A KINEMATIC-GRAPHICAL METHOD FOR THE 24 HOUR PROGNOSIS OF THE 500-MB CHART

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ABSTRACT

A quantitative technique for the 24-hour prognosis using kinematic principles with graphical methods is described at hand of eight models. An example of an actual forecast made is added.

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The analysis of surface charts over nearly 100 years has taught us that the variety of synoptic situations is never ending, and that these situations can take the most surprising turns inside of twenty-four hours. In spite of extensive development and improvement of net and quality of observations, and in spite of many theoretical and synoptic studies, the short-term prognosis based on the surface charts alone has not led to results which are even approximately satisfactory. In the past two decades, forecasters have drawn more and more on current upper air charts, most recently hemisphere charts, to assist in the surface prognosis, since the upper layers exert marked control on the low levels. Evidently, this approach would be more satisfactory if methods are developed that predict the upper flow independent of any surface considerations, so that both current and prognostic upper air charts are available for aid in the surface prognosis. Here it is not just a question of displacing prognostically a certain wave structure. It is of special importance to predict concentrations of the contour lines and areas with weak gradients, since those properties of the upper wind field are closely linked to predictions of development and motion of the surface pressure disturbances. This article has the objective of presenting such a method.

The problem of predicting of the upper contour field, even for 24 hours, is not an easy one. It has been attacked in various ways, all qualitative or semi-qualitative, and none sufficiently satisfactory to have found general acceptance in forecast offices. The prediction of the upper height field must be completed with <u>sufficient speed</u> so that it is completed when the time for prediction of the surface pressure field arrives. In general, one hour at most is available for the upper prognosis, usually less. This is a nearly insuperable obstacle for all methods which have a theoretical basis and which attempt, given initial or boundary conditions, to predict the upper pressure field by integration. Methods that utilize high speed computing machines, now in the research stages, are to be excluded from this comment. All other

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techniques with theoretical background work with models, thus neglecting factors that are more or less important. Their results are applicable only in cases in which the influence of these factors really remains insignificant.

The procedure to be described here will yield a prognosis for one-half to two-thirds of the hemisphere and covering latitudes 20° to 75° in not more than one hour. If subprofessional personnel is available to assist the forecaster, the time required can be reduced materially. Essentially, the technique consists of a routine of kinematic extrapolation. As will be seen, however, it also predicts the very important changes of contour configuration aloft, and the deepening and filling of troughs and ridges. Further, it yields the weakening and disappearance of pressure centers and it suggests, though it does not actually predict, whether centers will deepen or new centers form.

Operation with kinematic methods on weather charts of course is an old tool. Most well known is the system of Petterssen (1940). The present paper applies the kinematic principles with a graphical technique designed to yield in the end a complete quantitative prognosis of the whole upper contour field except for the appearance of new contours.

It is the opinion of the author that the method produces good results for the short-term prognosis (not exceeding 24 hours) of the upper height charts. He formed this opinion during his stay at the Department of Meteorology, University of Chicago, when he participated as guest in an advanced course in forecasting offered under the direction of Professor Herbert Riehl in Autumn, 1951 at the Chicago Forecast Center of the United States Weather Bureau. On the basis of former experiments he constructed daily 24-hour prognoses at 500 mb over a period of two months. These prognoses were judged to be satisfactory by most of the large group of experienced forecasters present.

Outline of the routine: (1) It is necessary to have available 500-mb analyses that are drawn very carefully and maintain excellent continuity. Otherwise the computations cannot succeed. The region analyzed must extend far outside of the forecast area, in middle latitudes mainly toward the west. For prognoses of the United States, the analysis must cover the Pacific to 180°, as well as Canada and Alaska.

(2) Three successive 500-mb charts, 24 hours apart, are used. Generally, this is better than successive 12-hour charts. In view of the uncertainty of placing characteristic features such as troughlines in an open network, the 24-hour displacements are more reliable than the 12-hour displacements.

(3) All three charts are combined into a single chart on a light table. The contours of each time period are drawn in different colors, blue for 48 hours ago, red for 24 hours ago and green for the current map. In order to avoid an excessive tangle of lines on the working chart, it is recommended to prepare several such charts that contain only two contour lines for each period. At 500 mb, for instance, if 400-foot contours are drawn, we treat separately the 19,200 and 18,800 foot lines, the 18,400 and 18,000 foot lines, etc. The separate prognoses obtained must be reconciled at the end. For the sake of clarity, it may also be convenient to enter one set of contours -- say the 18,400 contours -- with solid lines and the 18,000 foot contours with dashed lines. This whole step can be handled by subprofessionals.

(4) We displace the characteristic features of each contour line. Such features are intersections of trough and ridge lines, closed centers, intersections of equal contour values on successive days, and auxiliary quantities to be described. We include simple calculations of the acceleration.

The use of three days is important. Only three continual positions of a significant point permit a reliable estimate of the fourth position. In addition, at least three positions are requisite to determine the accelerations. It is of interest that the use of two 24-hour intervals for the computation of acceleration in general does not produce serious errors, contrary to what one might expect. Occasionally, however, strong accelerations develop within the 24-hours prior to forecast time. These the method cannot notice and forecasters therefore are advised to inspect the last 12-hourly chart as an additional aid.

It is important to treat each contour line by itself. Only in this way is it possible to obtain a correct picture of the details of the future height chart. For instance a short wave trough may be present on one day in two certain contour lines. On the following day, it shows up in the two next higher or lower contour lines, while those of the first day assume the opposite curvature of a ridge. Also the formation of the so-called cut-off lows where closed contours are formed in the south can only be noticed by following each contour alone.

