APPLICATION OF NUMERICAL METHODS TO EXTENDED FORECASTING PRACTICES IN THE U.S. WEATHER BUREAU*

JEROME NAMIAS AND COLLABORATORS**

Extended Forecast Section, U.S. Weather Bureau, Washington, D.C.

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ABSTRACT

New procedures are described for applying numerical methods to extended forecasting. These form a firm base which serves as a point of departure for the final forecast. The methods are sufficiently organized that training and actual forecasting are speeded up and the level of skill of prediction is higher than ever before.

1. INTRODUCTION

In a statement dealing with "Meteorological Research Tasks" prepared for the Natural Science Research Council of Sweden in the spring of 1956, the late Carl-Gustaf Rossby wrote, "The comments made above indicate that objective numerical methods of integration, based on current models of atmospheric behavior, probably will find their greatest practical application in the preparation of general circulation pattern forecasts of moderate range (a few days to a week), while it is more uncertain if they will be able to contribute significantly to the short-range forecasting of detailed weather phenomena." It is the purpose of the present report to indicate that at least in the first part of this statement, Rossby displayed his characteristic foresight.

Up to quite recently, methods employed in making predictions for periods up to a week in advance [1] have involved a judicious combination of physical, statistical, and synoptic techniques, but the weighting procedures have often been so subjective that Lord Kelvin's classical remark of the meager and unsatisfactory charactor of merely descriptive knowledge comes to mind. Today, after years of research in the application of numerical methods to extended forecasting, new procedures, while still not completely objective, are nevertheless sufficiently organized that (1) it takes much less time to train forecasters, (2) medium range forecasts can be prepared more easily and faster than ever before, and (3) most important, the level of skill of predictions is higher than ever before. A preliminary report of some of this research was presented earlier by the author [2]; further experiments and results are described in the present report.

The fundamental 5-day forecasting procedure still involves two steps: first, the prediction of time-averaged circulation patterns for mid-troposphere and sea level; and second, the interpretation of these patterns in terms of climatic anomalies, particularly for fields of temperature and precipitation. Once the mean patterns for the advance 5-day period have been predicted, it is also possible to estimate the general course of cyclones, anticyclones, fronts, and air masses, and thereby prepare prognostic day-to-day charts up to 6 days.

The first and most important task is to predict the 5-day mean circulation pattern which will prevail for the *forecast period which covers from 2 to 7 days in advance*, for this is the large-scale quasi-stationary flow pattern which appears to guide the fronts, air masses, and storms and which, to a large extent, can be interpreted in terms of regional climatic anomalies. Three numerical procedures, not independent of one another, have been developed for arriving at a prognostic 500-mb. mean contour pattern, and all three are considered carefully by the forecaster in arriving at a final prediction. While a large portion of the skill of the final forecast lies in these numerical prognoses, their improper consideration of some factors and, in fact, complete omission of others, makes it presently desirable to permit the forecaster some flexibility in the use of his experience and judgment. The three procedures are referred to as (1) the trend method, (2) the summation method, and (3) the basic current method.

2. THE TREND METHOD

Essentially this procedure utilizes recent gains made in short-range numerical prognoses by objectively viewing short-period changes in flow pattern against the background of slower-evolving time-averaged patterns. This is done by automatic construction (on the IBM 704) of a 5-day mean 500-mb. chart centered on the day of the forecast (the "trend" map). Three days of height values for this 5-day mean are observed, while the predicted information for 24 and 48 hours is extracted from short-range numerical (barotropic) prognoses.† This mean chart is quite similar in appearance to the Fjørtoft space-

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**This report represents the work of many individuals in the Extended Forecast Section of the U.S. Weather Bureau—researchers, forecasters, and technical assistants. Carlos R. Dunn, Arthur F. Krueger, and Billy M. Lewis have been especially active in the formulation and testing of these ideas.

†The barotropic forecasts referred to in this paper are derived from an older operational model used by the Joint Numerical Weather Prediction Unit at Suitland, Md. This did not include a correction for erroneous long-wave retrogression as did later models based on the work of Wolff [9] and Cressman [6].

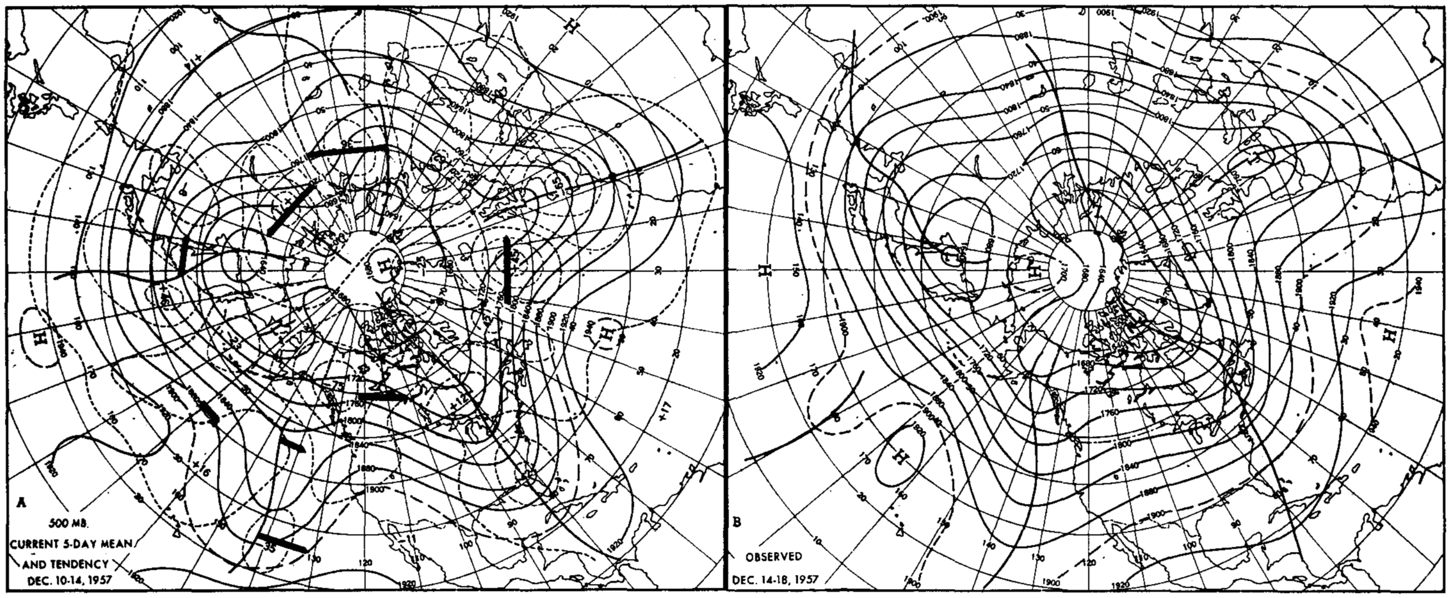

FIGURE 1.—(A) 500-mb. 5-day mean contours (solid lines drawn for every 400 feet and labeled in tens of feet) and 2-day centered height tendencies (broken lines drawn for every 200 feet and with centers expressed in tens of feet) for the period December 10–14, 1957. This chart, called a "trend map," and constructed on December 12, permits kinematical computations of 4-day ridge or trough motion, indicated by heavy arrows. (B) Observed 500-mb. contours for December 14–18, 1957.

