Differences in Numerical Prognoses Resulting from Differences in Analyses[1]

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Abstract

This paper describes differences in numerical 500 mb prognoses, using the barotropic model, which result from different analyses of the same initial chart. Three synoptic cases are investigated, comparing the results of using routine analyses made by the Deutscher Wetterdienst, Frankfurt, Germany and the Royal Swedish Air Force Weather Service, Stockholm, Sweden.

It is a truism accepted by most forecasters that good chart prognosis starts with an accurate chart analysis. Nowhere should this be more evident than in numerical weather prediction where the forecast evolves, without subjectivity, from solving the applicable forecast equations using initial data extracted from the current analysis. It is also recognized that weather map analysis has a certain non-unique character insofar as different analysts can arrive at different conclusions in drawing a weather chart. There are many reasons for this; varying degrees of analysis skill, our limited understanding of how the atmosphere behaves, an insufficient or inadequate network of observations, and poor communications are a few. Thus, while the state of the atmosphere at a given instant is obviously unique and single-valued, its description on charts in terms of instantaneous fields of wind, temperature and pressure (or pressure-height) is often non-unique.

Newton (1954) has given a comprehensive survey of the problems which can arise in numerical prediction from our inability to describe precisely the atmosphere at some initial time. He has suggested certain experiments to determine the observational requirements for numerical prediction, including tests of the effects of different possible interpretations of existing data. Following this suggestion, it is the purpose of this paper to show briefly the differences in numerical, machine prognoses with the barotropic model that can result from differences in analysis. It was planned to do this by experimenting with 500 mb patterns that could be defined analytically, and observing the prognostic differences that could be caused by modifying the descriptive equation. As a prelude, however, it was decided to investigate actual synoptic cases.

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It is certainly of operational interest to know the extent of prognostic differences that can result from analysis differences. In this way it may be possible to establish "tolerances", so to speak, that are acceptable in analysis. It has been alleged that the problems of non-unique analysis are made irrelevant with the introduction of objective (i.e. machine) analysis. Of course this is not so, since different objective techniques may, in fact, lead to different analyses. Furthermore it would seem that a good test of a machine analysis method would be how well it can determine those scales of horizontal motion on the current analysis which, in fact, significantly influence the ultimate machine prognosis. It is these scales with which this investigation is concerned.

The investigations described below were made while the writer was a member of the numerical prediction group at the University of Stockholm, Sweden, 1954—55. This group, under the leadership of B. Bolin, has for the past several years concentrated on an exhaustive study of the barotropic model in forecasting for periods up to 72 hours.

The analyses for 3 December, 8 December and 15 December 1954 were chosen for the experiment. Their selection was random insofar as the dates were specified several weeks before they occurred. It is believed, therefore, that the analysis differences observed are typical for the winter. Two sets of analyses were used:

A. The routine 0300GMT analysis made by the Deutscher Wetterdienst, Frankfurt, Germany. This set, including the prognoses derived therefrom, is referred to hereafter as Map A, Analysis A, or Prog A, and is represented on all figures by solid lines. Contour lines are labelled in tens of meters.

B. The routine 0300 GMT analysis made by the weather central of the Royal Swedish Air Force, Stockholm. This set, including prognoses derived therefrom, is referred to as Map B, Analysis B, and Prog B, and is represented on all figures by dashed lines.

It is emphasized that these are routine analyses prepared under operational duress and without benefit of late data and hindsight study.

The forecasts were made on the Swedish electronic computer BESK over a rectangular grid of 30×40 points on a polar stereographic projection (cf Fig 1, Bolin 1955). The grid width interval was 300 km at 50° N. Boundary assumptions consisted of keeping grid point values of height and vorticity constant. Values of the initial vorticity on the boundaries were calculated using height values at the row/column immediately outside the 30×40 grid. As has been pointed out before (Bolin 1955), these boundary assumptions will introduce errors in the forecasts which may be expected to "invade" the forecast area for increasing distances with increasing time. In discussing the prognoses, therefore, we shall confine our attention to exclude boundary areas and consider the east coast of North America, the Atlantic, polar regions, and west Europe.

