SOME ASPECTS OF CYCLOGENESIS IN THE GREAT LAKES REGION, SEPTEMBER 11-12, 1953

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INTRODUCTION

The cyclogenesis in the Great Lakes region during September 11–12, 1953, while not of record-breaking proportions, is nevertheless a good example of the usual cyclonic development that the average forecaster encounters.

Using the objective intensity criteria proposed by James [1], this Low, during the period in which we are primarily interested (0300 GMT, September 11 to 1500 GMT, September 12), was of "normal" intensity except at the beginning of the period when it was of "low" intensity. It did not enter James' classification of "intense" until shortly before it left the east coast of Canada.

Classification of this Low by James' method tells only part of the story, as this storm did deepen 15 mb. in a 24-hour period while in the Great Lakes area, and is therefore worthy of study.

In order to avoid confusion, this low pressure system will often be referred to by the name Delta, taken from the ICAO phonetic alphabet, a practice similar to that recently used by Malkin and Holzworth [2].

LARGE SCALE SYNOPTIC FEATURES

The 500-mb. chart, because of its strategic position in mid-troposphere, is well suited to present the large scale features of the atmosphere. It will, therefore, be used in describing the atmospheric processes occurring before and during the period of primary interest.

In the Atlantic, a closed Low near 45° N. latitude first appeared as a separate entity in the vicinity of 35° W. longitude through cyclogenesis in the southern portion of a trough oriented N-S along eastern Greenland on the 0300 GMT map of September 6, 1953. This Low drifted slowly southward (5 degrees) during the next three days and then moved northwestward, filling, and finally by 1500 GMT on the 11th becoming absorbed in a vigorous cyclonic circulation over the Newfoundland area. This Newfoundland Low then drifted east-northeastward to the British Isles. In the meanwhile in the southern Atlantic a tropical Low developed in the Puerto Rico area, and by the 9th it had become a system of hurricane portent. This was hurricane "Dolly". The trajectory of the storm had crossed Bermuda by 0630 GMT of the 12th.

The Atlantic High during the period of these occurrences was generally quite subdued, and its axis was located in relatively low latitudes.

The predominant feature in the Pacific from about the 5th through the 13th was a well developed low pressure system in the Gulf of Alaska with various attendant minor troughs sweeping across the eastern Pacific onto the North American continent. The Pacific High, insofar as the eastern part of that ocean was concerned, was never very dominant during this period.

The eastern portion of the North American continent was under mean trough domination from about the 7th through the middle of the month. The pressure pattern of the western portion of the continent during this period was essentially that of a stationary major ridge with minor troughs moving over it.

THE BIRTH OF DELTA

On the 9th, at about 1230 GMT, a small Low of 1003-mb. intensity with a partially occluded frontal system entered western Canada at latitude 53° N. The Low then moved northeastward and in six hours filled 9 mb. The trajectory thereafter was southeastward to the vicinity of The Pas, Manitoba, where it disappeared as a closed circulation by 1830 GMT of the 10th. Almost simultaneously a new weak center formed farther southward in the northwestern North Dakota area on the accompanying frontal system. This was Delta, a 1013-mb Low. Delta's subsequent path, together with the surface synoptic situation for 0030 GMT on the 11th, is shown in figure 1. For the development in the system 36 hours later, see figure 2.

THE THICKNESS PATTERN ABOVE THE CENTER OF DELTA

As we are primarily concerned with the deepening aspect of Delta, a study was made of the behavior of the thicknesses between the standard layers (1000–850 mb., 850–700 mb., 700–500 mb., 500–300 mb., 300–200 mb.)