Extension of the computations beyond 24 hours is not advisable. The acceleration terms augment rapidly with time and cannot be extrapolated linearly. Errors, unimportant in the 24-hour prognosis, multiply many times in the extrapolation to 48 hours and can produce out-of-phase relations between predicted and observed charts.

Finally, a comment on verification. A small deviation of predicted from observed 500-mb chart should not rate as a failure when simply a slight increase or weakening of the amplitude of the wave is involved. Out-of-phase prognoses, of course, are errors. Absences of contour divergences and convergences as well as the lack of strong concentrations or regions with weak concentration must be evaluated as very poor verifications, and their correct prediction must be rated as greatly to the forecaster's credit.

In the following we shall now illustrate the method with several models. It is not possible to cover in detail the whole multiplicity of situations that can occur and give examples for each. Only the more general aspects of the method can be illustrated and a forecaster must expect to acquire considerable experience before he can make successful predictions in the time interval available for the 500-mb prognosis in practice.

Models: Figure 1 shows the linear displacement of a wave. The trough and ridge lines on two contour lines are numbered 1, 2 and 3 for the three successive days. Extrapolation of these intersection points is linear and without acceleration. Two prognostic ridge points and two prognostic trough points result. In this case it is easy to find the new form of the wave by simple sinusoidal connection of trough and ridge points since all intermediate points move the same distance. The wave does not change shape and the trough and ridge lines remain oriented north-south.

In figure 2 we still see non-accelerated motion of trough and ridge points and the trough and ridge lines remain oriented north-south. The extrapolation, however, does not follow straight and parallel lines, but curved and non-parallel lines. We observe that the amplitude of the whole pattern has been increasing with time. In view of the inverse curvature of the extrapolation lines at troughs and ridges, this increase is about to terminate.

In figure 3 we add the complication that the two trough points and the two ridge points do not move in the same direction but diverge. The motion of the points is still without acceleration and the north-south orientation of troughs and ridges is maintained. Comparison of the distances D on the first day with the distances D' on the prognostic day shows that the contour gradient has weakened greatly and more so in the ridge than in the trough.

Figure 4 shows a difficult case. All trough and ridge points move differently and they are retarded at varying rates so that the trough and ridge lines rotate and at the end tilt in different directions. We again draw curves combining points 1, 2 and 3, and the prognostic points P will lie on the extrapolation of these lines as smooth curves. But now we must compute the distance by which the trough and ridge lines move along these curves. We define the acceleration as the percent increase or reduction of distance travelled per day. It is this percentage which we consider as a constant, not the actual reduction of distance travelled. For instance, the upper ridge point moves 22 length units (arbitrary) from 1 to 2, and 16 units from 2 to 3. This second distance is 73% of the first and we say that the distance from 3 to P will be 73% of 16 units, i.e., 12 units. We measure this amount downstream from 3 on the extrapolation line to arrive at the location of P. We next proceed in this way with each intersection between trough and ridge lines and the contours. As already mentioned, the prognostic trough and ridge lines are no longer oriented north-south but take on varying tilts even though on the three previous days their axis was north-south in figure 4.

As an aid in the construction of the complicated pattern, we now connect the intersection points of the contour lines on two successive days, i.e. the points A and B of zero 24-hour height change. We then determine approximately where points C -- the points of prognostic 24-hour zero height change -- will lie. This yields four additional points in determining the shape of the prognostic contours.

Figure 5 treats the development of troughs and ridges. At first, the contour is straight. After one day a trough has formed and it intensifies during the second day. We connect points 2 and 3 and extend the curve backward from 2 until it becomes tangent to the initial straight contour. This yields the auxiliary point 1'. Now we extend the extrapolation curve downstream and locate P with a calculation of the acceleration as before. The trough line is drawn normal to the extrapolation curve and thus rotates clockwise.

In order to draw the contours we connect the points A and B which, as in Example 4, represent points of zero 24-hour height change. Projection of this line to the contour of the current day yields point C -- a point where the height change will be zero during the next 24 hours.

We also wish to find a point ahead of the trough line. For this purpose we draw lines H_1 and H_2 parallel to the troughlines at points B and C. We extend H_1 to the straight contour of the first day and H_2 to the contour of the second day. These distances therefore measure how far the contour has shifted southward ahead of the trough.

In order to locate Hp and the desired prognostic point D, we must know the length of Hp and where it is to be put. H_1 = 17 units, H_2 = 32 units, an increase of 15 units or 88%. Again holding this percentage constant, the length of Hp = 60 units. To find the location of Hp we now draw h_1 perpendicular from H_1 to the corresponding troughline, and we draw h_2 in the same way. The length h_1 = 15 units, h_2 = 17 units, an increase of 13%. Herewith h_3 = 19 units. We draw Hp parallel to the prognostic troughline at a distance of 19 units from the troughline. Measuring 60 units from the intersection with the current contour we locate the prognostic point D.

If the reader turns the page around, he will see a corresponding ridge forecast.

Figure 6 shows the displacement of a contour line with two troughs without intermediate ridge. We determine the prognostic points P as before but again require the auxiliary distances H to draw the connection between the points P correctly.

Figure 7 shows schematically the development of a cut-off low. Given a strong bulging of a contour line, as seen on the third day, we draw the dashed line passing through the auxiliary point 3' in order to arrive at the prognostic points P.

The last example in figure 8 which illustrates the filling of a trough formed by no less than three isobars on the first day. Only one closed contour remains on the second day and it disappears on the third day. This model also indicates how to predict the disappearance of a closed center, for instance if the points 2 represented the current situation and points 3 the prognosis.

