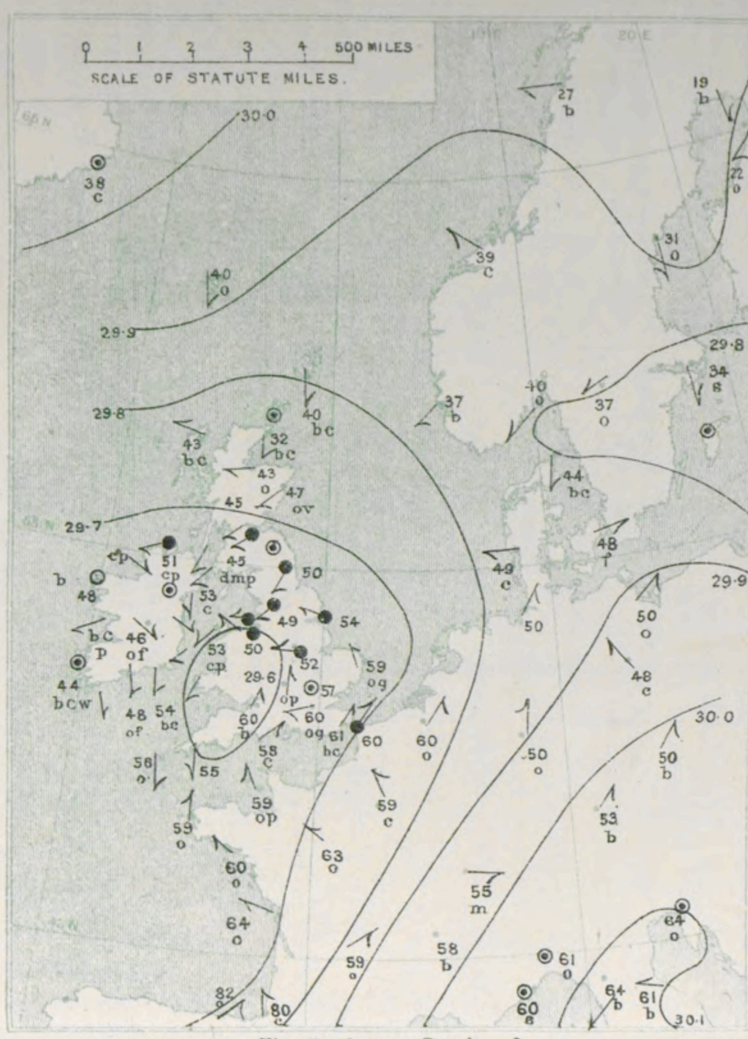

Fig. 5.—8 a.m. October 8.

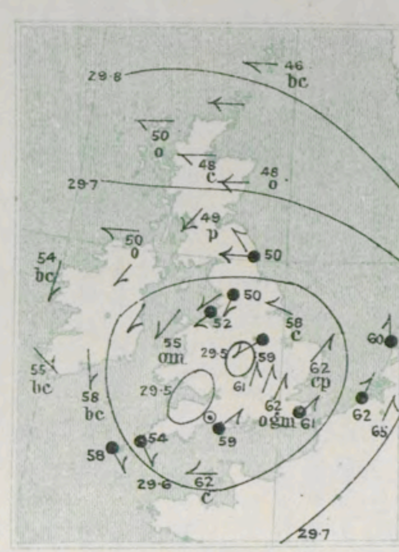
Fig. 6.—2 p.m. (14) October 8.

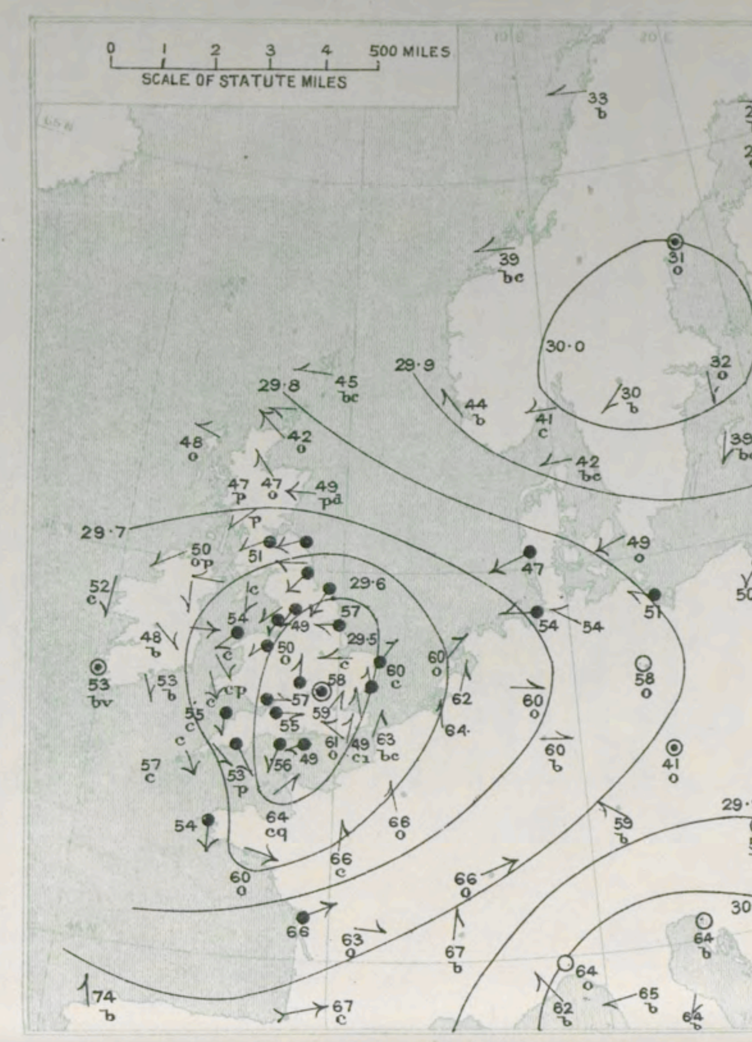

Fig. 7.—6 p.m. (18) October 8.

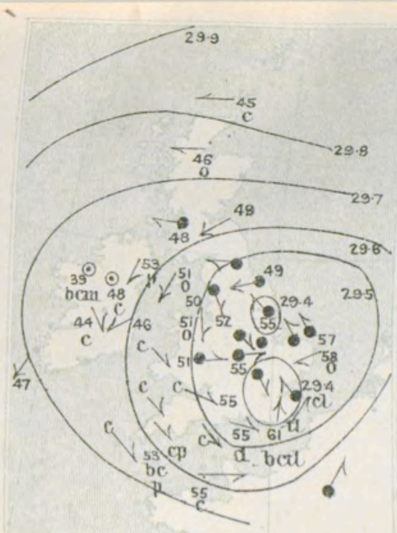
Fig. 8.—9 p.m. (21) October 8.

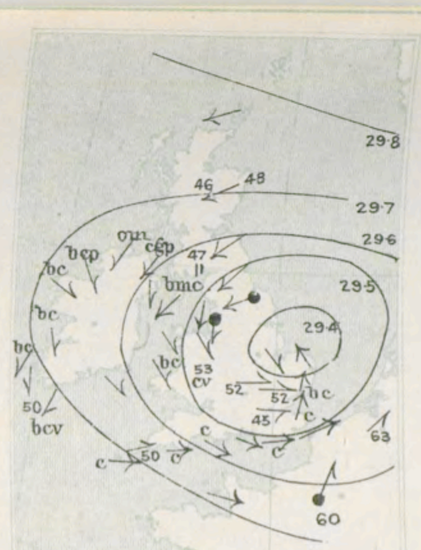
Fig. 9.—Midnight (24) October 8

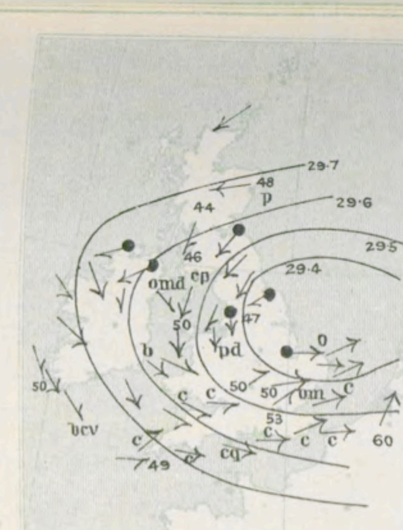
Fig. 10.—4 a.m. October 9.


Fig. 11.—Rainfall October 8-10.

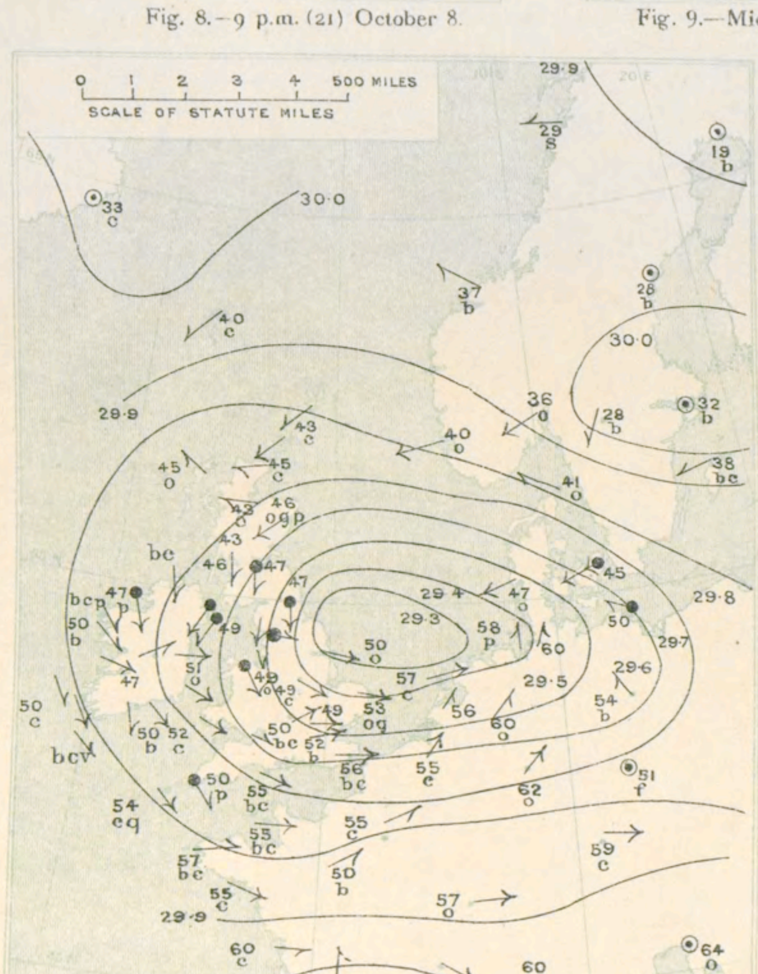

Fig. 12.—8 a.m. October 9.

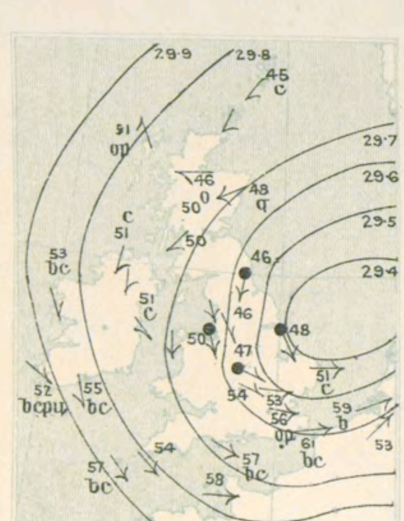
Fig. 13.—2 p.m. (14) October 9.

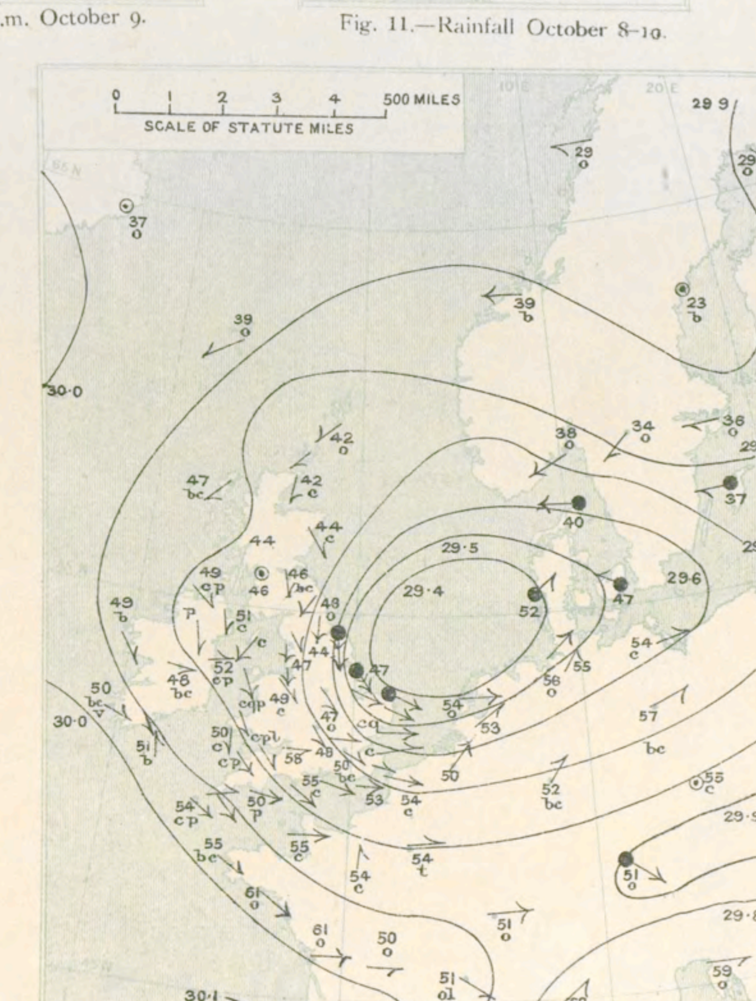

Fig. 14.—6 p.m. (18) October 9.

The mark ● denotes that rain was falling at the hour of observation.
The rainfall charted in Fig. 11 gives the sums of the amounts measured at 8 a.m. or 9 a.m. on October 8, 9 and 10

PLATE X.

No. 4. TRAJECTORIES OF AIR, OCTOBER 7-9, 1903.

Hours.	H V	H P 20+	H T	H W	K V	K P 20+	K T	K W	L V	L P 20+	L T	L W	M V	M P 20+	M T	M W	N V	N P 20+	N T	N W	O V	O P 20+	O T	O W	P V	P P 20+	P T	P W	Hours.
19	5	9·92	58	c	8	9·85	(60)	(c)																					19
23	7	9·87			8	9·79		c																					23
3	10	9·77		c	10	9·69			0	9·67			0	9·68			(5)	9·77	43										3
7	10	9·67	(60)	(c)	9	9·60	60	p	8	9·60	53	p	12	9·63		p	10	9·70	45	(p)					10	9·64	54	r	7
11	10	9·58		r	9	9·57	60	n	12	9·57		(c)	15	9·60	(57)	(c)	12	9·65	48	p	12	9·65	50	r	10	9·60		r	11
15	8	9·53	62	r	6	9·50	59	r	10	9·55		c	17	9·62		r	12	9·63	50	p	15	9·58	50	r	10	9·55		r	15
19	5	9·50	60	r	5	9·46	58	r	14	9·56	55	c	15	9·68	57	c	12	9·63	50	p	14	9·52	50	r	10	9·48	50	r	19

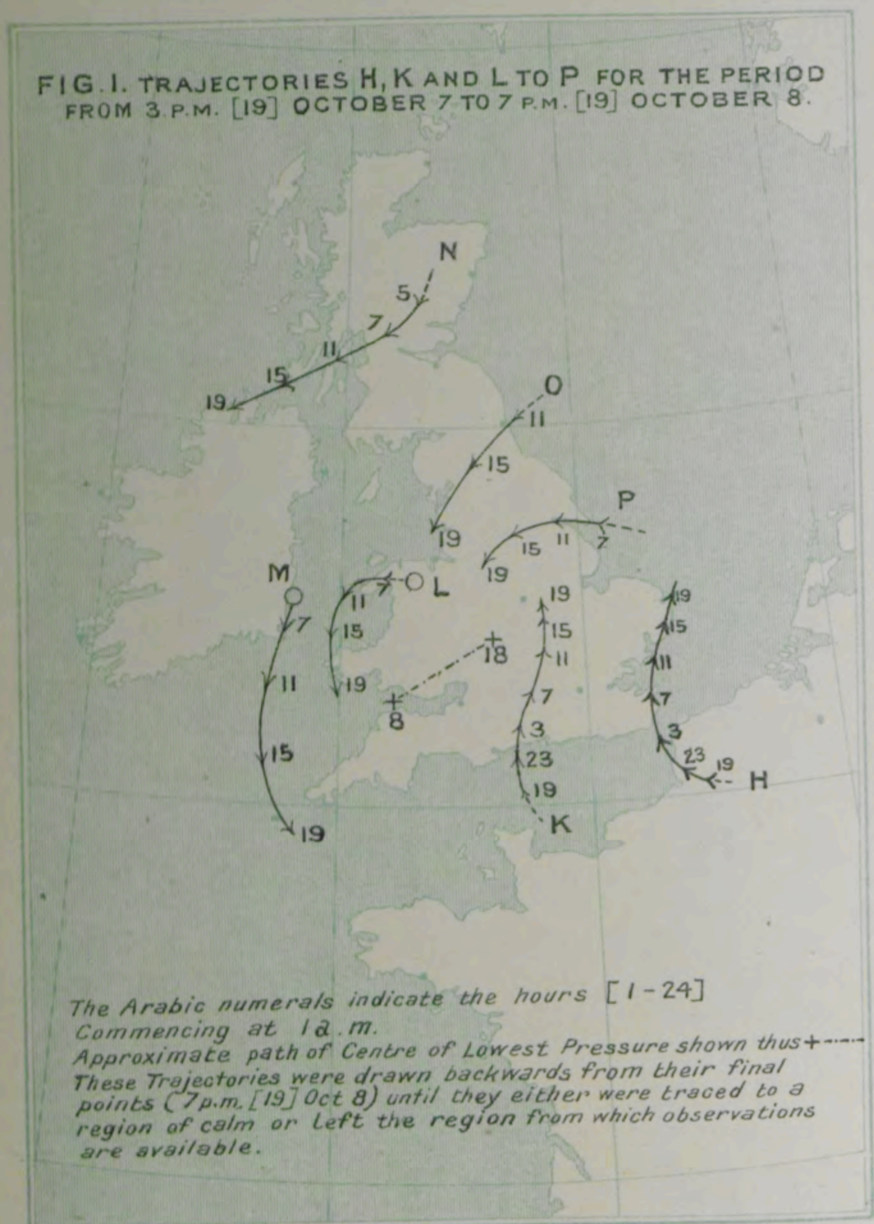

FIG. I. TRAJECTORIES H, K AND L TO P FOR THE PERIOD FROM 3 P.M. [19] OCTOBER 7 TO 7 P.M. [19] OCTOBER 8.

The Arabic numerals indicate the hours [1-24] Commencing at 1 a.m.
Approximate path of Centre of Lowest Pressure shown thus +-----
These Trajectories were drawn backwards from their final points (7 p.m. [19] Oct 8) until they either were traced to a region of calm or left the region from which observations are available.

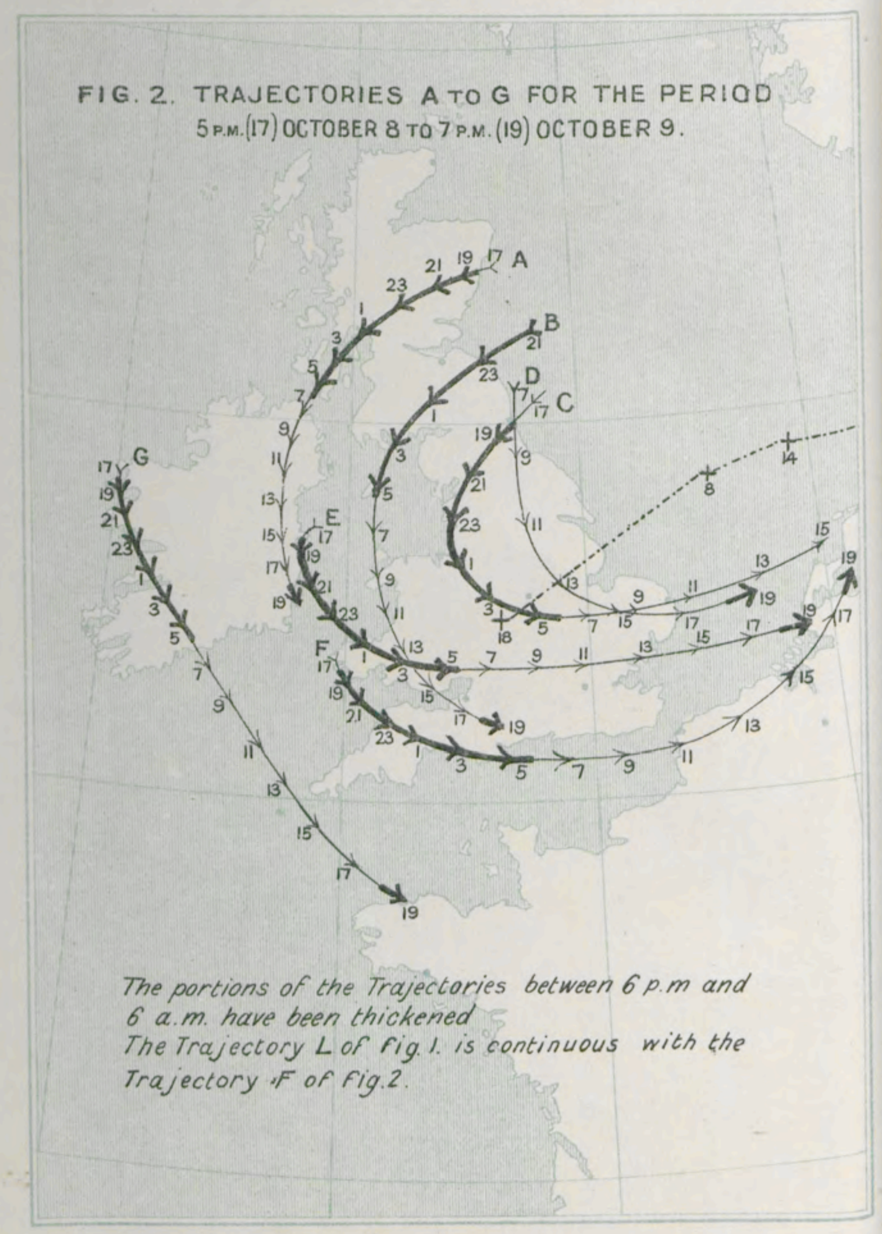

FIG. 2. TRAJECTORIES A TO G FOR THE PERIOD 5 P.M. (17) OCTOBER 8 TO 7 P.M. (19) OCTOBER 9.

The portions of the Trajectories between 6 p.m. and 6 a.m. have been thickened
The Trajectory L of Fig. I. is continuous with the Trajectory F of Fig. 2.

Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D V	D P 20+	D T	D W	E V	E P 20+	E T	E W	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	Hours.
18	16	9·75	49	p					22	9·55	50	r					15	9·59			15	9·56	55	c	10	9·67	52	c	18
20	16	9·73	(49)						22	9·53	(49)	r					15	9·58	(46)		15	9·56	53	(c)	10			bc	20
22	18	9·71	(48)		30	9·63	48	r	22	9·48	(49)	(r)					15	9·58			15	9·59			14	9·67			22
24	19	9·67	(47)		30	9·58	47		22	9·47	53	(n)					19	9·57		(bc)	15	9·60	(50)	(c)	15	9·68		(bc)	24
2	17	9·66	(46)		25	9·55			20	9·47							19	9·57			20	9·60		n	18	9·71	(50)	n	2
4	16	**9·63**	(46)		25	9·55		p	20	9·45	(50)	(n)					20	9·58		(c)	25	9·62		(c)	20	9·72	(50)	(bc)	4
6	15	9·64			24	9·55		p	22	9·43							20	9·55	(49)		25	9·63		(p)	20	9·73			6
8	15	9·67	(48)	(r)	20	9·60	51		25	9·40	(52)	(n)	30	9·43	47	r	21	9·56	(50)	bc	25	9·65	55	bc	20	9·75	(50)	b	8
10	15	9·68		n	20	9·65			28	**9·38**			30	9·50	(46)	r	22	9·58	54	(p)	25	9·65			22	9·80			10
12	15	9·72		(n)	20	9·67		p	30	9·40			30	9·50		(r)	22	9·53	56	(n)	28	9·65			22	9·85		(c)	12
14	15	9·75			20	9·69			35	9·40			30	9·50	(47)	(r)	25	9·53			35	9·59	(59)	(b)	22	9·87	(57)	(bc)	14
16	15	9·78			20	9·71		p					30	9·45		(r)	30	9·50			35	9·57	(56)	(p)	25	9·90			16
18	15	9·81	(50)	(bc)	20	9·77	55	p					30	9·50	(49)		30	9·55	(53)	(c)	25	9·57	53	n	25	9·91	55	(p)	18

The Trajectories are referred to by letters, A, B to P. The Tables give the Wind Velocity (V) in miles per hour, the Pressure (P) in inches, the Temperature (T) in Fahrenheit degrees, and the Weather (W) on Beaufort notation at the points on the Trajectories corresponding with the hours named in the margin. The symbol n indicates the absence of rainfall as shown by self-recording rain gauges. Figures in brackets are conjectural.

CONVERGENCE OF AIR, OCTOBER 7-9, 1903. CHANGES OF AREA.

Fig. 3.

	ABCDEFG	CDHKLMN
5 p.m. Oct. 8	5·59	12·2
1 a.m. Oct. 9	4·43	5·6

Fig. 4.

	ABCDE	DEF
7 a.m. Oct. 9	9·47	4·31
1 p.m. Oct. 9	9·14	1·59

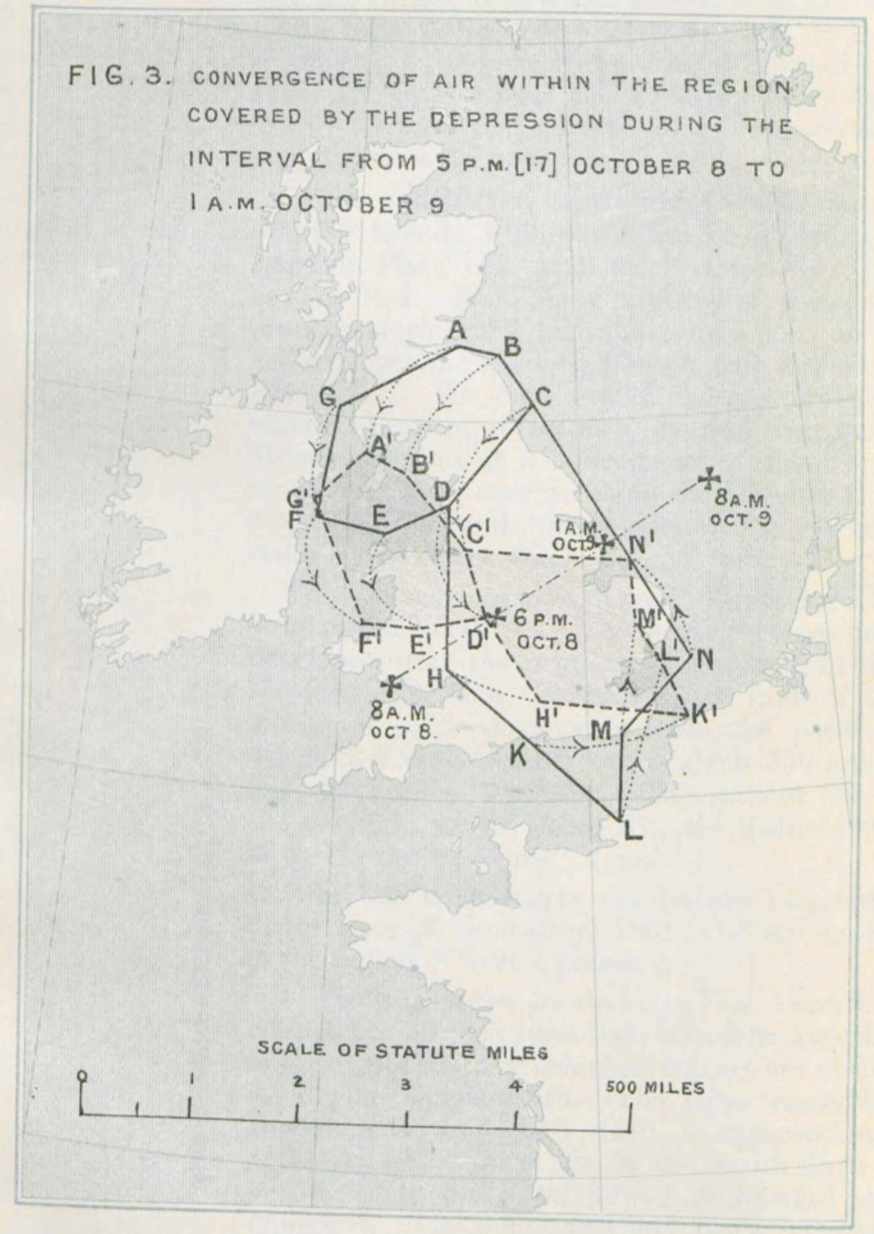

FIG. 3. CONVERGENCE OF AIR WITHIN THE REGION COVERED BY THE DEPRESSION DURING THE INTERVAL FROM 5 P.M. [17] OCTOBER 8 TO 1 A.M. OCTOBER 9

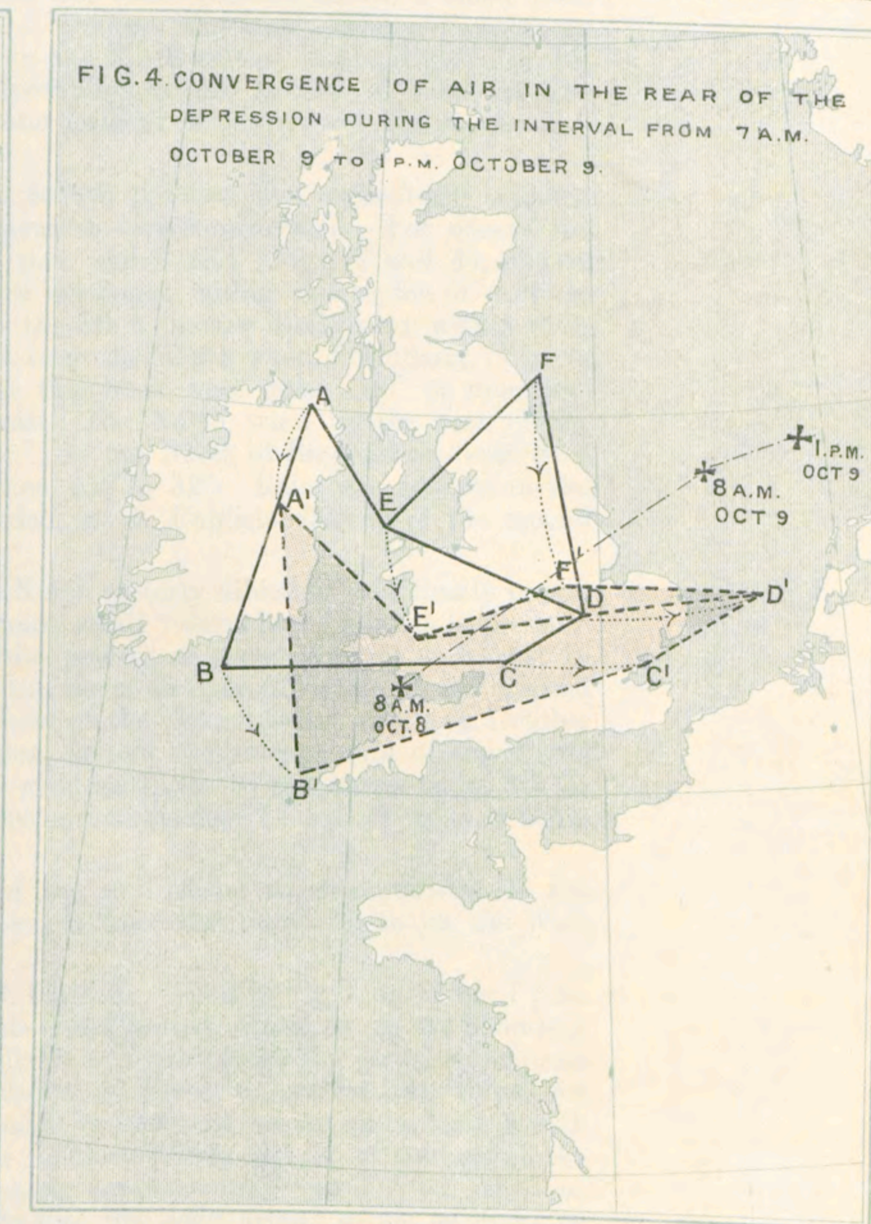

FIG. 4. CONVERGENCE OF AIR IN THE REAR OF THE DEPRESSION DURING THE INTERVAL FROM 7 A.M. OCTOBER 9 TO 1 P.M. OCTOBER 9.

The rectilinear figures in these diagrams have been obtained by joining simultaneous points on the Trajectories which are shown by faintly dotted lines. The initial positions are indicated by plain letters, the final ones by letters with dashes appended. The final areas have been shaded.

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No. 4. Development of a Slow Travelling Storm over the British Isles (Plates IX. and X.).

6 p.m. October 7 to 6 p.m. October 9, 1903.

During the 48 hours subsequent to 6 p.m. October 7th, 1903, a depression formed over the British Isles which proved to be almost the exact counterpart on a small scale of the gale of November 11th to 13th, 1901. Perhaps the most obvious resemblance is afforded by the exceedingly heavy rainfall in the North-east of England (*see* Fig. 11, Plate IX.) ; but from the following short description of the history of the depression it will be seen that several other characteristic features of the November storm were reproduced on this occasion.

Throughout the night from October 7th to 8th pressure was exceedingly uniform over our Islands, while the differences of temperature were considerable. For details the maps on Plate IX., particularly those for 9 p.m. and 4 a.m. (Figs. 2 and 4), should be consulted. Small local minima of pressure developed within this region of uniform pressure during the night, and by 8 a.m. on the 8th a shallow disturbance with a well-marked cyclonic wind circulation had formed over the South-west of England, (Fig. 5, Plate IX). The contrasts of temperature at this hour were great: 60° or more was registered at most stations in the South-east ; the North wind in the rear of the disturbance was at a temperature of about 55° ; in the North of England readings were about 50°, while over Scotland they ranged from 45° to 32°. Rain was general in the North of England ; at 9 a.m. it was recorded at all English stations of the second order North of the Wash.

This disturbance moved very slowly in a North-easterly direction and finally passed away to the North Sea. In the early stages many small "secondary" minima of pressure developed near the primary minimum, and the process of travel appears to consist in the formation of a "secondary" in front of the storm and the filling up of the original minimum. The distance between the positions of the storm centre at 8 a.m. October 8th and 6 p.m. October 9th is about 390 miles, so that the average rate of travel was only 11·5 miles per hour. The ratio of the wind velocities to this varies up to 3·5 for the strongest winds (force 8) ; the disturbance must therefore be looked upon as being of the "slow travelling" type.

In the later stages the isobars assumed the oval shape so characteristic of the disturbance of November, 1901, and strong winds from the North set in on the West of the region of lowest pressure.

The trajectories are shown in Figs. 1 and 2, Plate X. Those of Fig. 1 start from 7 p.m. on October 8th and have been traced backwards either to their origin or to the boundary of the region from which observations are available. Fig. 2 covers the period subsequent to 7 p.m. October 8th. The close resemblance of these trajectories to those for November 11th to 13th, 1901, is apparent and it is clear that we are again dealing with a case in which warm air in the South flows Northward over the top of cold air in the North, while the latter flowed Southward along approximately semicircular paths to replace it. The trajectories and maps indicate that the main ascent of air occurred in about the latitude of Spurn Head, while the rainfall was heaviest on the coasts of Northumberland, Durham and Northern Yorkshire, so that the condensed vapour must again have been carried forward by the rising Southerly current.

Great convergence took place over the storm area (Plate X.). The area of C D H K L M N (Fig. 3) which lay mainly in front of the storm, decreased from 12.2 to 5·6, or to less than half its original size, during the eight hours between 5 p.m. October 8 and 1 a.m. October 9, in consequence of the ascent of the warm Southerly current, while that of A B C D E F G which was situated within the region of cold North-easterly winds, decreased during the same interval in the ratio 0·78, showing that considerable ascent of air occurred in this region also. The triangle F E D (Fig. 4), which also lay in the rear of the storm, shows a still greater decrease. Between 7 a.m. and 1 p.m. on October 9th it diminished from 4·31 to 1·59.

The heavy rainfall in the North-east of England must thus have been due to two causes :—

1. The rising of the warm air in the South over the top of the cold air in the North.

2. Ascent of air in the cold North-easterly current.

The following Table, which separates the total rainfall into the amounts which fell in the front and rear of the storm respectively, affords some idea of the relative importance of these two causes :—

	Rainfall Measured on mornings of		
	October 8th and 9th.	October 10th.	Total Fall caused by Depression.
	Rainfall in Front of Storm, mainly due to Cause 1.	Rainfall in Rear of Storm, entirely due to Cause 2.	
Morpeth	3·01	0·60	3·61
Alnwick	2·72	·43	3·15
Newcastle	2·42	·23	2·65
North Shields	2·71	·54	3·25
Durham	2·76	·50	3·26
Scarborough	1·92	1·12	3·04
Garforth	1·42	1·24	2·66

Still further in the rear of the disturbance the changes of area were small. The polygon A B C D E (Fig. 4) decreased from 9·47 to 9·14 between 7 a.m. and 1. p.m. on October 9th ; this is in conformity with the fact that the weather over Southern England was fair generally, though showers fell at a number of stations ; most observers entered b., bc., or c. in their registers.

The changes in the meteorological elements recorded along the trajectories are very similar to those recorded during the storm of November, 1901 ; details will be found in the Tables on Plate X.

Ben Nevis again lies to the North of the region where the most important changes were taking place. During the first few hours of our period, while the uniform pressure distribution prevailed at the surface, calms or very light South-easterly breezes were experienced at the summit. While the depression was forming and during its passage Eastward, the wind at the summit increased in strength to values which vary between forces 3 and 5 on the Ben Nevis scale (approximately 5 to 8 Beaufort), but its direction remained South-easterly or East-south-easterly. The surface wind during this period was Easterly to North-easterly. Possibly this current derived its air from the ascending Southerly winds over England. At 2 a.m. on October 9th, by which time the centre of low pressure had passed to the Eastward of Spurn Head, a Northerly wind set in on Ben Nevis.

PLATES XI., XII.

No. 5. TRAJECTORIES OF AIR, DECEMBER 30-31, 1900.

FIG. 1. TRAJECTORIES E TO P.

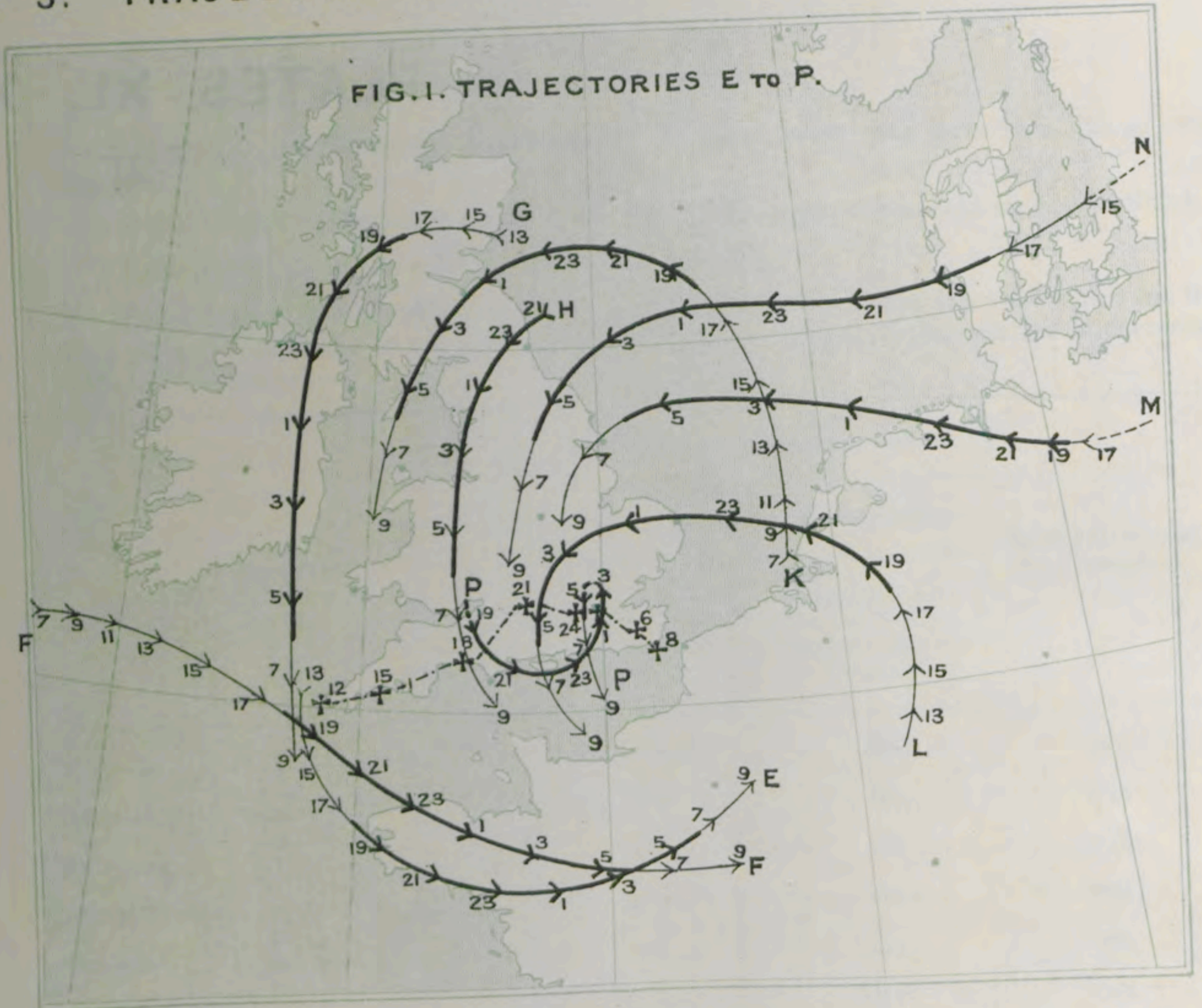
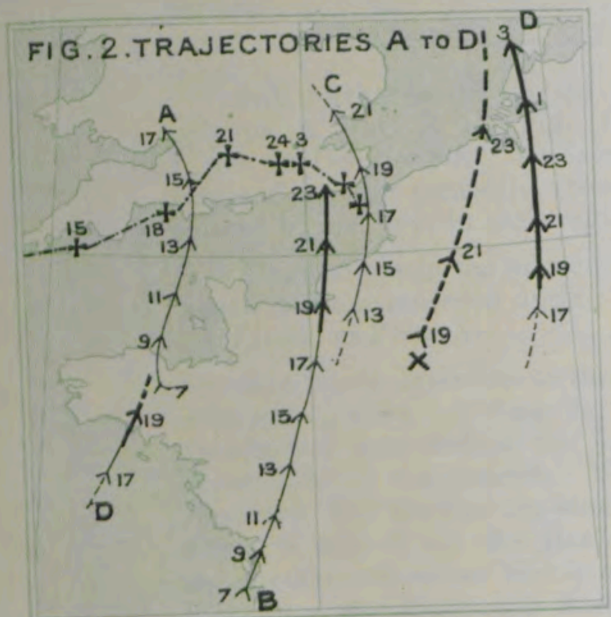


FIG. 2. TRAJECTORIES A TO D.



The Arabic Numerals indicate the hours [1-24] *commencing at 1 a.m.*

The portions of the Trajectories between 6 p.m. and 6 a.m. have been thickened.

Path of Centre shown thus +·—·+·—·+

For reference to Trajectory X *see page 47.*

Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D V	D P 20+	D T	D W	Hours.
8	21	9·78	51	o	19	9·92	53	o									8
10	21	9·65	49	o	19												10
12	23	9·55		(r)	22	9·75	(54)										12
14	25	9·35	51	r	22	9·71			20	9·60	(49)	(r)					14
16	25	9·26			24	9·60	(53)		20	9·55							16
18					25	9·38	(52)		20	9·36	48	r	20	9·63			18
20					25	9·25			25	9·23		(r)	20	9·53	(48)	(r)	20
22					25	9·10							25	9·40	46	(r)	22
24													25	9·32			24
2													25	9·30			2

Hours.	E V	E P 20+	E T	E W	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	H V	H P 20+	H T	H W
8					19											
10					19											
12					22											
14	27	9·32	47	r	24	9·35			20	9·43	(43)	(o)				
16	30	9·32			26	9·32			25	9·43						
18	30	9·38	46	o	26	9·32	48	o	28	9·45	(39)					
20	28	9·48	(46)	(r)	26	9·39			30	9·50						
22	28	9·50	(46)		28	9·38			30	9·52	(40)		19	9·42	(45)	
24	28	9·46			30	9·40			30	9·52			29	9·40		
2	28				30				40	9·55			32	9·40	43	n
4	28	9·40	(46)		30	9·45	(45)		40	9·63			36	9·40		
6	22	9·42			30	9·45			38	9·68			39	9·40		
8	22	9·41	(43)	(o)	30	9·46	(46)	(o)	30	9·74	46	c	43	9·40	47	c

Hours.	K V	K P 20+	K T	K W	L V	L P 20+	L T	L W	M V	M P 20+	M T	M W	N V	N P 20+	N T	N W	P V	P P 20+	P T	P W	Hours.
8	10	9·78	(41)	(o)																	8
10	12	9·75																			10
12	24	9·70																			12
14	29	9·70			19	9·72	(42)						37			n					14
16	30	9·62			22	9·71	(42)		10	9·88	(33)	n	39			n					16
18	30	9·55			25	9·65	(43)		12	9·86	(33)	n	39	9·88	31	o					18
20	30	9·53			31	9·55	(41)		22	9·83	32	n	39	9·81			30	9·05		(r)	20
22	30	9·58			37	9·31			30	9·80	(31)	n	39	9·65			30	9·05	(41)	o	22
24	25	9·59	(41)		43	9·11			37	9·65	32		39	9·61			19	9·00			24
2	28	9·62	(40)		34	9·05			39	9·52			39	9·52			12	8·98			2
4	32	9·62			31	9·05			45	9·40			39	9·48			o	8·97	(40)	(n)	4
6	32	9.68			30	9·20			45	9·45			39	9·45			18	9·07	42	r	6
8	30	9·71	46	c	25	9·20	43	(r)	35	9·48	(42)	r	39	9·50	41	r	24	9·18	(43)	(r)	8

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No. 5. DEVELOPMENT OF A CIRCULAR STORM DECEMBER 30-31, 1900.

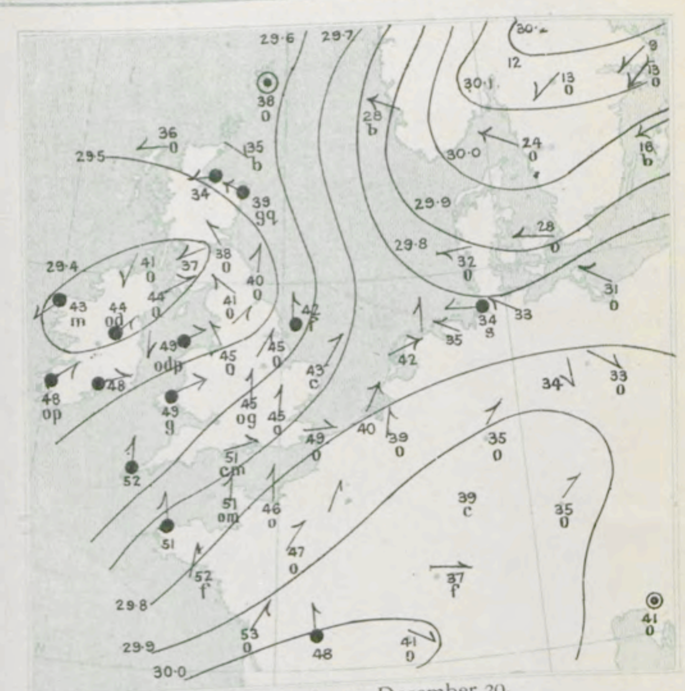
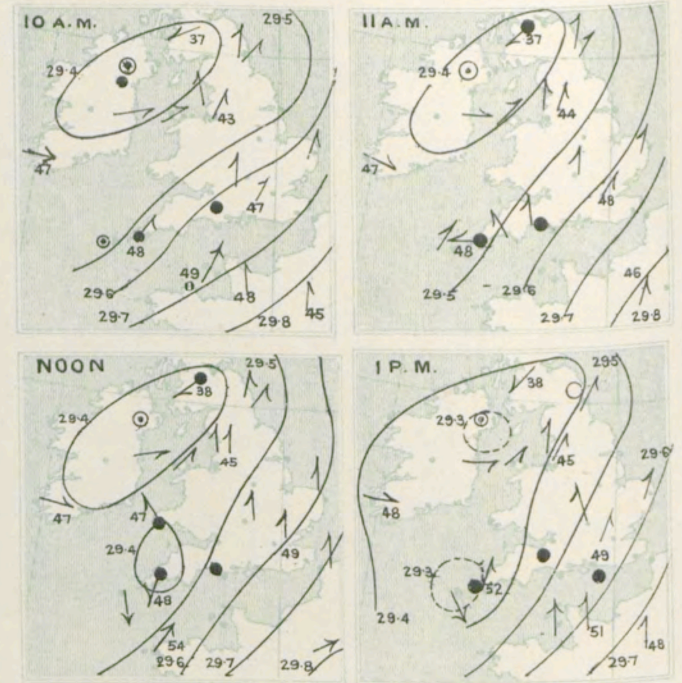


Fig. 1.—8 a.m. December 30.



