CONGRESS OF SCANDINAVIAN GEOPHYSICISTS IN GOTHENBURG AUGUST 28-31, 1918.

By HANS PETTERSSON, General Secretary.

[Dated: Gothenburg, Nov. 27, 1918.]

At the invitation of Dr. G. Ekman, Prof. O. Nordenskjöld, Prof. O. Pettersson and other scientists of Gothenburg, Sweden, a highly representative congress of about 50 Danish, Norwegian, and Swedish geophysicists met in that city during the last days of August this year. Representatives from Finland had also been invited but were unable to be present.

At the opening meeting Prof. Hildebrandsson, of Upsala, was unanimously elected president, supported by three vice presidents, viz. Director Ryder (Denmark), Prof. Bjerknes (Norway), and Prof. Nordenskjöld (Sweden); General Secretary, Dr. Hans Pettersson.

Prof. Bjerknes, of Bergen, opened the first general meeting with a paper on weather forecasting, describing a new and most successful method of short-range prognostics for agricultural purposes established in western Norway during the summer 1918. [Published pp. —, —, of this REVIEW.]

During the following days meetings were held, partly general and partly by sections. In all, 30 papers were read, many of these of very great interest.

One afternoon was devoted to the aurora borealis phenomenon, a forenoon to prognostics, and the last afternoon was occupied by very animated discussions of future Scandinavian cooperation within different branches of the geophysical science.

Finally a number of resolutions were moved and adopted by the congress in pleno and a committee formed with the object of calling together a second congress in due time.

Abstracts of the papers read before the congress will shortly be published.

RESOLUTIONS ADOPTED BY CONGRESS.

I. In favor of an extension of the existing system of simultaneous photographic altitude measurements of the aurora borealis started by Prof. Störmer, to comprise the whole of Scandinavia during the winter 1918–19. (Moved by Prof. Störmer, of Christiania.)

II. In favor of the plan proposed by Prof. de Geer that measurements of the yearly deposits of loam occurring in lakes blocked by ice and in shallow bights, which derive from the melting of Scandinavian and arctic glaciers, should be carried out in connection with de Geer's *geochronological measurements of the annual* striæ in post Tertiary deposits of similar origin. (Moved by Prof. de Geer.)

III. In favor of establishing a system of continuous synoptic observations of the internal movements in the sea round the coasts of Scandinavia compared with simultaneous meteorological phenomena and fishery statistics. (Moved by Dr. Hans Pettersson (Sweden) and others.) [See Dr. Pettersson's paper on this subject on pp. 100–105 of this REVIEW.]

IV. In favor of the establishing of aerological observations in different parts of Scandinavia. (Moved by Prof. Hesselberg, Christiania.)

V. Emphasizing the need for cooperation between the geophysicists of the Scandinavian countries, both with regard to laboratory and field research, which proposal the Governments of these countries are requested to facilitate as much as possible.

VI. In favor of the project drafted by O. Pettersson that a first-class scientific institute shall be established in Gothenburg for oceanography, marine meteorology, and aerology with the object of studying the dynamics of the movements occurring in the atmosphere and the sea, which determine the climate and the weather of the Scandinavian countries, and of studying the influence of these factors on agriculture, fisheries, navigation, and aeronautics. (Moved by O. Pettersson and seconded by 10 representatives for Denmark, Sweden, and Norway.

WEATHER FORECASTING.

By Prof. V. BJERKNES.

[Address delivered at the meeting of Scandinavian geophysicists at Gothenburg, Aug. 28, 1918.]

It is possible that more than one solution may be found to the problem of satisfactory and practical weather forecasting. It is also possible that among these we may be able to find methods which obviate the necessity of a complete understanding of the phenomenon whose development we are to forecast. Personally, I have no interest in such methods. I am interested in only that method which is based upon a full understanding of the phenomena involved.

Even if this method is difficult, we have at any rate a safe guide. The leading idea is the following: All atmospheric processes obey the laws of physics, first of all those of mechanics and thermodynamics. We are, therefore, really in possession of all the theoretical knowledge necessary to determine future weather. It resides in the equations of mechanics and thermodynamics, or more generally expressed, in the equations of physics. These contain the answer to all questions about the future weather, if only the observations can give us the concrete data with which we are to deal.* The problem of determining the future weather may therefore be reduced to the solution of two special problems:

1. The practical, the obtaining of the necessary concrete data through observation.

2. The theoretical, the evolving of the methods whereby the knowledge contained in the equations can be applied to the observations.