smoothed chart. It suppresses undesired short-wave perturbations and brings into focus slow-moving long-wave phenomena. A field of centered 2-day height tendencies of the mean is also computed automatically and these are superimposed on the mean contours. The resulting fields of height and height tendency permit kinematical computations of long-wave motion and development, and thereby assist in prognosis for the desired 5-day period (which is centered 4 days in advance of the "trend map"). An example is shown in figure 1 together with the subsequent 5-day mean chart which may be inferred from the indicated kinematic evolution of the trend map. Note the fundamentally correct motions predicted for most systems except the trough over eastern United States. In this case eastward displacement of the trough must be estimated indirectly because its neighboring ridges are indicated as moving eastward.

This numerically produced trend chart, by automatically including 24- and 48-hour numerical prognoses, rather than the formerly employed statistical estimates based on auto-correlation methods, has not only made the procedure faster and more reliable, but has made it possible to eliminate many tedious and outmoded types of computation [3].

Regardless of how accurate the above-described trend map becomes, however, it will not solve the fundamental 5-day forecast problem, but will at best indicate the broad-scale, slower-evolving trends that often point the way. Therefore, experiments designed to make predictions of 5-day mean patterns centered each day up to 4 days in advance have been performed. Such charts afford not a static picture, but rather an evolving mean state, which is also a changing steering pattern for synoptic scale systems. While such a prognostic mean series might be derived from the trend method, it should be made clear that the real atmosphere is not so simple in its behavior. For example, the centers of height change often move with speeds differing from the planetary ridges and troughs, so that pure extrapolation methods based on instantaneous speed are bound to have failures.

3. THE SUMMATION METHOD

Although the accuracy of the present numerical daily prognoses employing the barotropic model declines rapidly after 48 hours, especially when verified on the basis of root-mean-square errors, numerical predictions have been carried out to 96 hours and then averaged together with the initial day's chart to form a 5-day mean (the "summation" chart). As shall be demonstrated later, the mean pattern thus obtained appears to be reasonably accurate when compared to the observed 5-day mean centered 2 days in advance. The agreement in mean ridge and trough positions, as well as cellular features, in the face of rapid decay in the 72- and especially 96-hour interval, suggests that (1) persistence (serial correlation) operates to such an extent in the real atmosphere that the first few maps imply the major features of the pattern, and (2) compensations occasionally take place wherein an error made on an early prognosis may be rectified later on (or the atmosphere appears to have a "built-in" feature for restoring itself to barotropy). Thus the most useful features (ridges, troughs, etc.) can be appreciably erroneous in intensity, yet this may not interfere with reasonably effective use of the prognosis. The summation chart has two principal functions: (1) to afford a look at the 5-day mean centered 2 days in advance so that comparison with earlier observed mean maps and with the trend map may permit further inferences regarding evolution, and (2) to obtain estimates of 5-day mean temperature anomalies as described below.

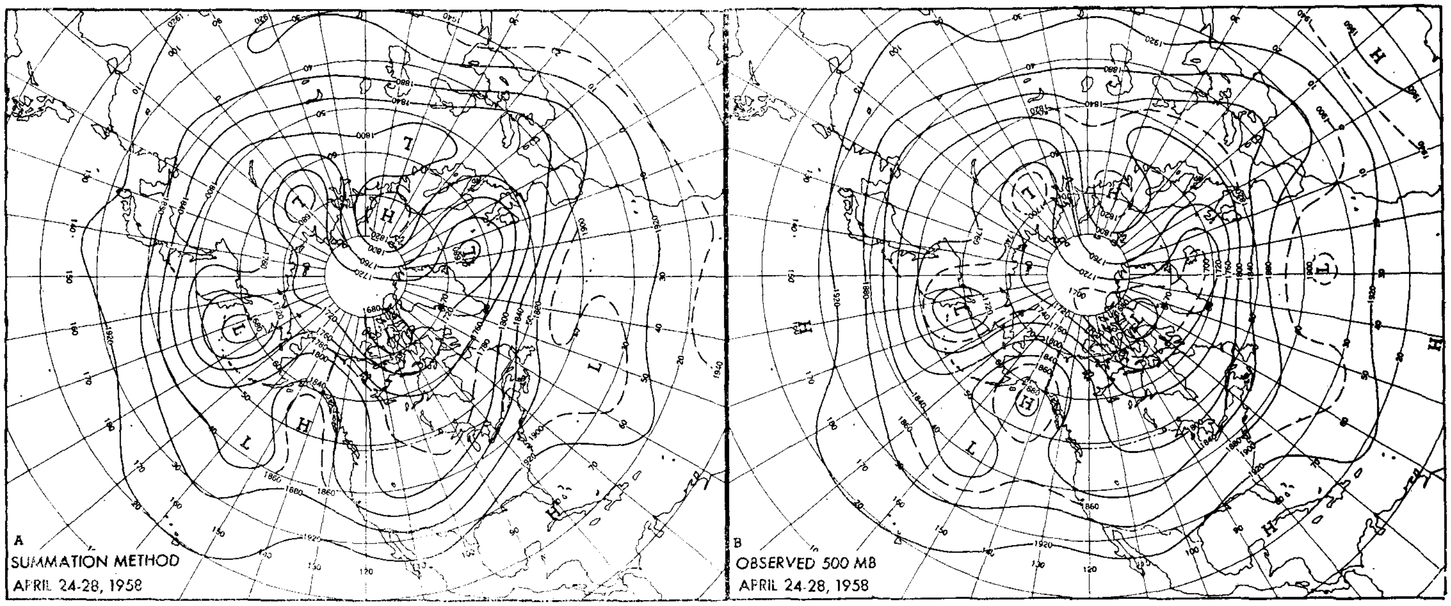

Figure 2.—(A) 500-mb. contours for the period April 24–28, 1958 objectively predicted by the summation method (see text). Contours drawn for every 400 feet and labeled in tens of feet. Intermediate contours dashed. (B) 500-mb. contours observed for April 24–28, 1958.