Map example: We shall now present the 500-mb prognosis actually made for December 14, 1951, 0300Z. Figure 9 is the work chart for the contours 76[1], 68 and 60, figure 10 for 80 and 84, figure 11 for 88 and 92. It is advisable to begin with the most pronounced features. A large trough is just moving off the East Coast. Prediction of the troughline in the contours 76 and 68 is handled as in the models. Slight deceleration is indicated. The contour 60, however, was not present on the first day and only appears on the second day over the eastern part of Hudson Bay as a closed center. In this case we utilize the lowest point of the contour field on the first day to obtain point 1. Herewith we obtain three prognostic points for the troughlines which lie approximately on longitude 65°W. We also extrapolate the low center over Hudson Bay and the northernmost point of the contour 60 in a similar way.

In the westernmost part of the map we can move a ridge line from the Aleutians clear to 80°N. The ridge over northwest Canada and Alaska has nearly disappeared on a southeastward path as it is overtaken by [illegible] ating short wave trough moving in from the middle of the Pacific. We [illegible] this trough in the contour 76, and also another trough that comes [illegible] from the arctic in the contour 68.

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[1]Stands for 17,600 feet, 16,800 feet, etc. To avoid an exce[illegible] of drawings, the prognosis for the contours 72 and 64 is not [illegible].

Figure 10 shows the displacement of the contours 80 and 84. Special treatment is necessary in the southwest, but they also enclose a cut-off low off San Diego with path extrapolated to northwestern Arizona. Thus the low will come in contact with the circumpolar current and we can expect that it will be absorbed into it.

Over Alaska, a ridge point moves sharply northeast in the 80 contour while the 84 contour over the Gulf of Alaska executes only a rounded simple rotation without acceleration (cf. model, Fig. 3).

In the low latitudes (Fig. 11), the prognosis of the west Atlantic trough is beyond our forecast area. In the eastern Pacific a closed 92 contour, present initially, has disappeared on the third day. The extrapolation of the probable center of the high pressure area indicates a cyclonic path, somewhat unusual. We also move two ridge points on the 88 contour. One of these travels clockwise south of the Gulf of Alaska; the other executes an accelerated rotation southward to 32°N 103°W.

We observe a rotation of the 92 contour over Mexico and the Gulf of Mexico which aids in the construction of this contour in that area.

We now plot all prognostic points, computed in figures 9-11, on a single chart (Fig. 12), then by simple logical combination obtain a first approximation to the prognosis. We already note a close resemblance to the observed 500-mb chart of December 14, 1951 (Fig. 13). We see the low over Hudson Bay; the high over the east Pacific; the trough with concentrated contours and the trough over western North America with widely spaced contours. We also observe the contour convergence over the central and eastern United States, further the current parallels the western coast of the United States and the high pressure over the Arctic Ocean and Alaska. We now proceed to compute additional points for the areas intermediate between the points calculated so far and marked with dashed lines in figure 12.

As an example, figure 14 again shows the 80 and 84 contours over the United States. The problem corresponds to that of model 6: how to combine the troughs over the Atlantic and over California when there is no intermediate ridge. Corresponding to the model, it is best then to watch the contour changes west of the trough now in the Atlantic. We go somewhat to the west from the trough position 1 of the first day and find that the 84 contour is displaced northward a distance D_{12} from first to second day as indicated by the arrows. Similarly we find the distance D_{23} for the change from second to third day. Comparison of D_{23} with D_{12} shows an increase. D_{12} = 10 units, and D_{23} = 18 units, an increase of 80%. If the percent increment continues constant, D_{34} should be 32 units. We enter this prognostic distance normal to the contour line of the third day to the rear of the trough and obtain the auxiliary point A. In a similar way we calculate point A' for the 80 contour. These auxiliary points determine the shape of the contours between the troughs over the Atlantic and California.

Figure 15 gives a further example using the contour 76. Application of the same method for construction of an auxiliary point shows here D_{12} pointing to the south, i.e. heights continue to fall west of the trough. D_{23}, on the other hand, points toward north. D_{12} = -2 units, D_{23} = 12 units, therefore D_{34} = 28 units. If this last quantity is entered, we obtain the auxiliary point A correctly. Such auxiliary computations are often necessary and can be applied in manifold ways. It must be left to the sharp eye of the forecaster to pick on the best indications for their prognosis.

The final result of the forecast appears in figure 16 which should be compared with figure 13.

SUMMARY: Twenty-four hour prognoses of individual contour lines on upper pressure surface are possible by following characteristic points. In general, errors made during determination of direction and acceleration of displacement remain within limits which do not invalidate the forecast. Practical experience to date covers the period October to December 1951, when the writer prepared daily forecasts for the region from the east coast of Asia to Europe. Even over the oceans where data is sparse the result in general was satisfactory. For this whole area, the prognosis can be prepared in one hour without undue stress. It serves as a good aid for prognosis of the surface pressure field. Finally it should be repeated that the technique is valid for forecasts not exceeding 24 hours.

Acknowledgment

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REFERENCE

Petterssen, S., 1940: Weather Analysis and Forecasting. McGraw-Hill Book Co., Inc., New York, N. Y., 503 pp.

