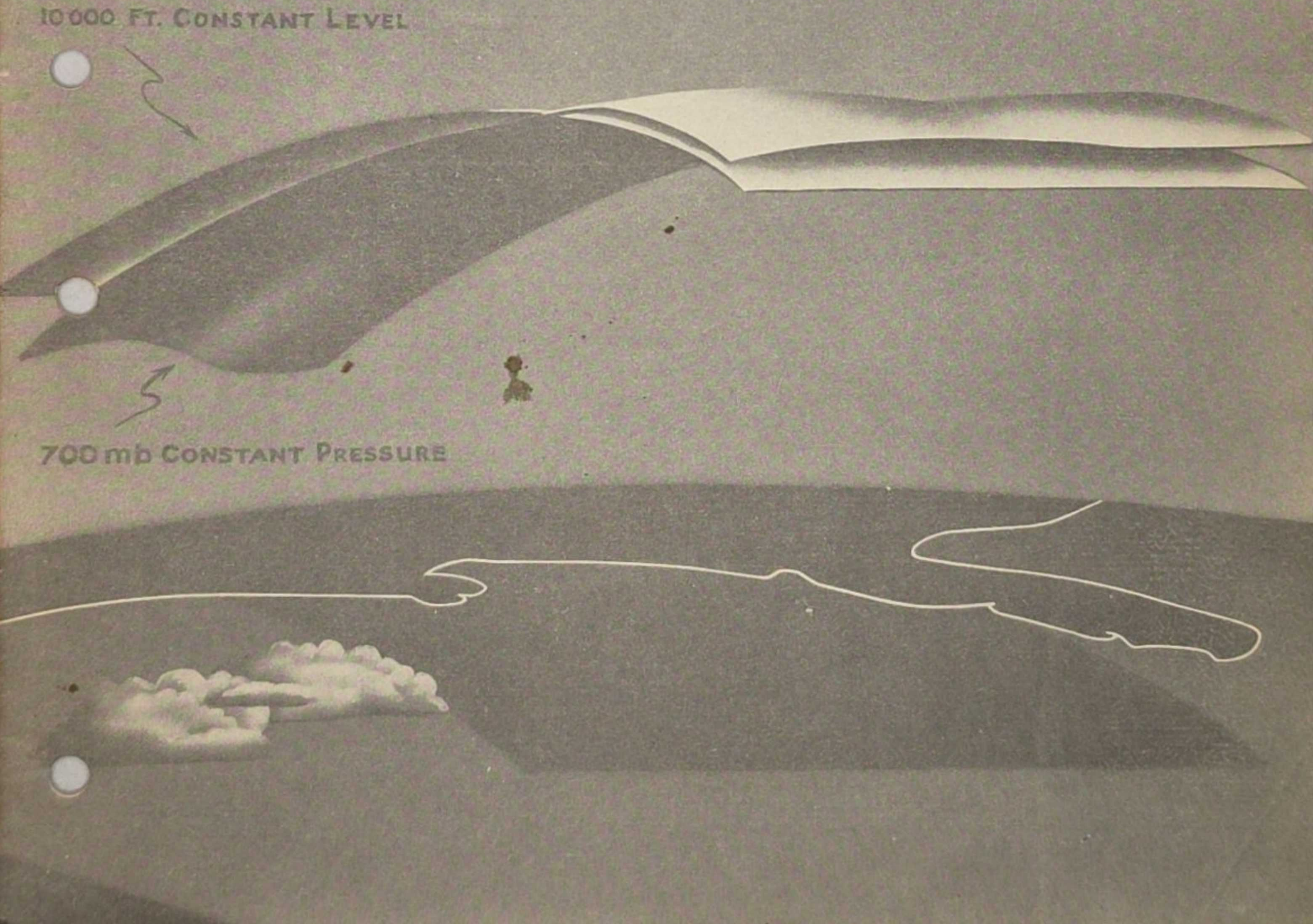
T/OPN
TM/SXN

WEATHER SERVICE Bulletin

ARMY AIR FORCES HEADQUARTERS WEATHER WING
APRIL 1945 ASHEVILLE, N.C. VOL. 3 NO. 4



From Colonel Senter

Upon relinquishing command of the AAF Weather Wing, it is my desire to communicate sincere appreciation to the officers, enlisted men and women, and civilian employees of this command for their admirable devotion to duty and for their wholehearted cooperation. These qualities have enabled this command to carry out its mission as assigned by higher authority.

To explain my pride in the personal qualities which have been displayed throughout the Weather Service, I would like to point out at length the ways that *courtesy*, *integrity*, *responsibility*, and *military bearing* have a vital relationship to the soldier-specialist duties which are typical of our organization.

When a number of men participate in a common enterprise, even one where competition is profitable, they soon find that certain activities by an individual do harm to all. Then it is not long before the whole group approves restraints upon its members for the common good, in a code called *ethics*. In the Weather Service, for example, one can see that special agreements about our behavior are spontaneously growing out of day-to-day experience in combat, in isolation, and in peaceful but responsible duties.

These ethical precepts deserve a particular allegiance when they act to maintain a justified faith in weather technology among those who must wager lives upon forecasts and observations. Aircraft would be wrecked, artillery shells misaimed, ground force effectiveness curtailed, supplies ruined, and general operations endangered if a military official should be influenced to disregard Weather Service advice. In this regard, ethics seek to eliminate those personal faults in a weatherman which might be interpreted as indication of shortcomings throughout the Service.

I. *Professional Courtesy.*

The condemnation of his fellows is certain to fall on that weatherman who ridicules the map, observation, or forecast of an associate in the presence of flyers, other clients, or anyone who might interpret such cross-fire among meteorologists as evidence of a general unreliability in weather service. Every AAF forecaster in the United States is superior to climatology at the 12-hour range, and 9 out of 10 are more effective than climatology for 48-hour forecasts. This fact demonstrates that any qualified forecaster at all---every one who has been disparaged---has very valuable advice to give. Yet some few weathermen still are irresponsible enough to destroy the effectiveness of a colleague by rash comments to his clients, not realizing that the one subjected to attack must continue to serve them.

(concluded on back cover, inside)

William Oscar Senter, Colonel and command pilot at 34, has fulfilled a succession of Weather Service responsibilities. He accepted authority over newly-created organizations when they were crucial to the development of military meteorology, and left them as smartly-efficient units. Shortly before Pearl Harbor he became RCO of the Fourth Weather Region: he met the pilot training crisis of 1941-42 by the establishment of many new weather stations, by an unprecedented program of in-station training, and by adroit utilization of personnel. In July 1942, Colonel Senter became the first Chief of the Operations Division, Weather Directorate, at Headquarters AAF. The Operations Division was actually the field headquarters of AAF weather service, which recommended and prepared for the activation of seven new weather squadrons (principally in combat theaters) among other accomplishments. Almost a year later, the AAF Weather Wing was established at Asheville with Colonel Senter as commanding officer---authorized to command thirteen weather squadrons and to exercise technical control over all others within the AAF Weather Service. Colonel Senter recently relinquished command of the Wing for a combat assignment, as commanding officer of the Far East Air Forces' Weather Group.

Contour Charts

The military and civilian weather services of Allied countries probably will adopt constant-pressure methods as a universal system for reporting and examining upper-air data within a year. The U.S. Army, Navy, and Weather Bureau anticipate changing over to this system by June 1945 in conjunction with other North American countries. Radiosonde data would be reported for mandatory pressure values, and be plotted on isobaric "contour charts." Present methods of reporting and plotting winds-aloft data are expected to remain in force.

Fortunately, the forecasting experience and techniques which have been derived from constant-level analysis may be applied to contour charts without basic modification. But certain aspects of the new system will be novel to many meteorologists, and much of this issue therefore is devoted to detailed, official statements about pertinent technical problems. Page 6 contains a discussion of the isopleths which might be drawn on a constant-pressure surface. Constant-level and contour charts of the upper air for a recent period of five days are shown on pages 7-19: one of each type---two charts which agree in time and (roughly) in altitude---is given on a single page for the sake of comparison. An exposition of the prognostic techniques which can be applied to contour charts, in particular to the 700mb surface, occupies pages 20-23. A procedure for utilizing reliable, low-level data in 300mb analysis appears on page 24. And finally, the current usage of upper-air data is reviewed and supplemented by "Vertical Motions" on pages 2-5.

The familiar decrease toward the north of pressures in the temperate zone indicates that a given pressure surface slopes upward from north to south in middle latitudes. But the mean slope of isobaric surfaces is slight, only about 1 to 10,000: in winter the average 700mb surface is 500 feet below the 10,000 foot level at the U.S. - Canadian border, and 200 feet above that level at the Gulf Coast (see the front cover). Because the spatial difference between a constant-pressure surface and some fixed level is small, the representations of wind flow, temperature, and humidity on one frame of reference closely resemble the corresponding patterns on the other.

The minor differences which do exist express certain superiorities of the contour chart over the constant-level map. Many isopleths assume a multiple meaning when they are drawn on an isobaric surface, serving to define several different variables with one set of lines. Quantities which can be obtained by graphical subtraction (weight, mean density, mean virtual temperature) are precisely determined only when isobaric surfaces are the upper and lower limits. The constant-pressure chart has a wider utility than its counterpart because it permits a richer interpretation of atmospheric structure after a simpler mechanical analysis.

Regulations ultimately will fix the standards for constant-pressure terminology; but in the meantime, this table gives the British Air Ministry's nomenclature, which has been adopted by the AAF Weather Service in Europe and in North Africa:

Constant Level	Constant Level Chart	10,000 ft Level	10,000 ft Chart	Prognostic Chart
Isobaric Surface	*Contour Chart*	*700mb Surface*	*700mb Chart*	*Prontour Chart*

Isobars	Isotherms	Prognostic Isobars	Pressure Change $\left[\frac{\Delta p}{\Delta t}\right]$	Pressure Tendency $\left[\frac{dp}{dt}\right]$
Contours	*Isotherm*	*Prontours*	*Height Change*	*Height Tendency*

What the problem is, and what is being done about it:
A review of research by the AAF Weather Station at NYU.

Vertical Motions

by IT. O.E. DEWS

The ultimate aim of ninety per cent of analysis---surface and upper-air alike---is to locate and forecast those areas where isobaric and adiabatic cooling promote the occurrence of condensation products. In the free air of middle latitudes, the isobaric temperature changes which affect parcels of air are relatively small compared to the adiabatic changes; and parcels are brought to condensation primarily as a result of adiabatic cooling due to upward vertical motion. Near the surface of the earth, isobaric cooling predominates, but its effects would be confined to an exceedingly shallow layer if it were not for the vertical flux of heat and moisture associated with the vertical components of eddy motion. Considered basically, almost all types of "weather" ---clouds, precipitation, and icing---are the consequences of appropriate combinations of moisture and vertical motion. It follows that any satisfactory system of analysis of atmospheric processes, either in the lower layers of the atmosphere or in the free air, must provide a means of dealing simply and directly with the field of vertical motion.

The value of the synthesis provided by the frontal system of surface analysis lay especially in this: that it associated ascending currents of relatively warm, moist air with a particular pattern of surface phenomena. Upper-air analysis requires a similar generalization which will relate the field of vertical motion with the abundant aerological data now available on upper air charts. In the absence of such a generalization, the direct use of aerological data in short range forecasting is limited almost entirely to the analysis of individual radiosoundings. Constant level charts are used primarily as a means of extending the indirect aerology of the polar front a little farther into the future; and the surface prognostic chart serves as an essential intermediary between the current upper-air data and the forecast. With few exceptions, the forecasting value of upper air charts is limited to the contribution which they make to the construction of the surface prognostic chart. Future patterns of vertical motion in the free air are deduced indirectly from the surface prognostic chart in much the same way as the current patterns of vertical motion are deduced by indirect aerology from the current surface chart. In short, the forecaster takes his upper air data and "works down" to obtain his surface prognostic chart, then "works up" from the surface prognostic chart in order to forecast the occurrence of condensation products in the free air.

In this method of procedure the emphasis is usually placed upon those features of upper-air charts which give a clue to the future development of surface pressure systems. Research has therefore been directed toward determining the field of horizontal density advection at high levels, by means of isobar-isotherm relationships and by means of weight charts; and the result is that a very good 24-hour forecast of surface pressures is now possible. Braun and Douglis have shown that an accuracy of ± 2 millibars can be attained for 24-hour forecasts for individual stations in the summer. (1)

It is probable, indeed, that most forecasters can forecast the pressure pattern with more facility than they can interpret a correctly-forecast pressure pattern in terms of the associated weather phenomena. This conclusion is supported by the experience of the Weather Bureau's five day forecasting unit. Figures based upon interpretation of five-day-mean surface and 3 kilometer pressure patterns indicate that about one-half of all errors in forecasts were made subsequent to the completion of the prognostic pressure charts. The scores suggest that efforts to improve the interpretation of prognostic pressure patterns would have the same opportunity for success, in terms of immediate improvement of forecasts, as would efforts to improve the accuracy of the prognostic pressure patterns. (2)

If what has been said so far is true, it is obvious that there is a pressing need for a system of upper-air analysis which will deal with the problems of vertical motion by relating the field of vertical motion directly to the observed and forecast data at upper levels, without the necessary mediation of an indirect aerology based upon prognostic surface charts.

It is now believed by some meteorologists that the concept of convergence and divergence will provide the basis for a new synthesis. It has been well known for years that a relation exists between the patterns of horizontal flow and the field of vertical motion. What has not been known is an easy way to relate the field of vertical motion with the data which normally appear on an upper air chart. Mathematical analysis shows that convergence in the horizontal flow is associated with increasing upward motion with respect to height; divergence, with increasing downward motion with respect to height. Furthermore, convergence and divergence themselves are determined by the trajectory of the air as it changes latitude. Bjerknes and Holmboe(3) have recently shown how the areas of convergence and divergence may be related directly to the pressure pattern at upper levels. According to Bjerknes and Holmboe, the atmosphere is divided along the vertical into two layers, separated by a surface of non-divergence. Above the level of non-divergence, convergence occurs to the west of trough-lines and divergence to the east; below the level of non-divergence, convergence occurs to the east of trough-lines and divergence to the west. If these conclusions can be confirmed experimentally, there is little doubt that they will provide a principle of upper-air analysis which can be widely applied under field conditions.

Unfortunately, the whole problem of upper-air charts and the field of vertical motion is complicated by the difficulty of obtaining direct measurements of vertical motion aloft. The best indirect measurements have been subject to considerable error, and few attempts have been made in the past to correlate the results of different methods of measurement. Realizing this deficiency, personnel of the AAF Weather Station at New York University undertook an investigation(4) with a threefold purpose: to discover the accuracy to be expected from several indirect methods of measuring vertical velocities, to develop the best of these for practical use, and to study the pattern of vertical velocity in selected weather situations.

These investigators computed the vertical velocities by three different methods:

First, streamline divergence charts were used to determine the horizontal velocity divergence at 3,000, 5,000, 7,000, and 9,000 feet(5). From these charts a mean value of the divergence was obtained for the layer from the surface to 10,000 feet. By integrating the equation of continuity according to the method developed by H. A. Panofsky of the Department of Meteorology, New York University, the vertical velocity at 10,000 feet was computed as a function of the mean divergence.

The second method was based upon the variation of the potential temperature at a point on a constant-level chart. The local time rate of change of potential temperature is equal to the advection of potential temperature plus the change of potential temperature due to vertical motions plus the non-adiabatic change(6). If the non-adiabatic change is neglected, all the other terms except the vertical motion can be evaluated independently from constant-level charts and radiosoundings, and it is possible to solve for either the instantaneous or the mean 12-hour vertical velocity.

The isentropic chart provided the third method of computing vertical motions. The 12-hour trajectory was obtained from the isentropic streamlines at the beginning and end of the period, and the difference in pressure from the beginning to the end of the trajectory was converted into height units to give the mean vertical velocity for the middle of the period.

Since the constant-level streamline method is least dependent upon assumptions, it was used as a standard against which to check the reliability of the other methods. The vertical velocities computed from the constant-level streamlines were found to be correlated with those computed from the local variation of potential temperature by a coefficient of +.7. This correlation was considered to be high enough to indicate that each method measured the same quantity with satisfactory accuracy. The correlation between the results based on the local variations of potential temperature and those based upon the isentropic trajectories was equally high. The conclusion drawn was that the three methods produced similar results, and might be used interchangeably.

The isentropic trajectory method is the one recommended for practical use, at least until enough Rawins are transmitted to provide concentrated winds-aloft data in all weather conditions. The streamlines on the latest isentropic chart are assumed to represent the trajectories for the last six hours. The pressure at the beginning of a six-hour trajectory is determined by linear interpolation between the latest isentropic chart and the chart twelve hours earlier. The pressure at the end of the six-hour trajectory is read directly from the latest isentropic chart. The difference between these pressures, translated into units of height, is assumed to represent the mean vertical displacement of the parcels of air in six hours.

The report also discusses a means of taking into account the non-adiabatic temperature changes occurring in the free air. Two effects were considered: (1) the diurnal temperature change at 10,000 feet, (2) the change in radiation balance as the air parcels move between warmer and colder regions. By averaging separately the 0400Z and the 1600Z temperatures at 10,000 feet for six stations during January, February, and March 1944, it was found that the average diurnal change was about 0.3° C. per 12 hours, or little more than the probable observational error. When the non-adiabatic temperature change was evaluated in a number of cases in which the effects of advection and vertical motion could be determined independently, it was found possible to fit a curve to points of non-adiabatic temperature change plotted against the meridional component of the wind velocity. Thus, for a region including most of the United States east of the Rocky Mountains, it was possible to represent the non-adiabatic change in terms of the change of radiation balance due to the north-south component of flow.

Finally, the report describes a method by which the effects of vertical motion and non-adiabatic cooling can be combined in an expression which defines the total cooling or "condensation factor." This expression has the form

$$\chi = \mathbb{V}_2 \, \gamma_d - \left(\frac{dT}{dt}\right)_n$$

where χ is the condensation factor, $\mathbb{V}_2$ is the vertical component of the velocity, $(dT/dt)_n$ is the non-adiabatic term given as a function of the north-south flow, and γ_d is the dry-adiabatic lapse rate. The condensation factor is computed in units of degrees centigrade per twelve hours. The temperature change necessary to bring a parcel to saturation (ΔT_c) is computed in degrees centigrade and plotted below the condensation factor.

Where ΔT_c exceeds the condensation factor, saturation should not be reached in 12 hours; where the condensation factor exceeds ΔT_c, the ratio of the two is an indication of the time of saturation. Figure I shows χ plotted above ΔT_c on the 302°A isentropic surface, 2200Z, 3 March 1944. Isolines of condensation factor are drawn for intervals of 2°C per twelve hours. Figure II is the corresponding surface chart for 063Z, 4 March 1944. It will be observed that the areas delineated by values of $\chi/\Delta T_c$ greater than unity are in general characterized by nimbostratus or cumulonimbus clouds, and precipitation.

In addition to proposing a method for relating vertical motions directly to the saturation process, the report describes the fields of vertical motion and divergence computed for a number of selected weather situations. It was found that vertical motion contributes on the average about 40 per cent of the temperature change observed at a fixed point in the free air, while horizontal advection contributes most of the remainder. The field of vertical motion at the 5,000-foot level was found to agree closely with what could be deduced from the surface chart by the methods of indirect aerology. The divergence above 10,000 feet was frequently but not always of opposite sign from that below 10,000 feet, presumably because of variations in the height of the level of non-divergence; convergence predominated to the east of trough lines below 10,000 feet and divergence to the east of trough lines above 10,000 feet.

These results emphasize again the importance of the field of vertical motion in the analysis of atmospheric processes. They point out the inadequacy of thinking which is based solely on concepts of horizontal advection, and they provide observational evidence in support of the theories which relate the fields of vertical motion and divergence to the pressure patterns in the free atmosphere.

REFERENCES

(1)Braun and Douglis; "Weight Charts," *Weather Service Bulletin*, January 1945.