Case 1, 3 December 1954, was run with 1 hour 12 minute forecast time steps using the barotropic code, the characteristics of which have been described by Bolin (1955). Cases 2 and 3, 8 and 15 December 1954, were run with 1 hour forecast time steps using a barotropic code similar to the one used by Staff Members, University of Stockholm (1954). In the latter a smoothing routine was introduced such that in the initial 500 mb height field and in the prognostic height fields for 24h, 48h and 72h each grid height is replaced by a "smoothed" value:

$$\bar{\phi} = \phi_o + \frac{1}{16} \nabla^2 \phi$$

where ∇^2 is the finite difference Laplacian operator. The previous code had no smoothing; smoothing has been introduced to damp the appearance of so-called "wiggles", that is, relatively high amplitude-short wave length oscillations, on some 48h and 72h progs (cf Bolin 1955). It is interesting to note that thus far no such oscillations have been observed using the new code.

Case 1. 0300 GMT, 3 December 1954

Fig. 1 compares the 2 initial 500 mb analyses, A and B. It is seen that the major differences between them occur with respect to the LOW northwest of Greenland, the small LOW over southeast Greenland on Analysis A (solid lines), and in the shape of the several contour lines running from southeast

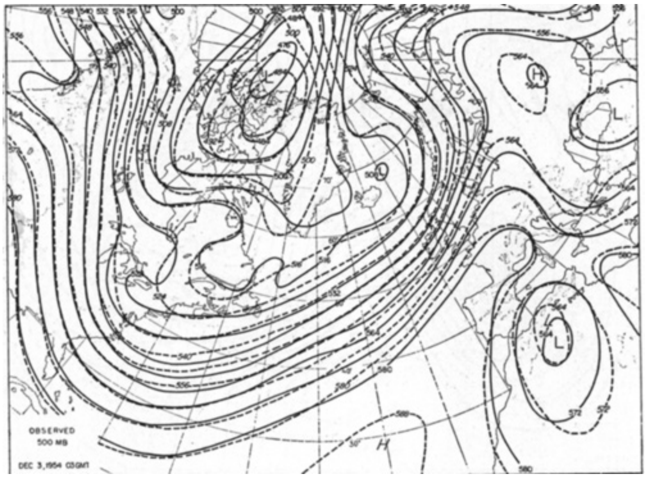

Fig. 1. Observed 500 mb map, Dec. 3, 1954, 03 GMT. Solid lines indicate analysis from Deutscher Wetterdienst. Dashed lines indicate analysis from Swedish Air Force.

Canada to Iceland. Otherwise the analyses are quite similar.

Figs. 2 and 3 compare the 24 h and 72 h prognoses derived from the 2 analyses. It is seen that the major difference between the 2 prog series results from the different evolution of the pattern from southern Greenland to northwestern Europe. At 24h, Prog A shows a small amplitude wave south of Grenland, compared to a uniform southwesterly flow on Prog B. On the 48h (not shown), the wave on Prog A has progressed eastward and increased in amplitude so that a pronounced trough lies west of Scandinavia. No similar development is evident on Prog B. On the 72h, the trough on Prog A has intensified and moved to western Europe. Prog B does not show this development but gives northwesterly flow from Greenland to central Europe.

A striking feature of this prognostic series is the development of an intense subtropical HIGH. This will be discussed later.

The conclusion from Case 1 is that analysis differences of the scale and type shown in Figure 1 lead to prognostic differences that are probably not too significant at 24h from the forecaster's point of view. On the other hand, the resulting prognostic differences at 48h and

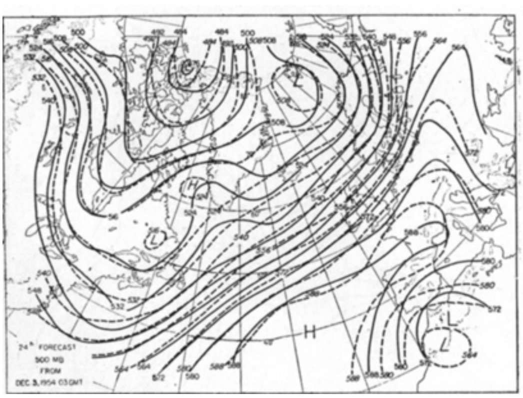

Fig. 2. 24h forecast 500 mb from Dec. 3, 1954, 03 GMT (cf Fig. 1).