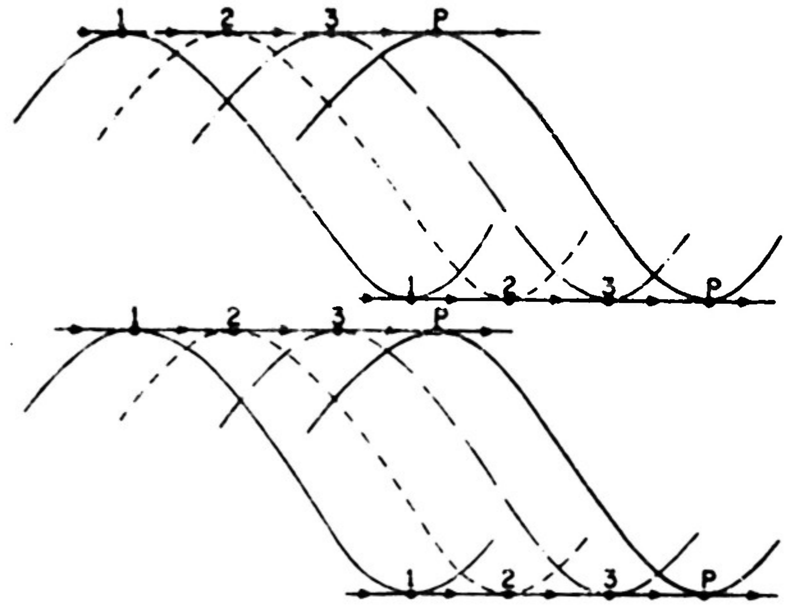


Figure 1

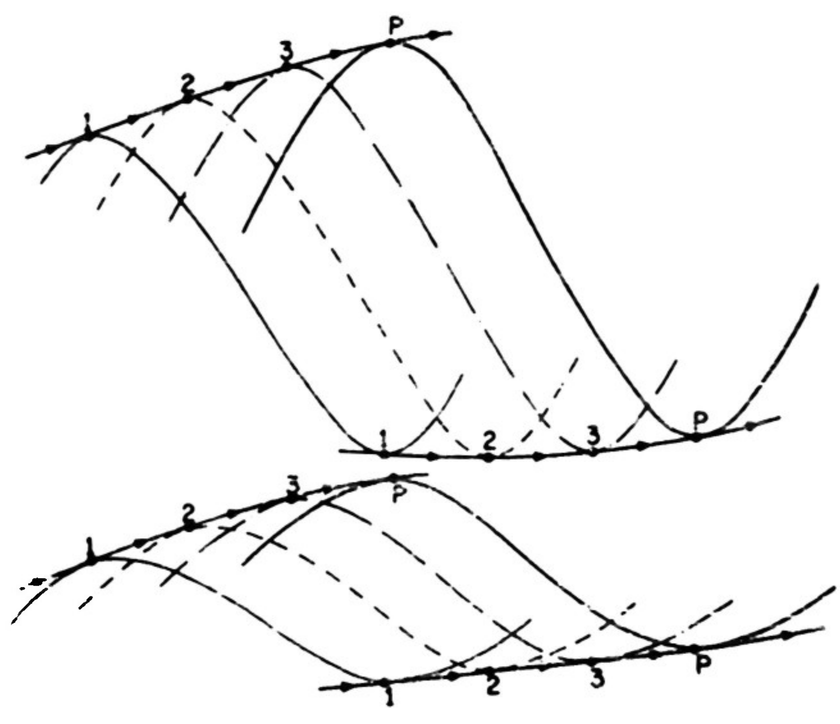


Figure 2

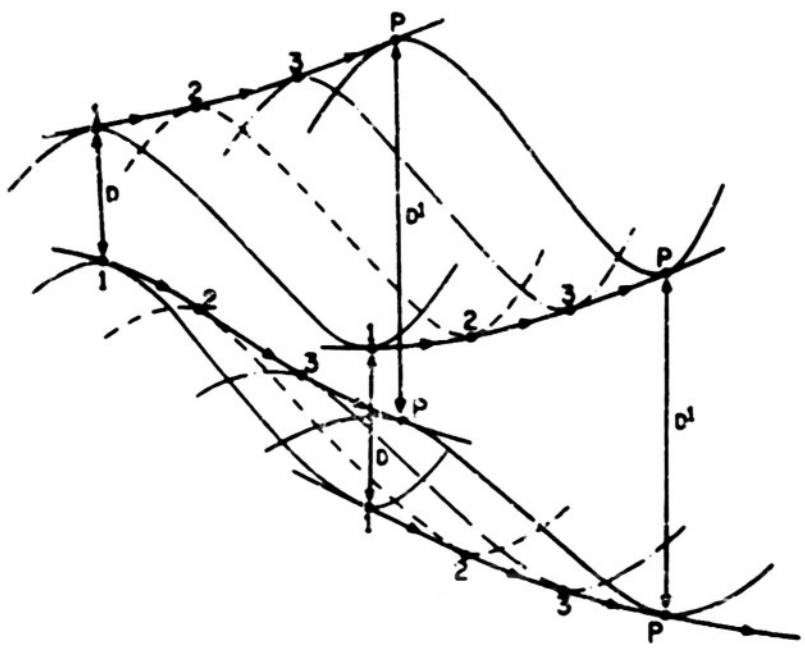


Figure 3

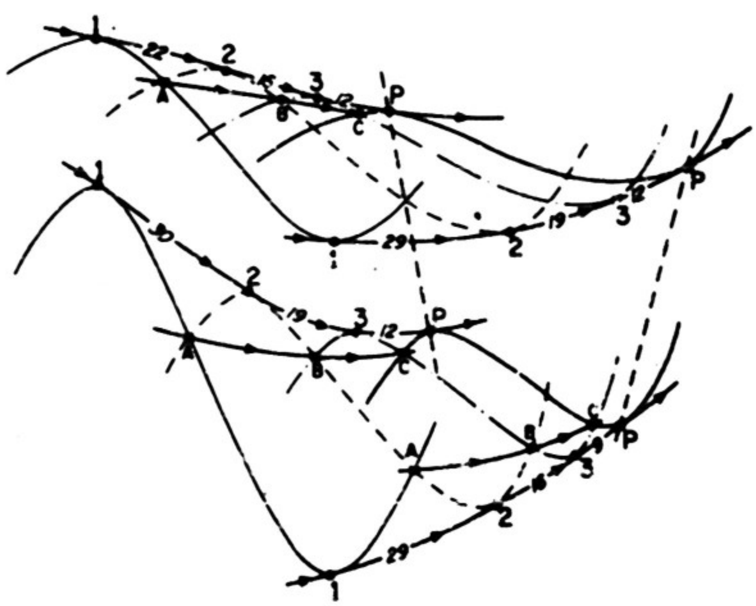


Figure 4

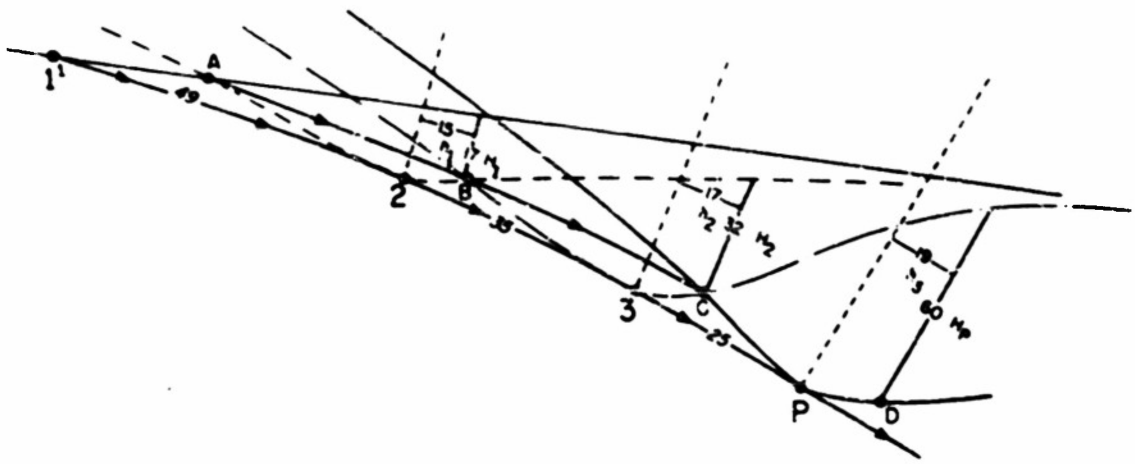


Figure 5