Figs. 2-5.—10 a.m. to 1 p.m. December 30.

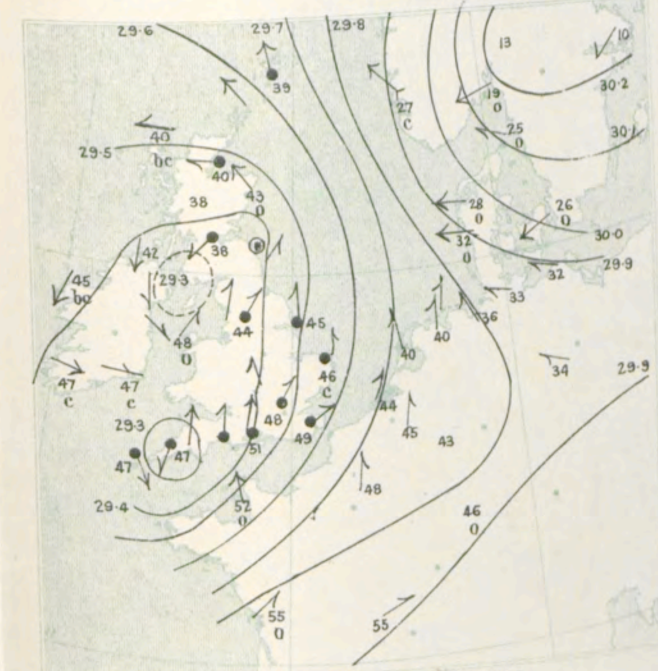


Fig. 6.—2 p.m. (14) December 30.

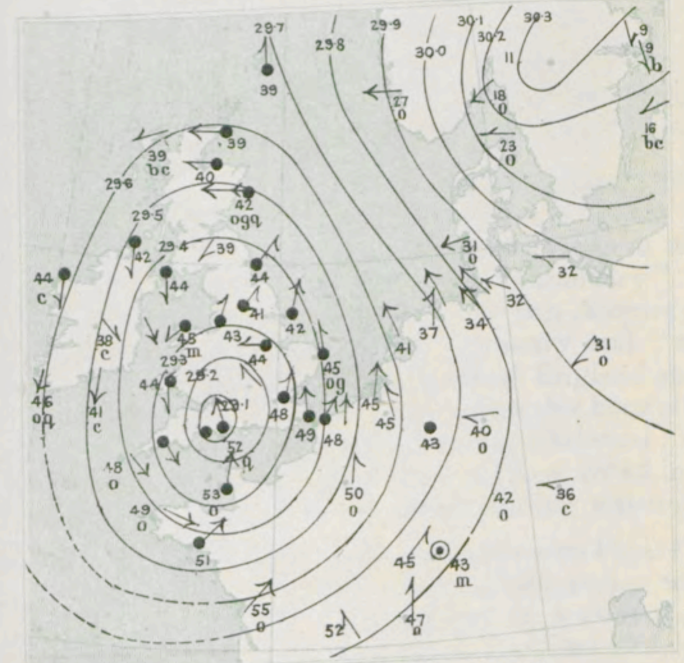


Fig. 7.—6 p.m. (18) December 30.

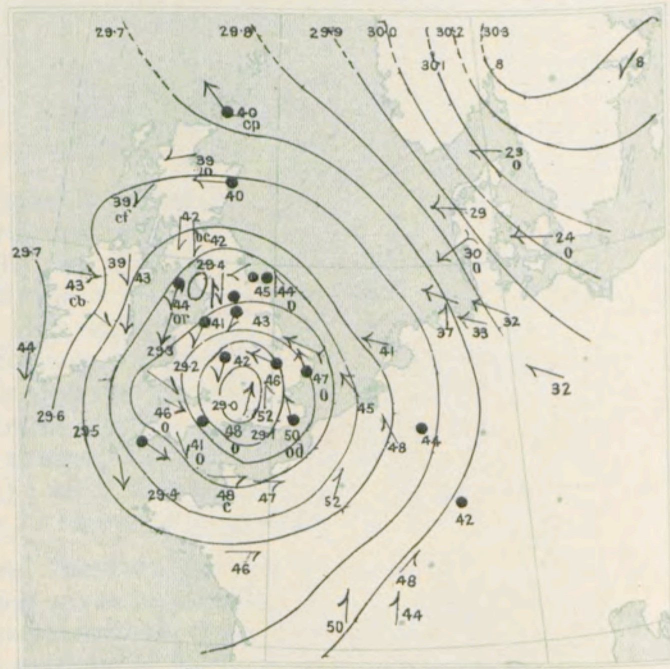


Fig. 8.—9 p.m. (21) December 30.

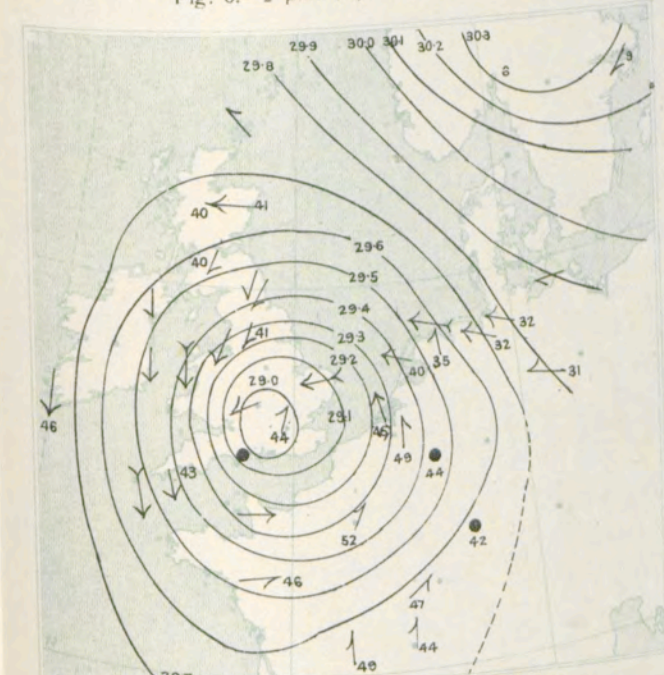


Fig. 9.—Midnight (24) December 30.

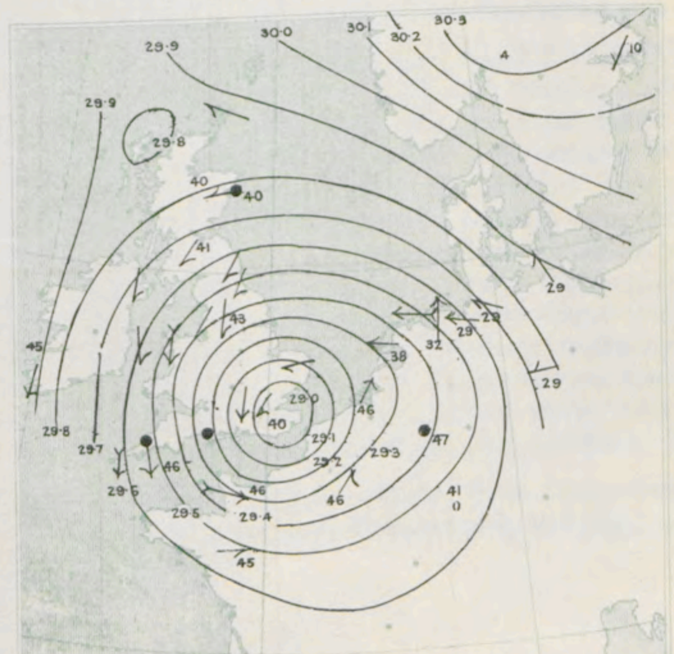


Fig. 10.—4 a.m. December 31.

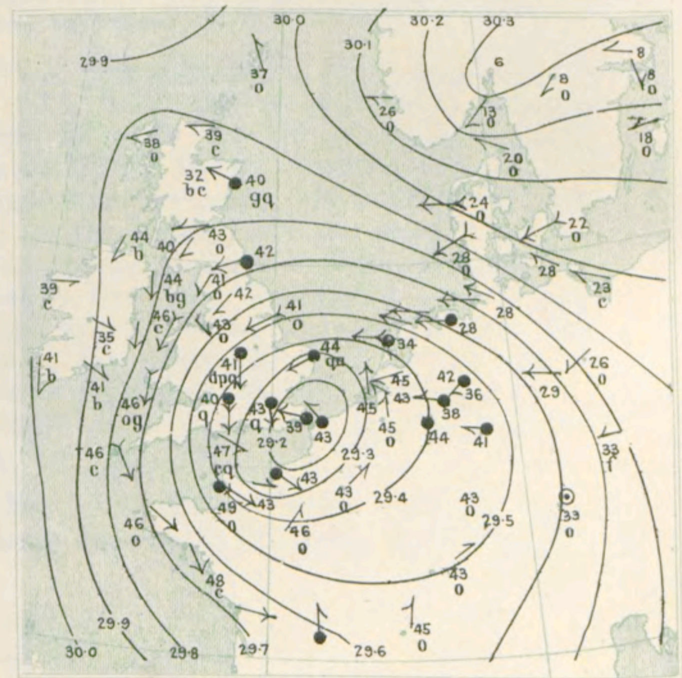


Fig. 11.—8 a.m. December 31.

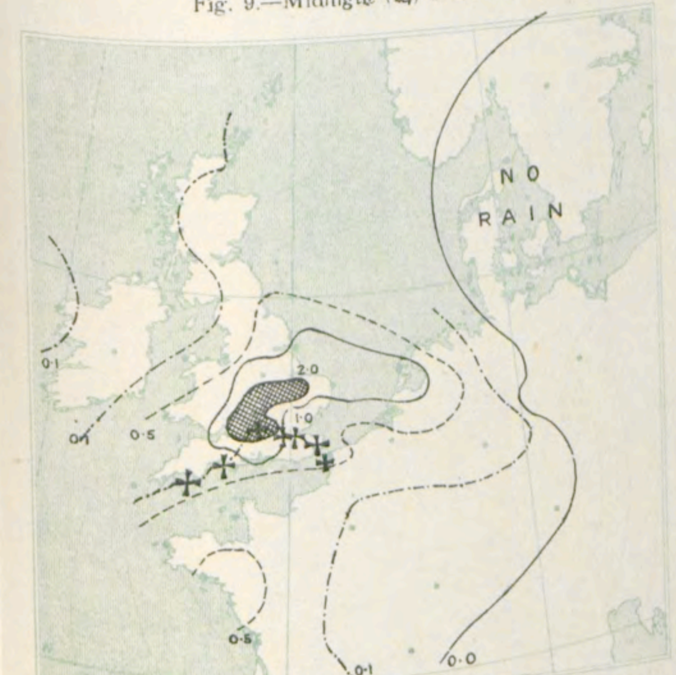


Fig. 12.—Rainfall measured on December 31.

The mark ● denotes that rain was falling at the hour of observation.

No. 5. Development of a Circular Storm from a Secondary over the South-west of England (Plates XI., XII.).

8 a.m. December 30th to 8 a.m. December 31st, 1900.

The map for 8 a.m. December 30th shows no trace of the disturbance about to be discussed, but when considered in connection with its subsequent development it presents some interesting features. Three distinct air currents may be distinguished on it :—

1. A rapid drift of very cold air from the East, over the Baltic and Southern Scandinavia, on the Southern side of a ridge of high pressure which extended South-westward from an anti-cyclone over North-western Russia. The continuation of this current to the Westward formed the Northern half of the circulation round a shallow depression over Ireland. In Scotland and the North of Ireland the temperature of the air was slightly below 40°.

2. A current from West-south-west over Wales and the South of Ireland, in which temperatures were below 50°, on the Southern side of this depression.

3. A current from the South over England, France, the Netherlands, and the West of Germany, blowing out of an anti-cyclonic ridge stretching into France from a region of high pressure over Spain. In the Eastern and Northern portions of this current temperatures were between 40° and 45°, but in the West readings were generally above 50°.

Up to 11 a.m. changes were slight ; the most important modification took place in the region between Scilly and Valencia, where pressure became very uniform. Shortly after this hour a fresh Northerly wind set in at Scilly, so that the map for noon on December 30th shows a well-marked "secondary" to the original disturbance, over Cornwall. During the subsequent hours this deepened very rapidly, while the original disturbance filled up. The rôles of "primary and "secondary" were very soon reversed, but the wind records from the North of England show that the original "primary" continued to exist until about 10 p.m. ; after this hour all traces of it became lost. The new disturbance in the South-west moved slowly Eastward ; it attained its greatest depth about 1 a.m. when the centre was near London (Kew 28·93 ins.) ; after this hour it also commenced to fill up and at 8 a.m. the lowest reading was only 29·12 ins. at Dungeness.

The length of the path shown on Figs. 1 and 2 between the epochs, noon December 30th and 8 a.m. December 31st, is 300 miles, which gives an average rate of progress of 15 miles per hour. Wind forces of 8 were of general occurrence to the North and in the rear of the disturbance, while at Portland Bill, an extreme of force 10, was noted. The ratio of the velocity of the wind to that of the storm centre was, therefore, between 2 and 3, so that the disturbance must be classed as a slow traveller.

The trajectories (Figs. 1 and 2, Plate XI.) also bear a distinct resemblance to those of November 11–13, 1901, and October 7–9, 1903. The velocities used in constructing these trajectories have been, as usual, taken from the winds observed at exposed stations at the surface of the earth. The records from the Eiffel Tower show that at a level of only 1,000 feet above the ground very much larger velocities prevailed ; while the direction of motion was in general tangential to the isobars ; the trajectory X (shown dotted) has been constructed on the assumption that the direction of motion is along the isobars and the velocity equal to that registered on the tower. Its general course is very similar to that of the trajectories traced with the help of the surface observations. The warm current from the South is represented by the trajectories A, B, and C. As in the previous cases, this warm current rises over the top of the cold air further to the North, and the forced ascent of warm moisture-laden air gives rise to the heavy rainfall on the Northern side of the path shown in Fig. 12, Plate XII.

The synoptic charts show that over the Continent the warm Southerly wind gradually encroached Eastward, and by 1 a.m. on the 31st we find that the temperature at Brussels had risen to 50°. Trajectory D represents this flow of warm air over the Netherlands. As the wind at The Helder remained persistently Easterly and the temperature low, it is clear that the region of ascent must have been situated to the South of this station, and the heavy rainfall experienced in the North of Holland confirms this view. A second region of forced ascent of warm air is suggested on the map for 6 p.m. December 30th. At this hour there was a strong North-westerly wind at Brest and a temperature of 48°, and a rather less brisk South-westerly wind at a temperature of 51° at the neighbouring station of Lorient. These two currents, which are respectively represented by the trajectories E (Fig. 1) and O (Fig. 2), were thus blowing at right angles to each other, and it seems probable that the cold North-westerly wind forced its way underneath the warmer South-westerly one, and in doing so gave rise to effects similar to those which will be described in discussing the events of the night from October 14th to 15th, 1903 (*see* p. 51); the rainfall map (Fig. 12, Plate XII.) which shows a fall of over half-an-inch in this part of France supports this hypothesis.

The cold air which took the place of the warm Southerly wind was derived from various sources. In the first instance, the Northerly wind shown on the map for noon, December 30th, can hardly be looked upon as other than a descending current; no surface source of supply from which this air could be drawn is indicated on the map for 11 a.m., the distribution of pressure at this hour would lead us to expect light breezes from between South and West over the Bristol Channel. The subsequent course of this air is shown by the trajectory E. It becomes directed towards the South-east, and then to the East on the Southern side of the depression, and finally it appears to approach the storm centre a second time.

Trajectory F shows that a further supply of air at a lower temperature than the Southerly current was drawn from the West or North-west; this air also flows to the South-east and finally to the East as it reaches the Southern side of the storm.

The air situated over South-western England, in the rear of the storm on the morning of December 31st, can be traced back to the North of England or the South of Scotland in the trajectories G and H. Of these G passes in a North to South direction along the Western side of the original disturbance, which became a "secondary" to its more vigorous offshoot: Northward of Ireland it comes from the East and the origin of the air must be sought over the North Sea; H can be traced backwards as far as the neighbourhood of North Shields at 9 p.m. on December 30th, but here we find ourselves in the region of light winds associated with the "secondary" in the North.

Perhaps the most striking trajectories are those which represent the flow of the cold air from the Continent round the centre of low pressure (K, L, M, N). These may again be sub-divided into two groups. K and L start in the relatively cold Southerly winds (temperature slightly above 40°) which were blowing along the Dutch coast and over Western Germany on the morning of December 30th. They subsequently turn to the West and finally to the South, tracing out approximately semicircular paths round the centre of low pressure. M and N, on the other hand, commence in the very cold Easterly winds blowing over Southern Scandinavia and Northern Germany. Throughout the 24 hours under discussion strong Easterly winds, showing a very great "in-curvature," were blowing in this region; on the maps for 2 p.m. and 6 p.m. the direction of motion of the air here was more nearly along the gradient than tangential to it. It is therefore probable that Easterly winds were blowing across the North Sea during the night from December 30th to December 31st, and that the trajectories as drawn represent the actual occurrences with sufficient accuracy. The temperature of this air was close on the freezing point as it left the Continent, but it was raised several degrees during its passage across the German Ocean, of which the temperature, as measured at our East coast light-ships and light-houses, was between 44° and 47°. Unfortunately no temperature observations are available from the North-east of England, which would enable us to determine the temperature of the air on its arrival at our shores, but the minimum temperatures at North Shields and and Spurn Head, 38° and 39° respectively, enable us to assign an inferior limit. At 8 a.m., when the air had reached our Midland districts, its temperature was about 41° or 42°.

The changes occurring near the storm centre were particularly interesting. At 10 p.m. the temperature at Kew, then not far from the centre (barometer 28·98 ins.), was 52°, while the wind was Southerly. During the following hours the wind direction remained unchanged, but the temperature fell rapidly, and at 2 a.m., when the storm centre was almost over the station (barometer 28·93 ins.), the reading had fallen to 39°, the lowest value in the district.

Trajectory P represents an attempt to trace the origin of this cold Southerly wind. The process of drawing trajectories becomes particularly hazardous so near the storm centre. The only guide to the direction of motion of the air available is afforded by the isobars, and not only does a considerable amount of uncertainty attach to the amount of in-curvature, but the course of the isobars themselves is more than ordinarily affected by small errors in the adopted barometric values. The cold air of the trajectory appears to have been derived from the Northerly wind blowing in the immediate rear of the disturbance at 7 p.m. Some confirmation of the general correctness of the trajectory is afforded by the temperature observations at 9 p.m. These show a reading of only 41° at Parkstone in Southern Dorsetshire, at a time when the air of the trajectory lay off the South-west coast of the Isle of Wight.

The temperature contrasts over the Netherlands and Northern Germany at 8 a.m. on December 31st (*see* map, Fig. 11, Plate XII.) were very great; Brussels reported 45°, de Bilt (Utrecht) 42°, but Groningen only 28°, and Bremen 26°, and from this we might be led to expect that the disturbance would again become deeper or, at any rate, continue to exist; but this was not so. The process of filling up went on rapidly; at 2 p.m. the lowest pressure recorded over Germany was about 29·5 ins., and by 6 p.m. the secondary shown in the morning over the Gulf of Genoa had become the centre of disturbance, the lowest pressure readings being 29·39 ins. at Nice and 29·37 ins. at Florence. The rainfall measured on the morning of January 1st in Holland and North-western Germany was also small; the largest amount recorded in the Daily Report of the Deutsche Seewarte was only 0·47 inch.

The Tables of Plate XI. again give the meteorological elements along the trajectories; as many of the steps lay over the Ocean, the number of blanks is larger than usual. The Southerly winds show the usual decrease of pressure, but the increase of velocity as given by the wind observations, is very small. It must, however, be remembered that most of the observations are from the land stations, so that the effects of surface friction were considerable.

Observations of weather, at other than the fixed hours, are almost entirely wanting from the Continent; in England rain fell in the region of the Southerly winds.

In the case of the cold air trajectories a marked decrease of pressure occurred, while the direction of motion was from East or North-east; but when in the rear of the storm it became directed towards the South or South-east the rate of change became very slight.

No. 6.—Circular Storm in which the Direction of the Path changed from N.E. to S.E. (Plates XIII. to XVIII.).

6 p.m. October 14th to 6 p.m. October 17th, 1903.

In this case observations from the second order stations in Iceland and the Faroe Islands, kindly supplied by Dr. Paulsen, the Director of the Danish Meteorological Institute, and a barogram from Stavanger, near Skudesnaes, lent by Prof. Mohn, the Director of the Norwegian Meteorological Service, have enabled us to extend the area dealt with in the two-hourly charts further to the North than is usually possible. As the changes were exceedingly complicated during the early stages, the whole series of maps for the period 6 p.m. October 14th to 8 a.m. October 15th has been reproduced; for the later stages only a selection is given. The distribution of rainfall measured on each morning during the period considered is shown on the small circular maps, Plates XIII. to XVIII. The charts show a minimum of pressure over the West of Ireland on the evening of October 14th, which moved in a North-easterly direction during the night from October 14th to October 15th. At 8 a.m. on the 15th it was situated between Wick and Stornoway. The depression at this hour shows a steep gradient on all sides of its centre, in marked contrast with the circular storms of March 23rd, 1902, and September 10th, 1903, already discussed, in which the gradient was very slight on the Northern side. During the following 24 hours the centre of the disturbance remained almost stationary off the North coast of Scotland. Shortly after 8 a.m. on the 16th a change set in, which it was not possible to forecast from the information available at the time; if we had been cognisant of the increase of pressure which was taking place over Iceland and the Faroe Islands the fact that the centre of the disturbance would shortly commence to move in a South-easterly direction might have been anticipated. By 2 p.m. on the 16th a very steep gradient for Northerly winds had developed over the region between Stornoway and the Faroe Islands, and at 6 p.m. we find the centre of the disturbance near Aberdeen. The subsequent changes were again very complex; as the centre of the disturbance lay over the North Sea, the changes in its position cannot be traced even with the help of the barogram from Stavanger. At 8 a.m. on the 17th the lowest reading of the barometer was shown over the Head of the Skager Rak, and a long furrow of low pressure extended across the North Sea from Skudesnaes to the Helder. During the day this trough continued to move slowly Eastward or South-eastward, and a gradient for Northerly winds prevailed over our Islands.

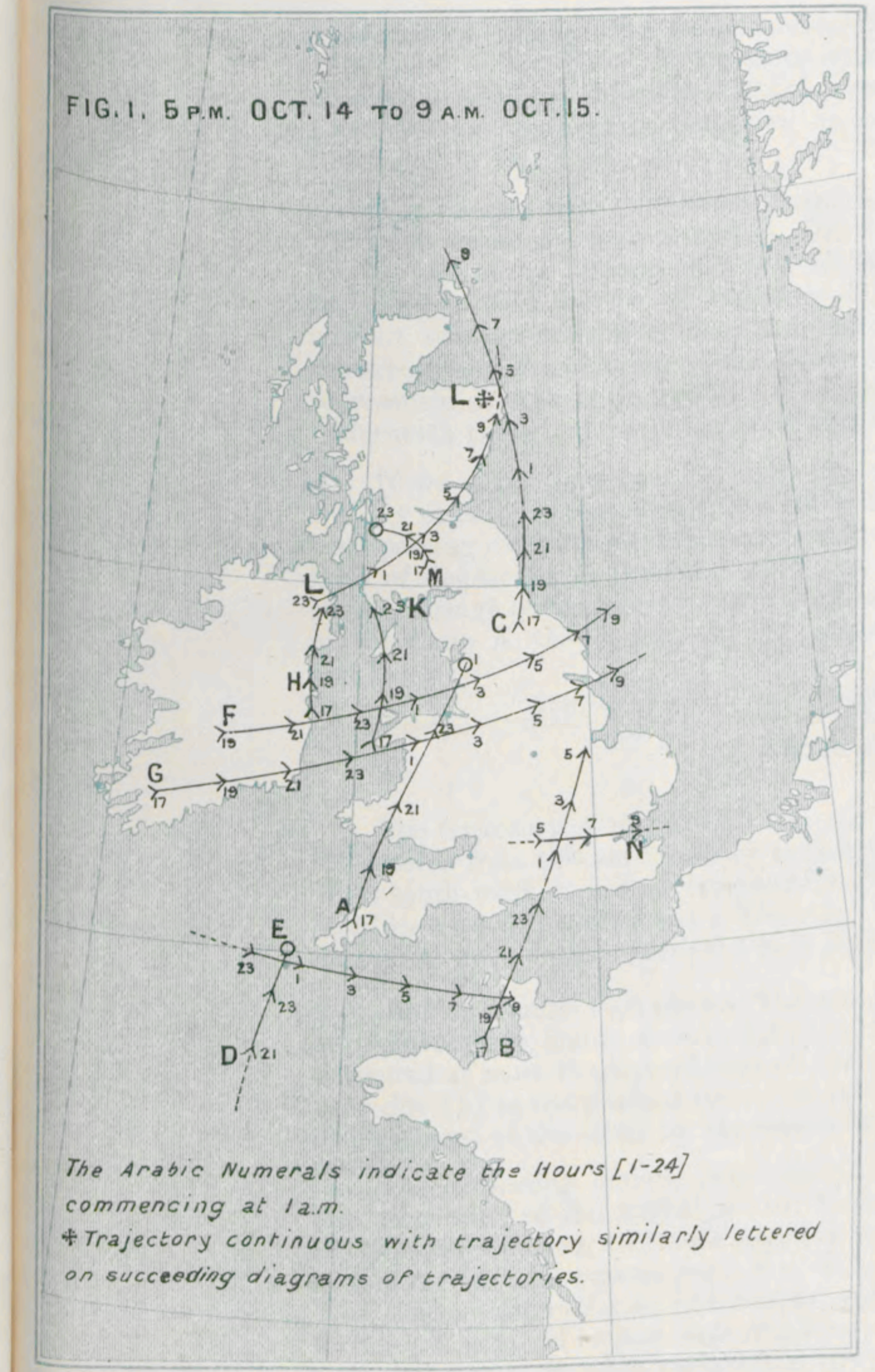
The trajectories constructed from these maps are shown in six diagrams on Plates XIII. to XVIII., each of which gives the motion of the air during the successive intervals between the hours of observation at the telegraphic reporting stations (8 a.m. and 6 p.m.). In a number of cases it was possible to continue a trajectory for a longer period, so that the same trajectory appears on two successive diagrams in different parts of its course. In these cases the curves have been similarly lettered and asterisks have been placed against the steps which are common to two diagrams.

Plate XIII. The trajectories for the period of Northward motion of the minimum of pressure are shown on Fig. 1, Plate XIII. At 6 p.m. on October 14th a strong Southerly to South-south-westerly wind was blowing over England and Scotland; this is represented by the trajectories A, B, C. It should be noticed that the wind force at the Channel stations at 6 p.m. (*see* map) was generally estimated as force 6 on the Beaufort scale, while in the North of England it was only 3 or 4. As the direction of motion was everywhere approximately the same, convergence of the second type, described on p. 19, must have been taking place, and we should, therefore, expect rain to be falling over the greater part of the country, an expectation which is borne out by the observations. At 9 p.m. a similar state of affairs prevailed.

The records of the anemometers all show a sudden veering of the wind by about 6 points or more at some time during the night, or early morning. Thus at Scilly a

Plate XIII.

No. 6. STORM OF OCTOBER 14 6 p.m. to OCTOBER 17 6 p.m.



Hours.	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	Hours.
	A				B				C				E				
18	25	9·50	(57)	r	15	9·81	60	o	15	9·44	52	o					18
20	30	9·43			25	9·73			15	9·43							20
22	37	9·32			25	9·70			15	9·35							22
24	30	9·32	54	r	25	9·62	(58)	c	21	9·28			22	9·58			24
2					25	9·52	55	p	21	9·12	(51)	p	22	9·56	(50)		2
4					24	9·38			21	9·00			22	9·58			4
6									25	8·98			22	9·63			6
8									31	8·80	48		22	9·62	54	o	8
	F				G				K				L✻				
18					30	9·25	(50)	(c)	20	9·37	52	r					18
20	30	9·22			30	9·27		(bc)	20	9·30	53	r					20
22	30	9·28			30	9·30			20	9·15							22
24	26	9·32			30	9·35							29	9·15		bcp	24
2	26	9·32	52	n	26	9·35							24	9·12	47		2
4	26	9·30			25	9·34							24	9·08			4
6	20	9·30		cp	20	9·34							20	9·05			6
8	17	9·32	48	b	15	9·36	48	b					20	8·96	46	b	8

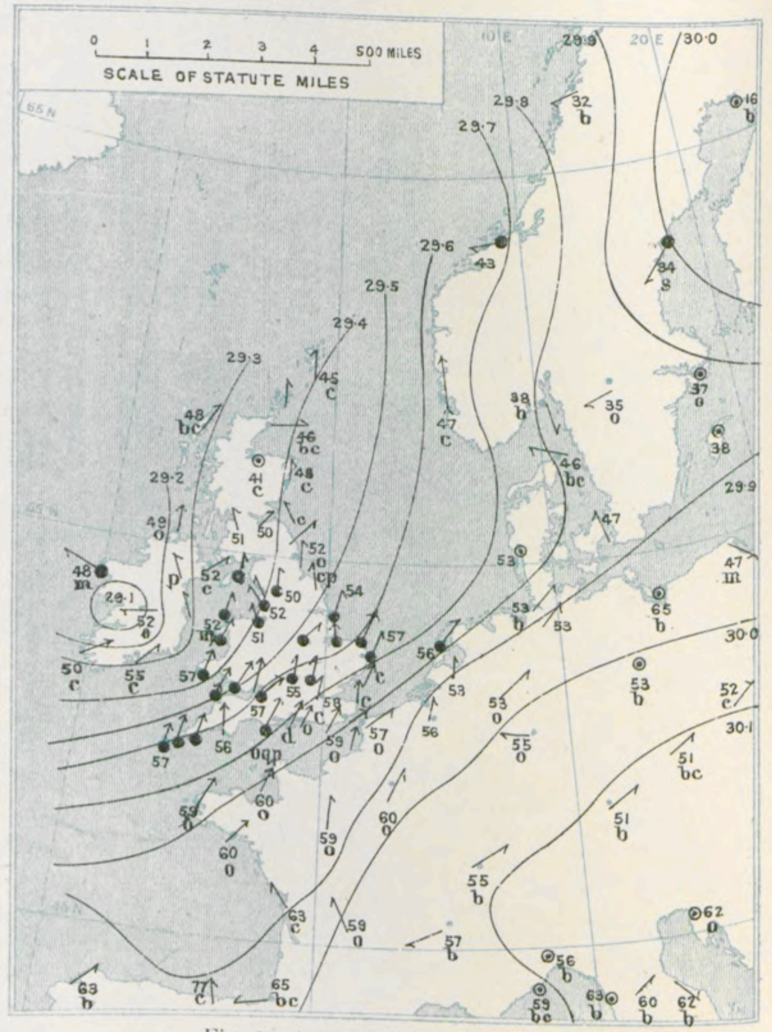


Fig. 2.—6 p.m. (18) October 14.

Fig. 9

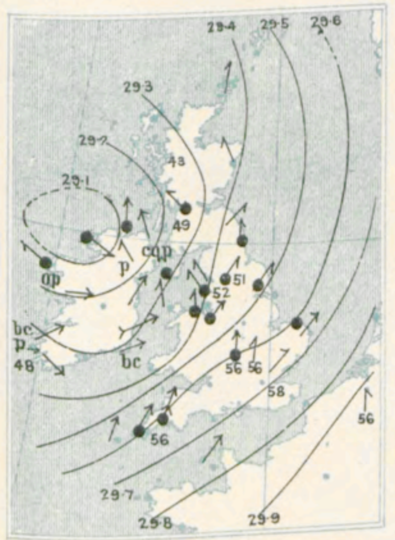


Fig. 3.—8 p.m. (20) October 14.

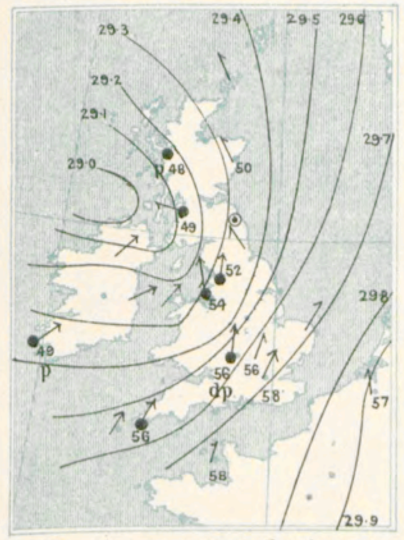


Fig. 4.—10 p.m. (22) October 14.

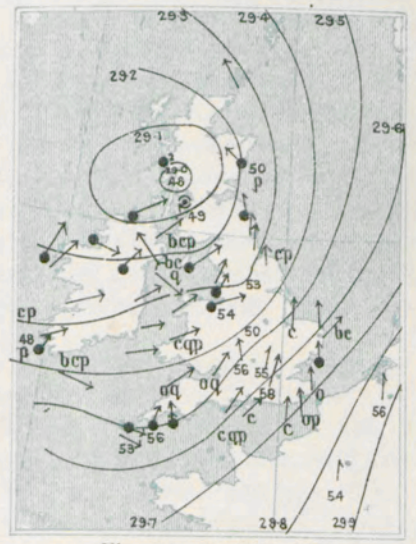


Fig. 5.—(24) Midnight.

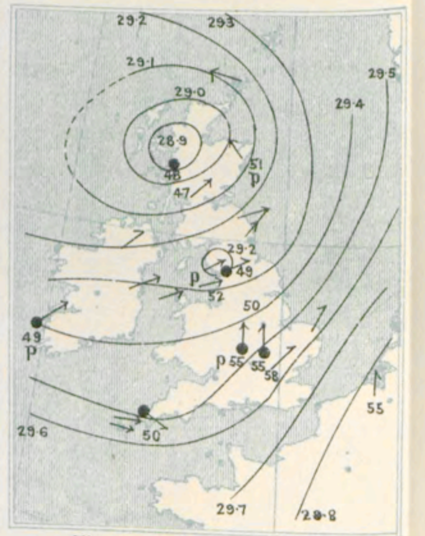


Fig. 6.—2 a.m. October 15.

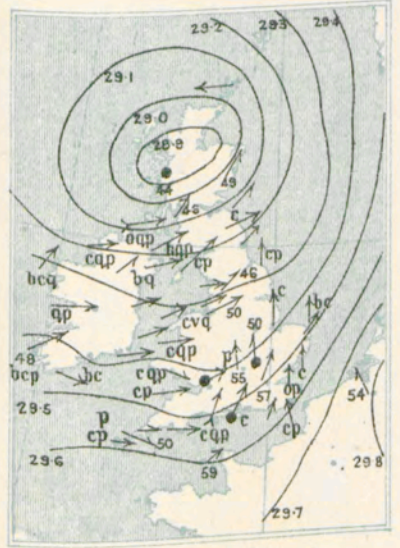


Fig. 7.—4 a.m. October 15.

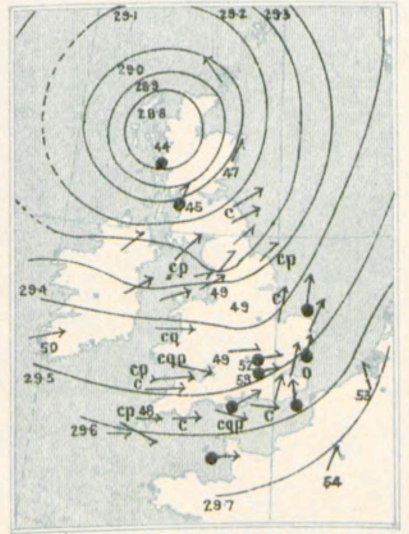


Fig. 8.—6 a.m. October 15.

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The symbol ● indicates that rain was falling at the hour of observation.

The rainfall charted on the circular maps is that measured at 8 a.m. or 9 a.m. on the dates given.

✻ Trajectories continued on other diagrams.

sudden shift of the wind from South-south-west to West-by-North was registered at 11.40 p.m., and at Falmouth a similar change took place at 0.40 a.m. Between these two epochs the winds at these two stations were blowing almost at right angles to each other (*see* map for midnight), furnishing an excellent example of the type of convergence illustrated in Fig. 11, p. 19.

The records of the self-registering instruments at Falmouth show that the change of wind was accompanied by a sudden fall of temperature from 56° to 50°, by an equally sudden increase of pressure of about ·02 inch and by a heavy fall of rain. There can be little doubt that the air of trajectory D, which formed part of the steady Southerly current referred to above, rose from the surface of the earth at the time when the wind changed, and that its place was taken by the colder current from West-north-west represented by the trajectory E. The bank of cold air, in this case, pushed its way underneath the warm Southerly wind and forced it to ascend.

If we allow ourselves to make the assumption that the increase of pressure was entirely caused by the substitution of a layer of cold air for the warm air which had been passing over the station, we can find an approximate value for the thickness of the layer of displacing air from the amount of increase of pressure. If we assume that the surface change of temperature of 6° represents the average change throughout the layer of thickness h, the density of the whole layer would change in the ratio 497 : 491 and hence :—

$$\frac{h(\text{in feet}) \times 12}{\cdot 02} = \frac{13\cdot 6}{\cdot 00129 \times \frac{497-491}{491}}\text{; whence } h = 1{,}440 \text{ feet.}$$

The trajectory A underwent a similar fate at Southport at 11.30 p.m., at which hour the records from this station show a change of wind direction from South-south-west to West-south-west, a fall of temperature from 55° (the maximum for the day) to 52°, a rapid increase of pressure and a heavy fall of rain. The latter phenomenon was also very marked at Stonyhurst, where 0.3 inch fell between 0.30 a.m. and 1 a.m.

Similar changes took place at Valencia at 4 p.m. on October 14th, at Oxford at 4.10 a.m. on October 15th, and at Kew at 5.30 a.m. on October 15th. The large amount of rainfall measured at most English stations on the morning of October 15th is thus seen to have been due (1) to the gradual ascent of air within the Southerly current, and (2) to the displacement of the latter by the colder Westerly wind.

The displacing current from the West was steady in direction and velocity during the remainder of the night in the South, but over Northern England many minor fluctuations occurred, and some question may arise as to the correctness of the trajectories in this region. The anemogram from Kingstown shows a sudden veering of the wind to West-south-west at 9 p.m. (21 hours), and if this West-south-westerly current be traced forward, it is found to pass over Anglesey shortly after 11 p.m. (23 hours), at which hour a similar change of wind occurred at Holyhead, and to reach the coast of Lancashire at 2 a.m. when West-south-westerly winds were recorded at Fleetwood, Southport, and Stonyhurst (*see* map for 2 a.m., Fig. 6). There is thus good reason for supposing that the trajectories F and G represent satisfactorily the chief characteristics of the flow of air over Northern England, after the interruption of the current from the South.

It is probable that the Westerly wind was, in part, a descending air current. Oxford is situated about 40 miles West of Kew, and as the interval between the shift of the wind at the two stations was 1 hour 20 minutes, the Westerly component of the displacing wind, supposing it to travel entirely along the earth's surface, would have to be 30 miles an hour for it to keep pace with the rate of progress of the change. The velocities recorded by the anemometers were only about 16 miles per hour (factor 3), and, therefore, we are forced to the conclusion that the displacing air must have descended from above, even if we allow a wide margin for the effects of surface friction in retarding the motion of the lowest layers of the atmosphere. The fact that the sky was cloudless at the stations in the Midlands at 8 a.m. October 15th (*see* map, Fig. 1, Plate XV.), while rain was still falling at Yarmouth and on the extreme East coast, supports this view.

The changes in the North-west of our Islands were exceedingly complex. Very rapid barometric fluctuations occurred between 10 p.m. and midnight. At the former hour there is good evidence for the existence of a centre of low pressure off the North coast of Ireland; not only is the reading of the barogram at Malin Head, 28·97 in., the lowest shown on the map, but we have also an Easterly wind at Glasgow. By Midnight a decided rise of the barometer had taken place at Malin Head, and a very rapid fall had occurred at Fort William, so that the centre of low pressure was then situated over Western Scotland. The changes are so abrupt that the suggestion arises that we are not dealing with the same disturbance in both cases, but that the minimum shown on the map for 10 p.m. had dispersed, while a new one had formed near Fort William by Midnight.

The trajectories H and K represent the course of the Southerly winds blowing at Holyhead and Kingstown at 6 p.m. They can be traced Northward until about 10 p.m., at which hour they had reached points somewhat South of Belfast and the Mull of Galloway respectively, but their subsequent courses are doubtful. The air passing over Aberdeen at 8 a.m. on October 15th, when traced backwards (trajectory L), is also found to have been in the extreme North-east of Ireland at about 11 p.m.

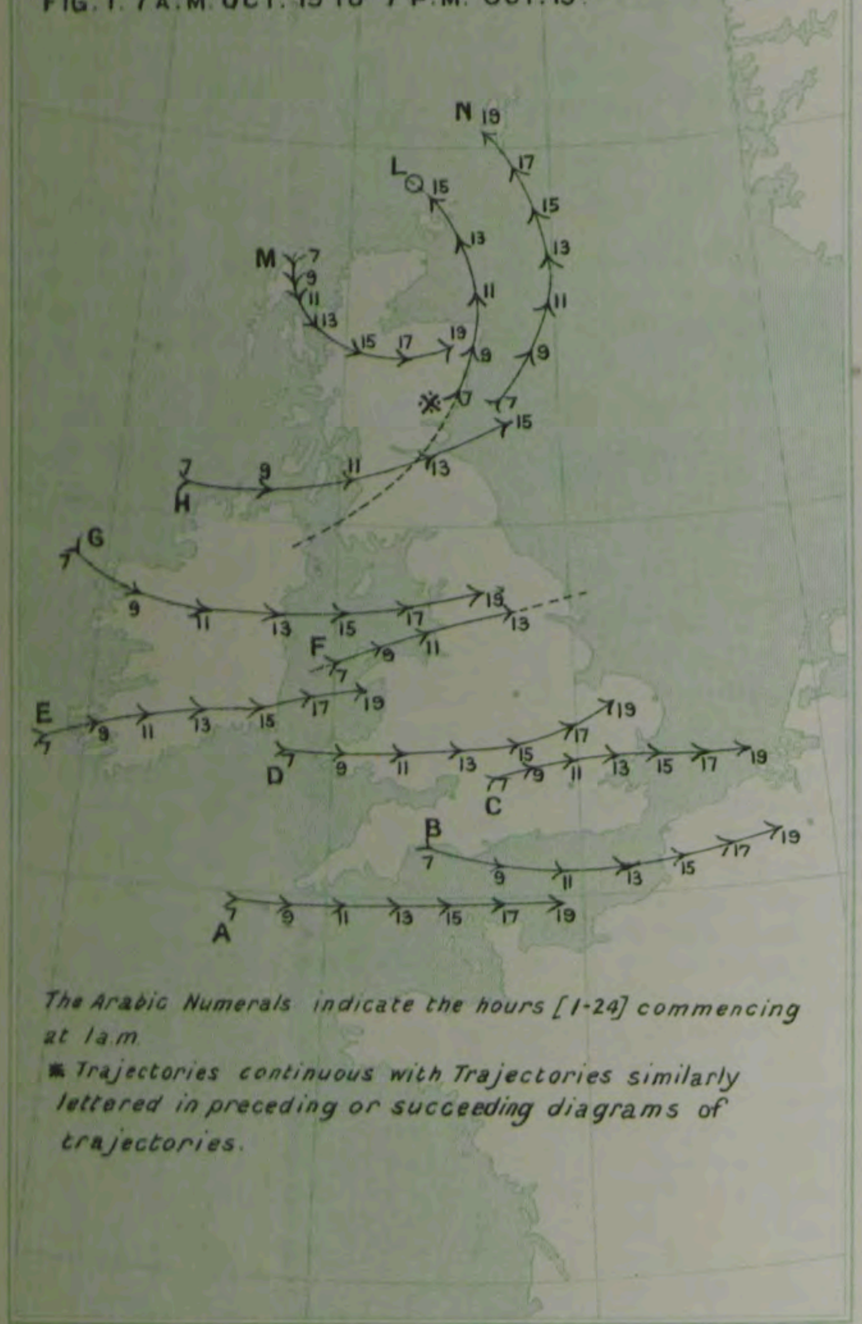
The question arises whether the trajectories H and L may be regarded as continuous, *i.e.*, as representing the flow of the same air. Temperature considerations do not favour this view. At 6 p.m. the temperature at Holyhead, Donaghadee, and Birr Castle was 52°, so that we may assume that the air in both trajectories H and K was originally at this temperature; at 9 p.m., when K had reached Douglas in the Isle of Man, 53° was recorded at that station. On the other hand, the air in trajectory L, as given by the readings at Glasgow and Aberdeen at 2 a.m. and 8 a.m. respectively, was at a temperature of 46° or 47° throughout its course. Such a rapid change of temperature is difficult to explain, and, moreover, the assumption that it occurred involves a rapid change in the direction of motion of the air from South, or in the case of K from South-south-east, to West-south-west. It is more probable that the warm air of the Southerly current rose to the upper strata of the atmosphere, and that its place at the surface was taken by the colder descending air of the trajectory L. There are, however, difficulties in the way of this supposition also. The rainfall measured in the North-east of Ireland on the morning of October 15th was small (0·15 inch at Belfast, 0·13 inch at Armagh, and only 0·04 inch at Donaghadee), while in the South-west of Scotland we have a small area within which no rain fell. As the Southerly current was warm and almost saturated (relative humidity at Douglas at 9 p.m. 99 per cent.) its ascent must have been accompanied by much condensation, so that we should expect heavy rainfall. It is of course conceivable that the rain was carried along by the upper winds and that it fell at some distance from the place where it was formed. Heavy rain fell in the extreme North of Ireland and in the West of Scotland (*see* map, Fig. 9, Plate XIII.).

The records from Ben Nevis afford little help in unravelling the complex changes which occurred in these parts, though the disturbance appears to have passed almost over the mountain. From 6 p.m. to 8 p.m. a strong South-easterly wind prevailed at the summit, but subsequently as the centre of low pressure approached, the wind increased considerably in force and backed to East-south-east. At Midnight, when the centre of the disturbance was very near the mountain, the reading entered is East-south-east 7 (Ben Nevis scale, approximately 63 miles per hour). South-easterly winds continued to 3 a.m., but for 4 a.m. we find the entry South, variable, 2–6, and for 5 a.m. West, variable, 4–7. We cannot determine whence the air of the South-easterly wind at the summit was derived; the most obvious suggestion is that it came from the Southerly wind blowing over England and Scotland during the early part of the night, which, as we have seen, was an ascending current. Adopting the adiabatic temperature gradient for saturated air of 0°·54 C. per 100 metres, or 0°·3 F. per 100 feet, we get a decrease of temperature of 14° F. for an ascent through 4,400 feet, so that the temperature of 30° which prevailed on Ben Nevis would

PLATES XIV., XV.

