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USE OF TREND METHODS IN FORECASTING FIVE-DAY MEAN PRESSURE CHARTS

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Introduction

The basic technique of extended forecasting as practiced by the Five-Day Forecast Section of the United States Weather Bureau is the construction and prognostication of five-day mean pressure charts, both at sea level and at 10,000 feet. These charts represent the means of ten twice-daily charts, and are made twice a week, covering the periods Saturday through Wednesday, and Wednesday through Sunday. Thus, the successive half-week charts overlap one another by one or two days. In making his forecast on Monday, for example, the forecaster must make a prognostic mean pressure chart for the advance period Wednesday through Sunday, but he is also interested in the probable appearance of the next half-week chart, ending Wednesday.

The following report is a discussion of some methods used in preparing these prognostic mean charts based on a quantitative analysis of long-period trends.

One of the principle tools employed for many years by forecasters has been the evaluation of trends indicated by past weather maps. Thus the practice of forecasting the movement of highs or lows by following their successive positions from day to day is familiar to everyone. But some meteorologists have also long been aware of the fact that, apart from fluctuations of day-to-day weather, there are longer period weather trends. For example, the continued use by many forecasters of the 12-hour pressure change map in addition to the 3-hour pressure tendencies is probably due to the fact that the 12-hour pressure changes iron out minor fluctuations in the pressure change field, and thus offer an indication of the major day to day weather trends. Another way to eliminate local and irregular fluctuations and bring out longer period trends is by the construction of mean pressure charts. H. Helm Clayton[1] was one of the first to recognize long period trends in mean charts, and concluded that the slow and regular changes which he observed on mean charts were due to large scale physical processes often completely masked by the detail in the daily weather chart.

In a qualitative fashion it is often possible to follow a gradual movement and modification of the atmospheric centers of action from week to week with the help of mean charts. It is the purpose of this report to suggest more quantitative methods of detecting and evaluation these longer period trends.

I. Relationship of Daily Chart to Mean.

Experience with mean forecasting soon led to the use of the last available daily chart as a further indication of trends in the mean charts. Since they represent the latest information available, daily charts may indicate a continuation or a reversal of the trends first shown by the mean charts.

An investigation of the relationship between daily charts making up a mean chart, and the mean chart, reveals the fact that a daily chart bears maximum similarity to the five-day mean (of which it is a part) if it is the middle map in the series. This means that either the 5th or 6th twice daily charts, making up a five-day mean, should look like the mean. This is illustrated by Figures 4 and 5 in which are shown the daily 10,000 foot map for 2300 EST, January 12, 1942, and the corresponding mean map for the period January 10 - 14. On the mean map are other elements which will be treated later on.

This empirical conclusion is further supported by a statistical evaluation of the coefficient of correlation between the mean pressure patterns for twelve cases selected at random and the daily charts making up these means. These coefficients were determined by correlating daily and mean pressures over North America at 24 points at the 10,000 foot level and at 40 points at sea level*. These coefficients are shown below:

Maps during the 5-day period (10 maps, a.m. and p.m. make up the mean)

	1	2	3	4	5	6	7	8	9	10
Sea Level Maps	.56	-	.67	-	.71	.78	-	.78	-	.59
10,000 foot Maps	.81	-	.83	-	.92	.88	-	.82	-	.82

*The statistical procedure used is discussed in a recent report by the Extended Forecast Division of the U. S. Weather Bureau, entitled "Verification of Prognostic Pressure Patterns".

One conclusion we may draw from this result is that, more often than not, the variations of pressure at one point show gradual rising and falling trends lasting more than five days, although there are small irregular fluctuations in the twice daily values making up the means. The degree of similarity between the mean and middle daily map will be greatest when there is a regular, and preferably a linear, variation of pressure in given regions during the five-day period. In other words, when the pattern of the daily chart is simple and when movements are slow there will be great similarity between the middle daily and mean chart, but when the pattern is complex, with rapid movements, the similarity will not be as good.

It has been found that in the majority of cases the daily pressure ridges and troughs are stronger than the corresponding ones on the mean charts. This is the result of the greater variability of pressure on the daily charts.

The concept that any daily chart bears a similarity to the mean in which the daily chart is in the middle of the period has certain direct practical uses in forecasting:

1. It offers an indication of the instantaneous trend taking place in the mean charts, and
2. Once having a prognostic mean map, it offers fairly definite clues as to the appearance of the mid-period daily map corresponding to the prognostic chart.

Obviously, the concept is not infallible, and borderline cases arise where the forecaster must be careful in attempting to evaluate his last available daily chart in terms of the latest mean. Thus, considering the 10,000 foot chart, when two fairly weak troughs of equal intensity appear relatively close together on a daily chart, the corresponding mean will most likely contain only one trough located between the two on the daily chart.

The limitations on the use of the concept are perhaps most readily seen if one considers the well-known fact that daily troughs and ridges almost always move faster than mean troughs and ridges. Thus a mean five-day trough is usually made up of more than one daily trough, each of which undergoes variations in intensity. If each daily map corresponded exactly with the five-day mean in which it makes up a part, then the speed of the daily and mean troughs would be the same.

A. Quantitative Applications

The development of trend methods was originally along qualitative lines. One of the first attempts at a quantitative approach was to simply plot on a map a selected isobar, such as the 700 mb. isobar, for the latest mean maps as well as the latest daily map. By continuation of existing trends of the same isobar, an attempt was made to locate some features of the mean map a half week and a full week in advance. This was not very satisfactory because it gave only one isobar of the desired pressure distribution, but it led logically to the next and latest method of expressing trends quantitatively; namely, to plot as a graph the mean pressure as a function of time for standard inter-sections of latitude and longitude; in other words, to construct what might be termed "a mean barogram" (Fig. 6). In this figure observed mean pressures (plotted against the last day of the five-day period) are indicated by dots, while pressures taken from the latest available daily maps (which correspond to the mean pressures of which they are the middle value) are indicated by crosses. It will be noted that the daily values indicate the trend in the mean barogram quite well in most cases. Also, the higher daily values lie well above the mean curve, while the lower values are below it, indicating the greater variability of the daily values.

II. Trend Maps

A. Extension of the Mean Barogram

The most obvious way to make ~~prognostic use~~ of these mean barograms or "trend graphs," as they are called, is to find methods of extending them to include the dates of the next half week and full week maps and then read off the appropriate pressures. By plotting these pressures at each standard intersection we can then construct what is known as a "trend chart". Two methods have been used to do this.

The first method consists of extending the trend indicated by the last two or three points, including the last daily value. In other words, a straight line is drawn which is approximately an extension of the slope indicated by the last few points. This method has the advantage of being purely objective, so that any two analysts can get the same results, but it sometimes gives impossible results for some of the pressures. Moreover, when the forecast values are plotted and the isobars drawn, it has been found that this method has a tendency of "stopping" the movement indicated by the half-week trend chart. The effect is to over-emphasize the deepening and filling of troughs and ridges and under-emphasize the movements.

The method of extrapolation now in use is to make use of the past history of the trend curves as well as the indications expressed in the last few points. This suggests the use of "periods", a method of forecasting which has been long under trial without a great deal of success. However, no attempt is made here to use periods rigorously. The basic assumption is merely that the convolutions of the trend curve at any given point in space will remain approximately similar. For example, fluctuations in pressure at high latitudes usually are characterized by large amplitudes and short wave lengths, while at low latitudes a small amplitude and long wave lengths prevail. No rigid period exists for a long time, but in general it appears that the slopes of the rising and falling portions of the curves remain approximately the same for any given geographical point, as does the curvature of the troughs and ridges. Then, too, by taking account of the past history of the curves, impossible values of pressures are eliminated. The method, then, involves the extension of the curves by a reasonable spacing of the troughs and ridges, and by considering past slopes and curvatures. To some extent the method makes use of the idea of symmetry points proposed by Weickmann[2]. Our method suffers the disadvantage of being not entirely objective, since the exact shape of the extended curve is to some extent a matter of individual interpretation. No test has been made to determine how closely two different analysts would agree, but it is felt that in general there would not be fundamental disagreement. An example of this method of extrapolation may be seen in the right hand portion of Figure 6, where below the third curve from the top are entered the legends corresponding to numbers beside the barogram.

B. Examples of Trend Maps.

It now remains to be seen how well or how badly these prognostic trend charts work out in practice. This question will be treated more fully later on in the statistical section of this report, but we will illustrate here some examples of trend charts.

Figure 8 is one of the first trend charts that was made for a full week in advance, and in comparison with Figure 7, the mean chart available at the time of forecast, represents a radical change in pattern. An unusually strong and extensive polar anticyclone is forecast where no previous sign was indicated. Figure 9, the observed chart a week later, shows how well this forecast succeeded. This amazing result was soon found to be rather unusual, and subsequent sea level prognostic charts based on this method were so poor that the use of sea level charts for the application of trend methods was abandoned. It was felt that the poor results were in large part due to the complicated nature of the sea level patterns, together with some errors in the method of reduction of pressure to sea level.

There are reasons for believing that trend methods, such as that described above would have more success when applied to 10,000 foot pressure charts. In the first place these charts are much more simple in their appearance than are surface charts. They consist mainly of extensive ridges and troughs, giving the appearance of a wave train of sinusoidal character. The waves on the mean maps move with speeds which are quite slow relative to the daily troughs and ridges, and while the continuity of sea level mean maps is frequently very difficult to determine, the continuity aloft is easily determined in perhaps 90% of the cases. One of the reasons for the greater complexity of sea level pressure maps is the fact that the weight of the layer of air between the surface and 3 km. is something which varies tremendously depending upon the source of the air masses involved.

An example of a 10,000 foot trend chart prepared for full week in advance is shown in Figure 2, while the observed chart is shown in Figure 5, and the antecedent observed chart in figure 1. At times the trend methods fail, and a case of this kind is shown in figures 10, 11, and 13.

Trend charts prepared for a half week in advance almost always work out quite well. The degree of success of these, as well as the charts prepared for a full week ahead, will be treated later.

III. Computation Methods:

A. General Considerations

Trend graphs, or mean barograms, suggest the possibility of applying extrapolation formulae to the movement as well as deepening and filling of mean troughs and ridges on the 10,000 foot chart. Since mean pressure patterns are continuous, both in space and time, there is no theoretical reason why the use of extrapolation formulae is not perfectly valid.

On the other hand there are practical difficulties, which are so great that it seems at first impossible to expect good results. If, as Petterssen[3] states, extrapolations should be carried out on daily charts only as far as 12 hours in advance, and certainly no further than 24 hours, it seems difficult to see at first glance how we can have any success when extrapolations are carried out as far as a week in advance. There are, however, a number of considerations in favor of applying the formulae to mean charts, particularly 3 km. charts, which are so appealing as to suggest that the method should at least be thoroughly tested.

Firstly, one of the basic principles involved in the use of mean charts is that they eliminate minor details in the pressure system which are subject to rapid and irregular fluctuations, and reveal only the large scale "semi-permanent" centers of action, which are subject to much slower changes in structure and position. We should expect therefore, that pressure centers, troughs, and ridges on mean charts would move in a much more regular fashion than they do on daily charts, and for this reason extrapolations based on velocity computations alone can be carried out for much greater periods of time.

Secondly, consider the simplicity of the patterns on mean 3 km. charts. On these upper level charts there is almost always a simple wavelike pressure distribution, with only one trough and one ridge over an area as large as the United States (Figure 5). Such a simple pressure pattern allows the choice of several points for the application of formulae. In other words, the choice of points is not so painfully restricted as in the case of daily pressure charts. Furthermore, if the isallobaric pattern is equally simple, large lenth units may be chosen. The use of larger length units, without violation of any of the theoretical principles underlying kinematical computations, strengthens one's confidence in the numerical accuracy of the velocity computation.

Finally, we should consider the question of the reliability of the data. One of the restrictions to the application of formulae to daily charts is the unreliability or unrepresentativeness of the data, particularly the three hour tendencies. Unrepresentativeness is entirely eliminated on mean 3 km. maps, and there can hardly be any question about the reliability of the pressure data, at least over the United States, since it represents the mean of 10 daily maps. The mean pressure tendencies are a little more uncertain. These are obtained for each of the standard intersections from the slope of the mean barogram at the point representing the latest mean pressure map (Fig. 6). This portion of the trend curve is estimated partly from the last daily value and for this reason the estimated tendencies may be in error. In order to evaluate the magnitude of this source of error, observed tendencies were obtained for the same points after the trend graph had been completed. The two isallobaric fields constructed from these different estimates of the tendency were very similar, and in fact velocity computations made with both sets of isallobars gave practically the same results. Thus, it may be concluded that the mean tendencies are fairly accurate.

B. Technique of Making Velocity Computations

In practice the pressure tendencies are obtained from the graphs by taking the pressure difference between points one day on either side of the point representing the mean (Fig. 6).

In other words, a two-day tendency is used, and in most cases this is a very good approximation to the slope of the curve. Pressure tendencies are obtained in this way for all the standard intersections, and mean isallobars are drawn (Fig. 1).

Trough and ridge lines are defined by their minimum or maximum latitude positions, since it is generally difficult to define points of maximum curvature on mean charts. It is clear from the derivation of kinematic formulae that it is not necessary to define a trough or ridge line by the region of maximum curvature as long as the pressure profile is approximately parabolic. This is true in the case of the mean charts because of the large scale of the pressure waves.

Another departure from usual day to day practice in making computations, is to choose latitude circles as computation axes (Fig. 1). According to Pettersson[4] it does not make any difference whether the axes are straight or curved, but all the values of pressure or pressure tendency used in the formula must be taken from the chosen axes. The use of minimum or maximum latitude points for defining troughs or ridges, and the selection of latitude circles for axes simplifies the identification of pressure systems from one map to the next.

The formula to be used for a full week computation based on velocity alone is:

$$S = 3.5 \frac{b^{\frac{1}{2}} - b^{-\frac{1}{2}}}{(p^{1} - p^{\circ}) + (p^{-1} - p^{\circ})}.$$

where S is the number of length units traveled in a week, b is the pressure tendency in millibars per two days, and p is the pressure. The ratio is multiplied by 3.5 since there are 3.5 tendency intervals in a week.

In applying this formula to mean maps one must observe the same rules for choice of units as apply in the case of daily maps[5]. In general, it is found that the units which can be chosen are quite large, so as to increase confidence in the velocity computation (Fig. 1).

Deepening or filling may be obtained in the usual manner by using the pressure tendency at the trough or ridge line.

An example of a computation based on mean maps is shown in Figs. 1, and 3, while the observed map corresponding to the prognostic chart is shown in figure 5.

C. <u>The Acceleration Term - Quantitative Methods</u>

As will be seen later, many of the computations of displacement, particularly for the full week, give poor results. This may be due to an inaccurate estimate of the velocity, but in most cases it is probably due to failure to include in the displacement computation the acceleration term, or perhaps terms of even higher order.

Two attempts were made to find quantitative expressions for the acceleration term.

The first method makes use of the mathematical expression for acceleration. If we assume that the velocity of isallobaric centers and pressure centers are the same, then the expression for acceleration[6] is:

$$A = -c \; \frac{(b^{1} - b^{\circ}) + (b^{-1} - b^{\circ})}{(p^{1} - p^{\circ}) + (p^{-1} - p^{\circ})}$$

Where c is the velocity of the pressure system, the numerator of the ratio is the curvature of the isallobaric profile, and the denominator is the curvature of the pressure profile.

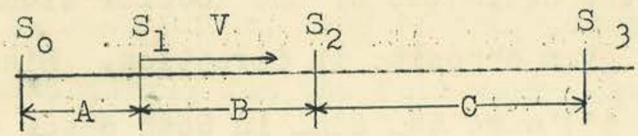
It was felt that more reliable estimates of tendencies, than it is possible to obtain on daily maps, might make it possible to estimate the curvature of the isallobaric profile. The above formula was applied to two mean maps using both the estimated isallobaric field and that obtained from the completed (observed) trend curve, as explained before. However, unlike the velocity term, the two estimates of the acceleration term did not agree, and were even opposite in direction. Since c and $(p^{1} - p^{\circ}) + (p^{-1} - p^{\circ})$ were the same in both cases the lack of agreement must be due to the curvature term of the isallobaric profile.

One may conclude that the errors in mean tendencies are still too large to permit accurate computations of accelerations or that the grid obtained by plotting tendencies at every 10° intersection is too wide to allow an accurate determination of the isallobaric curvature.

The second method of considering acceleration makes use of two past movements of the trough or ridge to obtain the acceleration. Thus, if we have three successive positions of a trough or ridge and if we assume constant acceleration or retardation, then it is quite simple to get the future position of the trough or ridge by direct extrapolation.

This method may be applied to mean troughs or ridges, but since the time interval between successive positions is approximately a half week, a forecast for a half week in advance would involve the assumption that the acceleration remain constant for a week and a half. As will be shown later, this is a rather poor assumption.

Another method of the same type makes use of the past half week movement and the instantaneous velocity on the current map. This method may be illustrated in the following diagram:



(Successive positions of constantly accelerating point)

Assuming for the moment constant time intervals, then it can be shown by using the formula $S = V_0 t + 1/2(A_0 t^2)$ that the acceleration is 2(V-A) where V is the velocity at point S_1 and A is the past displacement in a unit time interval. The displacement during the next unit time interval is:

$$B = V+(V-A) = 2V-A \quad .$$

The displacement during two time intervals is:

$$B + C = 2V + 4(V-A) = 6V-4A$$

The advantage of this method over the previous one is that it assumes constant acceleration over a shorter interval of time, for in this case a forecast for a half week in advance requires only that the acceleration remain constant for a week.