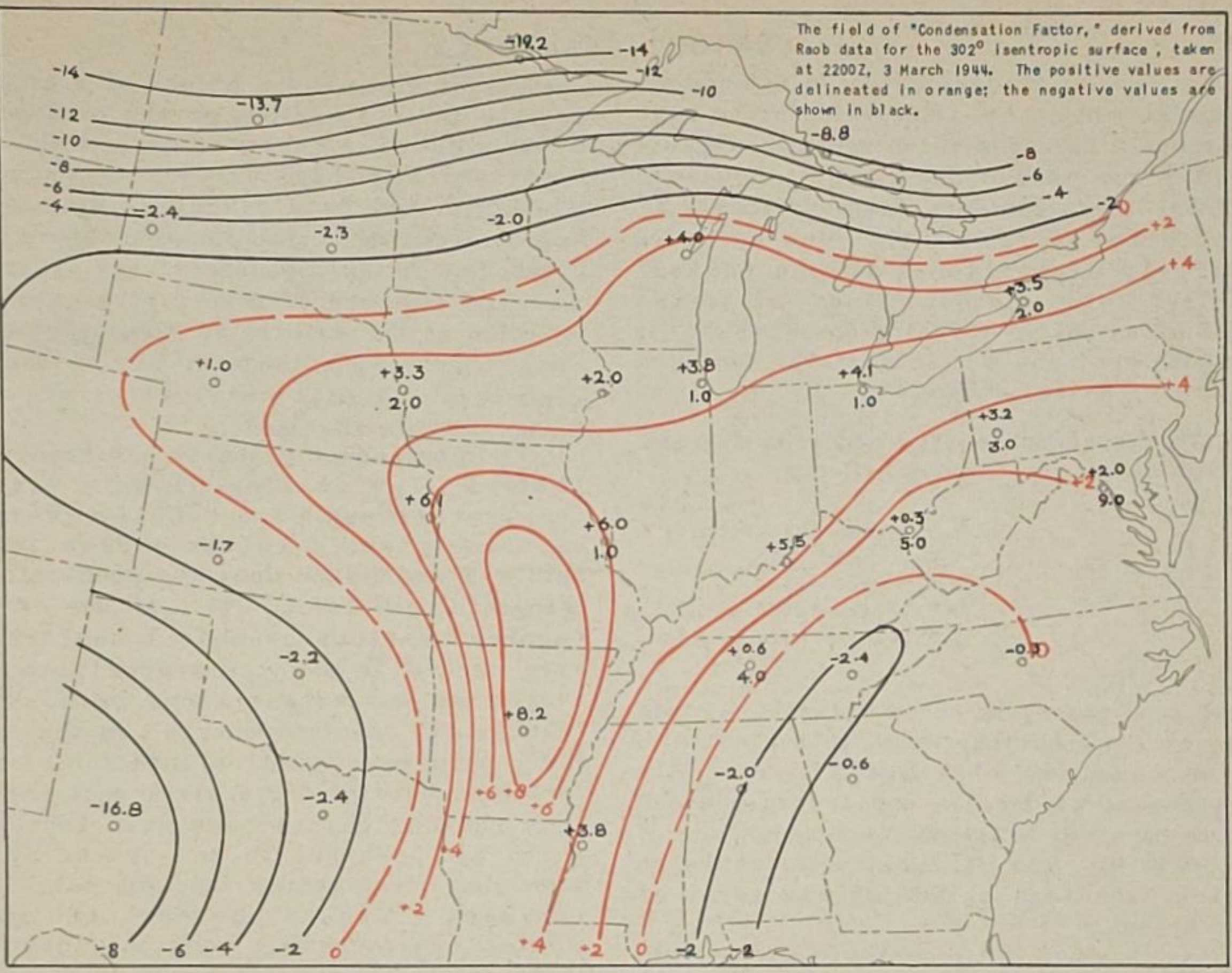
(2)Norton, Brier, and Allen; "A Project to Test the Potential Usefulness of Pressure Patterns for Forecasting," *U.S.W.B. Research Paper No. 2*.

(3)Bjerknes, J, and Holmboe; "On the Theory of Cyclones," *Journal of Meteorology*, September 1944.

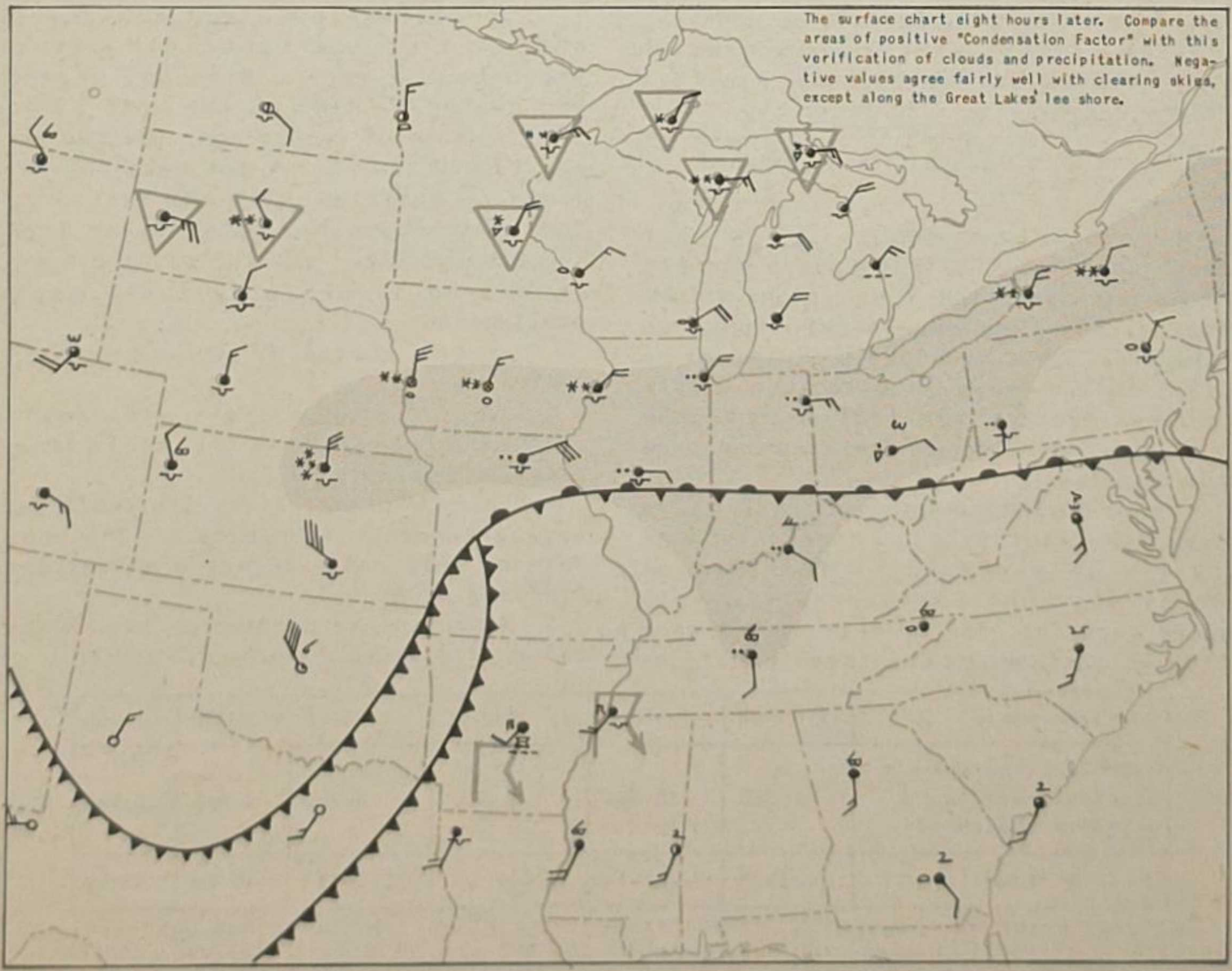
(4)"Determination of the Field of Vertical Motion in the Atmosphere," *Report #3*, AAF Weather Station, New York University, January 1945.

(5)Bjerknes, V, and Sandstrom; *Dynamic Meteorology and Hydrography*, 1910.

(6)Panofsky; "The Effect of Vertical Motion on Local Temperature and Pressure Tendencies," *AMS Bulletin*, September 1944.



The field of "Condensation Factor," derived from Raob data for the 302° isentropic surface, taken at 2200Z, 3 March 1944. The positive values are delineated in orange; the negative values are shown in black.



The surface chart eight hours later. Compare the areas of positive "Condensation Factor" with this verification of clouds and precipitation. Negative values agree fairly well with clearing skies, except along the Great Lakes' lee shore.

CONTOUR CHARTS II

Wind flow is delineated on a constant pressure chart by isopleths of height (contours), data for which would be reported in a new raob code. The winds aloft parallel these contours just as closely as they follow isobars. The wind speed is inversely proportional to the contour spacing. High contour values are to the right of an observer facing downwind in the northern hemisphere. In summary, *contours are analogous to isobars*.

The geostrophic wind equation for the contour chart (p = constant) is:

$$V = \frac{g}{f}\frac{\Delta z}{\Delta n}$$

V = horizontal velocity
$f = 2\,\Omega \sin\phi$
z = height value
n = horizontal distance
g = gravity acceleration

Density obviously is not a variable in this form of the equation; so if g is considered to be constant with height, a single geostrophic wind scale applies to contour charts at every altitude. Contour spacings at 1,000 mb. are directly comparable to contour spacings at 200 mb. in terms of wind speed.

An isotherm on an isobaric surface has a quadruple significance because it can be labelled in terms of temperature, density, potential temperature, and saturation mixing ratio simultaneously. Familiar equations demonstrate this fact:

$$\rho = k\frac{p}{T} \qquad q_s = k\,\frac{f(T)}{p} \qquad \theta = T\left[\frac{1000}{p}\right]^{.288}$$

High temperatures on a constant pressure chart in the troposphere usually are associated with the high contour values. Similarly, low temperatures are found at low heights. This paradox is explained by the fact that a warm, light column of air occupies a greater vertical extent than does a cold, heavy column between the same pressure limits.

The pressure tendency, which plays such an important role in constant-level analysis, is replaced by the "height tendency" in constant-pressure usage. Pressure surfaces rise or fall over a raob station as the atmosphere there undergoes changes of state. The height of a pressure surface is at a minimum in the presence of a Low, and at a maximum for a High. The phase relationships between contours and isotherms indicate advective changes in the same manner that isobar-isotherm patterns do. Height tendencies are always of the same sign and of comparative values in relation to the associated pressure tendencies. The height tendency can be used in kinematic calculations just as pressure tendencies are now used.

During recent years it has been found that the forecasting of *mean* virtual temperature and *mean* density (weight) patterns gives a better indication of future changes than does the prediction of changes at one level. To make use of this theorem, various graphical subterfuges were needed to produce approximate mean isotherms and weight lines on constant level maps. Contour charts, on the other hand, permit an exact delineation of mean variables by direct graphical subtraction. Only contour charts have mean isotherms which are parallel to and spaced by the mean wind shear vector (the Thermal Wind). The mean isotherms between two given contour charts have a constant interval; their constant-level counterparts do not.

Constant-level and contour-chart analysis of the upper air situation throughout a recent five day period are shown side by side on the next 13 pages. For the sake of comparison, the 700 mb. and the 10,000 ft. charts for each day between 6 and 10 February 1945 are included, and four pairs of other maps appear for both the 8th and 9th. The following conventions were used in drafting these maps for publication:

Solid, black lines are isobars or contours.

Solid, orange lines are isotherms.

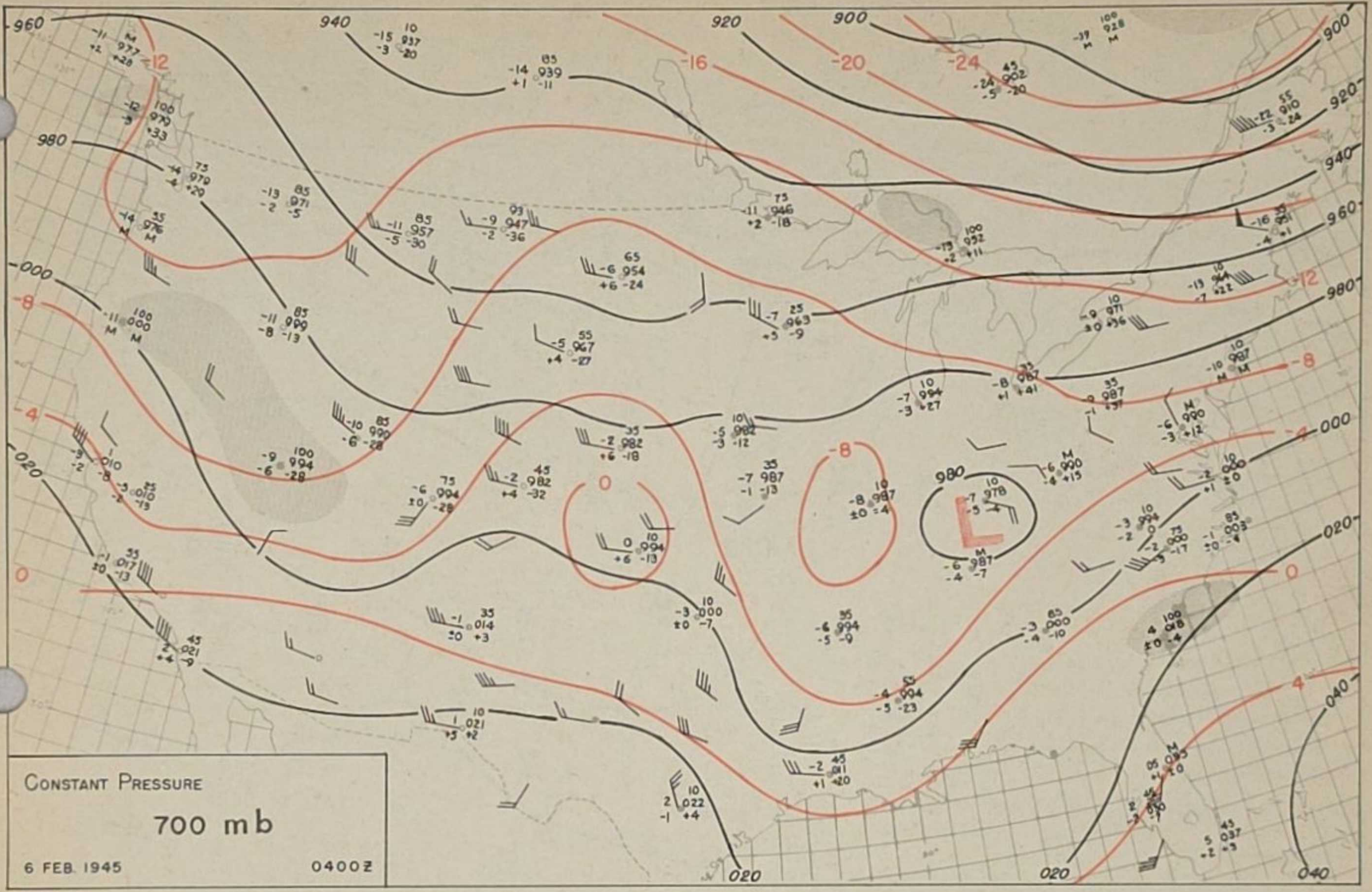
Stippled, gray areas indicate a relative humidity of 100%.

Dashed, orange lines are isallobars or height-tendency isopleths. (The unorthodoxy of this representation solves special printing problems).

A pennant is plotted on wind arrows in place of five full barbs (50 mph).

On this chart:	1,000mb	850mb	700mb	500mb	300mb	200mb
A 200-foot height changes equals a pressure change of:	7.5mb	6.4mb	5.3mb	3.7mb	2.3mb	1.5mb
On this fixed level:	Surface	5,000 ft	10,000 ft	20,000 ft	10 km	13 km

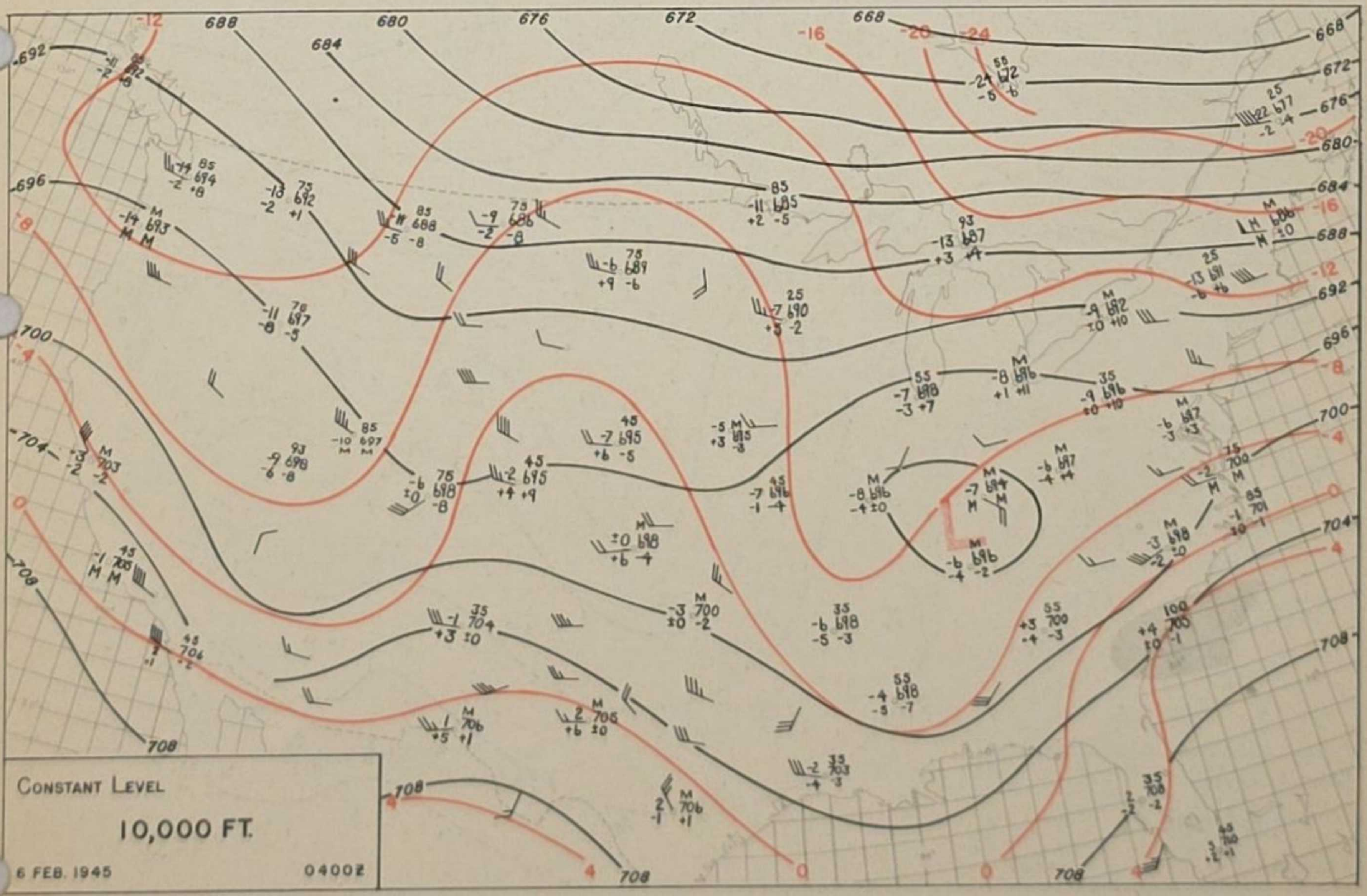
THE PRESSURE VALUE OF A 200-FOOT HEIGHT CHANGE. THIS TABLE IS USEFUL FOR COMPARING HEIGHT CHANGES WITH PRESSURE CHANGES, AND FOR COMPARING CONTOUR GRADIENTS WITH PRESSURE GRADIENTS.