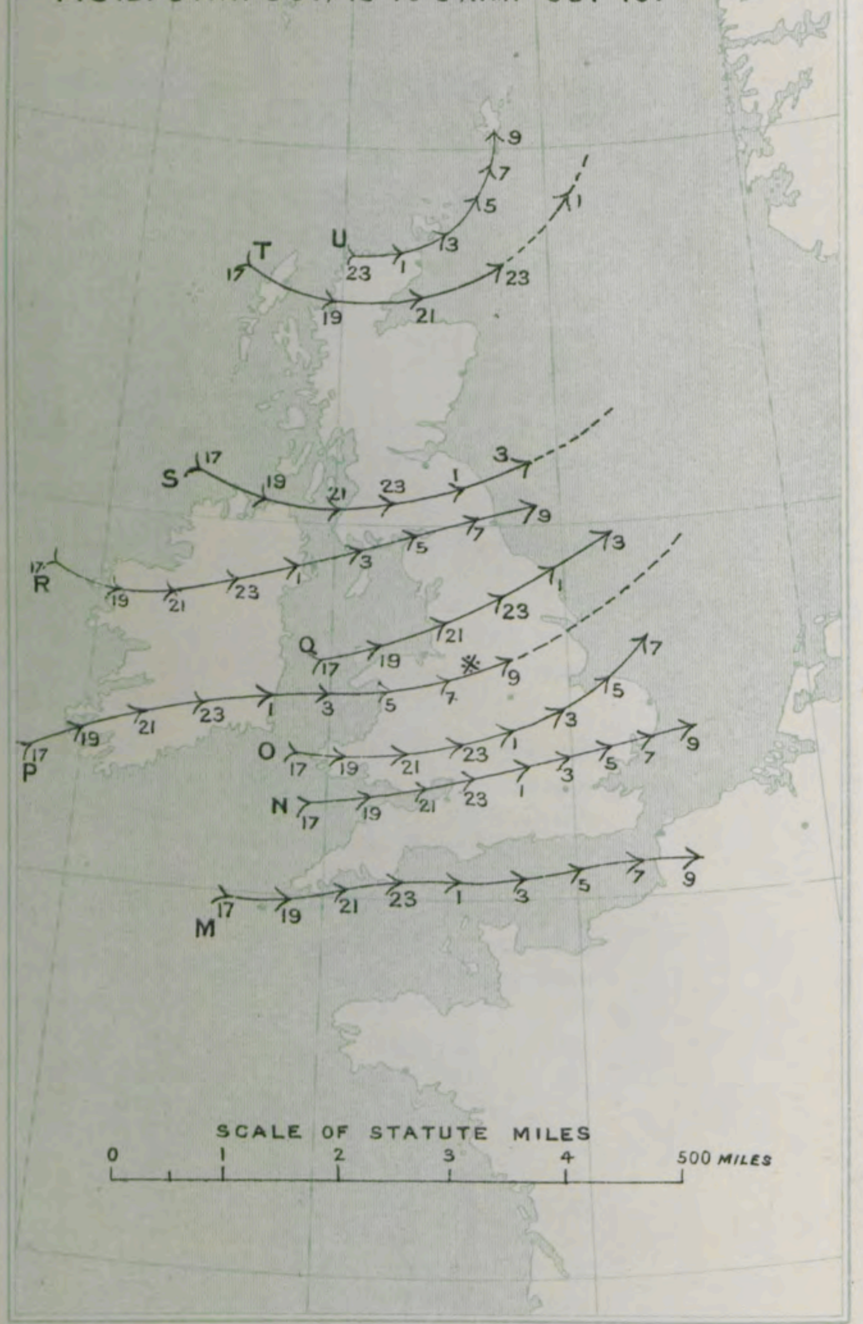
Nº 6. Continued

FIG. 1. 7 A.M. OCT. 15 TO 7 P.M. OCT. 15.



The Arabic Numerals indicate the hours [1-24] commencing at 1 a.m.
* Trajectories continuous with Trajectories similarly lettered in preceding or succeeding diagrams of trajectories.

FIG. 2. 5 P.M. OCT. 15 TO 9 A.M. OCT 16.



TABLES CORRESPONDING TO TRAJECTORIES OF Fig. 1.

Hours.	A				B				C				D				E			
	V	P 30+	T	W	V	P 29+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W
8	22	9·66	54	chq	31	9·56	53	c	18	9·52	49	b	25	9·47	53	cpq	22	9·55	50	cpq
10	22	9·70			28				18	9·53	53	n	25	9·52			22	9·55		
12	22	9·71			25				18	9·55	55	n	25	9·55		(cp)	22	9·58		
14	22	9·75			25	9·68	(58)		18	9·55	55	bc	25	9·58	(53)	(bc)	22	9·58	(52)	(bc)
16	22	9·75			20				18	9·55			25	9·58			22	9·56		
18	22	9·78			20	9·72			18				20	9.60	(52)	(bc)	22	9·55	(50)	cptq

G				L*				M				N				Hours.
V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	
30	9·36	50	bcq	20	8·96	46	b	8	8·69	46	(r)	26	9·02	(46)	(b)	8
30	9·43			25	8·90			8				27				10
30	9·43			25	8·80			15	8·80			20				12
30	9.45	(52)	c	20	8·72			20	8·85	46	c	20				14
30	9·47			0	8·70			20	8·90			20				16
30	9·48	48	p	-				20	9·10	(44)		20	8·76	47	o	18

TABLES CORRESPONDING TO TRAJECTORIES OF Fig. 2.

Hours.	M				N				O				P*				Q			
	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W
18	24	9·78	53	c	25	9·69			25	9·61	52	c	25	9·65	48	chp	25	9·52	50	cpt
20	24	9·82			25	9·73			25	9·61			25	9·65			30	9·53	47	p
22	24				21	9·72			25	9·68			25	9·65			26	9·51	43	r
24	25				21	9·71	(44)	(n)	25	9·66	(44)	(n)	25	9·65			25	9·48		(bc)
2	25				18	9·70	45	(n)	25	9·64	(44)	(n)	25	9·63			25	9·43		
4	25				18	9·69			25	9·60			25	9·62		cql				
6	25				18	9·70			25	9·58			25	9·58						
8	25	9·80	(52)	(b)	18	9·71	45	b					25	9·60	(47)	(b)				

R				S				T				U				Hours.
V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	
25	9·50	48	cp	31	9.32	48	cq	37	8·88	46	r					18
25	9·50	(41)	bc	30	9·38		(r)	37	8·99	45	r					20
25	9·48			30	9·38			37								22
25	9·49		r	30	9·38							23				24
25	9·45			30	9·33	(46)						23				2
25	9·42		(c)									21				4
25	9·42											14				6
25	9·37	48	o									10	8·98	46	c	8

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Nº 6 continued

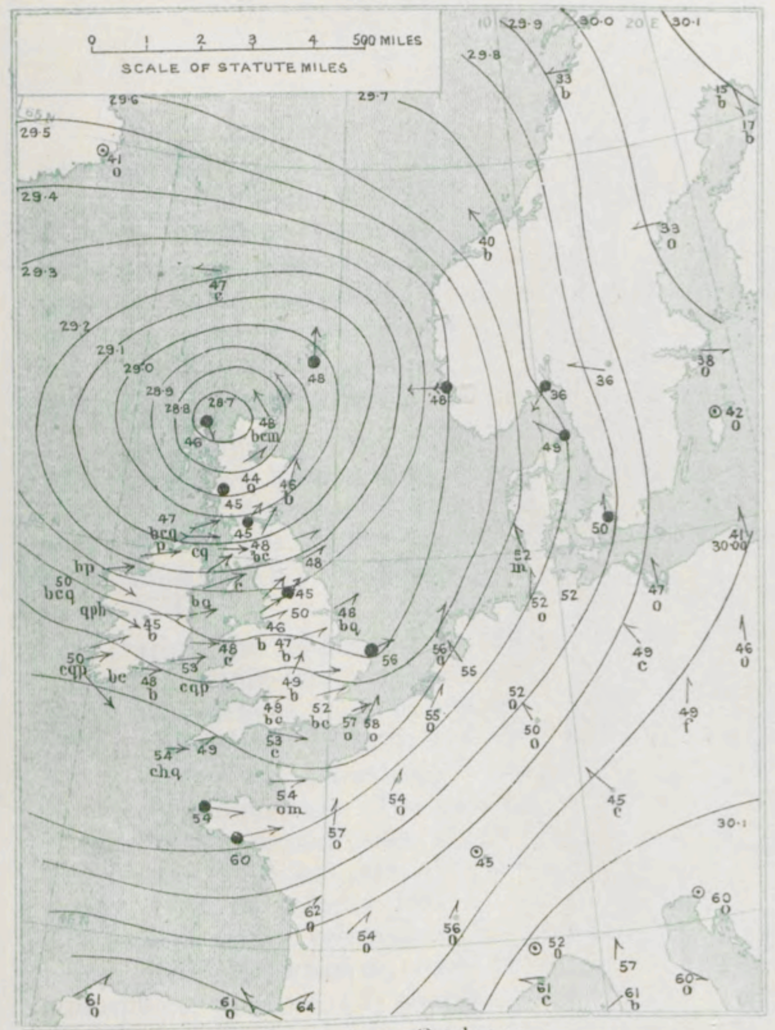

Fig. 1.—8 a.m. October 15.

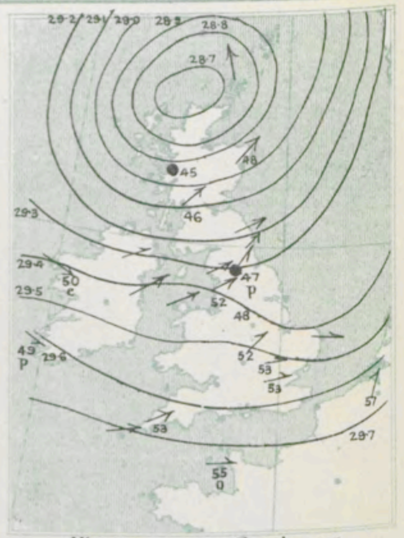

Fig. 2.—10 a.m. October 15.

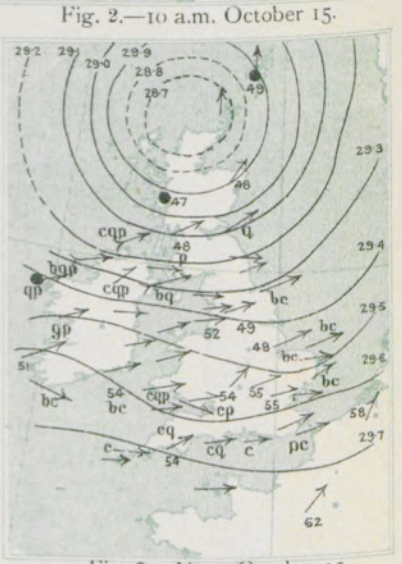

Fig. 3.—Noon October 15.

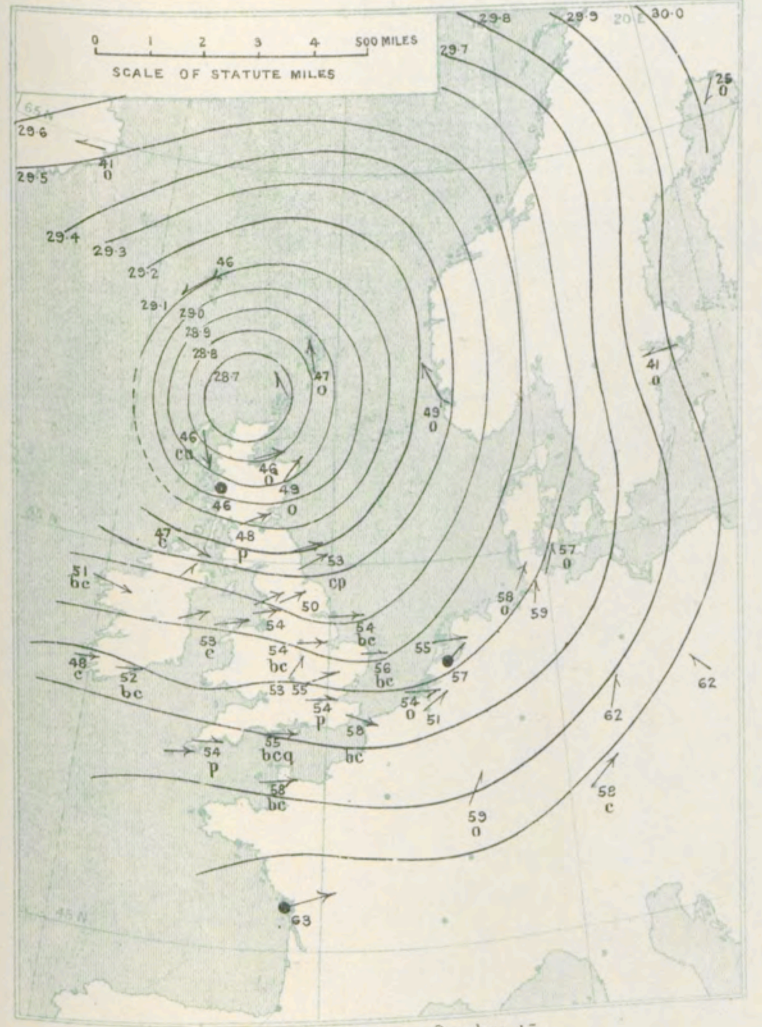

Fig. 4.—2 p.m. (14) October 15.

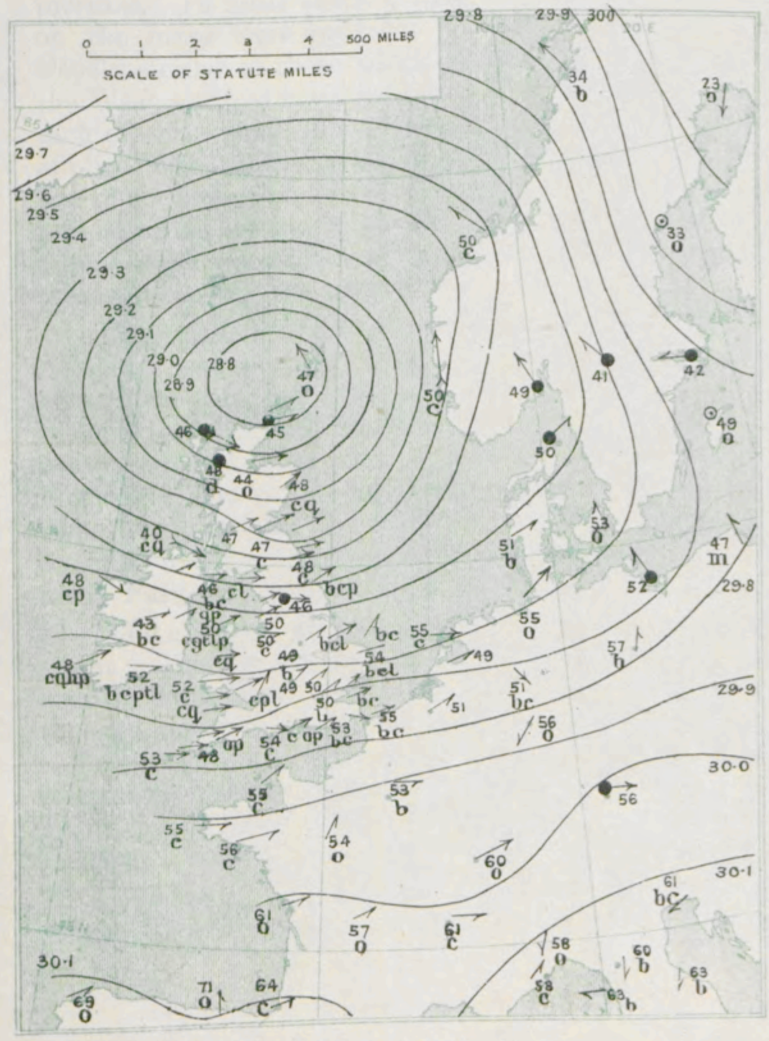

Fig. 5.—6 p.m. (18) October 15.

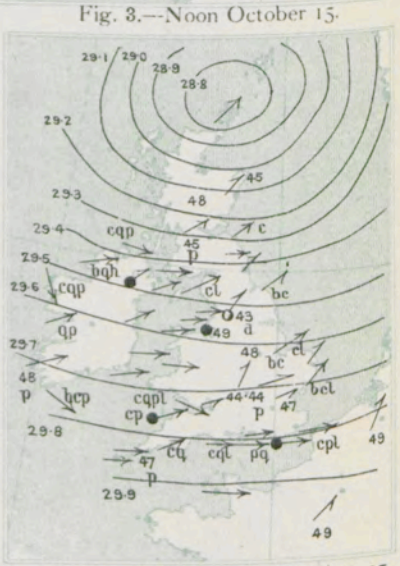

Fig. 6.—Midnight (24) October 15.

Fig. 7. Rainfall October 16

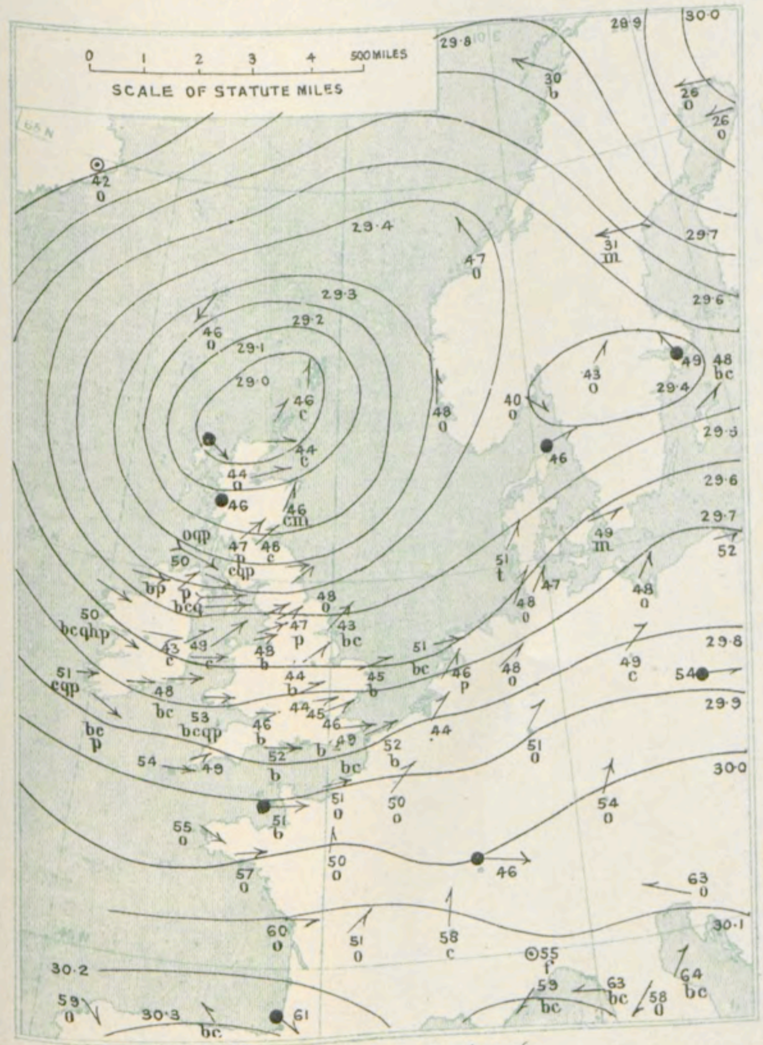

Fig. 8.—8 a.m. October 16.

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correspond to 44° at the surface. The temperature prevailing at the surface in the Southerly wind over North-western England was, as we have seen, generally about 52°, so that the Ben Nevis values are lower than what we should expect on the above hypothesis. The kite experiments carried out from Crinan have, however, shown that the readings on the mountain are generally somewhat lower than those obtained at similar altitudes in the free atmosphere.

The Westerly wind which set in as the disturbance passed Northward appears to have formed part of the Westerly current which became general at the surface.

The changes of wind velocity and air pressure in the Southerly winds show features with which we have already become familiar in other cases; the pressure decreases steadily while the velocity in general shows an increase. In the case of the Westerly winds the changes of pressure were slight, though a general tendency towards an increase may be recognised; the wind velocity was approximately constant as far as we are able to judge of it.

During the 24 hours from 8 a.m. October 15th to 8 a.m. October 16th, *i.e.*, during the period within which the centre of low pressure remained almost stationary off the North of Scotland, the trajectories (Plate XIV.) show a general Westerly flow of air over England, Ireland, and the South of Scotland. On Ben Nevis fresh to strong North-Westerly to Northerly winds prevailed, and it is difficult to account for the Northerly component. The occasional cloud observations, noted in the returns from the stations of the second order, all give West or South-west for the direction of the upper air over the Southern part of the British Isles. The Westerly current was much less steady, both in velocity and direction, than the Southerly current which it displaced. The records of the self-registering instruments from the stations of the first order show many small disturbances, each of which was marked by (1) a sudden increase of atmospheric pressure, (2) a sudden decrease of temperature, (3) a sudden veering in the direction of the wind, and (4) a sudden decrease in its intensity after a more gradual increase. In most cases a sharp shower also fell. The sinuosities in the isobars shown on the maps were probably connected with these disturbances.* The changes were so closely similar to those which took place at the displacement of the Southerly current by the West-south-westerly wind, that it is impossible to resist drawing the inference that each of these small disturbances, to which the name "secondary" might very fittingly be applied, was caused by the upward displacement of the air at the surface by air moving from a rather more Northerly direction and probably descending from above. Observations are, unfortunately, not sufficiently numerous for us to determine to what extent these "secondaries" travelled with a fixed velocity, or for us to take account of them in drawing the trajectories. Plate XIV.

The rainfall for this period is shown in Fig. 7, Plate XV. The heavy fall in the West of Scotland was probably due to orographical causes; on the Eastern side of the country very little rain fell (Braemar ·06 inch, Aberdeen, nil). Further South orographical factors also influenced the distribution of precipitation to a considerable extent. Moderately heavy falls of rain were recorded in parts of Ireland, in Lancashire, the West of Yorkshire, and in North Devon. Fuller information from Wales would probably show some heavy falls in the principality. Over the greater part of the country rainfall was confined to a few showers which, at most stations, did not yield an aggregate of 0·1 inch; many East coast stations escaped entirely.

The changes of pressure of the air shown along the trajectories were, as a rule, slight. The air suffered an unmistakable decrease of velocity in its passage across the country from West to East. This was, no doubt, largely due to surface friction, and if the anemometers at our inland and East coast stations could have been raised to a sufficient height, it is probable that the effect would have been much less, but it is interesting in this connection to note the decided divergence shown by the trajectories. Those which start North of the latitude of Pembroke all turn to the North over our Eastern counties, *i.e.*, they become South-westerly winds, whereas a steady Westerly

* The isobars have been drawn on the ordinary convention. It is, however, not unlikely that the facts would be better represented by "faults" in the isobars than by sinuosities. *See* also p. 63.

wind was blowing along the whole of the English Channel. Such divergence, if accompanied by undiminished wind velocity, is only possible if there is considerable descent of air. The effects of surface friction are too little known and the observations available are not sufficiently numerous to enable us to determine whether the divergence of the trajectories and the decrease of velocity were proportionate to each other by the method of shrinkage of area. The weather was consistent with the assumption that considerable descent took place; it was generally fine (b. or bc.) over the Midlands and South of England, with the exception of the showers connected with the "secondaries" mentioned above.

We have now reached the time at which the centre of low pressure began to move towards the South-east (Plate XVI.), and the most remarkable feature of the remaining diagrams of trajectories is afforded by the currents from the North on the Western side of the disturbance. At 8 a.m. on October 16th (Fig. 8, Plate XV.) the East of England was still in the Westerly to West-south-westerly current which formed the characteristic feature of the two preceding diagrams of trajectories (Plate XIV.); but in Ireland the air was moving from the North-west and, as it advanced, it gradually assumed a more Westerly course over the Midlands. In Scotland conditions were more complex. A Southerly current is shown on the East coast flowing Northward to meet the centre of low pressure (trajectory M, Fig. 1, Plate XVII.). In the West a North-westerly wind is shown at Stornoway at 8 a.m. This can be traced forward for a short distance (trajectory N), but soon after 11 a.m. it approaches very near the centre of low pressure and its course can no longer be determined. The wind subsequently veered to the North at Stornoway; when this air is traced forward (trajectory O, Figs. 1 and 2, Plate XVII.) its velocity is found to increase rapidly, while its direction of motion becomes North-westerly and ultimately Westerly as it reaches more Southern latitudes; it leaves our Islands as a Westerly wind near Spurn Head at about 2 a.m. on October 17th. We have too few observations from the region lying to the North of our Islands for us to be able to trace this trajectory O backwards with certainty, but if we assume a constant velocity of 25 miles an hour, and attempt the process, we reach a point somewhat South of the Faroe Islands at 8 a.m., at which hour the wind at Thorshavn was North-north-east 6 (Beaufort), and the temperature was 46°, and we may conclude that the course of the trajectory as drawn represents a very fair approximation to the truth.

In the diagram of trajectories (Fig. 2, Plate XVII.) which covers the period from 5 p.m. October 16th to 9 a.m. October 17th the trajectories of North-westerly winds shown over Ireland become Westerly over England, in a similar manner to O (Fig. 1), but the Northerly to North-north-westerly winds prevailing in the West of Scotland at 6 p.m. on October 16th maintain their direction much more completely; thus the trajectories G, H, and L of Fig. 2, Plate XVII., are continuous with the trajectories similarly lettered in Fig. 4, Plate XVIII., so that we see that the air which was in the North of Scotland at 6 p.m. on the 16th reached the English Channel 24 hours later. From the observations from Iceland and the Faroe Islands it has been possible to infer the general shape of the isobars over the Northern Atlantic and the character of the changes which occurred in them, and from these we can, in turn, infer the general course of the trajectories G, F, O, etc., of Plate XVII. in their passage over the Northern Atlantic. There can be little doubt that they turn to the East somewhat to the North of the Faroe Islands, and that ultimately they may be connected with the Easterly or South-easterly winds which blew off the coast of Norway during the 15th of October.

The origin of the trajectories H and L (Fig. 2, Plate XVII.), which lie further to the East, is not so clear. H appears to arise very near the centre of the closed isobars shown on the map for 2 p.m. on October 16th, which suggests that its air supply was derived from above, while L forms a loop round the centre of low pressure similar to the loops discussed in dealing with the circular storms of March 24th, 1902, and September 10th, 1903.

The changes of pressure shown along those trajectories in which the motion was from North-west, were small, but a rather rapid increase of pressure took place in the

PLATES XVI., XVII., XVIII.

Nº 6. Continued.

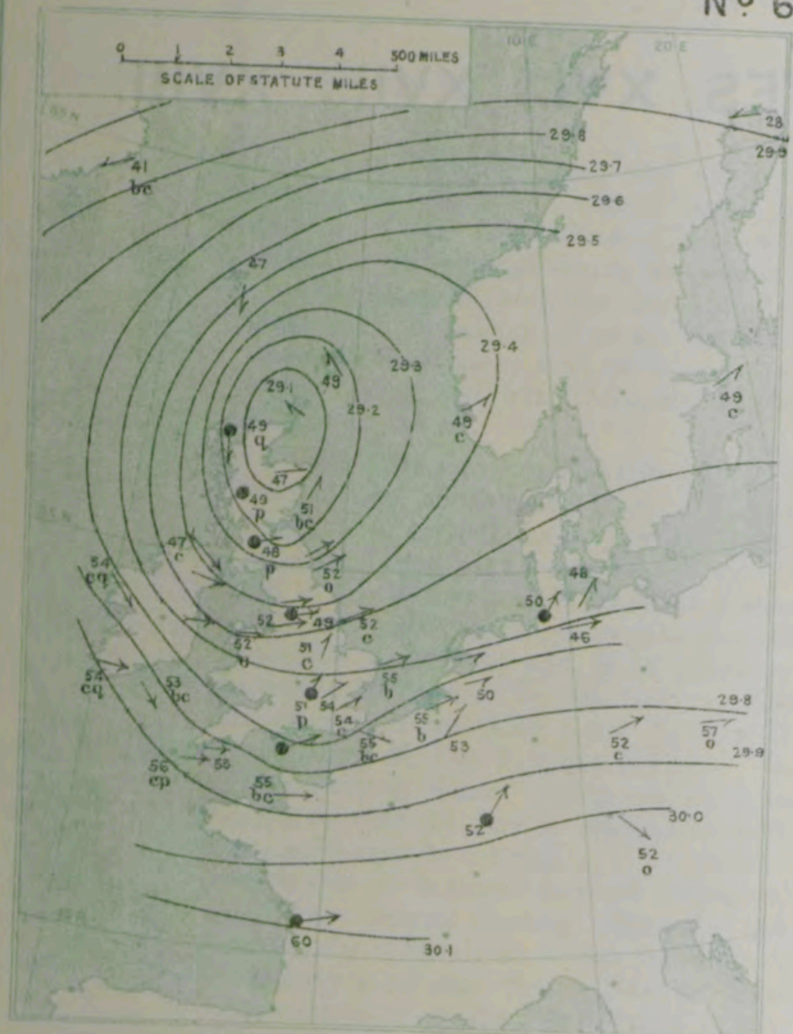


Fig. 1.—2 p.m. (14) October 16.

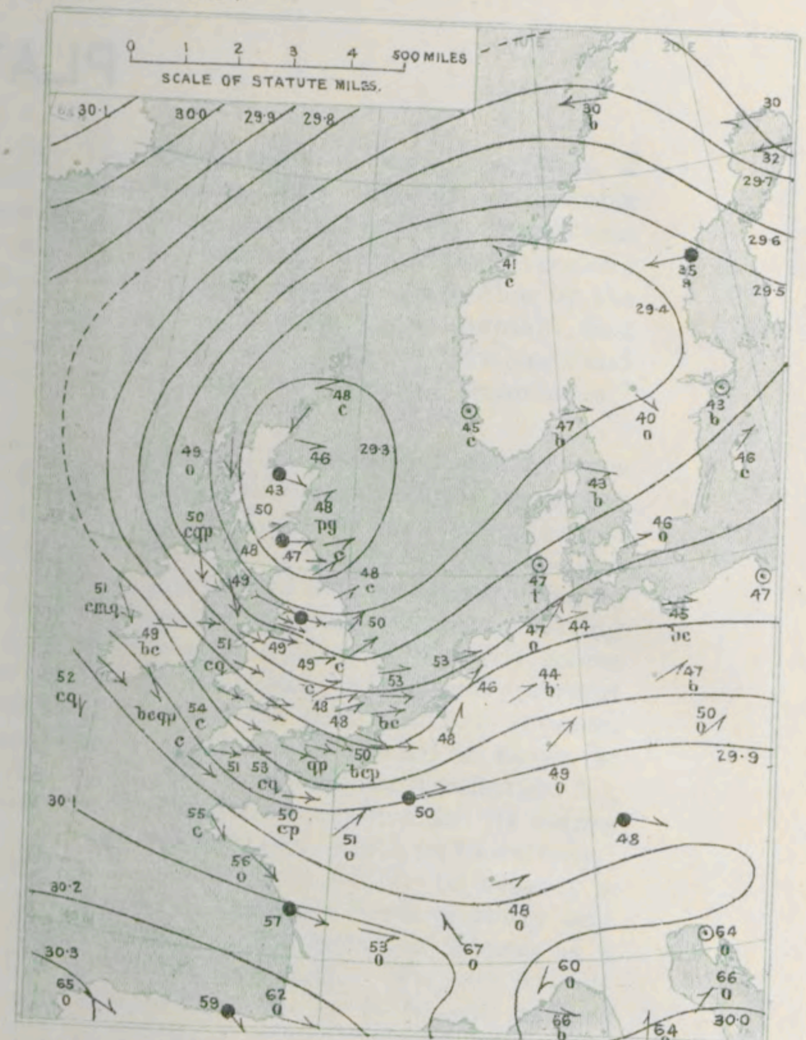


Fig. 2.—6 p.m. (18) October 16.

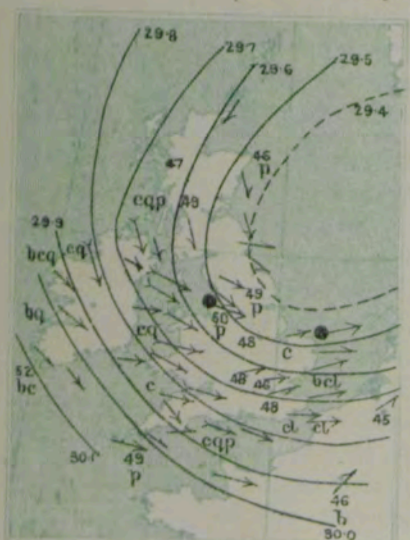


Fig. 3.—Midnight October 16.

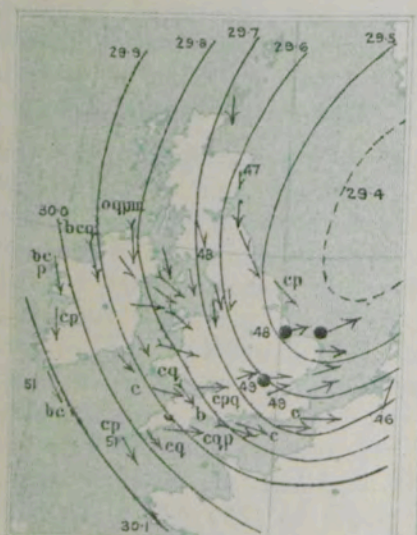


Fig. 4.—4 a.m. October 17.

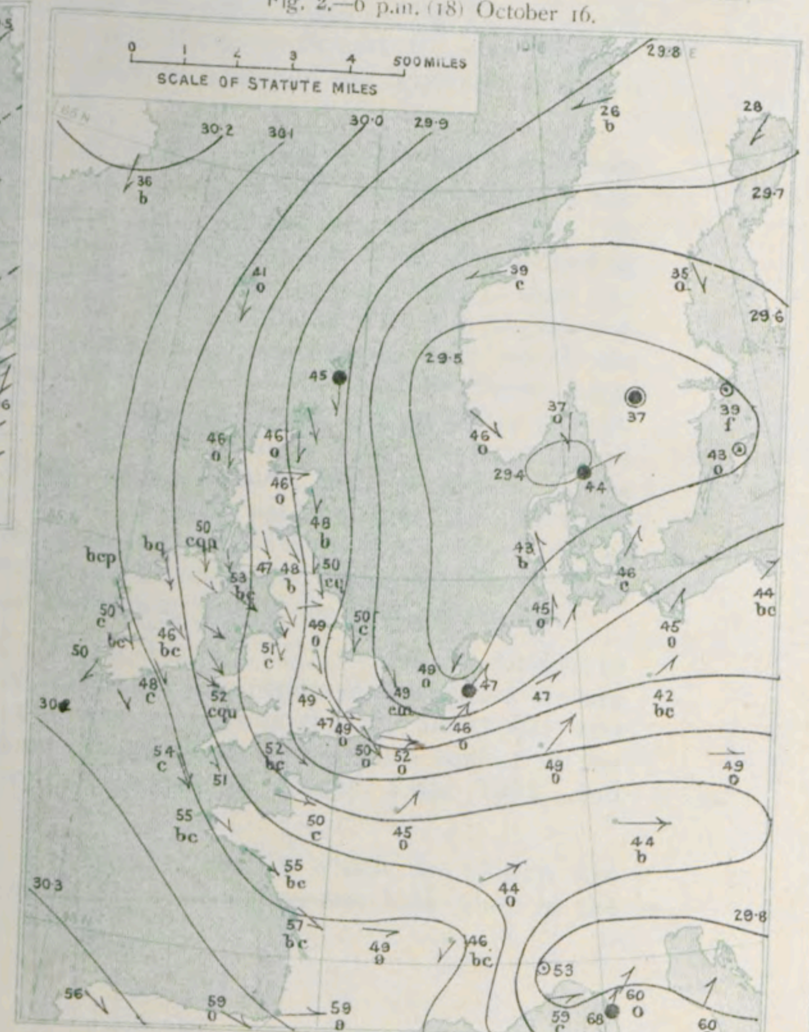


Fig. 5.—8 a.m. October 17.

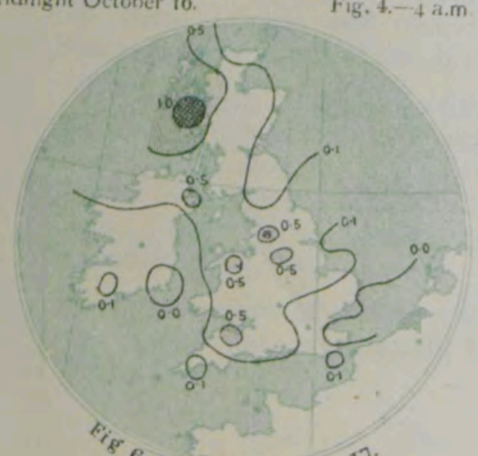
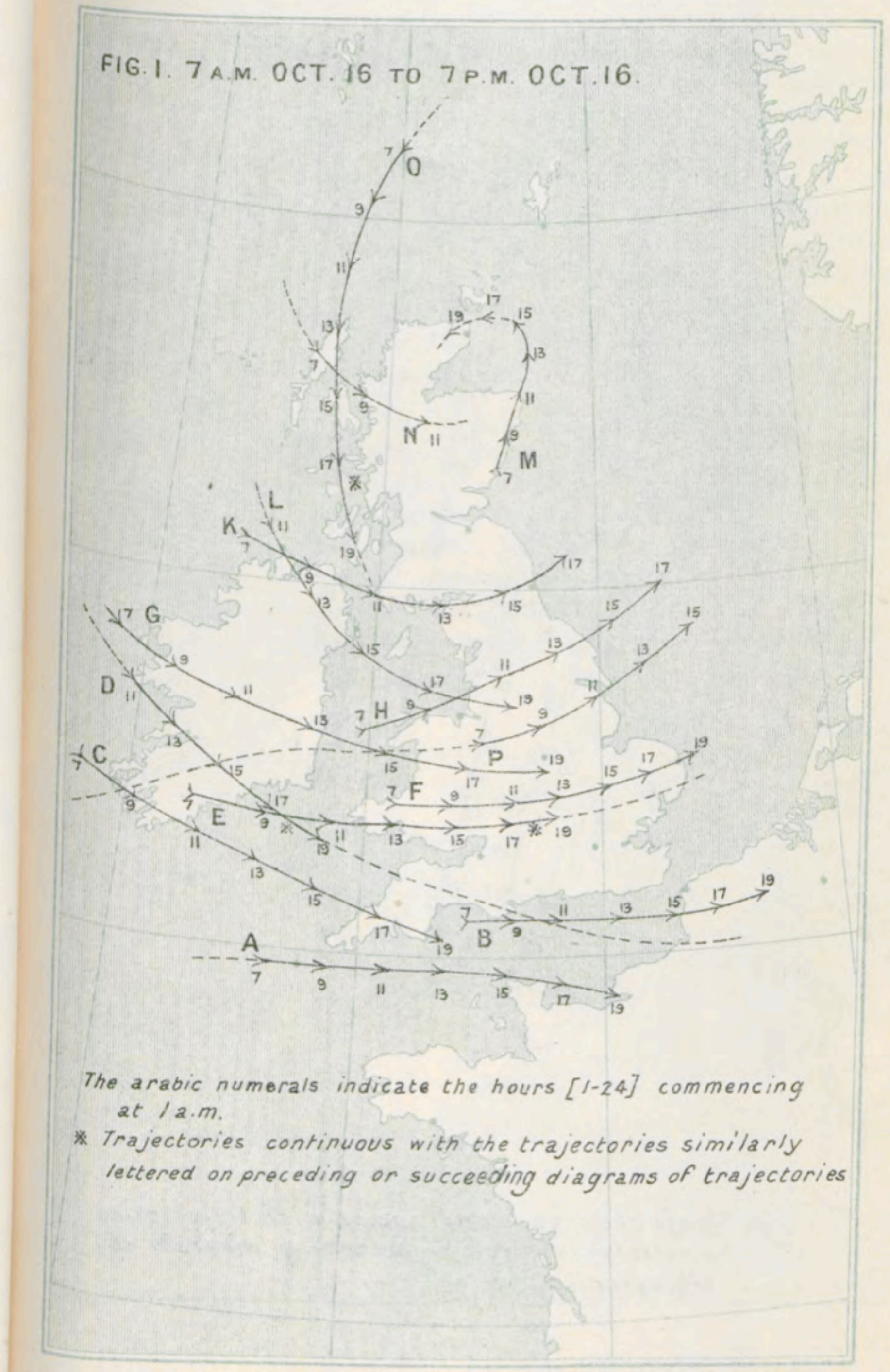
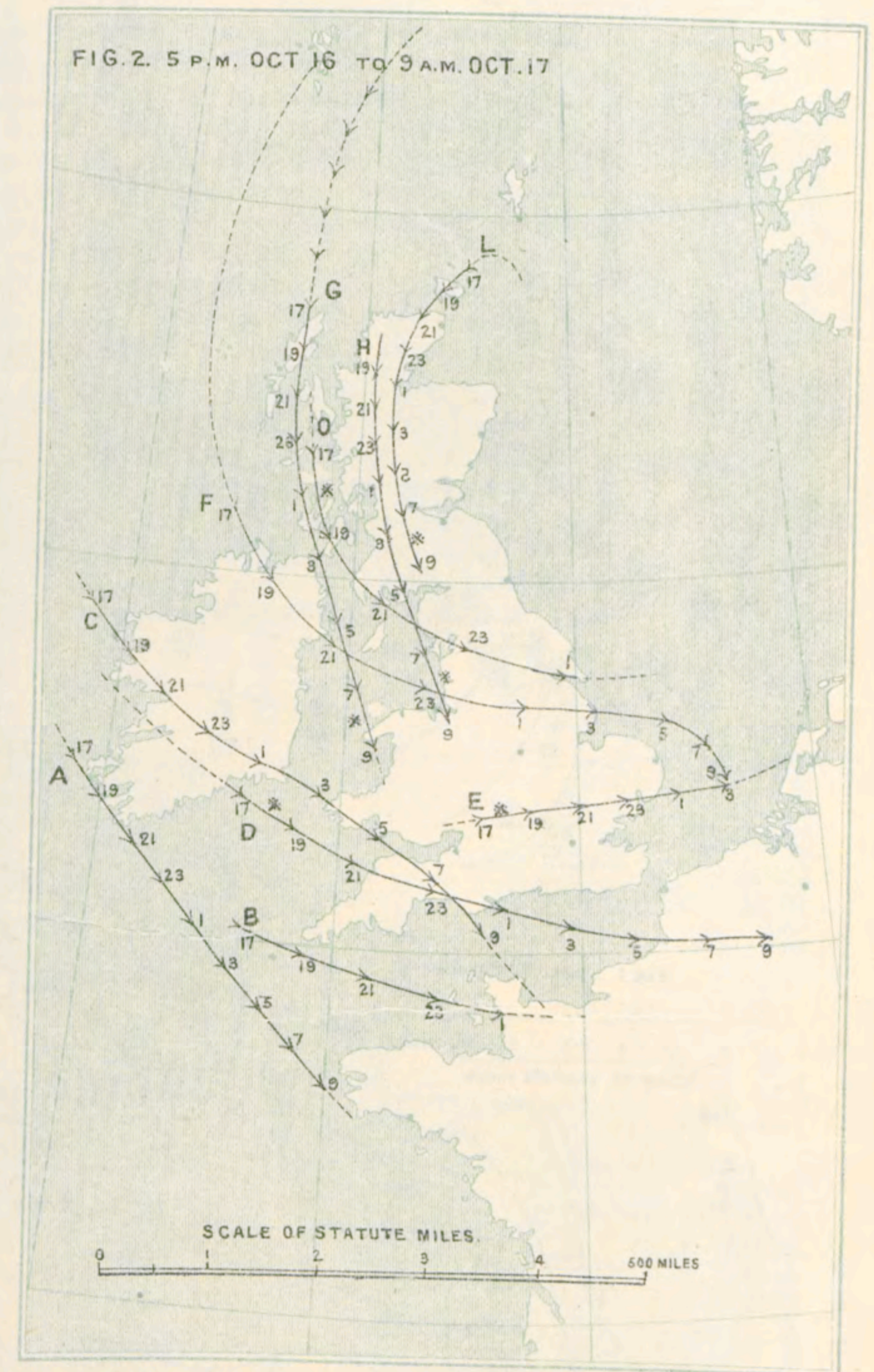


Fig. 6. Rainfall October 17.

Nº 6. Continued.





TABLES CORRESPONDING TO TRAJECTORIES OF FIG. 1.

Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D※ V	D※ P 20+	D※ T	D※ W	Hours.
8	26	9·83	54	c	20	9·78	52	b	29	9·74	51	cqp					8
10	25				20				29	9·80							10
12	25				25				29	9·82			26	9·72			12
14	25	9·85	(54)		25	9·72	(55)		29	9·80			26	9·75			14
16	25				20				29	9·85			26	9·78			16
18	25	9·79	(52)	(cp)	20	9·74			29	9·84	(52)	(cq)	26	9·83			18

Hours.	E※ V	E※ P 20+	E※ T	E※ W	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	P V	P P 20+	P T	P W	Hours.
8	30	9·68	48	bc	25	9·66			30	9·57	50	bcp	25	9·60	(47)	(b)	8
10	30	9·70			25	9·68			30	9·55			25	9·57			10
12	30	9·67	52	bc	20	9·63	(53)	n	35	9·62			25	9·53			12
14	25	9·67			20	9·62	(54)	n	35	9·58	(52)	(o)	25	9·50			14
16	23	9·65			20	9·60			35	9·60							16
18	23	9·66	48		20	9·56	53	bc	35	9·58	(49)						18

Hours.	H V	H P 20+	H T	H W	K V	K P 20+	K T	K W	L V	L P 20+	L T	L W	O※ V	O※ P 20+	O※ T	O※ W	Hours.
8	30	9·57	49	c	30	9·32	50	cqp					26				8
10	34	9·52	50	n	31	9·32							26				10
12	25	9·48	(48)	(r)	31	9·38			35	9·31		cqp	26	9·00			12
14	25	9·40	(52)		31	9·33	(49)		35	9·41			26	9·11	49	rq	14
16	25	9·40			31	9·30			35	9·48			30	9·25		r	16
18									39	9·50	51	n	35	9·40	(49)	(p)	18

TABLES CORRESPONDING TO TRAJECTORIES OF FIG. 2.

Hours.	A V	A P 20+	A T	A W	C V	C P 20+	C T	C W	D※ V	D※ P 20+	D※ T	D※ W	E※ V	E※ P 20+	E※ T	E※ W	F V	F P 20+	F T	F W	Hours.
18	22	9·98	52	cq	25	9·84	51	cq	26	9·83			23	9·66	48		36	9·47	50	cqp	18
20	22				25	9·83			30	9·82			24	9·60	(47)	(n)	40	9·55			20
22	22				25	9·86			35	9·83			24	9·60			44	9·55			22
24	22				27	9·88			30	9·83			24	9·56			44	9·54	50	p	24
2	22				32	9·87			30	9·83							31	9·46			2
4	22				33	9·88			30								30	9·46		r	4
6	22				30	9·88			30								20	9·46		r	6
8	22	0·04	55	bc	30	9·82	52	bc									16	9·50			8

Hours.	G※ V	G※ P 20+	G※ T	G※ W	H V	H P 20+	H T	H W	L※ V	L※ P 20+	L※ T	L※ W	O※ V	O※ P 20+	O※ T	O※ W	Hours.
18	20	9·37	49	o					16	9·29	(47)	(c)	35	9·40	(49)	(p)	18
20	20	9·48			16	9·38			16	9·46	(48)		35	9·43			20
22	20	9·58			16	9·50	49	n	16	9·51			40	9·50			22
24	25	9·65			16	9·58			16	9·60			45	9·45	49	p	24
2	27	9·75			22	9·65	48	n	20	9·68							2
4	30	9·78			25	9·70			20	9·72	(47)	n					4
6	30	9·85			29	9·78			20	9·80							6
8	25	9·90	54	bcp	30	9·84	52	n	24	9·85	47	n					8

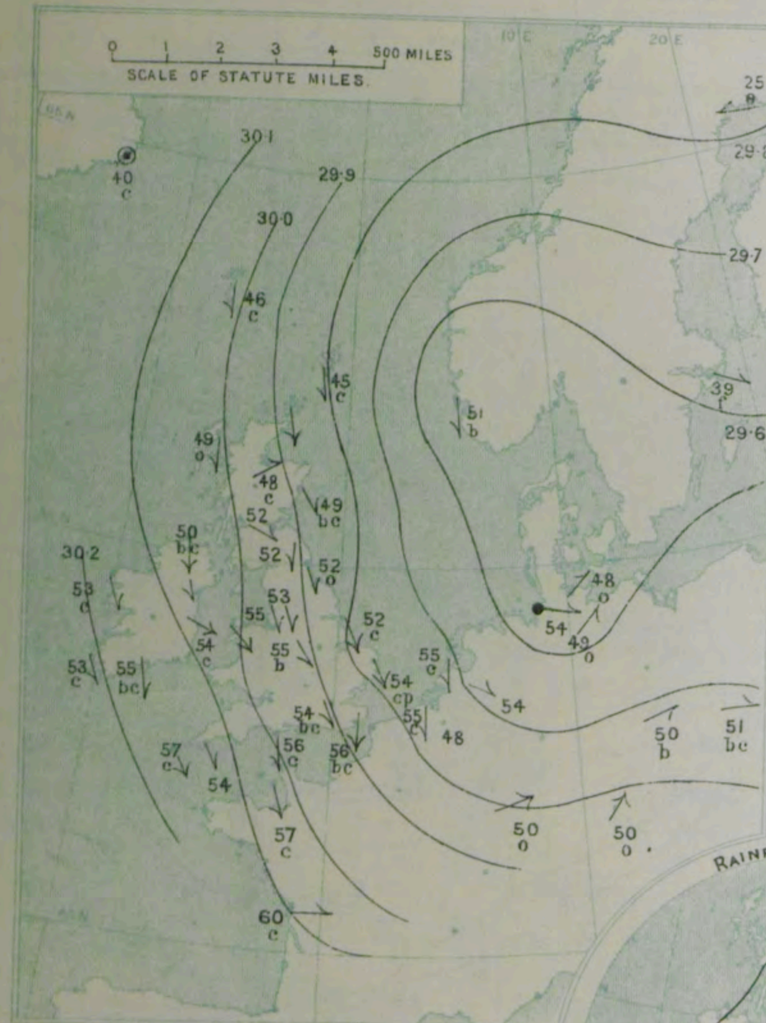


Fig. 1 2 p.m. (14) October 17.