Thus, displacements of mean troughs or ridges, taking acceleration into account, may be made by using the past half week movement together with the velocity computation.

The actual formula for displacement is complicated by the fact that the time interval from one half-week map to the next is not constant, varying between 3 and 4 days. Therefore the formula to be used in a given case depends on whether the forecast is for a full week or a half week, and whether the past half week interval is 3 days or 4 days. The formula for a half week displacement, with a past half week interval of 3 days is:

$$S = 4/3\, V_1' - 16/9A$$

Where S is the displacement, usually expressed in centimeters, V_1' is the velocity computation for a full week, and A is the past half week movement. The formula is most easily evaluated by means of a graph, where the coordinates are V_1' and A and on which are drawn iso-lines of S.

This method of extrapolation was tried in a number of cases for a half week in advance, and the results were quite negative. It was found that in the majority of cases the extrapolation made by using the velocity alone was better than that obtained by correcting for acceleration. This means that either the estimate of acceleration is incorrect or that the assumption of constant acceleration for a week at a time is incorrect. Now from what has been said before it is probable that estimates of the instantaneous velocity (V_1') are quite good. Estimates of A based on observed positions of trough and ridge lines should also be good, so that at the worst the acceleration obtained should be a fairly good estimate of the mean acceleration during the past half week. It is believed that the failure of the method to give positive results is due to the fact that accelerations do not remain constant for a week at a time. In other words, even if the correct accelerati terms could be found, another term should be added to the extrapolation formulae.

D. Acceleration Term - Qualitative Methods

In spite of the fact that no good method of estimating accelerations or change in acceleration was found, it may still be possible to get qualitative estimates of the sign and magnitude of accelerations, or at least to estimate when the velocit formula is likely to work well. It will be most convenient to bring out this point by a discussion of the various possible errors in the extrapolation. These are as follows:

1. An error may be made in the velocity computation. This has been discussed before, and it was stated that in general the pressure and isallobaric fields are so aligned that a good deal of confidence may be placed in the uniqueness of the computation. However, there are sometimes cases where the isallobaric field is quite complicated, so that a short length unit must be chosen. In such a case it is often impossible to select a unit so as to satisfy all the criteria of a good computation. This is especially true if the isobaric profile is flat. Such cases can easily be distinguished with practice and may be eliminated.

2. Accelerations may occur due to extreme flatness of the pressure profile. A case of this kind is illustrated in Figs. 10, 12, and 13. Figure 10 shows that the computations were applied to a pressure field that was extremely flat, and comparison of Figs. 12 and 13 shows that the results were about as bad as could be expected, with ridges forecast where troughs occurred and vice versa.

On the other hand Figs. 14, 15, and 10 show a case where large accelerations occurred with a very deep pressure system. This illustrates the fact that the criterion of the pressure profile cannot be applied to mean maps in the same way as it can to daily maps. As will be shown later, the increased time interval causes deepening and filling to take a much greater part in determining the change in velocity than it does on daily maps.

In the case illustrated by Fig. 14 there was an abnormally deep trough off the coast and perhaps due to dynamic interaction between the two low pressure systems the western-most one filled very rapidly and therefore was subject to increasing acceleratio

However, it may be possible to determine when a deep trough is subject to deepening and filling, and therefore to accelerations. Fig. 1 shows the case of an extensive warm high and a cold low. Such a system dominates the whole weather pattern so that we do not expect rapid deepening or filling. Therefore accelerations may be expected to remain small.

Thus, to sum up, we may expect large accelerations with flat profiles on mean charts as well as on daily charts, but if the profile is sharp we must first consider the possibility of deepening or filling during the interval before we can state that accelerations will remain small.

3. Another indication of the validity of a computation is the relative motion of adjacent pressure systems[7]. If computations indicate, for example, that a ridge is moving into a trough, or that a trough is retrograding while a ridge

is moving eastward, then, since on the average adjacent pressure systems must move with approximately the same speed, this indicates either that the computations are wrong or that accelerations will occur during the interval, such that the resulting motion will be different from that computed. In either case little reliance can be placed in the computations unless there is reason to expect that one or the other is wrong. Thus, if one of the computations has been made over ocean areas where data are scarce, then less reliance should be placed on this than a computation made in a region of plentiful data.

4. From what has been said above, it is clear that not only are accelerations large, but they may vary considerably during the interval of a week. Thus, even if it were possible to find the correct instantaneous accelerations it is doubtful that this would be of great help in forecasting, since we must still take the variation of the acceleration into account.

It is convenient to think, not in terms of acceleration, but in terms of changing velocity. It is easy to see from the simple velocity formula that a change in speed is due to only two things: (1) a change in the slope of the isallobaric profile, and (2) a change in the curvature of the pressure profile. A change in curvature of the pressure profile is due mainly to deepening or filling. If a mean trough or ridge is expected to weaken then rapidly increasing velocities may be expected (Fig. 14). If a mean trough or ridge is expected to become stronger, then velocities will decrease.

As an important cause of changing speed, we may often neglect the change of the isallobaric slope due to changing intensity of isallobaric centers. Usually such changes in intensity accompany deepening or filling and therefore only serve to modify the resulting change in speed. For example, if a trough deepens it will often be found that the intensity of the isallobaric centers, and therefore the isallobaric slope, has increased. However, the percentual increase usually is much less than that of the curvature, so that it only serves to make the resulting decrease in velocity less than that which one would otherwise expect.

A very important cause of change in isallobaric slope is found in the relative motion of pressure and isallobaric centers. Complete reversal of slope may be caused by this factor, and it is probably the greatest single cause for large errors in computation. Fig. 1 shows a case where a good computation was accompanied by equality in the speeds of isallobaric and isobaric centers. It will be noted by comparing Fig. 1 and 5 that the position of the isallobaric centers relative to the troughs and ridges remains about the same.

To test this idea further and to see whether or not it might be used as a forecasting tool, a graph was constructed on which the positions of isallobaric and isobaric centers at 40°N were plotted against time. (Fig. 16). The period chosen was from the end of April to the end of June. This particular series was chosen because the computations seemed to give fairly good results during the early and middle part of May while they broke down almost completely beginning about the first of June. May was characterized by a more or less normal atmospheric circulation with pressure systems moving in a normal fashion from west to east. Beginning about the first of June, however, abnormal pressure rises appeared in North Atlantic. This is generally associated with so-called "blocking" during which a general dropping of circulation is noted over the Western Hemisphere, and pressure centers move slowly or even retrograde. It will be noted from Fig. 16 that during most of May, not only are the curves for pressure and isallobaric centers approximately parallel, indicating equal speed, but they are also approximately linear, indicating fairly constant speed. After the first of June, however, the general picture is quite chaotic. Not only do both the isobaric and isallobaric centers show retrogression, but the lines continually cross one another, indicating that the systems are not moving at the same speed. There is even some suggestion that abrupt changes in the motion of isallobaric centers precede similar changes in the isobaric centers by at least a half week.

However the length of record is entirely too short to draw such a conclusion. Nevertheless it is considered a part of the forecasting procedure to investigate first whether or not there is evidence of erratic behavior of isobaric and isallobaric centers before evaluating a computation.

5. Another method of taking care of changing velocity is based on the construction of an intermediate mean map. As will be shown later, the half-week prognostic trend maps usually give quite good results. If we construct such a map, then, and construct isallobars upon it in the manner described before, we may make computations and obtain a prognostic map for the following half week. In other words, we use the half week trend map as an intermediate "stepping stone" to the final full week prognostic chart. This method has recently been tried, and it is apparent that the actual numerical values of the computations based on the intermediate map can not be trusted. However, it is believed that the relative positions of isobaric and isallobaric centers may be trusted, and thus may throw a good deal of light on whether or not there will be relative motion between isobaric and isallobaric centers. In this way we may obtain a clue as to whether the full week computation will work out well.

IV. Statistical Results

In order to test some of the extrapolation methods decribed above, a series of mean charts were chosen from the period Feb. 23 to about June 6, 1942, comprising about 29 successive mean maps. Trend maps both for a half week and a full week in advance were made for this period, as well as computations. In making the computations, points were chosen on each mean map where there was reasonable assurance of good results. Whenever possible, one point was chosen for each trough or ridge, and thus the number of points chosen on individual mean maps varied from 1 to 4, the total number of computations being about 65. For each of these points, computed displacement as well as deepening and filling were compared to the corresponding observed values for both a half-week and a full week in advance. The computed values were obtained from trend charts as well as from the kinematic computations.

We have described how the estimates of displacement were made by means of kinematic computations. It will be recalled that troughs and ridges were defined as moving along latitude circles. Thus, in order to compare observed with computed displacement the same trough or ridge was located on the following observed half week or full week mean chart, and the observed displacement was then the movement indicated along the chosen latitude circle. The computed displacements from trend charts were obtained in a similar fashion by identifying the chosen troughs and ridges on the half week or full week trend charts. The computed deepening or filling was obtained in the case of the computation method by simply extrapolating the observed 2-day tendency at the point in question, just as is done in the case of deepening and filling on daily charts. The observed deepening or filling, and the deepening or filling as estimated from the trend charts, was obtained simply by finding the difference in pressure at the chosen latitude circle for successive positions of the trough or ridge.

It should be pointed out that the identification of troughs and ridges on successive observed or trend charts is not always easy. This is due to the fact that changes in the structure of mean charts are sometimes so rapid that 3 or 4 days or a week is too large an interval of time to follow an individual trough or ridge. However, as will be shown later, this uncertainty in the continuity occurs in only some 10% of the cases.

Computed values were plotted against observed values on graphs to be described below. Since the same points were chosen regardless of the method used, these graphs are strictly comparable.

The first graph (Fig. 17) shows the results of computations for a half week in advance, (a half week comprising 3 or 4 days). Particular note should be taken of the number of points where the continuity is uncertain. There are seven of these points out of a total of 65. This is a fairly small percentage, but it must be remembered that there can be little hope of applying extrapolation methods if uncertainty exists as to the identification of troughs and ridges from one map to the next. If these points are eliminated it will be seen that fair correlation exists between computed and observed values.

However, correlation alone does not tell the whole story, for the scatter of the points may still be so great that estimates of trough or ridge position will be too greatly in error. A distance of 7° of longitude at 45°N has been chosen as the maximum allowable error for a good forecast. This is quite reasonable, since the average wavelength at 45°N is about 60°, so that an error of about 30° must be made in order to place a ridge where a trough is observed and vice-versa. 7° of longitude at 45°N represents about 350 to 400 miles. Lines representing an error of this magnitude have been drawn parallel to the line representing perfect correlation. All points lying within these lines, then, are satisfactory from the point of view of the forecaster. It will be noted that about 75% of the points lie within these lines.

Fig. 18 shows the results of computations for a full week in advance. Very little correlation is shown and 65% of the points lie outside the maximum allowable error. It will be noted, too, that the number of points where the continuity is indefinite has increased to 14.

This means, of course, that velocity computations alone, without any modification, cannot be used blindly as a forecasting tool. However, the criteria mentioned above may be used to select those cases that may work well.

Fig. 19 shows the results of half week computations obtained from half week trend charts. About the same results are shown as in the case of the kinematic computations. There is good correlation and in this case 77% of the points lie within the maximum allowable error.

Fig. 20 shows the results of the trend chart method for a full week. Here, as in the case of the computation method, most of the points lie outside the maximum allowable error. However, it is important to note that, unlike the case of the full week computations, there is definite correlation present, and the regression line (drawn by inspection) lies to the left of and has a greater slope than the line representing perfect agreement. In other words the full week movements as given by the trend charts have a tendency to be less than the observed movements, especially when the observed movement is large. This peculiarity of the trend charts was mentioned before in connection with the technique of their construction. If the maximum error limits were drawn about the true regression line instead of the theoretical regression line, many more points would fall within them.

Another graph (not reproduced here) shows the results of computations of deepening and filling for a half week by means of the tendencies at the center of the troughs or ridges. No correlation exists. Even the sign of the pressure change is the same in only 49% of the cases - about what one would expect by chance. This result is rather disappointing.

Another graph (not reproduced here) shows the same elements as the previous one, but for a full week. Again no correlation is shown and the sign of the pressure change is not indicated.

Fig. 21 shows deepening and filling for a half week by the method of trend charts. Here definite correlation is shown and about 50% of the points lie within 2 mb. of the correct value.

Another graph (not reproduced) shows the same thing for a full week. Very little correlation is shown.

Since neither the trend method nor computation method gave good results for full week deepening, another method, based on normal pressures was tried. This method is based on the simple assumption that the departure from normal pressure of troughs or ridges will remain constant. This means, of course, that the computed deepening or filling is simply the difference in normal pressure between the observed position and forecast position of the trough. Thus, if a trough moves into the region where normally a ridge prevails it should fill, and if it moves into a region in which a trough is normally found, it should deepen. The physical significance of normal troughs and ridges is that in the long run mean ridges are favored locations for anticyclogenesis and mean troughs are favored locations for cyclogenesis.

In order to test this hypothesis the observed deepening and filling was compared, not with the difference in normal pressures between current and forecast positions of the troughs or ridges, but with the difference in normal pressures between their observed positions. This is important, for two basic assumptions are made here. First, that the original hypothesis is correct, and secondly, that the movements are forecast correctly. We wish here to test only the original hypothesis. The graphs for both a half week and a full week in advance do not show good results, but nevertheless, the method is the one now currently used in the construction of computation charts. The method does not give the erratic and often ridiculous results obtained by the tendency method, and in the long run it should give better results than a forecast of no change in trough or ridge depth.

V. Summary

These statistical results indicate that considerable skill is shown in applying these quantitative methods mechanically for a half week (3 or 4 days) in advance. This applies to displacements by both trend and computation methods, and to deepening and filling by the trend method. For a full week in advance little skill is shown except by the trend displacements. These results are quite satisfactory from one point of view. They verify the fundamental assumption that mean maps may be extrapolated for a longer time interval than can daily maps (3 or 4 days as against 12 or 24 hours), due to the more gradual trends shown on mean maps. However, as far as the half week extrapolations are concerned, it must be remembered that due to the overlapping of successive half week periods, 1 or 2 maps which go to make up the half week mean map are already available to the forecaster. In view of what has been said about the resemblance of mean maps to the middle daily map of the period, the last available daily map in itself gives the forecaster some idea of what the next half week mean map will look like. However, the prognostic half week trend chart is a much closer picture, and has appreciable forecasting significance.

The whole week charts can be of appreciable help to the forecaster, providing that he considers their limitations as set forth previously in this report.

It must be borne in mind that the methods described in this report are used only as auxiliary tools in extended forecasting. They at least give the forecaster the best indications possible from existing trends, - much better than he can obtain merely from a visual inspection of the observed charts.

VI. Appendix:

Qualitative Criteria Applied To Computation and Trend Displacements

A. Introduction

In the preceding section of this report, certain qualitative criteria for estimating the degree of success of a computation were discussed. These criteria had to do with such elements as the curvature of the pressure profile, deepening and filling relative position of isobaric and isallobaric centers, and use of the half week trend chart. It is the purpose of this section to treat the results of statistical tests of these criteria, which in the main seem to uphold the statements made in the preceding section.

It was pointed out that the forecasting of displacements for a full week in advance left much to be desired, whether they were computed by means of extrapolation formulae or by trend charts. This result carries with it the implication that on the whole the computation and trend methods are not of much practical value. However, even though the computed displacements do not show up too well when they are lumped together indiscriminately, we should consider the possibility of selecting those cases which have a high probability of success. This problem arises in almost any method of forecasting. Most forecaster recognize, for example, that there are certain weather situations which are easier to forecast than others. It is the purpose of the present study to show how this process of selection may be applied to computation and trend displacements on 5-day mean 10,000 ft. charts.

It may be stated from the outset that qualitative criteria can never guarantee the success or failure of a forecast. As long as it is not possible to make quantitative estimates of errors in the computations, it is also not possible to state definitely that an estimated displacement will remain within certain limits of the observed displacement. The best we can hope for is that there will be some association between the criteria and the success or failure of a forecast.

The criteria suggested in this study were developed essentially for use in connection with extrapolation (kinematic) formulae. Nevertheless, it is assumed that they may also be applied to extrapolations based on trend charts. The justification for this assumption lies in the following statistical material. It is clear, however, that there cannot be exact correspondence between computation and trend displacements much of the time. In the first place, if the trend graphs are extrapolated correctly, they will automatically take into account the changing velocity of a given trough or ridge. Thus, there is a tendency for the trend charts to correct somewhat for accelerations which affect the velocity computations. Nevertheless, the difficulties of extending the trend graphs exactly are so great that in rapidly changing situations the trend curves will fail just as the formulae will fail to give the correct displacements.

Secondly , it has been pointed out that there is a tendency for the trend maps to underestimate displacements, and that this error can be corrected in part by means of an empirical regression curve. No attempt has been made to do this in the present study, however, so that this source of error will tend to make the trend displacements less successful than those made by computation.

B. <u>Definition of Criteria</u>

The criteria used in this study are, with one exception, the same as those outlined in the preceding section of this report. They will now be defined individually.