If we state the problem in its most precise form, as a mathematical problem, we can not hope to solve it in the near future. But if we put it into a more practical form, we will then see that the line of progress lies in the continuation of the methods which the meteorologists followed when they began the study of atmospheric processes by drawing synoptical maps, from which they found the baric wind law [Buys Ballot's law], etc. We therefore need not doubt that in this way we will arrive at results which will give us a better understanding, and which will thus react upon meteorological practice.

To a certain extent this has already been confirmed. But the idea of engaging myself in meteorological practice was unthought of, even a few months ago. When, however, the critical time came, when duty demanded

*The effects due to discontinuities in the amount of the atmosphere due to evaporation and condensation are necessarily included.—W. J. H.

our best service in the aid of agriculture, I doubted my right to hold back any longer. From the point of view of my theoretical work it was not yet feasible to take such a step; and the conditions of the start were as unfavorable as possible. It concerned the weather forecasts in the west of Norway, where even in time of peace we had not yet tried the problem, and where now in time of war there is lacking even that which, judging from all our meteorological experience, ought to be the most important, namely weather telegrams from the west—from the the British Isles, the Faroe Isles, and Iceland.

That which gave me hope, however, was some of our newest results. When we wish to proceed rigorously in the theoretical way an unavoidable demand is that we take into account all the variables upon which the solution of the problem is based. A variable which can no longer be kept in the background as before is the wind. Among meteorologists it has not yet reached a synoptical representation. This representation is now given by maps of the lines of flow and of the strength of the wind.[1] These maps present a series of interesting peculiarities, which had to be discussed. Very conspicuous were what we now call the lines of convergence and of divergence, i. e., lines *to which the wind blows in* from both sides, or lines *from which the wind blows out* on both sides. They had been found already on the first maps of this kind, which were drawn at Stockholm at the beginning of this century by J. W. Sandström, who was my assistant at that time. Since then they have been increasingly the object of our attention, particularly of late, after one of my collaborators had succeeded in deducing the law of their propagation as a consequence of the general law of the formation of vortices.[2] In a qualitative form the law reads simply: A line of convergence will always move to the right, a line of divergence always to the left, of an observer who looks along the line in the direction of the wind. Further, the velocity of propagation may, for the main term, be determined by measuring the "divergence" and the "curl" in the nearest surroundings of the lines.

To test these results, observations from a very close net of stations had to be prepared. Observations were therefore gathered from the second and third class climatological stations in the Scandinavian countries, from the light-keepers' journals, etc. The maps confirmed the law with as great an accuracy as it was possible to obtain, though not sufficient for a sharp quanitative test. But, on the other hand, they showed with full sharpness an important empiric law, viz, there belong to every cyclone which is not stationary but in motion two characteristic lines of convergence. (See figure 1*). They both come in from the right side of the path of the cyclone. The one runs almost normal. But the other one always clings nearer to the path of the cyclone the nearer it comes to the cyclonic center, and in the center itself it seems to have the same line as the path. If we, therefore, have a sufficient number of observations to be able to draw this line right into the center of the cyclone, then it will show us the momentary direction of propagation of the cyclone. For this reason we may call it the cyclone's *steering line*. At the same time it ought to be possible on a sufficiently accurate map, by simple measurements near the one or the other of the two lines, to decide at what speed the cyclone is proceeding in the direction which is thus found.

The importance of the two lines of convergence will be still more conspicuous when we look upon their thermal properties. It has been found that the warm air, which is carried to the cyclone and imparts the energy* flows in the sector between the two lines. Under the propagation of the cyclonic system, the steering line will therefore mark the front of a warm wave, and the other line of convergence the front of a cold wave.

This involves also very important meteorological properties. The cold wave, which is, as a rule, marked out sharper than the warm, is followed by violent rain. This falls from the warm air which is raised by the advancing cold wedge of air. It often appears as thundershowers with violent gusts of wind, and in reality this line of convergence is identical with that squall line which we have long known as a frequent follower of cyclones. Also the steering line is associated with rain, at any rate, sufficiently near the cyclone center. But this rain is not in the form of violent showers. It comes not only after the line but also up to 200 km. or more before the line. This