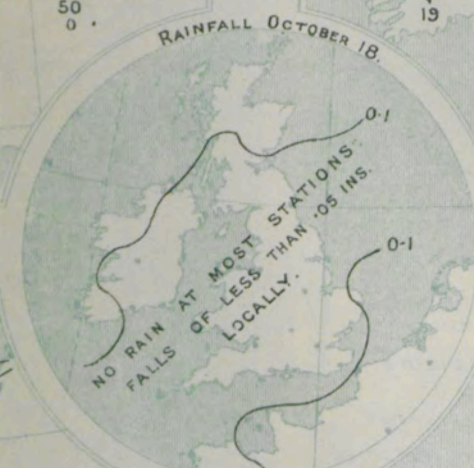
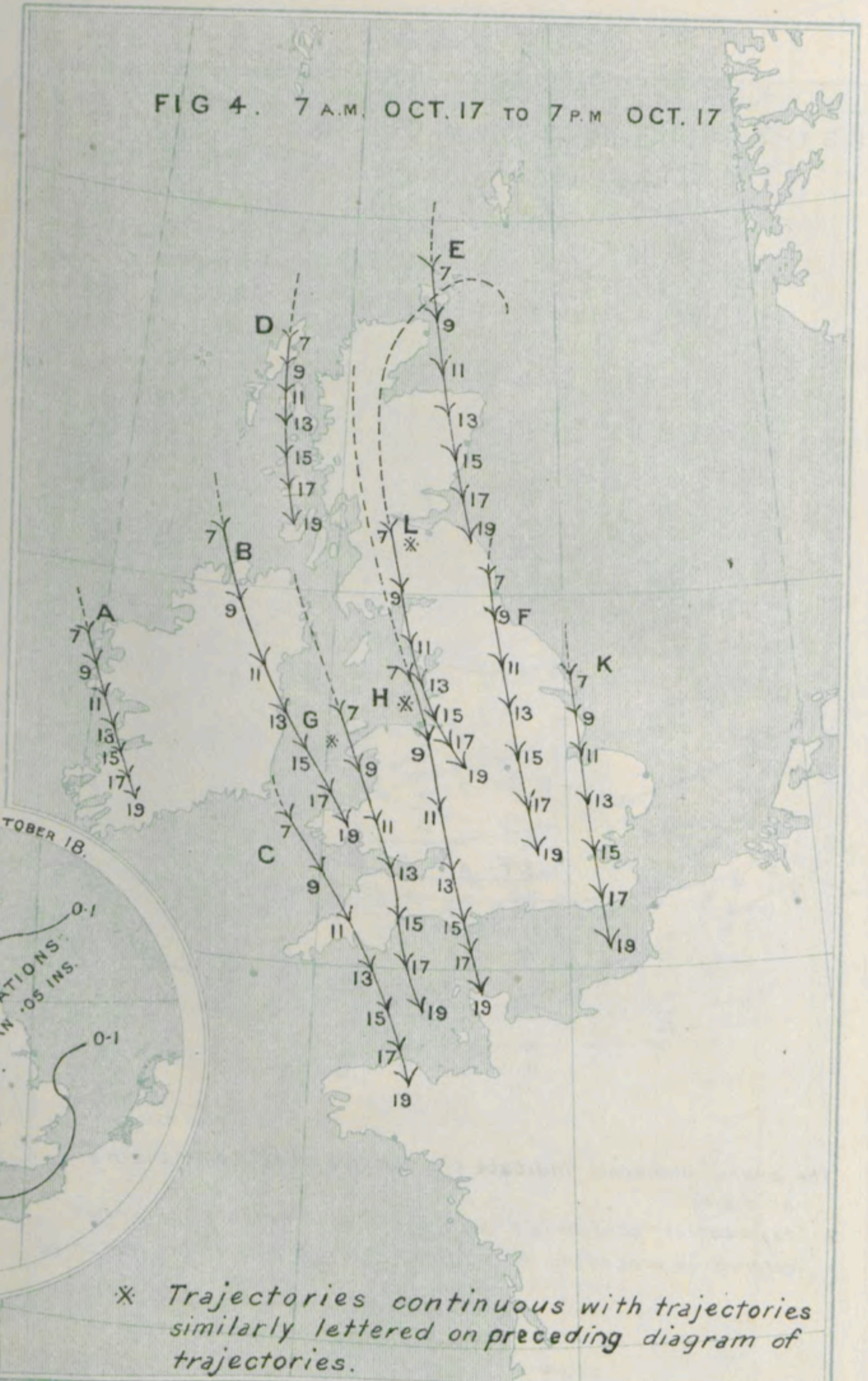


Fig. 3.



⁎ Trajectories continuous with trajectories similarly lettered on preceding diagram of trajectories.

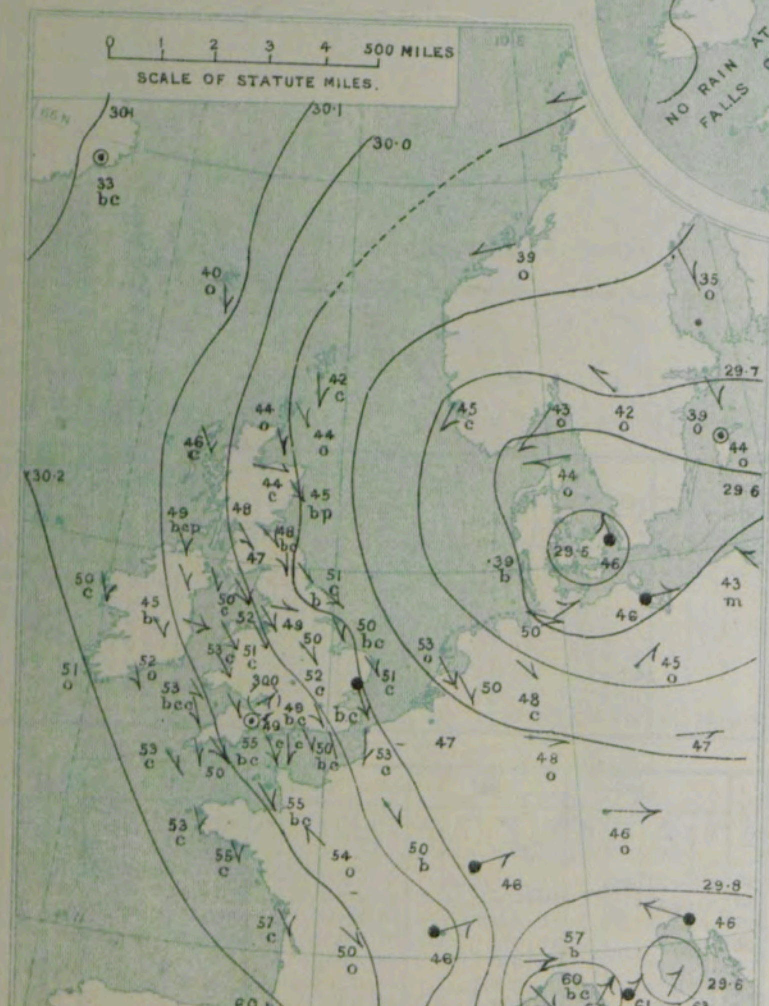


Fig. 2 6 p.m. (18) October 17.

Hours.	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W
	A				B				C				D				G⁎			
8	15	0·10	50	c	31	9·95	50	bcp	22	9·96	52	cq	10	9·92	46	o	25	9·90	54	hqp
10	15	0·12			27	0·00		n	22	0·00			10	9·96			25	9·95		
12	15	0·15			20	0·04		(b)	18	0·05			11	9·98			25	0·00		
14	11	0·16	(53)	(c)	20	0·05	(52)	(c)	18	0·08	(55)		12	0·02	50	n	20	0·00		
16	11	0·18			20	0·06			15	0·10			12	0·03			20	0·00		
18	10	0·18			15	0·08	53	c	15	0·12	(54)	(bc)	12	0·04	(48)	(c)	20	0·08	(55)	bc
	H⁎				L				E				F				K			
8	30	9·84	52	(c)	24	9·83	47	n	22	9·76	46		17	9·76	50	cp	17	9·66	50	c
10	30	9·89			21	9·89			21	9·81			19	9·81			17	9·75		
12	30	9·95			17	9·95			21	9·85			19	9·90			20	9·82		
11	20	9·98			15	9·96	55	n	19	9·91			20	9·88	(52)	(bc)	20	9·83		
16	15	0·02			15	9·97			17	9·90	47	n	20	9·95			20	9·94	(54)	
18	15	0·04	53	(bc)	10	9·99	(52)	(c)	17	9·92	(48)	(bc)	20	9·97			20	9·97	52	bc

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region where the motion was from the North; thus in the case of the trajectory G (Fig. 2, Plate XVII., and Fig. 4, Plate XVIII.) the pressure increased from 29·37 ins. to 30·08 ins. in 24 hours. The wind velocities show an increase during the first 12 hours, but a decided decrease occurred in all cases during the period covered by Fig. 4, Plate XVIII. The weather was generally fair. The rainfall associated with the passage Southward of the disturbance is shown in the maps, which give the amounts measured on the mornings of October 17th and 18th. Some large falls occurred locally on the rainfall day ending on the morning of October 17th, and showers yielding an aggregate of between 0·05 and 0·30 inch of rainfall occurred generally. The Northerly wind on October 17th yielded hardly any rain at all. A few light showers occurred, but the total amount of rainfall was less than ·05 inch at almost all stations.

The observations from Ben Nevis suggest that the Northerly winds in the rear of the disturbance were surface currents of slight thickness. From 2 p.m. on October 16th, when the Northerly wind set in in the North-west of Scotland, to the end of our period light Northerly breezes, generally of about force 2 and never exceeding force 4 (Ben Nevis scale), prevailed at the summit, while winds of force 6 to 8 (Beaufort) were of general occurrence on the North coast of Ireland and the West coast of Scotland. The qualification "variable" is also used very frequently, from which it appears that the Northerly current was much more pronounced at the surface than at the 4,000 foot level.

No. 7. A "V" Shaped Depression (Plates XIX., XX.).
6 p.m. January 5th to 6 p.m. January 7th, 1900.

The map for 6 p.m. on January 5th showed a tongue of high pressure extending South-westward over our Islands from an anticyclone over Scandinavia, and a cyclonic disturbance advancing towards our Western coasts. Though a slight increase of pressure occurred subsequently in the South-east of England, the changes during the following night may be summed up as a gradual giving way of the high pressure system and a simultaneous encroachment of the depression from the West. At 8 a.m. on January 6th the "V" shaped character of the latter was well developed and the greater part of our Islands had come under its influence. During the ensuing ten hours the gradient on the Eastern side of the trough was steep, but the differences of pressure to the West of it were small; after 6 p.m. on the 6th, however, the gradient in the rear also became steep and the two arms of the "V" gradually approached each other, so that at 8 a.m. on January 7th, when the trough extended from Biarritz to Sumburgh Head, the disturbance might well be described as "U" shaped. The peculiar narrowness of the trough is illustrated by the anemograms from stations over which it passed. The record of the pressure tube and Robinson instruments at Kew show that a Southerly wind was maintained throughout the night until 8.10 a.m. During the following 25 minutes the air remained absolutely calm, and at 8.35 a.m. a wind from the North, of over 10 miles per hour, set in abruptly. As the rate of travel of the trough was about 15 miles per hour, it follows that the width of the calm region on it was only about 6 miles. The records from Oxford and Berkhamsted show similar characteristics.

Dividing the whole disturbance into three portions—(1) the Southerly wind, (2) the trough, and (3) the Northerly wind—its passage across the country has been traced in Fig. 3, Plate XX., in which the broken lines mark the positions of the trough at the epochs indicated, while the continuous lines have been drawn so as to separate the first stage of the disturbance from the anticyclonic region in the front of it. A station was regarded as having come under the influence of the disturbance when the wind velocity at it reached 10 miles per hour. At the epochs for which they are drawn (indicated by the numerals placed against them) these lines, therefore, separate a region of light airs generally from between North-east and South-east from a region of Southerly winds of over 10 miles an hour. The observations show that the wind directions remained almost constant until the trough was reached, from which it follows that the front of the disturbance consisted of a band of Southerly wind the position of which moved across the country in an Easterly direction. The width of this band, as given by the distance between continuous and broken lines for the same epoch, was rather less than 400 miles. The wind velocity in it was generally high; extreme forces of 8 or 9 on the Beaufort scale were reached at all light-houses and light-vessels off the Irish coasts and in the Irish Sea; over England rather lower values were recorded.

Trajectories for the front and rear of the storm respectively are shown in Figs. 1 and 2, Plate XX. Those for the front run very approximately in a South to North direction and they can all be traced backwards to the boundary of the storm, as indicated by the continuous lines on Fig. 3; here the motion of the air was from South-east or East, and its velocity was very small, so that the trajectories have been represented as commencing in a region of calms. We must, therefore, assume that the anticyclonic ridge on the Eastern side of the disturbance was a region in which the air needed to supply the Southerly winds, descended. This assumption is borne out by the fine weather which prevailed on the ridge. It is probable that the Southerly wind set in, in the upper air, considerably earlier than at the surface. At Paris the observations from the Eiffel Tower show a brisk breeze as early as 6 p.m. on January 6th, while it was not till some hours later that its influence was felt at the surface. The highest velocity recorded on the tower in the Southerly wind was 38 miles per hour; at Parc St. Maur force 3 on the Beaufort scale was not exceeded. Again at Jersey the observations at the Observatoire St. Louis are recorded by an anemometer placed on a tower at an elevation of about 360 feet above mean sea level and 190 feet above the ground. Here a wind from the South of 16 miles per hour was recorded as early as 6 a.m. on January 6th, while at 8 a.m. the observation at the telegraphic reporting station at St. Aubin was S.S.E. 2 (Beaufort). [The latter observation has been used in constructing Fig. 3.]

PLATE XIX.

No. 7. V-SHAPED DEPRESSION JANUARY 5-7. 1900.

Plate XIX

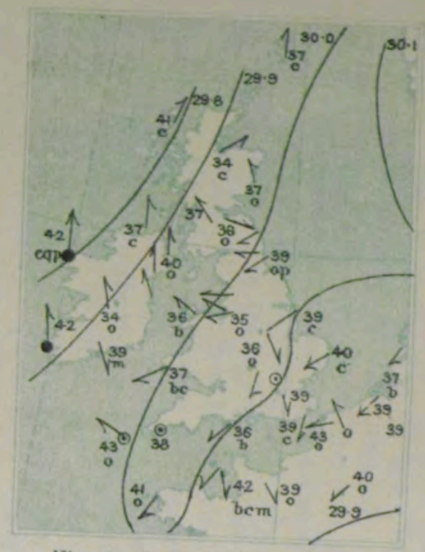


Fig. 1.—6 p.m. (18) January 5.

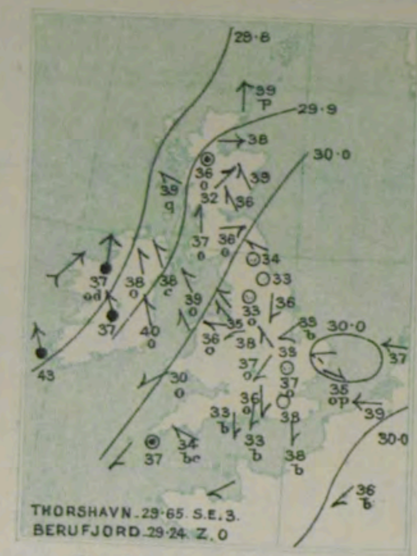


Fig. 2.—9 p.m. (21) January 5.

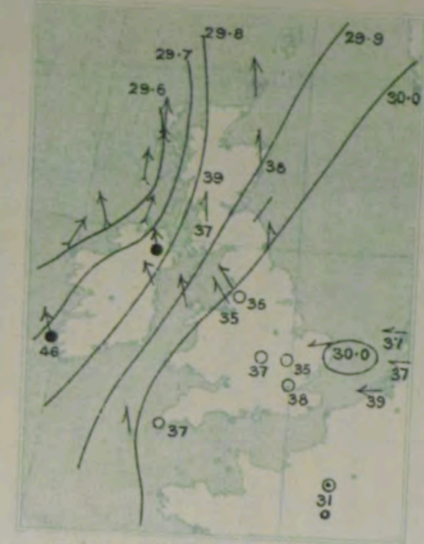


Fig. 3.—Midnight (24) January 5.

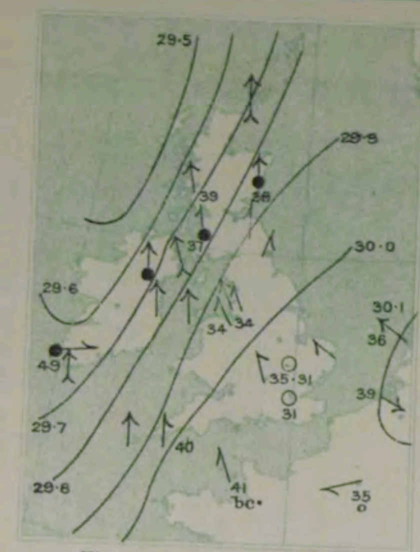


Fig. 4.—4 a.m. January 6.

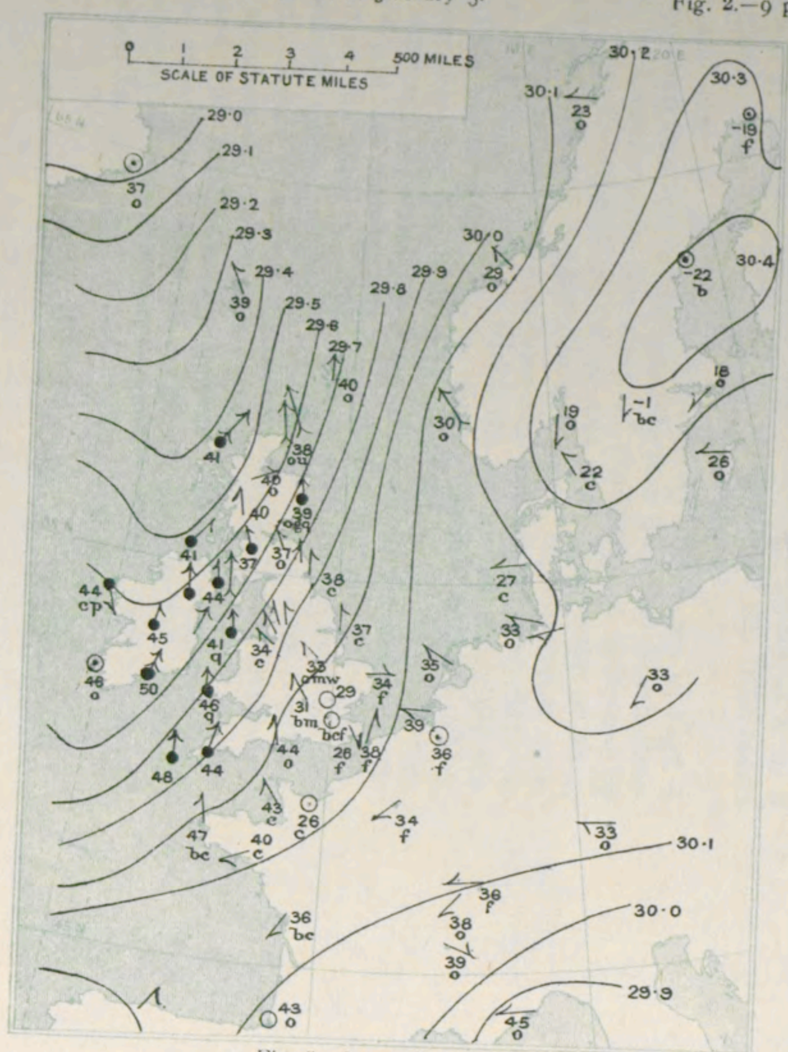


Fig. 5.—8 a.m. January 6.

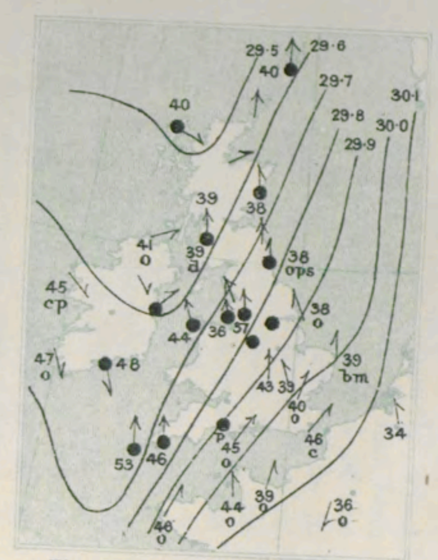


Fig. 6.—2 p.m. (14) January 6.

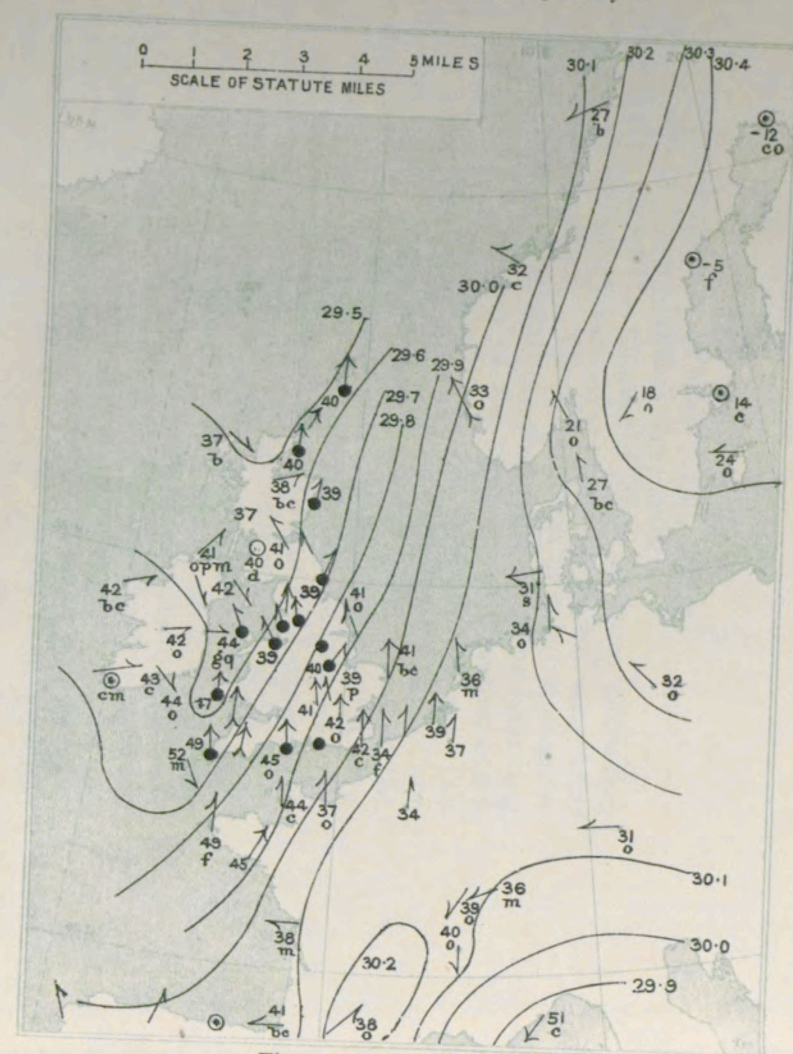


Fig. 7.—6 p.m. (18) January 6.

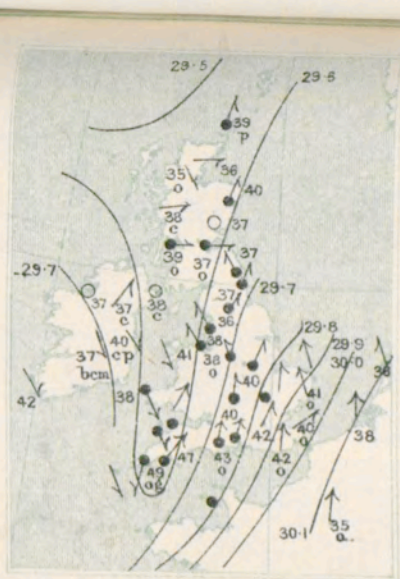


Fig. 8.—9 p.m. (21) January 6.

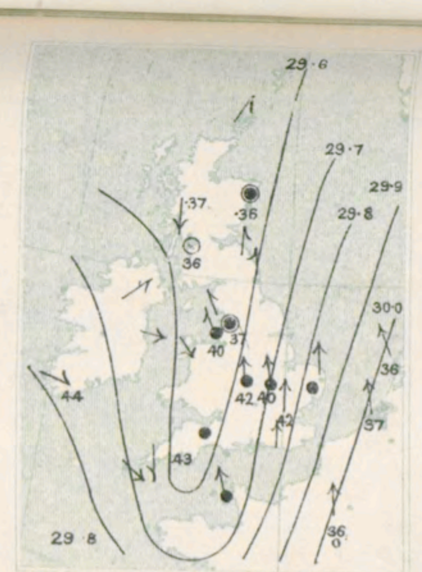


Fig. 9.—Midnight (24) January 6.

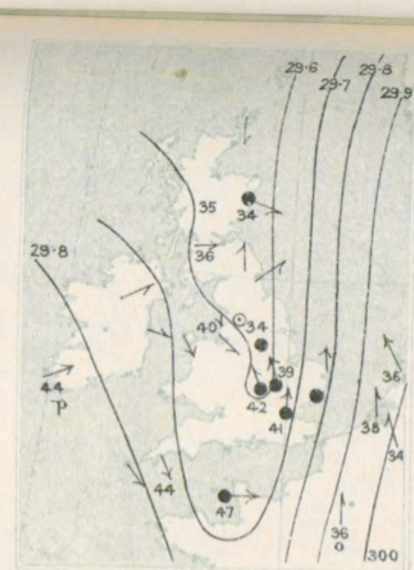


Fig. 10.—4 a.m. January 7.

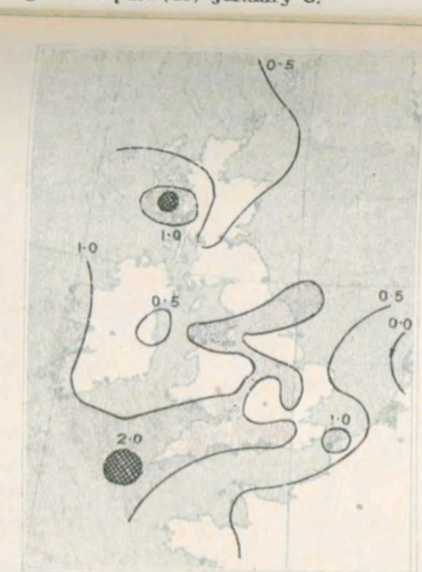


Fig. 11.—Rainfall January 6-8.

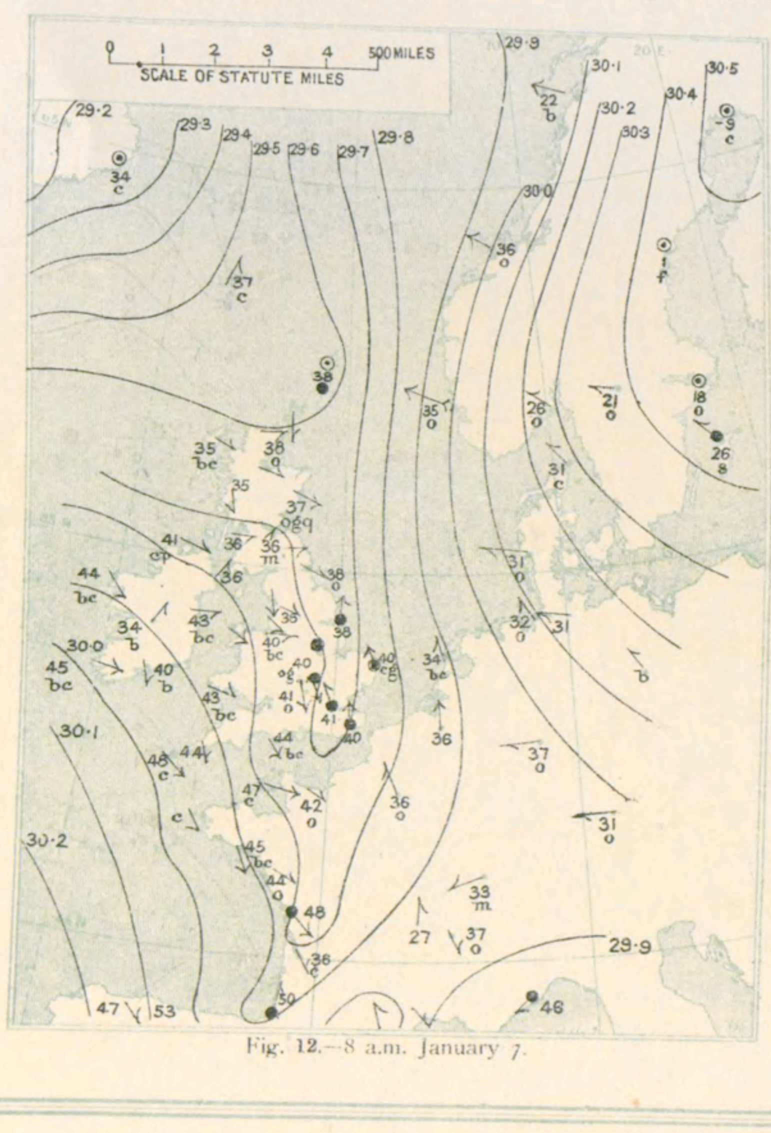


Fig. 12.—8 a.m. January 7.

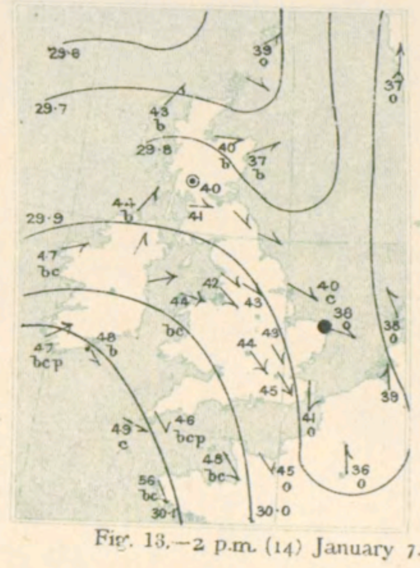


Fig. 13.—2 p.m. (14) January 7.

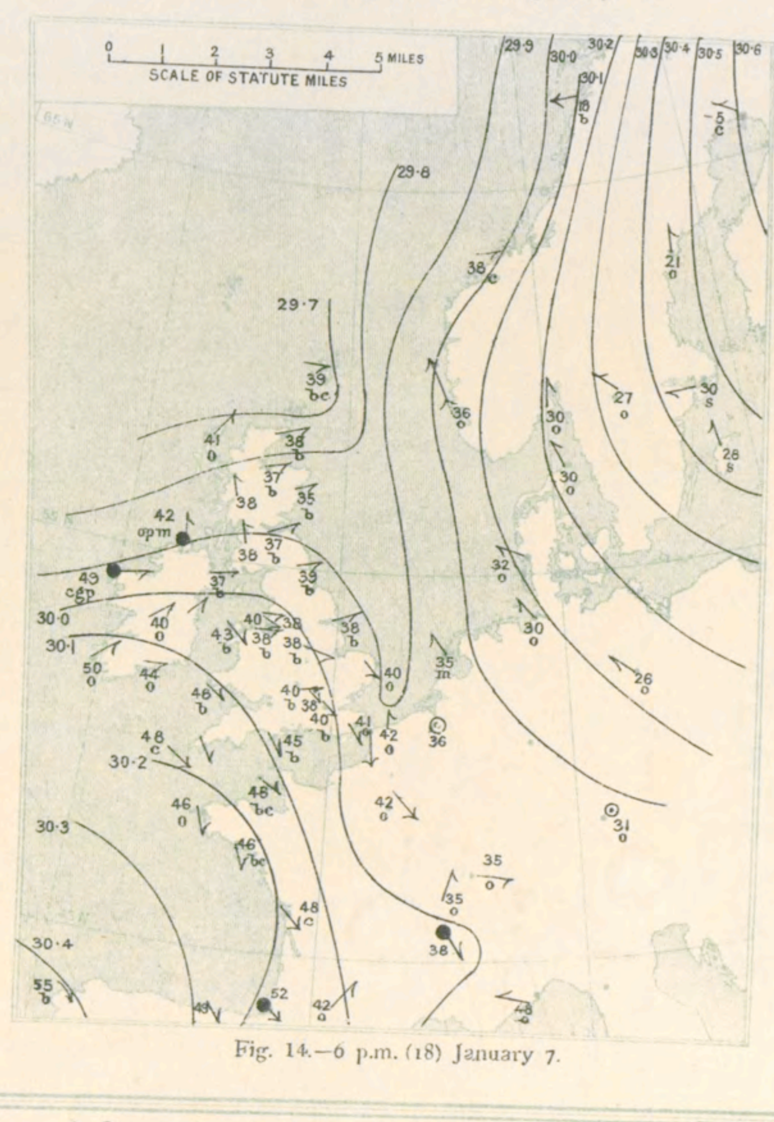


Fig. 14.—6 p.m. (18) January 7.

The mark ● denotes that rain was falling at the hour of observation.

The rainfall charted in Fig. 11 is the sum of the amounts measured at 8 a.m. or 9 a.m. on January 6, 7 and 8.

PLATE XX.

No. 7. TRAJECTORIES OF AIR, JANUARY 5-7, 1900.

Plate

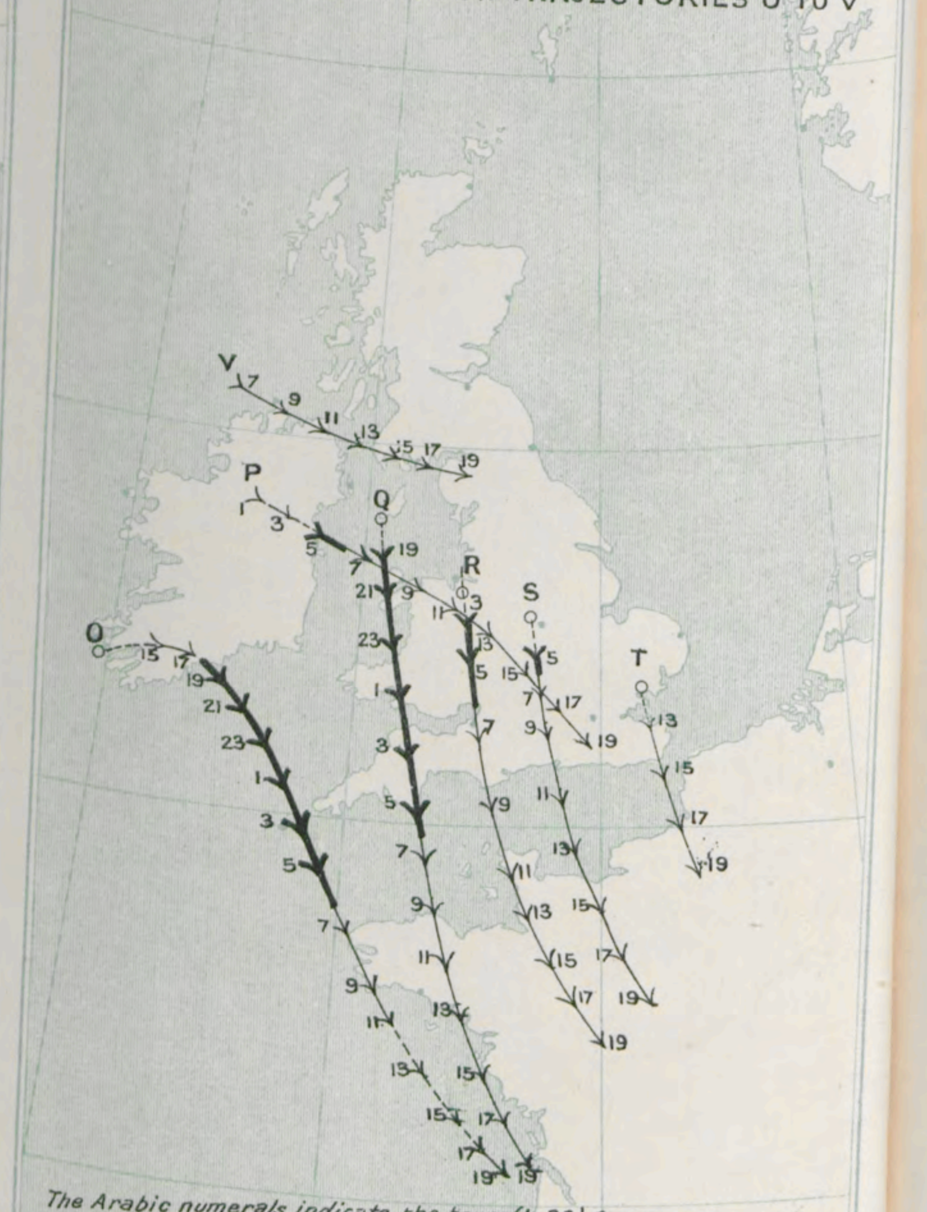
Date.	Hours.	A V	A P 20+	A T	A W	B V	B P 20+	B T	B W	C V	C P 20+	C T	C W	D V	D P 20+	D T	D W
5	18	20	9·87	42	r												
	20	25	9·79		r	15	9·86	(37)	r								
	22	30	9·72			25	9·84										
	24	45	9·58			30	9·75			12	9·94			12	0·00	(35)	(n)
6	2	45				37	9·63		(r)	15	9·92			15	9·93		(n)
	4					37	9·55			20	9·87			15	9·87		
	6					37	9·44			20	9·82			25	9·80		(r)
	8					37	9·42	41	r	25	9·72	46	r	25	9·73	(38)	(r)
	10									25	9·65		(r)	25	9·67	38	r
	12									25	9·61		r	31	9·60		(r)
	14													31	9·55		(r)
	16																
	18																
	20																
	22																
	24																

Date.	E V	E P 20+	E T	E W	F V	F P 20+	F T	F W	G V	G P 20+	G T	G W	H V	H P 20+	H T	H W	Hours.
5																	18
																	20
																	22
																	24
6	15	9·95															2
	20	9·93															4
	25	9·90															6
	25	9·81	(39)	(r)	18	0·00	47	b									8
	29	9·70			21	9·97							15	0·05	(43)	(o)	10
	32	9·65			25	9·90	(45)	(r)	15				20	0·05			12
	35	9·53	40	r	30	9·78		r!	20	0·10	(42)	(b)	20	9·95	(45)	(o)	14
					37	9·68		r	25	9·97		(n)	20	9·90	42		16
					25	9·55	44	r	25	9·87	(45)	(r)	20	9·81	(41)	r	18
									30	9·80		r	20	9·72	(39)	r	20
									30	9·66		r	20	9·55		r	22
													20	9·55	37	r	24

FIG. I. FRONT OF TROUGH TRAJECTORIES A TO K

The following portions of the Trajectories have been thickened Traj. A to E 6 p.m. Jan. 5 to 6 a.m. Jan 6. Traj. F to P 6 p.m. Jan 6 to 6 a.m. Jan 7.

FIG. 2. REAR OF TROUGH TRAJECTORIES O TO V



The Arabic numerals indicate the hours (1-24) Commencing at 1 a.m.

Date.	Hours.	K V	K P 20+	K T	K W	O V	O P 20+	O T	O W	P V	P P 20+	P T	P W	Q V	Q P 20+	Q T	Q W
6	16					15	9·68										
	18					15	9·64	44	o								
	20					18	9·63							24	9·55		
	22	30	9·95	(37)	(o)	20	8·68							25	9·58		
	24	30	9·83			20	9·70							25	9.58		
7	2	26	9·72	(41)	(r)	25	9·75	(44)		15	9·71			25	9·65		
	4	26	9·70		r	25	9·80			18	9·72			25	9·68	(44)	(n)
	6	26	9·70			25				20	9·76			25	9·75		(p)
	8	25	9·65	38	r	25	9·93	(45)	c	24	9·81	43	bc	25	9·90	46	(c)
	10					25				24	9·85			25	0·00		(n)
	12									24	9·91	42		25	0·06		
	14									28	9·95	(43)	(n)	25	0·06	(49)	(bc)
	16									22	0·03	43	(n)	22	0·19		
	18									19	0·04	43	b	19	0·21	(48)	(c)

Date.	R V	R P 20+	R T	R W	S V	S P 20+	S T	S W	T V	T P 20+	T T	T W	V V	V P 20+	V T	V W	Hours.
6																	16
																	18
																	20
																	22
																	24
7																	2
	31	9·65															4
	30	9·67			28	9·66	39	r									6
	31	9·72	44	bc	25	9·74	41	(bc)					15	9·77	41	p	8
	31	9·90			25	9·85							15	9.84			10
	25	9·97			25	9·91							15	9·85			12
	25	0·00			25	9·95	45	o	25	9·83	41	o	15	9·80			14
	25	0·08			25	0·00			25	9·93			15	9·85			16
	25	0·10			28	0·00		(b)	25	9·92	42	(o)	15	9·95	38	b	18

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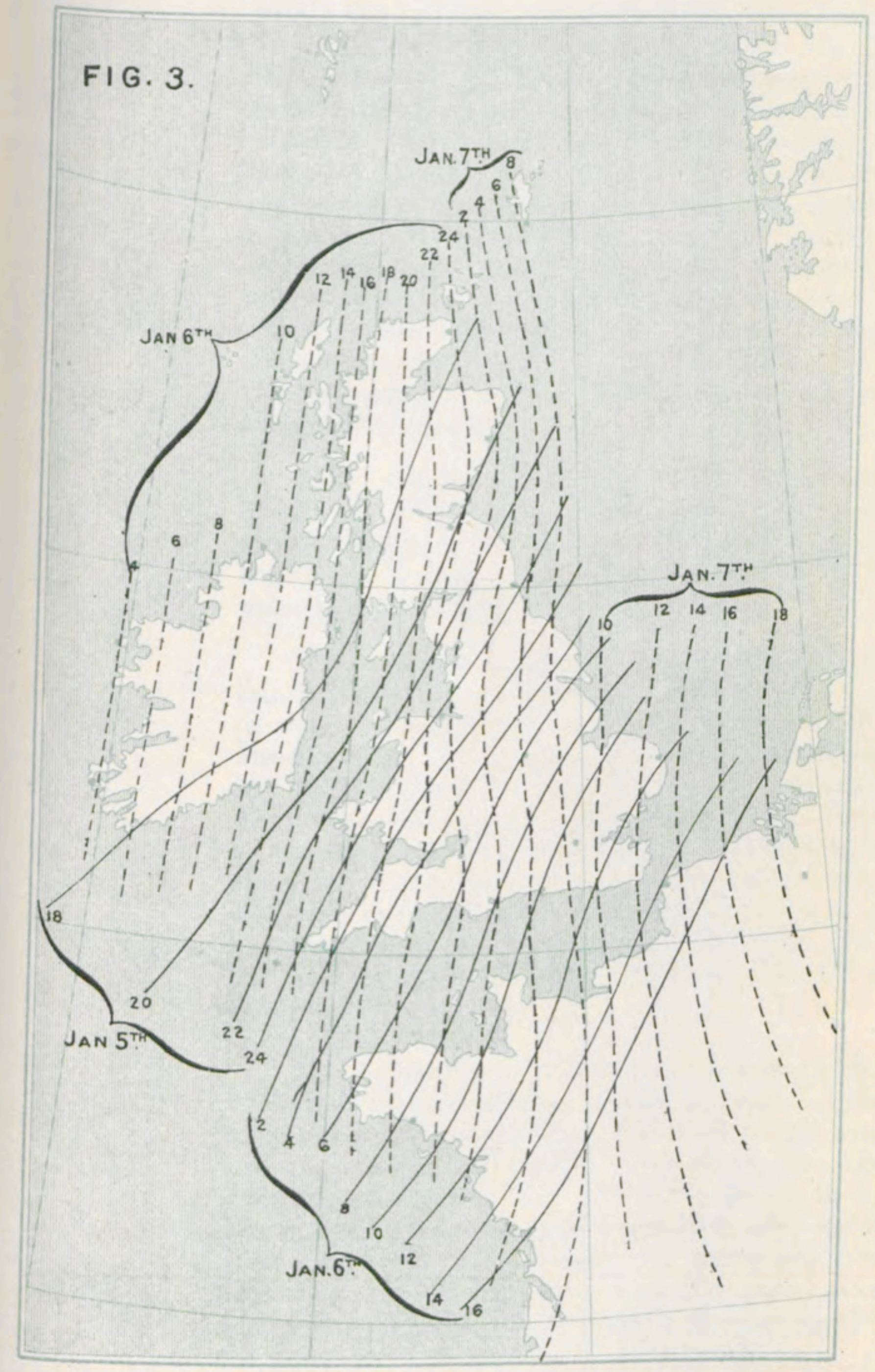
Plate XX

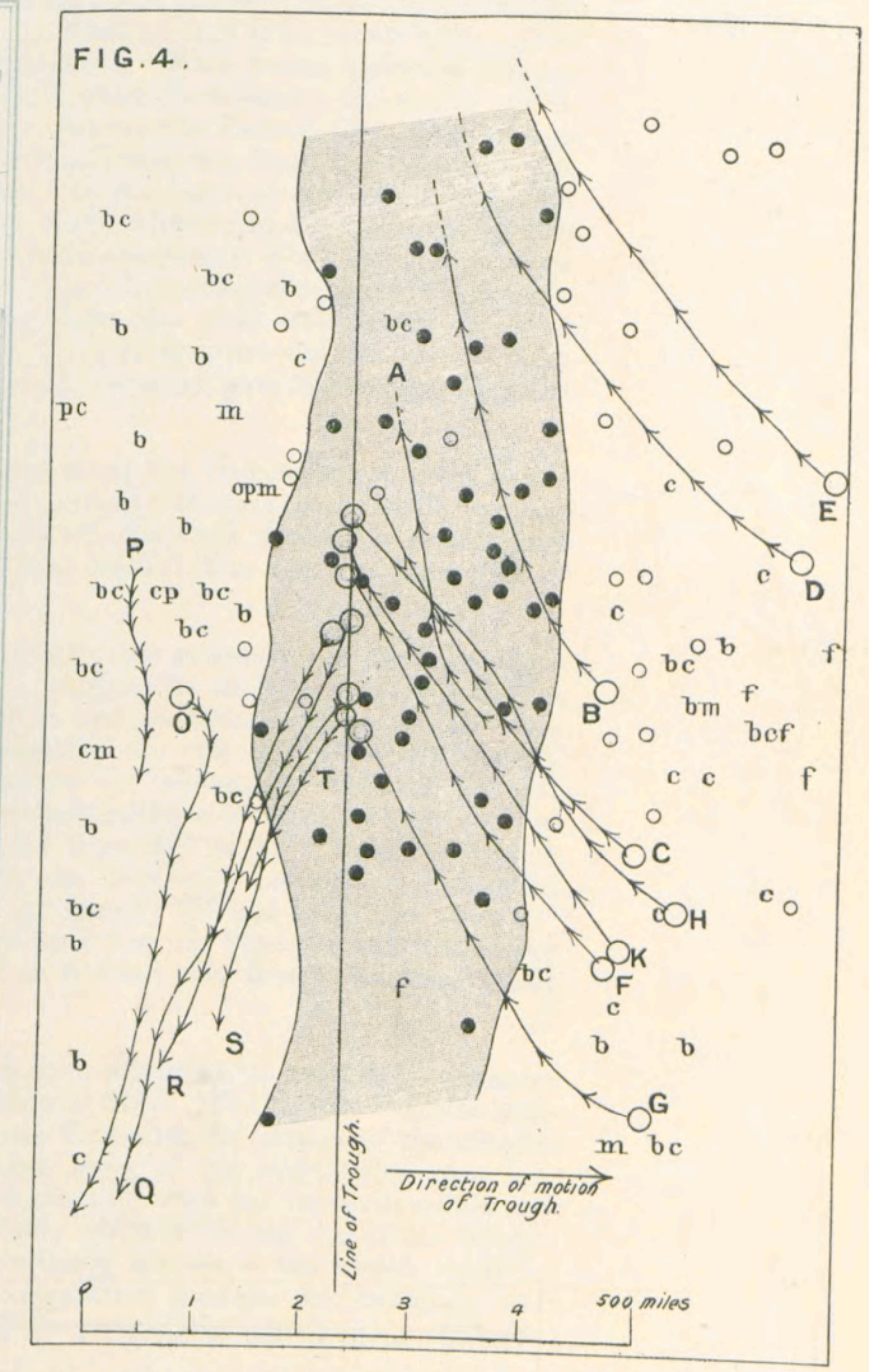
No. 7. JANUARY 5-7, 1900.

