IMPACT OF ANALYSIS ERRORS OVER DATA SPARSE EASTERN PACIFIC OCEAN ON THE ETA MODEL'S FORECASTS

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August 1993

NMC Office Note 399

ABSTRACT

Predictions from the Eta model in which analysis errors over the data sparse eastern Pacific Ocean induce forecast errors over the western United States in the shorter range (12-24 h) and over the eastern United States in the longer range (36-48 h) are discussed. The forecast errors that first appear in a trough (ridge) in middle and upper tropospheric westerlies over the west coast of the United States propagate eastward with the trough (ridge). The errors amplify when they reach a baroclinic zone and affect the development of predicted surface storms. A procedure that may help forecasters judge relative accuracy of two forecasts valid at the same time, one of the shorter range than the other, is also presented.

1. Introduction

In many operational models the analysis is carried out using short range (usually 6-12 h) forecast fields from the previous run of the model as a first guess. The inaccuracies in the analysis may give rise to large errors in a prediction. Toth and Kalnay (1993) have suggested that the increase of forecast errors in fast growing modes (high energy perturbations), such as the baroclinic waves, will be larger than in the low energy perturbations, like the gravity waves. Because of these prediction errors, the subsequent analysis that uses the short range predicted fields as a first guess will have a large error in the fast growing modes, especially over the data sparse regions.

It is difficult to diagnose errors in an analysis or a forecast in regions where data are sparse. However, the analysis errors over data sparse regions may propagate and give rise to forecast errors over data rich regions, where errors can be assessed. As an example, when a disturbance approaches the United States from the eastern Pacific Ocean the errors in the prediction of its location and intensity can be attributed, in many cases, to the analysis errors over the oceanic basin. We will show that the forecast errors that first appear along the United State's west coast propagate toward the east. The magnitude as well as the north to south extent of the errors are often larger in the upper troposphere than in the lower troposphere. The main purpose of this paper is to describe the impact of such a field of errors in cases where it approaches a baroclinic zone over the eastern United States. The errors extend mainly in the downstream direction and affect the intensification of the storm that develops in the baroclinic region. Two cases when analysis errors over the eastern Pacific Ocean induced forecast errors over the West Coast, and also in the prediction of a storm over the eastern Unites States are the subject of our investigation.

Forecast errors in the above cited two cases from the Eta Model of the National Meteorological Center (NMC) are discussed in this paper. Three different versions of the Eta Model are being tested. The version of the Eta Model used in this study is described in section 2. In the first (second) case the forecast central pressure in a disturbance over the eastern United States was higher (lower) than the observed in the longer range (36-48 h). The location and intensity of the storm at 24 h in the first case (initial time 1200 UTC 13 April 1993) were very close to the observed (section 3). Thus, the 48 h intensity error in this case can not be due to a slow spin up of the model physics. It will be shown that in both cases an error in forecast over the west coast in the first 12 hours leads to an error in predicting the intensity of a storm over the eastern United States at 48 h.

Forecasts from the Nested Grid Model (NGM) of the NMC were also examined. Both models (Eta and NGM) use the same initial analysis and produced similar errors. In the first case, a large positive error in the prediction of the height field in the middle and upper troposphere propagates from the west coast to the central United States between 12-48 h in both models (section 3). On the other hand, negative errors in the height field propagated from the west to east in the second case, where an over development of an East Coast storm was predicted. The Eta Model forecast in the second case are discussed in section 4. Finally, our concluding remarks are given in section 5.

2. The Eta model

It was noted in section 1 that three versions of the Eta Model are currently under development at the NMC for prediction of synoptic and meso scale circulations and rainfall. Either the initial analysis, or the size of the domain and resolution differ in these three versions. All versions use 38 layers and are run routinely at 0000 and 1200 UTC. A meso version uses a grid spacing of 40 km over a domain that covers the United States mainland and adjoining areas. Two versions of the model, early Eta and late Eta, use a grid spacing of 80 km over a domain that extends across the United States from the western Atlantic Ocean to the central Pacific Ocean. The early Eta has an early data cutoff time and uses an optimum interpolation procedure to analyze the data. The first guess fields are derived from the NMC's operational Global Data Assimilation System (GDAS). Both the Meso and late Eta use the analysis from NMC's Regional Data Assimilation System (RDAS). The Medium Range Forecast (MRF) model and the Nested Grid Model (NGM) are respectively used in the forecast cycles of GDAS and RDAS. Forecasts from the late Eta are discussed in this paper.