An example of a summation chart, together with the observed, is shown in figure 2. Such good correspondence is by no means rare.

4. THE BASIC CURRENT METHOD

The two methods described above essentially integrate or extend numerical short-range prognosis to bring into focus another class of motions characterized by slowly evolving systems. In both cases the final product desired, a prognostic chart of the mean circulation for the period 2 to 7 days in advance, must be inferred. If day-to-day numerical prognoses reach a point of much greater reliability than at present, it may be possible to produce medium-range forecasts by simply projecting these out to a week. In this event the concept of means would no longer be necessary, and a day-to-day description of future weather maps would be possible. However, at the present there appears to be some break-off point in the use of daily prognosis beyond which some form of statistical technique must be applied.

Since vorticity (including wavelength) concepts have been applied with some success to time-averaged mean charts for almost 20 years, a number of experiments have been performed in an attempt to employ a modified barotropic model to predict mean motions. Some of these are described below:

(1) Selected observed 5-day mean charts for the 500-mb. surface were run with the barotropic model as in routine daily forecasts by the Joint Numerical Weather Prediction Unit in Suitland, Md. These predictions were carried out to 8 days, and a print-out prediction was obtained for each day. The prognoses displayed a logical continuity throughout the period with no suggestion of computational instability; that is, the patterns remained smooth and of appropriately large scale. The patterns resembled those of the observed charts up to a few days, but they became increasingly discordant and characterized by flat fast westerlies thereafter.

(2) Next, the trend chart (the one using short-range barotropic estimates and described earlier) for one of the cases was used as initial or input data for the predictions and run for 5 days. The predictions were surprisingly similar to those obtained by using all known data (rather than half known and half estimated). This result indicated that the starting point for a 5-day mean prediction might be moved up 2 days.

(3) Although the above predictions were stable in the sense that they produced rational flow patterns, they became out of phase with the observed after a few days. It was felt that this failure was due largely to the neglect of physical processes not considered in the simple barotropic model that, after all, can only redistribute the existing vorticity. While the rigid incorporation of these missing factors is probably the central and most difficult problem facing weather forecasting, it is possible that certain statistical estimates may be used to improve the performance of the barotropic model—a philosophy that underlies current extended forecasting practice in the United States Weather Bureau.

The particular method used in the experiment was to make use of the fields of departure from normal of the initial chart (the trend chart, including 24- and 48-hr. estimates) in the manner described below.

If the earth were a smooth surface with no longitudinal temperature differences, the mean state of the general circulation would show no preferred regions for ridges or troughs in the upper westerlies and would thus consist of a vast circumpolar whirl of zonal winds. Many factors, such as mountains or other ocean-continent contrasts, that interfere with the successful operation of the barotropic model, particularly at long range, would be partially eliminated on the assumed fictitious earth. Now we can construct a fictitious 500-mb. circulation (corresponding to an observed pattern) as it might look on such an earth where the general circulation of the westerlies is everywhere zonal (parallel to the latitude circles), and yet has a meridional wind profile corresponding to the observed chart. To do this, we simply subtract from the actual map the latitudinal anomaly of the normal pattern for the appropriate time of year. Thus:

$$\text{Fictitious Chart} = Z-(Z_n-Z_n^{\phi}) \qquad (1)$$
$$\text{or} = (Z-Z_n)+Z_n^{\phi}$$

where Z represents the observed heights, Z_n is the time-averaged normal for the appropriate time of the year, and Z_n^{ϕ} is the average of the normal heights along a latitude.

Such a chart is used as the initial input data in the computer and run to 96 hours with a simple barotropic model. The resulting prognoses must then be reduced once more to the real earth that contains preferred areas where ridges and troughs congregate. This may be done by solving for Z in the above equation—a process whose purpose is to incorporate once more approximations for effects of such factors as mountains and heat sources. In a sense the fictitious chart may be viewed as a catalyst used to expedite the prognosis. Viewing it in another way, this method applies the vorticity concept to the departure from normal fields, as suggested by Clapp [4], but with the important difference that a carrying current is introduced. Objections can be raised to such an oversimplified solution of such a complex problem. For example, non-barotropic effects operate at each phase in the evolution of the pattern, and cannot be removed completely or considered in one fell swoop. Of course, in the final analysis one must judge the validity of such an idea by the success it attains. Some verifications are cited below.

(4) Experiments with a coarse 483-point (600-km. mesh length) grid and utilizing the geostrophic approximation succeeded just as well as those with the more elaborate models employing more closely spaced grids and use of the balance equation. Apparently because of the large scale of systems on mean charts, great detail is not required and the geostrophic assumption is quite applicable. Moreover, this simpler model consumes much less machine time.

Expressed in other words, the core of the method described above is the premise that the general circulation consists of a broad basic current on which are superimposed free perturbations. Undulations in the basic current are established partly by geographical and seasonal factors such as mountain chains and coast lines and in a given season partly by anomalous factors whose physical nature is obscure. Subtraction of the latitudinal anomalies of the appropriate normal map from the trend map is designed to uncouple the (5-day) free perturbation from the climatologically forced flow. It is this free flow which is fed into the computer and run out barotropically to 4 days. At desired intervals of 48, 72, and 96 hours the basic current or normal is re-introduced and the machine prints out a prognostic mean chart.

In this semi-dynamic model other basic currents may

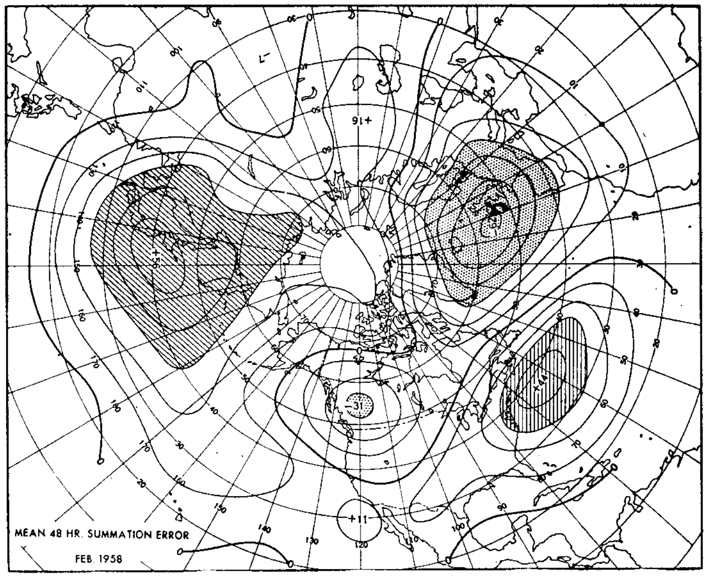

FIGURE 3.—Mean algebraic errors (isopleths drawn for each 100 feet and centers labeled in tens of feet) for summation predictions made during February 1958.