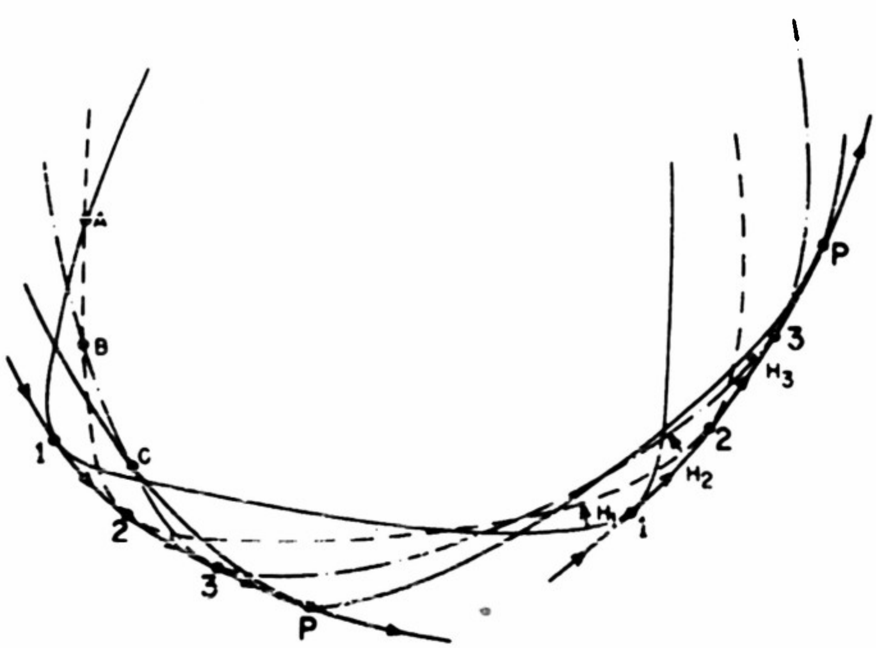


Figure 6

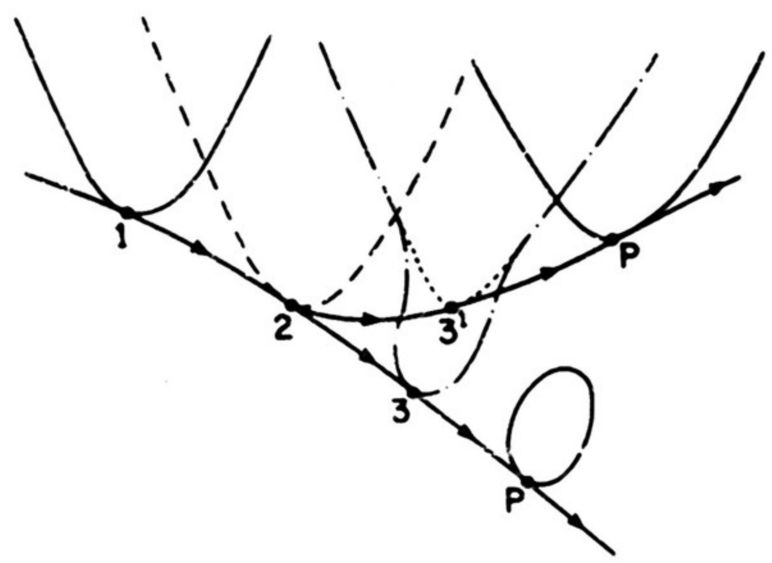


Figure 7

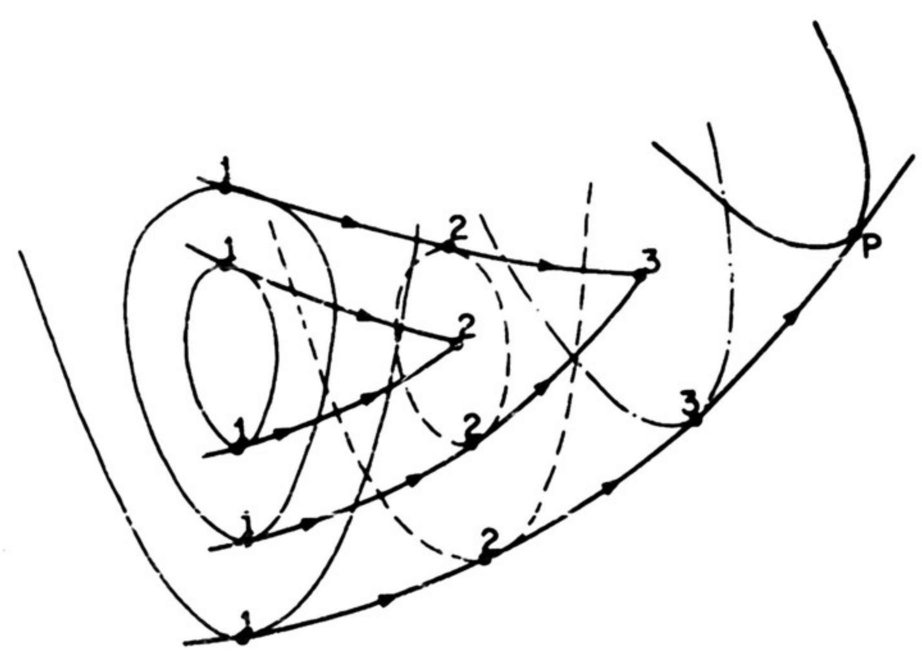


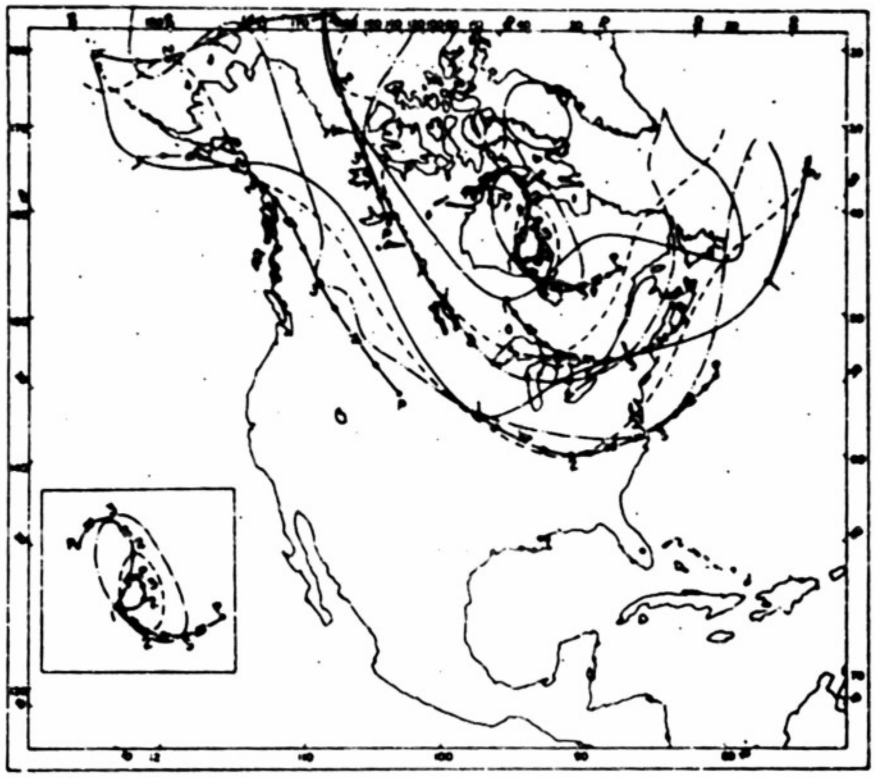
Figure 8

Figure 9

Superimposed 500-mb contour lines 16,000, 16,800 and 17,800 feet on December 11, 1951, 0300Z. (thin solid), December 12 (dashed) and December 13 (dash-dotted). Point 1, 2, 3, P and distances between them as in figures 1-8. Contours of Hudson Bay area repeated in insert in Pacific Ocean.

Figure 10

Same as figure 9, contours 18,000 and 18,400 feet.