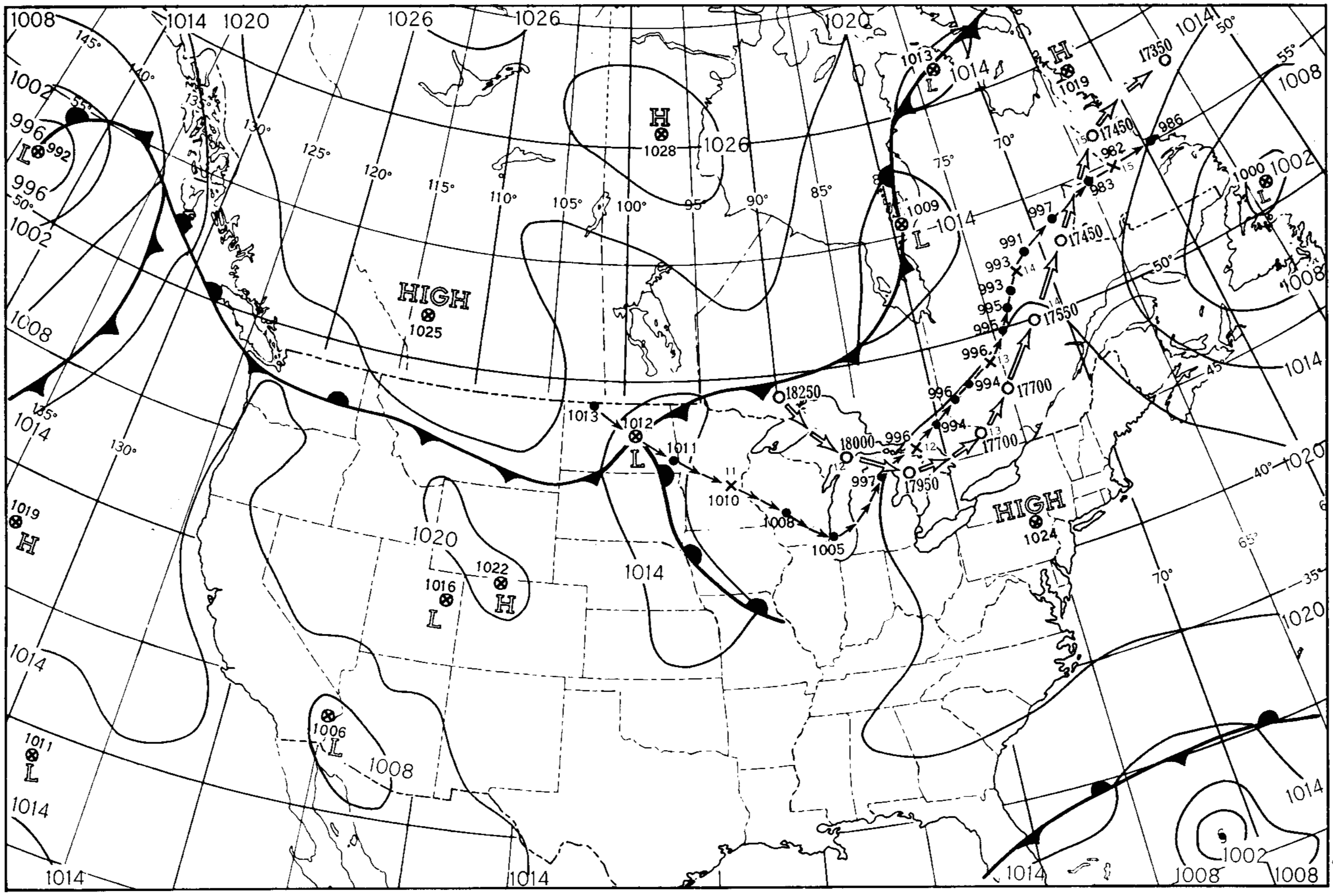

FIGURE 1.—Surface chart for 0030 GMT, September 11, 1953. Isobars (solid lines) drawn for 6-mb. intervals. Surface 6-hourly storm track dated at the 1230 GMT positions. 500-mb center track dated at 1500 GMT positions.

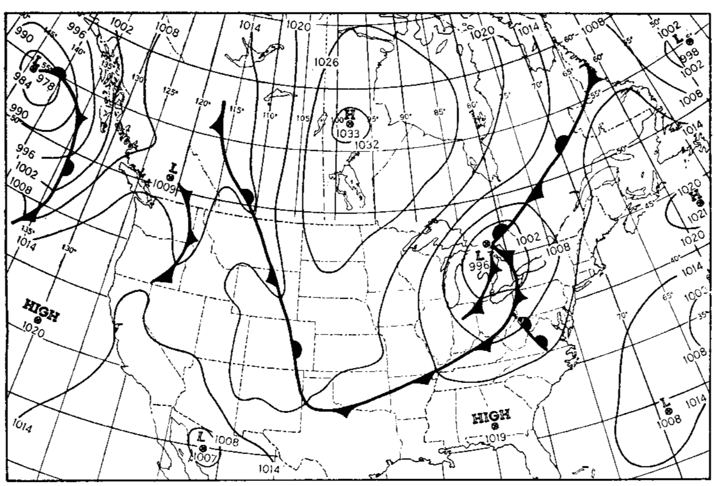

FIGURE 2.—Surface chart for 1230 GMT, September 12, 1953.

above the sea level [1] center as it moved along its trajectory. The behavior of the 200-mb. surface (above the center of the 1000-mb. Low) can also be studied in conjunction with these layers if one bears in mind that a decrease (or increase) in its height is in effect synonymous to an increase (or decrease) of the thicknesses of the layers below it. This technique is similar to the one used by Vederman [3] in his study of rapidly deepening extratropical storms.

The contribution of the 200-mb. surface and the various layers below it to the deepening of the sea level Low are illustrated in figure 3. A layer which becomes thicker (warmer) with time is considered to be a contributing layer while a layer which becomes thinner (colder) is considered to be a noncontributing [2] layer. Wherever any curve on this graph slopes downward with increasing time, the layer associated with this curve is a contributing layer. On the other hand, wherever a curve slopes upward with time, it is a noncontributing layer.

From this graph one can readily note that all the layers below 300 mb. could be classified as noncontributing throughout almost the entire period graphed. The 300–200-mb. layer contributed most of the time. The 200-mb. surface, however, made the most significant con-

[1] Since the low center on the 1000-mb. chart can be assumed to be almost vertically located with respect to the sea level Low, any geographical reference to the position of the Low can be applied to that of the sea level or the 1000-mb. Low indiscriminately.

[2] It should be noted that henceforth in our meteorological usage of the term "noncontributing" we are extending its denotation to include "negatively contributing" (i. e., favoring the filling of the sea level low center).

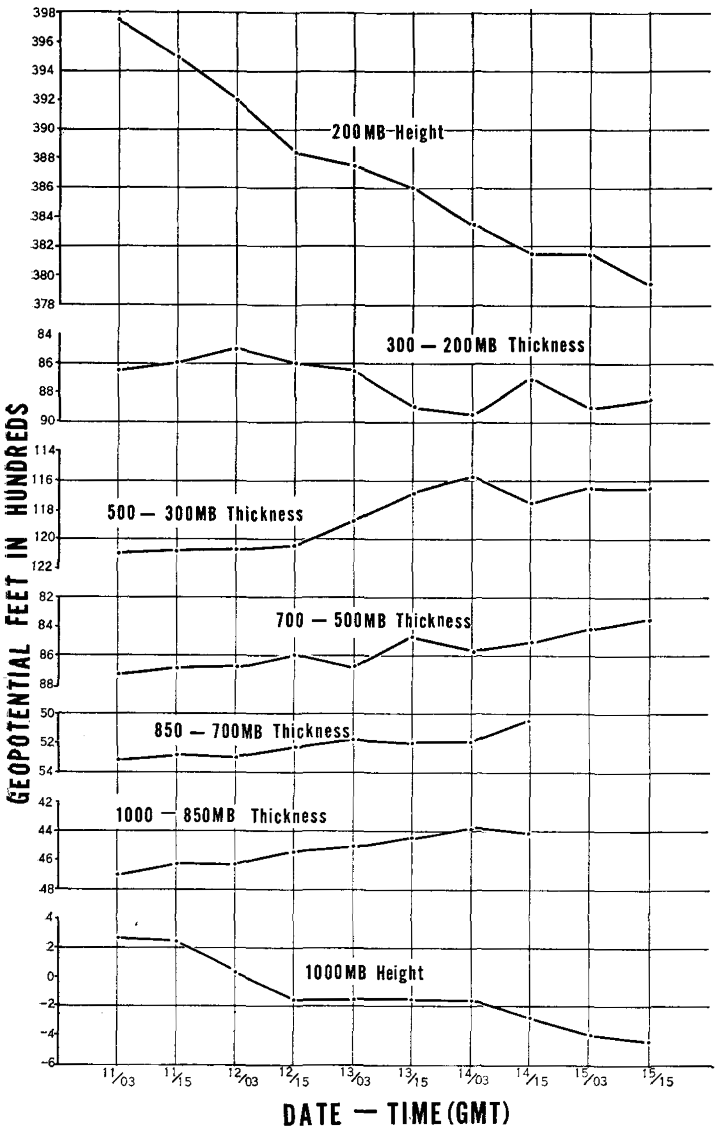

Figure 3.—Graph of thicknesses between mandatory levels and heights of 1000-mb. and 200-mb. surfaces above Delta. The ordinates of the thickness curves were inverted so that when a line slopes downward it indicates a contribution to a pressure fall at the surface. As the analyses were restricted to charts actually analyzed by the WBAN Analysis Center, the 1000-850-mb. and 850-700-mb. thicknesses are not continued beyond 1,500 GMT on the 14th when the Low was located north of the 850-mb. map base.