POSITION OF TROUGH AND BOUNDARY OF STORM.



The broken lines indicate the positions of the Trough of Lowest Pressure. The continuous lines separate the region under the influence of the disturbance from the anticyclonic region in front of it. A station was regarded as coming under the influence of the disturbance when the wind velocity at it reached 10 miles per hour.

MOTION OF AIR AND DISTRIBUTION OF WEATHER AND RAINFALL RELATIVE TO THE TROUGH OF LOWEST PRESSURE.



The circles at the beginning or end of the trajectories indicate that the trajectories commenced or ended in a region calm.

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The occurrence of a good deal of surface fog over the South-east of England and the adjoining parts of France and Belgium does not contradict the assumption that this was a region of descending air. Radiation of heat from the surface of the earth during the night was clearly the main factor in its production, and, in the light of some results recently obtained at the Aeronautical Observatory at Berlin,* the setting in of the wind above would rather tend to aid the formation of surface fog than to prevent it, as it would facilitate the mixing of the upper and probably warmer layers of air with the air which has been strongly cooled by contact with the cold surface of the earth.

When continued Northward all those trajectories of Southerly winds which remain within the area from which observations are available end in the calm region on the trough. The trajectories of the winds which blew over the Southern half of England in the rear of the depression (Q, R, S, T) all run from North to South. When traced backward they are found to originate in the calm region on the trough in which the Southerly trajectories ended. We must, therefore, conclude that the Southerly wind on the Eastern side of the trough ascended to the upper strata of the atmosphere, and that the Northerly current which replaced it at the surface descended from above. In the North of our Islands the wind in the rear of the disturbance was Westerly or North-westerly in direction and light in force, generally about 3 or 4 on the Beaufort scale (trajectory V). This corresponds approximately with a velocity of 15 miles an hour, a speed about equal to that of the trough. Further South and further in the rear of the storm the wind was also Westerly or North-westerly (trajectories O and P), but as the velocity exceeded 15 miles an hour the air gradually approached the trough, and as this occurred its motion became directed towards the South.

The changes in the meteorological elements along the trajectories are given in the Tables on Plate XX. The Southerly current exhibits changes with which we are already familiar; the pressure decreased rapidly while the wind velocity increased until the region in the neighbourhood of the trough was reached, here a slight diminution of velocity was indicated.

The weather along these trajectories was generally fair at first, but in the later stages rain fell steadily. The temperature depended on whether the air came from over the sea or over the land. In the South-west of England and in Ireland, where the air came directly from the Atlantic, maximum temperatures of over 50° were experienced, but further East the cold air from the Continent was warmed to between 40° and 45° during its passage across the channel. The temperatures of the sea water observed at the light-ships in the English Channel varied from 47° to 52°. Some very large changes of temperature were recorded within the Southerly current at individual stations; thus at Oxford the reading at 8 a.m. on January 6th had fallen as low as 31° in consequence of radiation during the night, but by 2 p.m. the warm air which was over the Channel in the morning (Portland Bill 43° at 8 a.m.) had flowed Northward, and the Oxford reading was 43°.

The trajectories in the rear of the trough all show a continuous increase of pressure, while the changes in velocity were less regular than in front. The records from the self-registering rain-gauges show that rain ceased some time after the passage of the trough, and the weather at stations near which the later steps of the trajectories pass was generally recorded as "b." or "bc." This is in conformity with the supposition that the Northerly wind consisted of descending air; the rain which fell in the rear of the trough must have been derived from the ascending Southerly current, a fact which could be accounted for by supposing that the plane of separation between the ascending and descending currents was inclined to the surface of the ground, the acute angle pointing in the direction of motion of the disturbance.

* *See* Ergebnisse der Arbeiten am Aeronautischen Institut, 1 Oktober, 1901, bis 31 Dezember, 1902

The temperature of the air in the rear of the disturbance was generally between 40° and 45°; it was, therefore, considerably colder than the warm air of the Southerly current in the South-west of England, but further East the difference of the temperatures of the two opposing currents were very small at the surface; at Oxford and Kew the passage of the trough was accompanied by a fall of temperature of less than 2°.

The distribution of the rainfall brought by the disturbance is shown in Fig. 11, Plate XIX. One inch, more or less, fell over the greater part of England, while in Ireland and Scotland the amounts were rather less. The heaviest fall occurred in the South-west of England (Scilly over two inches), where the warm moisture laden air from the Atlantic was forced to ascend. It is rather surprising that the fall over Ireland was not larger, possibly this is connected with the fact that the " V " shaped character of the depression was not so pronounced in its early stages.

From the manner in which the trajectories of Fig. 1 end we might be led to expect that the ascent of air, and consequently also the rainfall, was confined to the region immediately surrounding the trough, but this was not so. The synoptic charts and also the records from the self-registering rain gauges show that the region of rainfall extended through about 180 miles to the East of the trough and 40 miles to its West, so that a certain amount of convergence of the second type (*see* p. 19) must have taken place within the Southerly current. In all cases, however, the hourly values of the tabulations of the rain-gauge curves of the first class observatories, given in the table opposite, show some increase in the rate of fall, just about the time of passage of the trough. This phenomena was particularly marked in the West, where the ascending Southerly current was warmest and hence, probably, most highly charged with water vapour.

From what has been said above we are able to form a tolerably clear idea of the character of the changes taking place at the surface. To further elucidate the point the motion of the air relative to the line of the trough has been determined by a method similar to that described above (*see* p. 34). The result is shown in Fig. 4, Plate XX. When the actual motion of the air is compounded with a motion equal and opposite to that of the trough, the Southerly winds in front of the depression are found to give rise to curves which approach the line of the trough from a South-south-easterly direction and end on it, while in the rear the majority of the stream lines commence on the trough and flow away from a North-north-easterly direction. No stream lines are shown in the upper left-hand portion of the Figure, as it was found impossible to draw trajectories through this part of the depression, the winds being too light and variable.

The area within which rain was falling is very clearly marked out. In front of the storm a well defined region of overcast sky intervenes between the rain area and the anticyclonic regions still further to the East, but in the rear the transition from rain to a clear sky is much more rapid, a fact which agrees well with the supposition that the rear was a region of descending air.

It would be a matter of great interest to determine the character of the pressure distribution, or of the atmospheric currents, at higher levels. The difference in temperature of the two opposing currents was not large, and as we have no information on the subject of the vertical temperature gradients in them, we can form no estimate of their thickness. Unfortunately the wind circulation was very indefinite in the rear of the depression over the North of our Islands, so that little information is obtainable from the Ben Nevis records.

The Southerly current in front of the disturbance was very pronounced at the summit, and in it wind forces of 6 on the Ben Nevis scale were attained (9 Beaufort). For the 12 hours after the passage of the trough, *i.e.* from 1 p.m. on January 6th to midnight, the air remained almost calm, and after this Northerly breezes, estimated at force 1 to 3 (Ben Nevis scale) set in. Light Westerly to North-westerly breezes prevailed

at the surface during this period. The suggestion arises that the air at the 4,000 foot level was moving Southward to feed the more vigorous Northerly winds prevailing over Southern England in the rear of the trough.

	Falmouth.	Rousdon.	Oxford.	Berkhamsted.	Kew.
Northerly wind set in at	8.5 p.m. on 6th.	0.30 a.m. on 7th.	5.50 a.m. on 7th.	8.0 a.m. on 7th.	8.35 a.m. on 7th.
	Ins.	Ins.	Ins.	Ins.	Ins.
Jan. 6th 8–9 a.m.	·04				
9–10 "	·02				
10–11 "	·02				
11–Noon.	·05				
Noon–1 p.m.	·04				
1–2 "	·08				
2–3 "	·10	·02			
3–4 "	·06	·02			
4–5 "	·12	·11			
5–6 "	·09	·11			
6–7 "	·04	·07	trace.		
7–8 "	·17	·07	·01		
8–9 "	·25*	·08	·03		
9–10 "	·13	·08	·04	·05	
10–11 "	·28	·56	·03	·05	
11–Midnight.	·05	·56	·06	·08	
Jan. 7th, Midnight–1 a.m.	...	·40*	·06	·07	·01
1–2 "	...	·40	·05	·11	·07
2–3 "	...	·03	·06	·13	·05
3–4 "	...	·03	.05*	·16	·13
4–5 "	..	...	·10	·05	·08
5–6 "	...	...	·10	·10	·02
6–7 "	...	...	·03	·08	·07
7–8 "	...	...	...	·12*	·05
8–9 "	...	...	...	·04	·06*
9–10 "	...	...	...	·02	·02

* Indicates the time of the change of wind corresponding to the passage of the trough.

No. 8.—Sudden Decrease in Wind Force, accompanied by Change in Wind Direction (Plates XXI. to XXIII.).

1 a.m. to midnight, February 24th, 1903.

The following investigation was undertaken with a view to examining the circumstances attending a very sudden decrease in the force of the wind, which occurred in the South-west of England on February 24th, 1903. Attention was first called to the phenomenon by Mr. Victor Prigg, the observer at Plymouth, who was so struck by it that he forwarded to the Meteorological Office the trace of his pressure-tube anemometer (reproduced in Fig. 2, Plate XXI.). Examination of the records from other stations showed that the disturbance was not confined to the South-west of England, but that meteorological changes which could be brought into connection with it occurred in the course of the day over practically the whole of the three kingdoms. The most striking records are those from the observatory at Falmouth (Figs. 1 and 2, Plate XXI.), and we will accordingly proceed to give a brief description of them.

A gale from about South-by-west of average velocity of 60 miles per hour set in at about noon on the day in question. While this lasted the barometer fell continuously and the temperature remained approximately steady at 49° or 50°. Rain commenced at 5 p.m. At 6.48 p.m. the sudden decrease in the wind velocity which led to the present investigation occurred. It was accompanied by (1) a shift of the wind to the Westward through seven points, (2) by an exceedingly rapid rise of the barometer, (3) by an equally sudden fall of temperature, and (4) by a conspicuous increase in the rate of fall of rain. The wind remained Westerly till 7.30 p.m., but subsequently it gradually backed again, and by 8.30 p.m. it had become South-south-westerly. Rain ceased at 7.45 p.m., about one hour after the initial change of wind took place. At the remaining stations the sequence of events was similar. The following table, which has been compiled from the records of self-recording instruments, gives particulars of the character and, where possible, also of the magnitude of the changes shown.

TABLE I.

Changes in the Meteorological Elements recorded at Various Observatories on February 24th, 1903.

Place.	Time.	Change of Pressure (ins.).	Change of Temperature (°).	Change of Wind.		Rainfall (ins.).		
				Force.	Direction.	Commenced.	Heaviest.	Ceased.
Valencia ...	9.30 a.m. (9·5).	Sudden rise of 0·05.	Sudden fall, 49·1 to 45·6.	Fell from 55 to 35 miles per hour.	Veered from S. to W.S.W.	3 a.m.	9.30–9.40, 0·1".	10.45 a.m.
Armagh ...	12.18 p.m. (12·3).	—	—	Fell from 32 to 20 miles per hour.	Veered from S. by W. to W. by S.	8 a.m.	11.45–11.50, 0·04".	12.40 p.m.
Castle Townshend (co. Cork)	12.21 p.m. (12·4).	Sudden rise of 0·025.	—	—	—	—	—	—
Fort William ...	1 p.m. (13).	Slow rise of 0·02 between 1 and 2 p.m.	Fall from 48 to 44 between 1 and 2 p.m.	—	—	6.30 a.m.	1.10–1.25, 0·1".	2.30 p.m.
Kilkenny ...	2 p.m. (14).	Slight irregularity in trace.	—	—	—	—	—	—
Glasgow ...	2.30 p.m. (14·5).	Rise of 0·04 in 3 minutes.	Fall from 47·0 to 42·2.	Fell from 38 to 18 miles per hour.	S. S. W. at 2.30, W.S.W. at 2.40	6.30 a.m.	2.22–2.30, 0·05".	2.50 p.m.
Forgandenny ...	3 p.m. (15).	Sudden fall?	—	-	—	—	—	—
Kingstown ...	3.30 p.m. (15·5).	—	—	No marked change.	Veered temporarily from S.W. to W.	—	—	—

Plate XXI

SUDDEN VEER OF WIND.

FIG 1. TRACES OF SELF-RECORDING INSTRUMENTS.
at Falmouth Observatory
10 a.m. February 24 to 10 a.m. February 25 1903.

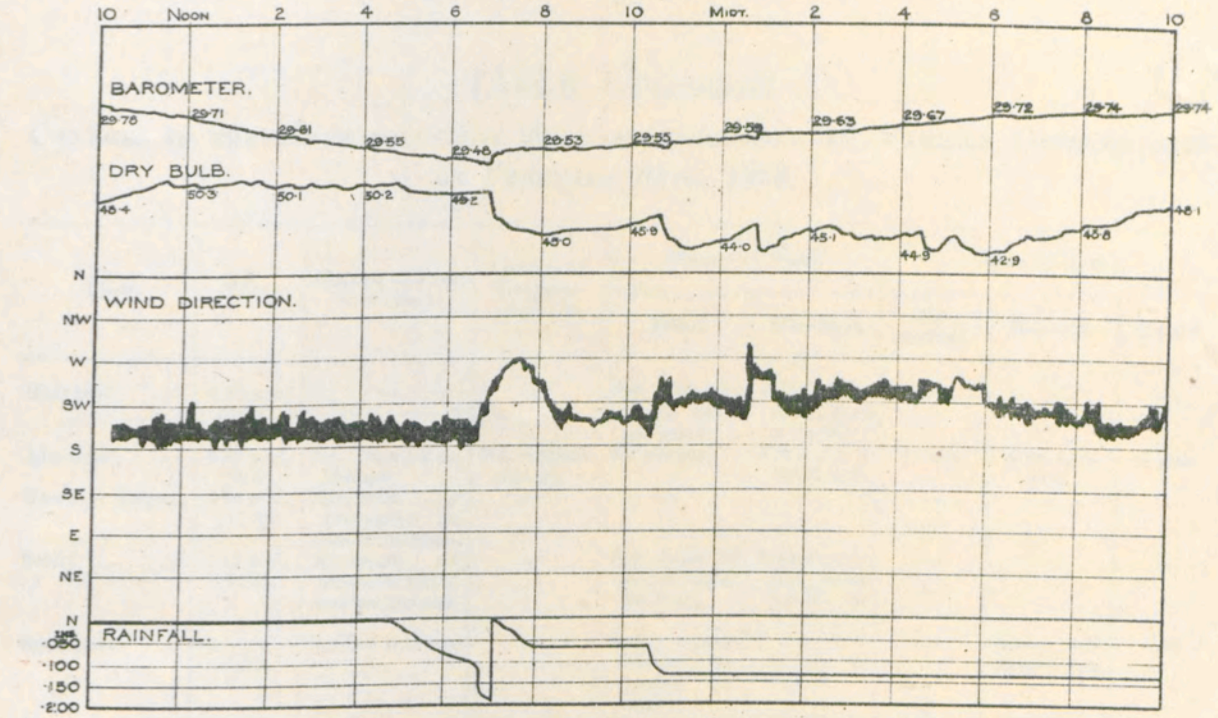

FIG 2. TRACES OF PRESSURE TUBE ANEMOMETERS.
at Falmouth and Plymouth

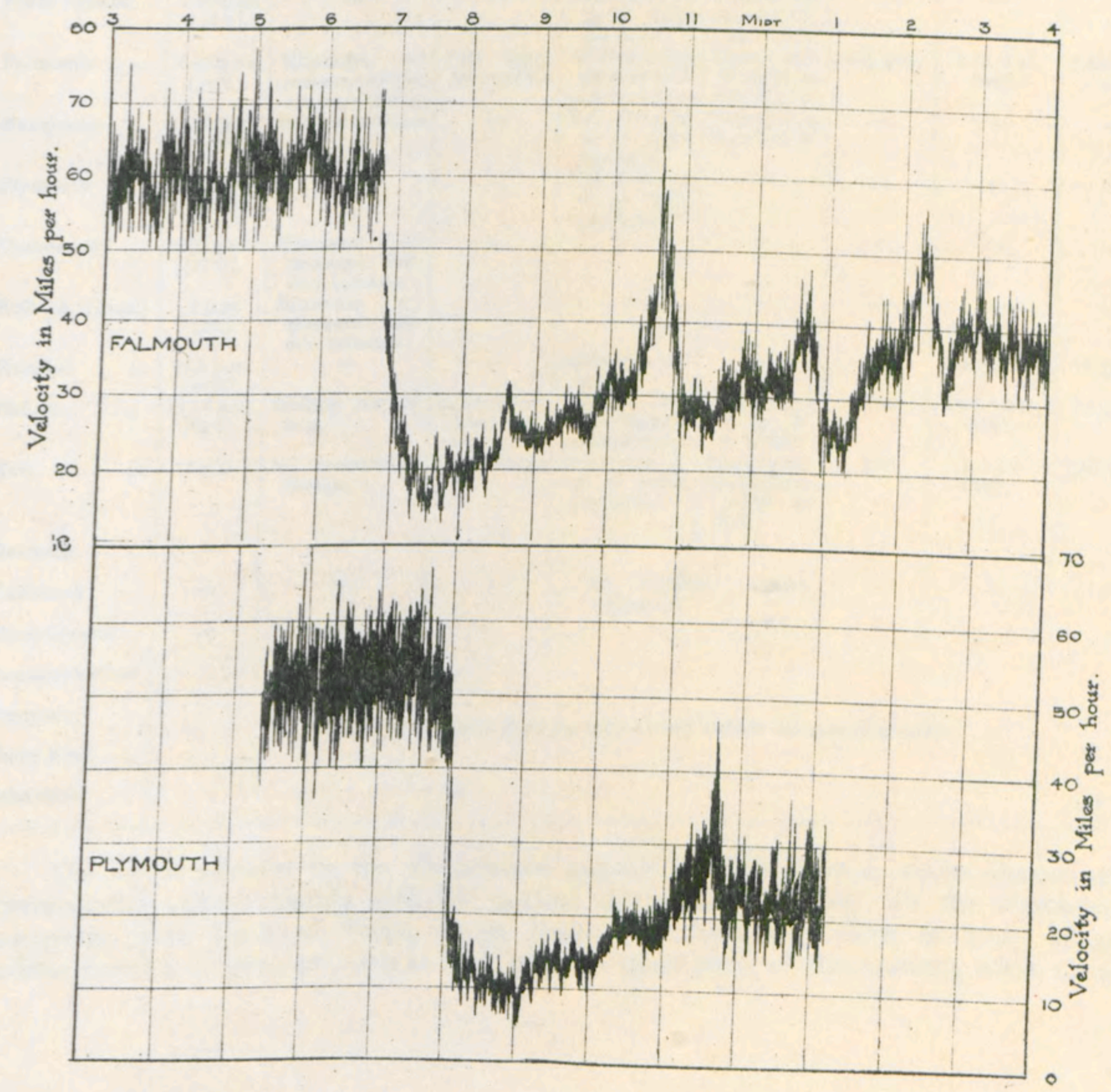

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TABLE I.—*continued.*

Changes in the Meteorological Elements recorded at Various Observatories on February 24th, 1903.

Place.	Time.	Change of Pressure (ins.).	Change of Temperature (°).	Change of Wind. Force.	Change of Wind. Direction.	Rainfall (ins.). Commenced.	Rainfall (ins.). Heaviest.	Rainfall (ins.). Ceased.
Holyhead ...	4.30 p.m. (16·5).	—	—	Fell from 35 to 20 miles per hour.	Veered suddenly from S. to W.	—	—	—
Aberdeen ...	4.35 p.m. (16·6).	No marked change.	No marked change.	No change	Veered S.S.E. to S.	11 a.m.	4.40–4.45, 0·05″.	4 p.m.
Newton Reigny	5.15 p.m. (17·3).	Minimum of pressure; no sudden increase.	—	—	—	—	—	—
Scilly	5.15 p.m. (17·3).	Minimum of pressure; slight sudden increase.	—	Fell from 50 to 25 miles per hour.	Veered suddenly from S.S.W. to W. by N.	—	—	—
Southport ...	6.3 p.m. (18).	Sudden increase	—	Heavy squall followed by gradual decrease.	Veered S.S.W. to W.S.W.	—	Heavy rain about 6 p.m.	7.15
Stonyhurst ...	6.30 p.m. (18·5).	Minimum of pressure; sudden rise of 0·04.	Fall from 46·5 to 44·0.	Fell from 42 to 18 miles per hour.	Veered from S. by W. to W. by N.	2 p.m.	6.25–6.30, 0·05″.	7.30 p.m.
Alnwick ...	6.40 p.m. (18·7).	—	—	Not recorded	Veered S.W. by S. to W.S.W.	—	—	—
North Shields ...	7.30 p.m. (19·5).	—	—	Fell from 30 to 25 miles per hour.	Veered slowly from S.W. to W.S.W.	—	—	—
Falmouth ...	6.48 p.m. (18·8).	Minimum of pressure; sudden increase of 0·06.	Fall from 52·3 to 48·3.	Sudden fall from 60 to 20 miles per hour.	Veered suddenly from S. by W. to W.	4·55 p.m.	4·40–4·45. 0·05″.	7.45 p.m.
Manchester ...	7.15 p.m. (19·3).	Sudden increase	—	Fell from 25 to 15 miles per hour.	Veered from S. to W.S.W.	—	—	—
Plymouth ...	8 p.m. (20).	—	—	Fell from 50 to 15 miles per hour.	—	—	—	—
Chatsworth ...	8.30 p.m.? (20·5).	Minimum of pressure; sudden increase.	—	—	—	—	—	—
Fulbeck (Lincs.)	9 p.m. (21).	Minimum of pressure; sudden increase.	—	—	—	—	—	—
Rousdon ...	9.15 p.m. (21·3).	—	—	Sudden decrease.	—	—	Heavy rain	10 p.m.
Oxford	10.10 p.m. (22·2).	Sudden rise of 0·04.	Sudden fall from 48 to 43.	Sudden fall from 50 to 18 miles per hour.	Veered from S. by W. to W.S.W.	8 p.m.	10·5–10·15, 0·08″.	11 p.m.
Kew	1 a.m.	No remarkable change.	Fall through 0·5.	Fell from 27 to 15 miles per hour.	Veered gradually from S.S.W. to S.W.	9.55	1–1.15, 0·04″.	1.30 a.m.
Deerness ...	—	—	—	No striking changes shown.				
Yarmouth ...	—	—	—	No striking changes shown.		—	—	—
Shoeburyness ...				No striking changes shown.				
Sumburgh Head	Barograms show no trace of any sudden increase of pressure.							
Stornoway ...	Barograms show no trace of any sudden increase of pressure.							
Malin Head ...	Barograms show no trace of any sudden increase of pressure.							
Belmullet ...	Barograms show no trace of any sudden increase of pressure.							

The region affected by the disturbance appears to have been a wedge-shaped area corresponding approximately with the outline of the British Isles. In the North-west barograms from Blacksod Point, Malin Head, and Stornoway show no trace of any sudden increase of pressure such as took place in other parts of the country, while on the

East coast the anemograms from Deerness, Yarmouth, and Shoeburyness show no sudden fluctuations of wind, and at Aberdeen and North Shields the changes were only slight. The phenomenon was most marked in the South-west of England and Ireland, where the rainfall was also heaviest (*see* Map, Fig. 5, Plate XXII.). No records are available from the French side of the English Channel, but from the small amounts of rainfall experienced there it is improbable that the changes of wind were very conspicuous.

When the hours at which the interruption of the wind from the South occurred are plotted on a map they are found to lend themselves to the construction of a number of approximately parallel isochronous lines, which cross the country in a South-south-westerly to North-north-easterly direction (Fig. 2, Plate XXIII.). The perpendicular distance between the lines for 1 p.m. (13), February 24th, and 1 a.m., February 25th, is 340 miles, from which we derive the rate of propagation of the disturbance at right angles to the isochronous lines as 29 miles per hour.

The resemblance which these lines bear to the isobrontal lines, with which we have been made familiar by the study of the manner of propagation of thunder and hailstorms, is obvious, and the returns from most stations contain references to thunder, lightning, or hail, but the time of their occurrences is not, as a rule, definitely stated. In what follows we shall attempt to show that the isochronous lines formed a line of separation between two distinct air currents, one from the South, the other from a more Westerly point.

Attention may here be drawn to the close similarity of the phenomena as observed at an individual station to those already described as occurring over England during the night from October 14th to October 15th, 1903 (*see* No. 6, p. 51). In that case we were able to bring forward evidence in support of the view that a cold descending current from the Westward forced its way underneath a warmer current moving from the Southward, and caused the latter to ascend and give rise to a great increase in the rate of rainfall. In the present case it is also probable that descent of air occurred in the Westerly displacing current, for the velocity of the Westerly wind was less than 20 miles per hour (*see* anemogram for Plymouth, Fig. 2, Plate XXI.), whereas the velocity of propagation of the disturbance was, as we have seen, about 29 miles per hour. The fact that rain continued for about an hour after the wind changed can again be accounted for on the assumption that the water condensed from the Southerly current during its ascent fell to the ground through the colder descending air. A calculation similar to that on p. 51, based on the values obtained from the Falmouth records, where the change in wind was accompanied by a rise of the barometer of ·06 inch and a fall of temperature of 4°, gives the height of the displacing current as about 8,000 feet.

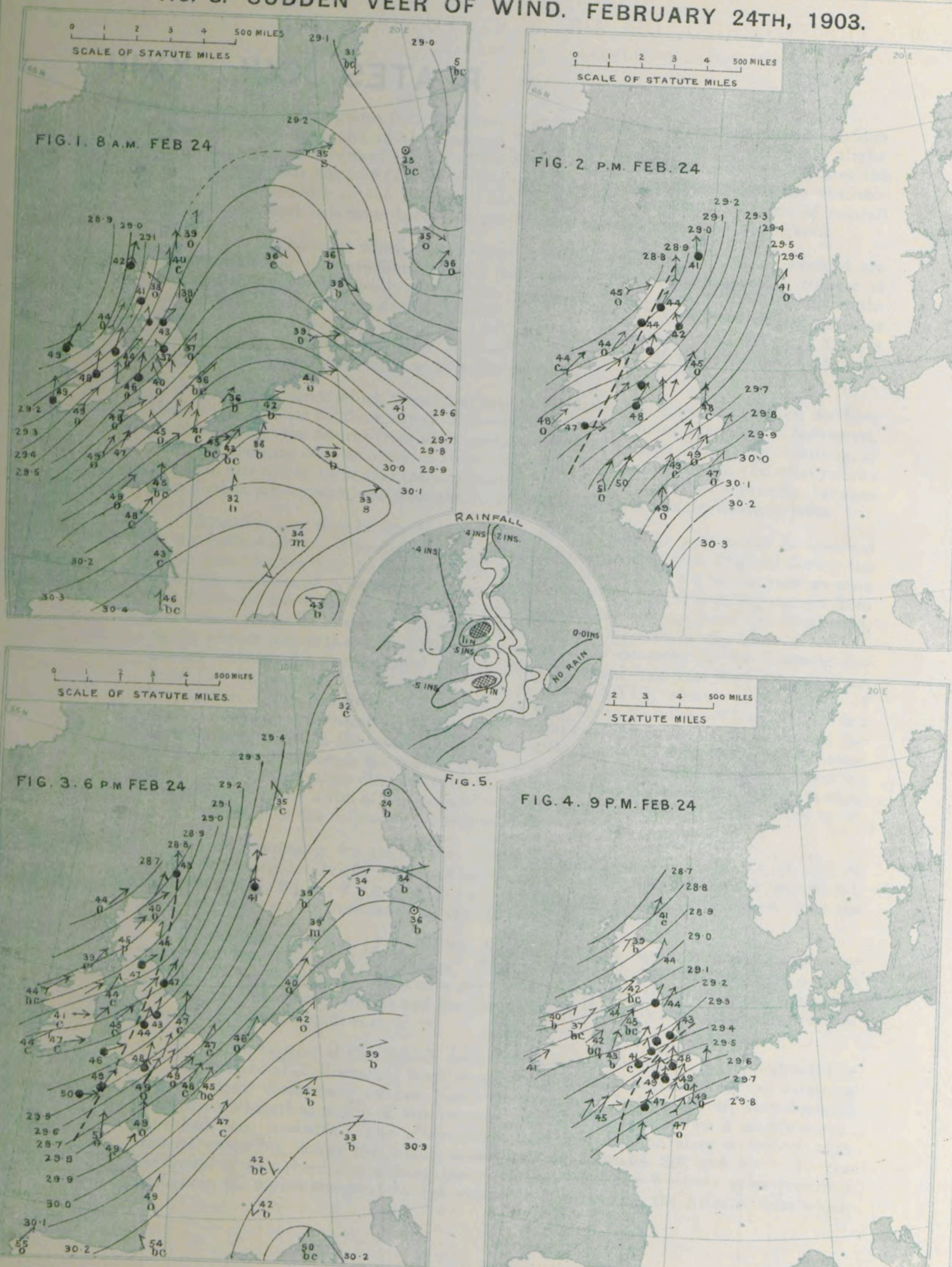
Before examining the trajectories which show the motion of the air, it will be necessary to consider briefly the distribution of pressure. The four maps reproduced, those for 8 a.m., 2 p.m., 6 p.m., and 9 p.m. on February 24th, are a selection from the 24 hourly maps which were drawn in the Meteorological Office.

On the map for 8 a.m. (Fig. 1, Plate XXII.) we find a region of high pressure over Spain and the South-west of France. Further to the Northward there was a steep gradient for South-westerly winds over the British Isles and the North of France, but over the Scandinavian Countries and the North-east of Germany the isobars are directed from North-west to South-east.

In the North-west of the British Isles the isobars are concave to a point situated in the neighbourhood of Rockall. Such concavity is usually attributed to the existence of a "cyclonic disturbance off our North-west coasts." It is, however, very doubtful whether a well-marked centre of low pressure would have been shown if more observations had been available. The observations from mid-Atlantic show a belt of high pressure extending across the whole ocean between latitudes 30° and 40°. To the Northward of this there was a steep barometric gradient, and Westerly gales prevailed throughout the region traversed by the steamer routes crossing the Atlantic, from which

PLATES XXII., XXIII.

No. 8. SUDDEN VEER OF WIND. FEBRUARY 24TH, 1903.

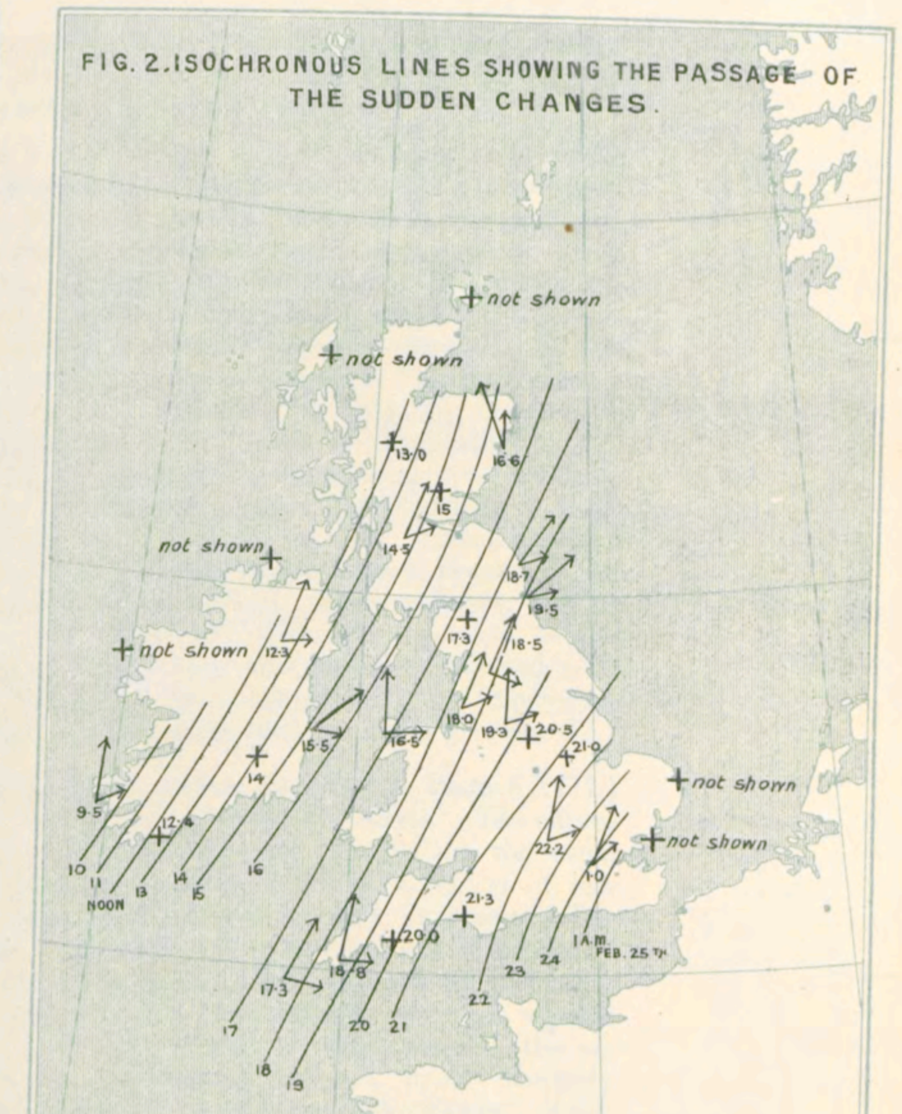


Note.—The dotted lines on Figs. 2, 3 and 4 indicate the positions of the lines along which the change of wind was taking place. See Plate XXIII. Fig. 2.
The mark ● shows that rain was falling at the hour of observation.

No. 8. TRAJECTORIES OF AIR FOR FEBRUARY 24th, 1903 (Figure 1)

And isochronous lines showing the passage of the sudden changes across the British Isles (Figure 2).

The portions of the Trajectories between 6 p.m and 6 a.m have been thickened.



The Arabic numerals indicate the hours [1–24] commencing at 1 a.m.
At stations provided with anemometers the arrows indicate the directions of the interfering air currents, the larger arrow representing the stronger wind.
Stations from which records of other elements are available shown thus +
"Not shown" means that the self recording instruments showed no sudden change.

Hours.	A				B				C				D				E				F				G				H				Hours.
	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	
1	26	9'67	46	n					15	9'75		(n)					20	9'92	(44)	(n)													1
3	31	9'45		(r)					20	9'60		(n)					20	9'90															3
5	35	9'25		(r)					30	9'50							29	9'82															5
7	45	9'05	(49)	(r)	35	9'55	(49)	(o)	39	9'30		r					30	9'73	(46)	(r)					31	9'95	(45,	l(c)					7
9					35	9'35	(50)	(r)	42	9'05	(42)	r	27	9'80	48	(n)	37	9'53	(47)	o					31	9'88	(45)	(o)					9
11					40	9'15		r	42	8'93	46	r	37	9'65		(n)	37	9'35							35	9'75		(n)					11
13													45	9'52			31	9'15		(r)					37	9'52		(n)					13
15													37	9'30	(50)	(r)									37	9'30	(49)	(r)					15
17																					(60)	9'60	50	r					31	9'78	(49)	(o)	17
19																					60	9'49		r					35	(9'75)	(48)		19
21																													35	9'58	49	r	21

Hours.					B'								D'				E'				F'								H'				Hours.
	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	V	P 20+	T	W	
13					20	9'14	(44)	(r)																									13
15					22	9'12											20	9'03															15
17					22	9'05	(45)	(n)					22	9'23	45	c	18	9'02	(44)	(o)													17
19					22	9'02							40	9'25			18	8'98	(44)	(n)	21	9'52	47	r									19
21					22	8'95	(38)	(b)					30	9'23			18	8'95	(44)	(n)	21	9'53	45	(n)									21
23					22	8'93	(40)						20	9'20			18	8'93			21	9'58							18	9.50	(45)	r	23

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alone observations are available. The observations from Iceland and Greenland are not yet published. During the day the high pressure over Spain and France decreased in intensity, and the South-westerly gradient encroached further Eastward.

On the maps for 2 p.m., 6 p.m. and 9 p.m. (Figs. 2, 3, 4) the positions of the isochronous lines of Fig. 2, Plate XXIII., corresponding to those epochs have been indicated by means of broken lines. The distribution of pressure on two sides of an isochronous line shows no striking differences, and the isobars, as drawn from the observations, when considered apart from the remaining elements, suggest no abrupt change. If observations trustworthy to within ·01 inch when reduced to mean sea-level, had been available from a sufficiently large number of stations, the sudden increase of pressure shown by all the barograms would presumably have found expression in the isobars as a "fault" running along the isochronous lines. The map for 9 p.m., February 24 (Fig. 4), for which observations from a large number of stations of the second order are available, presents some features of special interest. On the Eastern side of the isochronous line, which is shown dotted, we find gales (force 8 to 10, Beaufort), from the Southward, high temperatures (47° to 49°) and an over-cast sky or rain at all stations. Immediately to the Westward of the dotted line is a region of light breezes (forces 1 to 4, Beaufort) and low temperatures (41° to 45°). The wind direction here is rather variable, but at Plymouth it is Westerly; the weather is still rainy and dull. Still further to the Westward we find that the wind has freshened again, being now generally reported as of force 5 to 7 on the Beaufort Scale, while in direction it is South-westerly. Temperature is still low, while the weather has become fair or fine at most stations where it is noted.

We have now to consider the trajectories of the surface air (Fig. 1, Plate XXIII.) which have been constructed with the help of the hourly synoptic charts. The curves A to H represent the motion of the air in the Southerly gales. They show the usual characteristics of trajectories of Southerly winds on the Eastern side of a region of low barometer. Pressure decreases steadily along them, while velocity increases. The temperature is relatively high; the weather is generally fine at first, but it presently becomes rainy in all cases. These trajectories can all be traced Northwards up to a point where they either leave the area from which observations are available or reach a point where a sudden change of wind direction occurred. Here, we must assume, the air leaves the surface and its place is taken by air moving from a more Westerly direction. Trajectories B′, D′, E′, F′, H′ represent these displacing winds. Much greater uncertainty attaches to their courses. Examination of the records of the self-recording instruments at the observatories shows that the Southerly air current was very steady both in direction and in force, but within the region under the influence of the more Westerly winds conditions were much less steady. We have seen above that the Westerly wind which made its appearance at Falmouth at 6.48 p.m. gradually backed, and that at 8.30 p.m. it had become South-south-westerly. It remained so until 10.41 p.m., at which hour it was in turn displaced by wind of a more Westerly direction. The displacement was accompanied by a brisk increase of pressure, and a decided fall of temperature, and a sharp shower also fell. "Secondaries" of this nature were of frequent occurrence after the first interruption of the primary current had taken place.

It thus appears probable that the air of the displacing current from the Westward was gradually drawn to the Northward, as indicated by the trajectories B′ and D′, and that it was in its turn displaced by a more Westerly colder current.

In the case of the "secondary" disturbances the thickness of the colder displacing current appears to have been considerably smaller than in the case of the current which cut into the original steady Southerly wind. Thus at Falmouth the "secondaries" which passed at 10.41 p.m. on February 24th, and 0.49 a.m. on February 25th, each gave rise to an increase of pressure of about ·02 inch, while the corresponding falls of temperature were 4° and 3° respectively. The thicknesses of the currents calculated from these data are respectively 2,600 feet and 3,500 feet. Another point of difference between the primary and the subsequent disturbances is that the former brought about a permanent reduction of temperature, whereas the sudden falls of temperature associated with the latter were followed by more gradual rises until the values which prevailed before the passage of the "secondary" were again attained.

Attempts to trace the "secondaries" across the map in a similar manner to that shown in Fig. 2, Plate XXIII., met with only partial success. In the North of England the data are not sufficient to enable us to connect one disturbance with another. The times of passage of the more prominent "secondaries" over the stations in the South are given in Table II.; and when the intervals between the times of interruption of the steady current and the times of passage of the subsequent disturbances are worked out, as in Table III., we find that they are in many cases of approximately the same length at the various stations, and it is impossible to resist the conclusion that some, at any rate, of the "secondaries" travelled Eastward with a velocity approximately equal to that of the first pulse.

TABLE II.

TIMES OF PASSAGE OF "SECONDARIES" AT STATIONS IN THE SOUTH OF ENGLAND.

—	Scilly.	Falmouth.	Plymouth.	Rousdon.
Primary interruption of Southerly Current.	5.20 p.m.	6.48 p.m.	8.0 p.m.	9.30 p.m.
"Secondary" (a)	9.15 p.m.	10.35 p.m.	11.40 p.m.	0.45 a.m.
" (b)	11.5 p.m.	0.35 a.m.	Record not received.	2.30 a.m.
" (c)	3.30 a.m.	5.20 a.m.	Record not received.	—
" (d)	—	1.30 p.m.	Record not received.	4.30 p.m.

TABLE III.

INTERVAL BETWEEN INTERRUPTION OF SOUTHERLY CURRENT AND PASSAGE OF "SECONDARIES."

—	Scilly.		Falmouth.		Plymouth.		Rousdon.	
	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.
"Secondary" (a)	3	55	3	47	3	40	3	15
" (b)	5	45	5	47	?		5	0
" (c)	10	10	10	32	?		—	
" (d)	—		18	42	?		19	0

Some further interesting examples of similar changes occurred during the same week. Throughout the period from February 22nd to February 26th the general features of the distribution of pressure over North-western Europe remained unchanged. A series of barometric surges passed across our Islands, but the cyclonic centres, supposing such to have existed, remained to the Westward of our coasts. Each fall of the barometer was accompanied by a strong and very steady wind from some Southerly point, while during the period of rising barometer less strong winds from a more Westerly point, in which "secondary" disturbances were very conspicuous, prevailed. Thus at Falmouth a strong gale of about 50 miles per hour from the South-west prevailed on February 22nd up to 7.49 p.m., but at this hour the South-westerly current was suddenly cut off by a West wind of only 20 miles an hour. All the changes in the other meteorological elements described above occurred on this occasion also, and as before the current from the West proved to be much less steady than the one from the South-west, and frequent "secondaries" occurred in it. The barometer reached a maximum at midnight on February 23rd, and during the subsequent fall the wind backed gradually to the South and became very steady until, at 6.48 p.m., the changes considered above in detail occurred. The rise of the barometer which followed reached a maximum at 10 a.m. on February 25th, and during the subsequent fall the wind again became both stronger and more steady. Its direction backed gradually from South-west by South at 10 a.m. to South by West at 9 p.m., but no irregular fluctuation occurred during this period. At the latter hour the steady current was once more cut off, this time by a wind from South-west, in which "secondary" disturbances were again frequent. Over the Northern part of the Country the alternations between steady and unsteady winds were less marked, and we will confine our attention to the Southern Counties.

The times at which the steady currents of February 22nd to 23rd, and February 25th to 26th were interrupted at the various stations are shown on the maps of Figs. 14 and 15. As before the gradual extension of the region of more Westerly winds can be traced by a series of isochronous lines; unfortunately the stations from which records are available all lie approximately on a straight line, so that we can obtain no information as to the lateral extension of the front of the pulses.

Tables IV. and VI. give the times of occurrence of "secondaries," and in Tables V. and VII. the intervals between the occurrence of these and the first interruptions of the steady flow are worked out for the various stations. As on February 24th to 25th a considerable number of these "secondaries" appear to have travelled for longer or shorter distances, with velocities approximately equal to the rate of propagation of the first pulse.

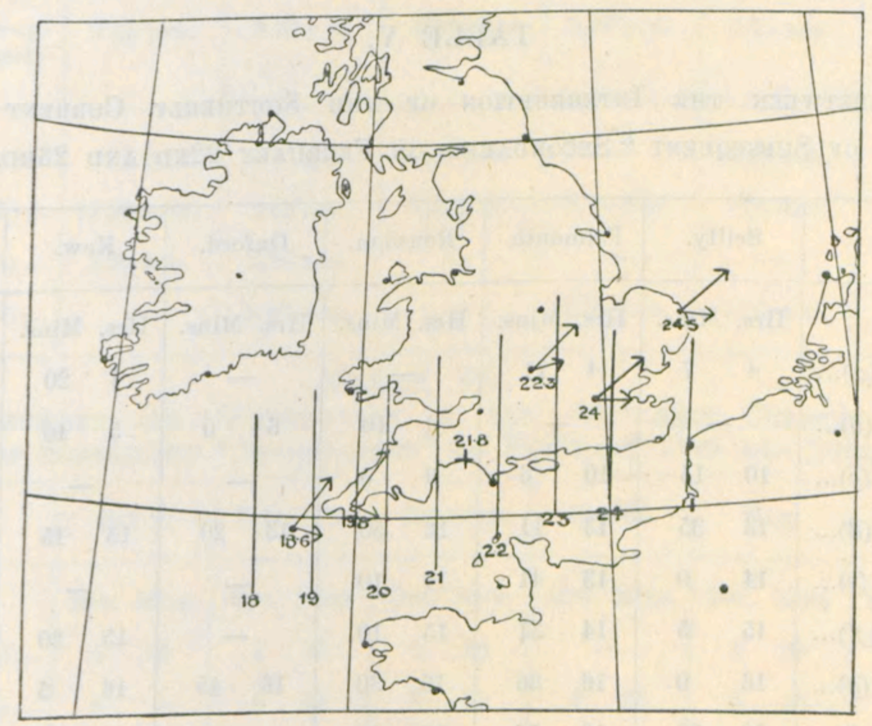


FIG. 14.

Times of Primary Interruption of Southerly Current, February 22nd and 23rd, 1903. *(See Table IV.)*

TABLE IV.

Times of Interruption of Southerly Air Current and of Subsequent "Secondaries" on February 22nd and 23rd, 1903.

—	Scilly.	Falmouth.	Rousdon.	Oxford.	Kew.	Yarmouth.
Primary Interruption of Southerly Current.	6.30 p.m.	7.49 p.m.	9.50 p.m.	10.20 p.m.	11.55 p.m.	1.30 a.m.
"Secondary" (*a*)...	10.37 p.m.	Midnight	—	—	4.15 a.m.	—
" (*b*)...	—	—	4.0 a.m.	4.20 a.m.	5.35 a.m.	8.0 a.m.
" (*c*)...	4.45 a.m.	5.55 a.m.	6.50 a.m.	—	—	—
" (*d*)...	8.5 a.m.	9.0 a.m.	10.40 a.m.	11.40 a.m.	1.0 p.m.	—
" (*e*)...	8.30 a.m.	9.30 a m.	Noon.	—	—	—
" (*f*)...	9.35 a.m.	10.20 a.m.	1.0 p.m,	—	3.15 p.m.	—
" (*g*)...	10.30 a.m.	12.15 p.m.	2.20 p.m.	3.5 p.m.	4.0 p.m.	—
" (*h*)...	1.0 p.m.	2.45 p.m.	5.0 p.m.	—	—	—
" (*k*)...	2.40 p.m.	3.50 p.m.	—	—	—	—

TABLE V.

Intervals between the Interruption of the Southerly Current and the Passage of Subsequent "Secondaries on February 22nd and 23rd, 1903.

