To the Comparison between Numerical Methods and Methods Now in Use for Forecasting Meteorological Charts

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Abstract

Methods now in common use for making prognostic charts to a large extent are based on time derivatives, while the numerical methods start from space derivatives. That is the fundamental difference between them. It is shown that the present methods give at times very good results, and that the degree of success varies with the weather situation, characterized e. g. by the average interdiurnal pressure change over the test area. Because of this variation it would be desirable that every test of a numerical method includes a comparison with results obtained at some forecasting center or, at least, with the results of pure extrapolation.

Introduction

At present, in forecasting the sea-level pressure pattern as well as the upper flow pattern, in particular methods of extrapolation are used, i. e. the forecaster knows the previous history of the flow pattern, and he studies the changes or tendencies, the time derivatives. He may then introduce, in addition, certain corrections to the extrapolated pattern, argued from space derivatives, such as advection, divergence, vorticity etc., but extrapolation will always be the first step. It may be the areas of 24-hour changes which are moved either in accordance with their previous movement or along the track of the preceding changes, or it may be the troughs and ridges that are moved in a similar way. By extrapolation he can also make ridges build up or weaken and make troughs deepen or fill. Such a graphical extrapolation is rather easy to carry out, and it is not very subjective.

In general, however, extrapolation is not enough. The forecaster also must try to find signs of real evolutions, and then the methods grow more and more subjective. He has to look for areas of confluence or other kinds of advection of warm and cold air, and he has to estimate the effects to be expected from interactions between patterns over different parts of the map. He also has to apply rules of experience, general rules, rules valid for a certain season as well as special rules, just applicable to a prevailing type of weather.

But we should keep in mind that all these more subjective steps are just refinements, and that pure extrapolation already can give surprisingly good results.

In contrast to this the numerical methods, actualized by the advent of high-speed electronic computing machines, are all based on space derivatives, and the time derivatives and the previous events do not enter at all. But at a meeting on numerical forecasting held in Stockholm in May 1952, there was briefly discussed if the time derivatives could not be entered in some way in the numerical prediction, e. g. to improve the analysis of the vorticity pattern in areas with sparse observations. Also the possibility of taking the previous events into account was mentioned, e. g. by introducing corrections in the forecasts for "past errors", as involving effects of neglected factors.

The development of the flow pattern is in present theories fully determined by the initial data, including all sorts of space derivatives. As however the time derivatives have proved invaluable for the non-automatic forecaster, it may be necessary to try to introduce them also in the numerical process. This ought to be done also if we do not want to replace the present methods entirely by numerical ones, but restrict ourselves to let the two kinds of methods supplement each other.

Present routines in forecasting

The goal for the meteorological prediction is in general to forecast the weather, i. e. surface wind, temperature, cloudiness and precipitation. It is true that forecast upper flow patterns may be used directly in preparing winds for aviation and ballistic purposes, but although this side of the problem is important, it will be neglected in the following.

To obtain a weather forecast we can either begin with an upper-air prediction and pass on to the sea-level and from there to the weather. Such a routine was recommended e. g. by RIEHL and collaborators (1951). Or we can begin with a sea-level prediction, as proposed by SCHERHAG (1948). In the latter case we can then pass to the weather almost directly, but our forecast will certainly improve if we construct an upper-air chart from the sea-level chart before making the weather forecast.

The advantage of the first way is that an aerological chart gives a much simpler picture of the weather situation than does the sea-level chart. The disadvantage is that upper-air charts must be translated into sea-level isobars and fronts before forecasting the weather.

The advantage of the sea-level way to the weather forecast, on the other hand, is partly the more direct relation between a sea-level chart and the weather, partly the existence of 3-hour tendencies on that chart. The disadvantage is the fact that sea-level prognostic charts can hardly be constructed directly for a longer time interval than 24 hours.

The choice between these two alternate ways depends on which one gives the best forecast in the actual case. Generally a compromise is the best way.

At the Aerological Division of the Swedish meteorological and hydrological institute the second method, in a form drawn up by SIMILÄ, is used for 24-hour forecasts, i.e. prognostic charts are prepared for sea-level pressure, relative topography and 500-mb topography in the said order. For 48-hour forecasts, on the other hand, the first method is used. Then the already prepared 24-hour 500-mb prognosis can serve as a hint.