1. Profile Curvature: In order to apply this criterion it is necessary to define what is meant by a sharp profile, and therefore one that is favorable for a good computation. No matter what numerical value of the curvature is chosen for the critical value, it will be quite arbitrary. It is perhaps best to choose this value such that half of the total observed curvatures are greater and half are less. After inspection of a series of mean maps, this critical value of the profile curvature was determined to be 7 mb., using a unit of 13 degrees of longitude at 45°N, and applying the usual formula for curvature $\left[(p^{1} - p^{\circ}) + (p^{-1} - p^{\circ})\right]$.
2. Deepening and Filling: It has been pointed out that deepening and filling play a much more important part in

evaluating displacements made on mean charts than on daily charts, because of the much greater time interval involved. It was also shown that the half week trend charts give a good indication of this deepening or filling. It will be assumed that they also indicate change of curvature. A change in curvature is defined as significant, and therefore unfavorable for a good computation, when the half-week trend chart indicates that the curvature will change by a factor of two.

3. Relative Motion of Adjacent Systems: Too much relative motion of adjacent troughs and ridges as indicated by extrapolations at the same latitude shows that one or more of the computations is in error, and therefore this situation is unfavorable for a good computation. The indication is defined rigorously as unfavorable if the adjacent systems are forecast to overlap.

4. Fast Relative Motion of Isallobaric and Isobaric Systems: Considered from a kinematic point of view, relative motion between isallobaric and isobaric systems is perhaps the greatest single cause of large errors in velocity computations. In order to obtain an indication of this relative motion we may make use of the last half-week observed mean map as well as the next half-week trend map. It is difficult to decide what amount of relative motion should be considered significant, but experience with mean maps

makes it clear that this criterion should be defined in such a way that it is unnecessary to identify individual isallobaric systems from one map to the next. It has already been explained in the case of observed maps that in about 10% of the cases it is difficult to identify individual troughs and ridges from one map to the next. It is much more difficult in the case of isallobaric systems. Furthermore, isallobaric patterns on the half-week trend maps are often crude, and in the majority of cases it would be extremely difficult to identify individual isallobaric systems on them. Therefore, relative motion is defined to be not too great, or favorable for a good computation, when the isallobars on the past half-week mean map or on the half-week trend chart indicate the same direction of motion of a trough or ridge as does the current mean map. This definition is unsatisfactory, since a good deal of relative motion may take place without actually reversing the direction of motion of a given trough or ridge from one half week to the next. As will be shown later, there are some cases where the half-week trend isallobars indicate considerable relative motion without a change in direction of motion, and the forecaster can take this into account in a qualitative manner. More will be said later about the qualitative use of these criteria, but for the purpose of the statistical analysis, the definition has been left in the above simple form.

5. Relative Motion Indicated by Prognostic Half-Week Trend Chart. The definition of this criterion is similar to that described in the preceding paragraph.

6. Relative position of Isallobaric and Isobaric Systems: Since relative motion between isallobaric and isobaric systems is important in evaluating a computation, it is clear that if the isallobaric centers (maxima or minima) are close to trough or ridge lines, slight relative motion may produce a complete reversal of the forecast displacement, while if the isallobaric and isobaric centers are far apart then considerable relative motion may take place before the direction of motion is changed. Therefore the relative position of isallobaric and isobaric centers on the current mean map has been defined as unfavorable for a good computation when the trough or ridge lies more than 3/4 of distance between isallobaric centers.

C. <u>Statistical Procedure and Results</u>

In order to test the application of the criteria defined above, it is only necessary to apply them to selected trough and ridge computations for a reasonably long series of mean charts. Presumably if the majority of the criteria prove favorable in a given case, the forecast should have a fair chance of turning out well.

Before applying the test in any particular case it is first necessary to define what is meant by a good forecast. It has been decided to use the same limits as were used before in defining a satisfactory forecast. Thus, an extrapolation is considered good when the forecast position is within ± 7 degrees (longitude at 45°N) of the observed position. When between 7 and 14 degrees, it is considered fair, and when beyond 14 degrees, poor.

The period chosen for this statistical study was from July 4 to December 16, 1942, or from the time half-week trend isallobars were first drawn as a regular routine, up to the last available mean maps. Thus, the period includes mainly the warmer season of the year, a period not too favorable for trend forecasts.

One or two trough or ridge points were chosen on each of 43 mean maps, making a total of 64 points. Unlike the previous tests of displacement, the points were chosen only within the United States, between about 60° and 120° West longitude, and generally fairly close to 45°N. The estimated full week displacement was in each case obtained both by the extrapolation formula and by means of the full week trend chart. These were then compared to the observed displacement and classified according to whether they were good, fair, or poor.

The statistical procedure used throughout this study is an application of the "chi-square" test to contingency tables. This procedure will be described only briefly here, and those unfamiliar with it can consult any standard textbook on statistics.[8]

The contingency table for the relationship between trend and computation displacements is shown in Table 1. The coordinates are the "value" of the trend or computation displacements, expressed as poor (P), fair (F), or good (G). The number in

TABLE 1

Trend

COMPUTATION / Value	P	F	G	Totals	
G	5 (13)	7 (4)	11 (6)	23	$X^2 = 24.87$
F	6 (7)	2 (2)	5 (4)	13	4 d/f
P	23 (14)	1 (4)	1 (7)	25	$P \ll .01$
Totals	34	10	17	61	

TABLE 2

Half Week Trend Chart

OBSERVED HALF WEEK CHART	Reversed	Not Reversed	Totals	
REVERSED	15 (12)	20 (23)	35	$X^2 = 2.51$
NOT REVERSED	7 (10)	22 (19)	29	1 d/f $.20 > P > .10$
Totals	22	42	64	

TABLE 3

Trend Chart

Value / Ratio	P	F	G	Totals	
60-100	16 (19)	5 (5)	12 (9)	33	$X^2 = 4.72$
41-59	7 (7)	2 (2)	4 (4)	13	4 d/f
0-40	12 (9)	3 (3)	1 (4)	16	$.50 > P > .30$
Totals	35	10	17	62	

TABLE 4

Computation Chart

Value Ratio	P	F	G	Totals
60-100	12 (13)	5 (7)	16 (13)	33
41-59	4 (5)	4 (3)	5 (5)	13
0-49	9 (7)	4 (3)	3 (6)	16
Totals	25	13	24	62

$\chi^2 = 4.27$

4 d/f

$.50 > P > .30$

TABLE 5

Trend Chart

Value Ratio	P	F	G	Totals
80,83,100	3 (7)	4 (3)	8 (5)	15
0,17,20	9 (4)	1 (2)	1 (4)	10
Totals	11	5	9	25

$\chi^2 = 11.17$

2 d/f

$P \ll .01$

TABLE 6

Computation Chart

Value Ratio	P	F	G	Totals
80,83,100	4 (7)	3 (2)	8 (6)	15
0,17,20	8 (5)	1 (2)	1 (3)	10
Totals	12	4	9	25

$\chi^2 = 6.09$

2 d/f

$.05 > P > .02$

the upper left hand corner of each square is the total number of cases which fall in that group. Thus, there are 11 cases where good trend displacements are associated with good computations, and 23 cases where poor trends are associated with poor computations. The number in parentheses in each square is the number of cases expected by chance in that group. "chi-square" is obtained by finding the difference between observed and expected, squaring it, dividing by the expected number, and then summing the resulting values for all the groups. The number of "degrees of freedom" in this case is 4, and the probability of getting this value of "chi-square" by chance is much less than 1 in 100. This means that beyond any reasonable doubt there is a real tendency for association between the results of trend and computation extrapolations. However, this statement should be modified somewhat due to the fact that there is not complete independence between the individual cases going to make up this test. Thus, for example, if a certain computation were to turn out well and the corresponding trend displacement also turned out well, then there would be a tendency for the same result to occur for a neighboring trough or ridge or for a trough or ridge from the next map in the series, simply due to the fact that they are closely associated in space or time. The result of this is to reduce the effective number of cases and therefore the numerical value of "chi-square". It means, in brief, that the probability of getting this distribution by chance is greater than is indicated by the test. No correction has been made for this error, but it will be assumed that it will not affect the conclusions materially.

Although the test shows that association is present (Table 1) the relationship is by no means perfect. There are, for example, 5 cases where the trend displacement is poor while the computation is good. Also it will be noted that there are more cases of poor trends associated with good computations than "vice versa". This is no doubt due to the tendency, mentioned before , for the full week trend displacements to underestimate the true displacements.

The next relationship investigated was that between the half-week trend isallobars and those on the observed half-week mean chart. Thus, the half-week trend isallobars should indicate the same direction of motion of a given trough or ridge as do the isallobars on the observed half-week map. To test this, the half-week trend charts as well as the observed half-week mean charts were classified according to whether the isallobars indicated that a given trough or ridge would continue in the same direction as on the current mean chart, or would reverse. These factors were then tested for association (Table 2). It will be seen that in only 7 out of 29 cases, where the observed half week isallobars showed the trough or ridge moving in the same direction, did the prognostic half-week trend isallobars indicate that it would reverse. However, in the 35 cases where the observed isallobars show a reversal, the trend isallobars fail to indicate that reversal in 20 cases. This result is to be expected, since when large changes take place the extension of the mean barogram becomes more difficult.

The test for significance shows that the probability fails to reach the one percent level, and that therefore the observed distribution could be obtained by chance. However, it should be pointed out that there were 5 cases, when the observed isallobaric field showed a reversal, where the trend isallobars definitely indicated marked relative motion, so that the forecaster could have been well aware that large changes were taking place. If these 5 cases were entered in favor of the association they would perhaps raise the probability above the level of significance.

The next relationship that was tested was that between the "value" of the displacements and the corresponding criteria. In order to have a quantity which represents the combined indication of all the six criteria, the ratio between the number favorable for the computation to the total number (6) was used. Thus, values of this ratio close to zero (indicating that few of the criteria favor a good computation) should be associated with poor computations, while values close to 1 should be associated with good ones. This test was carried out for both the trend and computation displacements (Tables 3 and 4). It shows that there is very little association present. However, when only the extremes are tested (Tables 5 and 6), the results are significant in the case of the trend charts, and come close to the level of significance in the case of the computations. Thus, in cases where not more than one of the criteria are opposed to the others, they do indicate success.

Finally, the association between each criterion taken separately and the "value" was tested (contingency tables not shown). This was done because of the possibility that some of the criteria are more important than the others. Since this test requires the treatment of 12 contingency tables it suffers from the fact that the probability of at least one significant association occurring by chance is increased, in view of the fact that we are dealing with a large number of tables. Nevertheless, none of these contingency tables reached the one percent level of significance, indicating that, taken alone, the individual criteria (as defined) cannot indicate the value of an extrapolation.

D. <u>Example of Application of Criteria</u>

Computations made during the period January 13 through January 24, 1943, have been chosen to illustrate the application of these criteria. The observed mean 10,000 ft. chart for January 13-17 (Fig. 22) shows a broad deep trough located over the eastern United States. Computations made on this trough indicate extremely rapid retrogression to a position just along the west coast. Such large retrogressions are seldom observed on mean charts. It is of special interest, therefore, to see if the criteria indicate whether the computations are likely to succeed.

Considering the particular computation made at 43°N 88°W, and on measuring the curvature of the trough at this point with the proper length unit, we see that the curvature just barely exceeds the critical value. However, we note also that the trough is very broad and extensive, dominating the entire area of the United States. Because of this, we can probably place more confidence in the favorable indications of the curvature measurement, and also in the assumption that the trough will not deepen or fill appreciably during the period. The half week trend chart (Fig. 23) indicates that the curvature of the trough (measured at 43°N) will not be changed appreciably, and the half week trend isallobars indicate that the trough will continue to move westward, with isallobaric maximum and minimum still quite far removed from the center of the trough. However, the isallobars on the past half-week observed map for Jan. 9-13 (not shown) indicate that the trough was then moving eastward, and that therefore there must have been a considerable change in the isallobaric field during the past half week. This is the only one of the criteria which is unfavorable for the computation. The current mean map (Fig. 22) shows that the trough is more than 1/4 of the distance between the isallobaric maximum at 43°N 74°W and the isallobaric minimum at 43°N 117°W. As far as the indications of adjacent systems are concerned, we note that the only other system on the map on which a computation was made is the trough at 50°N 55°W, and that this computation does not conflict with the others since the displacement is not large in comparison to the others, and would still result in a reasonable trough spacing. This criterion will therefore be considered favorable, although it is somewhat indecisive. Thus we see that since 5 of the 6 criteria are favorable for the computation, it should work out fairly well. On turning to the observed map for the period Jan. 20-24 (Fig. 24) we note that the trough has actually passed off the west coast*, and so we do not know its exact position because of the lack of observation in that region. However, if we accept the analyst's estimated position at 43°N 128°W we see that this is less than 7° from its forecast position at 43°N 123°W, and that under these circumstances the forecast should be considered good.

In practice the 6 criteria are arranged in a "check list" and the forecaster simply checks or crosses them off the list in making his evaluation.

E. Conclusions.

It is seen that if only the extreme values of the evaluation ratios are considered, some skill is shown in predicting the success of a forecast. However, it should be emphasized that in many ways the definitions given above are unsatisfactory since there is other important information to be derived from the criteria than is included in the definitions. The criteria were defined rigorously in this simple fashion for the purpose of the statistical study. A more satisfactory, but more compli-

* Intervening 5-day mean charts prove without doubt that the mean trough actually retrograded and that there is no doubt of the continuity.

cated, definition would probably not be justified, since it would be so involved as to obscure the practical value of the results. Nevertheless the forecaster should consider these criteria in a more qualitative fashion than suggested in the definitions. Such qualitative consideration is illustrated in the example. Thus, the extent of a trough or ridge, as well as its curvature, is important to consider when it is a question of possible radical changes. The qualitative use of the half-week trend isallobars has already been mentioned

Finally, it should be emphasized again that, strictly speaking, the above criteria apply only to computations and not to trend charts. Any technical improvement in the construction of the trend charts or experience in their use may invalidate these criteria as applied to the trend chart. Attempts at improving the trend method are now in progress.

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(5) Petterssen: ibid. Page 393

(6) Petterssen: ibid. Formula (1) Page 399 combined with formula (4) Page 393 and formula (11) Page 395.