CONSTANT PRESSURE

700 mb

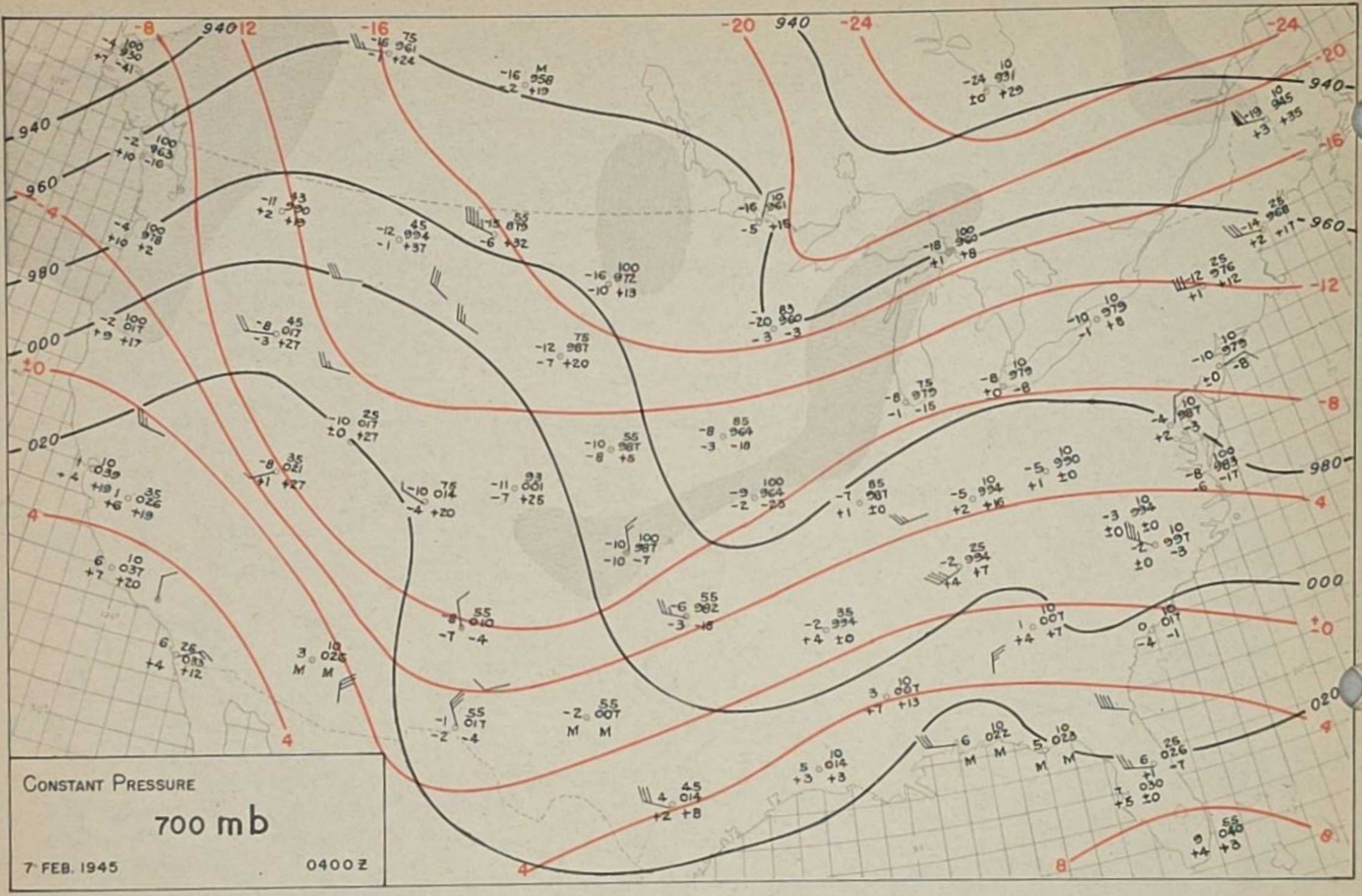
6 FEB. 1945 0400Z



CONSTANT LEVEL

10,000 FT.

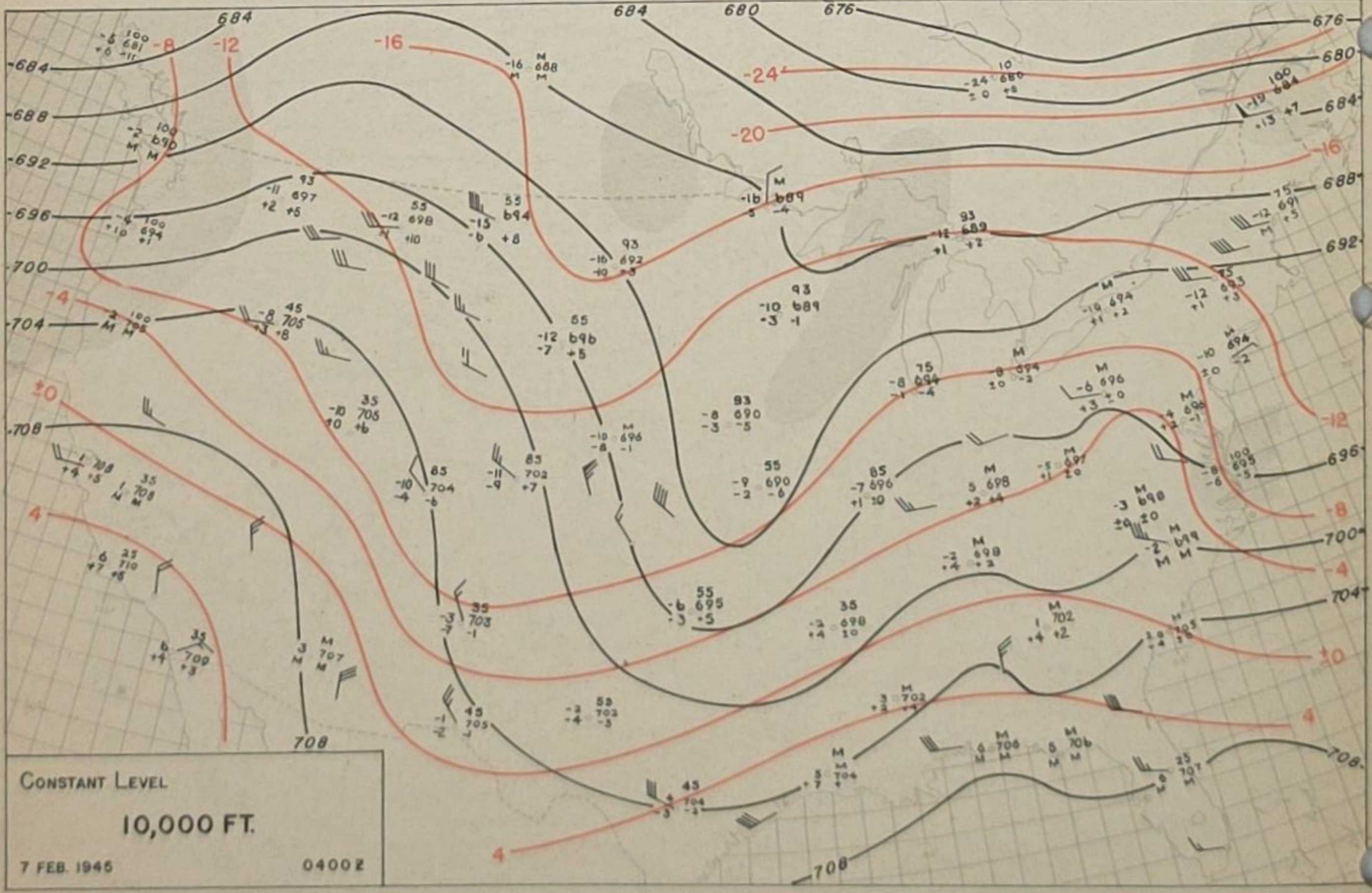
6 FEB. 1945 0400Z



Constant Pressure

700 mb

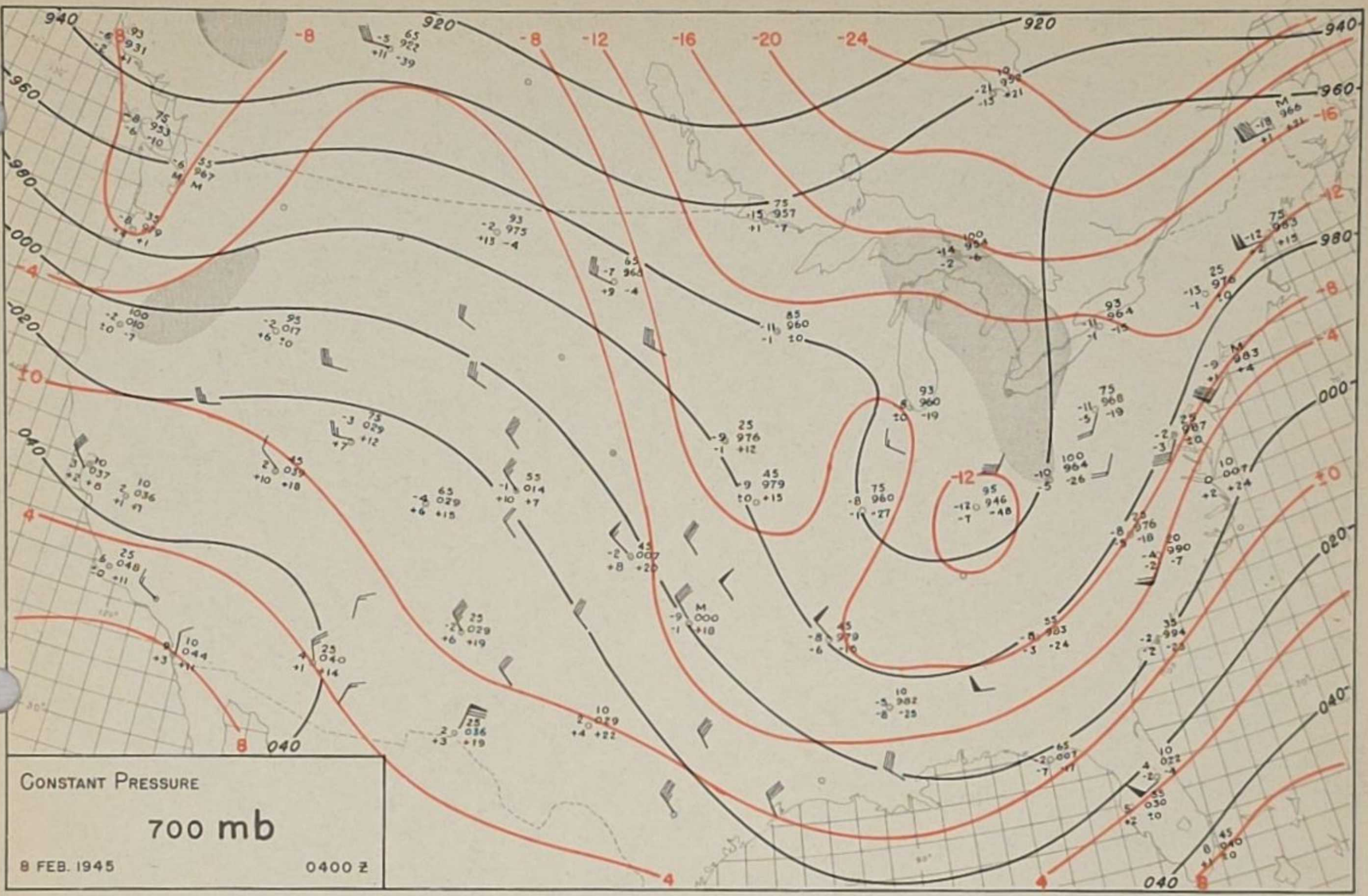
7 FEB. 1945 0400Z



Constant Level

10,000 FT.

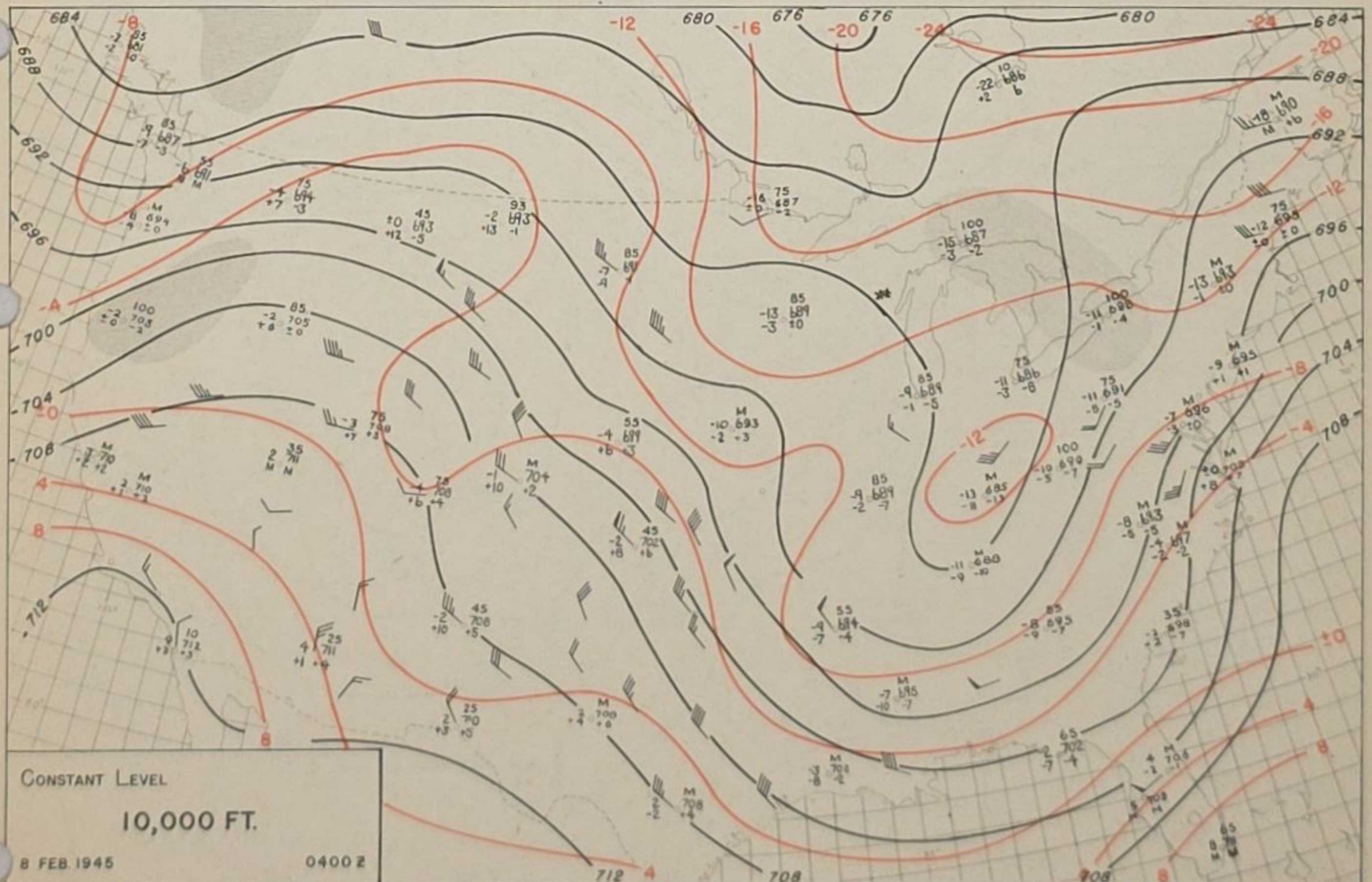
7 FEB. 1945 0400Z



CONSTANT PRESSURE

700 mb

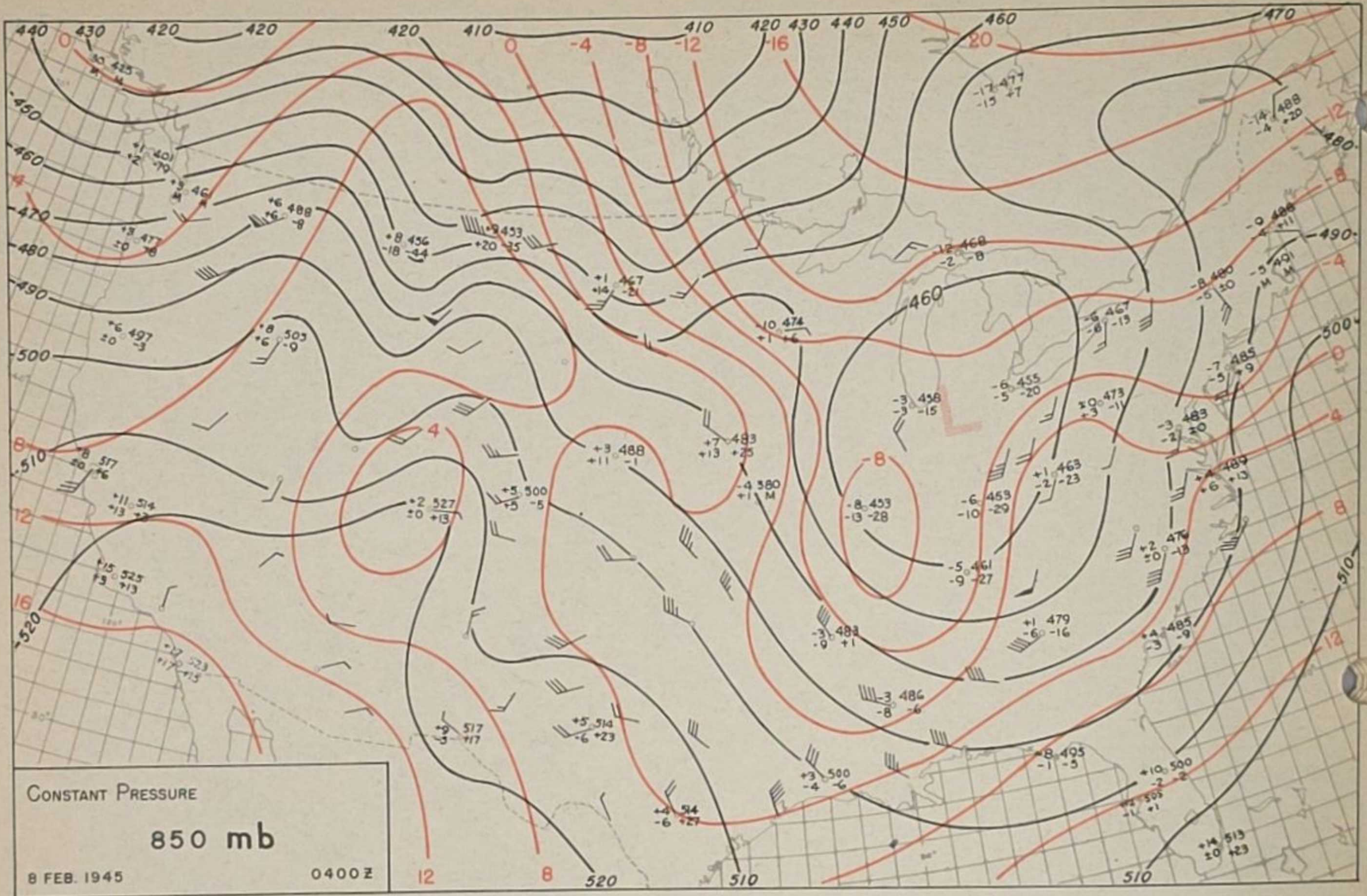
8 FEB. 1945 0400 Z



CONSTANT LEVEL

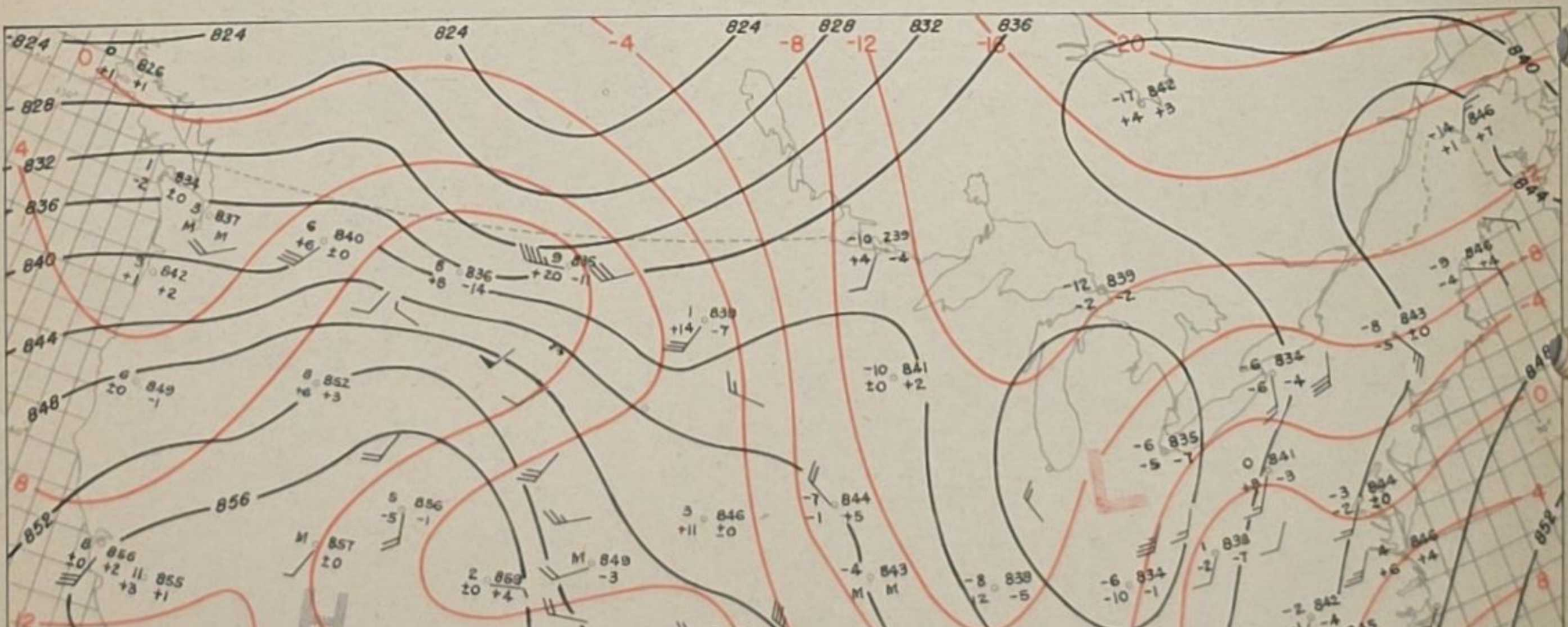
10,000 FT.