Testing prognostic charts

Forecasts made by numerical methods have been tested by computing the coefficient for the correlation between computed and observed changes. Such tests have been performed by BOLIN & CHARNEY (1951), SAWYER & BUSHBY (1951) and STAFF MEMBERS, University of Stockholm (1952). It can be questioned if the correlation coefficient is the most appropriate number to characterize the degree of success in forecasting. Other numbers could be and have also been chosen for that purpose, such as the mean error, the ratio between mean error and mean change etc. However, we shall accept here the use of correlation coefficients, in spite of the fact that such a coefficient is not sufficient to state if a certain numerical forecast was successful. It is a common suggestion made by experienced forecasters that you must know in addition the corresponding coefficient for the forecast chart made for the same day by means of the old methods. This is necessary since the degree of difficulty in forecasting varies considerably from one situation to another.

When the Swedish routine is used, the correlation figure for the first prognosis, the 24-hour sea-level chart, will in general be higher than the figure for the secondary 24-

hour 500-mb prognosis. That will be shown in the following (see Table I). When the opposite routine is used, e. g. by numerical forecasting, we should then expect that the correlation figure for the 500-mb level will in general exceed the one for the sea-level chart with about the same amount. Therefore, if only 500-mb forecasts are compared by correlation methods, a considerably higher coefficient for the numerical forecast is required than for the routine one before we can say that the two methods will give just as good sea-level charts, which are in fact the most important ones for the forecaster.

As to the last step, the weather forecasting, we do not know exactly to what a degree the success in forecasting depends on the qualities of the prognostic chart. Hence it is not quite sure that improved prognostic charts, made in an automatic way, will improve automatically the weather forecasts. But to make the prognostic surface charts we need at present a good deal of reasoning, and it is quite sure that this reasoning is very important for the success in weather forecasting.

Correlation coefficients obtained by present methods

For certain periods during the last two years coefficients have been calculated at the Swedish meteorological and hydrological institute for the correlation between expected and observed 24-hour changes in sea-level pressure. In all, 228 prognoses have been tested in that manner, and the obtained mean coefficient is 0.71. The success varied within wide limits. Thus the mean for the 30 cases in April 1951 was as high as 0.82. The variation may depend on varying ability of the forecasters. The variation due to the weather situation is probably more important. This effect has been studied in the following way (see fig. 1). In each one of the 228 cases, the coefficient of correlation, r, has been plotted against $\overline{|\Delta p|}$, i. e. the 24-hour change in sea-level pressure, averaged over the test area. This area covered northwestern Europe, and the number of points in the test grid was 26. The grid is shown in fig. 2.

We see from fig. 1 that forecasts of high quality are generally obtained when the average pressure change is large. When on the other hand the average pressure change is small, the success is highly variable, high correlations occur but also very low ones. In situations where the changes exceed in average 10 mb per 24 hours, the mean correlation is 0.85. The figures corresponding to the intervals 8—10, 6—8, 4—6 and 2—4 mb/24 hours are 0.83, 0.73, 0.69 and 0.55, respectively. The curve in fig. 1 represents this average relation between the correlation and the "intensity" of the weather situation, given in terms of the average diurnal pressure change over the test area.

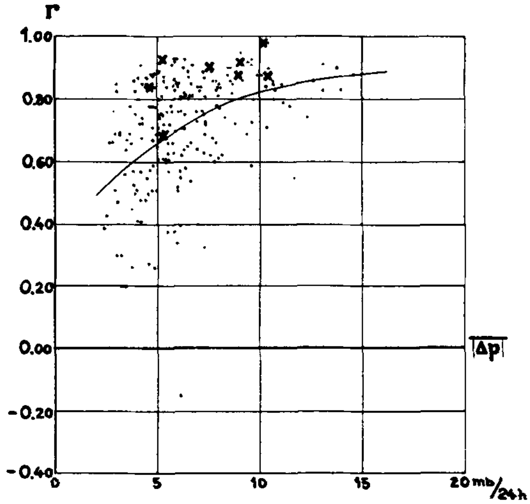

Fig. 1. Coefficients for the correlation between expected and observed pressure changes plotted as a function of the average diurnal pressure change over the test area. Crosses stand for cases studied in Table I. The curve represents average conditions.