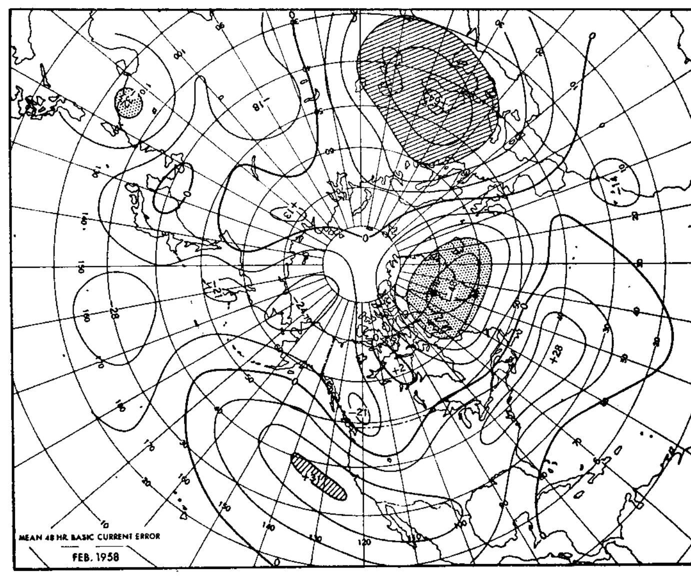

FIGURE 4.—Mean algebraic errors for basic current method predictions made during February 1958. Centers labeled in tens of feet.

be used besides the appropriate monthly normal. In fact, experiments have now proven that a better choice of a basic current is an estimate of the monthly mean circulation centered around the period of the forecast. In other words, there appears to be a controlling linkage between a fairly persistent long-period anomalous state of the general circulation and the 5-day class of motions, just as there is between 5-day phenomena and day-to-day systems. Approximations to the current long-period state of the general circulation may be obtained by statistical auto-correlation methods [5]. Thus a 30-day mean centered around the day on which a 5-day prediction is desired can be fairly well approximated by the expression:

$$\bar{h}_{30}=\frac{1}{30}\,(6.5h_5+8.5N+h_{-15}) \qquad (2)$$

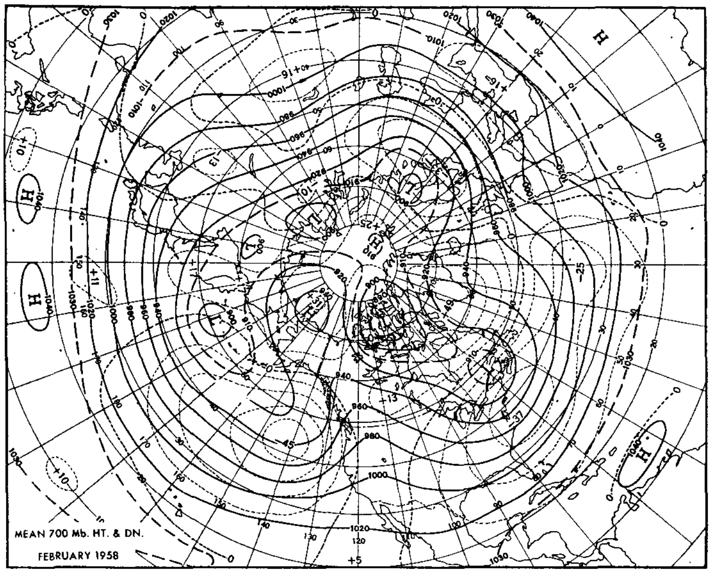

Figure 5.—Mean 700-mb. contours (solid lines drawn for every 200 feet) and departures from normal (broken lines drawn for every 100 feet with centers labeled in 10's of feet) for February 1958.

where $\bar{h}_{30}$ is the 30-day mean centered on forecast day, h_{-15} is the sum of the observed heights of the last 15 days, h_5 is the height given by the summation prognosis (average of next 5 days), and N is the appropriate normal.

5. VERIFICATION OF NUMERICAL PROGNOSES MADE BY SUMMATION AND BASIC CURRENT METHODS

Algebraic mean error fields for all forecasts made by the summation and basic current methods for a 5-day period centered 2 days ahead during February 1958 are shown in figures 3 and 4. The large positive errors in the summation prognoses off the east coasts of the continents appear to be due, at least in part, to the absence of heating terms in the simple barotropic model used. (The outflow of air off the Asiatic and North American coasts during February 1958 was even colder than normal for February.) The reduction in mean error over these areas indicated by the normal basic current predictions (fig. 4) suggests that to some extent these complex effects are being taken into consideration, although in some areas (e.g., over Europe) errors not found in the summation chart are introduced.

If one compares the mean error fields obtained by using the normal basic current method (fig. 4) with the departures from normal for the month during which the forecasts were made (February 1958, shown in figure 5), it is at once clear that a good *negative* correlation exists. In other words, the predictions are generally too high in areas where the month was below normal and too low in areas of positive anomaly. This strongly indicates that improvements would result from the use of a basic current bearing greater resemblance to the *anomalous* condition of the month. Indeed, material improvement results from substituting the estimated centered 30-day mean for Z_n in formula (1) when solving for Z at the end of the forecast interval. This abbreviated basic current method produces improvements, as seen from verifications shown in figure 6. Here two months of available verifications for summation and basic current charts are shown in terms of the correlation of the profile of predicted vs. observed departures from normal at latitudes 60° N. and 40° N. The changes in individual forecast scores from inserting the 30-day approximation instead of the normal are represented by arrows superimposed on the open bars. Average performances are shown by horizontal dashed lines.