(7) Petterssen: ibid. Page 400

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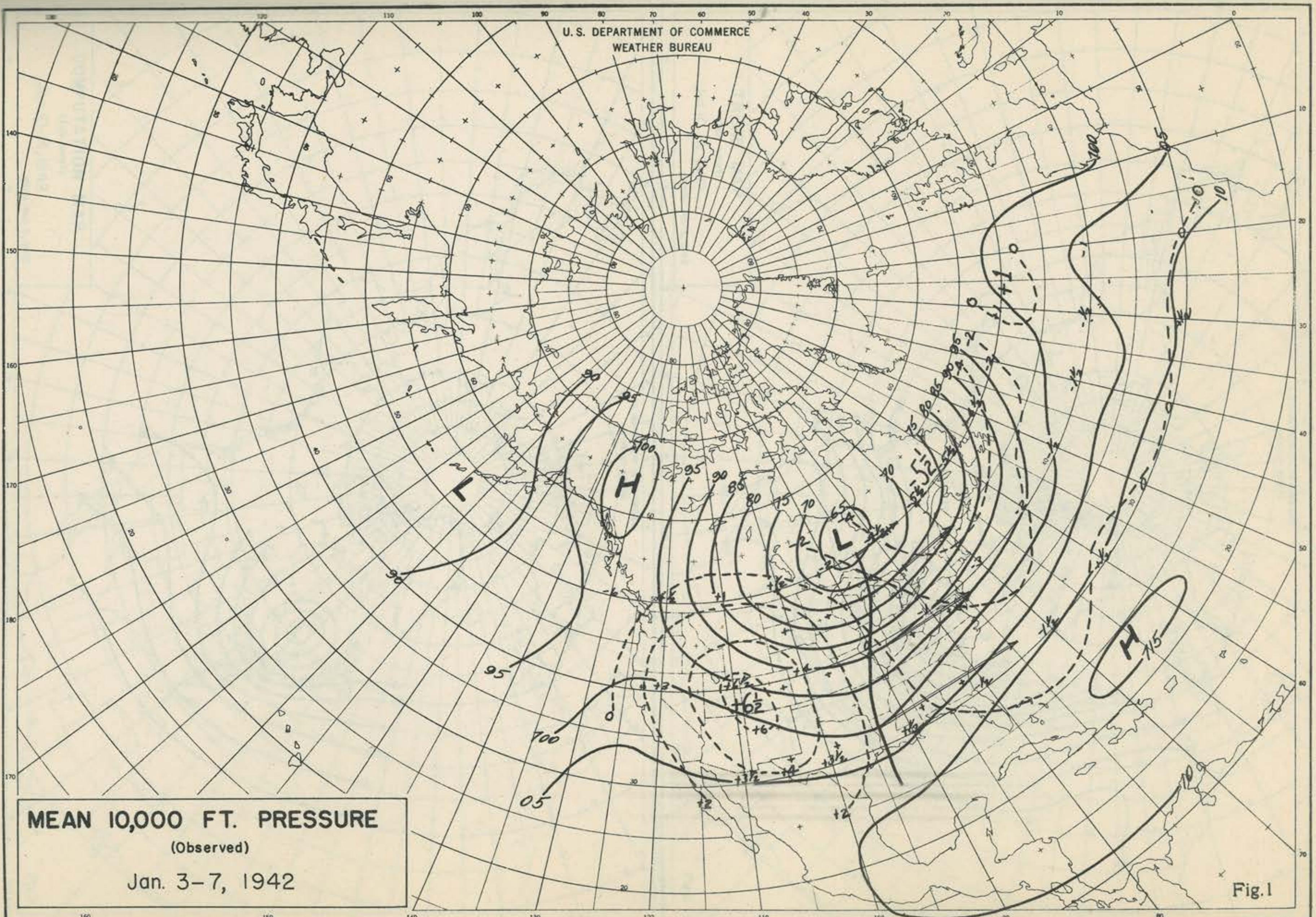
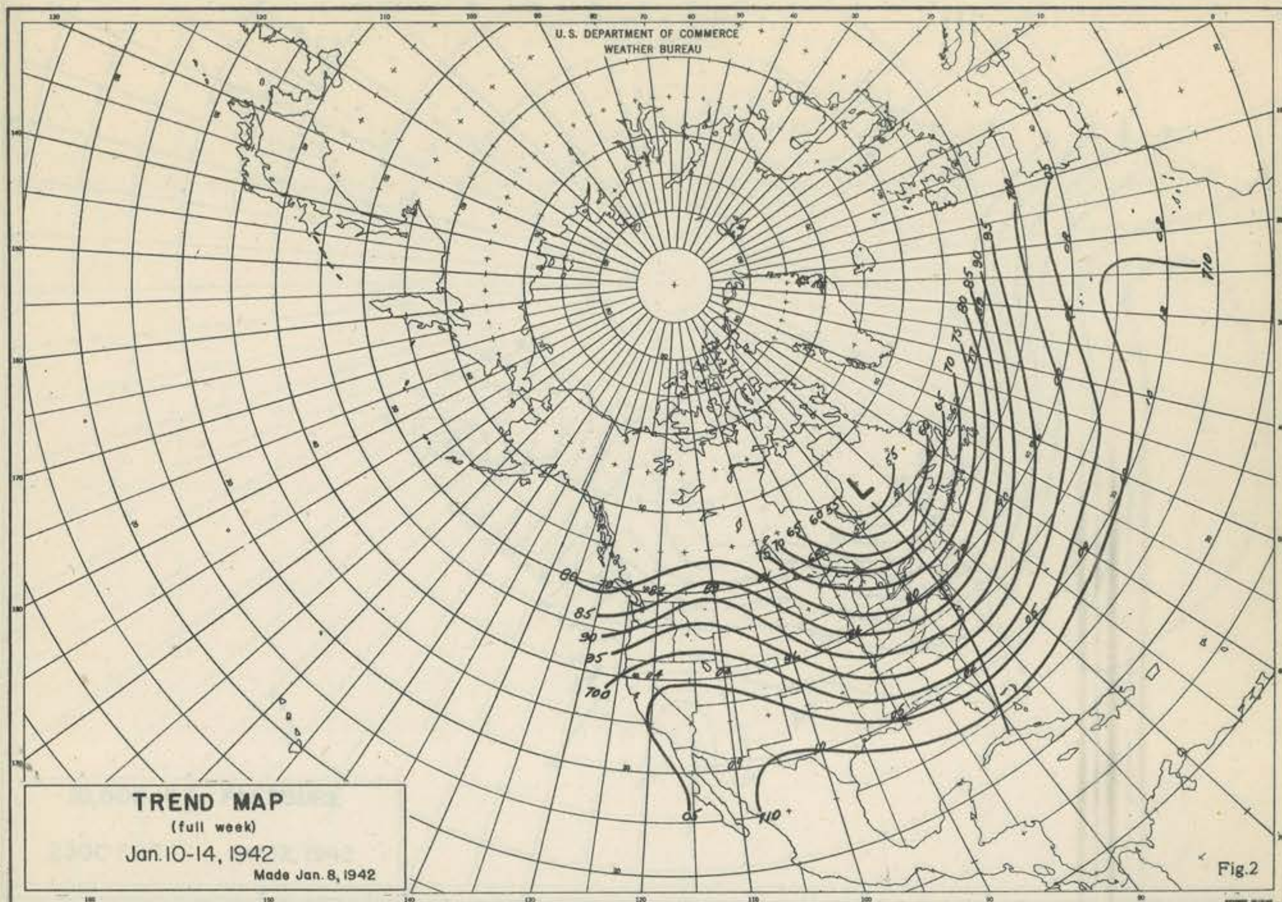


MEAN 10,000 FT. PRESSURE

(Observed)

Jan. 3–7, 1942

Fig.1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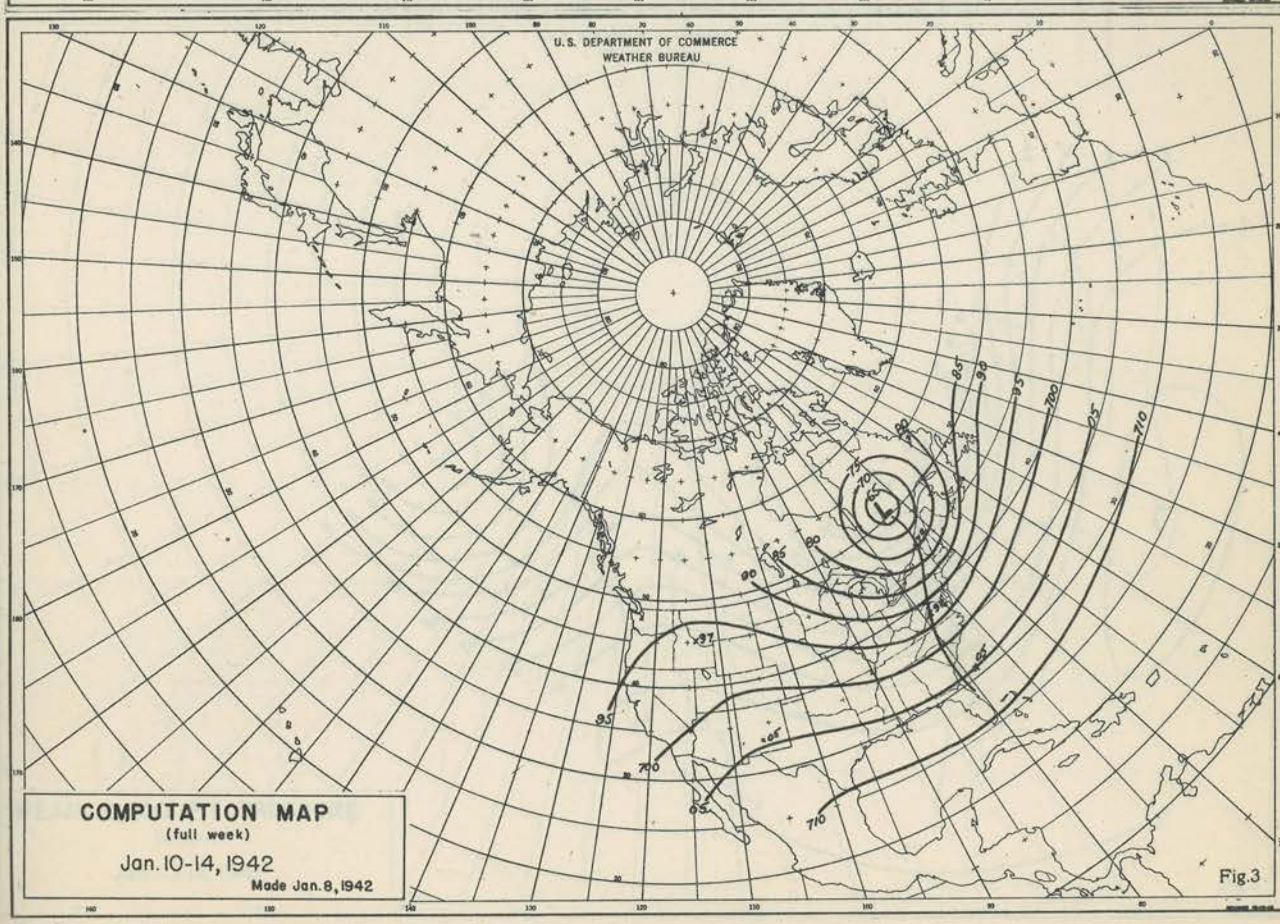
WEATHER BUREAU
TREND MAP
(full week)
Jan. 10-14, 1942
Made Jan. 8, 1942
Fig.2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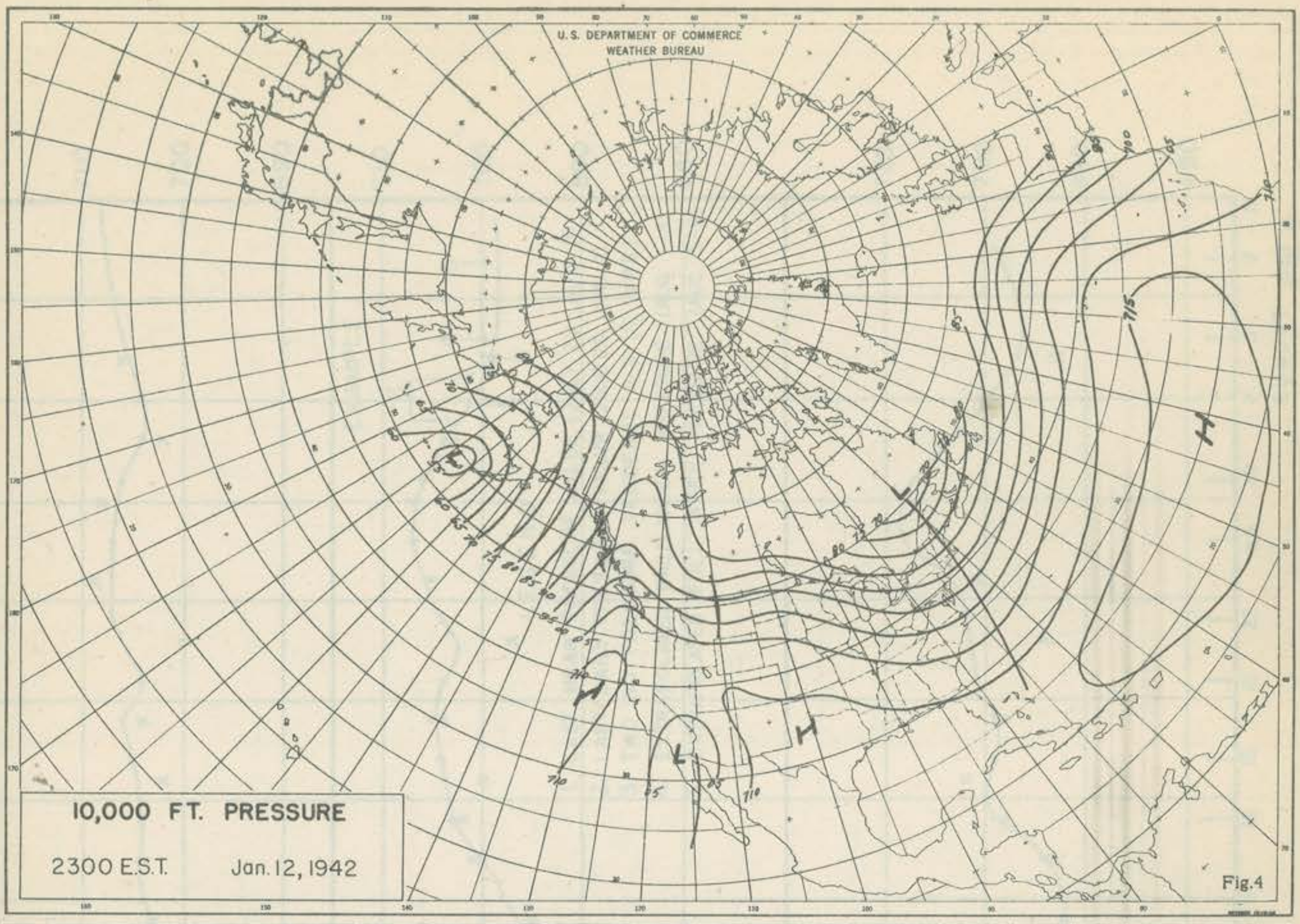
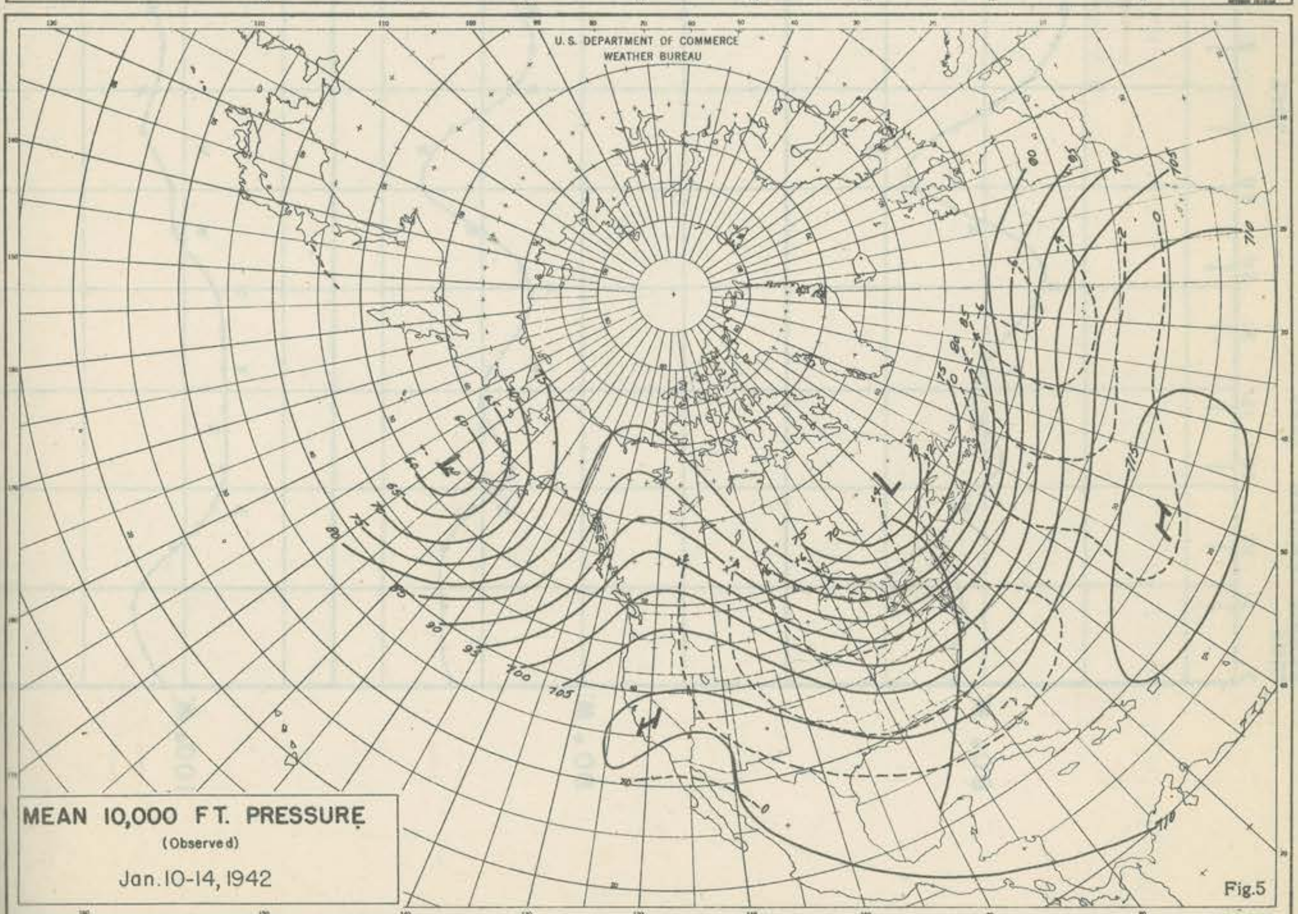
WEATHER BUREAU
COMPUTATION MAP
(full week)
Jan. 10-14, 1942
Made Jan. 8, 1942
Fig.3