8 FEB. 1945 0400 Z


CONSTANT PRESSURE

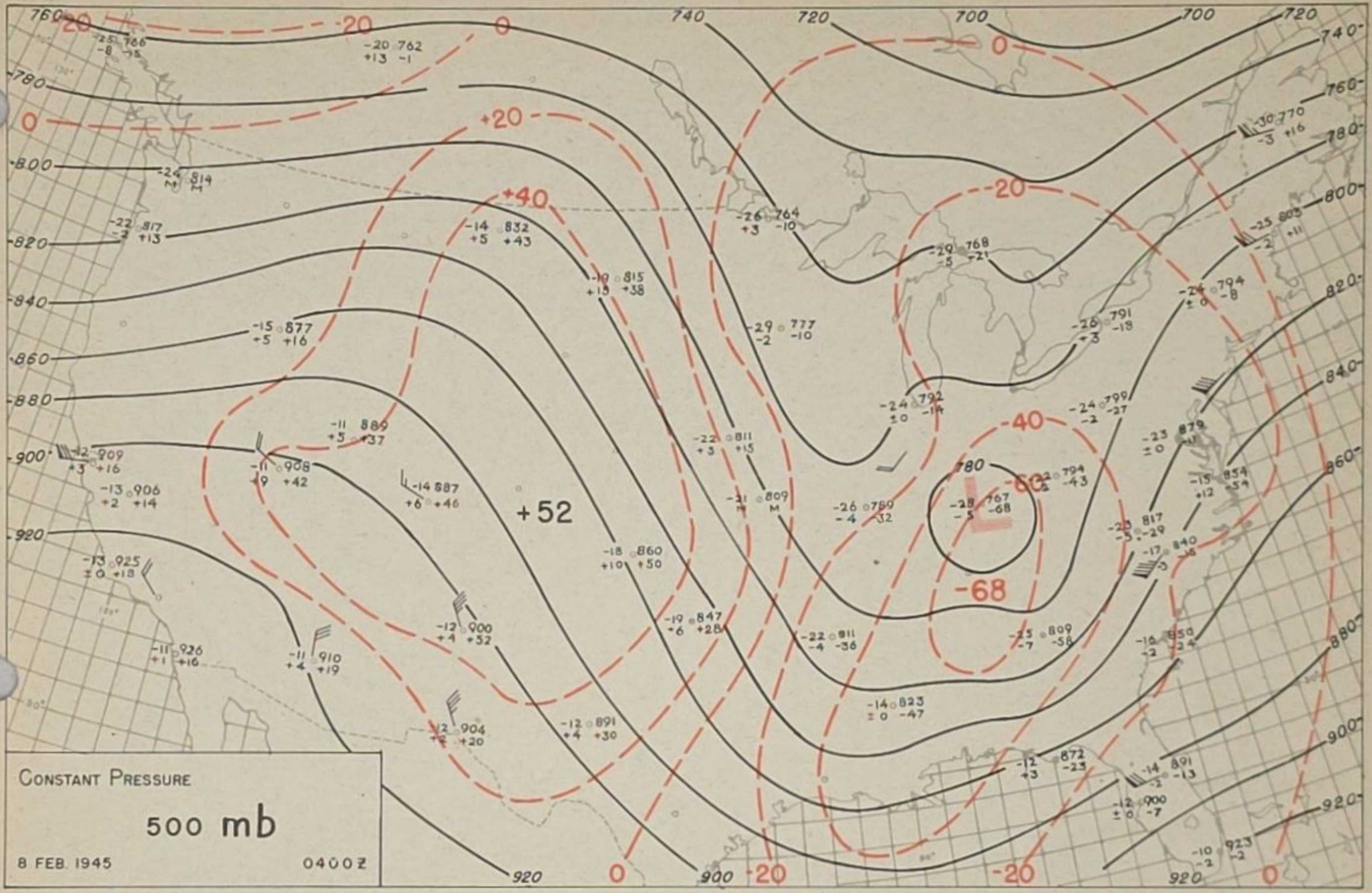
850 mb

8 FEB. 1945 0400Z


CONSTANT LEVEL

5,000 FT.

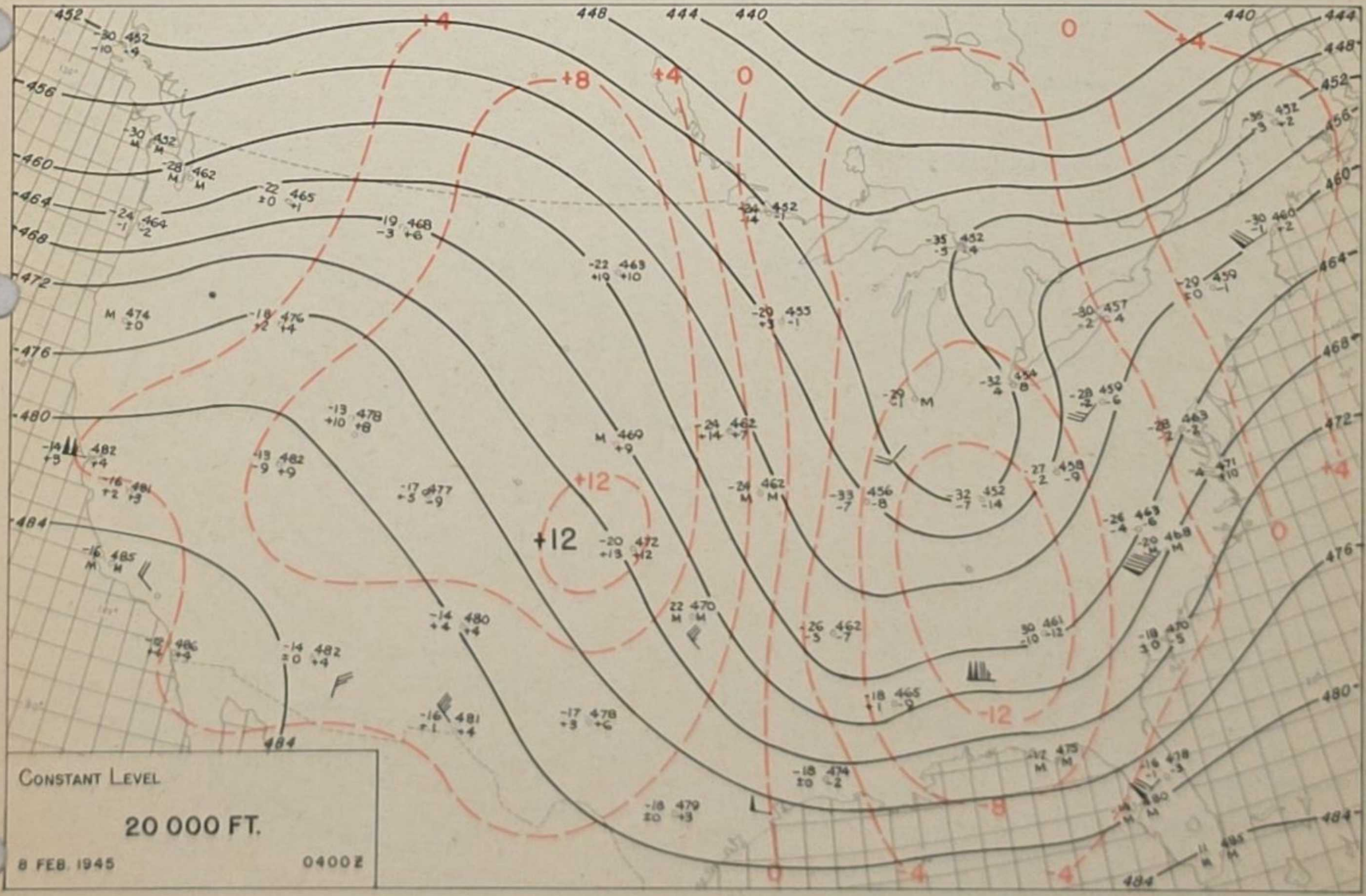
8 FEB. 1945 0400Z



CONSTANT PRESSURE

500 mb

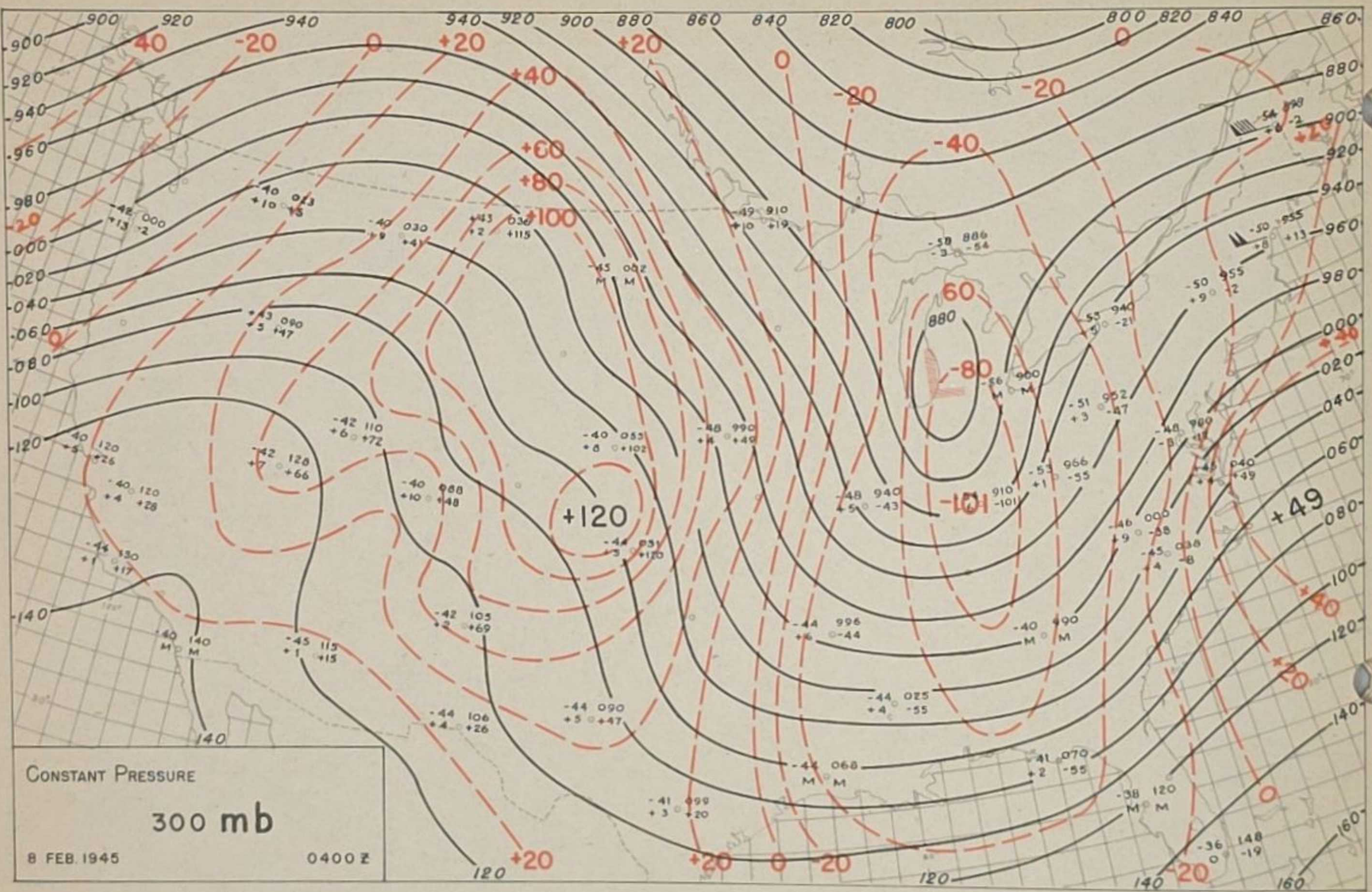
8 FEB. 1945 0400Z



CONSTANT LEVEL

20 000 FT.