Both convective and non-convective release of latent heats, surface effects including the sensible and latent heat transfers between land/ocean and atmosphere, and radiation physics are included in the Eta Model. The prediction over the lateral boundary points are obtained from a combination of model forecasts and forecasts from NMC's global Aviation spectral model. For a description of the Eta Model including the physical parameterization procedures, see Black (1988), Mesinger et al (1988), and Janjic (1990).

3. Case 1: Under-development in the long range (36-48 h) forecast (Initial time 12 UTC 13 April 1993)

a. Mean sea level pressure forecast

Forecast and verifying mean sea level pressure (MSLP) fields at 24 h and 48 h, for the initial time 1200 UTC 13 April 1993, are shown in Fig. 1. The central surface pressure and the location of the storm over Texas at 24 h (Fig. 1b) are close to the observed (Fig. 1a). At 48 h, the observed storm center is near 40°N 90°W and has a central pressure near 994 mb (Fig. 1c). The forecast storm (Fig. 1d) is located somewhat to the south of the observed position. The MSLP over observed storm area is 4-8 mb higher in the forecast than in the analysis (Fig. 2). Thus, the forecast for this storm was excellent at 24 h, but the intensification and motion of the storm between 24-48 h were not well predicted.

Higher pressures are predicted at 48 h from the observed storm center (40°N 90°W) southward to Texas and then toward the northeast up to south-eastern Canada (Fig. 2). The positive errors also extend northward from the storm center. It will be now shown that a deterioration of the forecast between 24 h and 48 h is at least in part related to initial analysis errors over the eastern Pacific Ocean.

b. Forecast errors at 500 mb

A short-wave trough moved from the eastern Pacific Ocean to the central United States between 13-15 April. The verifying and forecast 500 mb height fields at 12 h intervals up to 48 h are shown in Fig. 3. A comparison of the 552 isoline between 12 and 36 h shows that this trough is sharper in the analysis than in the forecast. At 48 h, in both analysis and forecast, the short wave trough has moved very close to a north-south trough that is located roughly along 93°W. Notice that the north-south trough is more (less) sharp in the analysis at northerly (southerly) latitudes than in the forecast.

Forecast errors in 500 mb height fields are shown in Fig. 4. Large errors (10-40 m) near the United States west coast at 12 h (Fig. 4a) are located close to the area of the observed short wave trough (Fig. 3a). Note that this trough moved over the West Coast from the eastern Pacific Ocean where data are sparse. The 12 h forecast errors over the West Coast are likely due to the analysis errors in the region of this trough at the initial time. As this trough moves toward the east (Fig. 3), the error field is also displaced toward the east (Figs. 4a-d). Also, the errors spread southward to the west of the north-south oriented trough (that is located along 93°W) by 24 h and to the east of this trough by 36 h. Positive errors (30- 60 m) occur at 48 h just to the east as well as to the west of the north-south trough. This distribution of errors made the southern portion of the trough sharper in the forecast than in the analysis at 48 h (Figs. 3g-h). Notice also that a closed low formed over the South Dakota area as the short wave trough approached the north-south trough in the analysis at 48 h (Fig. 3g). In the area of this closed low, the forecast heights (Fig. 3h) are 30-40 m higher than observed.

c. Forecast errors at 250 mb

Although the short-wave trough was weaker in the upper than in the middle troposphere, both the north-south extent and the magnitude of short range forecast errors (12-24 h) were larger in the upper atmosphere (Fig. 5). The ridge near the west coast and the north-south trough over the central United States at 250 mb were located close to their respective positions at 500 mb (Fig. 2). Large forecast errors at 250 mb developed in the ridge area at 12 h. As at 500 mb, the field of 250 mb height errors moved toward the east and extended to the east of the north-south trough by 36 h. The maximum error in the above cited eastward moving error field is larger at 250 mb than at 500 mb at all hours.