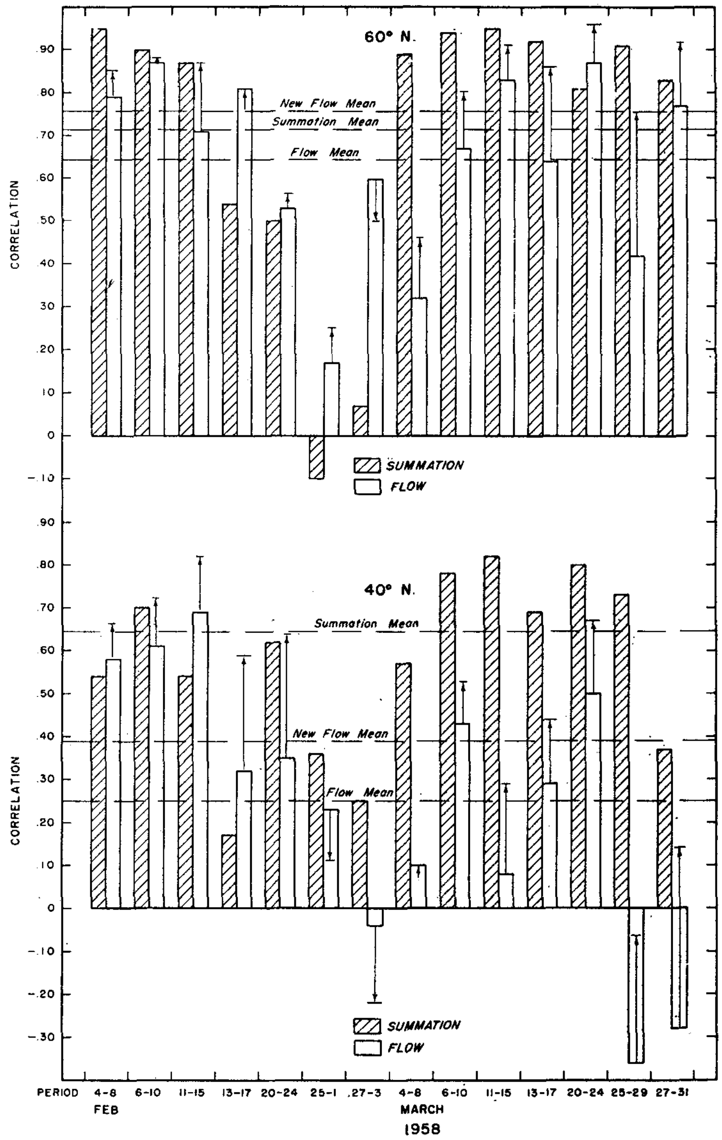

Figure 6.—Verifications for 5-day mean 500-mb. forecasts made by summation and basic current (labeled "flow") methods during February and March 1958. Bars indicate correlation between predicted and observed height anomalies at the indicated latitude. Horizontal lines show average of all forecasts at that latitude. Arrows indicate change in score from flow method to new flow method. See text for detailed explanation.

While the abbreviated basic current method was about the same as the summation chart at 60° N. it was inferior at 40° N. More recent verifications show similar results, although newly introduced short-range models [6] appear to have improved the summation chart.

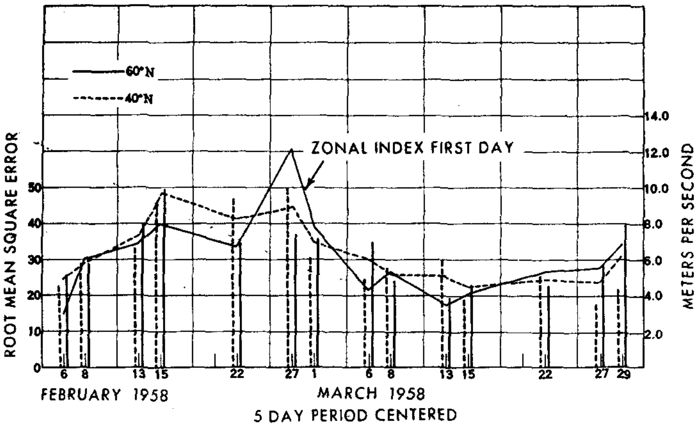

FIGURE 7.—Vertical bars show root-mean-square errors (in tens of feet, scale at left) of summation method predictions at 60° N. and 40° N. Irregular dashed line connects average RMSE for both latitudes. Thin line shows Western Hemisphere zonal index from 0° westward to 180° on initial day of prediction (in m.p.s., scale at right).

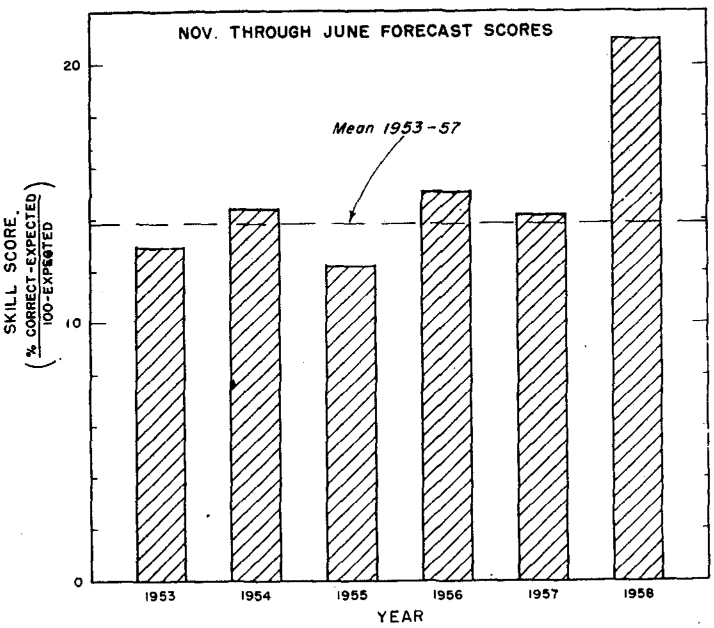

FIGURE 8.—Skill scores of temperature predictions for the United States for the 8 months November through June for the past 6 years.

Apparently, using as a yardstick the correlation of profiles of departure from normal along latitudes, the summation method of prognosis for a 5-day mean centered 2 days in advance is somewhat superior to the abbreviated basic current method. For a mean centered 4 days in advance the scores, while positive, are so low as to leave much room for improvement.

In view of these results work is currently proceeding to improve the prognoses by (1) applying the basic current method in the complete manner (i.e., by uncoupling the free perturbation from the 30-day mean basic current rather than from the normal), and (2) by introducing a more sophisticated model which also incorporates the philosophy of the basic current method.

In spite of the verification statistics cited, a subjective appraisal of routinely prepared numerical prognoses by both methods indicates that both have something to contribute to the final forecast. The choice of reliable features of each, while not easy, can be assisted by other factors not considered in the models—such things as the existing thermal fields, concepts of cyclone development, etc. In any event, the numerically produced charts form a fairly solid point of departure for the circulation prognosis, and, as will be seen below, can be translated objectively into a fairly skillful temperature prediction.

