Automation of 500 mb Forecasts through Successive Numerical Map Analyses

By BO R. DÖÖS, International Meteorological Institute in Stockholm

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Abstract

Two series of barotropic forecasts have been computed from numerically analysed maps. The first series consists of 31 forecasts and the second one of 4.

Due to the fact that it is possible to obtain the forecasts directly from observed data, which are punched immediately after they are received, it is possible to save both time (3 à 4 hours) and personnel.

The reliability of these forecasts seem to be at least as good as forecasts computed from conventionally analysed maps.

1. Introduction

During the autumn of 1954 the meteorological section of the Royal Swedish Air Force in cooperation with the Meteorological Institute of the University of Stockholm undertook a series of routine computations of barotropic forecasts. The results of these computations (BOLIN 1955) demonstrated the desirability of making such forecasts over a longer period. For this reason 72 forecasts were computed during the periods December 1—17, 1954, January 17—February 25 and April 12—May 24, 1955.

The results obtained during the first two periods have already been presented (BERGTHORSSON, DÖÖS, FRYKLUND, HAUG and LINDQUIST 1955). In this connection it should be mentioned that the final mean values of the correlation coefficients obtained were insignificantly affected by the introduction of the third period, April 12—May 24, 1955. These routine computations of barotropic forecasts were resumed in the Autumn of 1955.

The development of fast electronic computors does not only make it possible to apply numerical methods in forecasting upper flow patterns in the atmosphere but will also mean a revolution with respect to data handling and processing in general. In view of the very large amount of data that passes through a forecasting center it seems that automation will be particularly important here.

The development of methods for weather map analysis with a machine (BERGTHORSSON, DÖÖS 1955, hereafter denoted by NWMA) should be looked upon as a step in this direction. It is of some interest to see to what extent it already now is possible to automatise the analysis and forecasting of the 500 mb surface and the following experiment was carried out during the period November 14—December 22, 1955.

2. The Analysis

When computing the analyses, a preliminary value is required consisting of a weighted mean value of a forecast (12-hour or 24-hour barotropic forecast) valid for the same time as the analysis and the normal height of the 500-mb surface. The first analysis for a

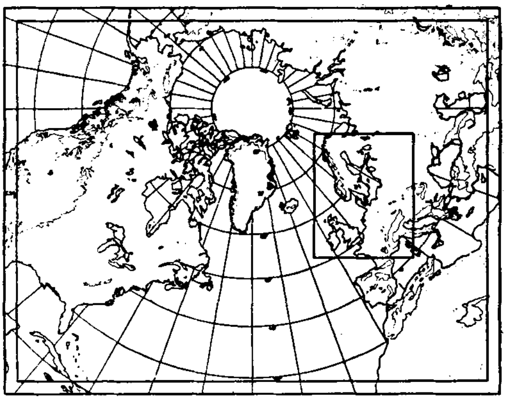

Fig. 1. Location of the grid used in the analyses and the forecasts. The analyses were made over the whole area, while the forecast computations were made over the area limited by the inner solid line. The small rectangle indicates the area over which the verification of the forecasts was made.

series of forecasts must thus be made through conventional means.

It has proved sufficient to use a 24-hour forecast in constructing the preliminary field. Hereby the necessity is avoided of analysing two maps a day and also of computing an extra 12-hour forecast, which is required in the case of the 12-hour alternative. No 48-hour and 72-hour forecasts were required on Saturdays and Sundays. On the other hand, the routine numerical analyses and 24-hour forecasts were made on these days. In this manner it was possible to achieve continuity without resorting to conventional analysis. The map for 1500 GMT was analysed throughout this period.

The observation data were punched on a tape as they arrived. The majority of the data had been received by 2400 GMT after which the analysis was computed, usually in 30—40 minutes, depending on the number of data received. The forecast computation—which required some 90 minutes—was made immediately afterwards. All forecast maps were completed by approximately 0300 GMT (0400 local time), and were then transmitted to the various Air Force units. The gain in time obtained by computing the analysis numerically amounts to some 3 hours.