The area of positive height errors in MSLP (Fig. 2) and 500 mb (Fig. 4d) at 48 h extending from the north of the storm center (40°N 90°W) to Texas and then toward the northeast nearly coincide. Except to the north of 45°N, the positive errors at 250 mb near the north-south trough region are also located close to the area of 500 mb positive error.

d. Forecasts from the Nested Grid Model with initial conditions at 1200 UTC 13 April 1993

Like the late Eta Model, the Nested Grid Model also uses the RDAS analysis for its initial conditions. The physical parameterization procedures, prediction scheme, vertical resolution and domain size in the NGM are quite different from those in the Eta Model. The domain of the NGM covers the northern hemisphere and adjoining equatorial southern hemispheric area. Forecast fields from the Aviation model are not required for prediction at points on its lateral boundary. (It was noted above that the Aviation model's forecasts are used for prediction over the Eta Model's boundary points.) The NGM uses 16 layers while the Eta Model uses 38 layers.

Forecast errors in the height of the 500 mb surface in the NGM at 12 h intervals for the initial time 1200 UTC 13 April 1993 are shown in Fig. 6. The positive height errors near the West Coast at 12 h are similar in the NGM (Fig. 6a) and the Eta (Fig. 4a). The maximum value (40 m) near 50° N 125°W is the same in both models. The eastward propagation of positive errors in both models is also similar. Note that at 48 h, positive errors (30-60 m) extend southward from the southeastern Oklahoma area and then toward the northeast to southern Canada in both models. Thus, two models that differ considerably from each other but use the same initial analysis produced similar errors in forecasting the 500 mb height field associated with a moving short wave trough. The MSLP in the NGM 48 h forecast was 3-6 mb higher than observed in the region of the eastern United States storm. Thus, the MSLP forecasts over the storm area were also similar in the NGM and Eta.

e. Mean sea level pressure forecast from 12 h later initial conditions

It was shown above that the MSLP forecast errors in the region of a storm over the eastern United States by the Eta Model were very small at 24 h but large at 48 h in a case (initial time 1200 UTC 13 April). This case will be referred to as Run 1 in the following. The forecast errors at 48 h were related to forecast height errors in the middle and upper troposphere that developed in the 12 h forecast in this case over the United States west coast. If the above deduction is valid, then the 36 h MSLP forecast from the analysis valid at 0000 UTC 14 April (Run 2) should be more accurate than the 48 h forecast in Run 1. This is because we expect that errors in the initial analysis that is used to begin Run 2 forecast will be small over the data rich United States west coast area. On the other hand, we have already noted that 12 h forecast errors near the United States west coast were large in Run 1. Thus, if the error in predicting the intensity of the storm over the eastern United States at 48 h in Run 1 was related to the 12 h 500 mb forecast errors over the United States west coast, then the 36 h forecast of the storm in Run 2 should come out to be more accurate. The 36 h MSLP forecast from Run 2 is presented in Fig. 7. Notice that the location as well as the intensity of the storm (40°N 90°W) are well predicted (compare Figs. 1c and 7).

The differences in forecast height fields at 500 mb from two Eta Model runs cited above were also examined. The difference field between the 12 h forecast from Run 1 and the initial analysis from Run 2 is the same as shown in Fig. 4a (valid time 0000 UTC 14 April). The eastward movement of the positive difference field initially located over the West Coast, during the next 36 h, was similar to that in the forecast error fields shown in Fig. 4. The positive difference area also spread to the east of the north-south trough by 1200 UTC 15 April (48 h forecast time for Run 1). A 36 h forecast can generally be expected to be better than a 48 h forecast valid at the same time. Because the 24 h forecast of the storm was excellent in Run 1, we believe that the 48 h forecast in Run 1 would have been much more accurate (similar to the 36 h forecast of Run 2) if the Run 1 analysis errors were small over the eastern Pacific Ocean.

4. Case 2: Over-development in the longer range (36-48 h) forecast (Initial time 1200 UTC 7 April 1993)

In section 3, we discussed a case with an eastward propagation of positive 500 mb height forecast errors that developed over the west coast at 12 h. These errors induced a higher than observed central pressure in a storm over the eastern United States in the 48 h forecast. A case where negative 500 mb forecast errors developed over the United States west coast and propagated to the east is discussed in the following.