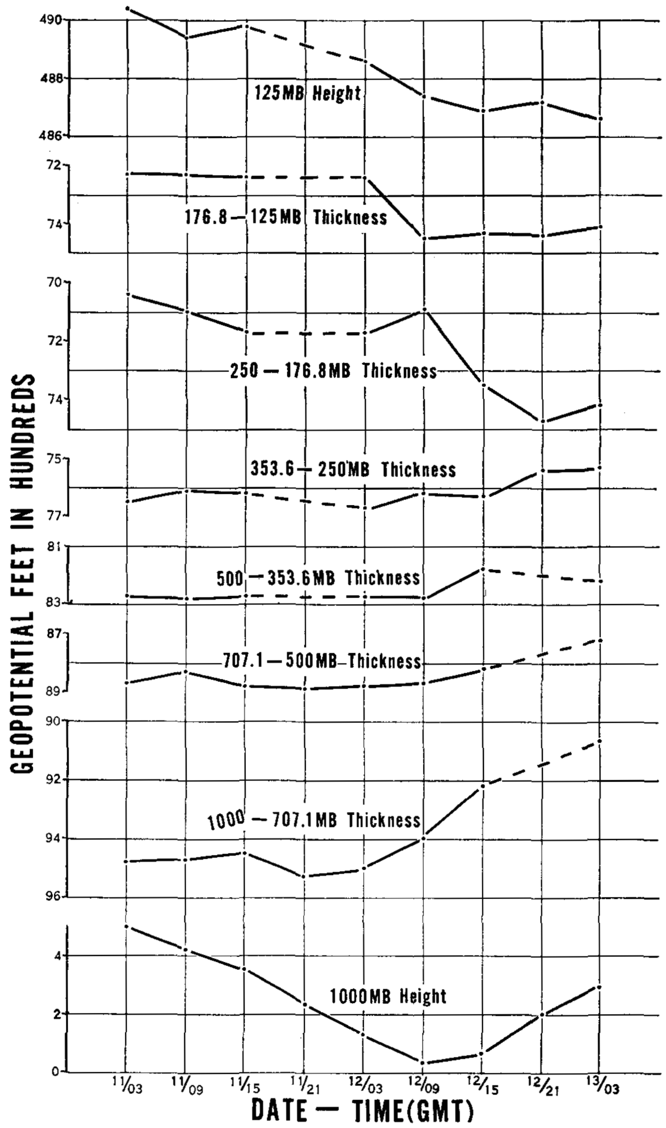

Figure 4.—Graph of thicknesses between selected levels and heights of 1000-mb. and 125-mb. surfaces over Sault Ste. Marie. As in figure 3, ordinates of the thickness curves were inverted so that when a line slopes downward it indicates a contribution to a pressure fall at the surface. Dashed lines represent linear extrapolation through times of missing data.

tribution to the deepening (especially during the critical period of 0300 GMT on the 11th to 1500 GMT on the 12th). Even during that portion of the time when the 1000-mb. surface Low was not deepening, the 200-mb. height curve was still conspicuous by its downward slope. The behavior of the several layers and the 200-mb. surface in the case of Delta agrees quite well with the results obtained by Vederman [3] for the average behavior of deepening Lows even though Delta, unlike the Lows selected by him, was not a winter case nor did it maintain a rate of deepening of 10 mb. or more per 24 hours throughout the *entire* period indicated in figure 3.

Another method for studying the behavior of a moving Low would be to graph the values of the 24-hour layer thickness changes and the 200-mb. height changes above the moving 1000-mb. low center as ordinates against time as the abscissa. In a graph of this type, from the nature of the slope of the curve, we can obtain information about the changing behavior with time of the local thickness (or height) tendency above the center of the moving 1000-mb. Low.

A graph of this type resembles somewhat in its nature the meteorological picture the forecaster gets when he examines successive height change charts for constant pressure maps. The results obtained by plotting such curves are in general different from those shown in figure 3. The graph itself is not presented in this article; its essence, however, is illustrated by table 1.