10,000 FT. PRESSURE

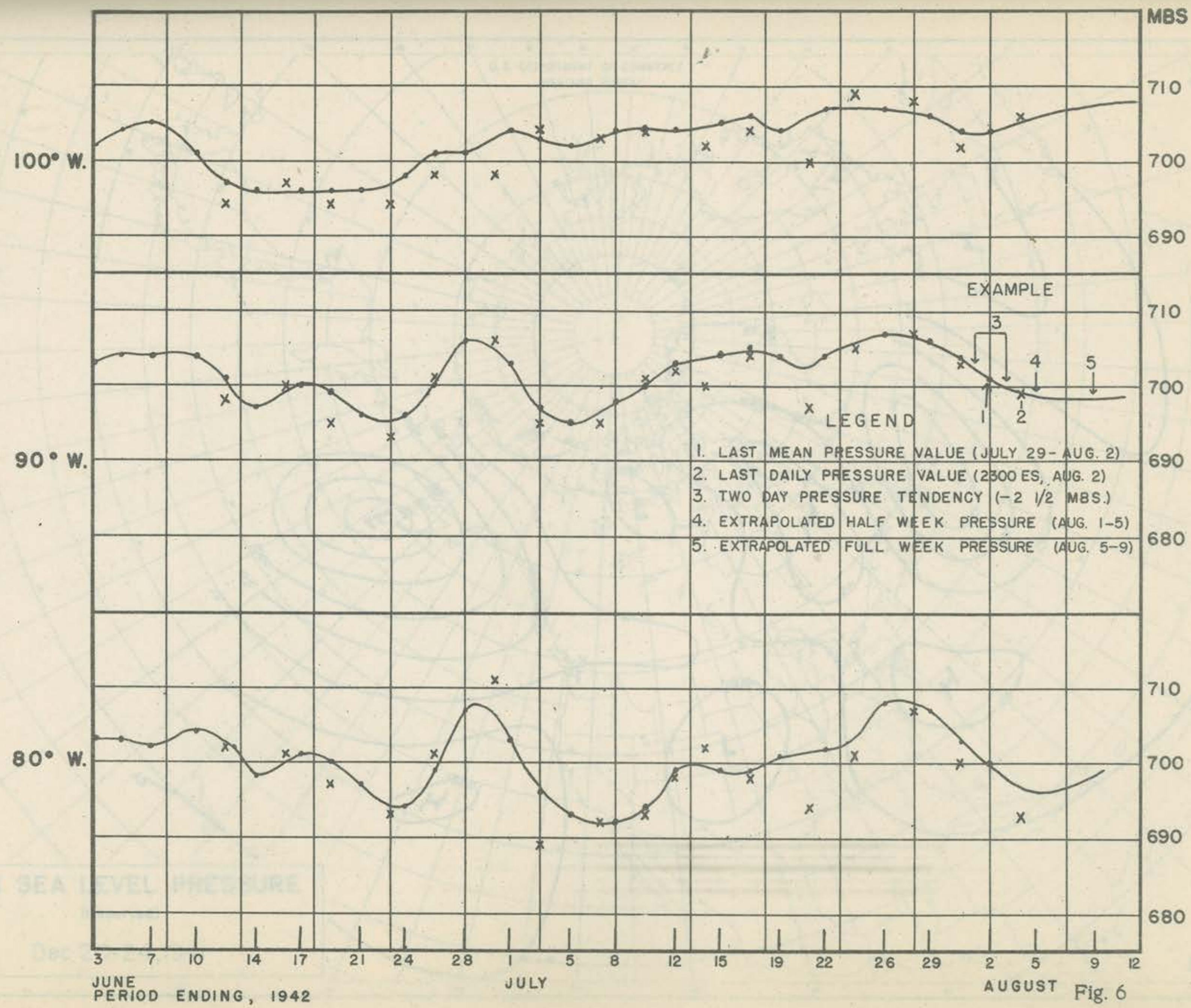
2300 E.S.T. Jan. 12, 1942



MEAN 10,000 FT. PRESSURE

(Observed)

Jan. 10-14, 1942


MBS
710
700
690
680
100° W.
90° W.
80° W.
EXAMPLE
LEGEND
1. LAST MEAN PRESSURE VALUE (JULY 29 - AUG. 2)
2. LAST DAILY PRESSURE VALUE (2300 ES, AUG. 2)
3. TWO DAY PRESSURE TENDENCY (-2 1/2 MBS.)
4. EXTRAPOLATED HALF WEEK PRESSURE (AUG. 1-5)
5. EXTRAPOLATED FULL WEEK PRESSURE (AUG. 5-9)
3 7 10 14 17 21 24 28 1 5 8 12 15 19 22 26 29 2 5 9 12
JUNE
JULY
AUGUST
PERIOD ENDING, 1942
Fig. 6

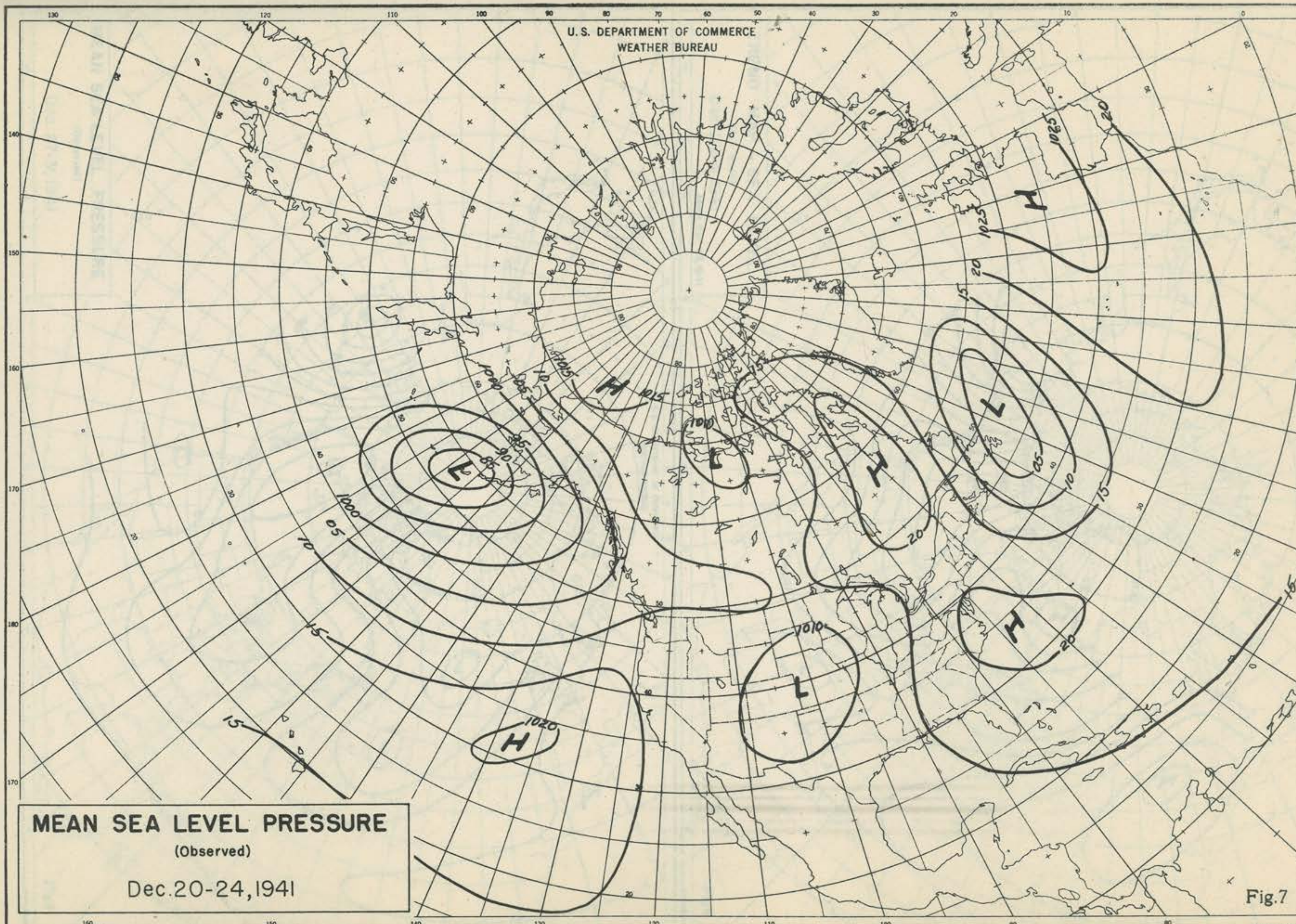
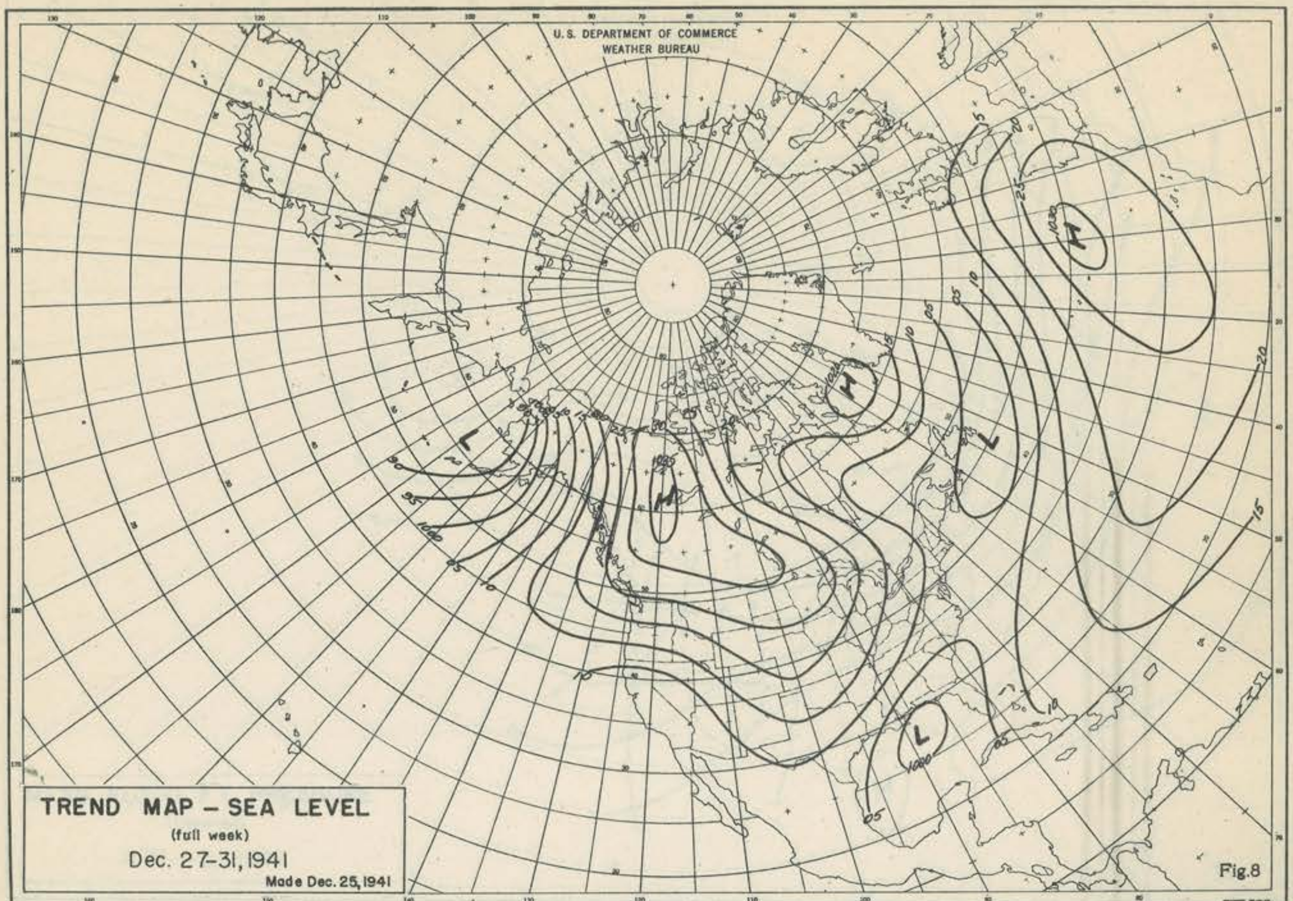
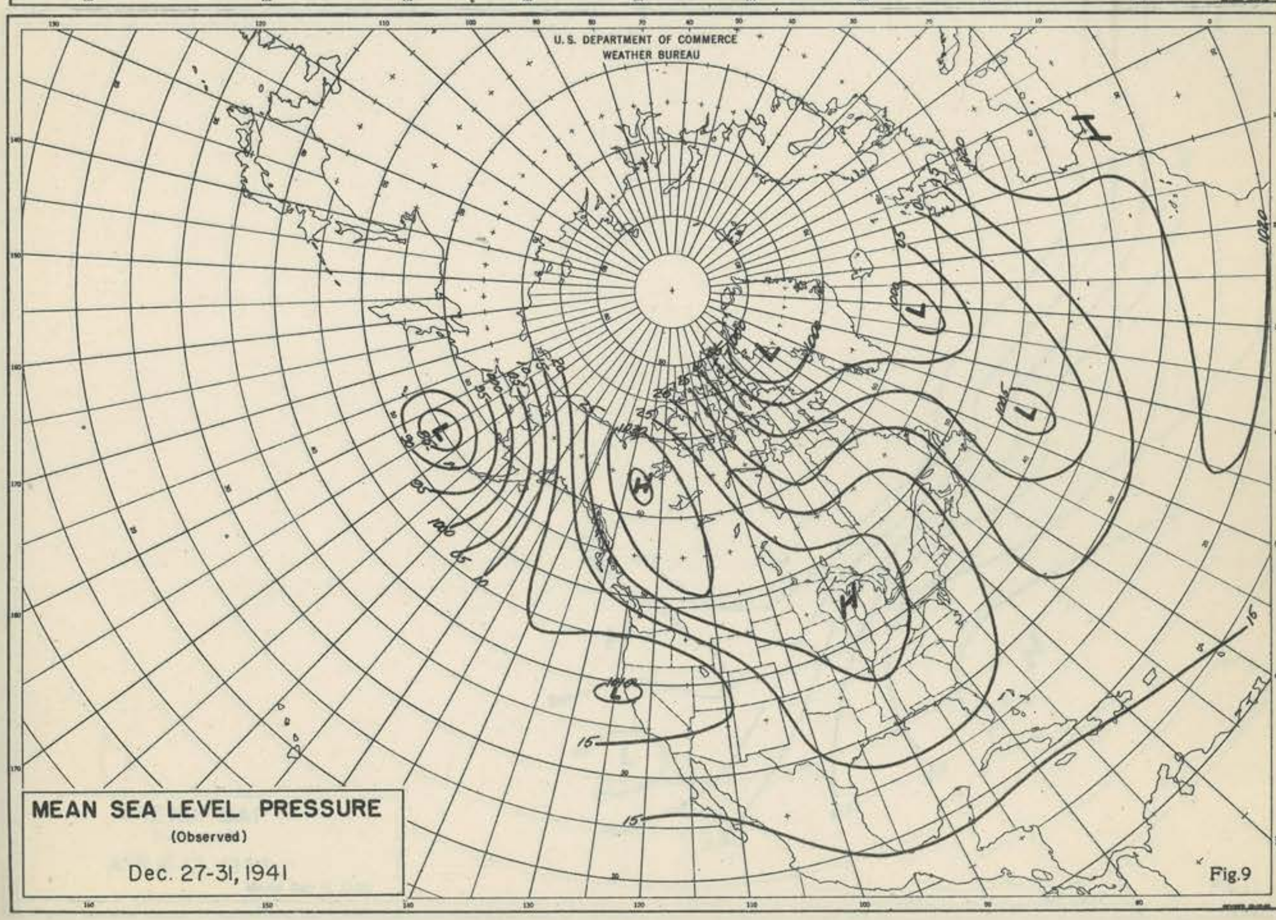

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN SEA LEVEL PRESSURE
(Observed)
Dec. 20-24, 1941

Fig. 7


U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
TREND MAP - SEA LEVEL
(full week)
Dec. 27-31, 1941
Made Dec. 25, 1941
Fig.8


U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN SEA LEVEL PRESSURE
(Observed)
Dec. 27-31, 1941
Fig.9

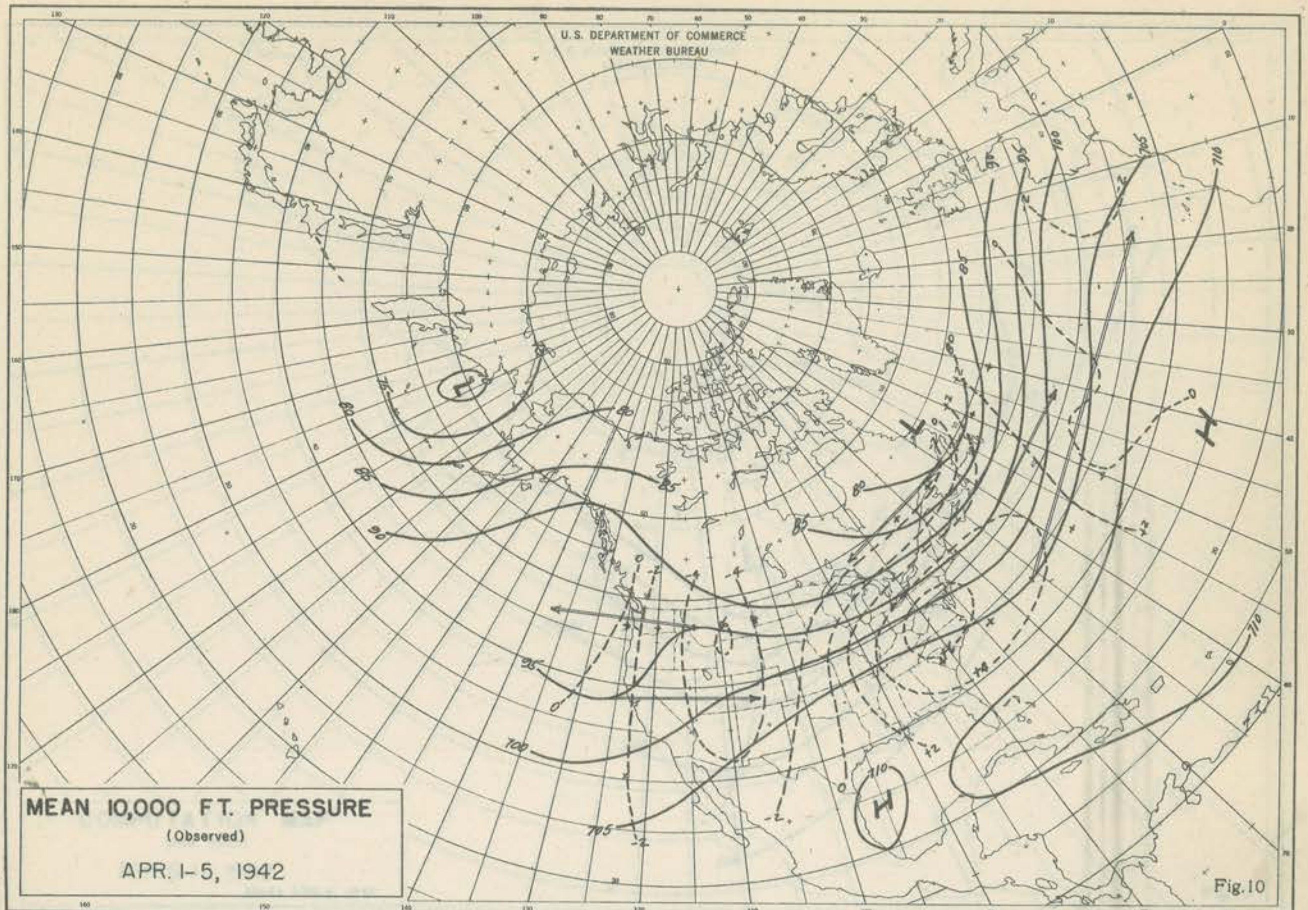

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN 10,000 FT. PRESSURE
(Observed)
APR. 1-5, 1942