a. Forecast errors at 500 mb

A trough in the westerlies that was located near 150°W at 1200 UTC 7 April, moved near the United States west coast by 1200 UTC 9 April. The Eta Model predicted lower height values at 12 h (Fig. 8a) in the ridge that was located over the United States west coast (ahead of the above cited trough) in the forecast beginning at 1200 UTC 7 April 1993. This ridge moves over the central United States by 48 h. The negative 500 mb forecast height errors in the ridge are also displaced eastward (see Fig. 8). The maximum negative error increases from -40 m at 12 h to -70 m at 48 h. New centers of large negative errors develop to the east of the ridge; two new centers are located near 30°N 88°W and 50°N 90°W at 48h. A maximum positive error center developed just to the south of the second negative error center cited above. Thus, in this case negative errors propagated eastward in a ridge and induced new maximum positive and negative error centers in the downstream direction.

b. Mean sea level pressure forecast

The analyzed and predicted MSLP at 48 h are shown in Fig. 9. Notice that two predicted low pressure centers (along 90°W) are located close to the 500 mb maximum negative error centers (Fig. 8d). The location error is larger for the MSLP southern center than for the northern center (Fig. 9). Also, the central pressure in the forecast centers is lower than at the observed centers. The observed low pressure trough at 24 h (not shown) was located just to the west of its 48 h position (90°W in Fig. 9a). The forecast surface pressures in this trough at 24 h were about 1-2 mb lower everywhere except in the northern portion where pressures were 4-6 mb lower. By 48 h when the 500 mb forecast height errors in the ridge reached the central United States, the magnitude of the MSLP errors increased and became 7-9 mb in the northern and 5-7 mb in the southern portion of the trough. In the region of large 500 mb positive height errors near 45°N 90°W (Fig. 8d) the negative MSLP error of 1-2 mb at 24 h changed to a positive error of the same magnitude at 48 h.

In this, and the previous, section we showed that the error field that developed over the United States west coast at 12 h in two cases, propagated eastward. Both the magnitude and longitudinal location of the maximum in the above cited error field, at different hours in both cases, are shown in Table 1. The magnitude of the maximum error is greater at 250 than at 500 mb in both cases at all hours. At 48 h, the 250 mb maximum error (70 m) near 92° W in the case 1 is located close to the observed surface low pressure center. The prediction of MSLP 4-8 mb higher than the observed in the region of the observed surface center (Table 1) at 48 h is linked to the positive height errors in the middle and upper troposphere cited above. A storm center over the eastern United States at 48 h in case 2 is located near 35°N and 90°W (Fig. 9a). The 250 mb maximum negative error (-110 m) near 108°W at 48 h in this case occurrs to the west of the observed surface center (Table 1). However, a local maximum negative error lies over the surface center at both 500 and 250 mb (values in the paranthesis in table 1). Consequently, pressures 5-7 mb lower than the observed are predicted in areas near two surface centers in this case (Fig. 9). Results presented in Table 1 and from other case studies suggest that the propagation of forecast errors that develop over the West Coast may induce prediction errors over the United States to the west of about 115°W (85°W) during the follwing 24 (36) h forecast.

5. Summary and concluding remarks

Toth and Kalnay (1993) have suggested that the growth of analysis errors in the baroclinically unstable regions is likely to be large in a prediction. In this connection, we discussed two cases in which a growth of prediction errors takes place in baroclinically active regions (sections 3-4). In both cases, a field of forecast errors appeared over the United States west coast at 12 h and then propagated eastward. In the first case (section 3), the amplitude of a short wave trough in the middle and upper troposphere was under-predicted over the West Coast at 12 h. The positive error field moved eastward with the wave. By 48 h in the forecast, this wave reached the central United States where a north-south quasi-stationary trough was located (Fig. 3). The positive height errors increased to the west of the north-south trough (especially in the upper troposphere) and positive errors also appeared to the east of the north-south trough (Figs. 4-5). A surface storm developed to the east of the north-south trough in the real atmosphere (Fig. 1). The storm development was well predicted up to 24 h. However, further development of the storm was under predicted (Fig. 1) during the period 24-48 h when the positive height errors mentioned above spread to the east over the storm area. In the second case the amplitude of a ridge over the west coast was under-predicted at 12 h (section 4). The field of negative errors moved eastward (Fig. 8) with this ridge and gave rise to lower than observed central pressures in two developing storms over the eastern United States at 48 h (Fig. 9). Thus, the forecast errors that first appeared over the United States west coast at 12 h influenced the longer range (36-48 h) numerical forecast of storms in the baroclinic regions over the eastern United States in both cases.