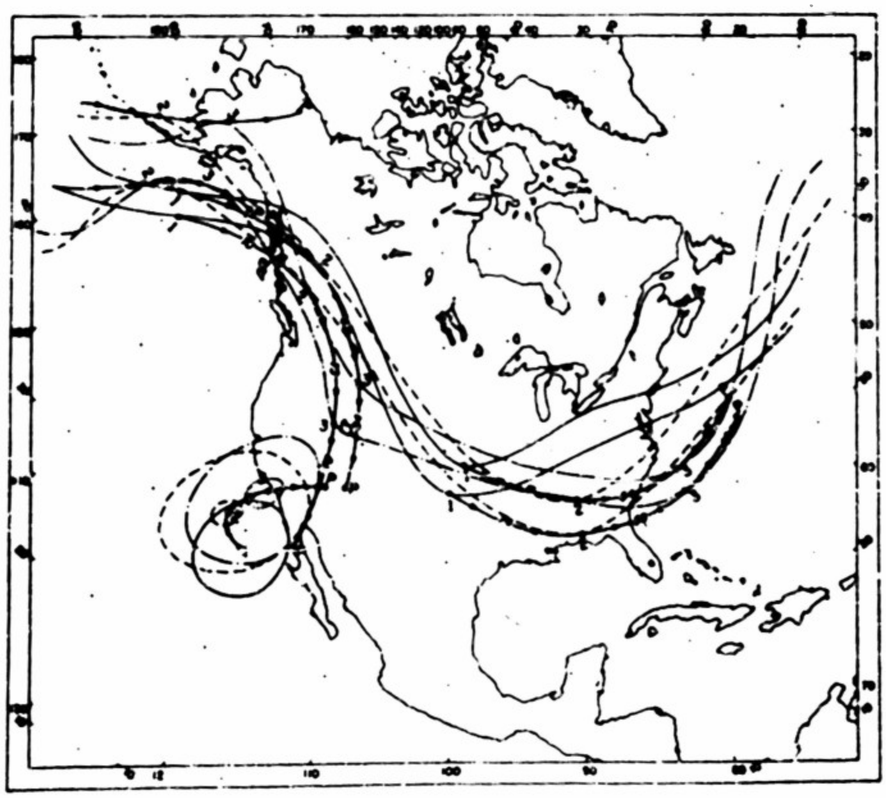
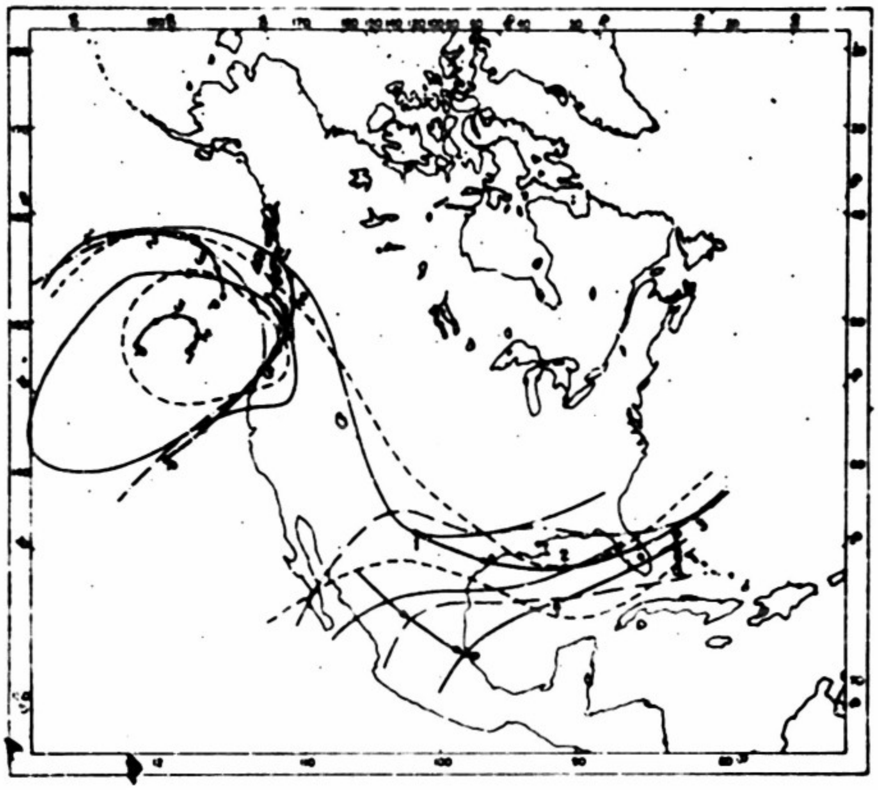


Figure 11

Same as figure 9, contours 18,800 and 19,200 feet.

Figure 12

Preliminary prognosis made with trough and ridge points alone. Final prognosis as yet uncertain in regions with dashed contours.