It was possible in most cases to eliminate erroneous data in the first test, by comparing observed heights and winds with the interpolated ones in the preliminary field. It should be remembered, however, that the difference between observed and interpolated value may occasionally exceed the prescribed tolerance without necessarily warranting the conclusion that the observed data are wrong. The preliminary field may of course have a higher or lower degree of exactness. This is particularly true in the areas near the boundaries when developments have been strong, in which cases the forecast for these areas is less exact. It may also be due to the fact that the true height strongly deviates from the normal.

The possibility was exploited of removing the influence of erroneous data when the observed data were compared with the interpolated values in the completed analysis after which the corrected values could be inserted.

3. The Forecast

The procedure indicated by Charney and Phillips (1953) has largely been followed for the integration of the barotropic equation.

In order to avoid amplification of small scale disturbances, describable neither by means of the barotropic model nor by the grid-system (one grid unit = 300 km at 50° lat.), the initial and thereafter every 24-hour field have been smoothed.

The smoothed field is defined by the formulas

$$\bar{\phi} = \phi + k\,\bar{\nabla}^2\phi$$

$$\bar{\zeta} = \zeta + k\,\bar{\nabla}^2\zeta$$

where ϕ denotes the height-value, ζ the relative vorticity and $\bar{\nabla}^2$ the finite difference Laplacian operator.

With $k = \frac{1}{16}$ satisfactory results have been obtained.

Further, a method was introduced which made re-starting possible from the previous time-step in the event of a break-down of the machine. Thus the field is doubly stored for each timestep, and on the computation of the immediately following time-step the computed relative vorticity is compared with the relative vorticity, extrapolated from the preceding two time-steps. If in any point the difference exceeds a given tolerance the machine will stop, after which it will resume operations from the immediately preceding time step.