—	Scilly.		Falmouth.		Rousdon.		Oxford.		Kew.		Yarmouth.	
	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.
"Secondary" (*a*)...	4	7	4	11	—		—		4	20	—	
" (*b*)...	—		—		6	10	6	0	5	40	6	30
" (*c*)...	10	15	10	6	9	0	—		—		—	
" (*d*)...	13	35	13	11	12	50	13	20	13	15	—	
" (*e*)...	14	0	13	41	14	10	—		—		—	
" (*f*)...	15	5	14	31	15	10	—		15	20	—	
" (*g*)...	16	0	16	26	16	30	16	45	16	5	—	
" (*h*)...	18	30	18	56	19	10	—		—		—	
" (*k*)...	20	10	20	1	—		—		—		—	

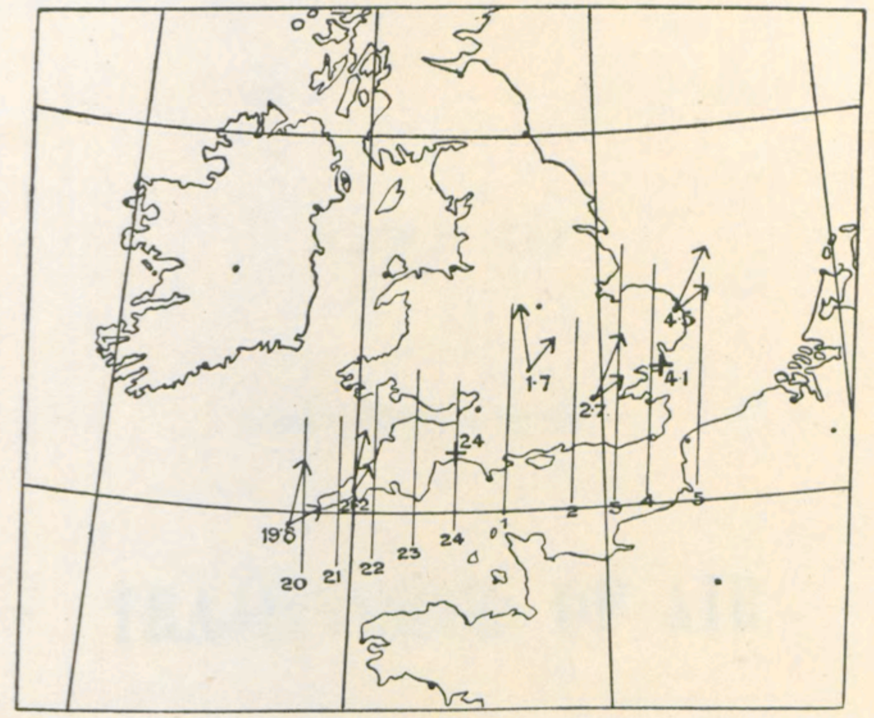


Fig. 15.
Times of Primary Interruption of Southerly Current, February 25th and 26th, 1903. *(See* Table VI.)

TABLE VI.

Times of Interruption of Southerly Air Current and of Subsequent "Secondaries" on February 25th and 26th, 1903.

—	Scilly.	Falmouth.	Rousdon.	Oxford.	Kew.	Yarmouth.
Primary Interruption of Southerly Current.	7.45 p.m.	9.10 p.m.	Midnight	1.40 a.m.	2.40 a.m.	4.30 a.m.
"Secondary" (*a*) ...	9.0 p.m.	10.45 p.m.	1.50 a.m.	—	5.15 a.m.	6.30 a.m.
" (*b*) ...	11.50 p.m.	1.45 a.m.	3.50 a.m.	6.10 a.m.	7.20 a.m.	9.0 a.m.
" (*c*) ...	2.20 a.m.	3.40 a.m.	—	—	—	—
" (*d*) ...	—	5.15 a.m.	—	10.0 a.m.	11.0 a.m.	—

TABLE VII.

Intervals between the Interruption of the Southerly Current and the Passage of Subsequent "Secondaries" on February 25th and 26th, 1903.

—	Scilly.		Falmouth.		Rousdon.		Oxford.		Kew.		Yarmouth.	
	Hrs.	Mins.	Hrs.	Mins	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.	Hrs.	Mins.
Secondary" (*a*) ...	1	15	1	35	1	50	—		2	35	2	0
" (*b*) ...	4	5	4	35	3	50	4	30	4	40	4	30
" (*c*) ...	6	35	6	30	—		—		—		—	
" (*d*) ...	—		8	5	—		8	20	8	20	—	

PART III.

TRAJECTORIES OF AIR

OVER THE

NORTH ATLANTIC OCEAN.

CHARTS AND DESCRIPTIVE TEXT.

PLATE XXIV.

For notes see Plate XXV.

FIG. 1.

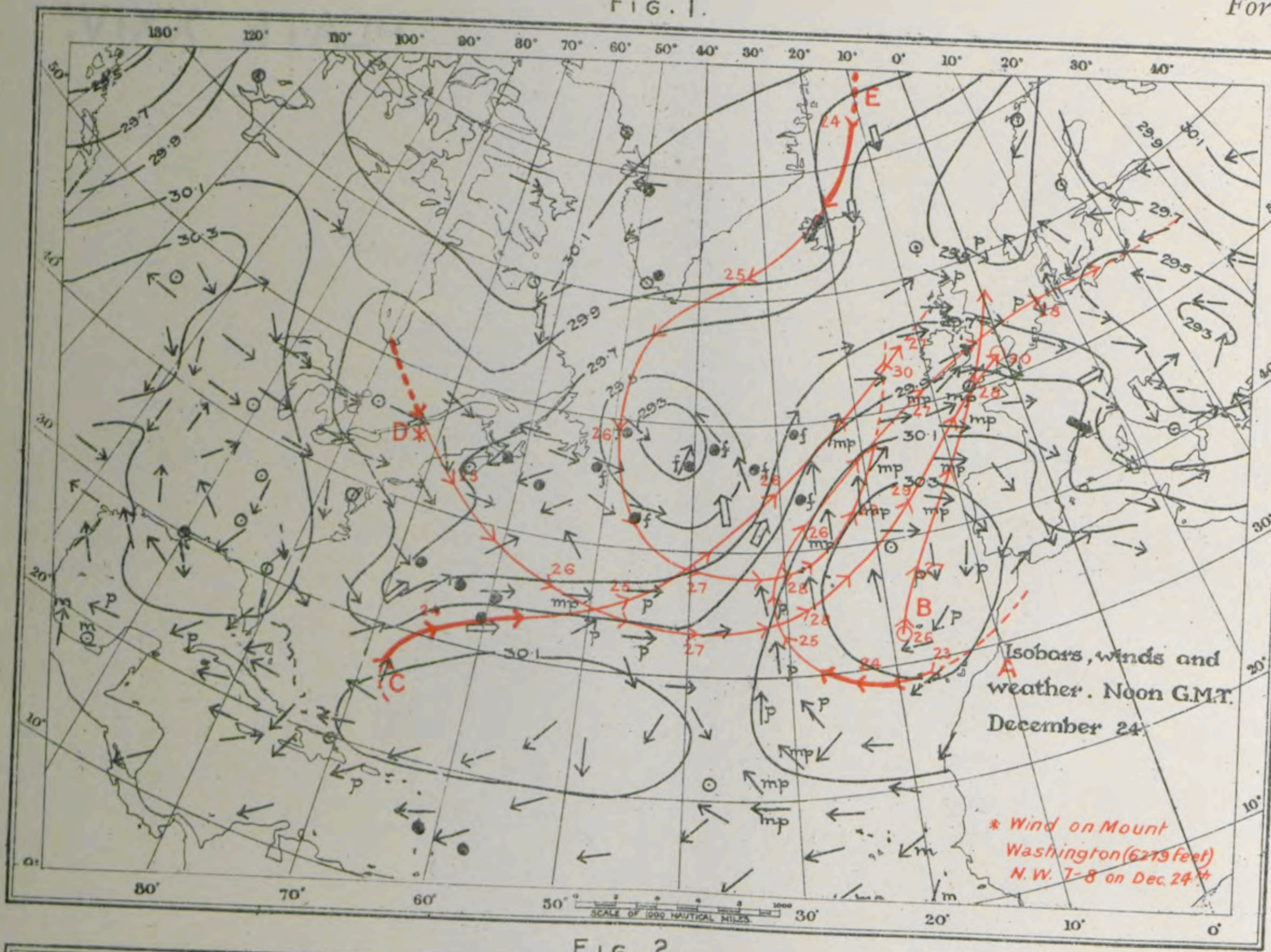
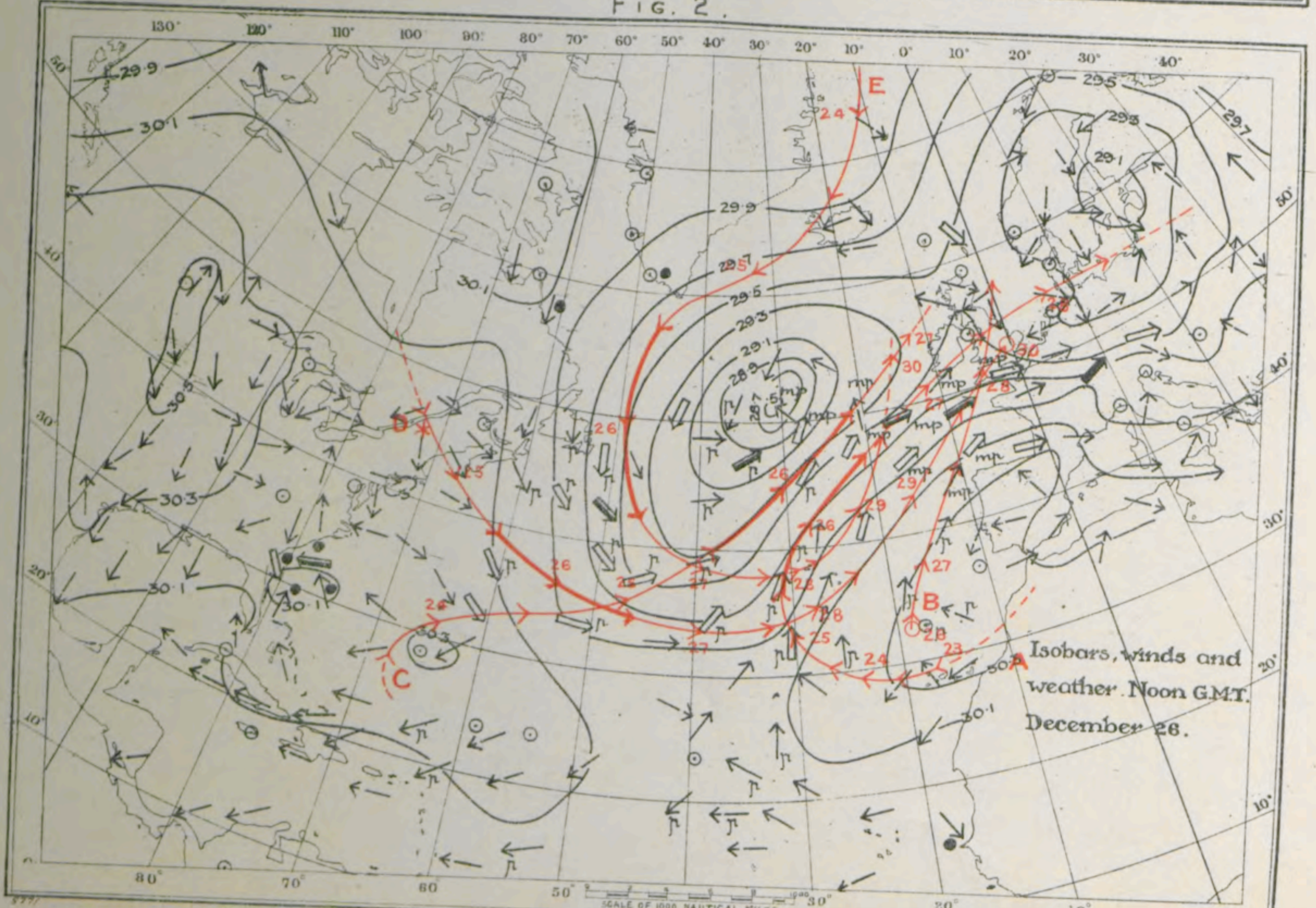


FIG. 2.



The Trajectories for December 23rd to 30th are shown by the red lines.

FIG. 3.

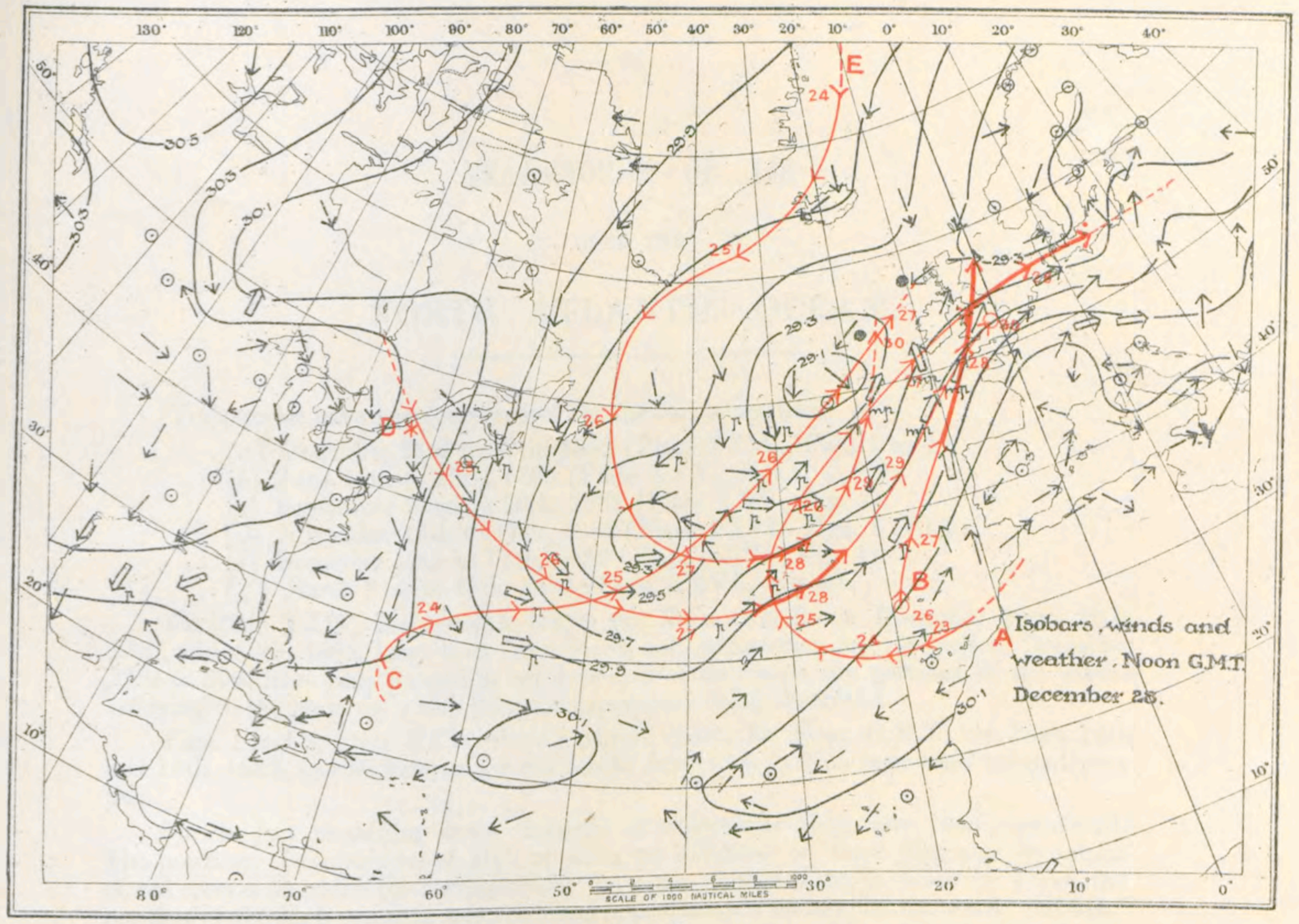
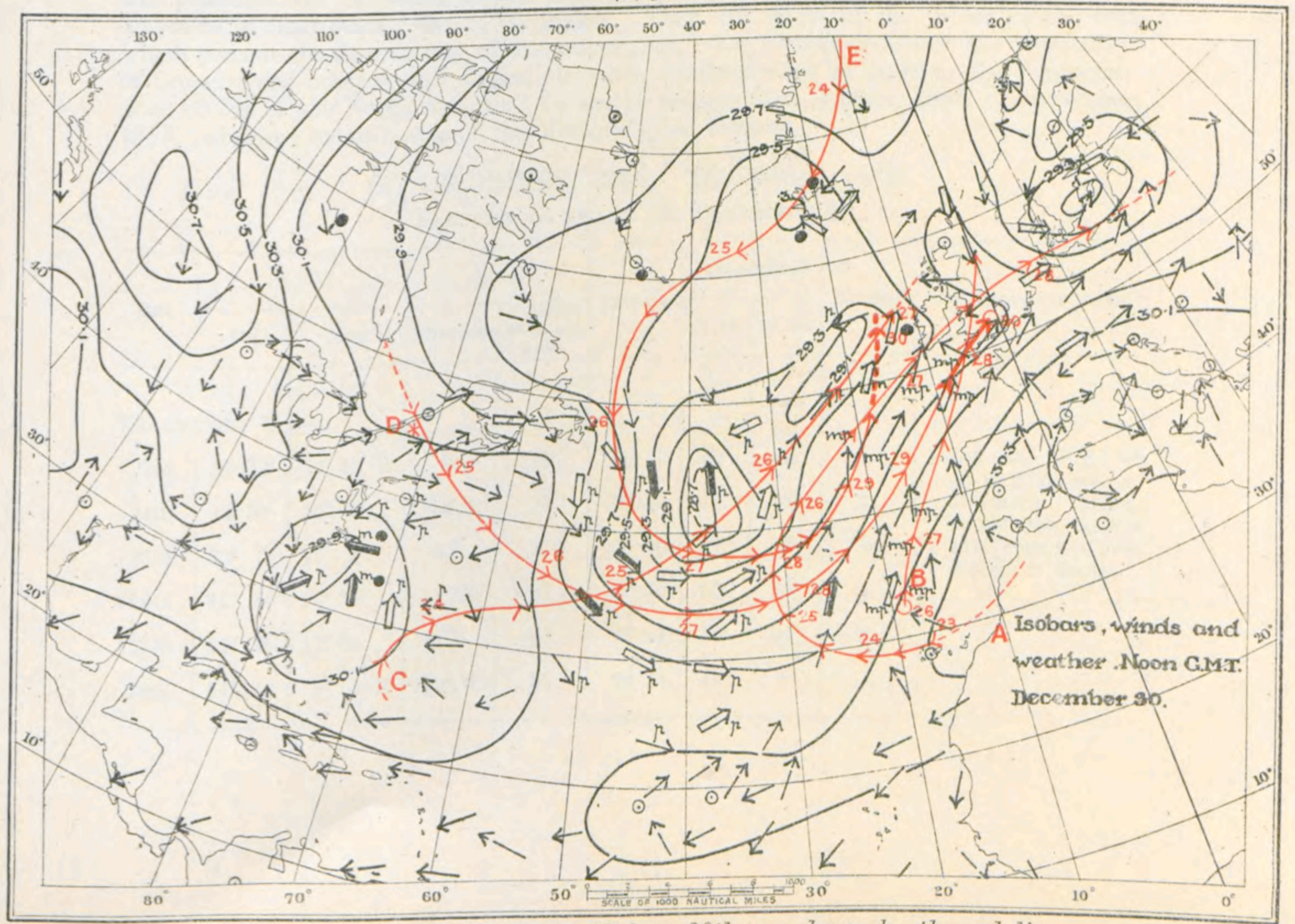


FIG. 4.



The Trajectories for December 23rd to 30th are shown by the red lines.

TRAJECTORIES OF AIR

OVER THE

NORTH ATLANTIC OCEAN.

Trajectories have been constructed for the following cases :—

(*a*) December 23rd to 30th, 1882 (Plate XXIV., Figs. 1 to 4).
(*b*) June 13th to 20th, 1883 (Plate XXV., Figs. 1 and 2).
(*c*) September 22nd to 28th, 1882 (Plate XXV., Fig. 3).
(*d*) November 13th to 17th, 1882 (Plate XXVI., Figs. 1 and 2).
(*e*) December 12th to 17th, 1882 (Plate XXVI., Fig. 3).
(*f*) March 21st to 28th, 1883 (Plate XXVI., Fig. 4).

On Plate XXIV. the synoptic charts for Noon G.M.T. on December 24th, 26th, 28th, and 30th, 1882, have been reproduced, and trajectories for the period December 23rd to 30th have been printed in red over each of the maps, the portions of the curves referring to the maps on which they are superposed being thickened.

Figs. 1 and 2, Plate XXV., show synoptic charts for Noon G.M.T. on June 14th and 16th, 1883, and trajectories for the period June 13th to 20th have been printed over them.

For the four remaining cases diagrams of trajectories only have been reproduced. The positions of the regions of high pressure are indicated on these diagrams by means of red crosses to which the corresponding dates are appended, or, in cases in which the position of the high pressure area remained approximately steady, by the word "HIGH." The positions and intensities of the minimum of pressure could not be shown on the diagrams without giving rise to confusion. They are given in the tables in the text which precede the descriptions of the trajectories. For further details of the distribution of pressure and other meteorological elements, reference must be made to the "Synchro nous Charts of the North Atlantic" for the 13 months from August, 1882, to September, 1883, published by authority of the Meteorological Council.

(*a*) DECEMBER 23RD TO 30TH, 1882.

TABULAR SUMMARY OF TRAJECTORIES.

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY A.									
23rd	28° 30′	16° 30′ W.	E.	20	30·45	68°	68°	n.	From the S.E. of an anticyclone off Northern Africa, round the Azores to a depression over Northern Russia.
24th	28° 30′	25° 0′	E.S.E.	17	30·25	70°	68°	n.	
25th	33° 0′	31° 0′	S.E.	17	30·20	67°	67°	n.	
26th	42° 0′	26° 30′	S.S.W.	37	29·70	60°	59°	p.	
27th	51° 0′	11° 30′	S.W.	40	29·55	56°	54°	m.	
28th	54° 30′	8° 0′ E.	W.S.W.	37	29·25	45°	?	r.	

TABULAR SUMMARY OF TRAJECTORIES—*continued.*

Date.	Position. Lat.	Position. Long.	Wind. Direction.	Wind. Velocity. Miles per hour.	Pressure.	Temperature Of air.	Temperature Of sea.	Weather.	General course of the air.
TRAJECTORY B.									
26th	31° 25′	18° 45′ W.	Z.	0	30·27	66°	67°	n.	From near centre of an anticyclone off N.W. Africa direct to a depression passing across Scotland.
27th	37° 10′	13° 15′	S.S.W.	25	30·15	64°	63°	p.	
28th	50° 45′	2° 45′ W.	S.S.W.	37	29·75	53°	54°	p.m. r. later.	
TRAJECTORY C.									
24th	30° 30′	63° 40′ W.	W.S.W.	33	30·00	73°	72°	n.	From the far Western side of the Atlantic anticyclone to the North of the Azores and onward to the S.E. side of a depression off N.W. of Ireland.
25th	35° 0′	47° 0′	W.S.W.	42	29·60	70°	68°	p.	
26th	45° 0′	30° 30′	S.W.	40	29·25	58°	58°	p.	
27th	55° 0′	12° 30′ W.	S.W.	40	29·05	53°	52°	p.	
TRAJECTORY D.									
25th	42° 0′	67° 0′ W.	N.W.	31	30·05	39°	37°	n.	From an upper current above a secondary depression (6,000 ft.) off Virginia round the Azores to a secondary depression over British Isles.
26th	35° 0′	54° 20′	W.N.W.	31	29·95	63°	69°	p.	
27th	32° 30′	40° 0′	W.	30	29·80	67°	69°	n.	
28th	35° 0′	28° 0′	W.S.W.	12	29·95	70°	67°	n.	
29th	42° 30′	16° 15′	S.W.	38	29·80	60°	59°	r.	
30th	51° 30′	2° 0′ W.	Z.	0	29·60	50° ?	—	r.	
TRAJECTORY E.									
24th	73° 0′	11° 0′ W.	N.N.E.	40	29·80	14° ?	?	?	From beyond the map East of Greenland over the Azores to a depression off W. of Ireland.
25th	61° 45′	33° 0′	E.N.E.	42	29·75	?	?	?	
26th	49° 0′	50° 0′	N.	42	29·55	35° ?	34° ?	?	
27th	37° 30′	40° 0′	W.N.W.	30	29·55	62°	66°	p.	
28th	37° 30′	30° 0′	W.S.W.	10	29·80	66°	66°	p.	
29th	42° 0′	22° 0′	S.S.W.	30	29·65	62°	61°	r.	
30th	54° 30′	15° 0′ W.	S.S.W.	37	29·10	47°	50°	r.	

In Figs. 1 to 4 of Plate XXIV. the synoptic charts for Greenwich Noon on the alternate days December 24th, 26th, 28th, 30th, 1882, are reproduced, and the corresponding trajectories have been superposed on the maps in red. The portions of the trajectories described during the days to which the maps refer are indicated by thickening the line for the corresponding interval. During this period the Northern Atlantic Ocean was occupied by a large low-pressure system showing shifting minima, while the tropical anticyclone was represented by a belt of high pressure stretching across the ocean, in about latitude 25° N.

The air flowing from the South-west over the Baltic on December 28th (trajectory A) traversed the British Isles on the previous day, and when traced further backwards it is found to have passed round the outer edge of an anticyclone off the Spanish coast, which formed the North-eastern portion of the high pressure belt. On December 23rd it was situated on the South-eastern side of this anticyclone, and it was then coming from the North-western part of Africa, and not from the region near the centre of high pressure. On the other hand the trajectory B, which represents the path of the air reaching England on December 28th, commenced on the 26th in a region of calm to the North of the Canary Islands, much nearer the centre of the anticyclone.

The general similarity between these two trajectories and those of the dust-laden air of February, 1903, is very striking, but we have no records of "dusty rain" being observed in North-western Europe on the occasion now being discussed; probably the primary cause which whirled such large quantities of African sand into the atmosphere was wanting.

A large proportion of the air which reached North-western Europe and the adjoining seas during the week under discussion, came from the Western side of the Atlantic Ocean. Trajectories C and D furnish examples of this. The origin of C lies on the Western side of an anticyclone over the Western Atlantic, and at some distance from its centre. When traced forward this trajectory gradually approaches the region of low pressure and ends in a disturbance off the West coast of Scotland on December 27th.

D was commenced in the North-westerly wind which blew in the rear of a disturbance shown over the North-western Atlantic on December 25th. If we trace this wind backward to the map for December 24th, we find ourselves near the centre of a "secondary" depression over the North-east of the United States. The observations on Mount Washington (6,279 feet), which lies in the track of this part of the trajectory, show a gale from the North-west on this date, so that it is probable that D commenced as a descending current in the South-west region of a cyclonic area indicated on the surface as a "secondary." When traced forward, it at first recedes from the region of lowest pressure, but subsequently its direction becomes more Westerly and then South-westerly, till finally it is lost in a "secondary" depression over the British Isles on December 30th.

On the Northern side of the low pressure we find a strong gale sweeping down from the North off the East coast of Greenland on the 24th; when traced forward (trajectory E) this becomes a North-easterly gale on December 25th, and then on December 26th a Northerly gale in the West of the region of low pressure. Its subsequent history is similar to that of D.

The general course of the air and the barometric conditions at the origin and end of the trajectories, and also the pressure of the air at Greenwich Noon, on each day, are given respectively in Columns 10 and 6 of the annexed Tables. Most of the curves show a continuous decrease of pressure throughout, but in the cases of D and E secondary maxima occurred on December 28th.

The temperatures of the air and of the water, as determined from the isotherms for local noon of the original charts, are also given in the Tables (Columns 7 and 8). As a general rule they show very small differences. Even the very cold air flowing off the American Continent rapidly gets warmed to within a few degrees of the temperature of the water, the largest difference shown on any trajectory is only 6° (trajectory D, December 26th). Consequently air reaching North-western Europe as a South-westerly wind, gives rise to mild weather, even though it be possible, as is the case with D and E, to trace it to a very cold region of origin.

One "S" shaped curve (C) is shown among the trajectories. It is on a very large scale, and much elongated.

(*b*) JUNE 13TH TO 20TH, 1883.

TABULAR SUMMARY OF TRAJECTORIES.

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY A.									
13th	45° 30′	49° 0′ W.	S.	17	29·75	50°	45°	r.f.	From a "col" between a depression and a "secondary" in Mid-Atlantic to a cyclonic disturbance off the West of Greenland.
14th	53° 0′	49° 0′	S.	20	29·90	48°	40°	f.	
15th	63° 30′	52° 0′	S.S.E.	31	29·50	45° ?	?	r.	
16th	75° 30′	60° 0′ W.	S.S.E.	31	29·65	?	?	r.	
TRAJECTORY B.									
12th	47° 0′	24° 0′ W.	E.	15	30·35	62°	60°	f.	From near centre on South side of an anticyclone in the Eastern Atlantic to depression over West of Greenland.
13th	50° 30′	36° 0′	S.E.	25	30·15	56°	54°	f.	
14th	57° 30′	43° 0′	S.S.E.	17	30·10	?	?	?	
15th	67° 30′	50° 0′ W.	S.S.E.	37	29·70	57°	—	r ?	
TRAJECTORY C.									
14th	71° 30′	9° 0′ W.	N.	25	30·00	32°	31°	f.m.	From beyond the North boundary of the map East of Greenland to Trade wind off West of Africa.
15th	60° 0′	11° 0′	N.	30	30·20	50°	49°	r.	
16th	49° 0′	10° 0′	N.	28	30·20	58°	58°	p.	
17th	38° 30′	12° 0′	N. by E.	25	30·25	66°	65°	m.	
18th	31° 0′	17° 30′	N.E.	22	30·30	73°	70°	p.m.	
19th	25° 0′	23° 30′	N.E.	22	30·15	73°	73°	p.	
20th	17° 0′	28° 0′ W.	N.E.	22	30·05	80°	77°	m.	
TRAJECTORY D.									
12th	47° 0′	4° 0′ W.	N.N.E.	10	30·45	62° ?	?	n.	From near centre on East side of anticyclone over the British Isles to cyclonic disturbance centre, 36° N., 34° W., West of the Azores.
13th	44° 0′	9° 0′	N.E.	15	30·40	61° ?	61° ?	p.	
14th	42° 0′	16° 30′	E.	12	30·20	64°	62°	n.	
15th	42° 0′	25° 0′	E.	19	30·10	64°	63°	n.	
16th	40° 0′	38° 0′ W.	E. by N.	30	29·85	67°	67°	r.	

TABULAR SUMMARY OF TRAJECTORIES—*continued.*

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY E.									
13th	45° 0′	13° 30′ W.	E.N.E.	10	30·45	62°	60°	n.	From South-east side of an anticyclone North-west of Spain to an elongated cyclonic disturbance in Lat. 35°.
14th	46° 0′	21° 30′	E.S.E.	15	30·20	63°	58°	n.	
15th	47° 30′	32° 30′	E. by N.	22	30·20	63°	59°	m.	
16th	45° 30′	44° 30′	E.N.E.	22	30·05	63°	59°	f.p.	
17th	38° 0′	55° 0′ W.	N.E.	30	29·95	72°	72°	r.	
TRAJECTORY F.									
15th	24° 0′	26° 0′ W.	Z.	0	30·15	75°	73°	n.	From a ridge between Atlantic depression and African low pressure system to cyclonic disturbance centre, 36° N., 33° W.
16th	32° 30′	26° 0′	S.S.E.	22	29·85	72°	71°	n.	
17th	38° 30′	32° 0′ W.	S.E.	22	29·85	66°	66°	r.	
TRAJECTORY G.									
17th	58° 0′	25° 30′ W.	W.	17	30·30	?	?	?	From a region of parallel isobars between a "high" and a "low" in the North Atlantic to a disturbance over Adriatic.
18th	56° 0′	13° 30′	N.W.	25	30·25	54°	55°	n.	
19th	48° 0′	4° 0′ W.	N.W.	20	30·15	56°	—	n.	
20th	44° 0′	4° 0′ E.	?	?	?	?	?	?	
TRAJECTORY H.									
16th	60° 30′	35° 0′ W.	W.	9	30·15	?	?.	?	From the same region of parallel isobars near a "col"; termination doubtful.
17th	60° 30′	27° 0′	W.	15	30·20	?	?	?	
18th	57° 0′	13° 0′ W.	W.N.W.	25	30·10	52°	52°	n.	

Trajectories and a selection of synoptic charts for the period June 13th to 20th, 1883, are shown on Plate XXV. An anticyclone over the North-west Atlantic Ocean forms the most constant feature of the synoptic charts. Of the trajectories, the most striking are those which represent: (1) a steady Northward flow of air on the Western side of the high pressure system; (2) an equally direct flow on its Eastern side from the Arctic regions to the Trade winds. The air supply for the former was derived partly from the "col" between a depression over Canada, and a "secondary" in Lat. 40° N., Long. 40° W. (trajectory A), and partly from the region between the main anticyclone and this "secondary" (trajectory B). The goal of both supplies was a deep low pressure system which lay to the West of Greenland. In the case of B the air pressure decreased steadily, but in that of A the changes were apparently less regular (*see* Tables) The wind velocity in general showed an increase from day to day, while the temperature got lower as more Northern latitudes were reached. We consequently find the temperature of the air at (local) noon above that of the water on the 12th, 13th, and 14th, and, as usually happens under these circumstances, the weather was foggy on these days. The Northward flow of warm, moist air gave rise to very warm weather, and heavy rainfall in the South of Greenland ; at Ivigtut the temperature on June 16th rose to 57°, and over two inches of rain were measured.

The current from the North (trajectory C) was first identified in the extreme North of the map for June 14th as a gale blowing along the East coast of Greenland ; thence it could be traced Southward through the region between the anticyclone and a depression over the North-west of Europe, until on the 17th it was off the coast of Spain. From here the air passed along the African coast and ultimately it joined the North-east Trade wind.

Pressure reached a maximum on June 18th, and then decreased again as the equator was approached. The unusually straight course of the trajectory, of which the path can be traced from Lat. 71° 30′ N. to Lat. 17° 0′ N., with only slight variations of longitude, suggested a comparison of the observed wind velocities used in constructing the trajectory with those calculated from the pressure gradient taken from the maps, according to the formula :—

$$\gamma = {\cdot}0380\ D\ V \sin \lambda$$

when γ is the pressure gradient in inches per degree of 60 nautical miles, D the density of the air in pounds per cubic foot, λ the latitude, and V the velocity of the air in nautical miles per hour.

The results of this calculation are given in the following table :—

Date.	λ.	sin λ.	Distance in Nautical Miles between consecutive Isobars drawn for each 0·1 in.	γ.	D.	V calculated.	V observed.
14th ...	71° 30′	·948	100	·060	·081	20·7	25
15th ...	60° 0′	·866	130	·046	·078	18·4	30
16th ...	49° 0′	·755	130	·046	·077	21·2	28
17th ...	38° 30′	·682	150	·040	·075	22·5	25
18th ...	31° 0′	·515	200	·030	·074	20·6	22
19th ...	25° 0′	·423	270	·022	·074	19·0	22
20th ...	17° 0′	·292	320	·019	·074	23·0	22

From June 17th to 20th inclusive, the agreement is surprisingly close ; for the earlier days the calculated velocities are smaller than those taken from the maps. Had smaller values been used for these days in constructing the trajectory, the general course of the curve would have been little altered, but the point of origin of the air would be thrown into the Northerly current blowing in the rear of a disturbance shown over the Northern Atlantic Ocean on June 13th.

Temperature readings showed a rapid increase as more Southern latitudes were reached. Throughout its course the air, though it came from the Arctic regions, acquired the temperature of the water over which it was passing, by noon on each day. On the 14th, 17th, 18th and 20th, it was even a few degrees warmer than the water, and on these days we again find the weather recorded as misty. The frequent occurrence of showers was another conspicuous feature along this trajectory.

PLATE XXV.

TRAJECTORIES OF AIR OVER THE ATLANTIC OCEAN

FIG 1. JUNE 13-20, 1883.

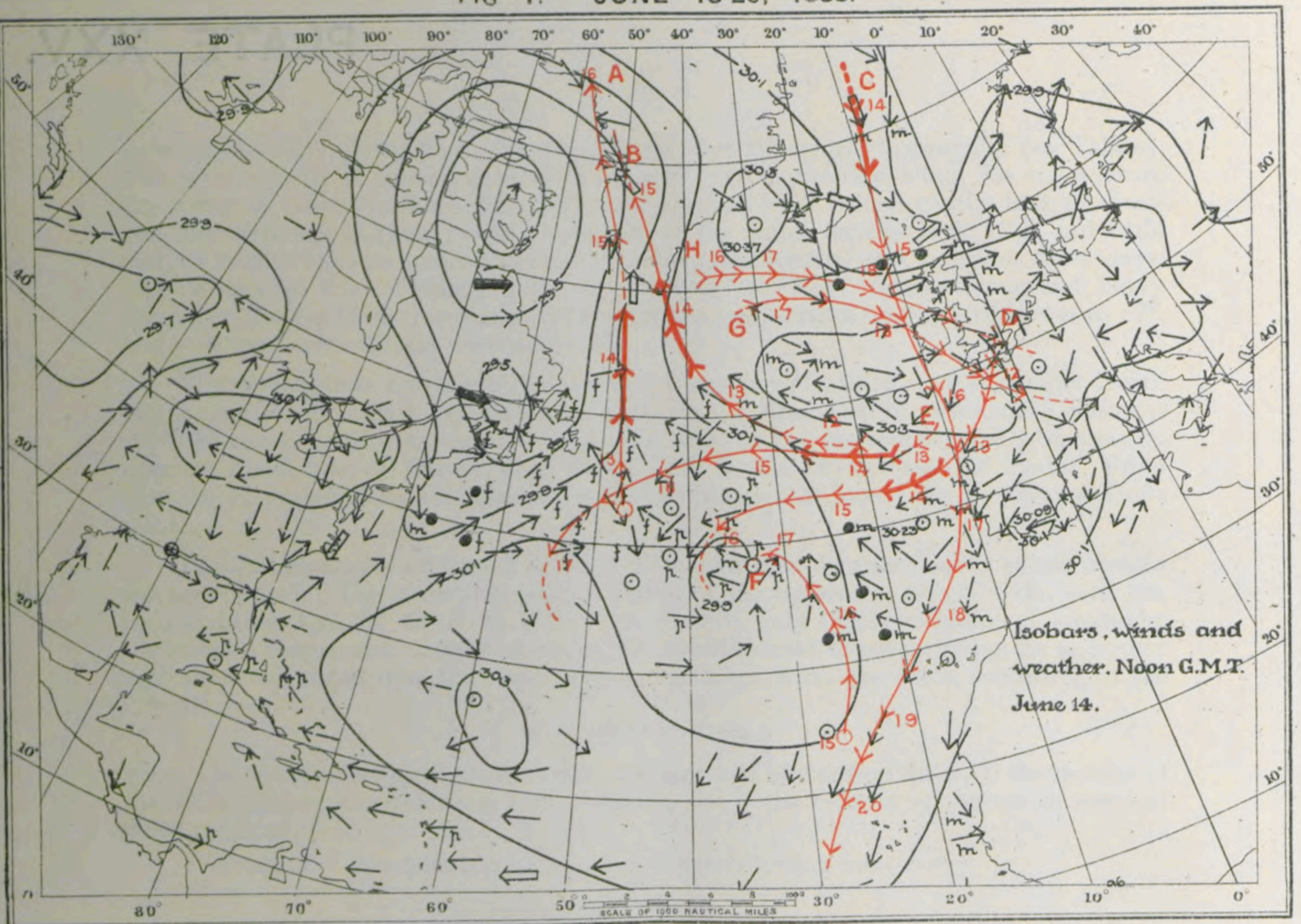
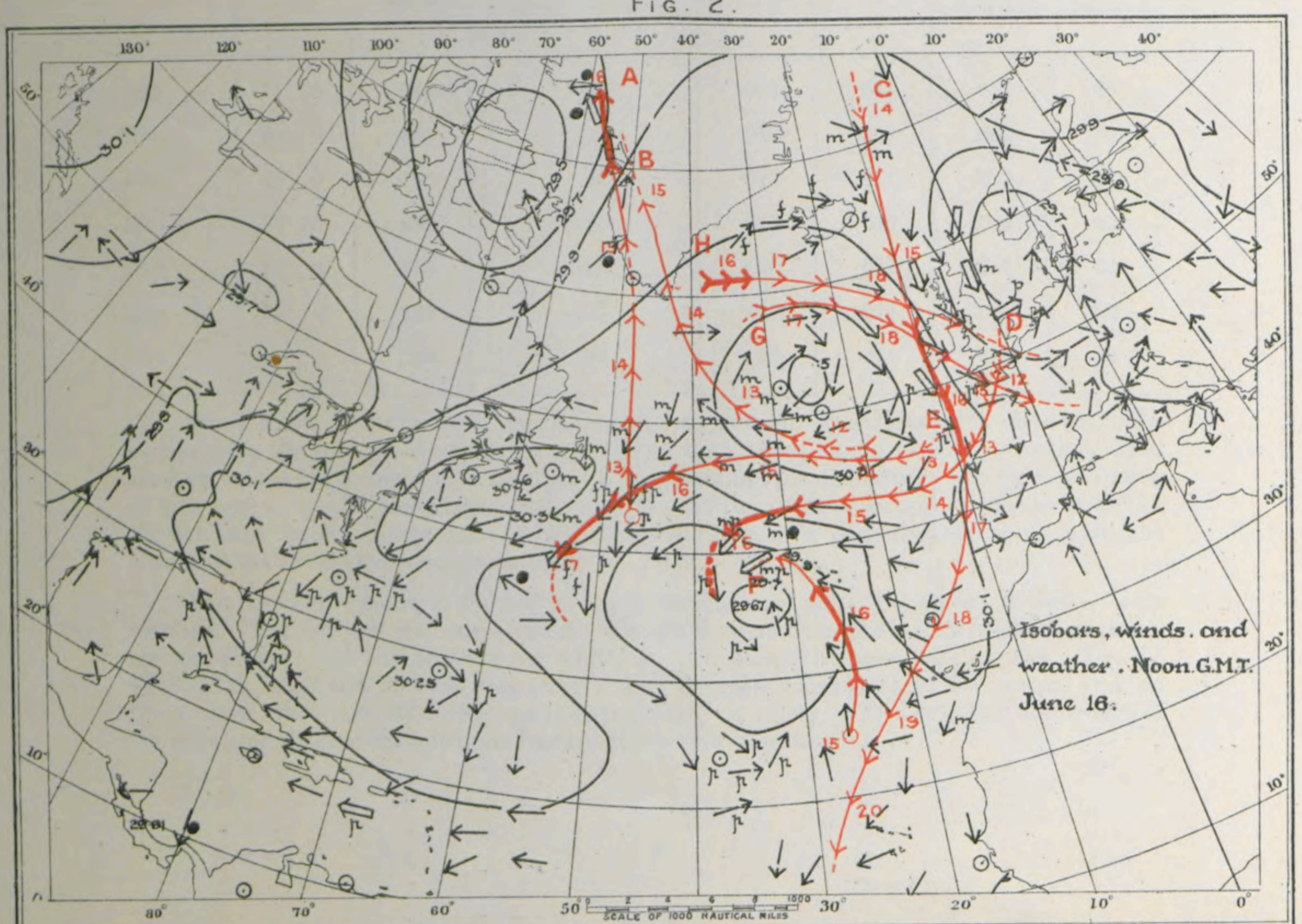
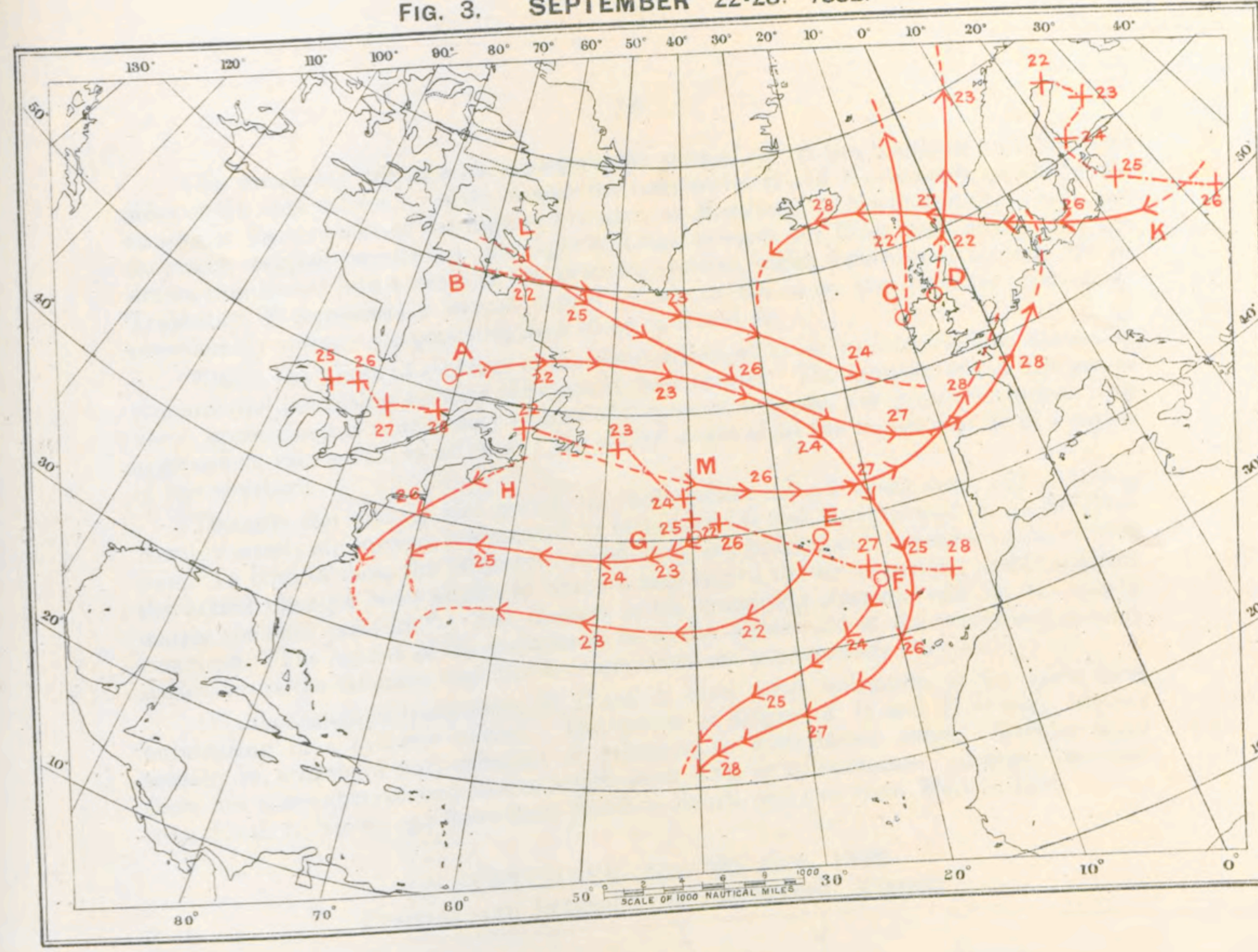


FIG. 2.



The Trajectories are shown by the red lines. The portions for the day of each map are thickened.

FIG. 3. SEPTEMBER 22-28. 1882.



NOTES.—In the Synoptic Charts on Plates XXIV., XXV. and XXVI. direction and force of wind have been indicated thus:— the numbers referring to the Beaufort wind-scale.

⊙	→	→	⇒	➡	➡
calm	1-3	4-6	7 & 8	9 & 10	11 & 12

Weather is indicated thus:—

•	ꞃ	m	f
rain	showers	mist	fog

On Figs. 1 to 4, Plate XXIV., and Figs. 1 and 2, Plate XXV., the portions of the trajectories appropriate to the maps on which they are superposed have been thickened.

On the remaining diagrams of trajectories, the red crosses indicate the positions of the centres of high pressure systems on the dates marked against the crosses. In cases in which the positions of these centres remained approximately constant, they have been indicated by the word "HIGH."

For positions and intensities of the barometric minima, see the tables which precede the descriptions of the trajectories given in the text.

The arrow heads with figures against them indicate the position of the air at Noon on the days corresponding to the figures. Intervening arrow heads indicate the position at Midnight.

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The remaining trajectories represent the flow of air on the Southern and Northern sides of the anticyclone. Of the former the trajectories D and E commence on the South-eastern or Eastern side of the highest pressure, as Northerly or North-easterly winds, but they soon become deviated to the right and flow towards the West until finally they get drawn Southward into a series of low pressure systems, which formed near latitude 35° N. Trajectory F represents a second supply of air to the same low pressure system, at considerably warmer temperatures than those of D and E.

Within the limits of accuracy of the observations, all those trajectories show decreasing pressure and increasing velocity throughout their course. The temperature of the air, as usual, approximated very closely to that of the water. As the low pressure systems were approached, rain set in, in all cases ; the earlier stages of all the trajectories lie in a region of fair weather.

Towards the end of our period the anticyclone moved Southward, and a strong North-westerly air current, represented by trajectories G and H, developed on its Northern side. In both of these the pressures varied very irregularly, and it seems probable that the actual changes were slight, so that we may regard the air as moving under approximately constant pressure.* The changes in the remaining elements call for no special comment. The courses of the trajectories lie to the Northward of the recognized steamer routes across the Atlantic, and direct observations are consequently very scanty.