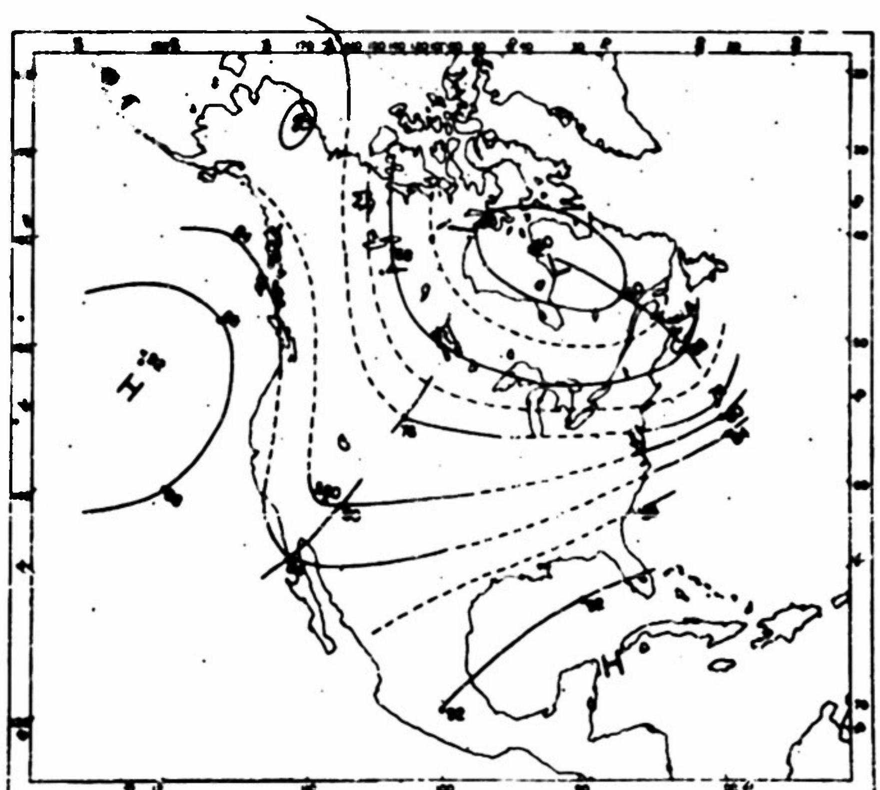
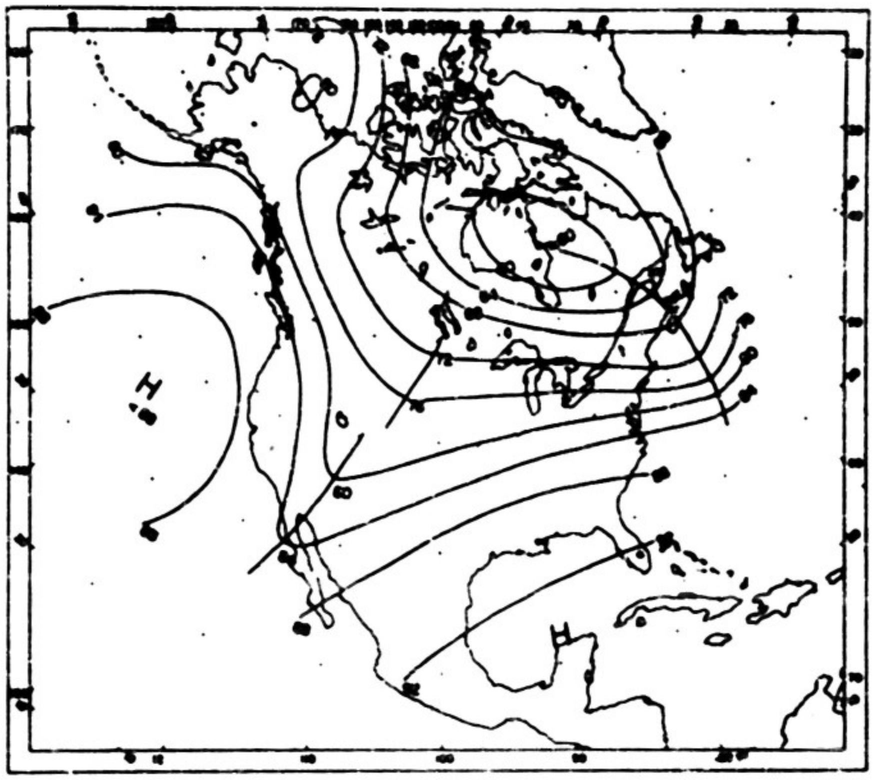


Figure 13

Observed 500-mb chart, December 14, 1951, 0300Z.

Figure 14

Illustrating construction of auxiliary prognostic points as in models figures 5 and 6 showing development of short wave ridge in contours 18,000 and 18,400 feet over eastern United States.



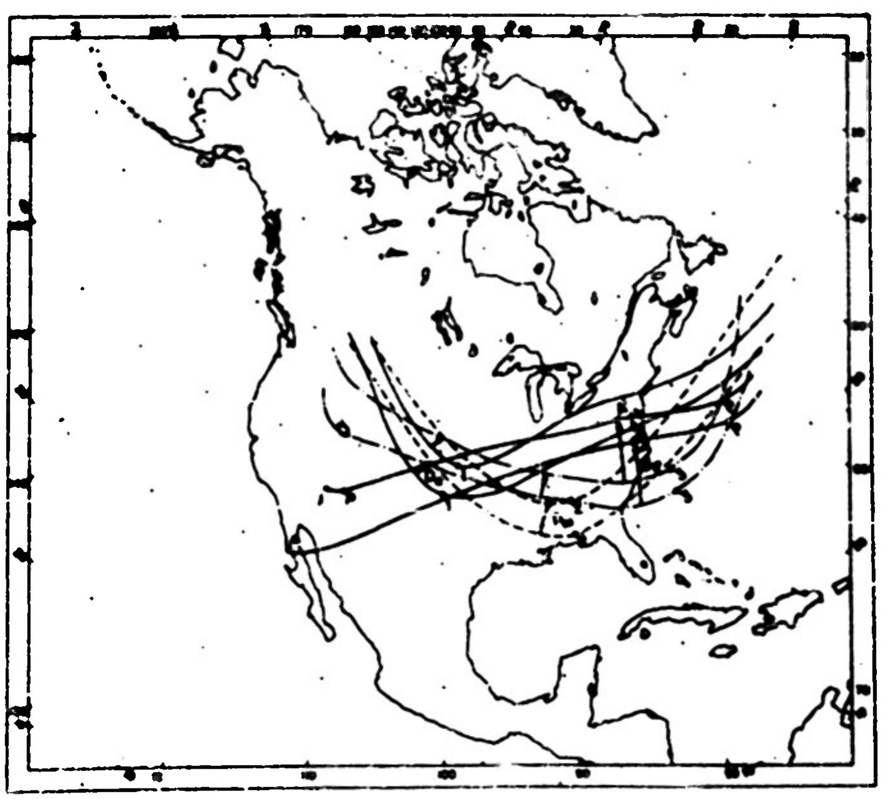


Figure 15

Same as figure 14 for contour 17,600 feet.

Figure 16

Twenty-four hour prognostic 500-mb chart for December 14, 1951, 0300Z, as prepared on December 13. R indicates ridge point, T trough point, I intersection point, H auxiliary point, and C denotes center. The figure shows all prognostic points that have been computed and the lines have been obtained by combining these points.