Date	q	D	24-hour forecast					48-hour forecast					72-hour forecast				
			r	σ_x	σ_y	ε	ε/σ_x	r	σ_x	σ_y	ε	ε/σ_x	r	σ_x	σ_y	ε	ε/σ_x
14/11—55 15	234	25	0.88	50	57	36	0.72	0.88	84	99	89	1.06	0.79	113	154	159	1.41
15/11—55 15	248	22	0.89	47	46	27	0.58	0.83	90	98	93	1.03	0.77	84	185	169	2.01
16/11—55 15	244	33	0.92	62	48	30	0.49	0.83	80	118	87	1.09	0.59	81	173	151	1.86
17/11—55 15	233	31	0.92	70	75	34	0.48	0.71	75	127	93	1.24	0.53	118	207	167	1.42
18/11—55 15	233	30	0.87	60	58	31	0.52	0.80	90	88	64	0.71	0.60	123	173	135	1.10
19/11—55 15	209	24	0.95	82	85	29	0.36	—	—	—	—	—	—	—	—	—	—
20/11—55 15	189	34	0.88	63	97	56	0.89	—	—	—	—	—	—	—	—	—	—
21/11—55 15	241	25	0.89	97	107	63	0.65	0.89	151	254	155	1.03	—	—	—	—	—
22/11—55 15	223	26	0.97	116	146	52	0.45	—	—	—	—	—	—	—	—	—	—
23/11—55 15	218	25	0.95	96	177	103	1.07	0.76	107	250	199	1.86	—	—	—	—	—
24/11—55 15	212	24	0.77	82	90	105	1.28	0.92	141	193	219	1.55	0.94	163	282	277	1.70
25/11—55 15	224	27	0.88	100	77	63	0.63	0.83	135	119	126	0.94	0.89	146	168	141	0.96
26/11—55 15	226	27	0.82	51	58	41	0.81	—	—	—	—	—	—	—	—	—	—
27/11—55 15	225	29	0.87	61	63	32	0.52	—	—	—	—	—	—	—	—	—	—
28/11—55 15	238	29	0.64	57	53	63	1.11	0.82	108	135	124	1.15	0.90	126	207	152	1.21
29/11—55 15	210	33	0.93	94	73	46	0.49	0.94	119	130	65	0.54	0.86	135	203	130	0.96
30/11—55 15	205	27	0.94	87	83	31	0.36	0.81	101	114	83	0.82	0.45	126	138	140	1.11
1/12—55 15	161	27	0.76	91	95	56	0.62	0.66	111	124	93	0.84	0.41	142	92	132	0.93
2/12—55 15	242	31	0.81	76	72	57	0.75	0.69	121	72	88	0.73	0.02	128	89	152	1.19
3/12—55 15	229	31	0.97	109	101	49	0.45	—	—	—	—	—	—	—	—	—	—
4/12—55 15	239	31	0.95	64	67	55	0.86	—	—	—	—	—	—	—	—	—	—
5/12—55 15	266	28	0.91	84	67	36	0.43	0.46	138	225	169	1.22	0.65	151	304	181	1.20
6/12—55 15	230	31	0.94	91	120	47	0.51	0.81	148	287	169	1.14	0.70	180	379	226	1.26
7/12—55 15	251	28	0.94	98	155	80	0.82	0.91	125	262	148	1.18	0.93	168	314	157	0.94
8/12—55 15	264	37	0.55	60	113	71	1.18	0.84	120	225	133	1.11	0.85	118	282	200	1.69
9/12—55 15	231	29	0.92	73	123	77	1.05	0.81	88	214	179	2.03	0.68	97	270	240	2.47
10/12—55 15	252	29	0.93	71	82	75	1.06	—	—	—	—	—	—	—	—	—	—
11/12—55 15	214	25	0.80	64	65	50	0.78	—	—	—	—	—	—	—	—	—	—
12/12—55 15	235	21	0.79	59	65	39	0.67	0.65	99	119	102	1.03	—	—	—	—	—
13/12—55 15	268	32	0.79	73	61	48	0.65	0.70	122	108	110	0.90	—	—	—	—	—
14/12—55 15	248	26	0.70	67	58	53	0.79	0.68	97	107	92	0.94	0.54	115	203	167	1.45
15/12—55 15	219	28	0.67	70	76	53	0.76	0.18	95	167	150	1.58	0.12	131	359	356	2.72
19/12—55 15	230	27	0.83	56	88	59	1.05	0.50	61	111	113	1.85	0.60	90	129	138	1.53
20/12—55 15	234	28	0.74	51	50	56	1.10	0.76	103	117	84	0.81	0.58	117	183	139	1.19
21/12—55 15	238	27	0.85	73	91	45	0.62	0.64	109	162	121	1.11	0.73	83	184	139	1.67
22/12—55 15	237	26	0.63	80	95	90	1.13	0.56	70	127	101	1.44	0.12	99	136	178	1.80
Mean	231	28	0.85	75	84	54	0.74	0.74	107	154	120	1.15	0.62	123	209	175	1.47

4. Results

The forecasts were made from two series of numerically analysed maps, for the period from 1500 GMT November 14 until 1500 GMT December 15, 1955 and for the four days 1500 GMT December 19—22, 1955. The first series consisted of 31 forecasts. 48 and 72-hour forecasts were made practically daily except on Saturdays and Sundays, whilst 24-hour forecasts were made every day.

Both these series begin with a conventional analysis of the 0300 GMT map. A 12-hour forecast was then computed as the basis for the 1500 GMT analysis.

The results of the forecasts are given in the table. r is the correlation coefficient between the observed and computed changes, σ_x and σ_y are the root mean squares of the observed and computed changes and ε is the root mean square of the difference between the observed and computed changes (the mean error). The verification was made over an area shown in fig. 1.

One may observe that the computed changes (σ_y) usually are larger than the observed ones (σ_x). In the cases where $\frac{\sigma_y}{\sigma_x}$ deviates strongly from unity the average observed and computed changes $\bar{x}$ and $\bar{y}^{*}$ usually are quite different. Thus an erroneous rise over a major part of the forecast area has been obtained from the computations in those cases. This means that there is no systematic error in the computed displacements of the troughs and ridges in the westerlies.

Such errors seem to be considerably reduced by incorporation of a total horizontal divergence in the troposphere picturing the varying height of the troposphere (BOLIN 1956).

The geographical distribution of the reliability of the forecasts has been investigated. The correlation coefficients for 24-, 48- and 72-hour forecasts have been computed in 27 points. The results are shown in fig. 2.