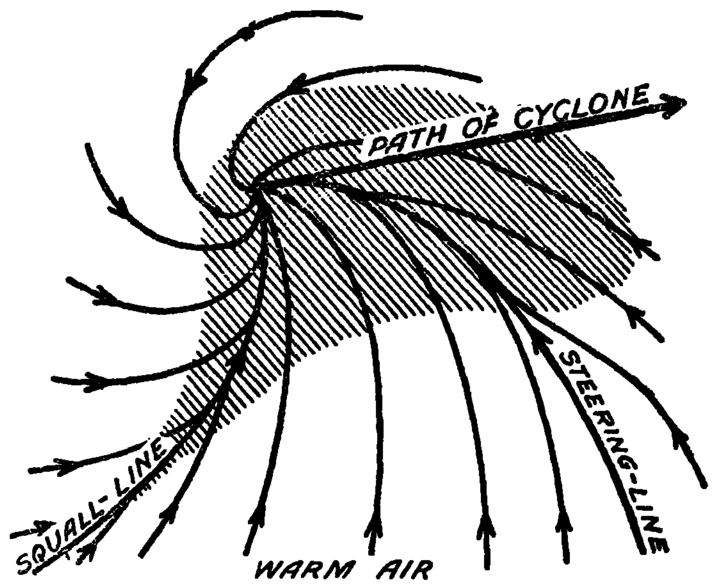

FIG. 1. Cyclone.

rain before the line comes from the warm air which glides up along that inclined plane which borders the underlying cold wedge of air, which is swept away during the forward movement of the cyclonic system.

Evidently we are here at the beginning of a cyclone theory which may be based on real knowledge of the phenomena.

But it is a practical view of the matter that interests us to-day. It is perfectly evident that these results will prove useful for weather forecasting within an extended area, where we get the entire cyclone with both its antennas on the map. But we are not able to try this free application on maps which have normal extension until after the war. It now concerns the application on a small scale, to western Norway, whose weather chiefly is governed by cyclones which pass outside the territory covered by our observations. The question is, have we not, in the identification of the passing cyclones' con-

[1] Cf. V. Bjerknes: Dynamic Meteorology and Hydrography, Vol. II, Kinematic, Washington, 1913.
[2] J. Bjerknes: Ueber die Fortbewegung des Konvergenz- und Divergenzlinien. Meteorologische Zeitschrift, 1917, p. 345.
* Cf. Shaw, Manual, pt. IV, p. 108, etc.—W. J. H.

* Not all of it.—*Ed.*

vergence lines, a new important means of supporting the forecasts under the present difficult conditions?

To serve the preliminary investigations hereof, we got weather reports from the signal stations of the navy district of Bergen. The results proved encouraging, and we went on. The Government granted the necessary means, and by and by the net of stations as shown on figure 2 was erected. It is seen to be a considerably closer net than any hitherto used for weather-forecasting. This is essential if we are to be able to discover and identify the lines of convergence with full accuracy. And it is a step toward the fulfilment of the theoretical demand, that a continuous image of the state of the atmosphere should form the base. An important feature is the double series of barometer stations, one on the islands farthest out to sea, and one at the heads of the fjords. Between them we have a great number of other

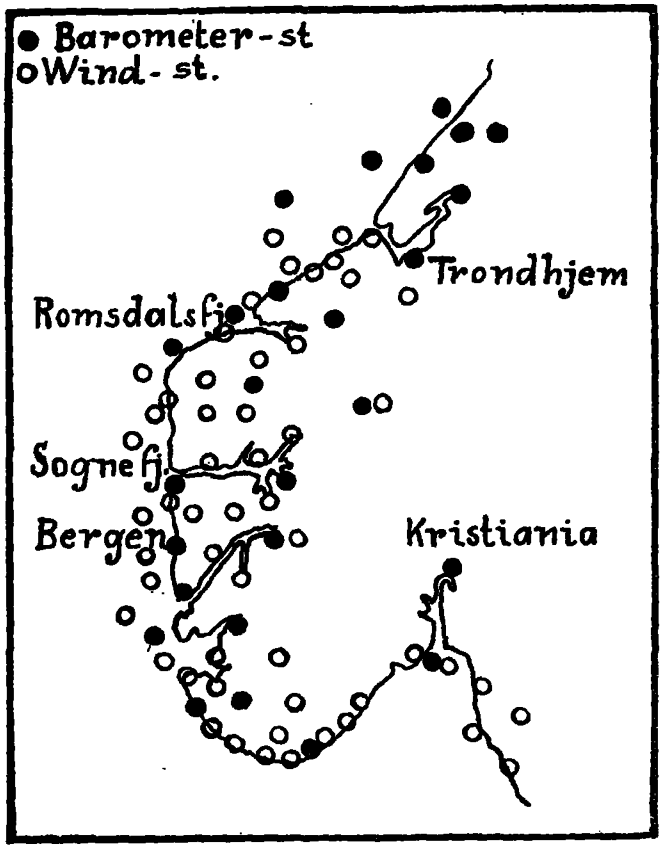

FIG. 2.—Meteorological stations.

stations observing wind and weather without the use of instruments. On the outer islands the direction of the wind is taken very exactly by azimuth dials.