Before treating objective methods of temperature prediction, an interesting by-product of the verification shall be mentioned. The root-mean-square errors at latitudes 40°N. and 60°N. of the summation forecasts verified in February and March 1958 are shown in figure 7. Plotted as a solid line on this figure is the 700-mb. zonal index for the day on which the forecast was made. Apparently the predictions are in general better at times of low index than high, a conclusion which at first glance comes as a surprise. However, it must be borne in mind that low index states are frequently characterized by cellular features with isotherms and contours in mid-troposphere in phase—states more barotropic than those of high index in which meridional temperature gradients are steep and sudden baroclinic developments are frequent.

6. OBJECTIVE TEMPERATURE PREDICTIONS

Once a mean circulation pattern has been determined it is possible to estimate from it the accompanying departures from normal of surface temperature. A detailed discussion of this problem will be found in references [5] and [7]. The essence of the presently used technique depends upon the position and intensity of key centers of height anomaly as determined by subtracting the appropriate normal contour pattern from the predicted. The key centers naturally vary from station to station and from one season to another, but in general a large part of the variability of surface temperature of 5-day means is accounted for by the departure from normal of mean mid-tropospheric height near the station and also, equally or more important, at a point a few thousand miles or more *to the northwest of the station—removed* by about one-half the length of a planetary wave. The location of the centers is determined by computing correlation fields between each station's temperature departure and the contemporary height anomalies—a procedure greatly facilitated by the use of high-speed computing machines. The latest studies in this direction have just been reported by Klein and Lewis [8].

While the mid-tropospheric height pattern accounts for a reasonably high (about 50 percent) proportion of sea level temperature variability, it obviously cannot uniquely specify the field, for it is probable that both the initial air mass distribution and the character of the earth's surface (e.g., presence or absence of snow cover) must be taken into consideration. The *net* influence of these complex factors is to some extent reflected in errors made by the initial objective estimates in a given case. Hence, if one is able to obtain the error field of objective estimates

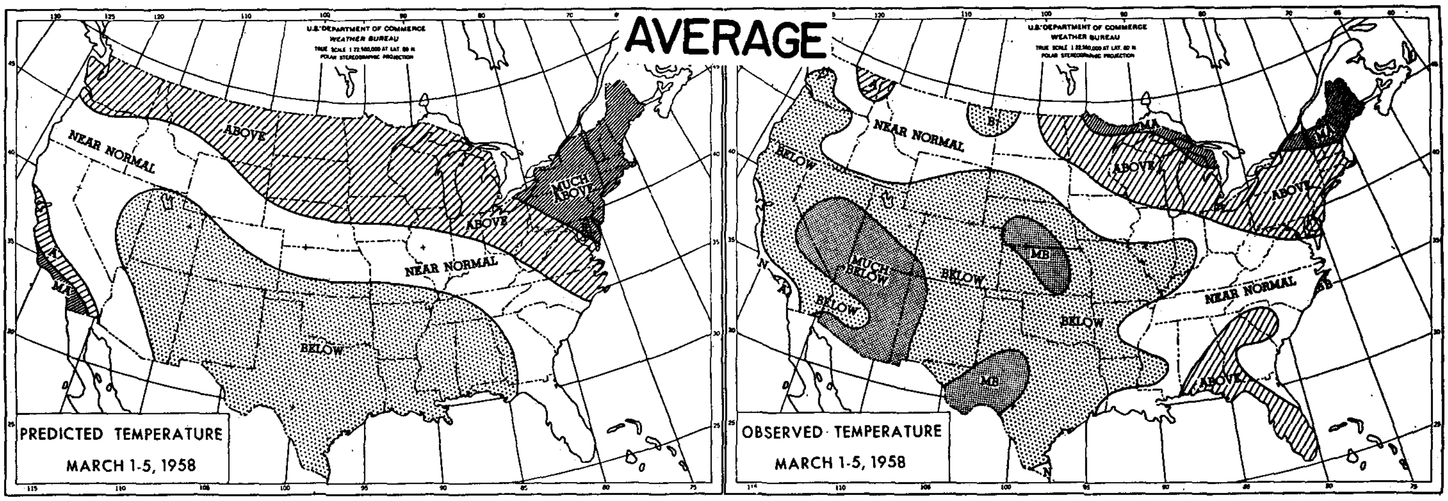

Figure 9.—Example of the success of an average temperature prediction made during the period November 1957 through June 1958, following the introduction of numerical techniques.

for a period close enough to the forecast period so that the changes in mean flow pattern are slight, he may reasonably suppose that the *errors* remain the same. Therefore, the initial error may be used as a correction term to the subsequent objective estimate based on the contour pattern alone. Now it will be remembered that a 5-day mean chart centered on forecast day is available. Likewise, it is possible to prepare a centered 5-day surface temperature estimate by making use of official short-range forecasts of maximum and minimum temperatures for the following 2 days in addition to 3 days of known values. This field of temperature anomaly is then compared with the objective estimate afforded by the trend map contour pattern and the "error" determined. This error is then applied as a corrective term to objective estimates made on the numerical prognosis. So far, this technique has been applied only to the summation chart. The results have been gratifying in that this method produces an anomaly forecast which, even when taken as a forecast for the 5-day period 2 to 7 days in advance, gives temperature scores equal to those obtained using all available tools in a subjective fashion during the pre-numerical period 1953–1957! In other words, an objective base has been established for temperature just as for contour pattern and this forms a good point of departure.