The general experiences represented by fig. 1 are probably well-known, viz. it is easier to make a good prediction of the changes to occur when large changes are going on than in a flat and diffuse situation. But it is necessary to remind of the important fact that even if a prognostic chart gives a low correlation figure in a situation with small changes, the chart itself often looks fairly correct and is of good help in weather forecasting.

In 8 cases of the 228 ones, correlation coefficients were computed also for the changes in relative topography between 1,000 and 500 mb and for the changes in the 500-mb topography. These cases are denoted by crosses in fig. 1. The results are given in

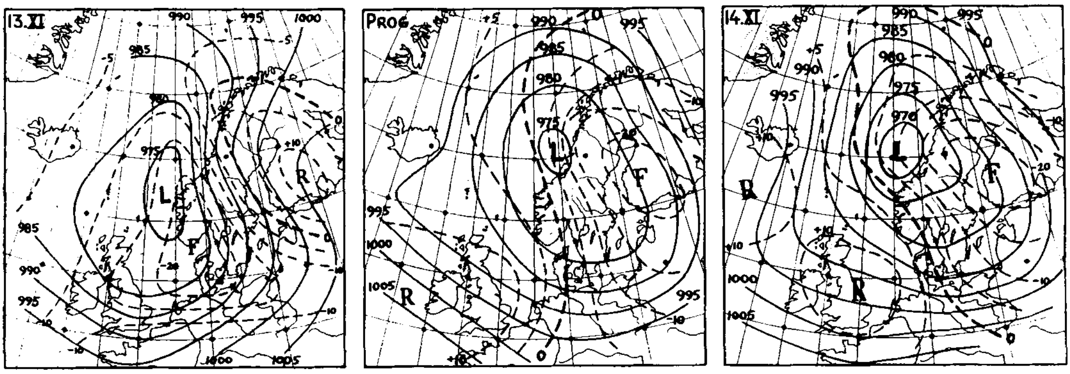

Fig. 2. Sea-level isobars (solid lines) and 24-hour isallobars (dashed lines) for the actual and prognostic chart of Nov. 13 and for the observed chart of Nov. 14, 1950. Contours labelled in mb. Correlation coefficient equal to 0.92. Test points inserted.

Table I. We see from the table that it seems to be easier to predict the sea-level pressure changes with accuracy than to predict the changes in the thickness pattern. We also see that there is in general, as mentioned above, a decrease in the agreement between expected and observed changes when the relative topography is added to the sea-level chart.

Table 1. Correlation between predicted and observed changes in sea-level pressure, relative topography and 500 mb topography.

Date	Sea-level	1,000—500 mb	500 mb
22—23 Oct. 1950	0.93	0.45	0.56
23—24 » 1950	0.84	0.76	0.84
24—25 » 1950	0.68	0.81	0.86
13—14 Nov. 1950	0.92	0.67	0.82
14—15 » 1950	0.88	0.18	**0.92**
10—11 Apr. 1951	0.90	0.73	0.75
11—12 » 1951	0.88	0.79	0.85
12—13 » 1951	**0.98**	**0.84**	0.78
Mean	0.88	0.65	0.80

Bold-face types are used for the best figure in each column. From the forecast for 12—13 April we see that the best sea-level forecast combined with the most successful relative topography forecast resulted in a 500-mb forecast which was one of the least successful of the forecasts studied here, and from the case of 14—15 November is seen that the best 500-mb forecast was obtained in spite of a failure in predicting the changes in the thickness pattern. This is peculiar, but we have not cases enough to see if it is just an accident. Anyhow, it demonstrates the complexity of the forecast problem but also, to some degree, the imperfection of the correlation method. In the case of 14—15 November the sea-level prognosis had its largest errors in some peripheric points in which the predicted changes in relative topography were also in error, while the agreement in the other points was good in the sea-level prognosis but moderate in the other one.

For the 48-hour changes in the 500-mb level the correlation coefficient has been computed in two cases, only, viz. 13—15 November and 14—16 November 1950. In both cases the figure was 0.79, i. e. a figure but slightly lower than the one for the 24-hour changes.