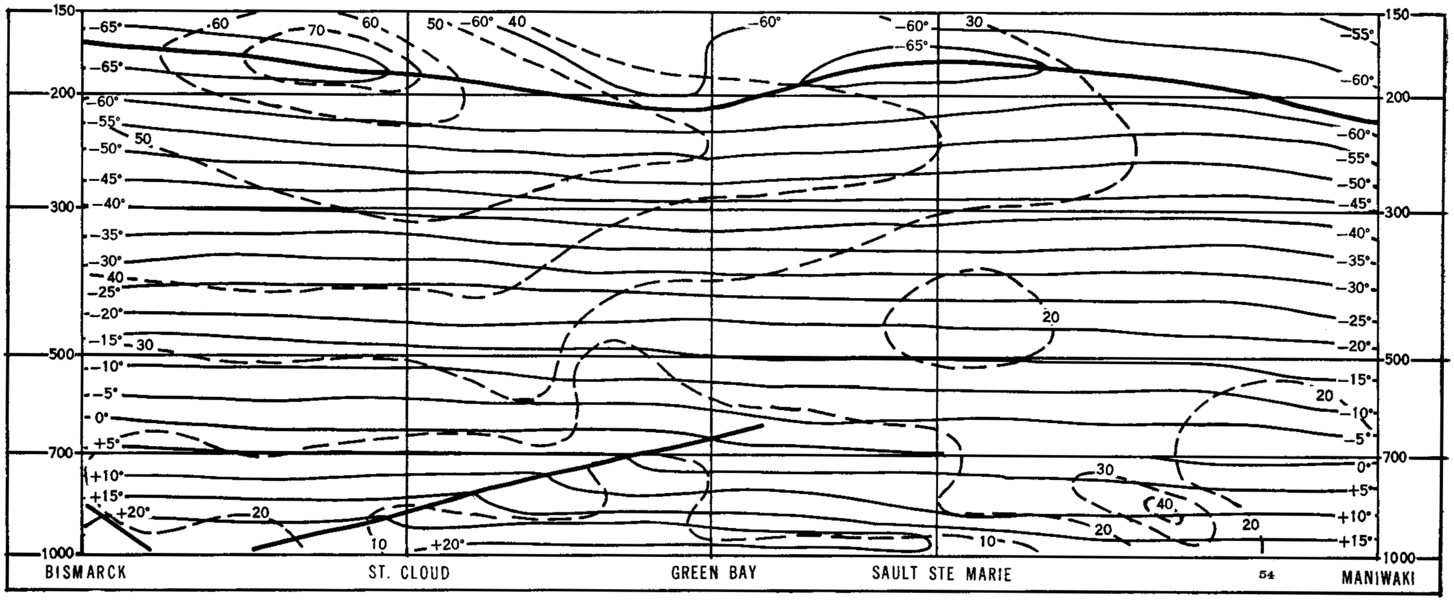

FIGURE 5.—Cross section at 0300 GMT, September 11, 1953, analyzed for temperature (solid lines) and isotachs of actual wind speed (dashed lines). Fronts and tropopause are in heavy solid lines.

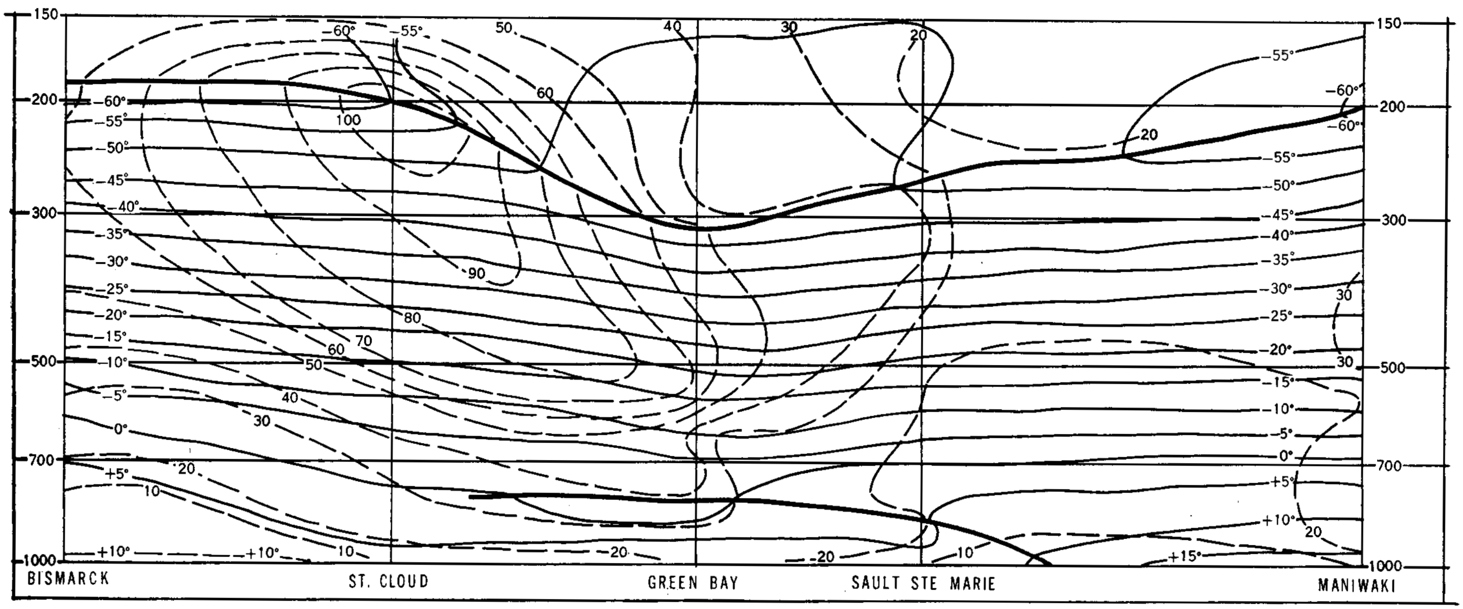

FIGURE 6.—Cross section at 1500 GMT, September 12, 1953.

In this table whenever any given value in any *thickness* change column represents an *algebraic* increase over the value immediately above it, then that layer is contributing at an *increasing rate* (or is noncontributing at a *decreasing rate*) to the deepening of the 1000-mb. Low. An *algebraic decrease* in successive values in a *height* change column would indicate contributing at an *increasing rate* (or noncontributing at a *decreasing rate*) to the deepening of the 1000-mb. Low.

Perusal of this table gives a new perspective of the situation. It shows, among other things, that in the case of Delta the 200-mb. surface was still a "friendly" level for sea level deepening and contributed on one occasion at an increasing rate in advance of any noticeable 1000-mb. deepening. Another interesting aspect is that the 500–300-mb. layer was essentially a "hostile" layer insofar as any deepening of Delta was concerned.

SAULT STE. MARIE TIME STUDY

In the discussion thus far, we have been concerned solely with the behavior of certain atmospheric parameters determined immediately above the center of the moving Low. A different approach would be to study the changing behavior with time of some atmospheric property above a fixed point on this 1000-mb. chart.