As the stations can never be too numerous, our observers are instructed to give as complete information as possible, not only of the state of the atmosphere at the place itself, but even in its surroundings. Our common instruments, barometer, thermometer, etc., can only give the measured quantities in one single point. But observations of what we call weather, permit more complete communications. Our observers have accordingly been instructed to report not only rain at the place, but even rain falling within sight, and the region of the sky where it is seen. Further, they specify the cover of clouds, not only in accordance with the common climatological rules, but add also the region of the sky where the clouds or the different forms of cloud appear. If the whole sky is completely covered, except for a narrow clear stripe on the horizon, the direction where this clear line is seen is reported. In case of a completely free horizon the cirrus clouds are seen at a distance of more than three hundred kilometers, and lower clouds at correspondingly shorter, but still at considerable distances. It is therefore quite possible to arrange a set of stations which will be able to give complete reports of the appearance of the sky over the whole region of observations.

These data concerning the appearance of the sky are of special importance from the stations at the edge of the sea. Here the observations have to be extended as far as possible into the inaccessible regions. But then the question is: What is to be looked for farthest away on the horizon? If the sky is covered at the station, it is evident that if a clear stripe is seen far away on the sea margin the report of this clear stripe will be most important. But we are more puzzled as to what should be reported on clear days. In order to get hints, I have visited most of our coast stations and talked with the people. It is well known that in many cases fishermen and seamen can predict coming weather with great accuracy. I have asked them concerning the signs which they use. It is not easy to come to the bottom of the matter. Evidently a complex of small signs is intermixed with much superstition. But now and then some safe hints have been received.

When a storm is brewing, a dark stripe is generally seen on the horizon. A pilot at Lindesnäs gave me the characteristic information that when this dark stripe approached from southwest, the rain would come with a southeast wind. After this, I could no more be in doubt concerning the character of the stripe. It must be formed by high clouds marking either the cyclone itself or one of its lines of convergence. These will, when they approach from southwest, give wind from southeast as soon as they have arrived. These results having been obtained, a number of coast stations were instructed to report "brewing up" when these signs were seen. The reports proved useful and should soon lead to further progress.

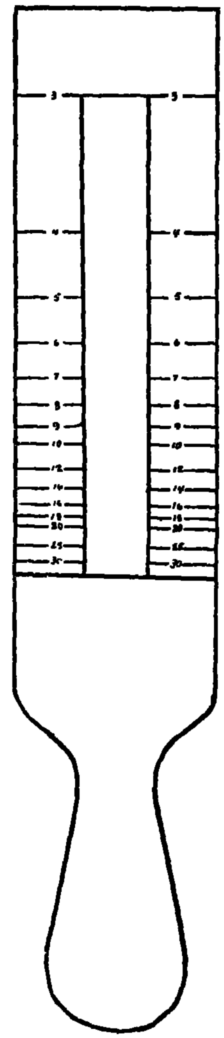

FIG. 3.—Distance measurer.

Naturally we must proceed carefully. Our observers have no scientific education, and, ignorant of the aspect of the phenomenon, we do not know which observations are worth while. As, however, on a later occasion, I heard the watchman at one of our stations state simply in degrees the height which the edge of the stripe might have been above the horizon, the next step was given. If the edge of the stripe is sharp enough to be spoken of in this way, it must be possible to determine the distance of the storm. *We know that the cirrus* clouds, which, seen from the side, form the stripe, have a height of about 10,000 meters above sea level. Their distance from the observer will then be obtained from their apparent height above the horizon. The result was the construction of the distance measurer shown in figure 3. It is to be kept 50 centimeters from the eye, so that the lowest divisional line is seen against the horizon. The figure at the divisional line coinciding with the edge of the stripe will then give the distance of the storm. If from time to time we take the azimuth of the bank of clouds, and determine the distance, it must be possible to determine approximately the course of the storm, and also if it will reach a given place, and when.