Both the Eta and NGM use the same analysis. We evaluated NGM forecast errors in the first case. Just like in the Eta forecast, the 500 mb errors in the NGM also developed over the United States west coast at 12 h and propagated toward the east (Fig. 6). The Eta Model's forecast with 12 h later initial conditions, when the short wave trough was located over the West Coast (analysis errors expected to be small over data rich west coast), gave a much improved forecast of the surface storm (Fig. 7) at 36 h (valid time same as the above cited 48 h Eta forecast in the first case). In our view, the above results further confirm that 48 h forecast errors over the eastern United States in the first Eta forecast cited above were related to 12 h forecast errors over the West Coast. The trough (ridge) that moved over the west coast at 12 h in the first (second) 48 h Eta forecasts discussed in the above paragraph, was located over the data sparse eastern Pacific Ocean at the initial time. We envision that the analysis errors in the region of this trough (ridge) gave rise to 12 h forecast errors over the United States west coast in the first (second) case.

It is obvious that longer range numerical storm forecast errors over the eastern United States, in cases like those cited above, will be reduced with improved analysis over the eastern Pacific Ocean area. Because conventional observations are unlikely to increase over the oceanic regions, special efforts should be made to fully utilize aircraft, and satellite derived observations. Development of procedures to construct synthetic data based on satellite imagery and the use of such data should be also considered for enhancing the analysis over the oceanic regions.

Our analyses (sections 3-4) suggests a procedure that may help a forecaster to estimate the relative accuracy of two predictions valid at the same time, the first being a longer range forecast than the second, that differ in the predicted intensity and location of a storm. The method entails evaluation of the difference in forecast fields valid at the same time from two predictions at 12 h intervals. As an example, consider the 48 h forecast from 1200 UTC 13 April (Run 1) and the 36 h forecast from 0000 UTC 14 April (Run 2) that were discussed in section 3e. It was noted that the surface pressure of the storm over the eastern United States on 1200 UTC 15 April was lower in Run 2 (36 h forecast, Fig. 7) than in Run 1 (48 h forecast, Fig. 1d). The differences in the MSLP (the heights of an isobaric surface) from two runs valid at the same time will be referred to as the difference field in MSLP (the heights of an isobaric surface) at the forecast hour of Run 1 in the following. Note that the 12 h difference field is also the 12 h forecast error for Run 1. As noted in section 3 (Fig. 4a) Run 1 produced positive height errors at 500 mb in the region of the short wave trough over the United States west coast. A comparison of forecasts in subsequent periods showed that the 12 h difference field at 500 mb over the United States west coast was displaced toward the east and it spread over the surface storm area in eastern United States by 1200 UTC 15 April. A similar propagation of the difference field occurred at 250 mb. Considering the above cited propagation of positive height difference and noting that the 12 h difference is also the 12 h forecast error for Run 1, one would conjecture that the 48 h predicted pressure in Run 1 over the storm area in the eastern United States would be higher than the observed. It was noted in section 4b that it takes 36 h for West Coast forecast errors to impact storms located near 90°W. Since analysis errors over the data rich West Coast are likely to be small, the 36 h forecast of the storm near 90°W from 0000 UTC 14 April can be expected to be not influenced by the analysis errors over the data sparse eastern Pacific Ocean.

In the example cited above we have considered impact of only analysis errors over the eastern Pacific Ocean. Forecast errors can be also due to analysis errors over other areas. Errors can be larger in an analysis valid at a later time than in one valid at an earlier time. Forecast errors may also arise due to deficiencies in the forecast model. Because of the above inadequacies in analysis and model, a longer range forecast that had significant 12 h errors over the west coast, may be better than a shorter range forecast in some cases.

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Table 1. Eastward propagation of forecast errors.