Because of the obvious oversimplification of the underlying objective method, it is possible to improve on this objective base, so that the net improvement in temperature scores over the 1953–57 period has been dramatic. The extent of this improvement is indicated in figure 8 where the averages of temperature scores for the 8-month period November through June for the last 6 years are presented. (November 1957 was the month of institution of the new forecast tools described in this paper—and also the month of discard of older outmoded techniques.) The scores consider only the percentage of the United States predicted in the exact temperature class out of five categories—above, near, and below normal and much above and much below normal. The first three named classes have a probability of occurrence of $\frac{1}{4}$ and the latter two $\frac{1}{8}$. The roughly 50 percent increase in scores in the post-numerical period (1958) over the preceding 5 years is striking. A statistical analysis of the monthly averages of scores entering into figure 8 indicates that the 1958 scores *are* higher than the earlier scores at a level of significance of 3 in 10,000! Some idea of the correspondence of such forecasts with observed conditions is afforded by an example (fig. 9) selected only because it fell on the average 1958 score. Of course, there are large areas of imperfection, but taken as a whole, predictions of this sort are economically valuable. Further demonstrating the skill of these forecasts is table 1 which shows the percent

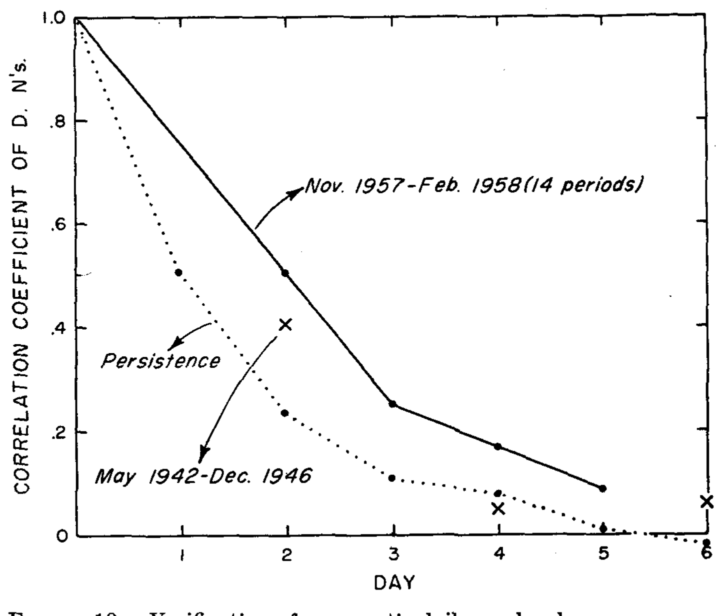

Figure 10.—Verification of prognostic daily sea level pressure maps for North America for 14 forecasts made from November 1957 to February 1958 (solid) and persistence scores from an earlier 8-month period (dotted). Crosses give scores for an earlier 4-year period. Ordinate is averaged correlation between predicted and observed pressure anomalies, and abscissa is number of days after forecast day.

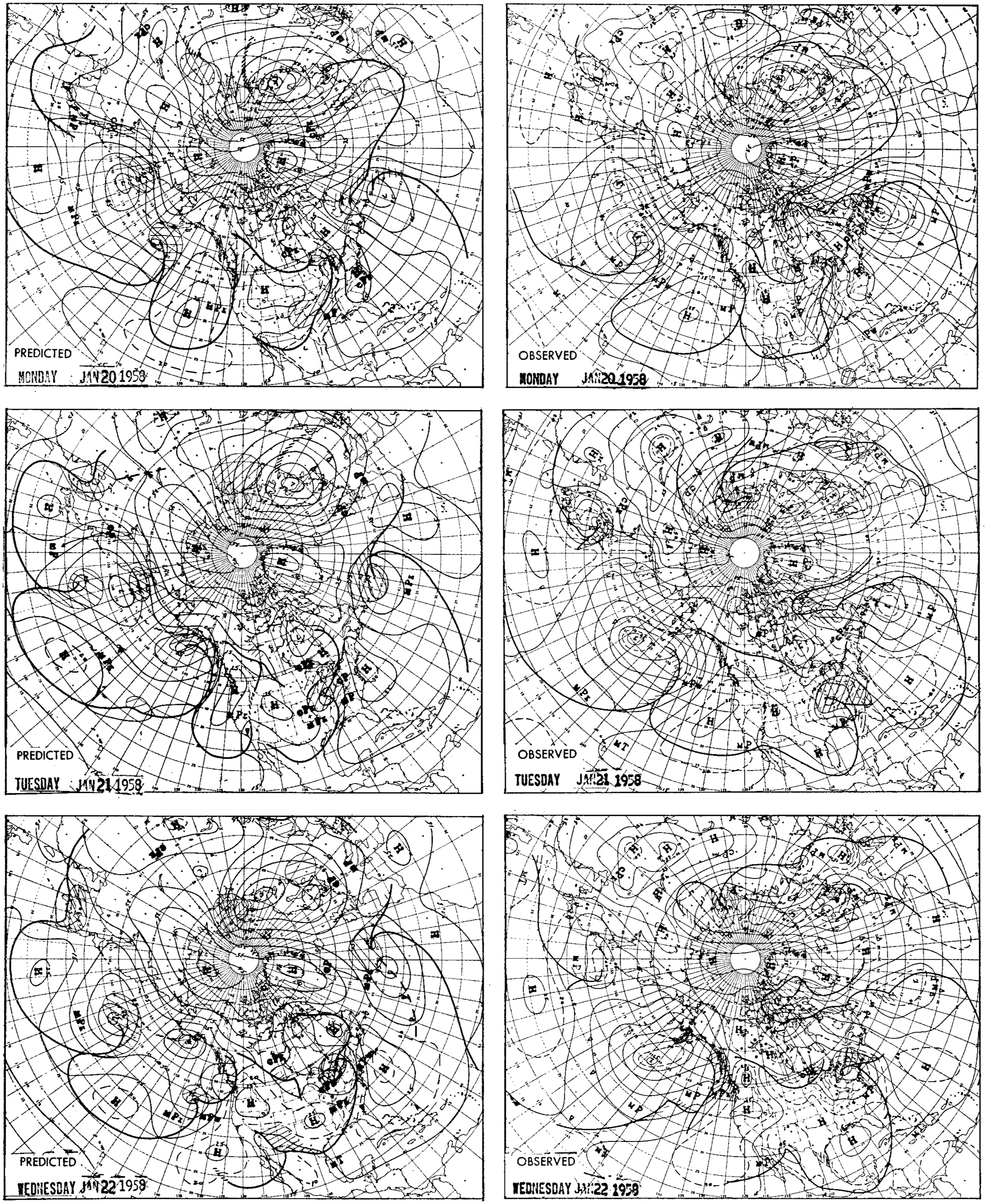

FIGURE 11.—Example of a predicted series of daily sea level charts and their verification. Precipitation areas are shaded.