Fig. 10

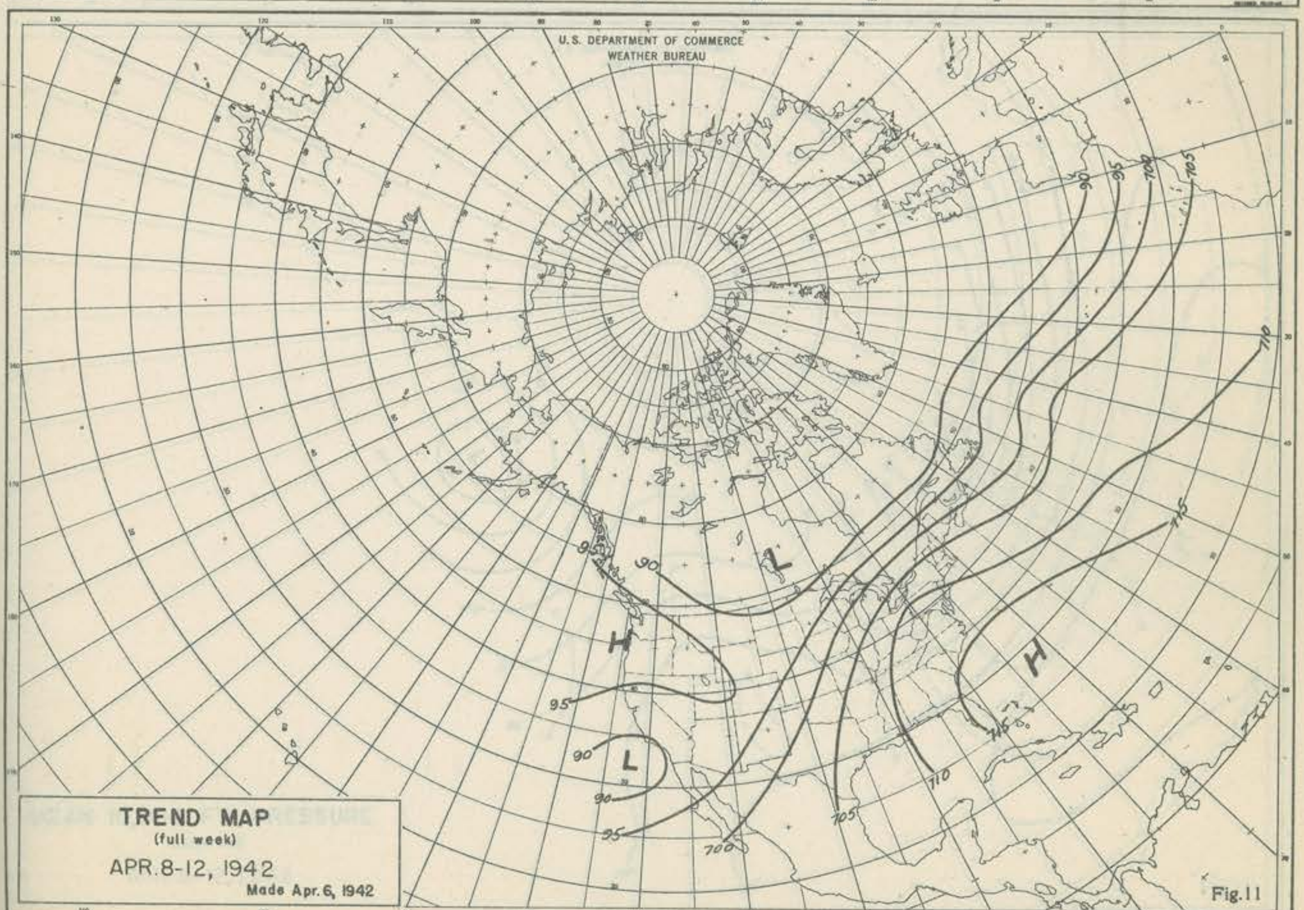

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
TREND MAP
(full week)
APR. 8-12, 1942
Made Apr. 6, 1942

Fig. 11

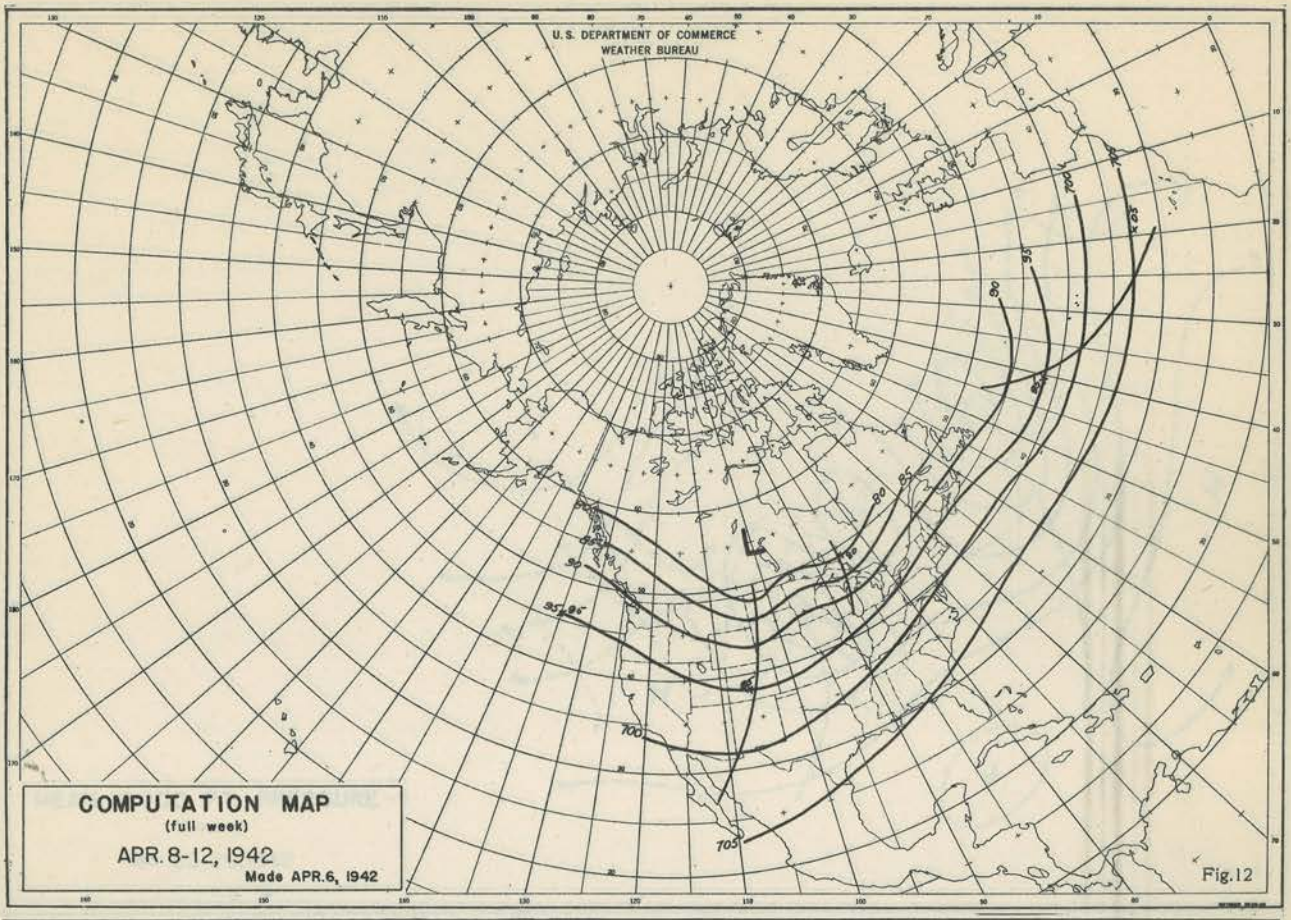

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
COMPUTATION MAP
(full week)
APR. 8-12, 1942
Made APR. 6, 1942

Fig. 12

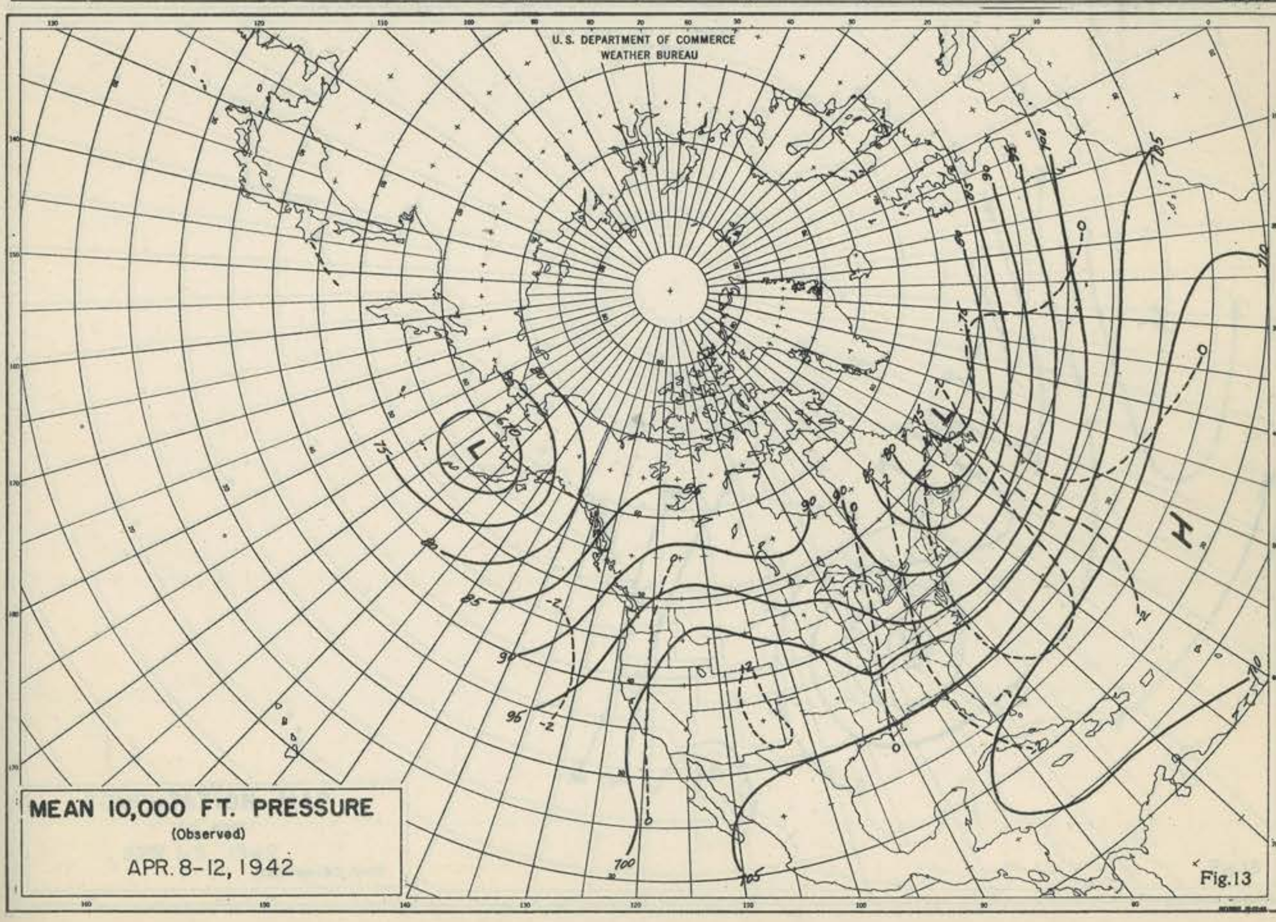

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN 10,000 FT. PRESSURE
(Observed)
APR. 8-12, 1942

Fig. 13

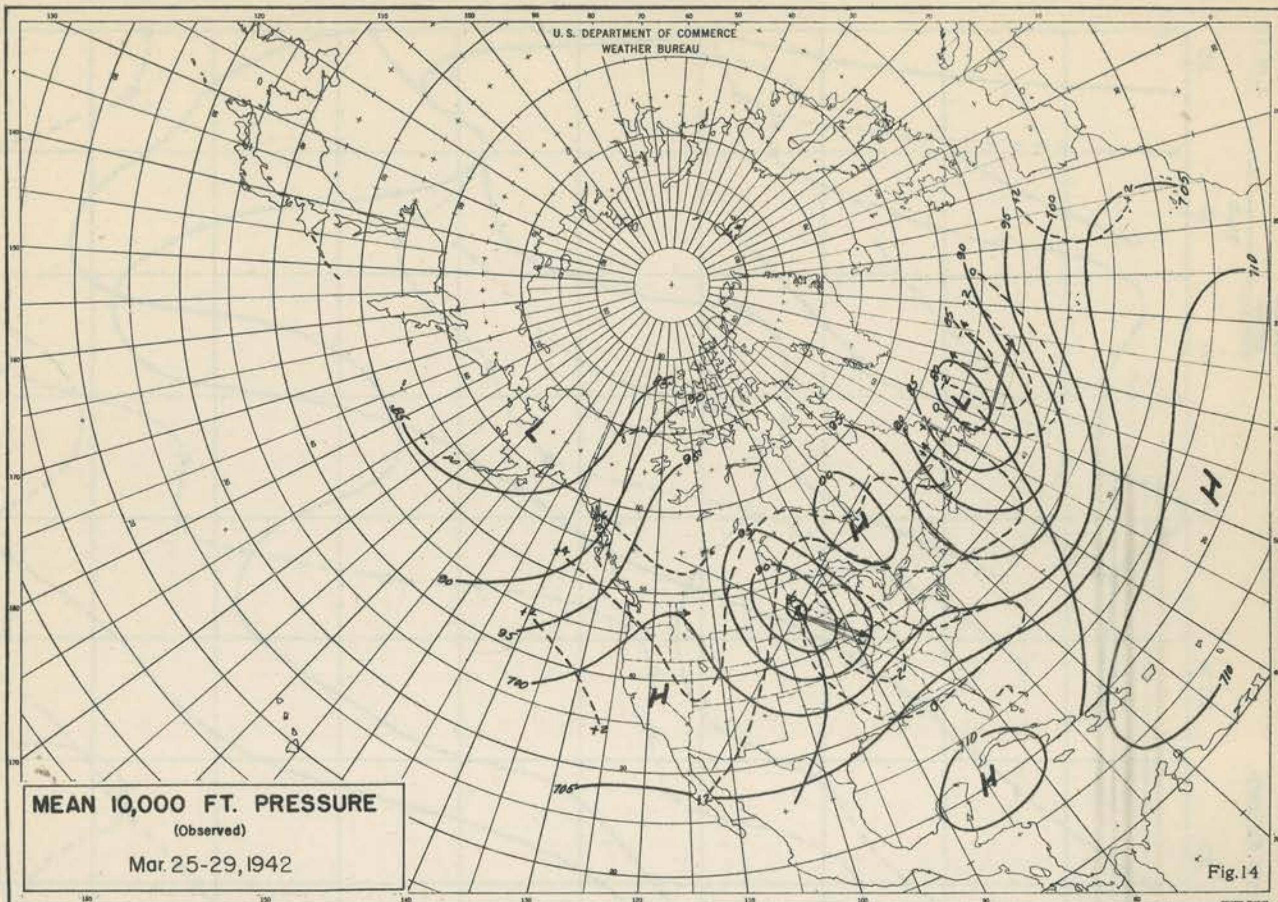

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN 10,000 FT. PRESSURE
(Observed)
Mar. 25-29, 1942