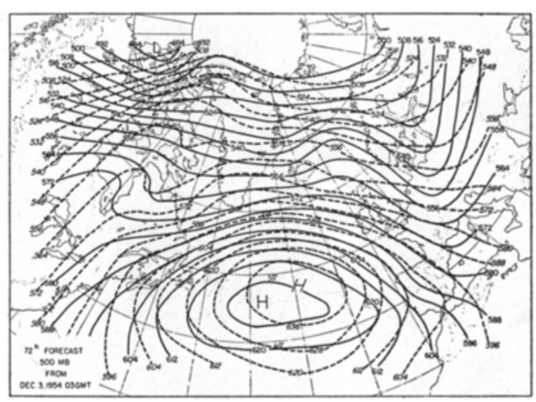

Fig. 3. 72h forecast 500 mb from Dec. 3, 1954, 03 GMT (cf Fig. 1).

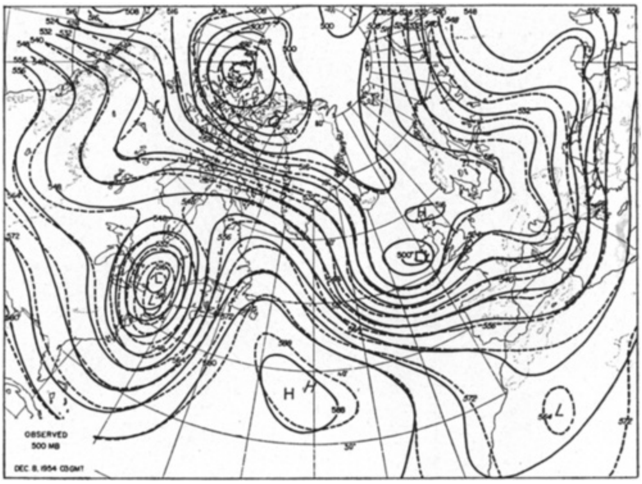

Fig. 4. Observed 500 mb map, Dec. 8, 1954, 03 GMT (cf Fig. 1).

at 72h seem to be of considerable forecast significance over an area far downstream from where the original analysis differences were.

Case 2. 0300 GMT, 8 December 1954

Figure 4, comparing the two 500 mb analyses, shows that the major differences occur in the location and intensity, but not the shape, of the strong cyclone over northeast U.S. A lesser difference is also noticeable, in isopleth curvature over the mid-Atlantic. The analyses over west Europe, showing several small HIGHs and LOWs, are essentially equivalent.

The evolution of the prognoses is shown for 24h and 72h in Figures 5 and 6. The prognosis for 48h is not shown. With regard first to the northeast U.S. LOW, the cyclone moves northeastward on the 24h and 48h progs of both series. By 48h, its central intensity on A is about the same as on B. It is evident that this feature has evolved similarly on both series. The development from 48h to 72h is rather different, however, as the Prog A LOW merges into the main LOW over Greenland and the Prog B LOW proceeds eastward as a small but nevertheless distinct center.

With regard to the pattern over west Europe, the 24h and 48h progs are essentially the same for A and B. However, the 72h progs show some difference; the trough and cut-off LOW appear 1,000 km further east on Prog B than on Prog A.

The conclusion from Case 2 is that analysis differences of the scale and type shown by

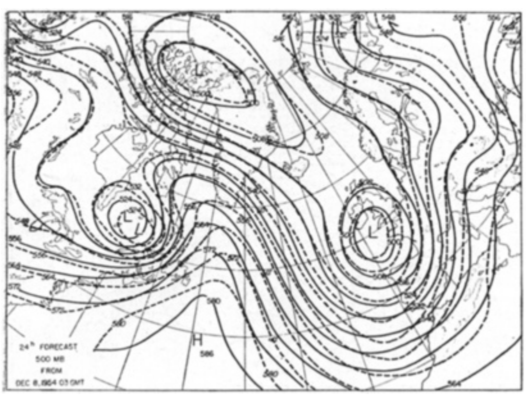

Fig. 5. 24h forecast 500 mb from Dec. 8, 1954, 03 GMT (cf Fig. 1).