Initial Time of Forecast	Longitude (LO)/Magnitude (M) of Maximum Error at 12h				Longitude (LO)/Magnitude (M) of Maximum Error at 24 h				Longitude (LO)/Magnitude (M) of Maximum Error at 48 H				MSLP Error near Observed Center at 48 h
	500 mb		250 mb		500 mb		250 mb		500 mb		250 mb		
	LO	M	LO	M	LO	M	LO	M	LO	M	LO	M	
Case 1													
1200 UTC 13 April 1993	125W	40	125W	50	115W	30	118W	70	95W	60	92W	70	(+)6-8 mb
Case 2													
1200 UTC 7 April 1993	125W	-40	130W	-80	122W	-90	105W	-110	105W (90W	-70 -70)	108W (90W	-110 -60)	(-)5-7 mb

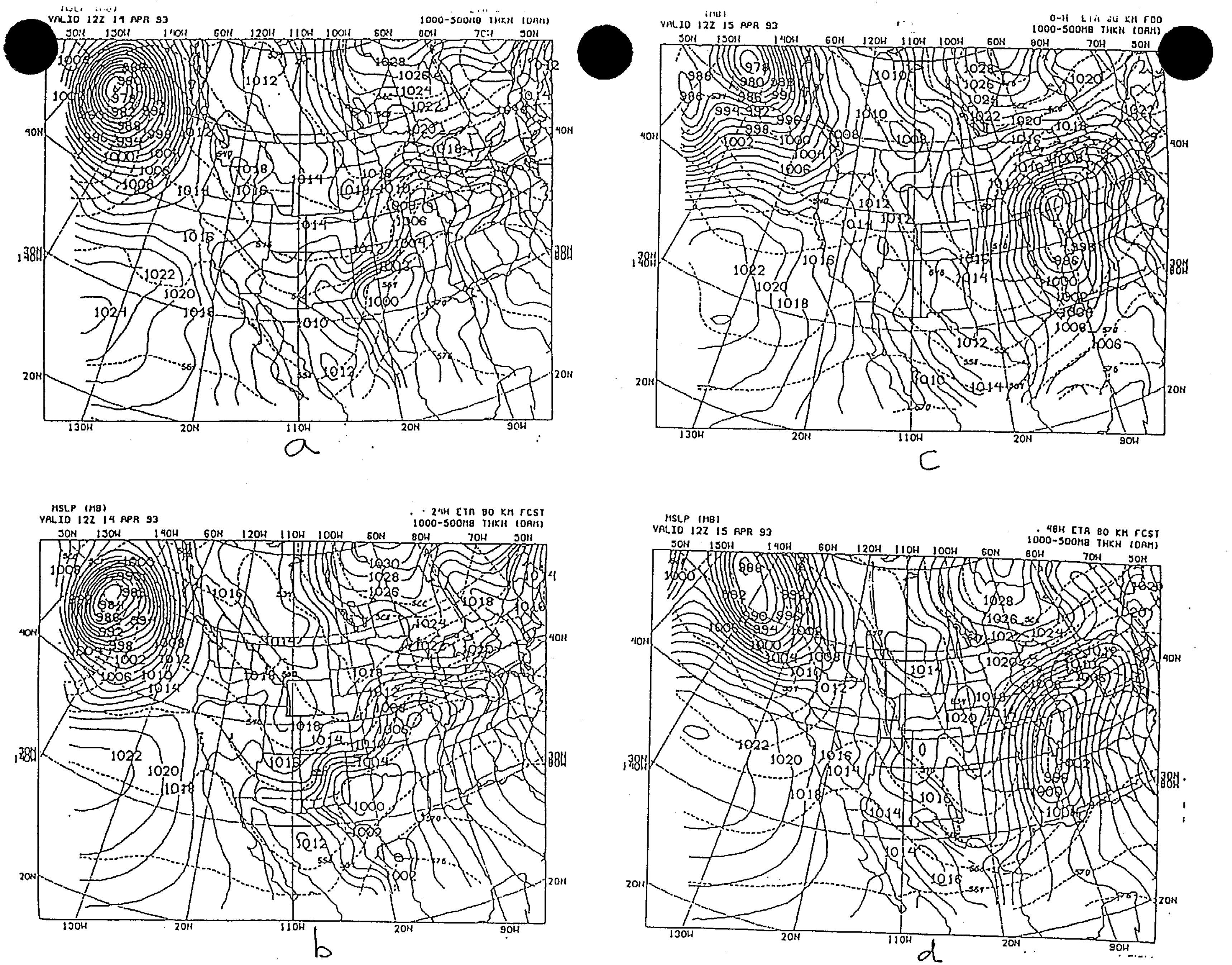

Fig .1. Verifying and forecast Mean sea level pressure (units: mb) and 1000 - 500 mb thickness (units: tens of meters) fields: (a) Analysis at 1200 UTC 14 April 1993, (b) 24 h forecast valid at 1200 UTC 14 April 1993, (c) analysis at 1200 UTC 15 April 1993, and (d) 48 h forecast valid at 1200 UTC 15 April 1993.