Fig. 14

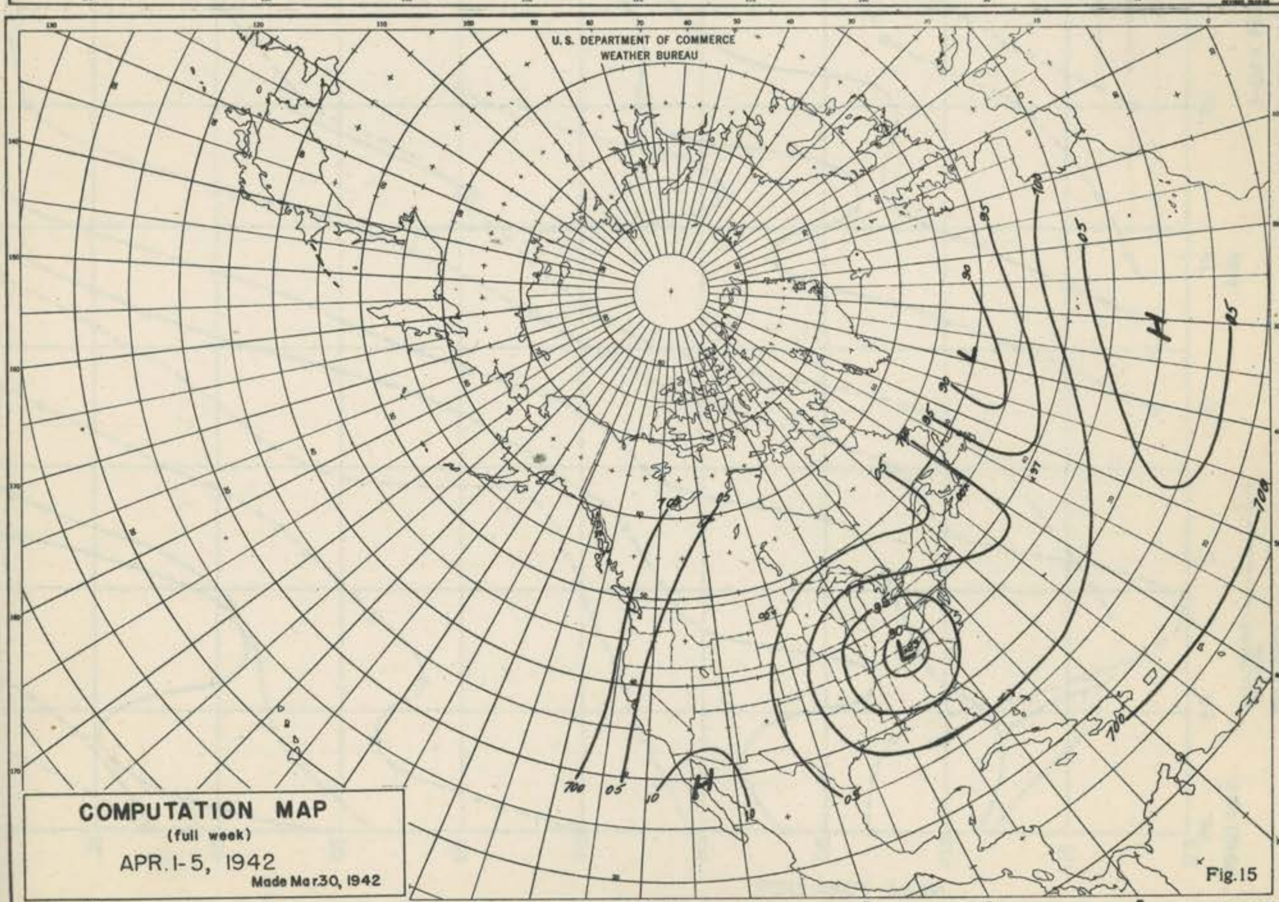
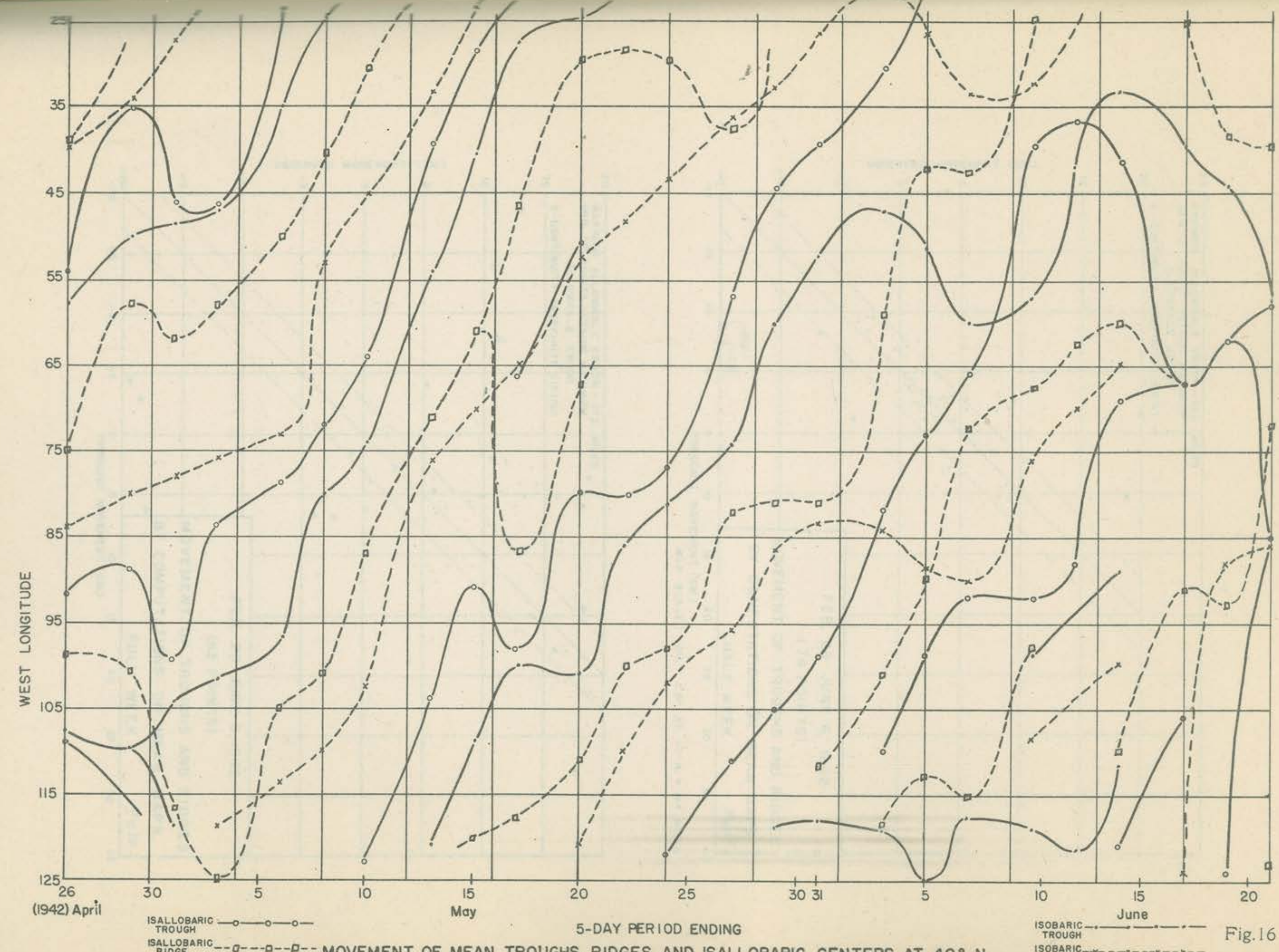

U. S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
COMPUTATION MAP
(full week)
APR. 1-5, 1942
Made Mar. 30, 1942

Fig. 15



MOVEMENT OF MEAN TROUGHS, RIDGES, AND ISALLOBARIC CENTERS AT 40° N.

Fig. 16

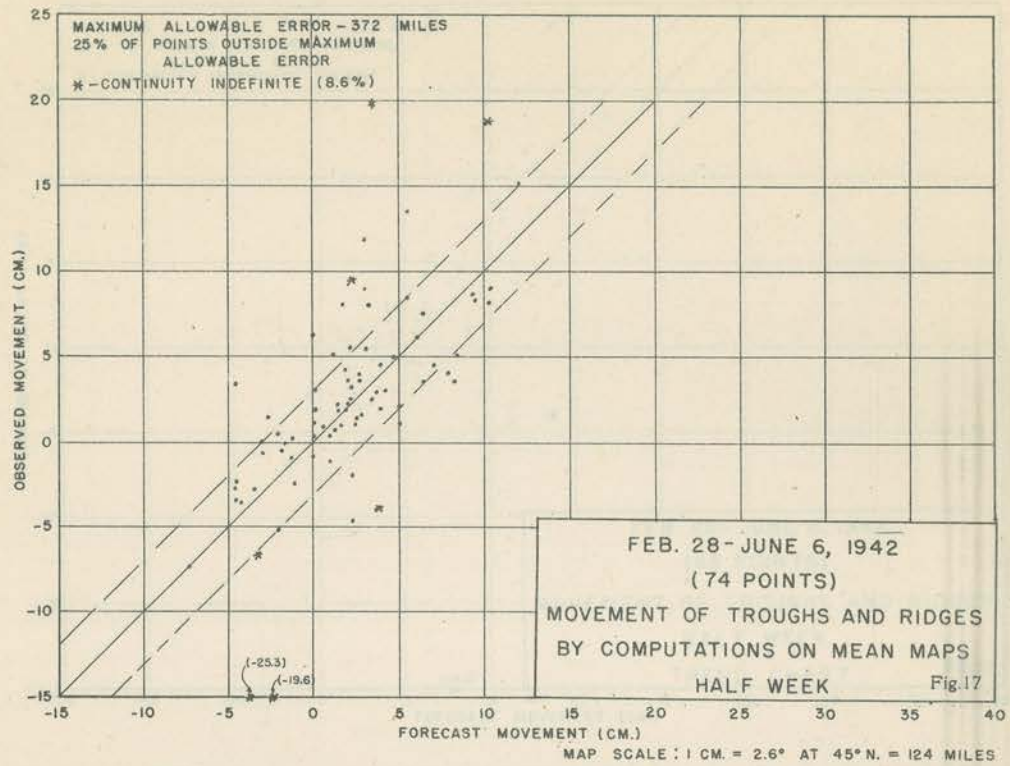

MAXIMUM ALLOWABLE ERROR - 372 MILES
25% OF POINTS OUTSIDE MAXIMUM ALLOWABLE ERROR
* - CONTINUITY INDEFINITE (8.6%)
OBSERVED MOVEMENT (CM.)
FORECAST MOVEMENT (CM.)
(-25.3)
(-19.6)
FEB. 28 - JUNE 6, 1942
(74 POINTS)
MOVEMENT OF TROUGHS AND RIDGES
BY COMPUTATIONS ON MEAN MAPS
HALF WEEK
MAP SCALE: 1 CM. = 2.6° AT 45° N. = 124 MILES

Fig.17

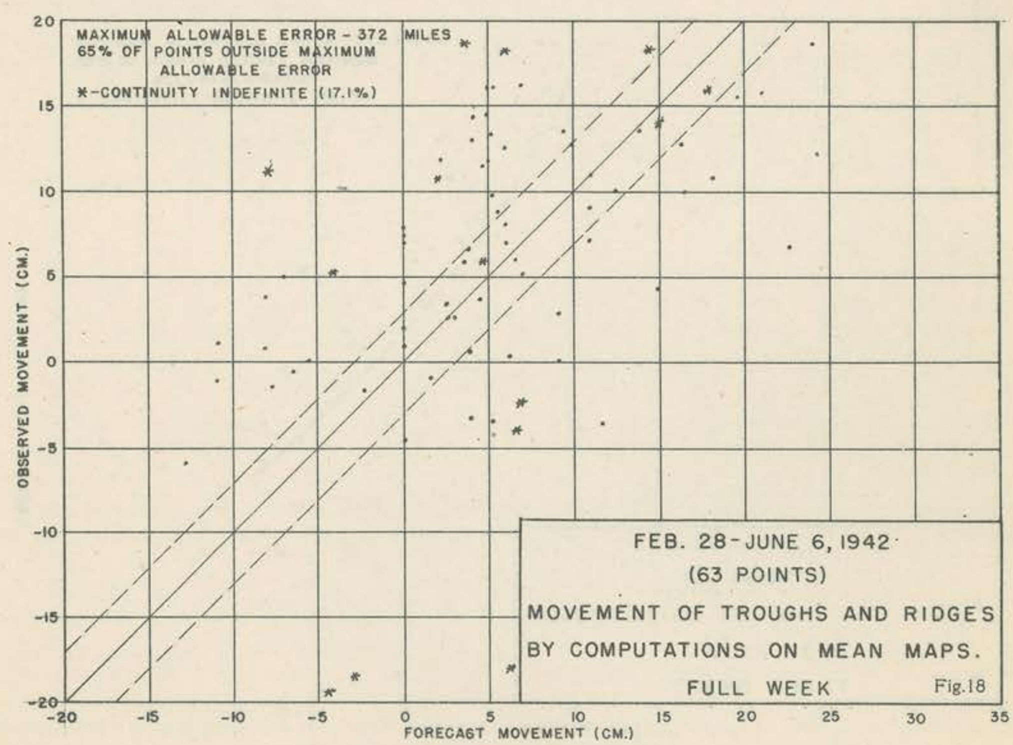

MAXIMUM ALLOWABLE ERROR - 372 MILES
65% OF POINTS OUTSIDE MAXIMUM ALLOWABLE ERROR
* - CONTINUITY INDEFINITE (17.1%)
OBSERVED MOVEMENT (CM.)
FORECAST MOVEMENT (CM.)
FEB. 28 - JUNE 6, 1942
(63 POINTS)
MOVEMENT OF TROUGHS AND RIDGES
BY COMPUTATIONS ON MEAN MAPS.
FULL WEEK

Fig.18

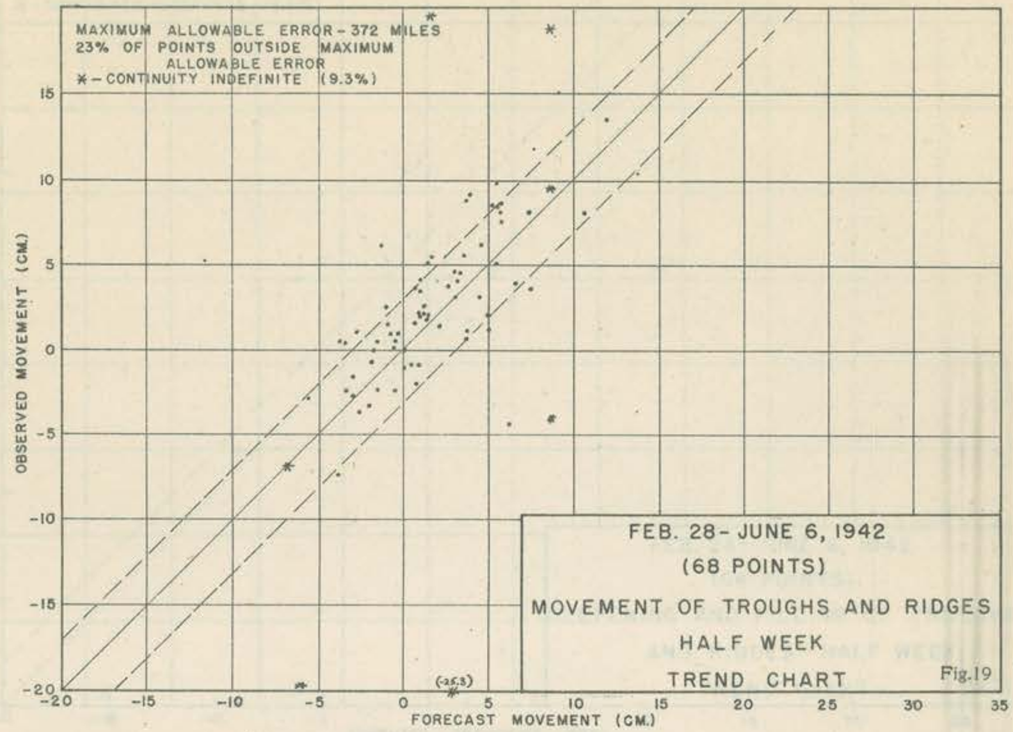

MAXIMUM ALLOWABLE ERROR - 372 MILES
23% OF POINTS OUTSIDE MAXIMUM ALLOWABLE ERROR
* - CONTINUITY INDEFINITE (9.3%)
OBSERVED MOVEMENT (CM.)
FORECAST MOVEMENT (CM.)
(-25.3)
FEB. 28 - JUNE 6, 1942
(68 POINTS)
MOVEMENT OF TROUGHS AND RIDGES
HALF WEEK
TREND CHART