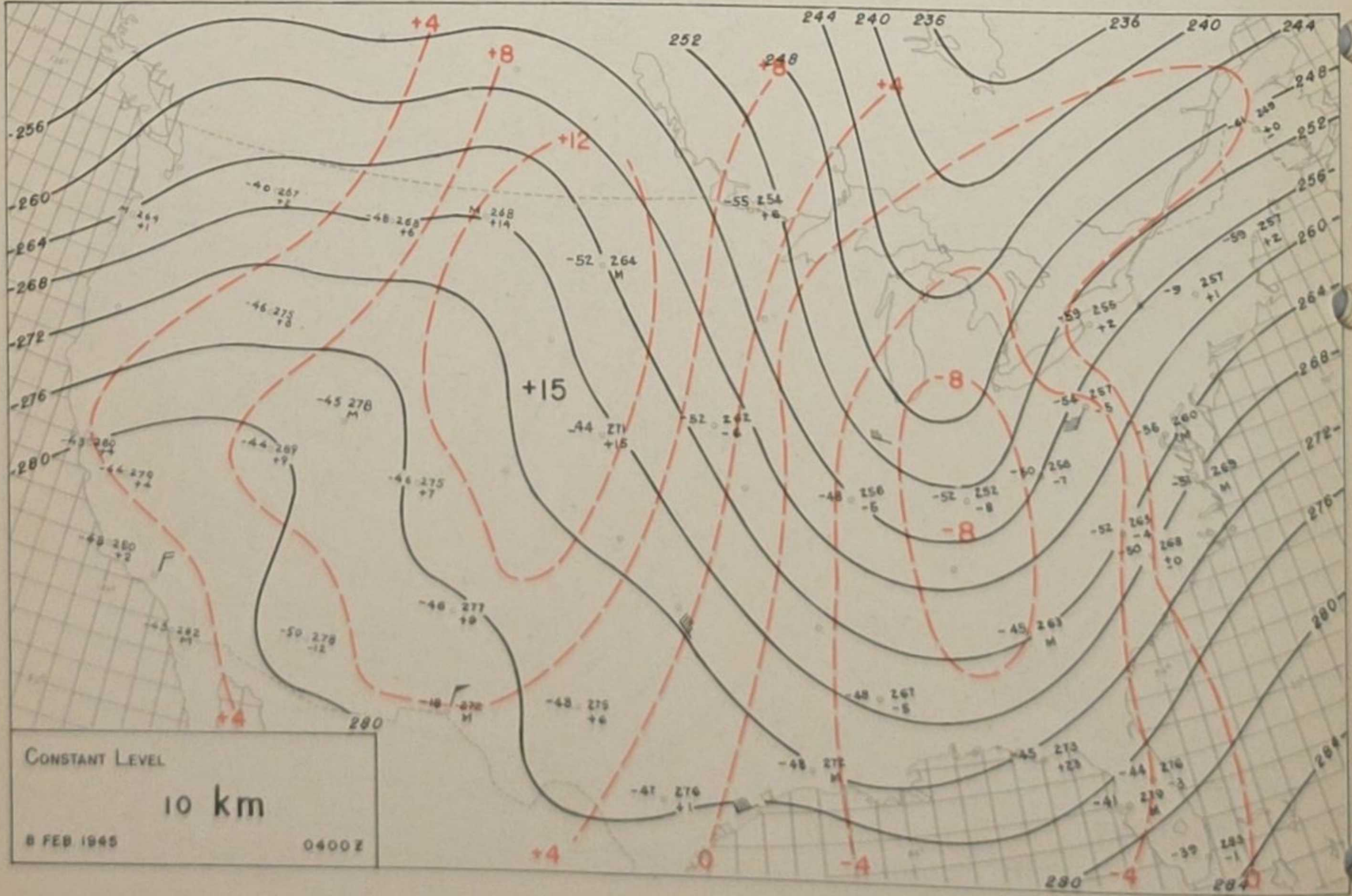
8 FEB. 1945 0400Z



CONSTANT PRESSURE

300 mb

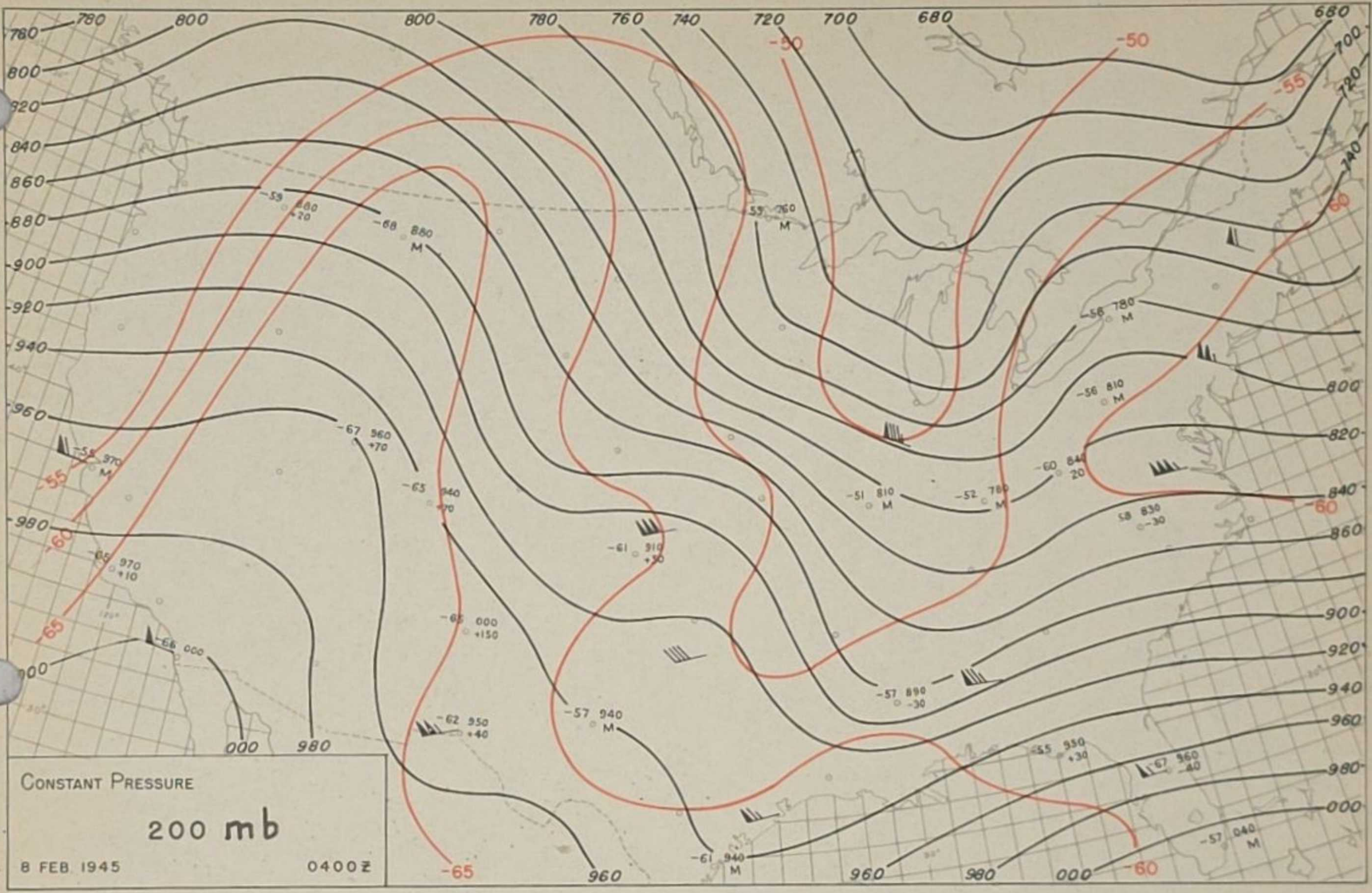
8 FEB. 1945 0400 Z



CONSTANT LEVEL

10 km

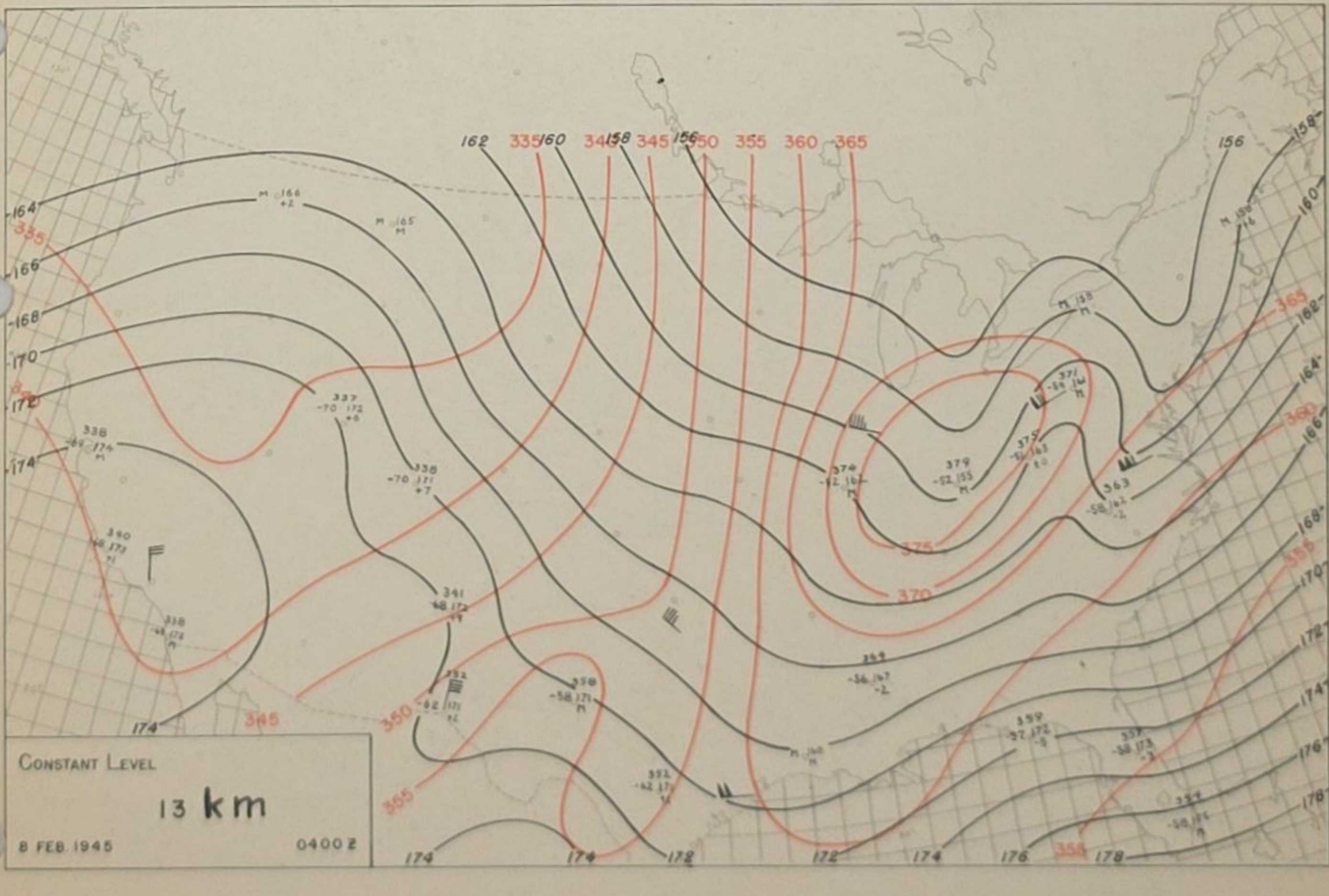
8 FEB. 1945 0400 Z



Constant Pressure

200 mb

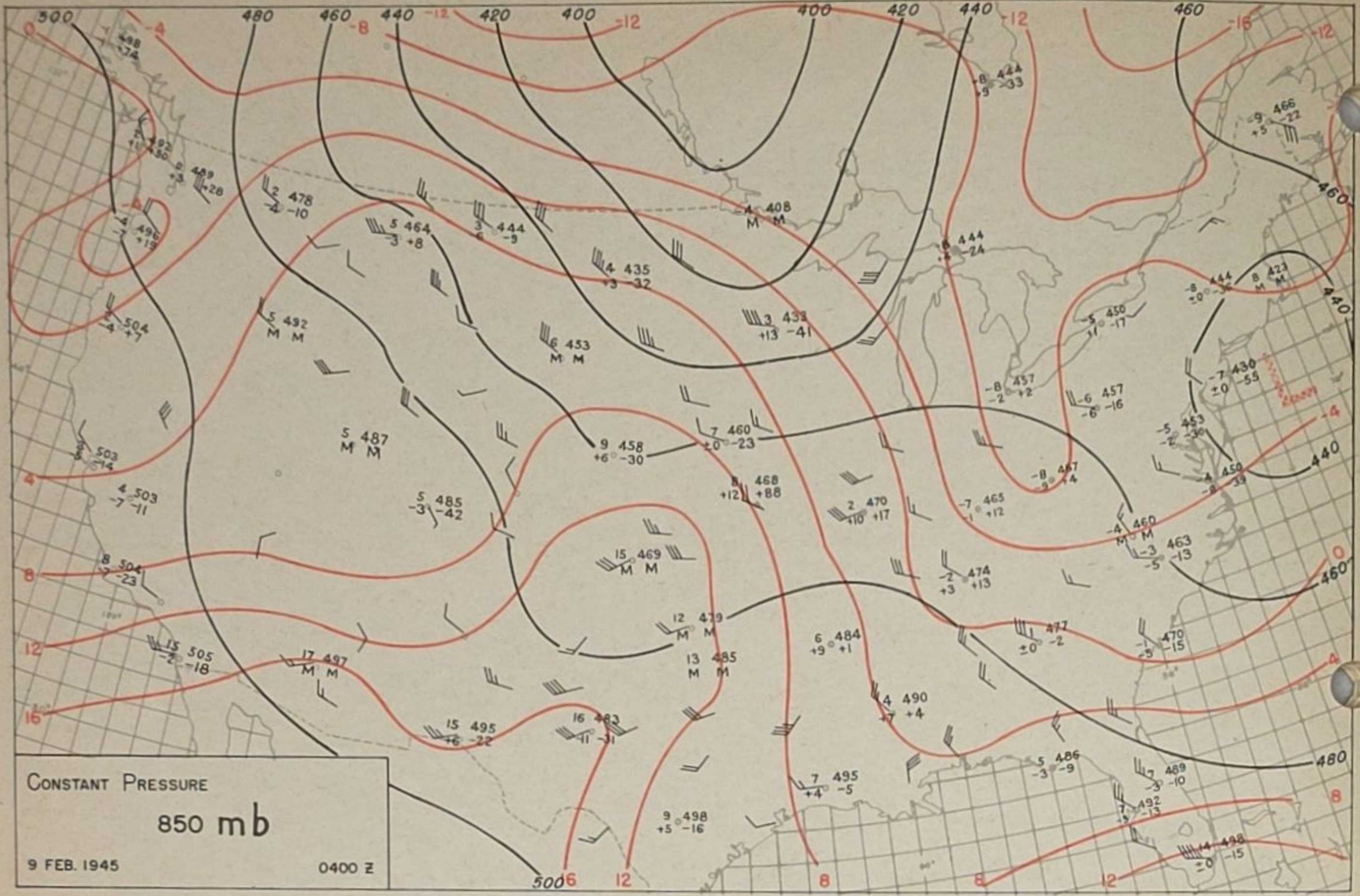
8 FEB. 1945 0400Z



Constant Level

13 km

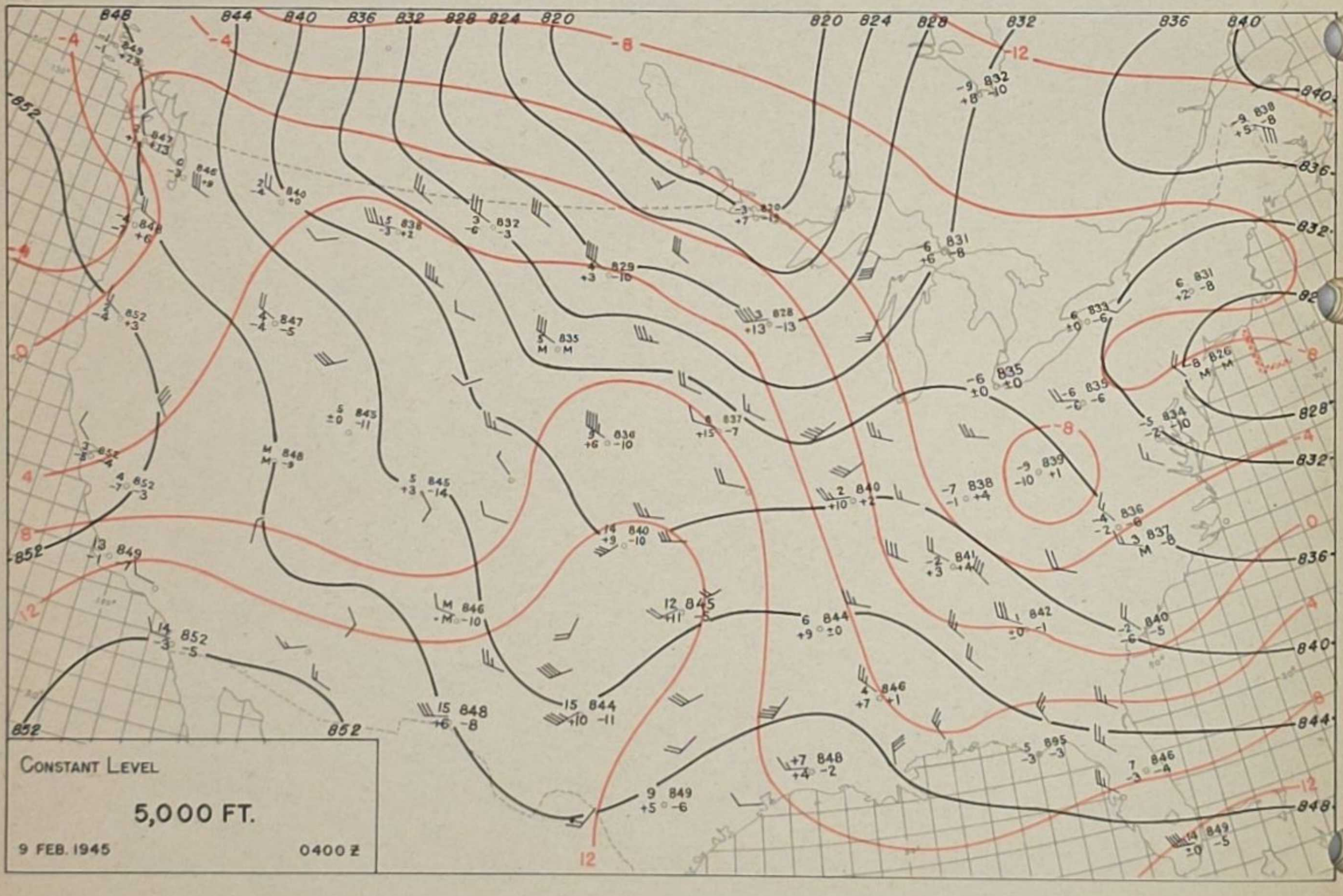
8 FEB. 1945 0400Z



CONSTANT PRESSURE

850 mb

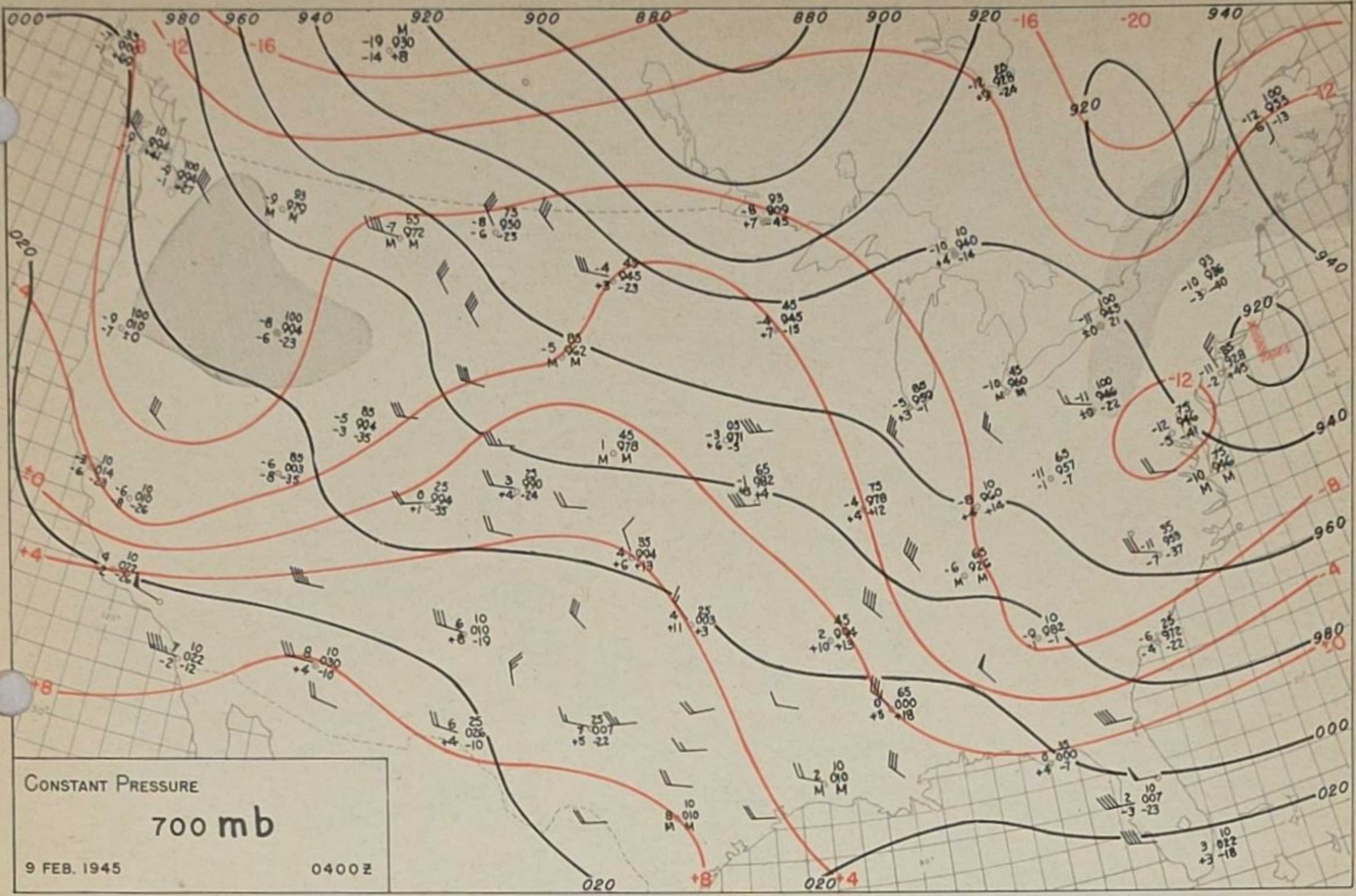
9 FEB. 1945 0400 Z



CONSTANT LEVEL

5,000 FT.

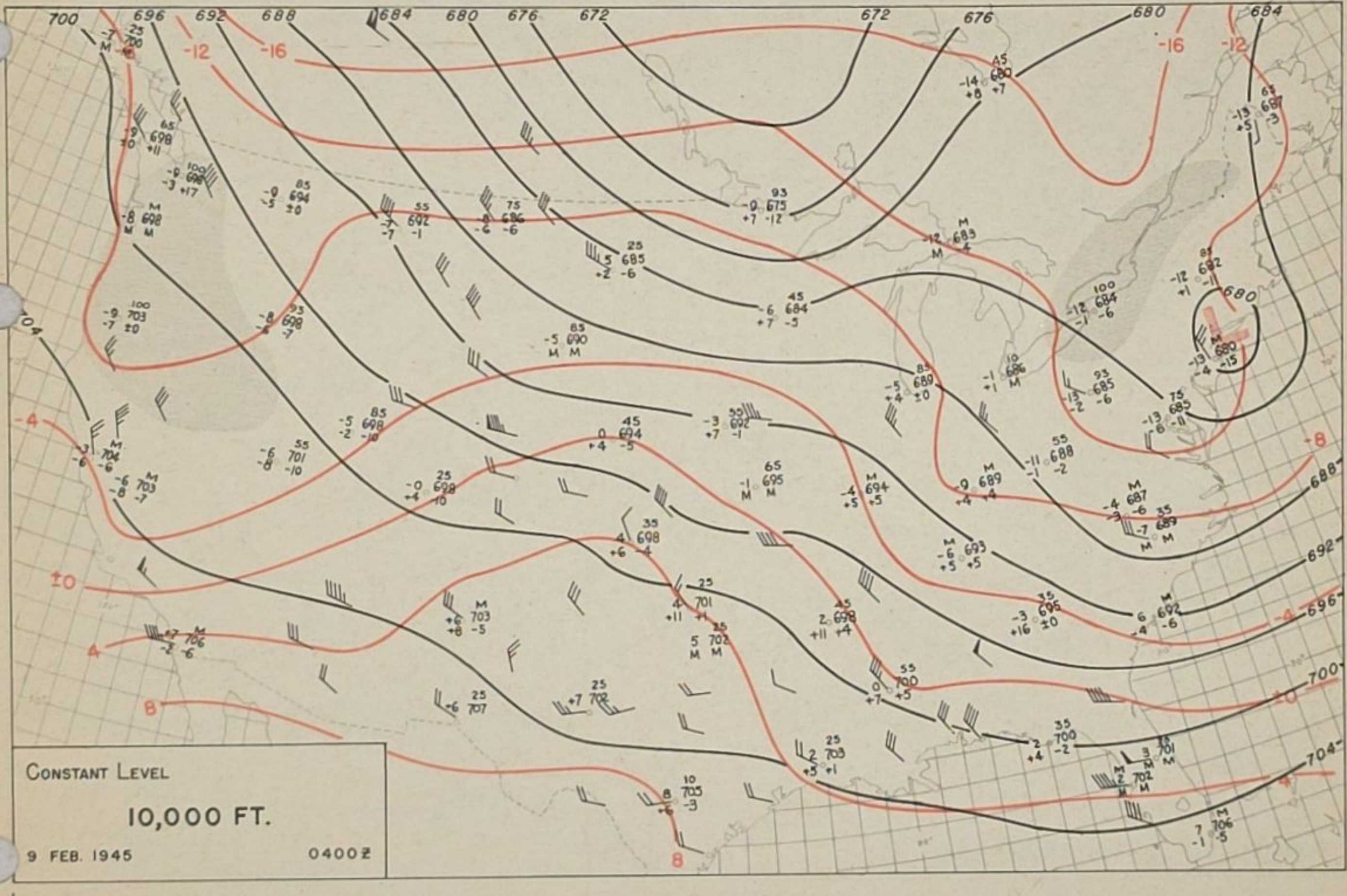
9 FEB. 1945 0400 Z



CONSTANT PRESSURE

700 mb

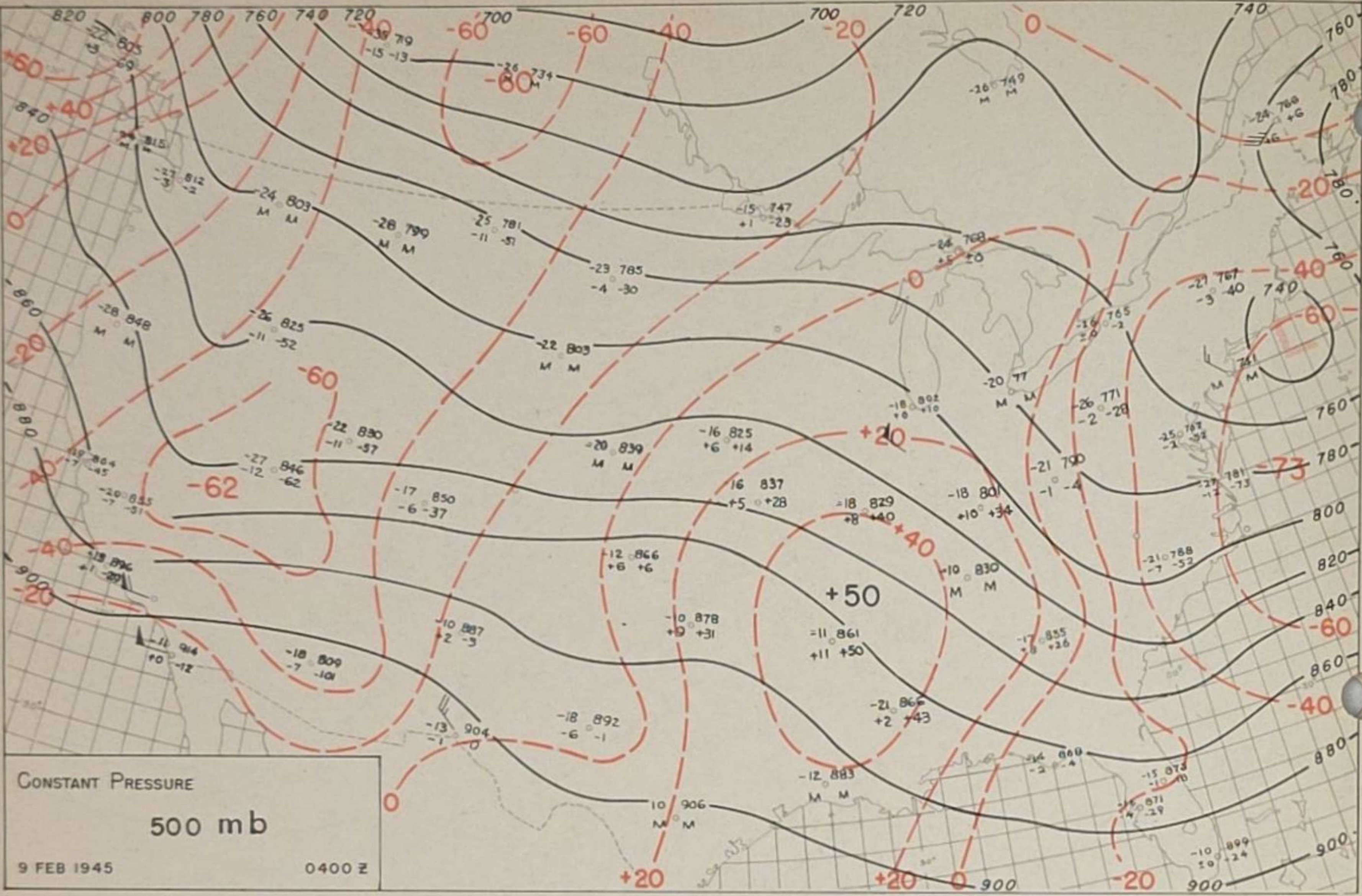
9 FEB. 1945 0400Z



CONSTANT LEVEL

10,000 FT.