The unexpectedly high correlation coefficient for the 24-hour forecasts in the Atlantic area is due to the influence on the analysis of the 24-hour forecast from the previous day being comparatively large in areas where the station network is sparse. The correlation coefficient for the 24-hour forecasts is therefore not a suitable gauge for the reliability in such areas.

When the actual changes are small, rather unreliable forecasts are obtained. This partially explains the low average correlation in the northern regions of the Scandinavian Peninsula and also in regions west of this area. During the period mid-November—mid-December the observed changes were comparatively small here. In this connection it is interesting to compare the distribution of the correlation coefficients with the mean circulation at the 500 mb surface for this period.

In the 24-hour forecasts the best results were obtained for an area east of the Baltic (> 0.90), whilst the best results in the 48-hours forecasts were obtained for an area running from Iceland across the British Isles and Central Europe up to southern Sweden (> 0.75). In the 72-hours forecasts the best results were for the region covering the British Isles, western France and northwestern Spain.

In the table are also given the number of stations (q) used in each analysis and the root mean square of the differences between observed and the analysed heights (D) at the stations. These values demonstrate that the degree of smoothing of the analysis is of the correct magnitude, as per the standard error in height observations (NYBERG 1952). In comparison with the numerical analyses where

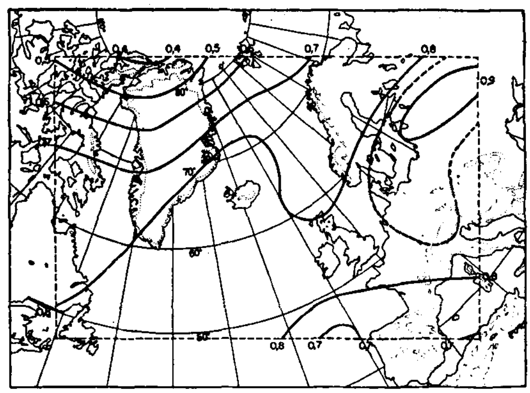

Fig. 2 a.

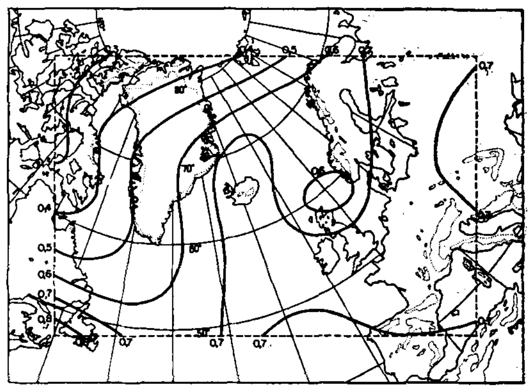

Fig. 2 b.

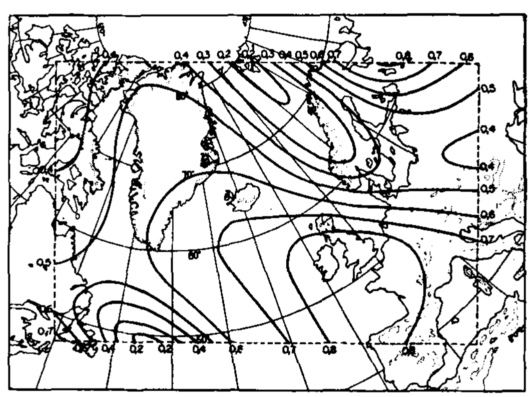

Fig. 2 c.

Fig. 2. Geographical distribution of the correlation between observed and computed 24-hour changes (a), 48-hour changes (b) and 72-hour changes (c).

12-hour continuity was used (NWMA), the smoothing is somewhat stronger.

As two independent conventional analyses of the 1500 GMT maps were not available, no comparison was made, such as that presented in NWMA.

An estimate of the reliability of the numerical analysis as compared with the conventional may be obtained by comparing the reliability of the numerical forecasts computed from conventionally analysed maps for the same season previous year. A certain improvement would then be noted. However, this does not prove that the numerical method is better than the conventional. Firstly, the volume of the material is too small to permit firm conclusions from being drawn and secondly, an improvement of the forecasts can be ascribed to the smoothing procedure introduced into the forecast computations.