The instrument is now being distributed among the coast stations, and reports on the situation of banks of storm clouds have already often proved useful. On the other hand, more complete reports, which might give the course and speed of the storm, have not yet been received.

But no matter how far we can look in this way into inaccessible regions, forecasts for an outpost district such as the west coast of Norway will remain precarious. The equation will determine the future state at any time, in every point of the atmosphere, only on condition that in addition to the exterior conditions, we know the initial state of the entire atmosphere. And the more limited is the region for which the initial state is known, the more limited will also be not only the district for which rational forecasts can be made, but even the period in which they will remain valid. A cyclone situated so far off that its bank of clouds can not be observed can very well reach the coast in 6 to 8 hours. This entails an important restriction: The forecasts can be issued for a very limited period only. We have chosen the shortest period which can still be of use: Based upon the observations made at 8 o'clock in the morning, forecasts are issued for the rest of the day, and even this will in some cases be beyond permissible limits.

I shall give a few examples of charts of lines of flow, which, in connection with the corresponding charts of pressure, temperature, tendency of barometer, etc., have been used for the forecasts.

A very instructive case occurred on August 14 and 15, in the morning. On the morning of the 14th rain was reported from the west coast north of Bergen. At the same time was reported a "brewing up" 180 km. west of a station on the Romsdal coast. This observation proved a considerable extension of the district of rain to the north on the sea. The barometer was falling rapidly on the west coast, more slowly at the coast of Romsdal. This seemed to indicate a cyclone taking the course southward along the coast. The circumstance that neither of the two lines of convergence could be identified seemed to point in the same direction, as lines of this kind are not to be found on the left side of the path of a cyclonic track.

The midday charts for the same day, fig. 4, show a slow fall of the barometer at the coast of Romsdal, but a very rapid fall on the west coast. This seems still to point toward a movement of the low pressure southward. But now the chart of wind shows a marked line of convergence that reaches land on the coast of Romsdal. Temperature is two or three degrees higher behind this line than in front of it. Consequently it is without doubt the steering line. And to judge from the situation of this line the cyclone should go toward the east, not toward the south. Thus the signs seem to be contradictory, and the question is which of the two signs are we to believe.