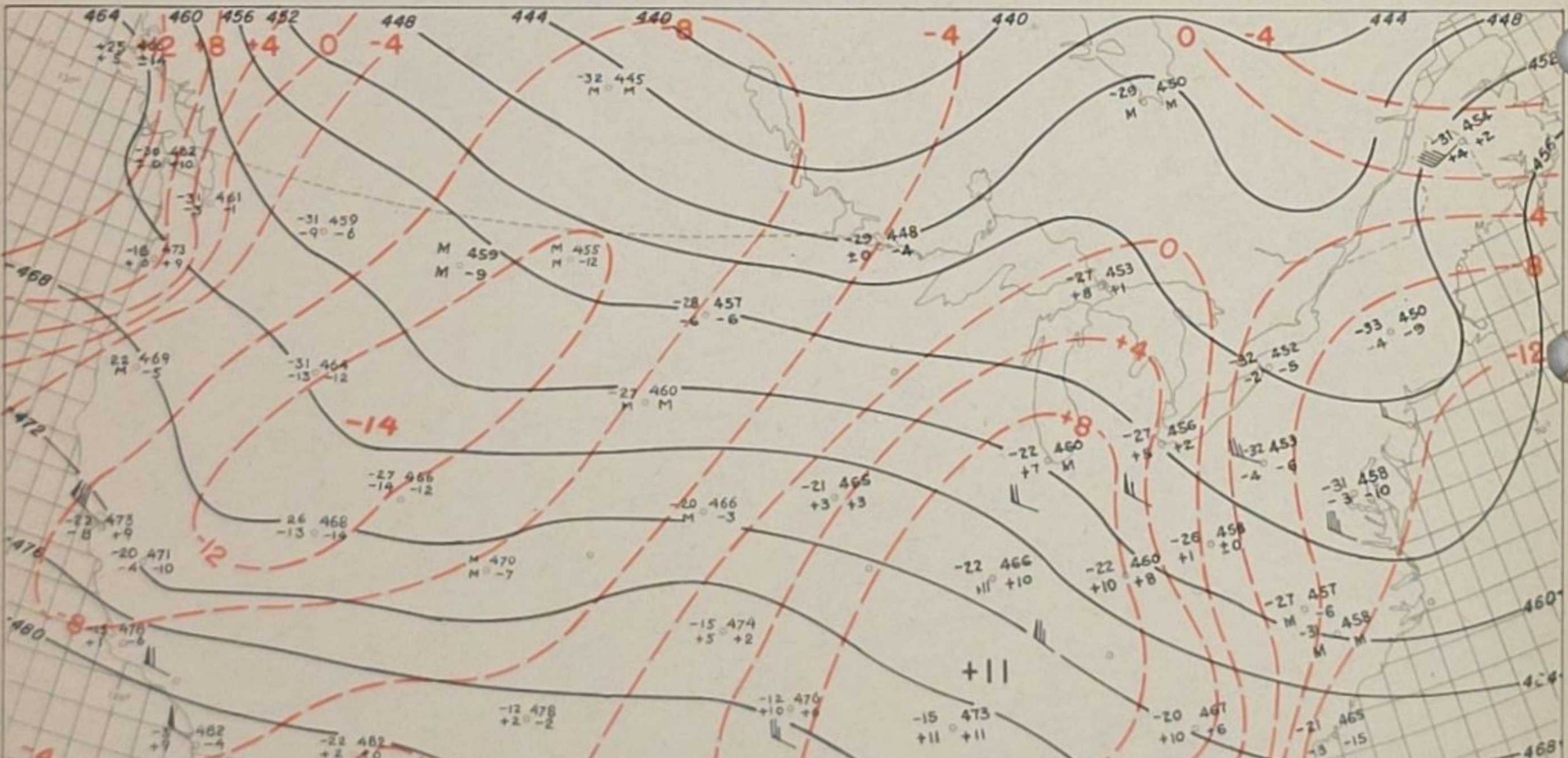
9 FEB. 1945 0400Z



CONSTANT PRESSURE

500 mb

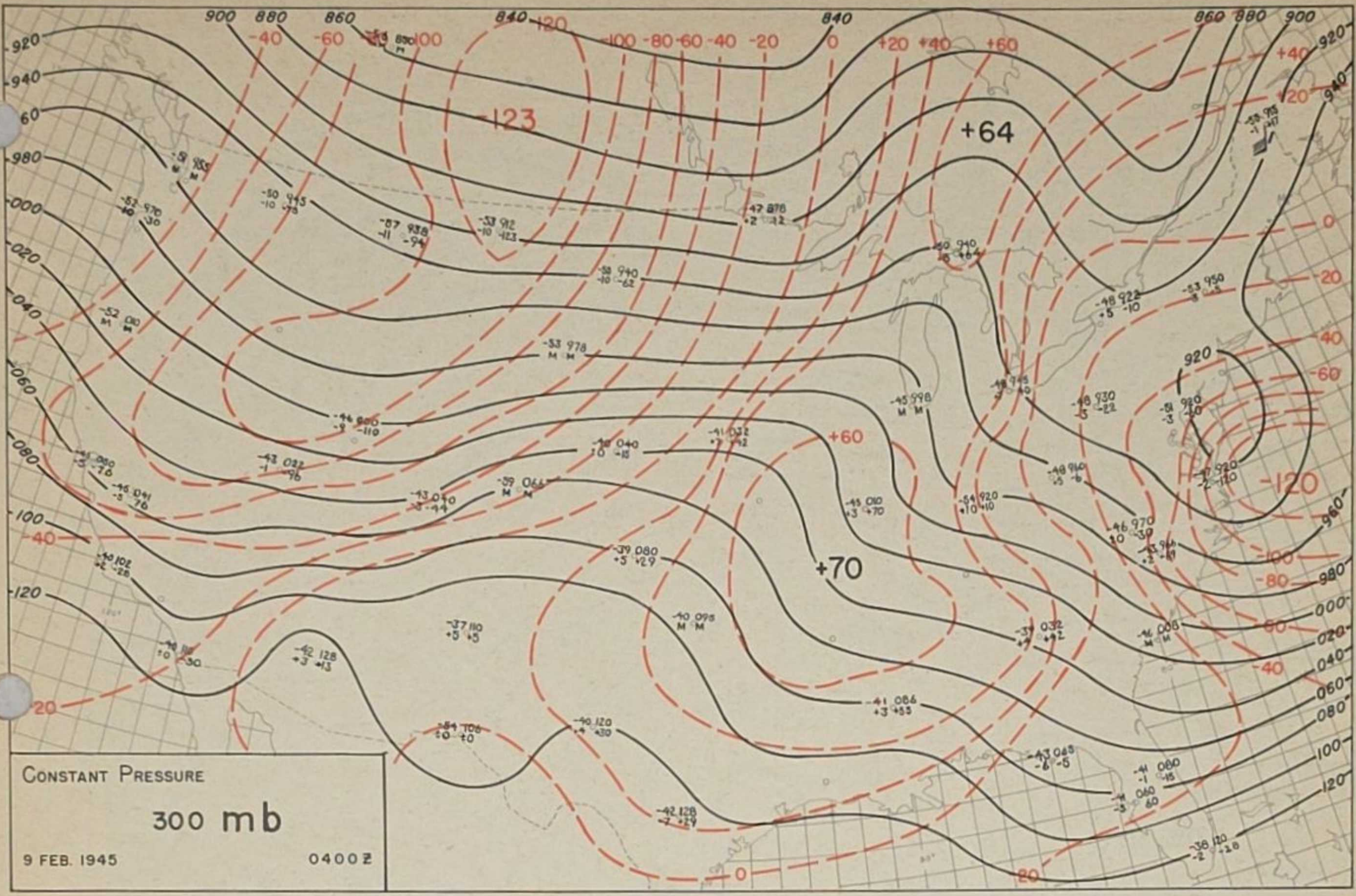
9 FEB 1945 0400 Z



CONSTANT LEVEL

20,000 FT.