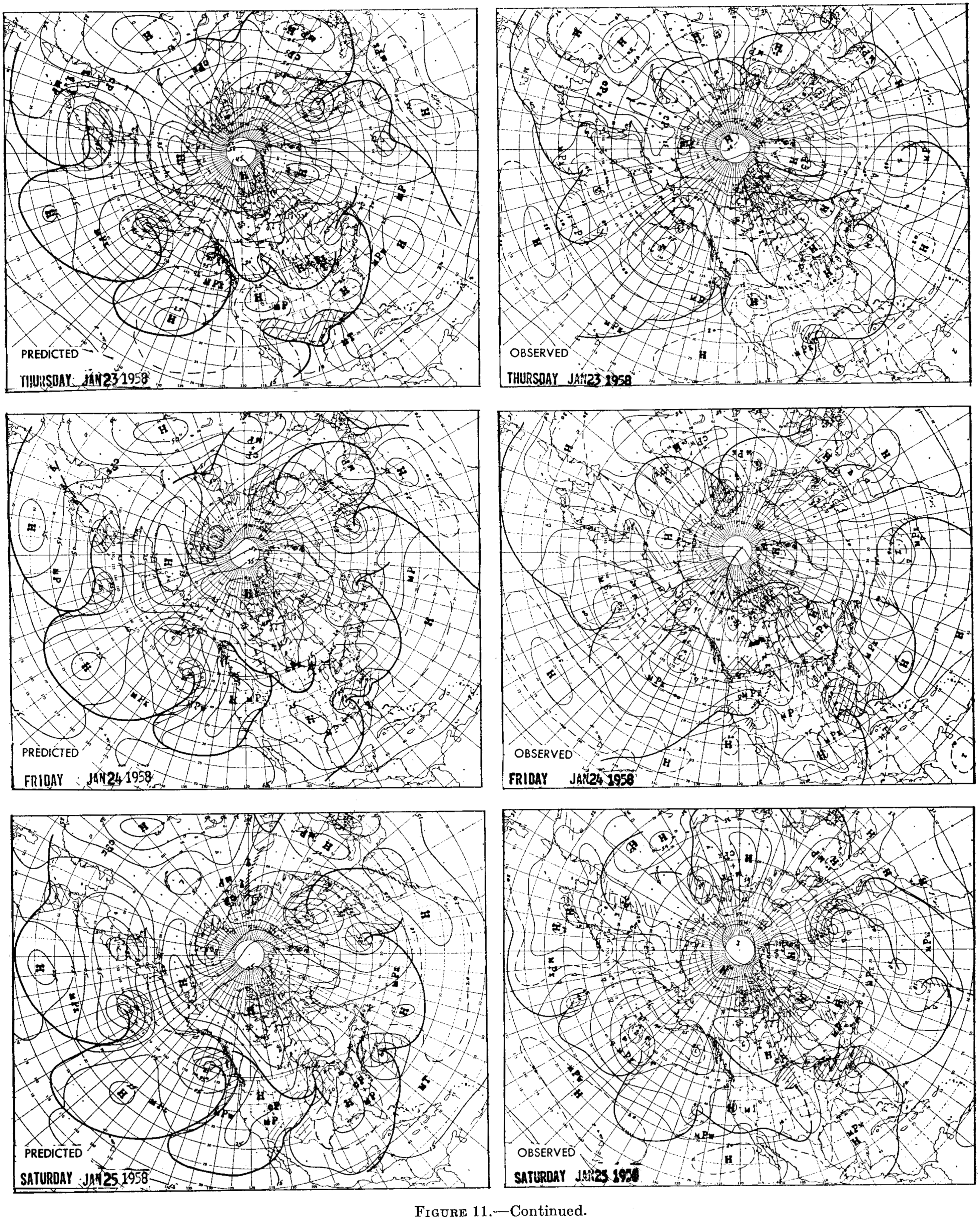

Figure 11.—Continued.

TABLE 1.—*Probability of obtaining temperature categories (percent).*

Observed	Forecast				
	MB	B	N	A	MA
MB	44.6	16.3	5.9	2.6	0.6
B	39.6	40.1	26.4	13.0	6.4
N	11.1	22.7	28.5	23.1	13.0
A	4.5	17.3	30.4	40.7	38.4
MA	0.3	3.6	8.8	20.6	41.6

of the time for the country as a whole each forecast class occurred or was observed in another category.

For example, when much below normal was predicted the observed category was much below normal 44.6 percent of the time and below normal 39.6 percent of the time. Note the almost negligible error of four classes; i.e., much below forecast and much above normal observed or vice versa.

It has been suggested that the high 1958 scores indicate that the temperature patterns were easier to predict because of more persistence than normal during the 8-month period. Actually, statistics show that (1) the period as a whole was certainly no more persistent from one 5-day period to another (and perhaps was less persistent) than during the past 5 years, and (2) earlier 5-day forecast scores show no correlation with persistence scores. It seems difficult to attribute the increase in skill to anything other than increased objectivity in which numerical contour predictions play a large role.

While precipitation forecasts were slightly improved over the averages of the past 5 years, no such significance as with temperature is indicated. Although this is a puzzling and disconcerting circumstance, the following facts undoubtedly play a part:

1. No objective methods have been developed for satisfactorily interpreting mean contour patterns in terms of precipitation.
2. Precipitation, a discontinuous element unlike temperature, is probably less related to mean contour patterns than temperature.
3. 5-day precipitation forecasts involve more degrees of freedom (subjectivity) on the part of the forecaster, and are often overly influenced by short period "indications" which may turn out to be erroneous. At any rate, the lack of comparable success in improving precipitation forecasts points up this problem as one of high priority.

7. THE CONSTITUENT DAYS OF THE FORECAST PERIOD

One of the most difficult tasks in the 5-day forecast routine is the preparation of a prognostic series of six sea level maps—the pressure distribution, the fronts, air masses, and precipitation. The methods for drawing these charts are far from objective, although there are broad guide lines:

1. The series of maps must possess a logical evolution.
2. The forecaster is tied down to the last observed map and to short period prognoses, and obtains some assistance from the daily numerical prognoses up to 72 hours in advance.
3. The steering and development of synoptic-scale systems must be consistent with the evolving mean patterns predicted (steering, etc.).
4. The daily series must be consistent with the broad-scale temperature field predicted.

While these constraints still leave considerable flexibility, the new methods have resulted in some improvement in the ability to prognosticate maps out to 6 days in advance. Some evidence for this is shown in figure 10 where the departures from normal of predicted and observed pressure patterns over North America are correlated for days 1 to 6 after forecast day. The scores for 14 weeks of forecasts (taking one forecast series a week) are shown along with persistence scores (computed from an earlier 8-month period) and also with earlier attempts over a 4-year period shown by crosses. Perhaps a better idea of the possibilities of such predictions is obtained from one of the better series, reproduced together with the observed charts in figure 11. Note the proper development and course of both major cyclones affecting the United States—the Texas wave at the first of the period and the wave from southern California moving eastward and then northeastward.

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