The property selected was the local tendency of the

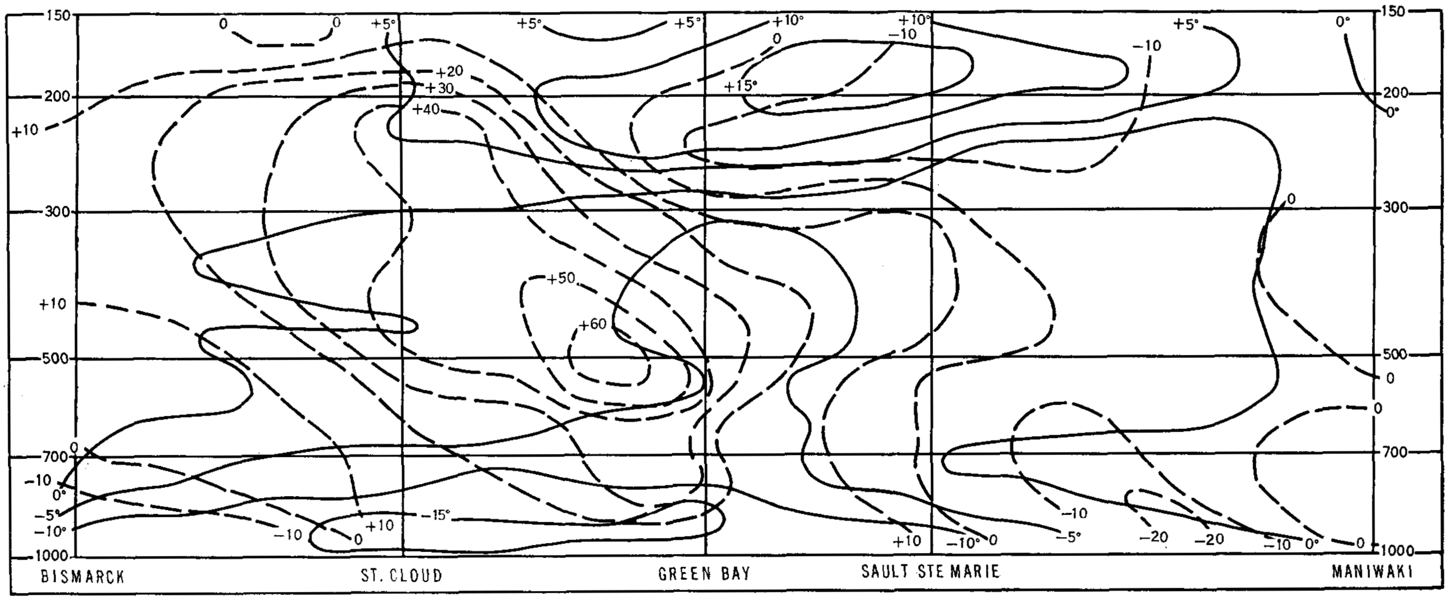

FIGURE 7.—36-hour cross section change at 1500 GMT, September 12, 1953, analyzed for temperature change (solid lines) and wind speed change (dashed lines).

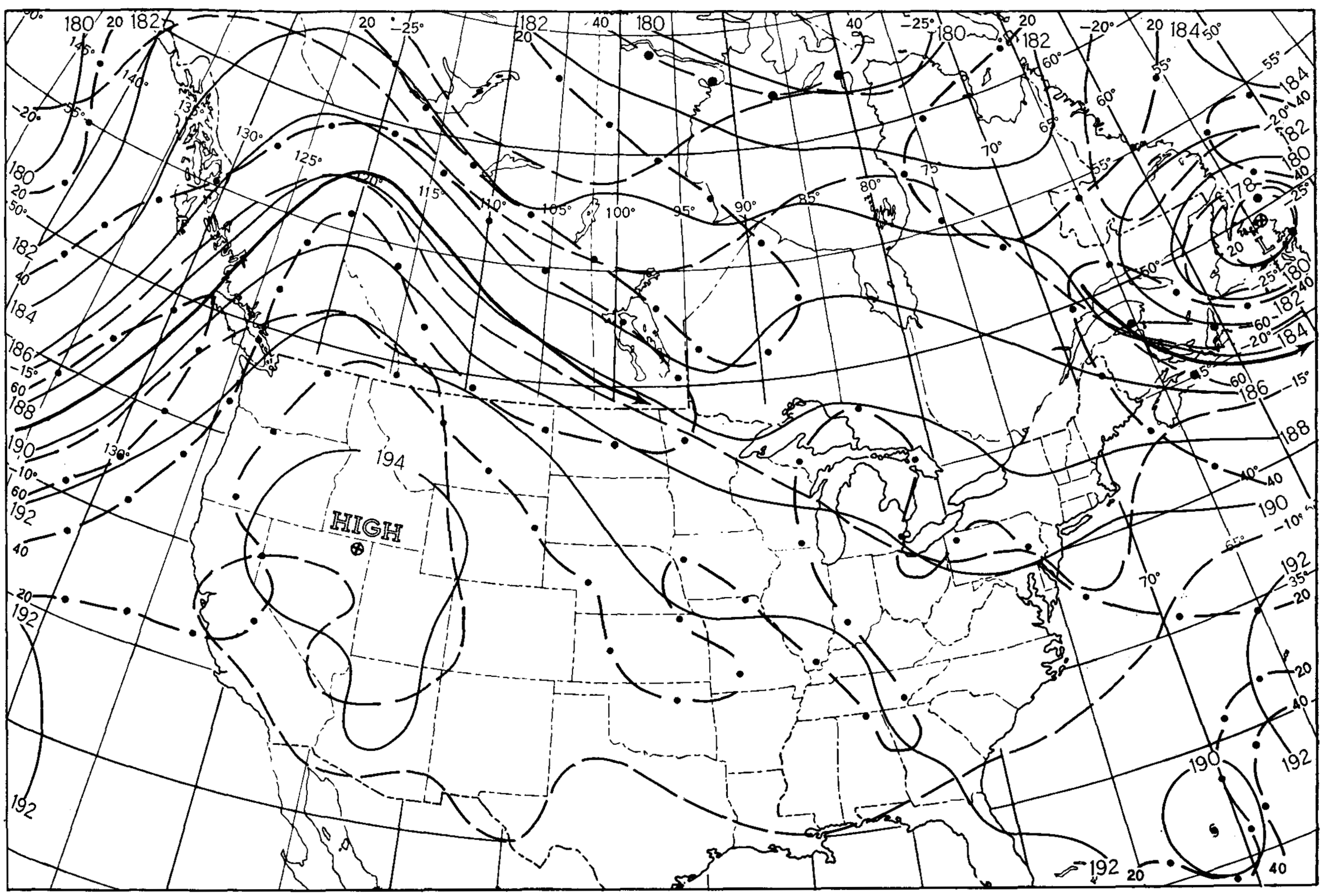

FIGURE 8.—500-mb. chart for 0300 GMT, September 11, 1953. Height contours (solid lines) are labeled in hundreds of geopotential feet and drawn for 200-foot intervals. Isotherm (dashed lines) are drawn for intervals of 5° C. Isotachs (alternate dashes and dots) are in intervals of 20 knots. Jets are in heavy solid lines.