9 FEB. 1945 0400 Z

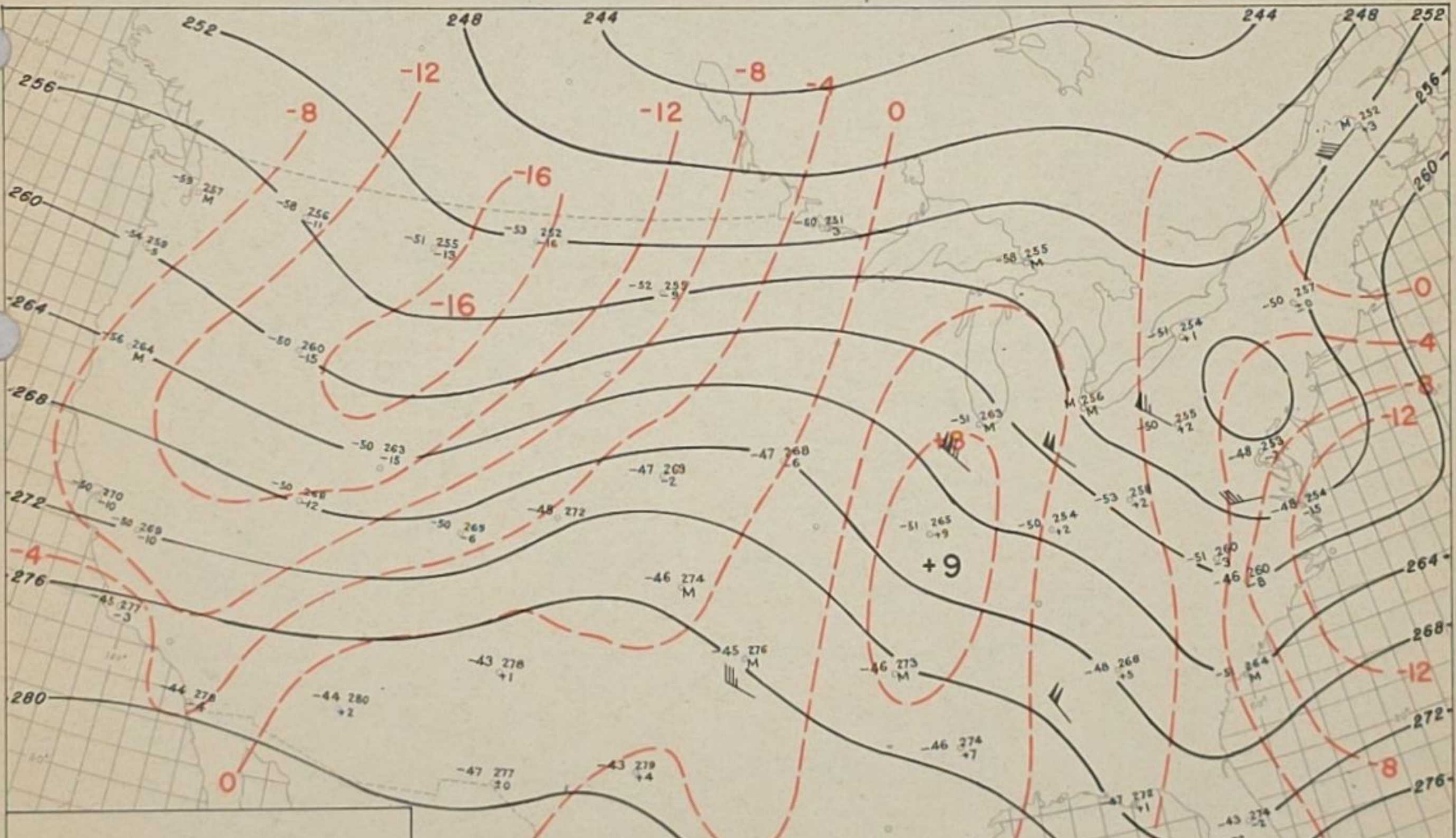


CONSTANT PRESSURE

300 mb

9 FEB. 1945

0400Z

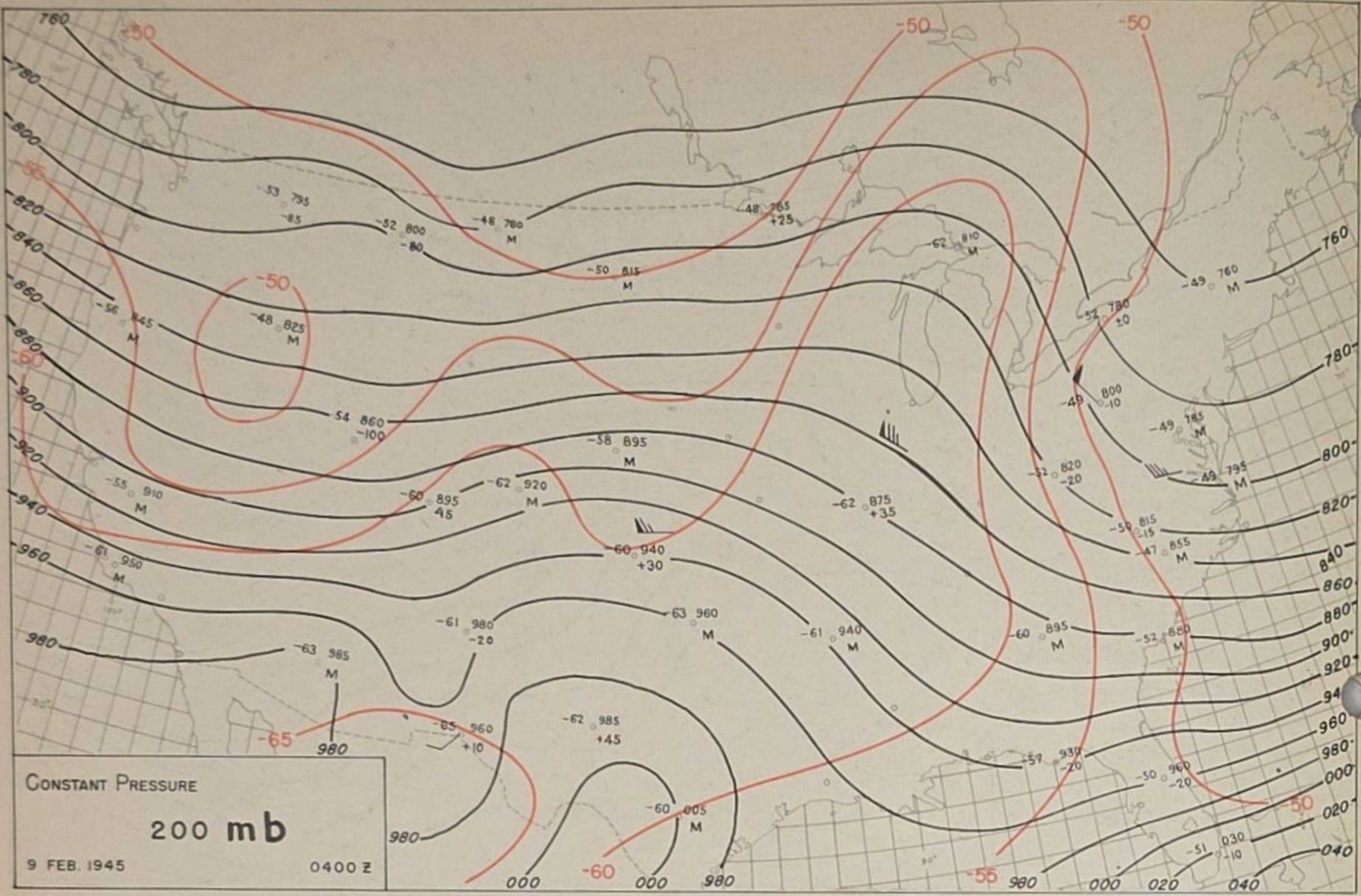


CONSTANT LEVEL

10 km

9 FEB. 1945

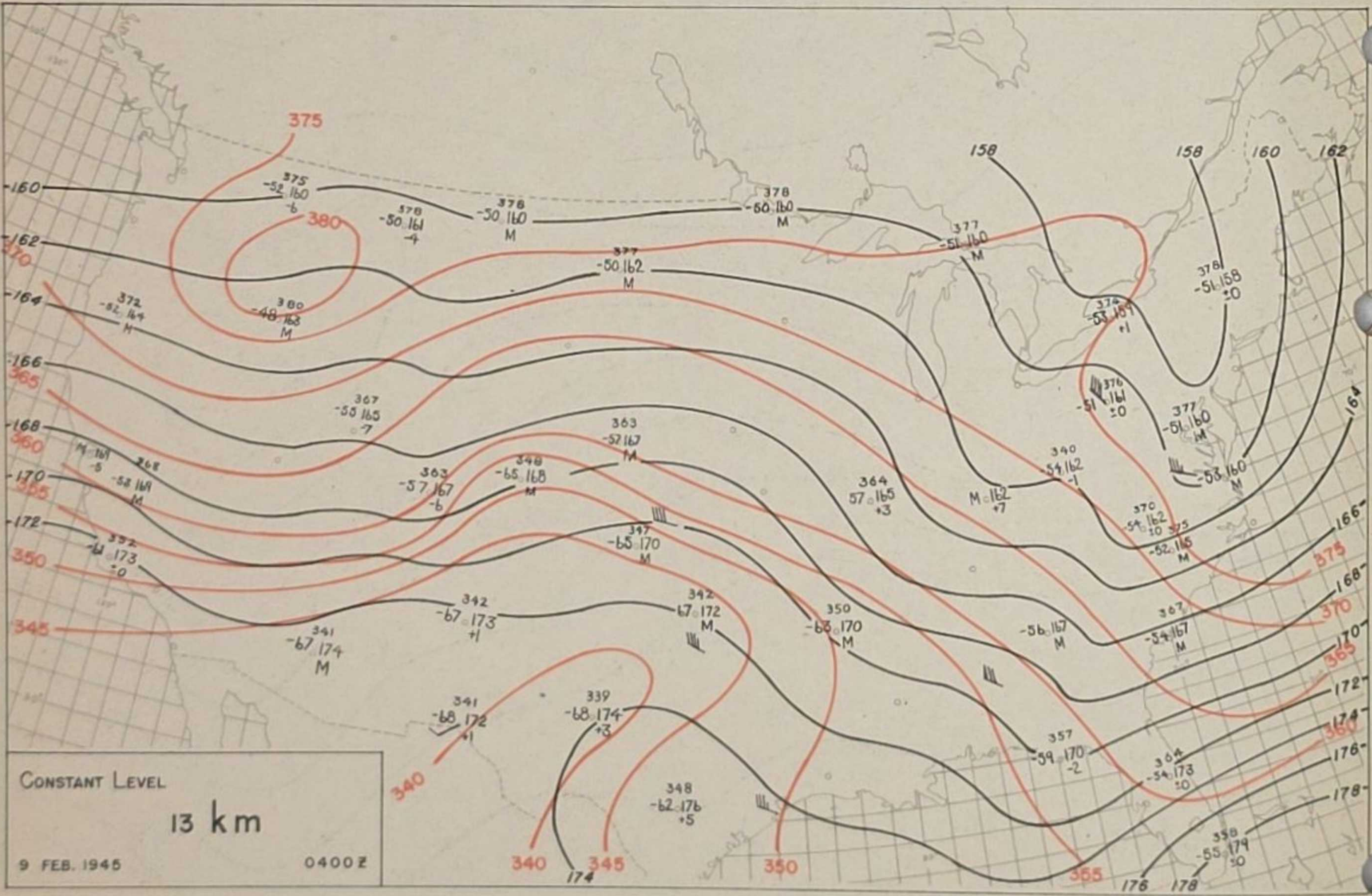
0400Z



CONSTANT PRESSURE

200 mb

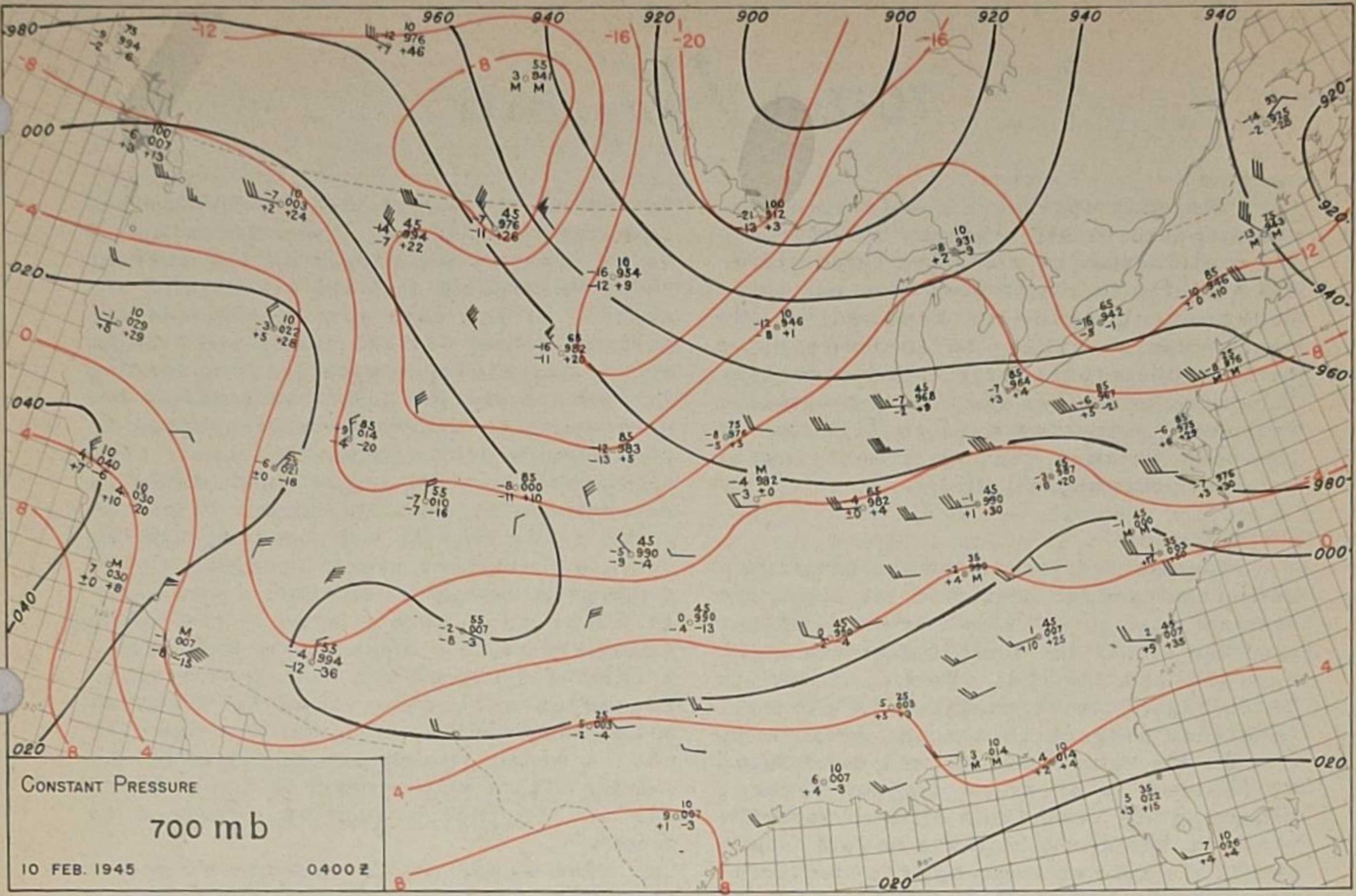
9 FEB. 1945 0400 Z



CONSTANT LEVEL

13 km

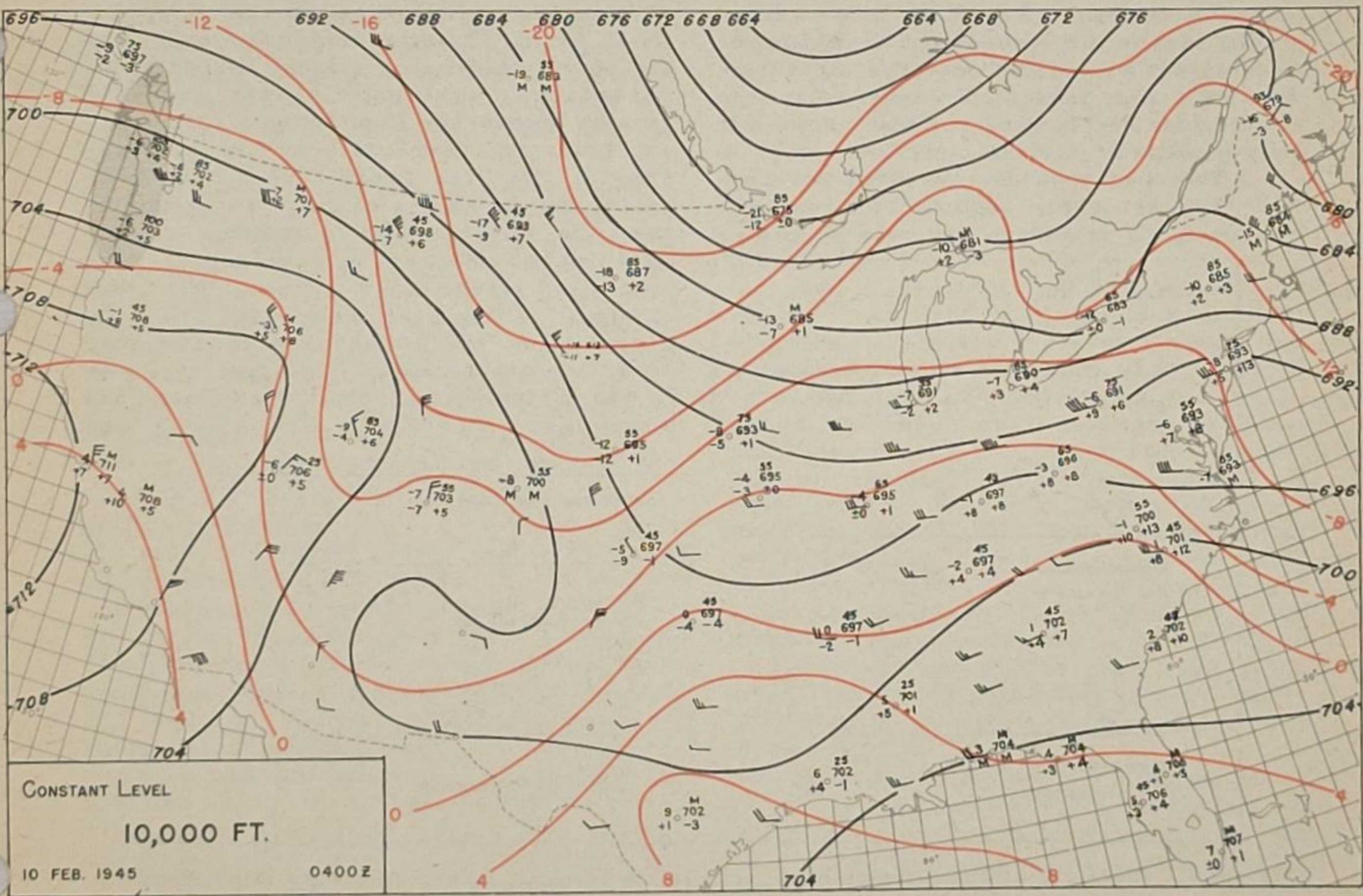
9 FEB. 1945 0400 Z



CONSTANT PRESSURE

700 mb

10 FEB. 1945 0400Z



CONSTANT LEVEL

10,000 FT.

10 FEB. 1945 0400Z

700 mb *Prognosis*

The many upper-air charts which are now prepared in AAF stations do delineate the distribution of windflow, temperature, and humidity in the troposphere; but their forecasting value is limited by the weatherman's ability to anticipate the daily redistribution of these elements. This article reviews the modern prognostic methods, presenting them in light of an imminent Weather Service transition to constant-pressure analysis.

EXTRAPOLATION

The average forecaster who constructs 24-hour prognostic charts of the upper air does not have enough time to make quantitative use of all the techniques which might be valuable to him. For that reason "*intelligent* extrapolation" is the most important prognostic method, because it reveals the future velocity and development of contour or pressure systems without requiring the evaluation of each variable which is involved. But the method is not properly a rule of thumb by which deliberation can be avoided: mechanical forecasting commonly leads to a haphazard combination of success and failure. Intelligent extrapolation---the *consideration* of *trends* in the *components* of motion ---requires little more time and offers far more promise of verification.

The charts which have been prepared for the last three raob collections are reviewed, to determine the rate of change in various characteristics of windflow and temperature patterns. The orientation of major troughs and ridges on the current chart is compared with the orientation and spacing of the same systems one and two periods before. If the ridges and troughs are moving closer together (or spreading farther apart), the indicated tendency for wavelength to decrease (or increase) is continued on the prognostic chart. The speed of individual troughs and ridges is determined for each of the two intervals between past charts; and when a system has shown a consistent trend in velocity, the prognostic movement is adjusted accordingly. If minor troughs and ridges are being steered by major systems at the same level, a careful study of the anticipated relationships will give valuable clues to sudden deepening or filling. For example, when a minor trough can be forecast to combine with a major trough on the prognostic chart, that trough is expected to deepen.

The speed and structure of moving troughs and ridges vary with the strength of the zonal westerlies, measured by the Zonal Index. Troughs with large amplitude and short wavelength, typical of Low Index situations, move more slowly and with greater regularity than troughs with small amplitude and comparatively longer wavelength, the High Index type. The forecaster who correctly anticipates trends in the Index from one type to another, thereby anticipates changes in wavelength, wave speed, and structure of systems. The broad changes which take place in westerly circulation are relatively continuous, slow, and *foreseeable*. Teletype circuits in the United States report the current and prognostic indices every Monday and

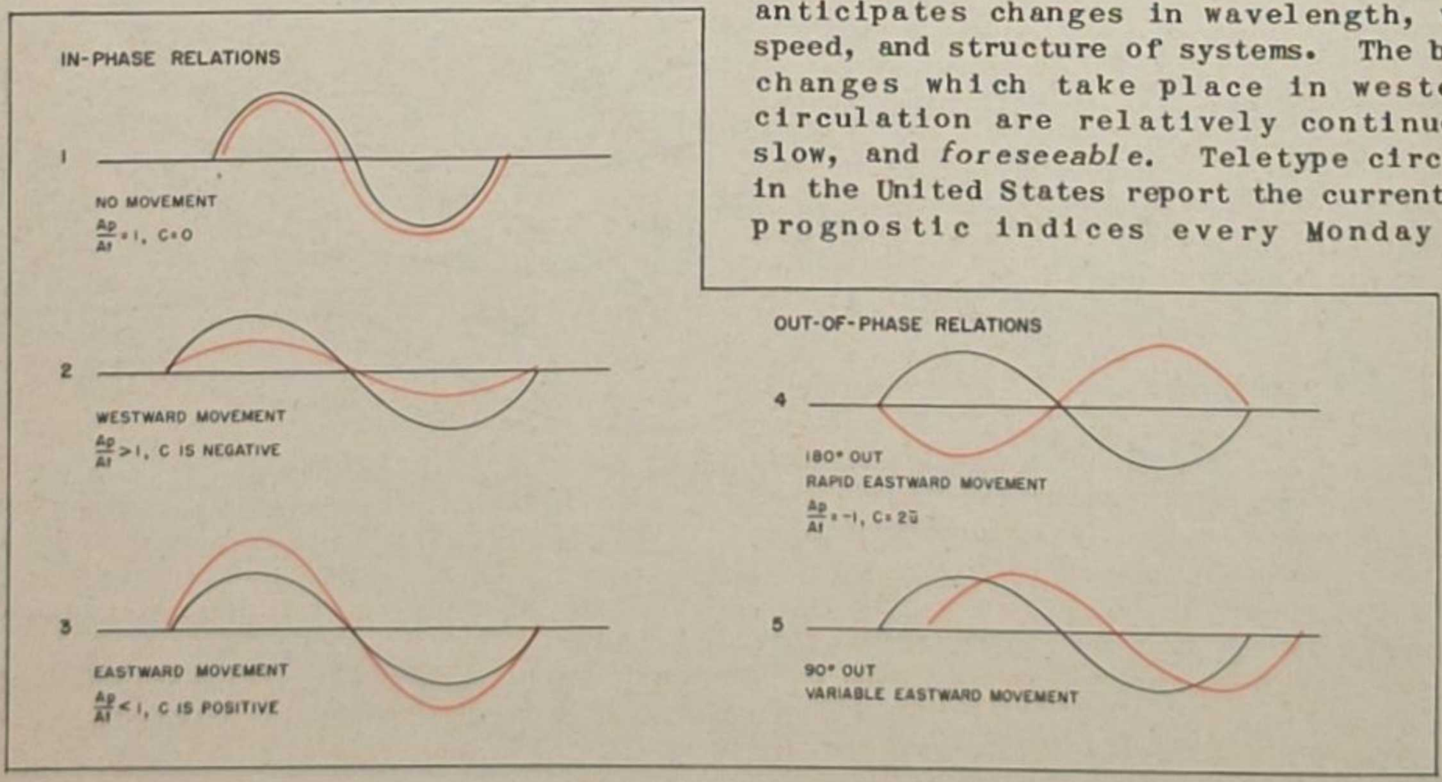


Figure 1: Contour-Isotherm Relationships foretell the movement of systems on the 700mb chart.

Thursday evening which have been prepared by the USWB's Extended Forecast Unit. The Index technique for 700mb prognosis is really a form of intelligent extrapolation which extends the forecaster's vision in time and space (1).

CONTOUR-ISOTHERM RELATIONSHIPS (2)

Advective changes in circulation and in temperature may be foretold from the phase relationship of contours (isobars) to isotherms. Mere inspection of their relative orientation indicates the speed and general direction to be taken by contour (pressure) systems, according to the rules stated in figure 1. A formulation of the phase relationship, applicable to both contour and constant-level charts, can be used quantitatively if sufficient time is available for accurate measurement. It is:

$$C = \overline{U}\left[1 - \frac{Ap}{At}\right]$$

where

C = speed of wave systems
$\overline{U}$ = Mean speed of the Westerlies
Ap = Amplitude of contours (isobars)
At = Amplitude of isotherms

Various contour-isotherm relationships are shown in figure 1, along with the ($\frac{Ap}{At}$) value which is appropriate for each one. Weather Wing policy restricts the application of this formula; only those stations which receive complete, reliable data for the Zone of Westerlies *on a hemispheric scale* may use it.

Cold-air advection in the northwest quadrant of a trough at 700mb (10,000 ft) usually is followed by intensification and retardation of the trough. Although this rule seems to contradict the statement contained in #4 of figure 1, it is intended for use only in such cases as that of #5 of figure 1. The rule holds good if a strong surge of arctic air is expected at all levels behind the trough, bringing in cold air in the lower troposphere and warm air above the tropopause.

COLUMNAR ADVECTION

Much of a local height change at 700mb (pressure change at 10,000 ft) is due to the movement of lighter or heavier columns of air over the area. This "mass advection" is proportional both to the packing of mean isotherms in the column above 700mb (10,000 ft) and to the force of the mean wind component normal to them. The arrival of warmer, lighter air above an area will produce falls there *when convergence is negligible;* the advent of heavier, colder air will cause rises to take place *when divergence is negligible.* However, height (pressure) changes above the column which can be analyzed thoroughly---above 300mb or 10km that is---can also modify the changes at lower levels.

Practical procedures for the computation of pressure (contour) changes according to these principles have been presented by Braun and Douglis (3). Weight lines (or isobaric mean isotherms) generally do not move exactly with the speed of the mean wind component normal to them, because convergence or divergence usually is taking place. Nevertheless, the displacement of weight lines (or isobaric mean isotherms) can be *extrapolated* empirically with success, giving due regard to changes in wind speed. Then the influence of convergence, vertical motions, and condensation to counterbalance advection need only be considered when the magnitude of these variables is *changing*. Forecasts of pressure (height) made on the basis of advection will be too high in regions of marked increasing horizontal divergence; too low in regions of marked increasing horizontal convergence.

Upper-air analysts in the ETO and research workers in the United States have found that extrapolation of layer patterns is a more "stable" basis for prognostication than mere extrapolation of systems on a surface. Simplified rules which attempt to relate temperature changes at a single level to pressure (contour) changes there are unreliable, except when the forecaster has a detailed knowledge of the atmospheric processes taking place, sufficient for the modification of such rules to fit the particular situation.

CLIMATOLOGY

The historical precedents which mean charts (4) describe for seasonal changes for steering patterns (5), for weather-pattern persistencies, for stationary maintenance of dynamic troughs and ridges induced by mountain ranges or continents, and for semi-permanent solenoidal fields adjacent to continental shorelines can often contribute to forecasts made with and of the 700mb (10,000 ft) chart. In particular the relationship of synoptic systems to the normal pressure patterns indicates much about the large-scale features, or Zonal Index, of the circulation. And a forecast of pressure (contour) change toward the normal value at a point will give correctly the sense of change on three occasions out of four.

Certain circulation patterns appear to be very stable in a particular season. A familiar winter regime in the U.S. at 700mb (10,000 ft) is composed of a strong ridge along the Continental Divide, a second ridge in the Southeast, and a deep trough in the Mississippi Basin. This situation usually lasts for several days, or even for two or three weeks with minor fluctuations. Minor systems which move into such a stable major pattern fill when they strike a dominant ridge in the West, deepen in the Central States, and fill again while passing over the ridge situated in the Southeast. A summer situation which is both common and persistent has a strong ridge in the East Central States and weak, semi-permanent troughs off the East and West Coasts. Transitory troughs tend to decrease in intensity when passing through the region dominated by the tropical ridge aloft.

The set of 700mb and 10,000 foot charts on pages 7-19 of this issue clearly shows the winter climate at that level. In the mean, a ridge predominates in the West, while a major trough covers the central and eastern section of the country. Each perturbation that moves into the eastern half of the country slows down and deepens considerably. In one instance a trough even retrogrades slightly in this region, combining with a secondary trough which was following it.

TRAJECTORY COMPUTATIONS(6)

The "Constant Vorticity Trajectory" technique for predicting the actual winds at 10,000 feet (700mb) has been confirmed by statistical verification(7) and by field weather central experience. The trajectories to be expected for selected points in the individual currents at that level are computed by use of a slide-rule or diagram, revealing a forecast wind velocity for periods as long as several days. The success of this procedure depends upon the forecaster's ability to select points on a 10,000 foot (700mb) chart which will not be subjected to important vertical motions during the forecast period. Maximum, minimum, or inflection points on a major wave system in the westerlies usually fulfill this condition best, especially when the current is broad, fast, consistent, and is not subject to thermal or frictional effects from high mountain ranges. Constant vorticity trajectories which verify after 24 hours are particularly reliable for subsequent wind forecasts. The largest number of dependable CVT winds is obtained if each prognostic chart contains vectors obtained from 72-hour trajectories starting with a two-day-old chart, 48-hour trajectories starting with a one-day-old chart, and 24-hour trajectories computed from points on the current chart.