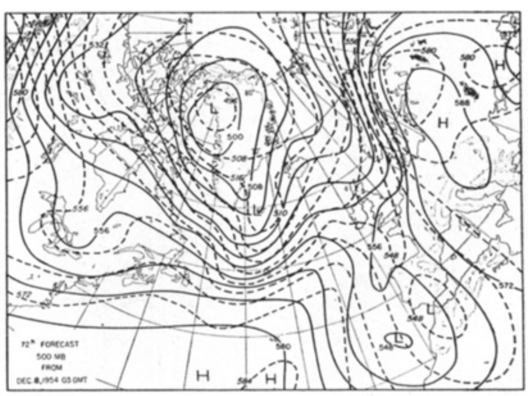

Fig. 6. 72h forecast 500 mb from Dec. 8, 1954, 03 GMT (cf Fig. 1).

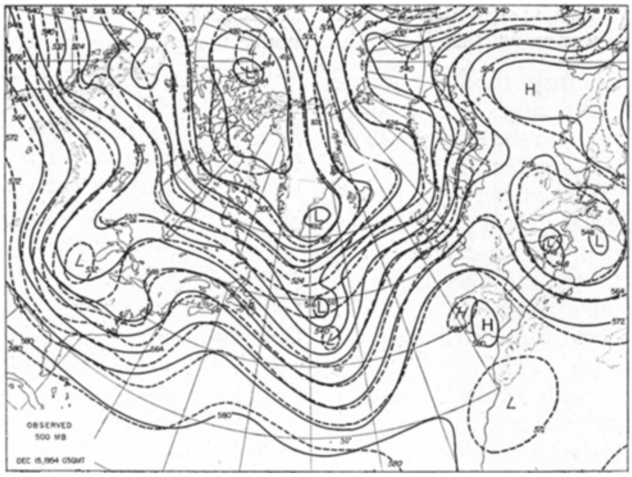

Fig. 7. Observed 500 mb map, Dec. 15, 1954, 03 GMT (cf Fig. 1).

Figure 4 cause prognostic differences of not especial significance at 24h and 48h. However, by 72h, the differences appear to become significant for forecasting weather over most of the area under discussion.

Case 3. 0300 GMT, 15 December 1954

Figure 7, comparing the two analyses, shows that the major difference occurs in the mid-Atlantic with respect to the location, intensity and surrounding pattern of the LOW. Of particular interest is the shape of the contours northeast of the LOW center; on Analysis A a ridge is apparent.

At 24h, Figure 8, Prog A shows a strong trough at 25° W and ridging over Britain. On the other hand, the northern portion of the trough on Prog B is flatter, its southern portion is sharper, and the ridge downstream is flatter and further northeast. The 48h (not shown) and 72h progs, Fig. 9, show that A and B evolve quite differently. On Prog A, the trough west of Britain is fairly sharp and a strong closed HIGH appears over eastern Scandinavia and western Finland. In contrast, on Prog B the trough is quite flat; furthermore, the HIGH over Spain and the Bay of Biscay at 24h moves westward. These prognostic differences should be sufficient to give quite different forecasts of wind and weather.

The conclusion from Case 3 is that analysis differences of the scale and type shown cause prognostic differences which are already be-

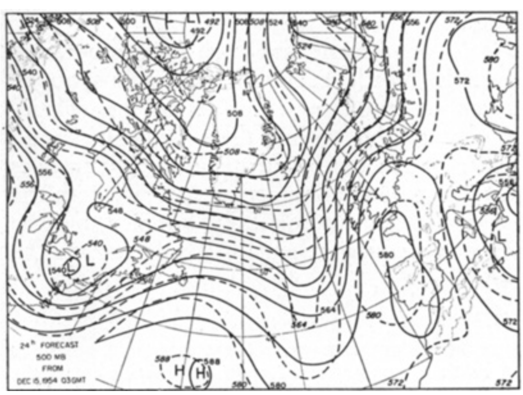

Fig. 8. 24h forecast 500 mb from Dec. 15, 1954, 03 GMT (cf Fig. 1).