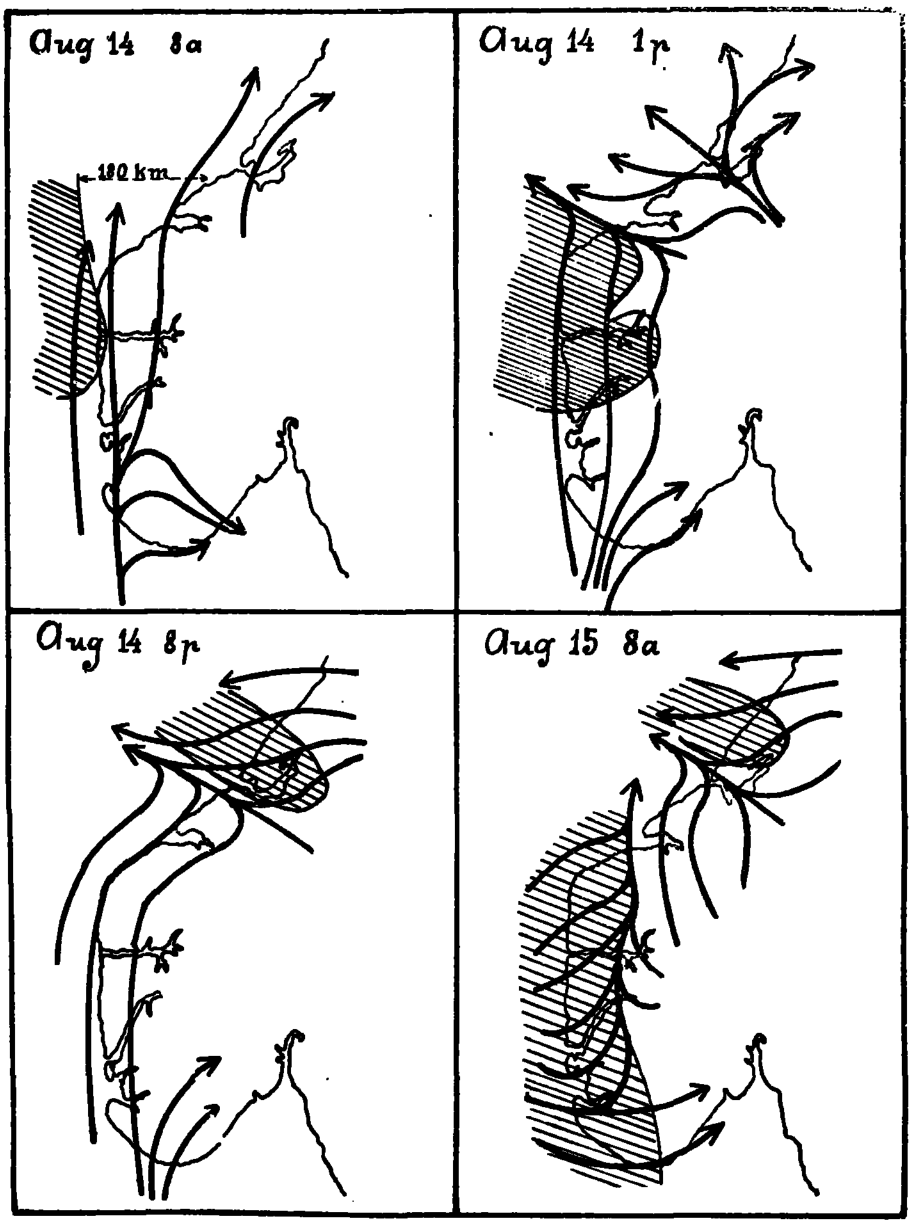

FIG. 4.—Lines of wind flow and rain areas, Aug. 14-15, 1918.

The evening chart shows that the steering line has moved considerably toward the east. At the same time its character as a steering line is further marked by rain from the inclined plane in front of it. Meanwhile the fall of the barometer has again been more rapid on the west coast than on the Romsdal coast. The barograph at Bergen shows a very sharp fall. This seems to indicate that the cyclone will take the course toward the south. Are we now to place our confidence in the fall of the barometer or are we to think that the cyclone will follow its steering line?

The morning chart for the next day gives the answer: The steering line has continued its propagation undisturbed toward the east, and now it has been followed by a squall line also, which has reached the west coast. The strange fall of the barometer on the stations of this coast has been the consequence of the propagation of this line toward the east, not of any propagation of the cyclone toward the south. As soon as the line had passed, the barometer also ceased to fall on the west coast but the fall continued on the Romsdal coast. The two lines of convergence now allow us to take a bearing of the cyclone on the sea. The lines are situated typically as on the schematic figure, the steering line with the region of rain in front of it, the squall line with the region of rain behind it. The air is cold in front of the steering line and behind the squall line, but warm in the sector between the two lines. The circumstance that all rain has ceased in this sector is evidently due to a foehn effect, the air current here coming down the mountains.

On the next day the cyclone has continued its movement towards the east to the coast north of Trondhjem. Here it has subsided and meanwhile a new cyclone has been formed on the Swedish side of the mountains. This seems to be the ordinary way in which the cyclones pass across a chain of mountains.

During the time the cyclone has been pressing against the west and the Romsdal coast, the weather has been dry in eastern Norway, with some rain only in the upper valleys underneath the range of mountains. The weather has probably also been generally dry in middle and southern Sweden and in Denmark. I do not know the forecasts of the Swedish and Danish meteorologists for these days. But it would not be surprising if led by the tendency of barometers on the Norwegian coast, they had predicted rain in all districts. The meteorologists in Christiania at all events fell into the trap. The tragic reason was that many of the midday telegrams from the coast of Romsdal were delayed so much that the true chart of wind, containing the obvious line of convergence, did not yet exist at the time when the Central in Bergen sent its report to Christiania concerning the situation. The forecast for eastern Norway had therefore to be founded upon the fall of the barometers, and concluded with rain over the whole district, except in the upper valleys, exactly the opposite of what happened.

Not least through this erroneous forecast, we are led to strongly accentuate:

I. The importance of a sharp watch on the Norwegian coast, not only for the benefit of the forecasts there, but as much for the forecasts in eastern Norway and the whole of northern Europe.

II. The importance of a close net of stations, which alone makes it possible to identify the two characteristic lines of convergence of the cyclones.

III. The importance of these two lines, the steering line and squall line, *by which the cyclone itself indicates its course.*

The experience of this summer has more than sufficiently shown us to what high degree our weather is controlled by the lines of convergence, which sweep over the country during the passing of the cyclones. I will supplement the preceding example with a simpler one.