Of this system of trajectories, D, E and F show some indication of the spiral form terminating in a cyclonic centre. The points of origin of D and E lie near, but not actually in, centres of anticyclones ; F arises in an anticyclonic ridge. Besides these there are a number of trajectories which show little or no curvature ; of these, two flow from South to North, one flows from North to South, and two from West to East.

(c) SEPTEMBER 22nd TO 28th, 1882.

Position and Intensity of Barometric Minima.

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
September 22nd	29·1	65°	20° W.	Over Iceland.
	29·5	52°	14° E.	Over Germany.
	30·0	39°	18° W.	Off Spain.
	29·8	33°	75° W.	Off American ocast.
	29·9	24°	58° W.	Western Atlantic.
September 23rd	29·1	72°	5° W.	Arctic Ocean.
	29·4	62°	25° W.	South of Iceland.
	29·7	50°	20° E.	Over Poland.
	29·9	37°	76° W.	Off American coast.
	29·8	24°	58° W.	Western Atlantic.
September 24th	29·6	60°	12° W.	Between Scotland and Iceland.
	29·8	50°	35° E.	Over Russia.
	29·6	30°	63° W.	Western Atlantic.
	29·5	65°	55° W.	West of Greenland.

* Compare Fig. 8 (frontispiece) and trajectories O, P, Q of No. 1, p. 15.

Positions and Intensity of Barometric Minima—*continued.*

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
September 25th	29·5	60°	17° W.	South of Iceland.
	29·7	47°	7° W.	Over Bay of Biscay.
	29·6	31°	66° W.	Western Atlantic.
	30·0	20°	32° W.	Eastern Atlantic.
	29·6	76°	60° W.	North-west of Greenland.
September 26th	29·4	60°	18° W.	Narrow loop stretching from Iceland to Ireland.
	29·3	49°	5° W.	Mouth of Channel.
	29·6	33°	66° W.	Western Atlantic.
	30·0	20°	35° W.	Central Atlantic.
September 27th	29·3	55°	2° W.	Over Great Britain.
	29·7	38°	59° W.	Narrow loop running in S.W. to N.E. direction off American coast.
September 28th	29·8	45°	23° E.	Over South-eastern Europe.
	29·0	59°	29° W.	South-west of Iceland.
	29·4	40°	52° W.	South of Newfoundland.
	29·6	38°	71° W.	Off American coast.

Tabular Summary of Trajectories.

For diagrams of trajectories, *see* Plate XXV., Fig. 3.

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
Trajectory A.									
21st	50° 30′	71° 0′ W.	Z.	0	30·4	—	—	—	From near the centre of an anticyclone over Eastern Canada, round the circumference of an extensive anticyclone covering the Western Atlantic to the North-east Trade wind near the African coast.
22nd	53° 0′	59° 0′	W.	17	30·1	40°?	—	n.	
23rd	53° 0′	42° 0′	W.	33	30·25	50°	50°	n.	
24th	45° 30′	22° 0′	N.W.	35	30·15	62°	63°	p.	
25th	35° 0′	18° 0′	N.	23	30·25	70°	71°	p.	
26th	28° 0′	20° 0′	N.N.E.	18	30·20	73°	73°	n.	
27th	24° 0′	30° 0′	N.E.	25	30·15	78°	75°	n.	
28th	21° 30′	38° 0′ W.	E.N.E.	12	30·05	82°	79°	p.	

Tabular Summary of Trajectories—*continued.*

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
Trajectory B.									
22nd	59° 30′	64° 0′ W.	W.N.W.	30	29·8	?	—	n.	From a "col" over the North of Hudson's Bay, Eastward to a V-shaped "secondary" off the South-west of Ireland.
23rd	57° 30′	40° 0′	W.N.W.	33	29·8	45°	46°	n.	
24th	50° 30′	17° 30′ W.	N.W.	44	29·8	54°	58°	r.	
Trajectory C.									
22nd	61° 0′	6° 30′ W.	S.S.W.	40	29·75	49°	49°	r.	From a "col" over Great Britain Northward to near the centre of a depression off the East coast of Greenland.
Trajectory D.									
22nd	59° 0′	0° 0′	S.S.W.	23	29·8	50°?	53°	r.	From the same "col" over Great Britain North-eastward to a depression off the North-east of Greenland.
23rd	70° 0′	10° 0′ E.	S.S.W.	33	29·55	?	?	?	
Trajectory E.									
21st	39° 0′	26° 30′ W.	Z.	0	30·35	72°	72°	n.	From an anticyclonic wedge, projecting from the anticyclone over the Western Atlantic to near the Azores, along the Southern edge of the anticyclone, to near the centre of a depression off the American coast.
22nd	32° 30′	34° 0′	N.E.	30	30·2	78°	77°	p.	
23rd	33° 0′	51° 0′ W.	E.	33	30·1	80°	78°	n.	
Trajectory F.									
23rd	33° 0′	21° 0′ W.	Z.	0	30·15	73°	73°	n.	From a ridge between a very shallow depression off Spain and the equatorial belt of low pressure Southwestward to a shallow depression in Lat. 20° N., Long. 40° W.
24th	30° 0′	25° 0′	N.E.	20	30·25	73°	74°	n.	
25th	26° 0′	34° 30′ W.	N.E.	28	30·15	77°	78°	p.	

TABULAR SUMMARY OF TRAJECTORIES—*continued.*

Date	Position		Wind		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY G.									
22nd	39° 30′	39° 30′ W.	Z.	0	30·4	76°	77°	n.	From the South-east side of an anti-cyclonic wedge extending towards the Mid-Atlantic from a high pressure system centred over Newfoundland, westward to a depression off the American coast in Lat. 31° N., Long. 66° W.
23rd	37° 30′	42° 0′	N.E.	10	30·45	76°	76°	n.	
24th	37° 0′	50° 0′	E.	23	30·35	76°	74°	n.	
25th	37° 0′	63° 30′ W.	E.	30	30·00	77°	77°	p.	
TRAJECTORY H.									
26th	38° 0′	70° 0′ W.	N.E.	30	29·90	72°	66°	n.	From a "col" off Nova Scotia between two well developed anti-cyclones, South-westward to the depression off the American coast.
TRAJECTORY K.									
26th	51° 30′	15° 0′ E.	E.S.E.	30	29·90	50°?	—	?	From near the centre on the South-east side of an anticyclone over Western Russia, westward to the centre of a depression to the South-east of Greenland.
27th	61° 0′	1° 30′ W.	S.E.	31	29·50	?	?	r.	
28th	63° 0′	19° 0′ W.	E.	20	29·20	45°	47°	r.	
TRAJECTORY L.									
25th	58° 30′	56° 0′ W.	N.W.	30	29·90	45°?	43°?	?	From a region of parallel isobars off the coast of Labrador, South-eastward to North coast of Spain and thence North-eastward to a large low pressure system over North-west Europe.
26th	52° 0′	33° 30′	N.W.	40	29·95	54°	53°	p.	
27th	45° 30′	14° 30′ W.	W.N.W.	30	29·90	61°	62°	p.	
28th	48° 0′	1° 0′ E.	S.W.	37	29·95	50°	?	—	

TABULAR SUMMARY OF TRAJECTORIES—*continued.*

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY M.									
26th	43° 0′	33° 0′ W.	W.N.W.	20	30·35	71°	71°	n.	From near Newfoundland, on the West side of a large anti-cyclone covering the central North-Atlantic, eastward to a large low pressure system over N.W. Europe.
27th	42° 0′	21° 0′	W.	20	30·15	69°	68°	n.	
28th	46° 30′	5° 30′ W.	S.W.	41	29·90	63°	63°	p.m.	

At the commencement of this period the greater part of the North Atlantic was covered by a large anticyclone, of which the central area, where readings were above 30·5 ins., was situated over Newfoundland. A second anticyclone lay over the Gulf of Bothnia, and a strongly developed "col" stretched across the British Isles, connecting the two high pressure systems. A deep disturbance was shown over Iceland, and another, shallower one, lay over Germany; shallow depressions also existed off the West Indies and the southern part of the North American coast.

During the following days the oceanic anticyclone moved slowly South-eastward, and by September 28th the region of highest readings had been transferred to the neighbourhood of the Canary Islands. The low pressure system near Iceland also spread South-eastward, and on September 25th, North-western Europe had come under its influence. During the remainder of the period under discussion, complex changes occurred within the low pressure system; the positions of the centres of low pressure on each day are given in the preceding tables. While these changes were taking place over the Eastern Atlantic the shallow depressions off the American coast were becoming deeper and spreading northward, and by September 28th a series of deep minima were shown over the Western part of the Ocean separating the original high pressure systems from an anticyclone which had appeared over Canada.

The most characteristic feature of the wind circulation was a strong North-westerly current on the Northern side of the region of high pressure. At the commencement of our period this divided into two parts. In the North the air (trajectory B, Plate XXV., Fig. 3) was drawn into a region of low pressure extending Southward from the Icelandic "low," but further to the South (trajectory A) it passed round the Eastern side of the anticyclone, and ultimately found its way to the Trade wind.

Trajectories C and D are simultaneous with the early stages of A and B. They represent the flow of air from the South on the Eastern side of the Northern depression. As is so frequently the case with Southerly winds, these trajectories are found to arise in the calm region on a "col" joining two anticyclones.

On the southern side of the Atlantic high pressure system, we have a number of trajectories, E, F, G, commencing as light North-easterly winds in the calms on a wedge-like projection from the region of high pressure. They flow towards the West with rapidly increasing velocities, and end in the low pressure systems off the coast of America. Trajectory H, which ends in a similar manner, commences in the "col" between the Atlantic and the Canadian anticyclones.

Towards the end of the period a second current from the East (trajectory K) makes its appearance in the North-east of the diagram, on the Northern side of a low pressure system over North-western Europe. It appears to flow out of an anticyclonic area shown over the North-west of Russia on the 25th, and ends near a centre of low pressure shown to the South-east of Greenland on the 28th. At the same time the North-westerly current no longer passes Southward to feed the Trade wind, but all the air turns to the East and finally to the North-east, and flows into the European low pressure system as a warm South-westerly wind (trajectories L and M).

On this chart four trajectories show the spiral form, E, G, H, and K. Three of these converge to supply the low pressure area off Florida, and the other ends in the normal position of the North Atlantic low pressure area. All four show a continuous decrease of pressure, and in E, F, and G, the corresponding increase of wind velocity is very obvious. C, D, and H probably underwent similar changes, but they can only be traced for short distances. The trajectories of the North-westerly winds, on the other hand, show much smaller variations ; like G and H of the trajectories for June 13–20, 1883, they appear to represent a flow of air at constant pressure. Along M, which enters the low pressure system over England as a South-westerly wind, the changes were similar to those in E, F, and G.

(*d*) NOVEMBER 13TH TO 17TH, 1882.

POSITION AND INTENSITY OF BAROMETRIC MINIMA.

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
November 13th	29·3	63°	45° W.	Over South of Greenland.
	29·7	48°	3° W.	N.W. of France.
	29·8	37°	51° W.	Mid-Atlantic.
November 14th	28·9	65°	26° W.	West of Iceland.
	29·7	48°	5° E.	Eastern France.
	29·3	50°	65° W.	Mouth of St. Lawrence.
November 15th	28·9	60°	20° W.	South of Iceland.
	29·8	53°	5° E.	Over Netherlands.
	29·6	45°	13° E.	Southern Austria.
	28·9	59°	65° W.	North of Labrador.
November 16th	29·1	51°	1° E.	Off Mouth of Thames.
	29·2	62°	65° W.	Hudson Strait.
	29·8	24°	32° W.	Mid Atlantic.
	29·7	31°	63° W.	Western Atlantic.
November 17th	29·3	45°	13° E.	Head of Adriatic.
	29·4	68°	40° W.	Over Greenland.
	29·8	23°	35° W.	Mid Atlantic.
	29·8	28°	58° W.	Western Atlantic.

TABULAR SUMMARY OF TRAJECTORIES.

For Diagram of Trajectories, *see* Plate XXVI., Fig. 2.

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY A.									
13th	57° 30′	70° 30′ W.	W.	30	29·8	15°	—	?	From a system of parallel isobars over Hudson's Bay to a depression over the Adriatic.
14th	55° 0′	50° 30′	W.N.W.	30	29·85	28° ?	33° ?	n. ?	
15th	53° 0′	28° 0′	W.N.W.	40	29·95	48°	50°	p.	
16th	45° 0′	5° 0′ W.	W.N.W.	45	29·95	53°	58°	n.	
17th	42° 0′	14° 30′ E.	W.	31	29·50	55° ?	—	—	
TRAJECTORY B.									
13th	51° 0′	3° 30′ E.	E.N.E.	45	29·95	—	—	—	From the Southern side of a very elongated anticyclone over Denmark and the Baltic, along the "col" connecting this anticyclone with the Atlantic high pressure system, thence along the South-Eastern margin of the latter to a depression situated in mid-Atlantic.
14th	42° 0′	7° 0′ W.	N.	25	30·10	56°	58°	n.	
15th	34° 0′	17° 0′	E.N.E.	30	30·20	67°	68°	p.	
16th	33° 30′	32° 30′	E.	30	30·25	73°	72°	p.	
17th	39° 30′	46° 0′ W.	S.E.	20	29·80	73°	73°	p.	
TRAJECTORY C.									
15th	53° 0′	14° 0′ E.	E.	40	30·15	20°	—	—	From an anticyclone over Russia, westward; to a depression over the English Channel.
16th	53° 30′	0° 0′	E.	31	29·3	40° ?	—	p.	
TRAJECTORY D.									
15th	58° 0′	7° 30′ W.	S.	40	29·5	43°	50°	r.	From the South-west of Ireland on a "col" between two anticyclones to a depression over the North Atlantic, South of Iceland.
TRAJECTORY E.									
14th	47° 30′	21° 0′ W.	S.W.	21	30·20	55°	58°	n.	From the centre of an anticyclone North of the Azores, North-eastward, to the depression over the North Atlantic.
15th	56° 0′	10° 0′ W.	S.	33	29·45	46°	52°	r.	

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TABULAR SUMMARY OF TRAJECTORIES—*continued.*

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
TRAJECTORY F.									
14th	36° 30′	33° 30′ W.	E.	15	30·25	70°	70°	p.	From near the Azores on the Southern extremity of an anticyclone to a depression off Greenland on 17th.
15th	41° 0′	38° 30′	S.	28	30·30	67°	68°	n.	
16th	52° 0′	32° 30′ W.	S.W.	31	30·00	55°	53°	p.m.	

The trajectories for this period are drawn in order to show the differences between the instantaneous lines of flow shown on a single map by the lines of Fig. 1, Plate XXVI., and the trajectories representing the actual paths of the air which are shown in Fig. 2.

Two well-developed anticyclones situated respectively over Scandinavia and near the Azores, formed the most constant features of the maps, one of which has been reproduced (Plate XXVI., Fig. 1); while deep low pressure systems traversed the region between Iceland and the Mediterranean. The stream lines corresponding to the distribution of pressure on November 15th (*see* Fig. 1) show the air circulating from the anticyclones to the centres of low pressure systems along well-defined "S" shaped paths, but the actual trajectories (Fig. 2), differ very materially from these. Some of the curves become very much lengthened, while others are greatly shortened.

The longest trajectory (A) represents a steady flow of cold air from a West-north-westerly direction. It commences on November 13th over Hudson's Bay in a region of parallel isobars, on the South-western side of a deep depression over Greenland. If we follow the air in its flow South-eastward, we find that it occupies a similar position with regard to a centre of low pressure, on each of the three following days, so that the trajectory for this period is approximately a straight line. Throughout this portion of its flow the pressure of the air was certainly not decreasing, and there appears even to have been a slight increase. The temperature was very low, only 15°, to commence with but the passage over the relatively warm ocean caused it to rise rapidly, and on November 16th, when the Bay of Biscay was reached, a temperature of 53° was attained. Subsequently the direction became more Westerly, and on November 17th we find the air approaching the centre of a disturbance over the head of the Adriatic at a temperature of 55°. Simultaneously a decided diminution of its pressure took place.

Trajectory B can also be traced for a long distance. Like A it represents a flow of air originally at a low temperature. It commenced on November 13th as an Easterly wind in the region between the Scandinavian anticyclone then over Denmark, and a low pressure system over Western France. Thence the air flowed along the Southern side of the "col" joining the two anticyclones, and on the following day it became directed towards the South, as the region on the Western side of the low pressure system was reached. On November 15th and 16th motion towards the West was resumed, and the trajectory ends near the low pressure systems situated in Lat. 24°, Long. 32° W. Trajectory C, which represents the flow from the East over Northern Germany at a later date (November 15th), did not succeed in passing the "col"; the air was absorbed in a depression over the Netherlands on November 16th. B shows a slight increase of pressure throughout its course, but in C a very decided decrease took place as the air entered the low pressure system.

The trajectories of the warm South-westerly to South-easterly gales on the South-eastern side of the disturbance over the North Atlantic can, as a rule, be traced for only comparatively short distances. D and E commence in the calm region on the "col" connecting the Scandinavian with the Atlantic anticyclone, which was thus a region of

PLATE XXVI.

For notes see Plate XXV.

FIG. 1. NOVEMBER 13-17. INSTANTANEOUS LINES OF FLOW.

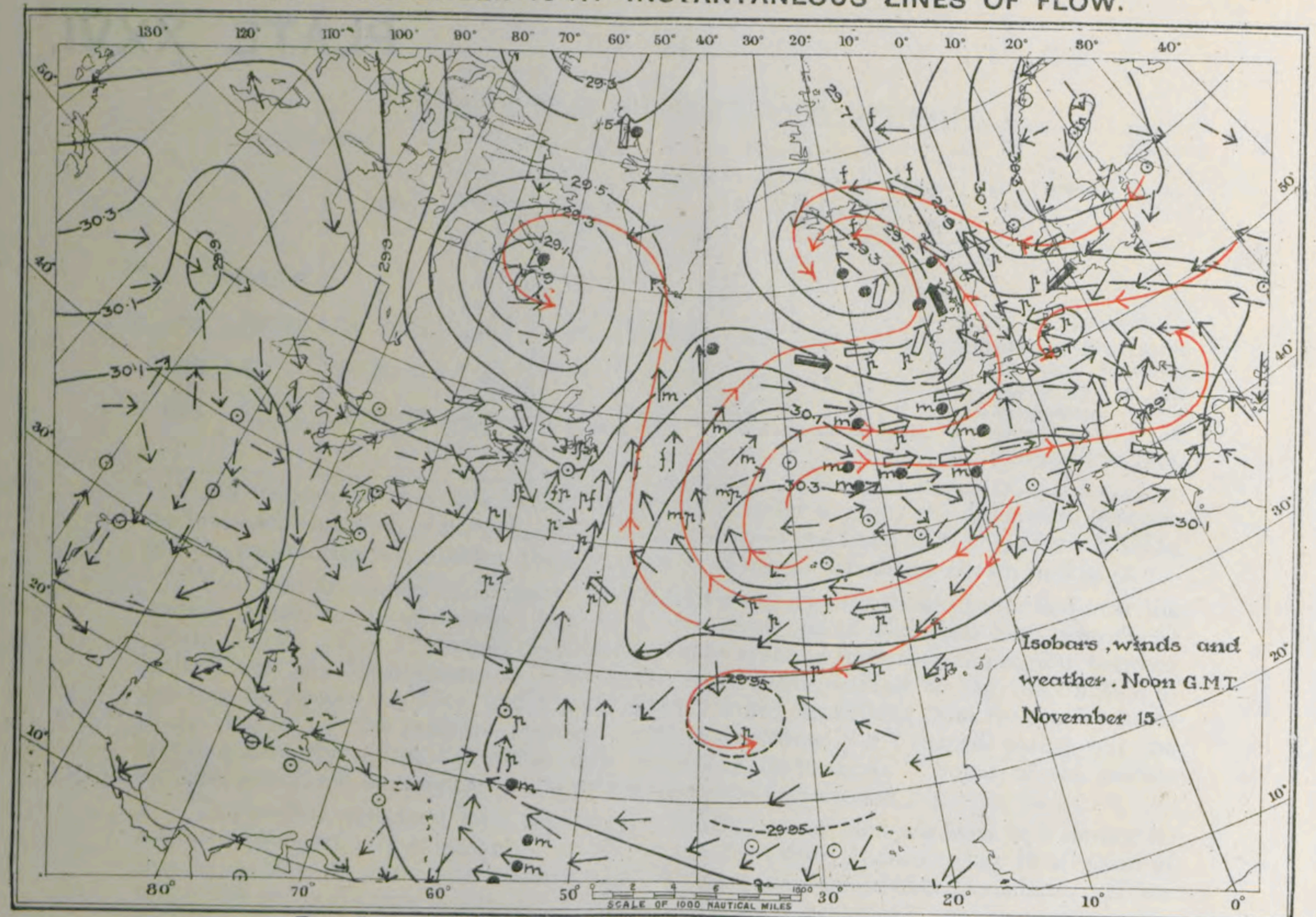
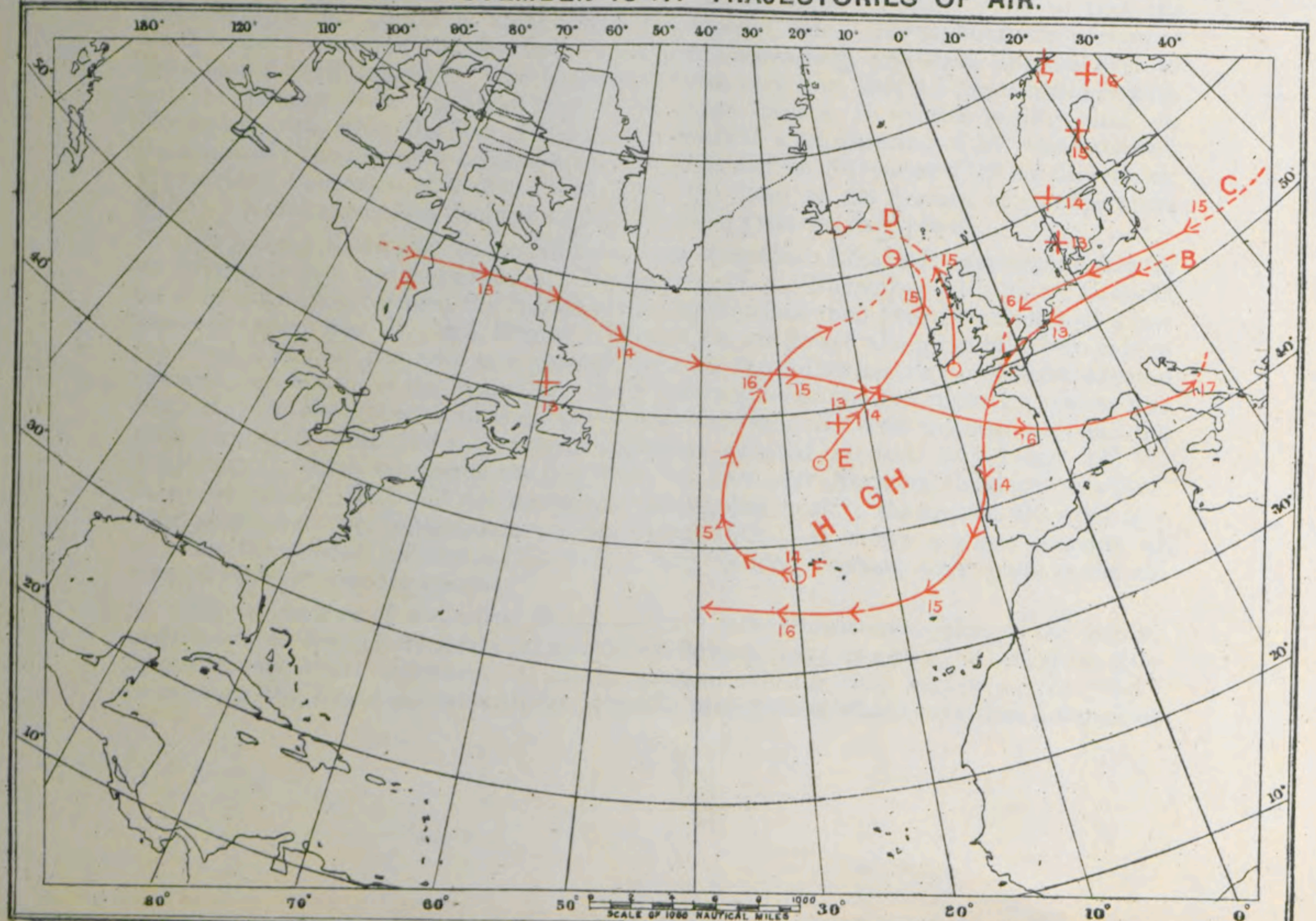


FIG. 2. NOVEMBER 13-17. TRAJECTORIES OF AIR.



The red lines in the upper map show the stream lines of instantaneous motion, and in the lower map, the trajectories of air.

FIG. 3. DECEMBER 12-17.

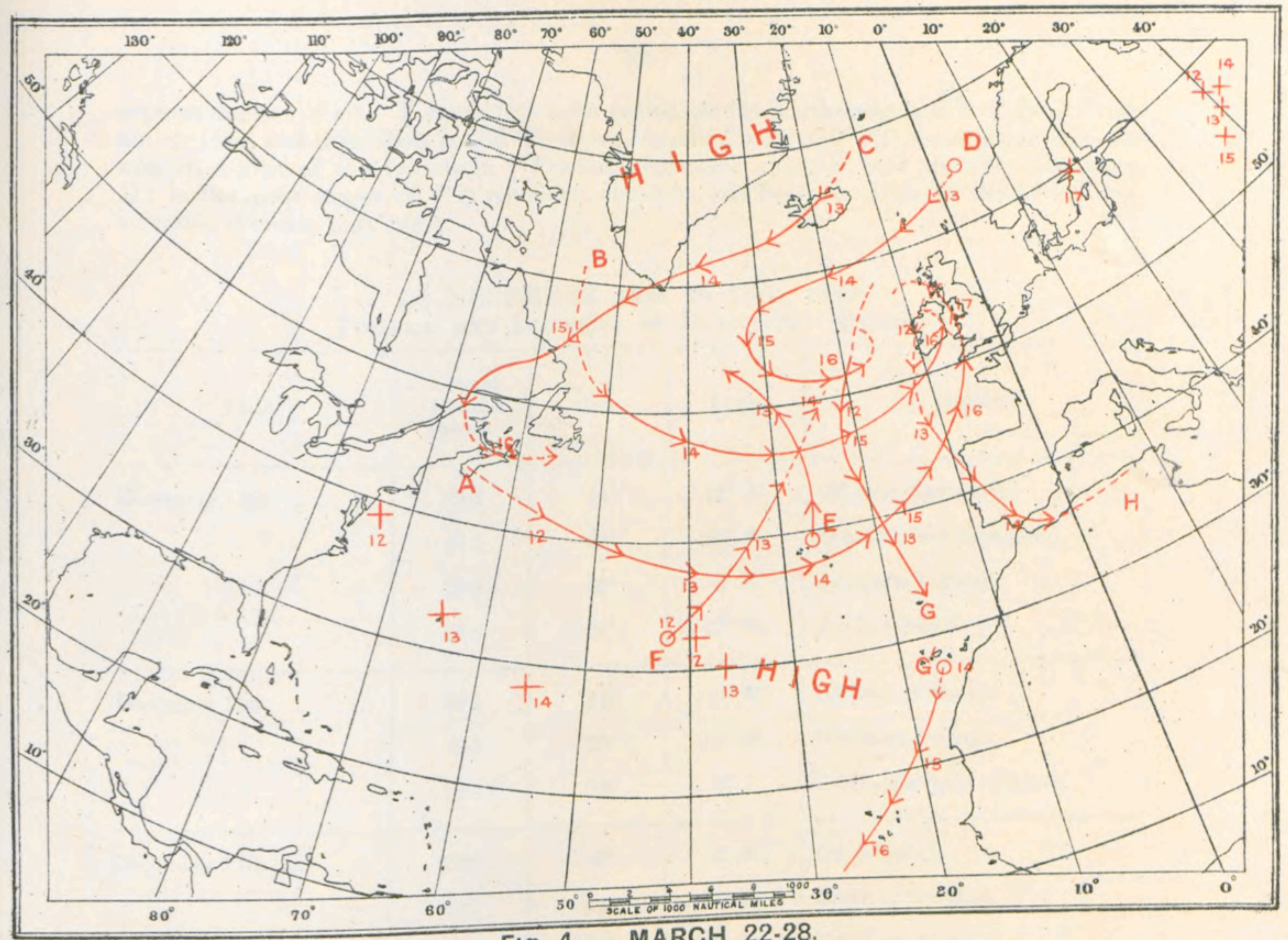
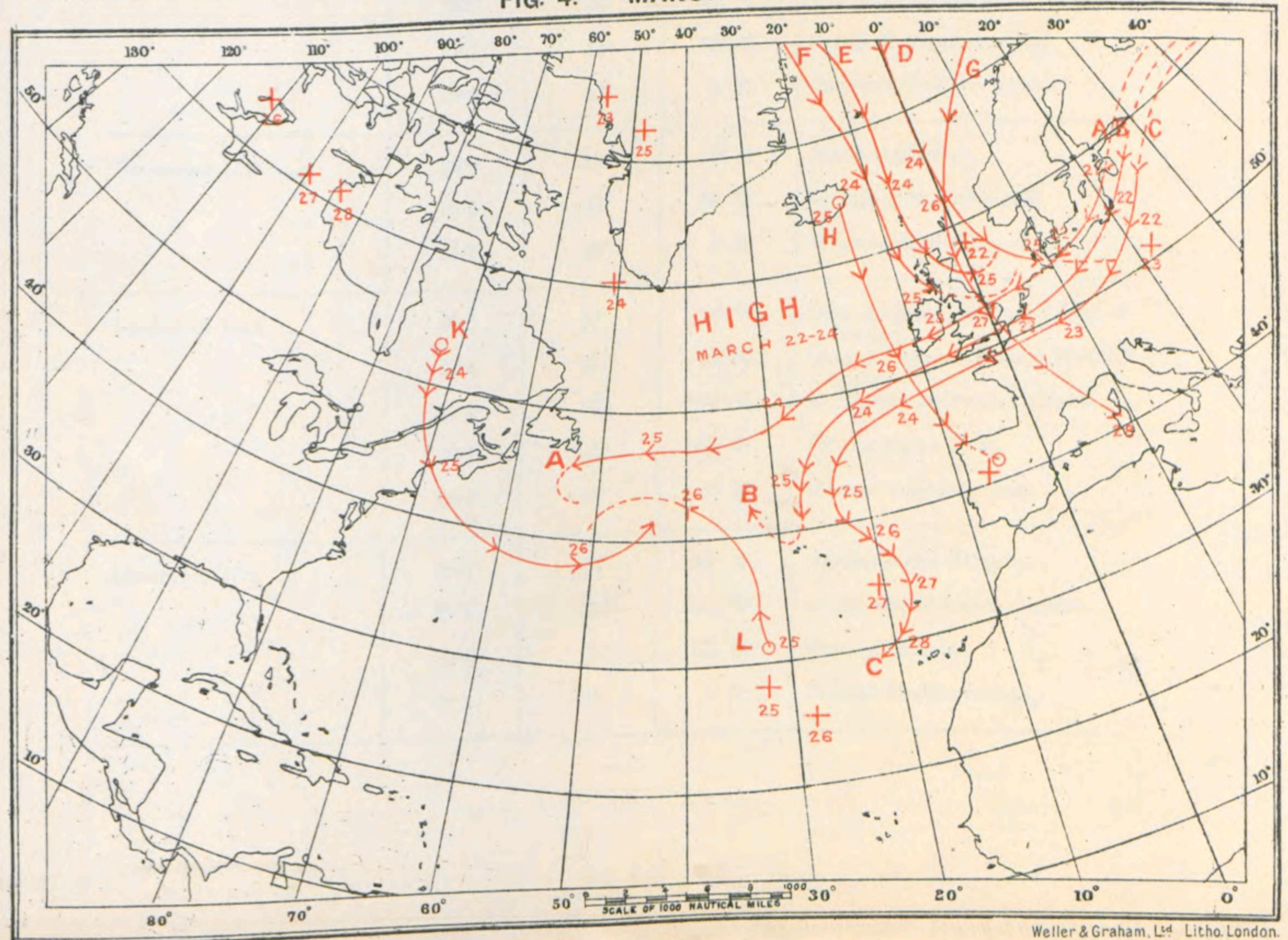


FIG. 4. MARCH 22-28.



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copious descent of air. F starts in a calm region on the South-eastern side of the Atlantic anticyclone, and then flows round the outer edge of the latter. All these trajectories end near the centre of the depression. Pressure decreased along E, and probably also along D; in the early stages of F it remained constant, but from the 15th to the 16th a considerable decrease took place.

(*e*) DECEMBER 12TH TO 17TH, 1882.

POSITION AND INTENSITY OF BAROMETRIC MINIMA.

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
December 12th	28·8	44°	12° W.	Off Cape Finisterre.
	28·5	48°	57° W.	South of Newfoundland.
	29·5	62°	8° E.	Southern Norway.
	29·8	64°	67° W.	Hudson Strait.
December 13th	29·4	47°	8° W.	Off Bay of Biscay.
	28·5	50°	46° W.	Northern Atlantic.
	29·6	39°	0°	South-east coast of Spain.
December 14th	29·6	48°	6° W.	Off Britanny.
	29·7	62°	4° W.	North of Scotland.
	28·9	50°	41° W.	Northern Atlantic.
	29·3	43°	63° W.	South of Newfoundland.
	29·8	40°	5° E.	Western Mediterranean
December 15th	29·0	53°	24° W.	North Atlantic.
	29·3	48°	65° W.	Mouth of St. Lawrence.
	29·7	38°	5° E.	Western Mediterranean.
December 16th	29·3	53°	20° W.	Over Atlantic, 500 miles West of Ireland.
	29·4	41°	20° W.	Over Atlantic, 500 miles West of Spain.
	29·4	53°	50° W.	North-east of Newfoundland.
	29·3	35°	69° W.	Off American coast.
	29·8	38°	9° E.	Central Mediterranean.
December 17th	29·1	53°	25° W.	North-central Atlantic.
	29·1	45°	51° W.	South-east of Newfoundland.
	29·4	47°	65° W.	Eastern Canada.
	29·9	38°	9° E.	Central Mediterranean.

Tabular Summary of Trajectories.
For Diagram of Trajectories, *see* Plate XXVI., Fig. 3.

Date.	Position. Lat.	Position. Long.	Wind. Direction.	Wind. Velocity. Miles per hour.	Pressure.	Temperature Of air.	Temperature Of sea	Weather.	General course of the air.
Trajectory A.									
12th	40° 30′	56° 30′ W.	W.N.W.	33	29·6	57°	62°	p.	From the rear of a cyclonic depression over Newfoundland round the Azores to a depression off the West of Ireland.
13th	36° 30′	40° 0′	W.	25	30·0	67°	68°	p.	
14th	36° 0′	28° 0′	W.	25	29·9	68°	68°	p.	
15th	40° 0′	16° 30′	W.S.W.	18	29·8	63°	59°	p.m.	
16th	46° 0′	9° 0′	S.S.W.	25	29·65	54°	54°	p.	
17th	54° 0′	6° 0′ W.	S.	18	29·7	46°	—	r.	
Trajectory B.									
14th	47° 0′	42° 30′ W.	N.W.	40	29·2	45°	53°	p.m.	From off Labrador in a wedge in the rear of the same depression across the Atlantic to a depression off Ireland.
15th	46° 0′	22° 0′	W.S.W.	33	29·4	55°	56°	p.	
16th	52° 30′	7° 30′ W.	S.	30	29·5	45°	—	?	
Trajectory C.									
13th	65° 0′	20° 0′ W.	N.E.	25	30·1	23°	—	p.	From a region beyond the area of the map lying to the East of Greenland, round and into a depression over Newfoundland.
14th	61° 0′	40° 0′	E.N.E.	30	30·0	?	?	n.?	
15th	54° 30′	58° 30′	E.N.E.	30	29·6	31° ?	?	n.?	
16th	44° 30′	64° 0′ W.	W.	30 ?	29·6	30° ?	—	r.?	
Trajectory D.									
13th	64° 0′	2° 30′ W.	N.E.	18	29·65	40° ?	45°	n.	From a "col" between two anticyclones, off the coast of Norway, round and into a depression off the West of Ireland.
14th	59° 30′	20° 0′	E.N.E.	33	29·7	40° ?	44°	n.?	
15th	54° 0′	43° 20′	N.	17	29·25	40° ?	45°	n.?	
16th	51° 0′	24° 0′ W.	W.	23	29·5	50° ?	50°	p.	
Trajectory E.									
12th	39° 30′	28° 0′ W.	Z.	0	?	62°	64°	?	From a "col" between two depressions, over the Azores, North-westward to near the centre of a depression off Newfoundland.
13th	48° 0′	29° 30′ W.	S.S.E.	30	29·5	53°	55°	r.	

Tabular Summary of Trajectories—*continued.*

Date.	Position. Lat.	Position. Long.	Wind. Direction.	Wind. Velocity. Miles per hour.	Pressure.	Temperature Of air.	Temperature Of sea.	Weather.	General course of the air.
Trajectory F.									
12th	31° 0′	43° 0′ W.	Z.	0	30·35	72°	73°	n.	From the centre of an anticyclone in mid-Atlantic to an elongated depression over the Northern Atlantic.
13th	38° 0′	35° 30′	S.W.	30	29·90	66°	66°	r.m.	
14th	49° 0′	25° 0′ W.	S.W.	30	29·25	52°	52°	p.	
Trajectory G.									
12th	48° 0′	22° 30′ W.	N.	30	29·75	48°	55°	p.	From a "col" between Iceland and Great Britain, southward to the North-east coast of Africa.
13th	38° 0′	19° 0′ W.	N.N.W.	25	29·95	59°	64°	p.	
Trajectory G′.									
14th	25° 30′	17° 30′ W.	Z.	0	30·15	68°	68°	n.	Round the eastern margin of an anticyclone off the North-east coast of Africa to the North-east trade wind.
15th	20° 0′	21° 0′	N.N.E.	20	30·05	69°	71°	n.	
16th	13° 0′	26° 0′ W.	N.E.	20	30·05	75°	75°	n.	
Trajectory H.									
12th	53° 30′	10° 0′ W.	N.N.E.	17	29·65	43°	47°	p.	From the North-west of Ireland on a "col" between two anticyclones Southward to a depression over the Mediterranean.
13th	45° 0′	12° 30′	N.	25	29·50	53°	56°	p.	
14th	36° 30′	6° 0′ W.	N.N.W.	20	29·9	50°	—	n.	

During this period the centre of the Atlantic anticyclone varied in position between 40° and 20° W. Long. and 30° and 25° N. Lat., while the Northern Atlantic was occupied by a number of deep low pressure systems. On December 12th minima of less than 29 inches were shown off Cape Finisterre and over Newfoundland. On the following days the former of these moved North-eastward towards the English Channel, filling up as it did so, while the latter moved Eastward with a velocity of about 500 miles in 24 hours. On December 14th the whole of the North Atlantic was covered by a large disturbance showing steep gradients on both its Northern and Southern sides. During the following three days these steep gradients on either side of the region of lowest pressure were maintained, but within the latter a number of minima were shown.

The trajectories (*see* Plate XXVI., Fig. 3), as in the case of those for December 23rd to 30th discussed above, show :—

(1.) A supply of air flowing across the Atlantic from West to East (trajectories A and B). These trajectories commence in the rear of cyclonic depressions as cold North-westerly winds blowing off the American Continent. The air in them gets heated during its passage over the warmer water of the ocean, and finally they flow into the low pressure systems off the British Isles as warm South-westerly or Southerly winds. The pressure changes in A were rather irregular; in B a tendency to increase is shown.

(2.) A supply of cold air flowing on the Northern side of the region of lowest pressure from the Arctic regions towards the South-west (trajectories C and D); D can be traced back to the "col" between two anticyclones shown on the map for December 13th over Northern Greenland and Central Russia respectively. The point of origin of C lies outside the area covered by the maps. When traced forward these trajectories curve round the centre of low pressure in a similar manner to those of the cold air in the storm of November 11th, 1901 (No. 3), discussed in detail above (*see* p. 43, and Plate VIII., Figs. 1, 2, 3). Ultimately the air in them gets warmed by passage over the ocean and they flow round, and finally end in, low pressure areas. The changes of pressure along these trajectories also suggest a resemblance to those of the November storm. A minimum is attained as the air reaches the rear of the depressions. In the case of D the increase of pressure, which occurs after the minimum has been passed, is soon checked, and a second region of decreasing pressure is entered as the air again approaches the centre of low pressure.

No air reaches the coast of Europe from the Atlantic anticyclone; E and F are examples of trajectories the origin of which lies in this region. E commences on December 13th on the "col" between the disturbance over Newfoundland and that off Cape Finisterre; F commences on December 12th near the centre of the anticyclone. If we follow the course of these two curves during the two following days, we find ourselves (on December 14th) in a region of Easterly winds, so that we must conclude that the warm air of E and F has undergone a similar fate to that of the warm currents over England in front of the depression of November 11th, 1901. In both trajectories pressure diminished continuously.

Trajectories G and H represent the flow of air from the North, on the Western side of the depression off the Spanish Peninsula on December 12th and 13th. Though the disturbance moved North-east the air of these trajectories continued to travel towards the South; H turned to the East off the Straits of Gibraltar, and appears to have been absorbed in a depression over the Mediterranean; but G maintained its direction and, on December 14th, reached a region of calm or light Northerly breezes, but not of low pressure, near the Canary Islands. Probably this air ultimately joined the North-easterly Trade wind, as indicated by the trajectory G′. The air pressure in this current from the North showed a distinct increase as more Southern latitudes were reached.

(*f*) MARCH 22ND TO 28TH, 1883.

POSITION AND INTENSITY OF BAROMETRIC MINIMA.

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
March 22nd	29·0	43°	15° W.	200 miles West of Cape Finisterre.
	29·5	75°	0	Arctic Ocean, East of Greenland,
	29·3	48°	63° W.	Mouth of St. Lawrence.

POSITION AND INTENSITY OF BAROMETRIC MINIMA—*continued.*

Date.	Lowest Isobars shown.	Lat.	Long.	Position.
March 23rd	29·4	43°	14° W.	400 miles West of Cape Finisterre.
	28·8	70°	20° E.	North of Norway.
	29·2	39°	65° W.	West of Atlantic.
	29·5	60°	68° W.	North of Labrador.
March 24th	29·5	42°	18° W.	Off Spanish coast.
	29·6	39°	12° W.	Off Spanish coast.
	29·9	40°	15° E.	Over Italy.
	28·8	60°	20° E.	Southern part of Gulf of Bothnia.
	29·5	48°	64° W.	Western Atlantic.
	29·5	37°	65° W.	Ditto.
	29·6	41°	55° W.	Ditto.
March 25th	29·6	44°	1° W.	S.W. Europe and adjoining portion of Atlantic.
	29·6	42°	8° W.	Ditto ditto.
	29·6	42°	15° W.	Ditto ditto.
	28·8	64°	23° E.	Gulf of Bothnia.
	28·8	42°	59° W.	South of Newfoundland.
March 26th	28·9	54°	9° E.	Mouth of Elbe.
	29·1	40°	55° W.	Western Atlantic.
March 27th	29·1	72°	25° E.	Complex "low" over Europe; centres over N. of Norway, Gulf of Riga, and Northern Italy.
	29·2	58°	25° E.	
	29·5	45°	13° E.	Ditto ditto.
	29·2	40°	47° W.	Mid Atlantic.
	29·3	35°	69° W.	Western Atlantic.
March 28th	29·2	72°	20° E.	North of Norway.
	29·7	43°	16° E.	Over Adriatic.
	29·5	60°	20° W.	North Atlantic.
	29·1	43°	35° W.	Mid Atlantic.
	29·3	35°	65° W.	Western Atlantic.

Tabular Summary of Trajectories.

For diagram of trajectories, *see* Plate XXVI., Fig. 4.

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
Trajectory A.									
21st	57° 0′	22° 30′ E.	N.E.	20	30·0	10°	—	n.	From the N.W. of Russia, round the Eastern edge of an anticyclone over Scandinavia, eastward round and into a depression over the W. Atlantic to the South of Newfoundland.
22nd	53° 0′	12° 0′ E.	E.	20	30·4	18°	—	n.	
23rd	52° 0′	6° 30′ W.	E.	35	30·2	34°	—	n.	
24th	48° 0′	28° 0′	E.N.E.	33	30·2	51°	52°	p.	
25th	46° 0′	45° 0′ W.	E.	30	29·85	48°	44°	f.	
Trajectory B.									
22nd	54° 0′	20° 0′ E.	N.E.	20	30·35	10°	—	—	From the N.W. of Russia, round the Eastern edge of an anticyclone over Scandinavia, eastward to near the Azores.
23rd	50° 0′	4° 0′ E.	E.	33	30·1	25°	—	n.	
24th	48° 0′	17° 30′ W.	E.N.E.	37	30·0	50°	53°	p.	
25th	41° 30′	27° 0′ W.	N.	10	29·90	57°	58°	p.	
Trajectory C.									
22nd	52° 30′	22° 0′ E.	N.N.E.	20	30·25	5°	—	—	From the N.W. of Russia, round the Eastern margin of the Atlantic anticyclone to the N.E. Trade wind.
23rd	48° 30′	8° 30′ E.	E.	33	30·0	—	—	—	
24th	47° 0′	13° 0′ W.	E.N.E.	37	29·9	50°	53°	r.	
25th	41° 0′	23° 30′ W.	N.	10	29·8	56°	58°	p.	
26th	37° 0′	21° 0′ W.	N.W.	12	30·0	60°	60°	n.	
27th	33° 0′	17° 30′ W.	N.	15	30·2	64°	64°	n.	
28th	28° 30′	19° 0′ W.	N.E.	10	30·3	67°	67°	n.	
Trajectory D.									
24th	66° 0′	0° 0′	N.	48	29·5	31°	40°	r.	From beyond the map, off the East of Greenland to a depression over Scandinavia.
25th	53° 0′	10° 0′ E.	N.W.	30	29·5	36°	—	?	
Trajectory E.									
24th	64° 30′	8° 0′ W.	N.	33	30·0	30°?	40°	n.	From beyond the map, off the East of Greenland to a depression over the North Sea.
25th	55° 0′	1° 30′ E.	W.N.W.	25	29·5	?	?	?	

Tabular Summary of Trajectories—*continued.*

Date.	Position.		Wind.		Pressure.	Temperature		Weather.	General course of the air.
	Lat.	Long.	Direction.	Velocity. Miles per hour.		Of air.	Of sea.		
Trajectory F.									
24th	65° 30′	11° 30′ W.	N. by W.	33	30·2	25°?	35°?	n.	From beyond the map, off the East of Greenland to a depression over the North Sea.
25th	55° 0′	6° 30′ W.	N.W.	25	29·6	36°	—	n.	
Trajectory G.									
25th	73° 0′	15° 0′ E.	N.E.	33	29·3	?	?	?	From beyond the map, off the West of Norway to a depression over the Mediterranean.
26th	61° 30′	0° 0′	N.N.E.	29	29·3	35°?	41°	r.	
27th	51° 0′	0° 30′ E.	N.	25	29·6	38°	—	p.	
28th	39° 30′	10° 0′ E.	N.N.W.	35	29·9	50°?	—	?	
Trajectory H.									
25th	65° 0′	17° 0′ W.	Z	0	29·9	35°	—	n.	From a "col" over Iceland to near the centre of a high pressure system over Spain.
26th	51° 0′	12° 30′ W.	N.	48	29·6	47°	50°	p.	
27th	43° 0′	8° 0′ W.	N.N.W.	15	29·9	50°?	53°?	p.	
Trajectory L.									
25th	30° 0′	33° 30′ W	Z	0	30·0	67°	68°	n.	From near the centre of an anticyclone, South of the Azores, Northward to a depression in Mid-Atlantic.
26th	41° 30′	41° 30′ W.	S.E.	45	29·5	58°	58°	rm	

On March 21st a very elongated band of high pressure, in which readings were between 30·3 inches and 30·5 inches, stretched across the Atlantic Ocean from the West of Norway, across Iceland to Lat. 43° N., Long. 45° W., while deep low pressure systems lay off the Bay of Biscay and to the South of Newfoundland. During the following days the anticyclone moved Southward, and as this movement took place, a further disturbance appeared over the Arctic Ocean between Greenland and Norway. The latter spread South-eastward, and by March 24th it formed the most conspicuous feature of the distribution of pressure. Its centre was then situated over Finland, and the whole of Northern Europe was under its influence. By March 25th the positions of the regions of high pressure had changed completely. Readings of over 30·8 inches were shown over the West of Greenland, and a second anticyclone, in which the barometer was relatively low, hardly exceeding 30·0 inches, lay off the coast of Africa (Lat. 20° N., Long. 30° W.). A well-marked "col" connected the two centres of high pressure. The positions of the minima of pressure had changed little. In the West the disturbance South of Newfoundland had deepened considerably; in the East the Northern depression was still in the position it occupied on the previous day, but the one off the Spanish coast showed no less than three minima of pressure.