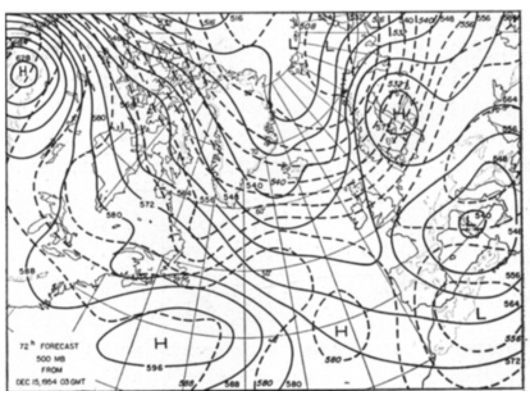

Fig. 9. 72h forecast 500 mb from Dec. 15, 1954, 03 GMT (cf Fig. 1).

coming important at 24h and which are of definite forecast significance at 48h and 72h.

We wish now to compare the behavior of 2 particular LOWS: the large cyclone over northeast U.S. on 8 Dec. and the smaller LOW in the mid-Atlantic on 15 Dec. The analysis differences are quite marked between the A and B maps for both dates. Grid point height differences between analyses, for example, are as high as 120 m on the 8th and over 200 m on the 15th. Yet the ensuing prognoses, A and B, diverge much more rapidly and strikingly on the 15th than on the 8th. Why?

In evaluating the results of these analysis differences, it should be recalled that numerical prediction involves advecting the absolute vorticity field, which is derived from the height field, in the height field itself. Thus, if two LOWs have the same shape, contour curvature and spacing, they should have, disregarding latitudinal changes the Coriolis parameter, the same vorticity distribution and be predicted along parallel paths for the same distance. Thus in the 8 Dec. case, the equivalent motion of the LOWs agrees with their having wind and vorticity distributions that are approxi- mately equivalent. On the other hand, although the 15 Dec. LOW is much smaller than the 8 Dec. LOW, the contours around the former are analyzed quite differently on Analyses A and B (Fig. 7). In particular, Map A places a definite ridge northeast of the LOW while Map B does not.

In Case 3, a striking feature of the prognoses is the intense anticyclogenesis predicted over western North America. The same phenomenon occurred in Case 1, with the spuriously intense anticyclogenesis forecast in the Atlantic. A possible cause of this overdevelopment has been suggested by Bolin (1955) to be the assumption of constant boundary conditions which, in effect, continuously advect anticyclonic vorticity around the west side of a HIGH situated near the boundary. To test this, Analysis A of Case 1 was re-analyzed to give a single-valued height at the lower boundary of the forecast area and hence make approximately zero the advection normal to the boundary. On the prognoses obtained from this re-analysis, intense anticyclogenesis was still present, but the forecast heights were as much as 100 m lower than those predicted by the original analysis. This would suggest that false vorticity advection across the boundary is at least partly responsible for building a synoptically impossible HIGH.

Conclusions

The following conclusions seem indicated by these 3 cases:

1. Differences in analysis over the area studied lead to differences in prognosis. The degree of the prognostic difference increases with the length of the forecast.

2. The prognostic differences do not appear to be of major importance on the 24h forecasts. However, for forecast periods of 48h and 72h, the prognostic differences seem large enough to be operationally significant.

3. Although objective analysis may minimize the effects of analysis differences such as are found here, it would seem that one important test of an objective analysis method is its ability to define those scales of horizontal motion which in fact affect the prognosis. This study indicates that those scales exist down to wavelengths of several grid widths.

4. In view of the numerical forecast procedure and the physical principles of the barotropic model, it appears that analysis differences with regard to the *shape* of the map features have at least as great an effect on prognoses as do analysis differences due to *location* of the features.

5. The present fixed observing network over the North Atlantic is, in certain synoptic situations, too sparse to define the characteristics of the 500 mb flow precisely enough for use with the barotropic model. This does not mean that a numerical forecast with the present net is automatically doomed, but the net is inadequate when LOWs occur over the ocean.

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