In Fig. 2, 3 and 4 is given an example of combined forecasts for sea-level pressure, relative topography and 500-mb topography. These forecasts were made on November 13, 1950, and the correlation coefficients are close to the mean values for the eight cases given in Table I. From fig. 2 we see that both the movement and the deformation of the principal fall-area are well predicted, but when the sea-level charts themselves are compared, we find a remarkable discrepancy as to the intensity of the low west of Norway, in spite of the high correlation 0.92. Regarding the relative topography we see from fig. 3 that the small changes were correctly sketched as to their main features. In fig. 4, giving the 500-mb charts, the movement of the pattern of 24-

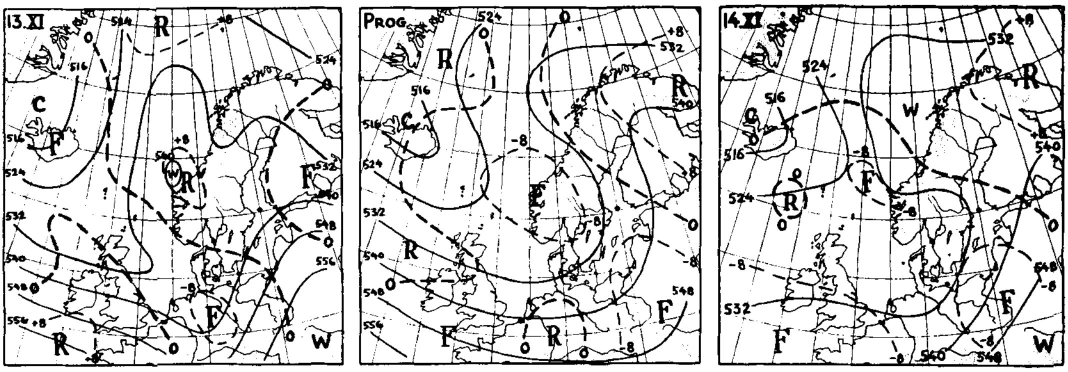

Fig. 3. 1,000—500 mb relative topography (solid lines) and 24-hour changes (dashed lines) for the actual and prognostic chart of Nov. 13 and for the observed chart of Nov. 14, 1950. Contours labelled in tens of metres. Correlation coefficient equal to 0.67.

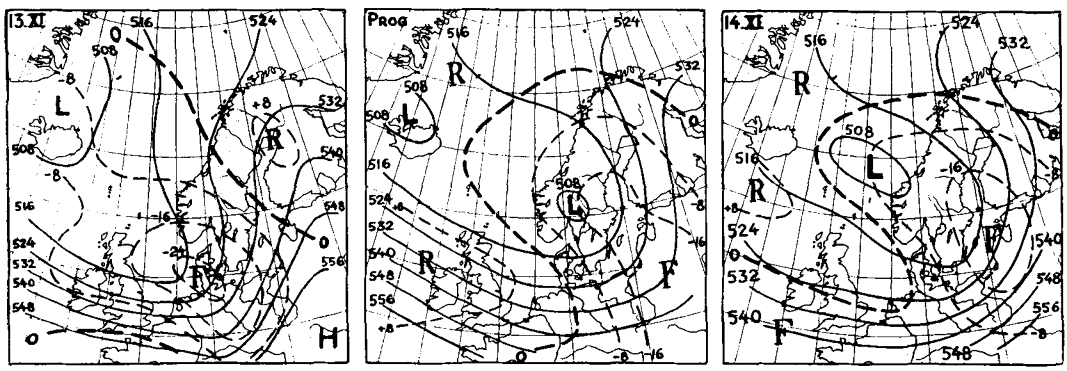

Fig. 4. 500 mb topography (solid lines) and 24-hour changes (dashed lines) for the actual and prognostic chart of Nov. 13 and for the observed chart of Nov. 14, 1950. Contours labelled in tens of metres. Correlation coefficient equal to 0.82.

hour changes turns out to be well estimated, giving an almost correct trough position. Over the southwestern part of the chart, however, there is a significiant discrepancy between the expected and observed upper flow pattern. Nevertheless the correlation coefficient is as high as 0.82.