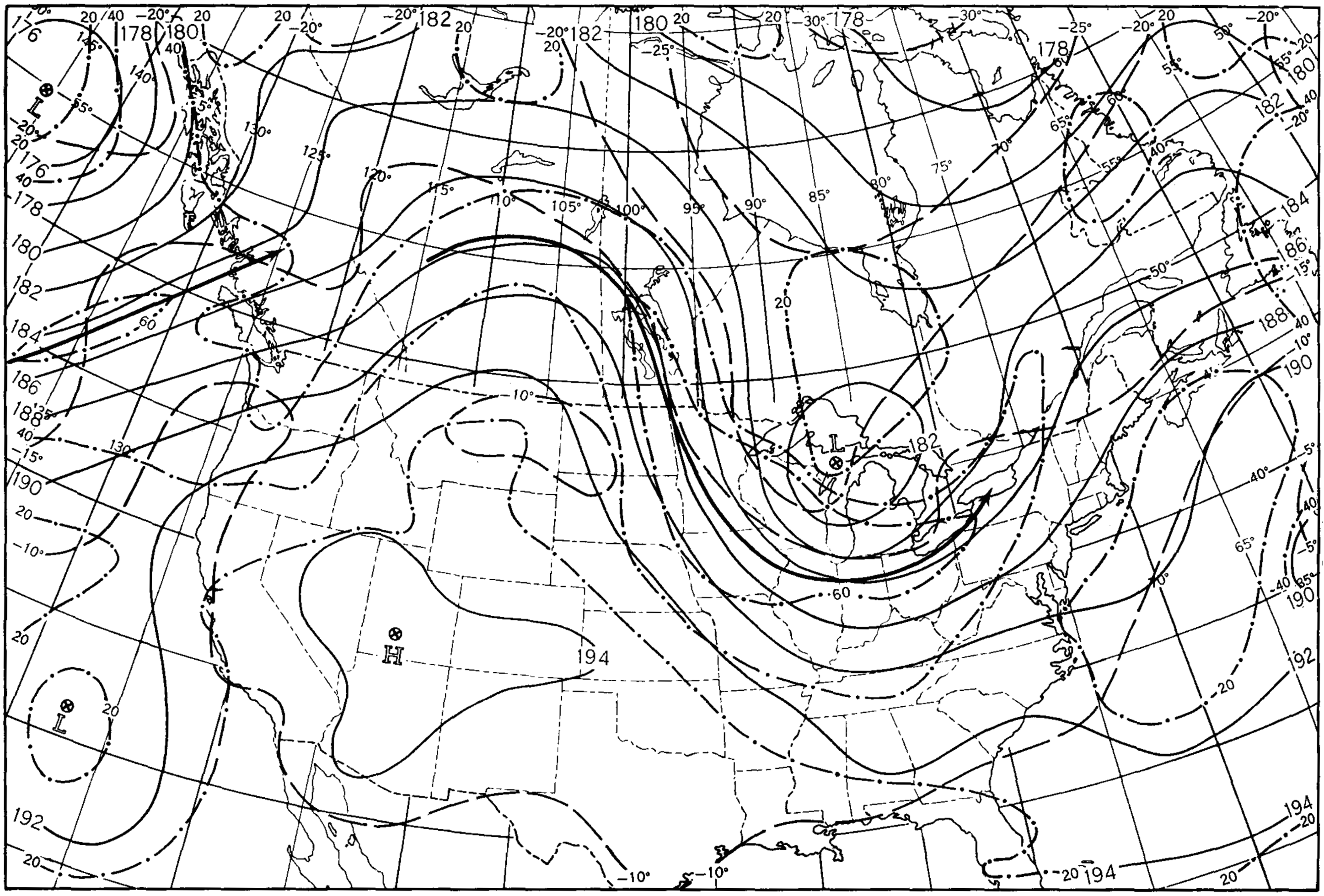

FIGURE 9.—500-mb. chart for 1500 GMT, September 12, 1953.

TABLE 1.—*Computed tendencies above the center of the moving 1,000-mb. level Low. Note that a vertical arrow indicates the time interval during which the tendency of the layer thickness (or constant pressure level heights) involved has become either more "favorable" or less "unfavorable" to the deepening of the 1000-mb. level Low.*

Date time (GMT)	1000-mb. height (Low center)	24-hour changes above center of Low at times given						
		1000-mb. height	1000–850-mb. thickness	850–700-mb. thickness	700–500-mb. thickness	500–300-mb. thickness	300–200-mb. thickness	200-mb. height
110300	+270	−170	+70	−10	+20	+90	+50	+50
111500	+240	↓ −260	+40	−20	−10	−70	↓ +100	↓ −80
120300	+30	↓ −430	+20	↓ +60	↓ +10	↓ +160	0	↓ −200
121500	−160	↓ −590	↓ +70	+30	0	+110	↓ +130	↓ −250
130300	−140	−400	+20	−70	↓ +150	+30	+110	−160
131500	−140	−340	↓ +50	↓ +40	−130	−360	↓ +410	↓ −290
140300	−160	−310	−100	↓ +120	↓ +40	−550	+310	↓ −650
141500	−270	↓ −350	↓ +100	−160	−110	↓ −280	+50	↓ −750
150300	−400	↓ −470			−210	↓ +190	−80	−550
151500	−430	↓ −500			↓ −200	−290	↓ +290	↓ −800

various layer thicknesses and the 200-mb. level height. The "fixed point" selected was Sault Ste. Marie, Mich. This place, incidentally, has become famous, meteorologically speaking, through a study of this type (but much more extensive) made some years ago by Penner [4].

In both of the previous time studies, a valid objection that can be raised is that the various layers in the atmosphere are not being compared on any impartial or equal basis. For example, the 1000–850-mb. layer is compared in its behavior with the 500–300-mb. layer which both weighs more and is always much thicker. There are various remedies possible. One would be to make the comparison on a basis of layers of equal weight. This method would be especially easy to apply if the radiosonde code required transmission of data for every 100 mb. of pressure (such as the British System). Another method would be to compare layers of equal thickness. This method, of course, was more feasible when "constant height" surfaces were in vogue.