On the morning of July 18 rain was reported from the southwest coast and a falling barometer on both sides of the southern point of the country. The chart of wind, figure 5, shows that a line of convergence has landed, and the fall of temperature characterized this as a squall line. The steering line could then point only to the north, parallel to the coast, and the unknown cyclone then had to move this way. The forecast was given with the empiric knowledge of the velocity of propagation of the squall line: More rain for the southern districts, rain soon for the next northern districts, rain after midday in the districts north of Sognefjord. The chart for 1 p. m. shows that the rain had reached the mouth of this fjord, and it continued northward during the afternoon. Later on I happened to visit a place where either this or another forecast of the same character had been useful. Alarmed by the forecast, the peasants began, in spite of the bright weather, to fetch in the hay even in the forenoon, and just in time, as they afterwards saw.

Such forecasts having the time of the occurrence of rain clearly indicated, have, of course, been issued only on rare occasions, but when given they have been successful. Considering the system of weather forecasting, which has in this way been improvised for western Norway, its results as a whole have, in spite of all difficulties, been *surprisingly satisfactory.* A verification, worked out by

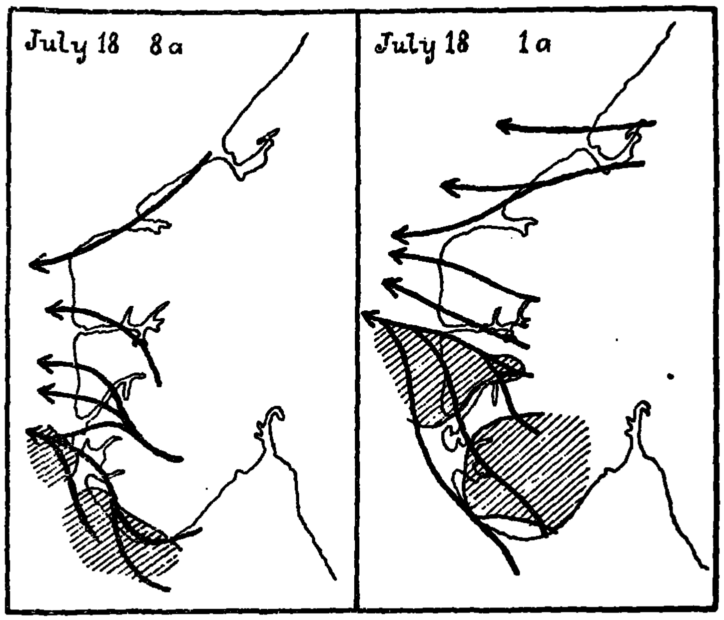

Fig. 5.—Lines of wind flow and rain areas on July 18, 1918.

comparing the forecasts with the midday and evening reports, gives for the first month of the forecasts, namely, July, the following percentage of hits for the eight different districts from the south point of the country to the districts north of Trondhjem: 81.3, 79.2, 77.1, 93.6, 86.4, 79.5, 88.7, 84.0.

An essential reason why the results for the three southern districts have turned out less favorable than for the others, is that in most cases they had to be issued before the arrival of the Danish telegrams. The average per cent of hits is 83.7. Although the results thus have proved satisfactory, owing to the war we must work for the present, as it were, with blinded eyes; nevertheless, we have every reason to expect that in the future the area from which the observations are obtained will be restored to its former extent.

The system, however, has certain failings which can not be remedied even by this extension. The smaller the cyclones the more difficult it is to make forecasts of them. Diminutive cyclones are very frequent. Formerly they slipped undiscovered through the wide meshes of the old net of observations. With our close net of stations we can, to a certain extent, follow and forecast them, and the closer becomes the network the farther we can advance. But at last the limit of what is obtainable is reached. We can not make it close enough to predict every local rain shower. There is, however, one way open by which the system can be completed, and this way I hope will be tried by next summer.

A similar view of the sky, only still more extensive than from the coast, can be obtained from favorably situated mountains. Everyone who has traveled in the mountains knows that we can see wandering rain showers at a great distance. The question is then to find practical methods by which their tracks can be determined, just as the course of distant banks of storm clouds are found from the coast stations. Now, if we study the view from the top of a mountain by the use of good charts, we can identify a great number of points on the ground, such as summits, ridges of mountains, rivers, lakes, towns, villages, and churches, etc. The chart can be especially prepared for the purpose by marking all the characteristic lines and points we are able to see and hatching the regions, which can not be seen. Then when the showers of rain advance the observer will be able to draw on the chart the part of the front line of the shower which is turned to him. By drawing this line from hour to hour he will see how the shower develops and propagates, which districts are being threatened, and when the rain will reach them. The observer will then not only be able to give valuable information to the central offices but he can also send forecasts direct to the threatened districts. From a comparatively small number of mountain stations, which cooperate and supplement each other, it must, in this way, be possible to organize a system of forecasting local showers for the greater part of the country.