After March 25th the "col" which stretched across the Atlantic in a North to South direction, increased in intensity and moved slowly Eastward; on the 28th it was represented by an elongated anticyclone which extended from the Spanish Peninsula to near the Canary Islands. The disturbance off Newfoundland also moved Eastward into the middle of the Atlantic. The large depression over Europe divided into two parts, on March 28th it showed one minimum of pressure over Italy and the Adriatic, and another to the North of Norway.

The first few days of the period were characterised by the rapid drift of air from the East, on the Northern side of the depression off the Spanish coast, represented by the trajectories A, B and C (Plate XXVI., Fig. 4). All these curves can be first identified as Northerly gales on the Eastern side of the large and narrow anticyclone which stretched from Norway towards Iceland. On the map for March 20th a shallow low pressure system lay over the Gulf of Finland, and we must assume either that the air descended to the surface on the Western side of this, or that it flowed round it from regions lying beyond the confines of the map. The direction of motion of the air soon became deviated to the right, and it flowed as an Easterly gale through the region between the anticyclone and the disturbance off Cape Finisterre. Further to the West the rate of motion gradually decreased. The trajectory A ends on March 26th in the deep disturbance in the West, then off the Banks of Newfoundland; on March 25th B had reached the calm region near the "col" between this depression and the one off Spain, and by March 26th the air in it had been drawn into the South-easterly current on the Eastern side of the Western "low"; the air of trajectory C ultimately found its way to the North-east Trade wind.

The pressure of the air was, in general, decreasing continuously in these trajectories, but C shows a minimum on March 25th; on the 27th the pressure in it had increased from 29·8 inches, the value on the 25th, to 30·3 inches.

March 23rd was the last day of Easterly wind over the British Isles; between this and the following day the supply of air from the East was cut off by a strong Northerly wind (trajectories D, E, F, G and H), which formed the Western part of the circulation round the low pressure system then over Europe. The air of this current can be traced to the extreme Northern confines of the map, where it took part on March 24th in a North-westerly gale blowing off the East coast of Greenland. The air of the trajectories D, E and F got drawn to the Eastward into the low pressure system during its passage over England; but the trajectory G, which refers to a somewhat later epoch, can be traced from the Northern limits of the map as far South as the Mediterranean. The trajectory H commenced in a calm on the Western side of the Northerly current; when continued Southward the North-west of Spain is reached at Noon on March 27th; if we attempt to trace the air still further forward we find ourselves, on the 28th, near the centre of the anticyclone then shown over the Spanish Peninsula. The pressure of the air in these trajectories, as a rule, shows a decrease, but in the last stages of both G and H the reverse is the case.

Trajectories K and L show further sources of supply to the depression over the Western Atlantic. K commences in a "col" between two depressions in the very cold region near Hudson's Bay. Thence the air flows Southward and then Eastward round the centre of low pressure, which it finally approaches as a South-westerly wind. The temperature at the starting point was below 10°, but it rapidly rose as the air passed over the ocean off the Canadian coast, where the temperature gradient of the water is very

great, and the reading on the 26th was as high as 60°. A slight increase of pressure was shown from the 23rd to the 24th, but the subsequent values tabulated show a decrease which became very rapid in the last stages. L represents the source of supply of the South-easterly to Easterly gales experienced on the Eastern side of the depression on March 26th; it is found to commence in the very shallow anticyclone shown off the African coast on the previous day. As the rate of motion of the air in these gales was very rapid the needful supply could only have been kept up if we assume that a copious descent of air occurred within the region covered by the anticyclone. The pressure of the air in the trajectory decreased from 30·0 inches to 29·5 inches in the interval between Noon on March 25th and Noon on the 26th.

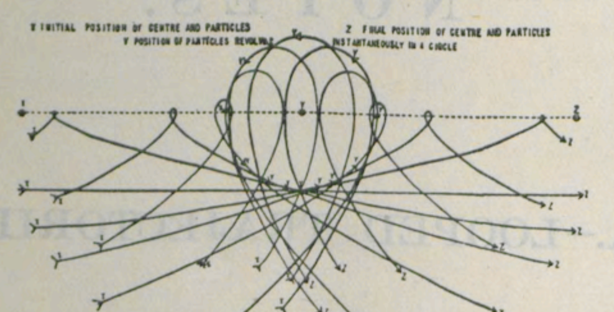
PART IV.

NOTES.

A.—LOOPED TRAJECTORIES.

B.—CALCULATION OF THE "DILATATION" OF AREA IN TRAVELLING STORMS.

Diagram of Looped Trajectories for an "Ideal" Storm of Circular Isobars and Uniform Wind tangential to the Isobars, travelling with the same Speed as the Wind.



The curves are represented by the equation

$$(a-y)(2a+y)^2=9ax^2.$$

See Quarterly Journal, Royal Meteorological Society, Vol. 29, 1903, p. 233, and Monthly Weather Review, Vol. 31, 1903, p. 218.

NOTES.

A.—LOOPED TRAJECTORIES.

I.—The Motion relative to the Centre in Circular Storms of Uniform Wind Velocity. By G. T. Bennett, M.A., Fellow of Emmanuel College, Cambridge.

For the motion of the air in the "ideal storm" here to be considered it is supposed (1) that the velocity of the wind has the same magnitude for all stations and times, (2) that at any instant the directions of the wind for different stations are tangential to a system of circles having a common centre, (3) that this storm centre itself moves uniformly along a straight line. Under these circumstances, it is desired to determine the trajectory which is described by any particle of air.

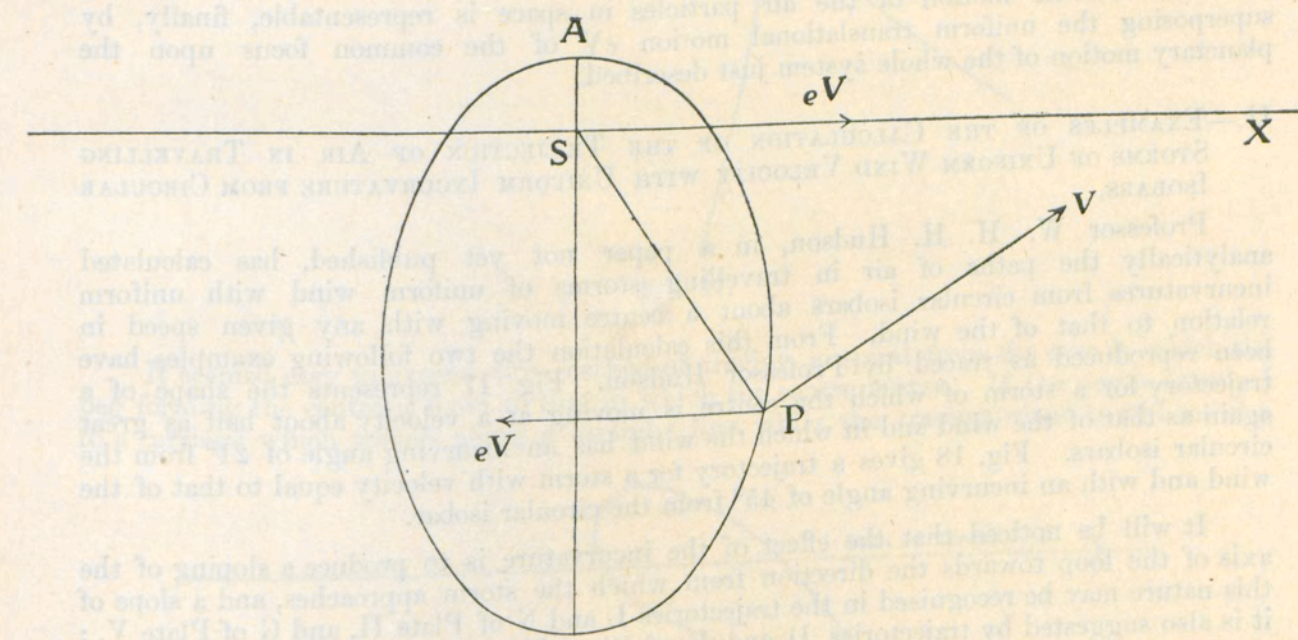


Fig 16.

Let P (Fig. 16) be any particle of air, S the storm centre, V the velocity of P perpendicular to PS, and eV the velocity of S along the straight line SX. Let the motion of P *relative* to S be considered. The velocity of P relative to S is the resultant of the absolute velocity of P, namely, V perpendicular to SP, and a velocity equal to the reversed velocity eV of S, as shown in the figure. The acceleration of P relative to S is the resultant of accelerations derived from these two velocities. The first velocity V is constant in magnitude, and has a direction which rotates with the same (variable) angular velocity as SP, say ω: it gives rise to an acceleration $V\omega$ along PS. The second velocity eV is constant in magnitude and direction, and gives rise to no acceleration. The acceleration, therefore, for the motion of P relative to S is $V\omega$ along PS. This being entirely radial, it follows that $SP^2\omega$ remains constant, and hence that the acceleration $V\omega$, varying directly as ω, varies inversely as SP^2. Hence the motion of P relative to S is planetary motion in a conic section, the conic having S for focus and the path of S as latus-rectum.

Further, to find the eccentricity of the conic, consider the instant when P passes the apse A, at which the component velocities V and eV coincide in direction. The velocity of P in its orbital motion is then $V + eV$, and hence the angular velocity of the radius vector is given by

$$SA\omega = V(1 + e)$$

The acceleration is $V\omega$ along AS: and it is also V^2/l, l, the length of the semi-latus-rectum, being (for any conic) equal to the radius of curvature at the vertex A. Hence

$$V^2(1 + e)/SA = V^2/l$$
$$\therefore l/SA = 1 + e$$

which shows that the eccentricity of the conic is equal to e, the ratio of the velocity of the storm centre to the velocity of the wind.

The paths of the air particles relative to the storm centre S thus consist of a system of similar conics of eccentricity e, having a common focus S and a common axis perpendicular to the path of the storm centre; and these paths are described each in planetary fashion, with uniform rate of description of area ($\frac{1}{2}Vl$) about S. The conics are ellipses, parabolas or hyperbolas according as e is less than, equal to, or greater than unity.

The absolute motion of the air particles in space is representable, finally, by superposing the uniform translational motion eV of the common focus upon the planetary motion of the whole system just described.

II.—Examples of the Calculation of the Trajection of Air in Travelling Storms of Uniform Wind Velocity with Uniform Incurvature from Circular Isobars.

Professor W. H. H. Hudson, in a paper not yet published, has calculated analytically the paths of air in travelling storms of uniform wind with uniform incurvatures from circular isobars about a centre moving with any given speed in relation to that of the wind. From this calculation the two following examples have been reproduced as traced by Professor Hudson. Fig. 17 represents the shape of a trajectory for a storm of which the centre is moving at a velocity about half as great again as that of the wind and in which the wind has an incurving angle of 21° from the circular isobars. Fig. 18 gives a trajectory for a storm with velocity equal to that of the wind and with an incurving angle of 45° from the circular isobar.

It will be noticed that the effect of the incurvature is to produce a sloping of the axis of the loop towards the direction from which the storm approaches, and a slope of this nature may be recognised in the trajectories L and N of Plate II. and G of Plate V.; it is also suggested by trajectories D and E of Plate II. and H and K of Plate V. A similar result can be traced in figures drawn by means of the anemoidograph which is described in the following section.

III.—The Anemoidograph, an Apparatus for Tracing Trajectories Mechanically. By W. N. Shaw, Sc.D., F.R.S.

Some years ago Mr. Horace Darwin designed and constructed an apparatus for tracing an equiangular spiral. The vital element of the mechanism was a vertical tracing wheel which could be set so that its axis was kept at any required angle to the length of a rod at the end of which the wheel was fixed. By keeping the rod loosely pressed against a peg, and pushing forward the wheel end, the rod revolved about the peg as centre, and described a circle if the axis of the wheel lay truly along the rod. But the set of the wheel in any other position determined the motion of the tracer always at a fixed angle to the rod, and the curve described was in consequence an equiangular spiral. Any necessary adjustment of distance of the wheel from the peg in the course of tracing the curve was provided for by the freedom of slip of the rod past the peg. In this way was described what may be called the trajectory of a stationary circular storm with

constant incurvature. In other words the curve described represents the path of air moving with a definite angular deviation from circular isobars. If there is no deviation from the circle the path itself is circular and there is no slipping of the rod past the peg.

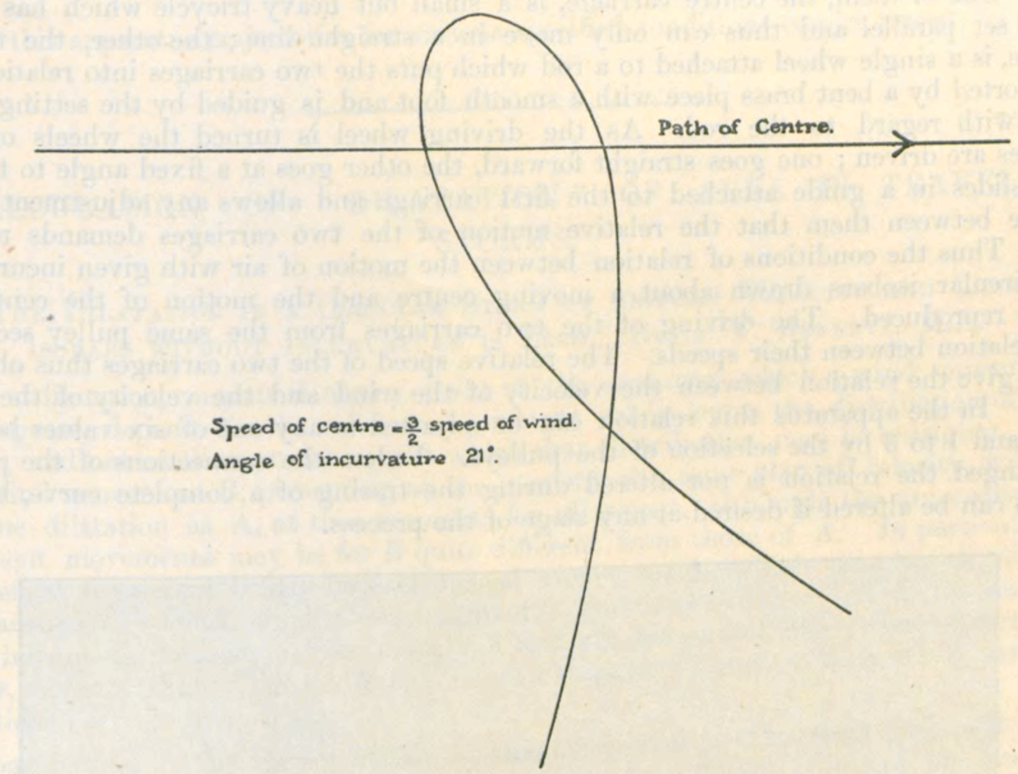


Fig. 17.

It seemed easy to extend this method of tracing a spiral from the case in which the peg forming the centre is fixed to that in which the centre moves. If the peg is attached to a carriage which travels along a straight line while the tracing wheel is still set at a fixed angle to a rod that is pressed against the moving peg but can slip backwards and forwards so as to adjust itself to the decreasing or increasing distance of the tracing wheel, the wheel will march with fixed incurvature round the moving centre—provided always that the velocity of the travelling wheel bears a proper relation to that of the moving centre.

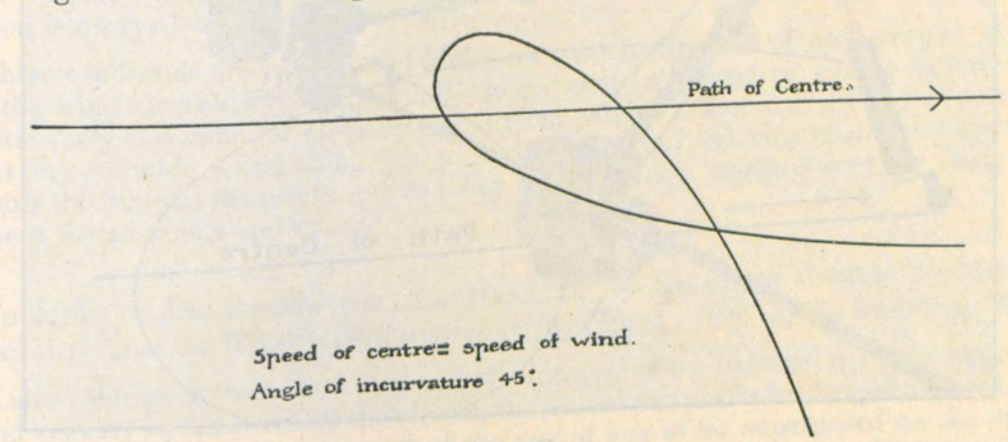


Fig. 18.

Accordingly in consultation with Mr. Darwin an apparatus was designed to carry out these requirements and constructed by the Cambridge Scientific Instrument Company. Two carriages are driven from a common driving wheel by a connection of pulleys and cords. One of them, the centre carriage, is a small but heavy tricycle which has all its wheels set parallel and thus can only move in a straight line; the other, the tracing carriage, is a single wheel attached to a rod which puts the two carriages into relation. It is supported by a bent brass piece with a smooth foot and is guided by the setting of its wheel with regard to the rod. As the driving wheel is turned the wheels of both carriages are driven; one goes straight forward, the other goes at a fixed angle to the rod which slides in a guide attached to the first carriage and allows any adjustment of the distance between them that the relative motion of the two carriages demands to take place. Thus the conditions of relation between the motion of air with given incurvature from circular isobars drawn about a moving centre and the motion of the centre are exactly reproduced. The driving of the two carriages from the same pulley secures a fixed relation between their speeds. The relative speed of the two carriages thus obtained should give the relation between the velocity of the wind and the velocity of the storm centre. In the apparatus this relation can be adjusted to any one of six values between 3 to 1 and 1 to 3 by the selection of the pulleys. Unless the connections of the pulleys are changed the relation is not altered during the tracing of a complete curve, but the pulleys can be altered if desired at any stage of the process.

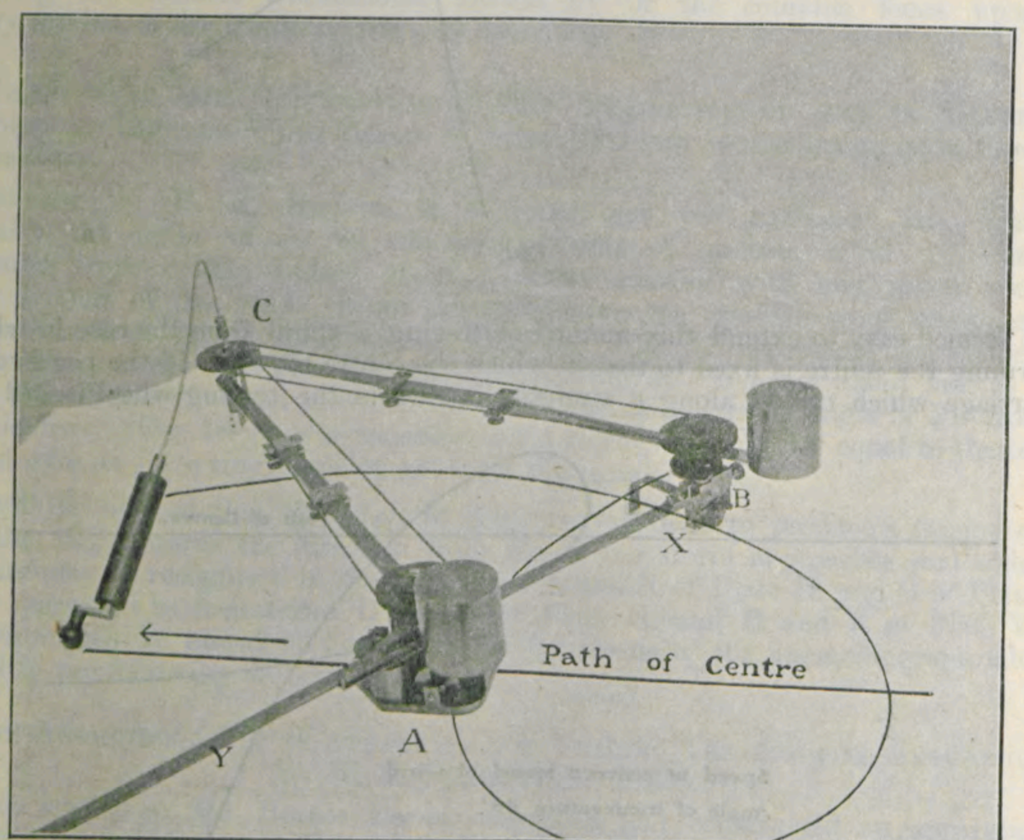


FIG. 19

The arrangement of the mechanism, without entering into details, will be understood from the figure. A is the centre carriage with its wheels fixed parallel to one another and thus compelled to traverse a straight course. B is the tracing carriage with its wheel adjustable. C is the driving pulley which is carried on a smooth foot connected with the carriages by rods, hinged on the axle of the driving wheel. XY is the guide rod with the end X attached to the tracing carriage, and the part marked Y lying in a hinged guide on the centre carriage so that it can turn round the upright peg fixed in the carriage and slip through the guide.

The driving pulley C is turned by a handle with flexible steel connection and in response to the rotation both carriages move, B travels round A and describes the looped trajectories which can be plotted from Professor Hudson's calculation.

With this apparatus trajectories for various specified conditions can be traced.

B.—CALCULATION OF "DILATATION" OF AREA IN TRAVELLING STORMS.

I.—THE DILATATION IN A CIRCULAR STORM OF UNIFORM VELOCITY AND CIRCULAR ISOBARS WITHOUT INCURVATURE IS ZERO. By G. T. BENNETT, M.A.

The dilatation, measured at any point of the area over which a wind movement A is in progress, depends for its value at any instant solely upon the distribution of wind velocity, and not at all upon the rate at which that distribution may be changing. Any other wind movement B, presenting at the moment the same plan of velocity, will give the same dilatation as A, at this moment, for all points, although the antecedent and subsequent movements may be for B quite different from those of A. In particular the hypothetical movement B may be that special movement for which the plan of velocity, instantaneous only for A, is taken as permanent. The "lines of flow" of the movement A at the instant considered, curves namely which are tangential everywhere to the wind velocity, become thus "stream lines" (each a trajectory common to a whole series of air particles) for the motion B.

Consideration of the narrow stream flowing between adjacent stream lines of B shows that the dilatation is everywhere zero if the velocity at different points of the stream is inversely proportional to the width of the stream; and, specially, that the dilatation is zero for a wind velocity constant along each stream line when the stream lines are a system of parallel curves. Hence any movement A with a wind distribution presenting a parallel system of lines of flow and a velocity constant for all points of each stream line has instantaneously a zero dilatation for all points. And if these conditions persist then the dilatation is everywhere permanently zero.

These conditions are present and also persistent in the case of any circular storm for which the wind blows always tangentially to a system of concentric circles with a velocity instantaneously the same for all points of any one circle. Otherwise the storm centre may move at any variable speed along any path, and the wind velocity round any circle may vary with the time as the circle moves; but the dilatation remains zero for such a wind movement for all places and times.

II.—TO FIND AN EXPRESSION FOR THE MEASURE OF DILATATION FROM SIMULTANEOUS WIND RECORDS AT THREE NEIGHBOURING STATIONS. By G. T. BENNETT, M.A.

If any contour be traced on a map and the integral of the outward normal component of the wind velocity be taken round the circuit, the value obtained affords (on the assumption of two-dimensional motion) a measure of the rate of loss of air superposed on the enclosed area. Divided by the total area itself the quantity becomes the mean dilatation for the area, and ultimately, if the area is indefinitely small, the dilatation at a point. It is here proposed to treat the case where the area in question is a small triangle.

Let ABC be the triangle (Fig. 20); a, b, c its sides; p, q, r the perpendiculars. Let the wind velocities at the stations ABC be represented each by two components, one perpendicular and one parallel to the opposite side of the triangle, as in the figure; the components perpendicular to the opposite sides and outward being u, v, w, and those parallel to the sides (and in the same cyclic sense) being u', v', w'.

The outward normal component of the wind velocity at points along BC varies uniformly (the triangle being treated as small) from

$$v \cos C + v' \sin C \text{ at B}$$
$$\text{to} \quad w \cos B - w' \sin B \text{ at C}.$$

The mean velocity across BC is therefore

$$\tfrac{1}{2}(v \cos C + v' \sin C + w \cos B - w' \sin B)$$

and the rate of flow

$$= \tfrac{1}{2}(v \cos C + v' \sin C + w \cos B - w' \sin B)a.$$

With similar results for the other two sides, the total rate of outflow

$$\begin{aligned} &= \tfrac{1}{2}(v \cos C + v' \sin C + w \cos B - w' \sin B)a \\ &+ \tfrac{1}{2}(w \cos A + w' \sin A + u \cos C - u' \sin C)b \\ &+ \tfrac{1}{2}(u \cos B + u' \sin B + v \cos A - v' \sin A)c \\ &= \tfrac{1}{2}[(b \cos C + c \cos B)u + (c \cos A + a \cos C)v + (a \cos B + b \cos C)w] \\ &+ \tfrac{1}{2}[(c \sin B - b \sin C)u' + (a \sin C - c \sin A)v' + (b \sin A - a \sin B)w'] \\ &= \tfrac{1}{2}(au + bv + cw). \end{aligned}$$

Hence, dividing by the area, in the forms $\tfrac{1}{2}ap$, $\tfrac{1}{2}bq$, $\tfrac{1}{2}cr$ we find

$$\text{Dilatation} = \frac{u}{p} + \frac{v}{q} + \frac{w}{r}.$$

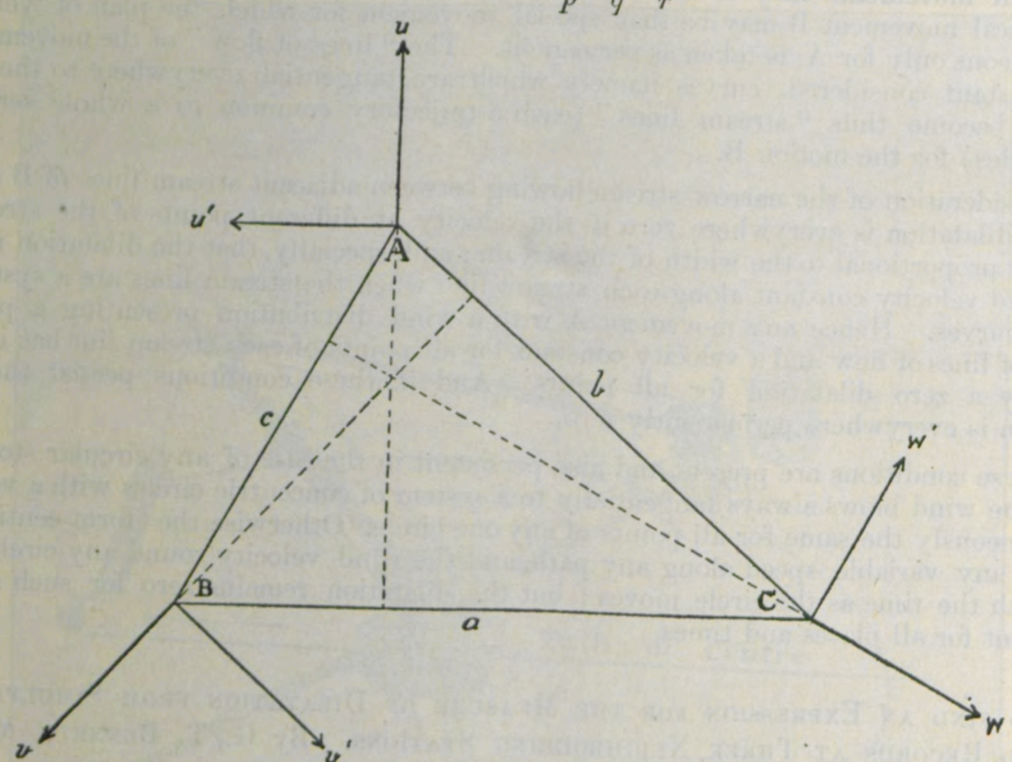


Fig. 20.

APPENDIX.

LIST OF STATIONS FROM WHICH OBSERVATIONS HAVE BEEN OBTAINED FOR THE PURPOSE OF THE INQUIRY.

1.—Stations supplying continuous records or hourly readings of Pressure, Temperature, Wind and Rainfall.

Station.	Authority.
Aberdeen	The Meteorological Council.
Ben Nevis	A. Rankin, for Directors of the Ben Nevis Observatory.
Berkhamsted	E. Mawley, F.R.H.S.
Falmouth	The Meteorological Council.
Glasgow	Prof. L. Becker, Ph.D., for the Meteorological Council.
Kew	The Meteorological Council.
Oxford	A. A. Rambaut, D.Sc., F.R.S.
Southport	J. Baxendell, for the Corporation.
Stonyhurst	Rev. W. Sidgreaves, S.J.
Valencia	The Meteorological Council.

2.—Other Stations supplying continuous records.

Station.	Nature of Information.	Authority.
Fort William	Pressure, Temperature and Rainfall.	The Meteorological Council.
Armagh	Wind and Rainfall	„ „
*Rousdon	„ „	C. Grover, for Hon. Lady Peek.
Scilly	Pressure and Wind	The Meteorological Council.
Yarmouth	„ „	„ „
Alnwick Castle	Wind	R. Kyle, for the Duke of Northumberland.
Deerness	„	The Meteorological Council.
Dublin	„	„ „
Fleetwood	„	„ „
Holyhead	„	„ „
Kingstown	„	Robert Gray, C.E., for H.M. Office of Works.
Manchester	„	Prof. A. Schuster, F.R.S.
North Shields	„	The Meteorological Council.
Plymouth	„	H. Victor Prigg, C.E., for the Corporation.

* Records supplied by the Royal Meteorological Society.

2.—Other Stations supplying Continuous Records—*continued.*

Station.	Nature of Information.	Authority.
*Ardgillan	Pressure	Captain E. R. Taylor.
Bangor (Co. Down)	"	J. S. McTear.
Belmullet	"	Lieut. F. H. Goldfinch, R.N.
Birmingham	"	Prof. J. H. Poynting, F.R.S.
Castle Townshend (Co. Cork) ...	"	Comr. W. Ricketts, R.N.
Chatsworth	"	The Duke of Devonshire.
*Cheadle (Staffs)	"	J. C. Philips.
Cheadle Hulme (near Manchester)	"	Ll. S. Lloyd, M.A.
Forgandenny (Perth)	"	C. L. Wood.
Fulbeck (Lincs.)	"	Rev. Vere F. Willson, M.A.
*Haverfordwest (Pembroke) ...	"	E. P. Phillips, F.R.C.S.
Kilkenny	"	H. Carlton, for the Marquis of Ormonde.
Malin Head	"	The Meteorological Council.
Newton Reigny (Penrith) ...	"	G. T. Benn.
Penbedw (Denbigh)	"	H. W. Buddicom.
Queenstown...	"	Lieut. O. P. Hodgson, R.N.
Stornoway	"	The Meteorological Council.
Streete (Co. Westmeath)	"	W. E. Wilson, F.R.S.
Sumburgh Head	"	The Meteorological Council.
Waterford	"	Harbour Authorities.
*Worksop	"	H. Mellish, J.P.

* Records supplied by the Royal Meteorological Society.

3.—Normal Climatological Stations supplying Observations at 9 a.m. and 9 p.m.

Name of Station.	Observer.
Ackworth	E. B. Ludlam, M.Sc.
Ampleforth	Rev. J. B. McLaughlin, B.A., O.S.B.
Aspatria	J. Smith Hill, B.Sc.
Aysgarth	The late Rev. F. W. Stow, M.A.
Belfast, Queen's College... ...	John Wylie, B.A.
Belvoir Castle	W. H. Divers, for the Duke of Rutland, K.G.
Bennington	Rev. J. D. Parker, LL.D.
Birmingham	Alfred Cresswell, for the Midland Institute.
Braemar	J. Aitken, J.P.
Bramley	J. Bartlett, M.A.
Buxton	W. Pilkington.
Cally	W. Thomson, for H. G. Murray Stewart.
Cambridge...	Miss A. Walker, for Sir Robert Ball, F.R.S.

3.—Normal Climatological Stations supplying Observations—*continued.*

Name of Station.	Observer.
Canterbury	A. Lander.
Carlisle	Studholme Cartmell, for the Corporation.
Cheadle	J. C. Philips.
Cheltenham	R. Tyrer, B.A. (the late), and F. O. Bell.
Churchstoke	P. Wright, F.C.S.
Cockle Path, Morpeth	J. H. J. Farquhar, B.Sc., for the Northumberland County Council.
Cromer	W. H. Archer, for Urban District Council.
Cronkbourne	A. W. Moore, M.A., J.P., C.V.O.
Deerness, Orkney...	M. Spence.
Dublin City	Sir John W. Moore, M.D.
Dundee	J. Carnochan.
Dunmow	Thos. Hacking, for the Countess of Warwick's Agricultural School.
Dunrobin Castle	D. Melville, for the Duke of Sutherland, K.G.
Durham	Professor R. A. Sampson, M.A., F.R.S.
Eastbourne	R. Sheward, for the Corporation.
Fort Augustus	Rev. C. von Dieckhoff.
Fulbeck	Rev. Vere F. Willson, M.A.
Garforth	Prof. Seton, for the Yorkshire College, Leeds.
Geldeston	E. T. Dowson.
Glencarron...	D. D. Munro, for Lord Maclaren.
Gordon Castle	C. Webster, for the Duke of Richmond and Gordon, K.G.
Guernsey, St. Peter Port ...	Adolphus Collenette.
Hereford (Belmont)	Rev. F. B. Harrington, O.S.B.
Hillington...	Rev. H. E. B. Ffolkes, M.A.
Hollesley Bay	Prof. C. G. Freer Thonger, F.C.S.
Hull	H. B. Witty, for the Corporation.
Lairg	Rev. John K. Maclean.
Laudale	A. Fletcher (the late), for T. H. G. Newton, M.A.
Llandudno...	William Little, for the Town Council.
Lowestoft	C. W. Edwards, for the Corporation.
Manchester, Oldham Road ...	J. Niven, M.A., M.B., for the Corporation.
" Whitworth Park ...	Prof. Schuster, Ph.D., F.R.S.
" Prestwich	T. R. H. Clunn, M.D.
Marchmont	J. A. Wood, for Sir H. P. Campbell, Bart.
Markree Castle	F. W. Henkel, B.A., and J. R. Armstrong for the Trustees of the late Colonel Cooper.
Newcastle, Co. Wicklow... ...	B. H. Steede, M.A., M.D.
Ochtertyre..	G. Croucher, for Sir P. K. Murray, Bart.
Parkstone	R. Hawkesworth Barnes, B.A.
Plymouth	H. Victor Prigg, A.M.I.C.E., for the Corporation.

3.—Normal Climatological Stations Supplying Observations—*continued.*

Name of Station.	Observer.
Ridgmont ...	H. M. Freear, F.C.S., for the Royal Agricultural Society.
Rothesay ...	J. Kay.
St. David's...	W. P. Propert, M.A., LL.D
Salisbury ...	Thos. Challis, for the Earl of Pembroke.
Scarborough ...	W. W. Larkin, for the Corporation.
Seaham Harbour ...	G. H. Aird.
Sheffield, Weston Park Museum	E. Howarth, F.R.A.S.
Southampton ...	A. Vaughan, for Director-General of Ordnance Survey.
Stokesay ...	Rev. W. La Touche, M.A., and Miss Tonkin.
Strathpeffer Spa ...	J. Maclean, for R. Fortescue Fox, M.D.
Tealby ...	Rev. S. Lewin, B.A.
Wessington Court ...	S. Lomas, for Miss L. Grafton.
Wolfelee ...	W. Gordon, for Major Elliot.
Woolacombe, Devon ...	B. Fanshawe.
York, The Museum ...	H. M. Platnauer, B.Sc.

4.—Returns from 27 British and 28 Foreign Stations as published in the Daily Weather Report, giving eye observations at 8 a.m. and 6 p.m. Observations at 2 p.m. were also available from 18 British Stations.

Observations for 1 p.m. or 2 p.m. from Foreign Stations were abstracted from Foreign Weather Reports.

In preparing the rainfall maps the observations from all the stations mentioned in the monthly summaries of the Weekly Weather Report were utilized.

5.—Foreign Observations Abstracted from Various Publications.

(1.) *Abstracted from Hourly Values or from the Reproductions of the Traces of Self-recording Instruments.*

France ...	Paris, Parc St. Maur.
" ...	" Eiffel Tower.
Belgium ...	Uccle (Brussels).
Holland ...	de Bilt (Utrecht).
" ...	The Helder.
" ...	Groningen.
" ...	Flushing.
Germany ...	Hamburg.
" ...	Bremen.
" ...	Aachen.
" ...	Frankfurt.
" ...	Magdeburg.
" ...	Borkum.
" ...	Wustrow.
Sweden ...	Stockholm.
Norway ...	Christiania.
Jersey ...	Observatoire de St. Louis.

(2.) *Published Returns from Stations of the Second Order.*

France ...	Nantes ...	Observations every 3 hours.
" ...	Besançon ...	" " "
" ...	Lyons ...	" " "
" ...	Perpignan ...	" " "
" ...	Sainte-Honorine-du-Fay ...	" " "
" ...	Toulouse ...	" " "
" ...	Marseilles ...	" " "
" ...	Dunkirk ...	Three observations per day.
" ...	Brest...	" " "
Denmark ...	Vesterwig ...	" " "
Faroe Isles ...	Thorshavn ...	" " "
Iceland ...	Berufjord ...	" " "
" ...	Grimsey ...	" " "
" ...	Stykkisholm ...	" " "
" ...	Vestmannoe ...	" " "

6.—Addition Foreign Information (Unpublished).

Returns from stations of the second order in Iceland and the Faroe Islands for October 7th to 9th (No. 4), and 14th to 17th (No. 6), hitherto unpublished, supplied by Prof. Paulsen, Copenhagen.

Barogram from Stavanger (Norway) for October 14th to 17th (No. 6), lent by Prof. Mohn, Christiania.

7.—Observations of Wind at Lighthouses, Light-vessels and Lloyd's Signal Stations.

Scotland, N.E.	North Unst, Dunnet Head, Pentland Skerries, Tarbet Ness, Kinnaird Head, Buchan Ness
Scotland, E.	Bell Rock, Inchkeith, St. Abb's Head
Scotland, N.W.	Cape Wrath, Butt of Lewis, Monach, Rona, Barra Head, Ardnamurchan
Scotland, W.	Skerryvore, Mull of Cantire
Ireland, S.W.	Coningbeg, Fastnet, Tearaght, Arran North Light
Ireland, N.W.	Eagle Island, Rathlin O'Birne, Tory Island, Rathlin Island, Maidens
Irish Sea	Mull of Galloway, St. John's Point (Killough), Rockabill, Bahamas Bank, N.W. Light Ship
St. George's Channel	Cardigan Bay
Bristol Channel	Scarweather, Lundy Island
England, S.W.	Eddystone, Start Point
England, S.	St. Catherine's Point, Owers
England, S.E.	Royal Sovereign, Varne, East Goodwins
England, N.E.	Outer Fern, Whitby, Flamborough Head, Outer Dowsing
England, E.	Lynn Well, Leman and Ower, Kentish Knock

LIST OF PUBLICATIONS

Issued by the Meteorological Office.

2. Occasional Publications and Reports—*cont.*

SUNSHINE :—

Sunshine Records of the United Kingdom for 1881. (Official, No. 56, 1883). 4*s*.

Ten Years' Sunshine in the British Isles, 1881–90. (Official, No. 98, 1891.) 2*s*.

TEMPERATURE :—

Temperature Tables for the British Islands. 10*s*. 6*d*. Supplement:—Difference Tables for each Five Years for the Extrapolation of Mean Values. (Official, No. 154, 1902.) 3*s*.

3. Instructions in the use of Instruments, &c.

Barometer Manual. (Official, No. 8, 1871.) [Out of print.]

Barometer Manual for the Use of Seamen. With an Appendix on the Thermometer, Hygrometer, and Hydrometer. Fourth Edition, extensively revised, 1902. (Official, No. 61.) 3*d*.

Fishery Barometer Manual. New Edition, 1887. (Official, No. 3.) 6*d*.

Instructions for Meteorological Telegraphy. New Edition, in preparation. (Official, No. 2.) Prepared for the use of Observers exclusively.

Instructions in the use of Meteorological Instruments. Reprinted 1892. (Official, No. 24.) [Out of print.]

Hints to Meteorological Observers in Tropical Africa, with Instructions for taking observations, and Notes on Methods of recording Lake Levels. (Official, No. 162, 1902.) 9*d*.

FORECASTING :—

Aids to the Study and Forecast of Weather.—By W. Clement Ley, M.A. (Official, No. 40, 1880.) 1*s*.

Principles of Forecasting by means of Weather Charts.—By the Hon. Ralph Abercromby, F.R.Met.Soc. Second Edition, Revised, 1885. (Official, No. 60.) [Out of print.]

4. Marine Meteorology.

CHARTS.—

Arabian Sea :—

Daily Weather Charts for the period of six weeks ending June 25, 1885, to illustrate the tracks of two cyclones in the Arabian Sea. (Official No. 80, 1891.) 10*s*.

Atlantic :—

Charts of Meteorological Data for the Nine 10° Squares of the Atlantic, which lie between 20° N. and 10° S., and extend from 10° to 40° W., with accompanying Remarks, ending with the Best Routes across the Equator. (Official, No. 27, 1876.) 24*s*.

Monthly Current Charts for the Atlantic Ocean. From Information collated and prepared in the Meteorological Office. Published by the Admiralty. (Official, No. 132, 1897.) 7*s*.

4. Marine Meteorology—*continued.*

CHARTS—*continued.*

Atlantic (North) :—

Charts of Meteorological Data for Square 3 Lat. 0°–10° N., Long. 20°–30° W., and Remarks to accompany the Monthly Charts, which show the Best Routes across the Equator for each Month, &c. (Official, No. 20, 1874.) 20*s*.

Charts illustrating the weather of the North Atlantic Ocean in the Winter of 1898–99. (Official, No. 142, 1901.) 6*s*. 6*d*.

Currents and Surface Temperature of the North Atlantic Ocean, from the Equator to Latitude 40° N., for each Month of the Year. With a General Current Chart. (Official, No. 12, 1872.) 2*s*. 6*d*.

Discussion of the Meteorology of that Part of the Atlantic lying North of 30° N., for the Eleven Days ending 8th February, 1870. With Charts. (Official, No. 13, 1872.) 5*s*.

Meteorology of the North Atlantic during August, 1873, with 31 Synoptic Charts. (Official, No. 32, 1878.) With Book of Charts. 15*s*.

Synchronous Weather Charts of the North Atlantic and the adjacent Continents, 1st August, 1882, to 3rd September, 1883. Parts I. to IV. (33 sheets each) (Official, No. 71, 1886.) 17*s*. each Part.

Atlantic (South) :—

Charts showing the Surface Temperature of the South Atlantic Ocean in each month of the year. (Official, No. 4, 1869.) 2*s*. 6*d*.

Wind Charts for the Coastal Regions of South America. From Information collated and prepared in the Meteorological Office. Published by the Admiralty. (Official, No. 159, 1902.) 7*s*.

Monthly Wind Charts of the South Atlantic. Published by the Admiralty. (Official, No. 168, 1903.) 6*d*. each.

The relation between Pressure, Temperature, and Air Circulation over the South Atlantic Ocean. (Official, No. 177, 1905.) 9*d*.

Atlantic, Indian, and Pacific Oceans :—

Charts showing the Surface Temperature of the Atlantic, Indian, and Pacific Oceans. (Official, No. 59, 1884.) 21*s*.

Charts showing the Mean Barometric Pressure over the Atlantic, Indian, and Pacific Oceans. (Official, No. 76, 1887.) 10*s*. 6*d*. Supplementary Chart, 6*d*.

Atlantic (North) and Mediterranean :—

Monthly Pilot Charts, commencing April, 1901. (Official, No. 149.) 6*d*. each ; subscription for one year, 5*s*. (exclusive of postage).

Indian Ocean :—

Monthly Current Charts for the Indian Ocean. From Information collated and prepared in the Meteorological Office. Published by the Admiralty. (Official. No. 124, 1896.) 7*s*.

Monthly Pilot Charts of the Indian Ocean. (Official No. 181.) In the press.

Indian Ocean (North) :—

Meteorological Charts of the portion of the Indian Ocean adjacent to Cape Guardafui and Ras Hafún. (Official, No. 92, 1891.) 6*s*.

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LIST OF PUBLICATIONS

Issued by the Meteorological Office.

4. Marine Meteorology—*continued.*

CHARTS—*continued.*

Indian Ocean (South) :—

Cyclone Tracks in the South Indian Ocean. From information compiled by Dr. Meldrum, C.M.G., F.R.S. (Official, No. 90, 1891.) 7*s.*

Meteorological Charts for the Ocean District adjacent to the Cape of Good Hope, with accompanying Remarks. (Official, No. 43, 1882.) Charts, 25*s.* Remarks, 7*s.*

Pacific Ocean :—

Quarterly Current Charts for the Pacific Ocean. From Information collated and prepared in the Meteorological Office. Published by the Admiralty. (Official, No. 134, 1897.) 5*s.*

Wind Charts for the Coastal Regions of South America. From Information collated and prepared in the Meteorological Office. Published by the Admiralty. (Official, No. 159, 1902.) 7*s.*

Red Sea :—

Meteorological Charts of the Red Sea. (Official, No. 106. 1895.) 21*s.*

Southern Ocean :—

Meteorological Charts of the Southern Ocean between the Cape of Good Hope and New Zealand. (Official, No. 123, 1899.) 12*s.*

OTHER PUBLICATIONS ON MARINE METEOROLOGY :—

Contributions to our Knowledge of the Meteorology of the Antarctic Regions. (Official, No. 18, 1873.) 2*s.*

Contributions to our Knowledge of the Meteorology of the Arctic Regions. (Official, No. 34, 1885.) Vol. I. : Part I., 2*s.* ; II., 10*s.* ; III. and V., 6*s.* each ; IV., 5*s.*

Contributions to our Knowledge of the Meteorology of Cape Horn and the West Coast of South America. (Official, No. 11, 1871.) 2*s.* 6*d.*

4. Marine Meteorology—*continued.*

OTHER PUBLICATIONS ON MARINE METEOROLOGY—*cont.*

Notes on the Form of Cyclones in the Southern Indian Ocean.—By C. Meldrum, M.A., F.R.S. (Non-Official, No. 7, 1873.) [Out of print.]

On the Physical Geography of the part of the Atlantic which lies between 20° N. and 10° S., and extends from 10° to 40° W. A Paper read before the British Association at Bristol, in August, 1875.—By Captain H. Toynbee, F.R.A.S. (Non-Official, No. 10, 1876.) [Out of print.]

On the Winds, &c. of the North Atlantic along the Tracks of Steamers from the Channel to New York. Translated from a Paper issued by the Deutsche Seewarte, Hamburg. (Non-Official, No. 5, 1872.) 6*d.*

Report to the Committee of the Meteorological Office on the Meteorology of the North Atlantic.—By Captain H. Toynbee, F.R.A.S. (Non-Official, No. 2, 1869.) 1*s.*

Report on the Gales experienced in the Ocean District adjacent to the Cape of Good Hope, between Lat. 30° and 50° S., and Long. 10° and 40° E.—By Captain H. Toynbee, F.R.A.S. (Official, No. 44, 1882.) 7*s.* 6*d.*

Routes for Steamers from Aden to the Straits of Sunda and back. Translated from a Paper issued by the R. Meteor. Inst. of the Netherlands. (Non-Official, No. 4, 1872.) [Out of print.]

5. Miscellaneous Publications.

Harmonic Analysis of Hourly Observations of Air Temperature and of Pressure at British Observatories. (Official, No. 93, 1891.) 12*s.*

Report of an Inquiry into the Connexion between Strong Winds and Barometrical Differences.—By Robert H. Scott. (Non-Official, No. 1, 1868.) 6*d.*

Report on the Storm of October 13–14, 1881.—By Robert H. Scott, F.R.S. (Official, No. 46, 1882.) 1*s.* 6*d.*

Report to the Committee of the Meteorological Office on the Use of Isobaric Curves.—By Captain H. Toynbee, F.R.A.S. (Non-Official, No. 3, 1869.) [Out of Print.]

Trajectories of Air in Travelling Storms. (Official, No. 174, 1905.) Part I. 7*s.* 6*d.*