A third available method for comparison would be to divide up the atmosphere with successive constant pressure surfaces in such a manner that the ratio of the pressure of the bottom bounding surface to that of the upper bounding surface for any one layer would be equal in magnitude to the corresponding ratio for any other layer. In such a system of layers a unit change in mean virtual temperature

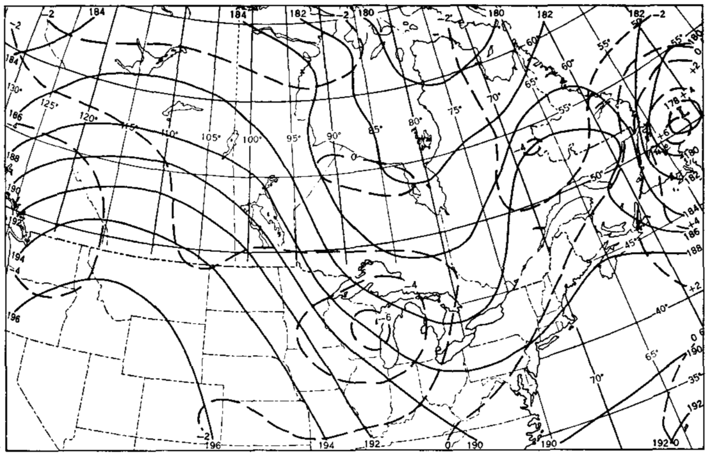

FIGURE 10.—36-hour 500-mb. prognostic chart (solid lines) verifying at 1500 GMT, September 12, 1953, using Fjørtoft integration technique. Dashed lines represent the magnitude of verifying contours minus prognostic contours in hundreds of geopotential feet

of any layer would be associated with the same fixed magnitude of thickness change.

In a division of the atmosphere into layers on this basis, it might be considered advantageous that certain specific pressure surfaces be retained. Two such surfaces are the 1000- and the 500-mb. levels. It is also desirable in this proposed division that the lower layers be thick enough so that there be no loss or damping out of significant details. These criteria are satisfied in a division of the atmosphere into layers bounded by the pressure surfaces 1000, 707.1, 500, 353.6, 250, 176.8, 125mb., etc. The ratio of any two successive surfaces is always $\sqrt{2}$.

By interpolating the radiosonde data from Sault Ste. Marie, it was possible to graph the values of thickness of the various layers against time. For practical purposes the upper boundary was limited to 125 mb and accordingly a curve of the height of the 125-mb. layer was also plotted. This graph is shown in figure 4. An interesting feature was the relatively large increase in thickness (warming) of the 250–176.8-mb. layer above the station during the time interval 0900 GMT to 2100 GMT of the 12th. During this same time interval the 1000-mb. height at Sault Ste. Marie had risen about 170 feet.

CROSS SECTIONAL ANALYSIS

Figure 5 presents a cross sectional surface for 0300 GMT on the 11th that extends through Bismarck, N. Dak., St. Cloud, Minn., Green Bay, Wis., Sault Ste. Marie, Mich., and Maniwaki, Quebec. From the upper air data, this cross section was analyzed for isotherms and isotachs (for total wind speed). Fronts and tropopause are also included. A second cross section for the same location was constructed for 1500 GMT on the 12th, figure 6, so that the vertical changes during the 36-hour period could be noted.

Isotherms on cross sections invariably exhibit too shallow an amplitude for adequate use. In order to emphasize for visual purposes the magnitudes of the thermal changes

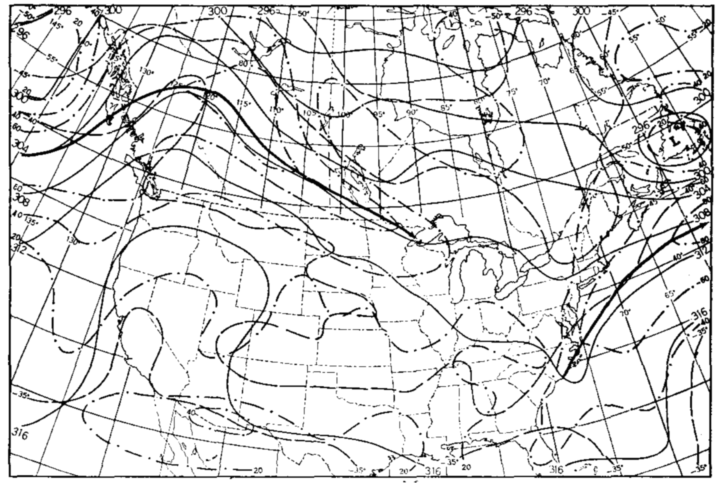

FIGURE 11.—300-mb. chart for 0300 GMT, September 11, 1953.

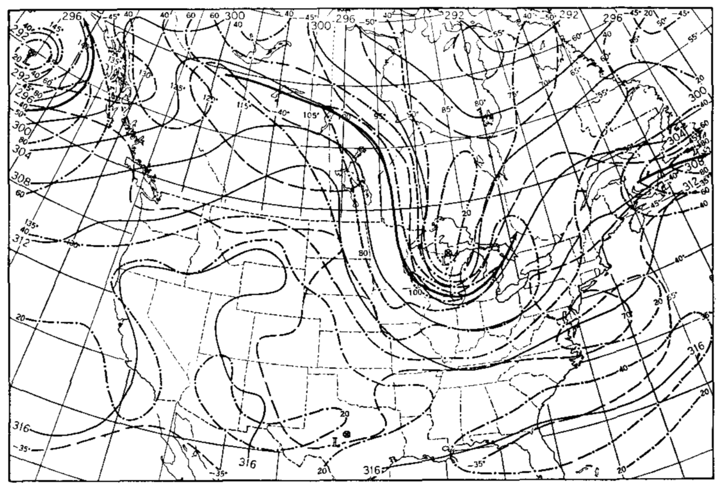

FIGURE 12.—300-mb. chart for 1500 GMT, September 12, 1953.