Fig.19

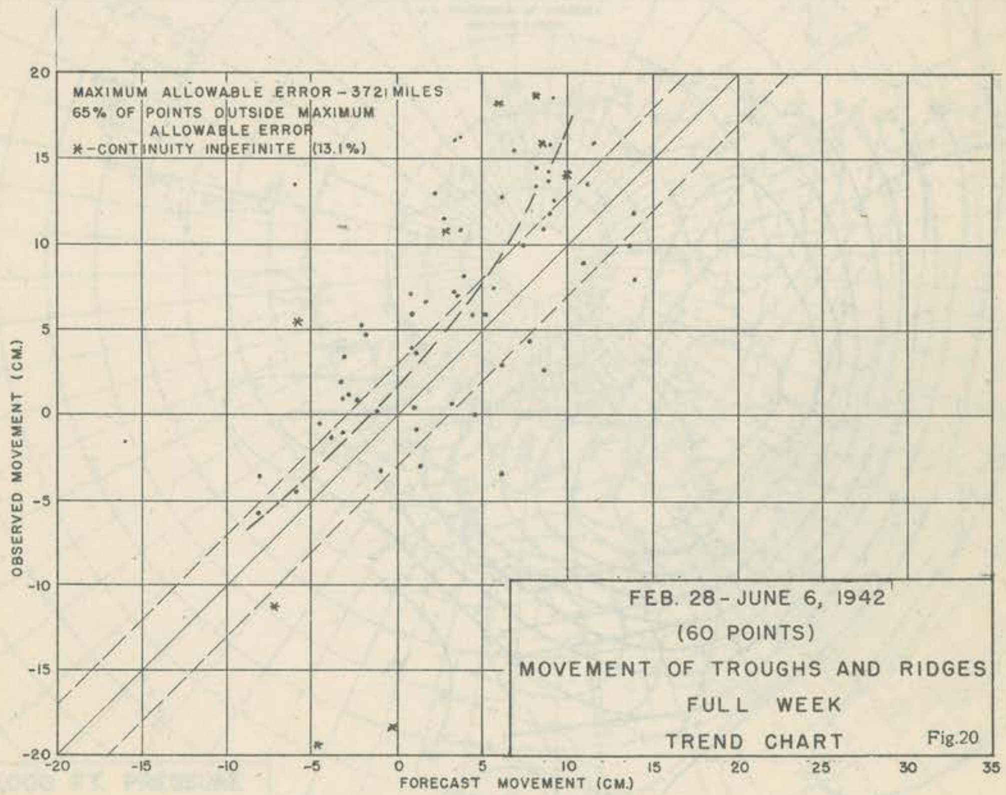

MAXIMUM ALLOWABLE ERROR - 372 MILES
65% OF POINTS OUTSIDE MAXIMUM ALLOWABLE ERROR
* - CONTINUITY INDEFINITE (13.1%)
OBSERVED MOVEMENT (CM.)
FORECAST MOVEMENT (CM.)
FEB. 28 - JUNE 6, 1942
(60 POINTS)
MOVEMENT OF TROUGHS AND RIDGES
FULL WEEK
TREND CHART

Fig.20

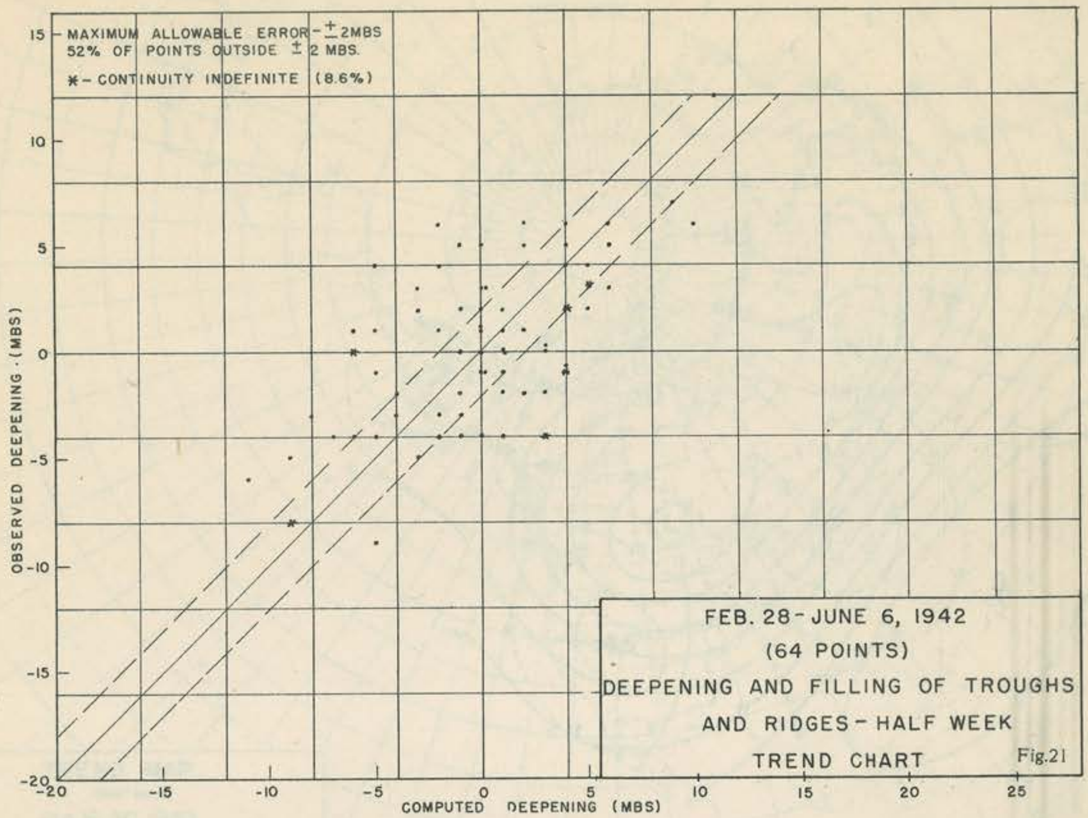

MAXIMUM ALLOWABLE ERROR - ± 2MBS
52% OF POINTS OUTSIDE ± 2 MBS.
✱ - CONTINUITY INDEFINITE (8.6%)
OBSERVED DEEPENING (MBS)
COMPUTED DEEPENING (MBS)
FEB. 28 - JUNE 6, 1942
(64 POINTS)
DEEPENING AND FILLING OF TROUGHS AND RIDGES - HALF WEEK TREND CHART

Fig.21

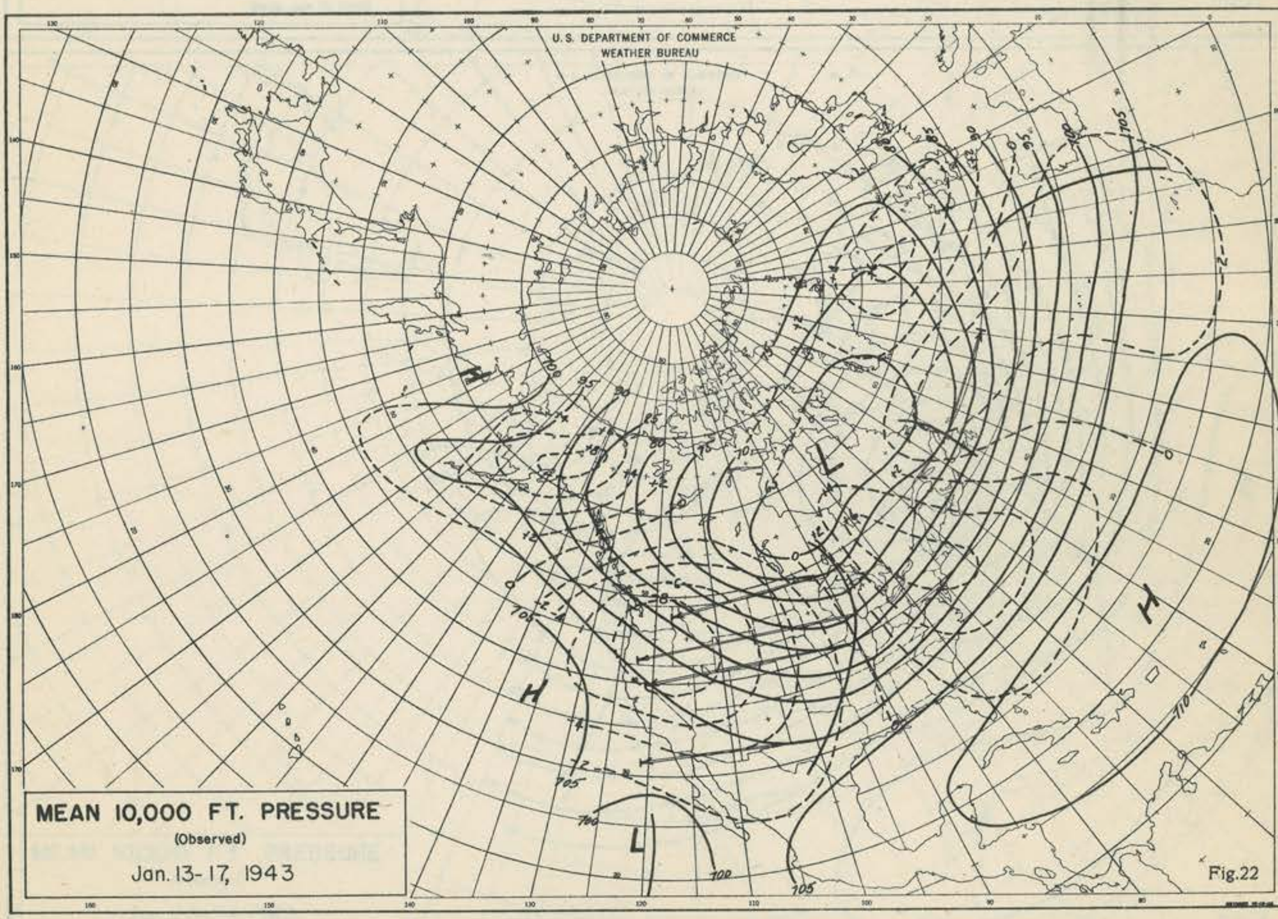

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN 10,000 FT. PRESSURE
(Observed)
Jan. 13-17, 1943

Fig.22

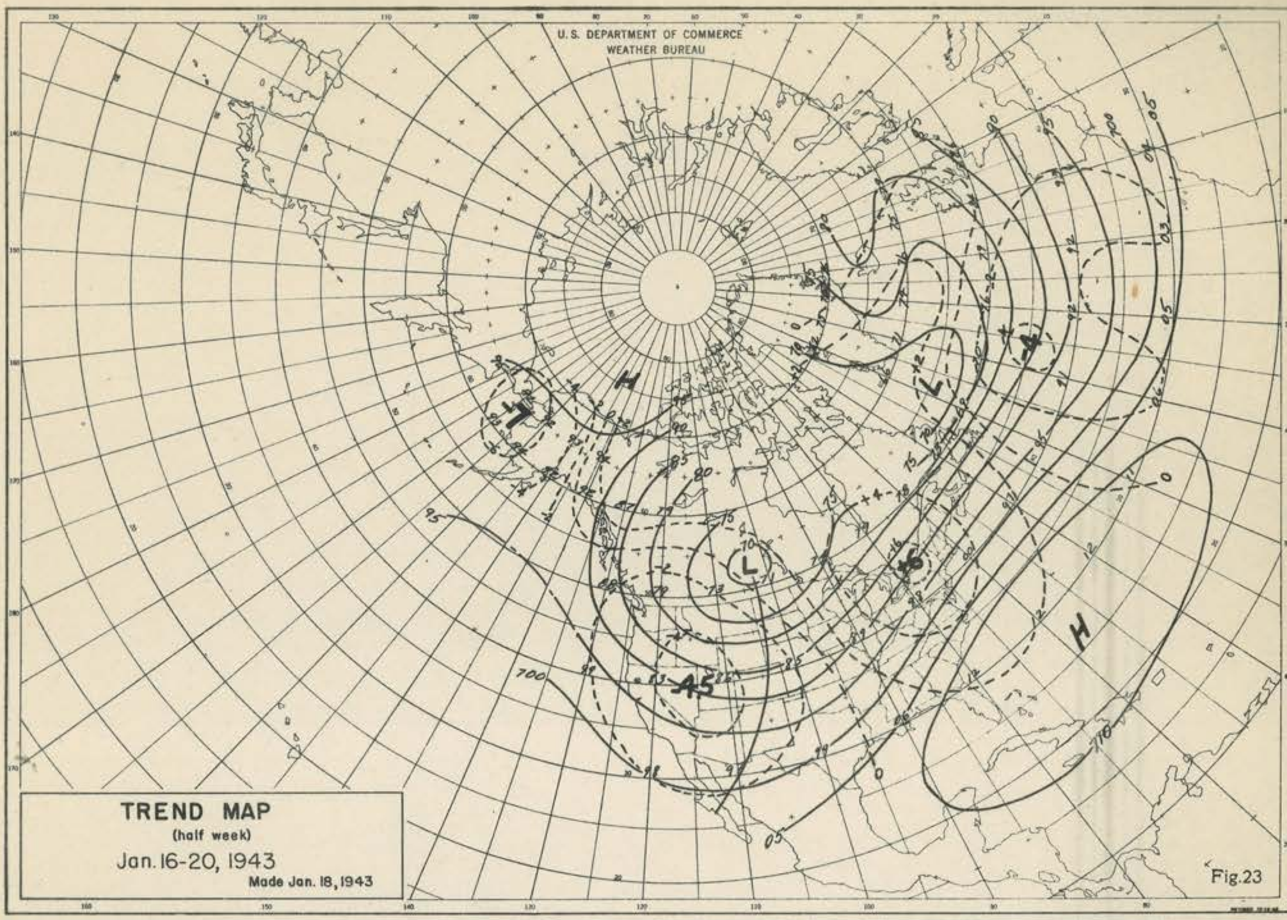

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
TREND MAP
(half week)
Jan. 16-20, 1943
Made Jan. 18, 1943

Fig. 23

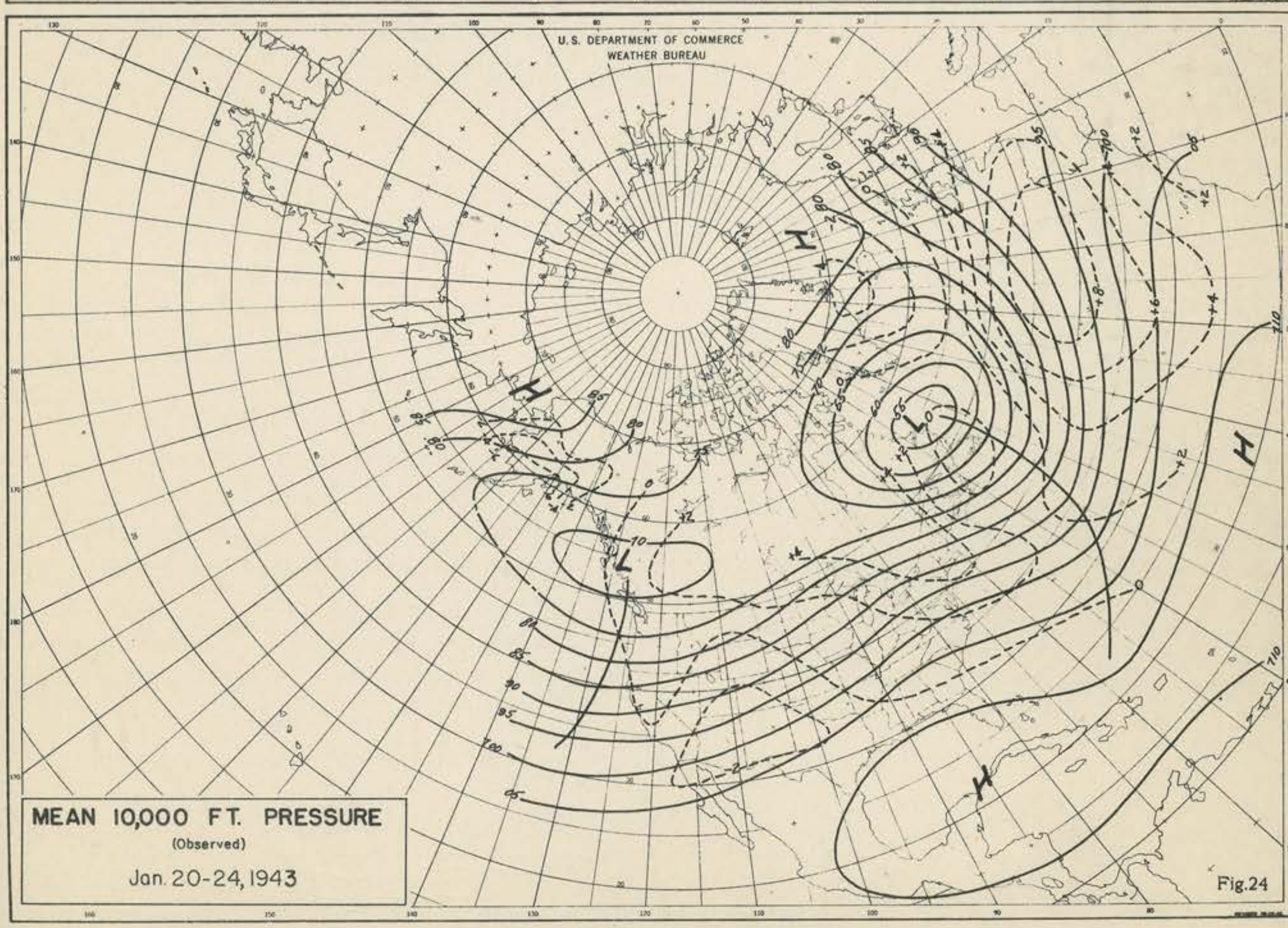

U.S. DEPARTMENT OF COMMERCE
WEATHER BUREAU
MEAN 10,000 FT. PRESSURE
(Observed)
Jan. 20-24, 1943

Fig. 24