Addendum, October, 1918.—For the same eight districts as above, the percentage of verifications for the months of August and September have been the following: August, 85.1, 77.7, 83.3, 79.5, 85.1, 92.4, 90.7, 96.3; September 94.0, 94.0, 92.0, 96.0, 90.0, 94.0, 88.0, 88.0.

The average percentage of verification has thus been for the three summer months: July 83.7, August 86.3, September 92. The decided progress at the end is due above all to the experience from August 14 and 15, as from this date the forecasts have, in dubious cases, been based with increased confidence upon the steering line.

ON THE STRUCTURE OF MOVING CYCLONES.

By J. BJERKNES.

[Dated: Bergen, October, 1918.]

When the equations of hydrodynamics are to be applied directly to concrete atmospheric motions, two conditions should be fulfilled: The distances between the stations giving the observations should be small enough to be considered as differentials of space, and the time intervals between the successive periods of observation should be small enough to be considered as differentials of time. Neither of these conditions is fulfilled by the observations available from daily weather maps and printed in yearbooks. Distances amounting to hundreds of kilometers and time intervals of six hours are too great.

In order to get at least the first of these conditions fulfilled, to some degree at least, I have collected detailed data from the archives of the meteorological institutes in Norway, Sweden, and Denmark, including observations from third-class stations. In addition I have examined the comparatively very detailed daily maps used for weather forecasting in western Norway during the summer of 1918, and combined them with the simultaneous study of the sky.

In this way I have been led to some general results concerning the structure of cyclones, which I shall outline in this paper, and shall consider in detail later.

THE STEERING LINE AND THE SQUALL LINE.

The lines of flow in a cyclone have approximately the character of logarithmic spirals. By increasing the number of observations, however, several deviations from the regular spiral shape appear. Among a multitude of details, certain characteristic traits seem to recur more or less markedly in all cyclones yet examined.

Every cyclone that is not stationary has two lines of convergence, which are greater and more conspicuous than any others, and are distinguished by characteristic thermal properties, as shown in figure 1.

The first of these lines comes in to the center from the front of the cyclone, lying in its entire extent on the right side of its path. The tangent to the line at its terminus in the cyclonic center seems to be identical with the path of the latter. As the line is thus giving the momentary direction of propagation of the cyclone, it may, with propriety, be called the *steering line.*

The other line of convergence comes in from the right rear of the cyclone, and is identical with the well-known *squall line*, which accompanies cyclones.

The steering line and the squall line are intimately related to the distribution of temperature, as they border

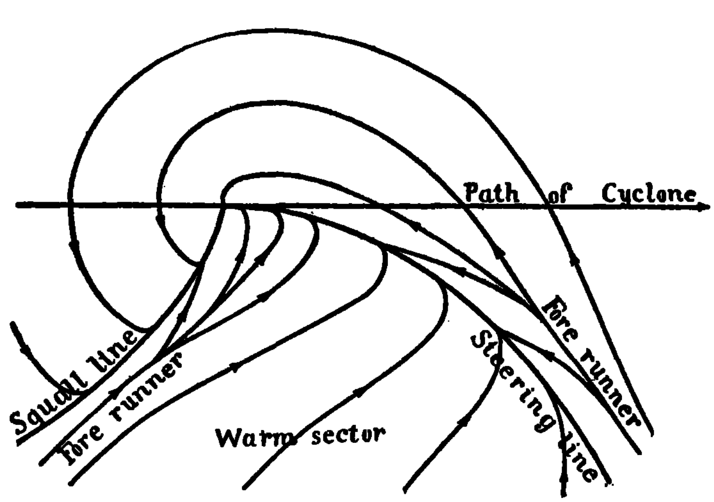

FIG. 1.—Lines of flow in a moving cyclone.

the warm area of the cyclone, or, as we may call it, its "warm sector."

Both the steering line and the squall line move according to the law of propagation for lines of convergence,[1] viz, in the northern hemisphere toward the right, relatively to the direction of the wind along the

[1] J. Bjerknes: "Über die Fortbewegung der Konvergenz- und Divergenzlinien." Meteorologische Zeitschrift 1917, 10/11.