CVT winds have been found to verify within 10° and 10mph when the effect of vertical motions has been avoided by successful selection of initial points for a constant vorticity trajectory. The CVT method is as valid for the 700mb surface as for the 10,000 foot level. Current research is directed toward a simplification of the computations, which are laborious and time-consuming at present: Weather Wing policy restricts the use of CVT computation to weather stations which have large forecasting staffs.

KINEMATIC FORMULAS

Kinematic formulas based on the simple geometry of contour (pressure) systems and on their tendency field(8) can be applied to depressions at 700mb (10,000 ft) if a short-period tendency field is calculated for that level. Simple, direct methods for arriving at these tendencies by the superimposition of charts have been published(9). A trough formula which applies to constant level charts is:

$$C = \frac{T_b - T_a}{P_b + P_a - 2P_o}$$

where

C = trough speed
T_a = pressure tendency ½ unit ahead
T_b = pressure tendency ½ unit behind
P_a = pressure one whole unit ahead
P_b = pressure one whole unit behind
P_o = pressure at the trough

For contour chart it becomes:

$$C = \frac{(ht)_b - (ht)_a}{H_b + H_a - 2H_o}$$

where
ht = height tendency
H = height

The height tendency is analogous to the pressure tendency, and can be determined in a similar way.

The various prognostic methods probably are coordinated best in the following procedure. Select a very prominent feature (High or Low) of the current chart which is well confirmed by reported observations. Determine carefully a future position and structure for it upon the prognostic chart; *then* place the associated systems accordingly. Deep (often closed) systems at 700mb, such as warm Highs and cold Lows, are reliable "cornerstones" for analysis: they move very slowly or not at all, and they have a quasi-permanent nature. Indeed, it is a common forecasting error to underestimate the persistence of closed systems.

CONSISTENCY CHECKS

Even when the completed prognostic charts for various surfaces in a given situation seem satisfactory when reviewed individually, comparison often reveals contradictions which invalidate one or more of the solutions. The temperature and contour fields on one surface are related to those on every other surface and to the frontal systems by the Hydrostatic and the Thermal Wind equations; and a consistent set of prognostic charts must show that relationship. The veering of windflow (contours) with height over a point is most pronounced ahead of a warm front position: backing of windflow with height is most pronounced behind a cold front. Low contour values are displaced toward the colder air aloft: the axis of high contour value tilts toward the warmer air above. The contours on any two charts determine a field of mean temperature which follows continuity and climatology. The mean isotherms for layers below 700mb are roughly parallel to fronts which maintain a sharp contrast.

The drafting of a prognostic chart upon a transparent overlay of the previous chart for the same surface makes apparent (and avoidable) any extravagant changes in displacement, contour gradient, flow direction, or structure of systems. A check list of the prognostic techniques (figure 2) used for recording their application and reliability helps to reveal the most appropriate forecasting procedures for a given situation. In this regard, reference to the check list during the forecast and the verification would point out an effective prognostic method which had been overlooked or ignored previously.

This review of the prognostic methods appropriate for 700mb analysis should reassure the forecaster who is faced with his first use of constant-pressure data. The methods which have been confirmed by experience with constant-level charts apply with equal success to contour charts.

REFERENCES

(1) Namias, "Methods of Extended Forecasting Practiced by the Five-Day Forecast Section," U.S.W.B., January 1944.
(2) Rossby, "Kinematic and Dynamic Properties of Long Waves in the Westerlies," *Miscellaneous Report No. 5*, University of Chicago, 1943.
(3) Braun and Douglis, "Weight Charts," *Weather Service Bulletin*, January 1945.
(4) "Normal Weather Maps, Northern Hemisphere Upper Level," and "Historical Weather Maps."
(5) Bowie and Weightman, "Types of Storms in the US and their Average Movements," *Monthly Weather Review*, Supplements #1 and #4.
(6) Starr, "Basic Principles of Weather Forecasting," Appendix, 1942.
(7) Dorsey and Brier, "An Investigation of a Trajectory Method of Forecasting Flow Patterns at the Ten-Thousand Foot Level," *Research Paper No. 8*, U.S.W.B., January 1944.
(8) Byers, "A Simplification of the Formulas for Displacement of Pressure Systems," *AMS Bulletin*, January 1943.
(9) Machta, "A Method for the Determination of the 10,000-foot Tendency Field," *AMS Bulletin*, November 1944.

	Use Made			Verification		
700mb PROGNOSTIC CHECK LIST	Date Time			Date Time		
	Great	Moderate	Little or none	Good	Fair	Poor
EXTRAPOLATION: of wave length, speed, structure, and minor system location---with primary reference to one prominent feature of the circulation; consideration of Zonal Index; use of kinematic formulas.						
CONTOUR-ISOTHERM RELATIONSHIPS: disturbing effect of vertical motions upon forecasting "rules"; comparison with regular types.						
COLUMNAR ADVECTIVE INDICATIONS: extrapolation of mean isotherms to forecast height (pressure) changes: validity of this procedure for current situation as affected by *increasing* vertical motions, condensation, etc.						
CLIMATOLOGY: reasonable deviations from normal, persistence of stable patterns, seasonal changes, dynamics.						
CONSISTENCY CHECKS: proper relation of frontal systems to marked turning of windflow with height; changes in wave speed and length consistent with expected changes in Index (W.B. forecast); hydrostatic consistency among mean isotherm, upper-air, and prognostic charts; persistence of closed systems.						

300 mb *Analysis*

T/SGT JOHN MacDONALD

AAF Weather Service units in the European and Mediterranean Theater have used contour charts for upper-air analysis throughout this war. Their experience is helping the domestic weathermen to learn constant-pressure methods; it has been drawn upon freely in the preparation of this issue. A recent communication from the ETO, for example, on the page below describes several original refinements of an important contour-chart technique.

The wealth of reports which are available each day for surfaces at low altitudes can be used indirectly to improve the analysis on high, sparsely-plotted surfaces. Such an accomplishment is possible because the *pattern* of mean isotherms generally is the same for every layer of air below the tropopause, in any particular synoptic situation. The forecaster determines the unique field of mean isotherms from a pair of surfaces at low levels, and then assumes successfully that the pattern so found will apply to higher layers. Once the mean isotherms in any layer are known, the contours of the highest surface can be obtained mechanically from the contours of the lowest surface.

The accuracy and efficiency of the method when it is applied to contour charts is one of the most convincing advantages of constant-pressure analysis. The 18th Region's RCO endorsed it as having "increased the accuracy of 300 mb. analysis over the North Atlantic and Europe." The 23rd Squadron has already applied some phases of the technique successfully to forecasting for Very Heavy Bombardment in the United States. The details of procedure which follow were initiated by Sgt. MacDonald at the weather central of the Strategic Air Forces in Europe, and have been used in a year of operations there:

(1) Plot the regular contour charts, then analyze all of them except the 300 mb. chart.

(2) Subtract *vectorially* (figure 1) the 850 mb. wind from the 500 mb. wind for each Rawin or Pibal ascent, and plot the mean shear winds so found upon the 500mb chart (in red, to distinguish shears from actual winds).

(3) Superimpose the 500mb chart on the 850mb chart over a source of light, and subtract *graphically* (see back cover) the contours on one surface from those on the other.

(4) Adjust the preliminary pattern obtained in step #3 so that it parallels the mean shear winds (red), and so that it satisfies the contour geostrophic wind scale as to spacing. These isolines of height differences bear quantitatively the same relationship to wind-shear vectors as contours bear to actual winds.

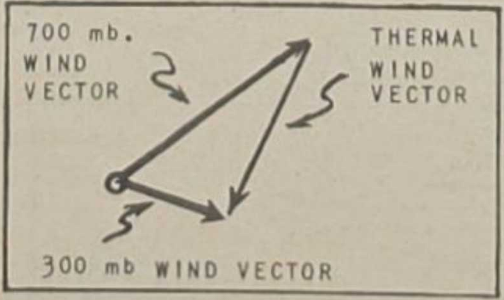
[The isolines of height difference are also *mean isotherms of the layer*, spaced evenly and at convenient values, which have an important forecasting significance of their own. However, the construction of these lines is merely an intermediate step in the technique being considered].

(5) Where Raobs extend to 300 mb., compute values of height difference between 700 mb. and 300 mb. and plot them on the 300 mb. chart (in red figures).

(6) In the manner of step #2, compute the mean shear winds for the 700 mb. to 300 mb. layer for ascents which reach to 300 mb. Plot the shears on the 300 mb. chart (again, in red).

(7) Place the 300 mb. chart over the 500 mb. chart on the light table, and draw mean isotherms according to the height difference values and the mean shear vectors, both already plotted at 300 mb. Where the lack of data makes this analysis uncertain, follow the pattern of mean isotherms visible from underneath on the 500 mb. chart.

(8) The goal of these eight steps, the construction of 300 mb. contours with the aid of data for lower surfaces, can now be accomplished. Place the 300 mb. chart over the 700 mb. chart on a light table. Then *add* graphically the 700 mb. contours (see back cover) to the mean isotherms already on the 300 mb. chart. The 300 mb. contours are produced mechanically therewith.



VECTORIAL SUBTRACTION: Plot both the upper and lower vectors downwind from the station. Connect the end of the lower with the end of the upper, thus forming a vector which is parallel to the mean isotherms and which determines their spacing.

Where station routine permits, the method described in these eight steps will materially improve forecasts of wind vectors for high-level operations, and will increase whatever forecasting value the 300 mb. chart is found to have.

(continued from front cover, inside)

I personally wish to extend this accepted principle slightly, and object strongly to any lack of the same professional courtesy in meteorology that exists in medicine, law, and engineering; *regardless of differences in rank among the individuals concerned.* It is elementary and essential that even superior weather officers should give comments about the worth of an observation, map, or forecast to its author in intramural confidence. Likewise, field forecasters should stifle their impulse to be sarcastic about the validity of master analyses; not only because the extent of information available is usually greater at central stations, but also in recognition that such criticism will be misinterpreted and warped when it is publicized.

II. *Professional Integrity.*

Weathermen agree that a forecast or an observation which is a result of their best efforts must remain unchanged, despite the pleas of any client whom it inconveniences. The relationship between a command pilot and a junior forecaster, for example, in this circumstance is not one where rank or "orders" should influence a professional decision. In fact, ethics and regulations concur at this point: it is a court martial offence for a military weatherman to give any advice which differs with his scientific concept of the weather situation.

III. *Professional Responsibility.*

When the various military agencies apply to Weather Service installations for meteorological information, they can expect a response which is based upon detailed observations and every pertinent proposition which science has accepted. Science is supplying effective equipment and techniques to AAF weather stations that make their accomplishments unique. But even more important to Weather Service success is the persistent effort of its personnel to improve their technical knowledge, even beyond an official "tour of duty." The emergencies of this war have placed such grave responsibilities upon the forecast and the observation that the Service as a whole condemns those few meteorologists who allow their technical knowledge to fall behind the advances of science.

IV. *Military Character.*

Army weathermen in general know themselves to be soldiers primarily; their ethics approve only that course of action which will satisfy both the military and professional requirements made upon them. For that reason soldierly appearance, organization, and efficiency are generally found to characterize the personnel, equipment, and housing of weather stations. Military courtesy is observed even when a client strains his welcome by attempting to violate the professional integrity of a weatherman on duty. These qualities have been accepted as ethical because it is realized that the whole weather technology attains a more important role in the Army if the Service is scrupulous about its military orthodoxy.

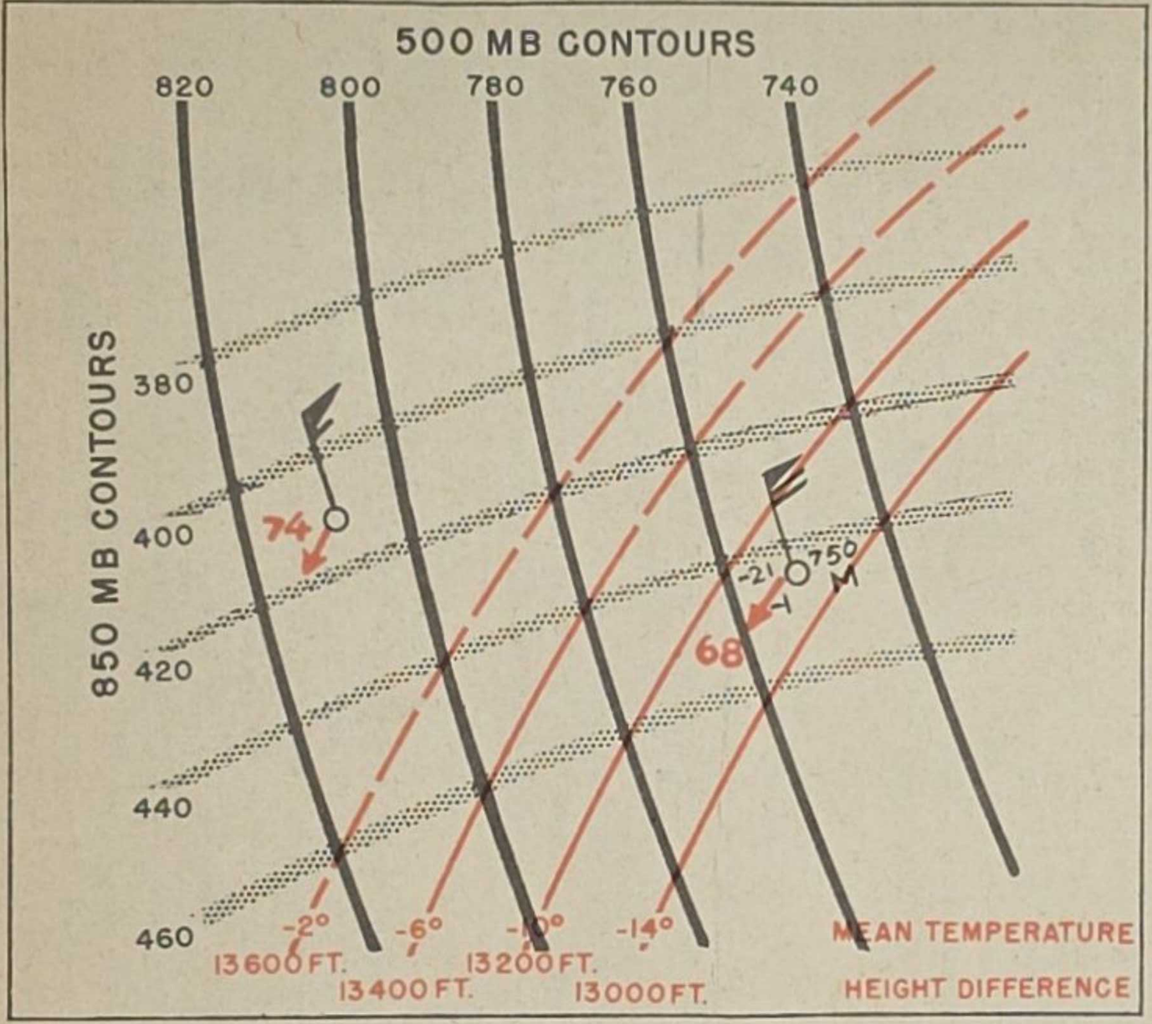
The recent development of meteorology and forecasting is a major addition to the army's striking power, but only in potential. Its direct application to military operations must partly wait for the confidence of air, ground, and service forces to catch up. That confidence in the Weather Service, with its military significance, now is coming into being through the merit of our ethics and our general adherence to them.

W. O. Senter

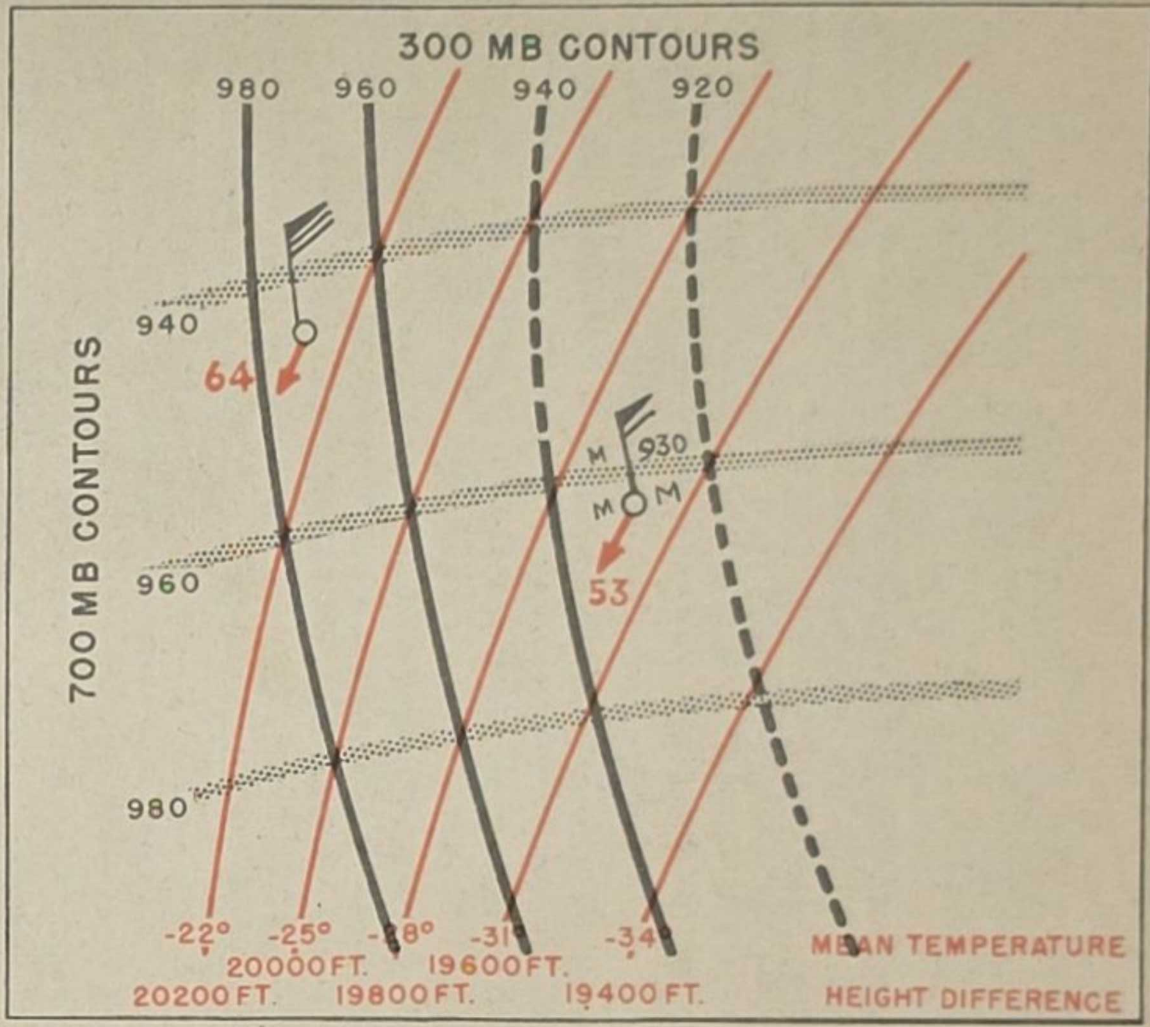
W. O. SENTER
Colonel, Air Corps

G R A P H I C A L   M E T H O D S

Three important [illegible]ecasting variab[illegible] are interrelate[illegible]y the Hydrostatic Equation: h_1, h_2, and T_m (or p_1, p_2, and T_m). If any two of them are delineated by isopleths drawn from plotted data, usually on separate charts, then the third field can be drawn mechanically by "graphical" addition or subtraction of the isopleths. The modern use of mean isotherms, and of contour (pressure) fields at great altitudes, creates a new importance for graphical arithmetic in forecasting routine.



Graphical Subtraction is accomplished in the following way: superimpose one chart upon another over a light source; then draw lines through consecutive intersections of isolines, proceeding from *low* to *high* values on both charts. When the contours of the lowest isobaric surface in a layer are subtracted from the contours of the highest surface in this manner, the lines so drawn are the mean isotherms of the layer.



Graphical Addition: Superimpose one chart upon another over a light source; then draw lines through consecutive intersections of isolines, going from *low* to *high* values on one chart and from *high* to *low* values on the other. When the contours of the lowest isobaric surface in a layer are added to the mean isotherms in this manner, the lines so drawn are the contours of the highest surface in the layer (see "300mb Analysis, page 24).