5. Conclusions

With the present size and orientation of the grid the area along the boundaries is particularly sensitive. This is partly due to the fact that the forecast used in computing the preliminary field is inaccurate along the boundaries because of the boundary condition ($\partial\phi/\partial t = 0$). This applies particularly to the upper boundary where the height changes may be considerable. The error is further aggravated by the necessity of extrapolating one grid unit along the boundary of the field, in compensation for the unit lost during the forecast computation. In addition there are fewer stations within this area. Variations in time of the topography of the 500-mb surface will then be damped. This may in turn cause abnormally strong gradients.

Thus a too intense anticyclone was formed between the North Pole and the upper boundary towards the end of the first period, presumably due to the unrealistic boundary conditions in the forecast computations. Because of the incapacity of the analysis on the following day to correct the erroneous preliminary field the anticyclone was further intensified in the next forecast. This resulted in a completely impossible analysis for this area three days later (December 16).

It is therefore particularly important to obtain as many data as possible in the vicinity of the upper boundary. The way in which the programme is written at present makes it impossible to include observations from stations outside the boundaries. These data, however, are both important and necessary and can be exploited. By using nearby stations it is possible to sketch the analysis for these areas. An imaginary station can then be inserted on the boundary. The error thus made has been found negligible if the distance between the real station and the boundary does not exceed 500 km.

Naturally it is possible to apply this method, to insert imaginary stations, inside the boundaries too.

This is particularly useful when data have not been received from areas where the station network is sparse.

The difficulties in obtaining a good analysis for boundary areas will obviously be reduced when it becomes possible to extend the grid so that the flow across the boundaries will be as weak as possible.

The analysis for the Atlantic and the Pacific Ocean have in most cases been satisfactory although upper air data only have been used. Data obtained from reconnaissance flights have been used when received.

It is possible, however, to improve the analysis for these areas by extrapolating the height of the 500 mb level from carefully chosen surface data. The stratification can then usually be so accurately estimated, that the error in the extrapolated height does not exceed 40 m. As a rule some five such reports are obtained from the Atlantic.

Another means of improving the analysis would be the use of the predicted 30-day means of the 700 mb surface which are issued two times a month by the Extended Forecast Section of the U.S. Weather Bureau. However, these must first be extrapolated for the 500 mb level. The simplest method of doing this is to add to the normal height of the 500 mb level 5/7 of the predicted anomalies of the heights of the 700 mb surface.

Particularly in high latitude regions where the normal has great influence (The Pacific Ocean) a better result would be achieved than when the ordinary normal heights are used.

It is possible to summarize the results as follows:

The numerical analysis is better than the conventional for areas where the station network is dense due to the fact that the smoothing necessitated by observation errors is more consistent.

Where the station network is sparse, as for instance over the Atlantic, the numerical method gives in most cases comparable results. By resorting to extrapolated surface stations there will be minor differences only in the results obtained from either method.

It has been found possible to save both personnel and time, some 3—4 hours.

Barotropic forecasts from numerically analysed maps are at least as good as those based on conventional analysis. In addition the numerical analysis is more objective than the conventional as the human factor in interpretation is eliminated.

REFERENCES

BERGTHORSSON, P., DÖÖS, B. R., 1955: Numerical Weather Map Analysis. *Tellus* **7**, pp. 329—340.

BERGTHORSSON, P., DÖÖS, B. R., FRYKLUND, S., HAUG, O., LINDQUIST, R., 1955: Routine forecasting with the barotropic model. *Tellus* **7**, pp. 272—274.

BOLIN, B., 1955: Numerical forecasting with the barotropic model. *Tellus* **7**, pp. 27—49.

BOLIN, B., 1956: Further studies of models for numerical forecasting. *Tellus* **8**, pp. 61—75.

CHARNEY, J., PHILLIPS, N., 1953: Numerical integration of the quasigeostrophic equations of motion for barotropic and simple baroclinic flows. *J. of Meteorology*, **10**, pp. 71—99.

NYBERG, A., 1952: On the comparison of Radiosonde Data in Payerne May 1950: *Sveriges Meteorologiska och Hydrologiska Institut, Communication, Series B* No. 9.

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