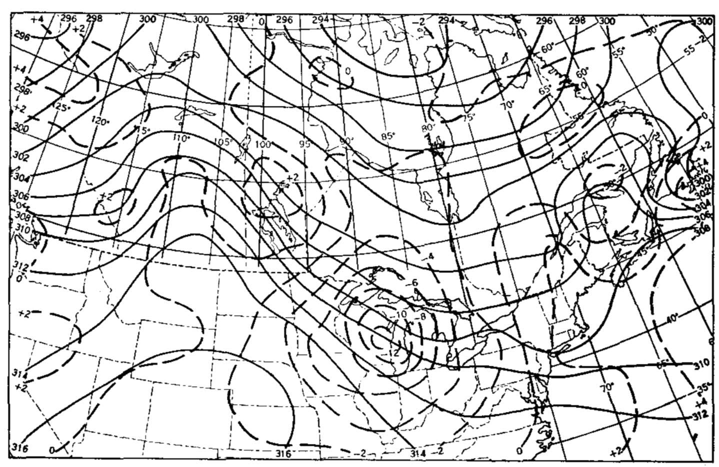

FIGURE 13.—36-hour 300-mb. prognostic chart verifying at 1500 GMT, September 12, 1953 using Fjørtoft integration technique. Dashed lines represent the magnitude of verifying contours minus prognostic contours in hundreds of geopotential feet. 200-foot intervals are used for greater accuracy in prognosticating the vorticity pattern.

during the 36-hour period, a third cross section depicting the change in isopleths during the period was constructed by graphical differential analysis, figure 7. This chart also contains the change in the isopleths of total wind speed. With the aid of these charts (especially the third one), various features may be noted.

The tropopause in the vicinity of Green Bay during the 36-hour period of cyclogenesis had lowered almost 100 mb. For simplicity, the tropopause has been drawn as a single continuous line. However, at Green Bay the predominant tropopause 1500 GMT on the 12th resembles somewhat better in character the Arctic type than it does the temperate type of tropopause (fig. 5). This lowering of the tropopause had the usual concomitant change: marked warming in the lower stratosphere and compensatory cooling in the troposphere. Both the positive and the negative isallotherm maxima show a definite lag behind the surface Low insofar as the cross section viewed is concerned.

The maximum center of the isotach (total wind speed) change field is situated near the 500-mb. level and is somewhat to the west of the largest temperature falls at that level. This would indicate that in the cross sectional area shown the gradient of the 36-hour height falls reached a larger magnitude at 500 mb. than at the 300-mb. or 200-mb. levels.

FORECASTING THE CYCLOGENETIC FIELD

In any post mortem investigation, great care should be taken to avoid falling into the pitfalls of the "apparently" obvious explanations. It is well to bear in mind that an ounce of forecast is worth more than a pound of "hind-cast". With this in mind two forecasting techniques are examined for their bearing on the deepening of Delta.

FJØRTOFT TECHNIQUE

A procedure currently in vogue for forecasting the 500-mb. chart is the Fjørtoft [5] graphical method for integrating the barotropic vorticity equation. This method was applied to the 500-mb. chart for 0300 GMT on the 11th (fig. 8). The verification map (1500 GMT on the 12th) is indicated in figure 9 and the Fjørtoft prognostic chart (for the same time) is shown in figure 10. In addition, a Fjørtoft prognostic chart was made from the 300-mb. chart of 0300 GMT on the 11th (fig. 11); the actual map 36 hours later and the Fjørtoft prognostic chart are shown in figures 12 and 13 respectively.

The results obtained by this technique were rather disappointing as a brief study of figures 10 and 13 will indicate. However, good results in cyclogenetic cases should not in general be expected from use of the barotropic model.

SCHERHAG "DIVERGENCE" PRINCIPLE

The next method that was inspected for "catching" the cyclogenesis was one made prominent by Scherhag [6].

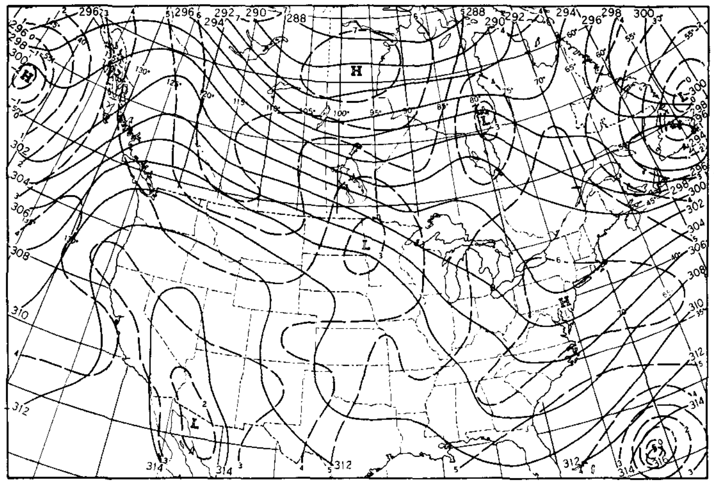

FIGURE 14.—Composite chart of 1000-300-mb. thickness (solid lines) and 1000-mb heights (dashed lines) for 0300 GMT, September 11, 1953. Heights and thicknesses are in hundreds of geopotential feet.

His divergence theorem states that divergent winds must, in general, cause a pressure drop at the surface unless they are compensated by a strong convergence below. (In his treatment of this concept, the divergent "contour field" is often substituted for the divergent "wind field".) An auxiliary requirement for this pressure fall, according to Scherhag, is that the isotherms show pronounced divergence which does not diminish towards the surface layer [7].

Examination of the charts for 0300 GMT on the 11th shows that a divergent contour field existed aloft (figs. 8 and 11). This field of divergent contours, in fact, extended from above the 200-mb. level to below the 850-mb. level. In addition, a divergent thermal field also existed in this same area (fig. 14).

Since both requirements appear to have been met in the case of Delta, it would seem that the ensuing cyclogenesis may be successfully explained by the Scherhag theorem. There are, however, some valid objections. As noted by Baum [7] there are "mathematical arguments for and against the theorem, examples in which the theorem appears to be verified and disproven." Cases can be found where the divergent contours aloft did not lead to any perceptible surface pressure falls. In fact, the typical blocking pattern is itself a sort of divergent contour field. In addition, the theorem as formulated does not "pinpoint" the cyclogenetic area, nor does it enable one through its use to make any quantitative forecast as to the amount of sea level pressure fall. It is, therefore, difficult to give a definite answer to the question: Has this development of Delta been uniquely forecast from the application of the Scherhag theorem, or is coincidence also involved?

ACKNOWLEDGMENTS

Thanks are due Mr. A. K. Showalter for suggestions during the preparation of this article and to Mr. R. R. Watkins and Mr. D. A. Richter for their assistance in preparing the charts.

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U. S. GOVERNMENT PRINTING OFFICE: 1953