Fig. 5 demonstrates an extraordinary good prognostic chart, tested in a somewhat different way. It is the 48-hour 500-mb forecast made December 17, 1951. It is tested in 54 points covering an area from Hudson Bay to Russia. The correlation coefficient was 0.92. If we leave out the nine westernmost points, the correlation goes up to 0.96. It is worth mentioning that in this case the situation was such that the forecast was made by pure extrapolation. Thus pure extrapolation can give a high correlation even for 48-hour changes over such a wide area, but the extremely good result is of course an exception. Nevertheless it demonstrates the well-known fact that the difficulty in forecasting meteorological charts varies considerably from one day to another. In this very case, numerical prediction must give just as high a correlation to be considered acceptable for practical use. In other cases, however, simple extrapolation gives perhaps not more than 0.20 correlation. Then the numerical prediction would be very successful even if the correlation is about 0.50. Therefore it is desirable that every test of a numerical forecast includes a comparison with result of pure extrapolation. Only such a comparison clearly points out the practical qualities of the numerical methods.

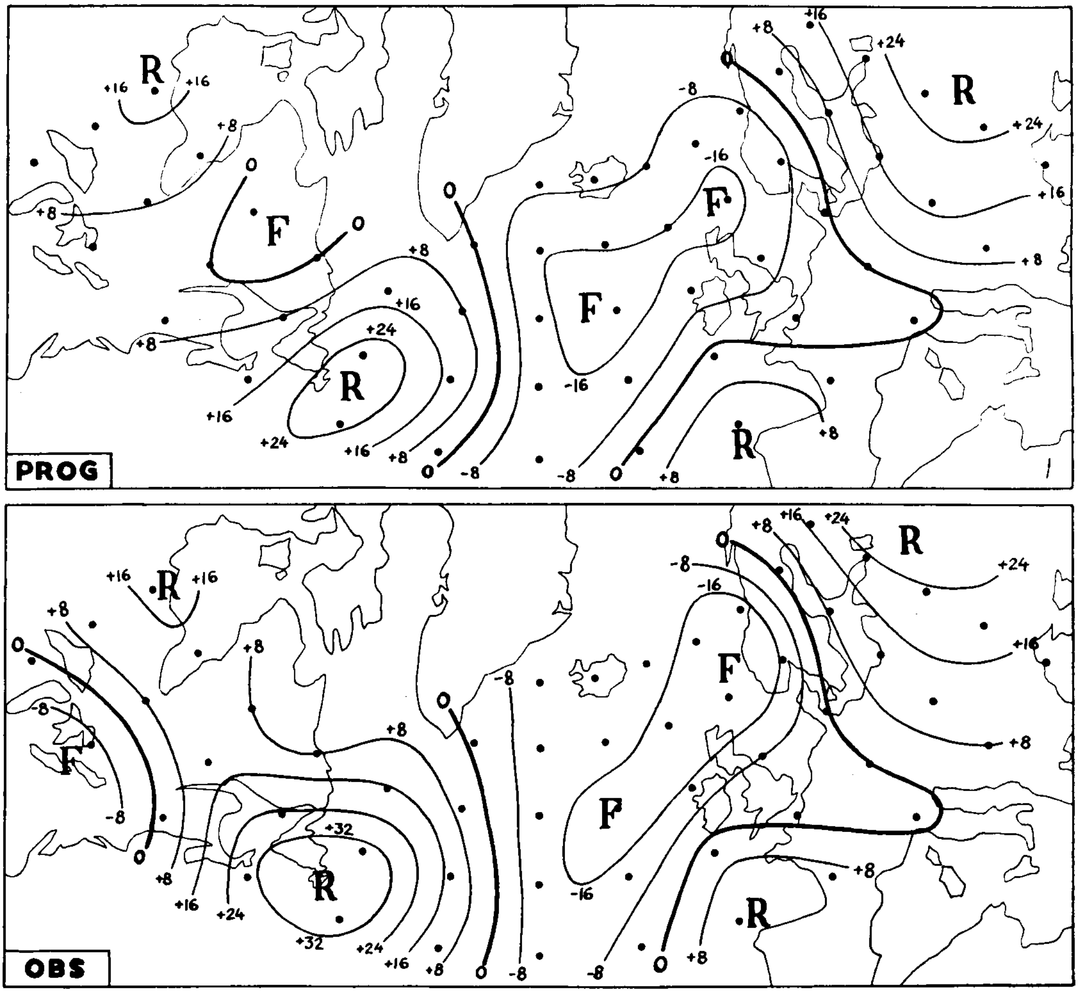

Fig. 5. A comparison between expected and observed 48-hour changes in 500-mb topography 17—19 Dec. 1951. Contours labelled in tens of metres. Correlation coefficient 0.92 computed from test points inserted.

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