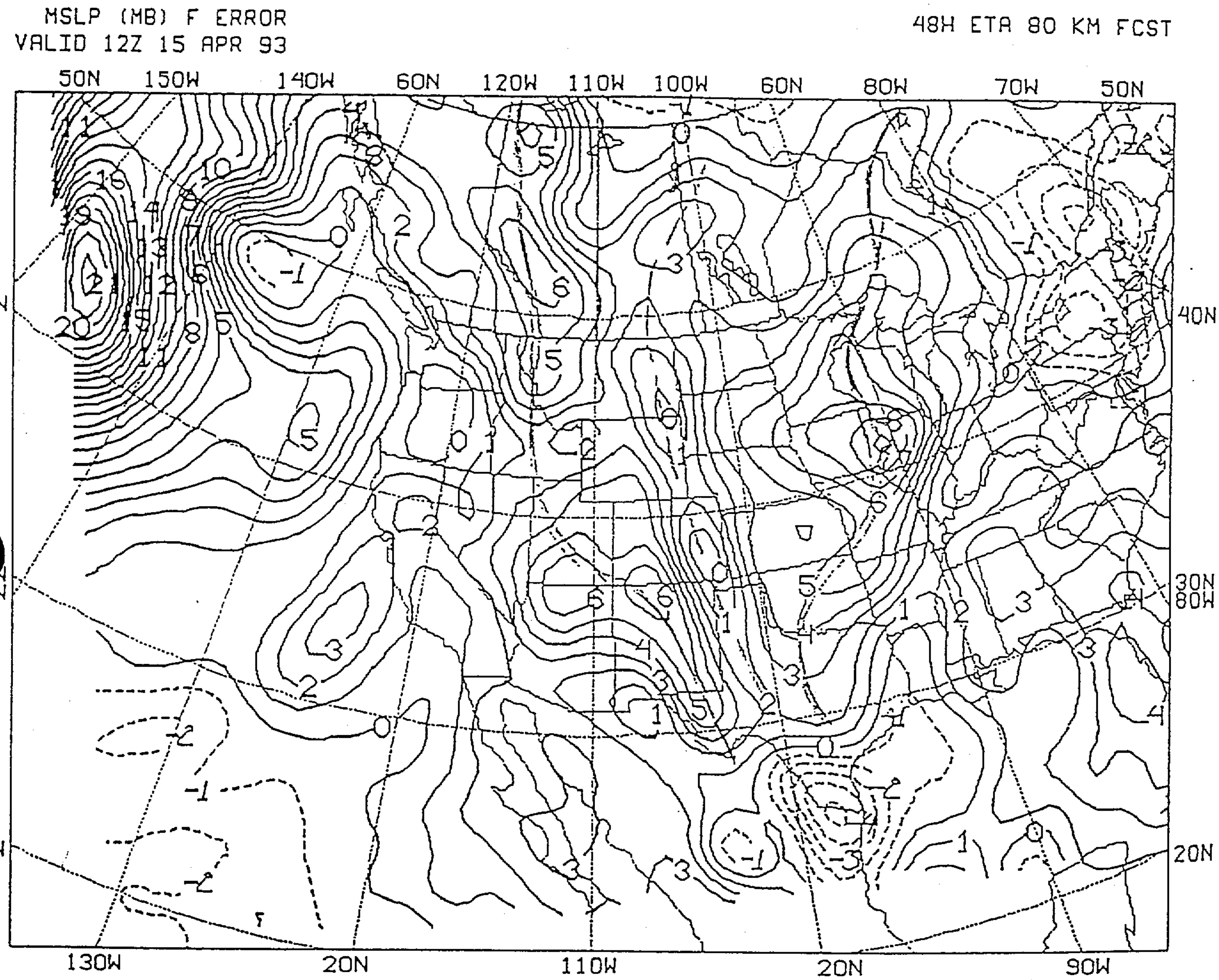

Fig. 2. Forecast mean sea level pressure errors at 48 h from 1200 UTC 13 April 1993. Units: mb.

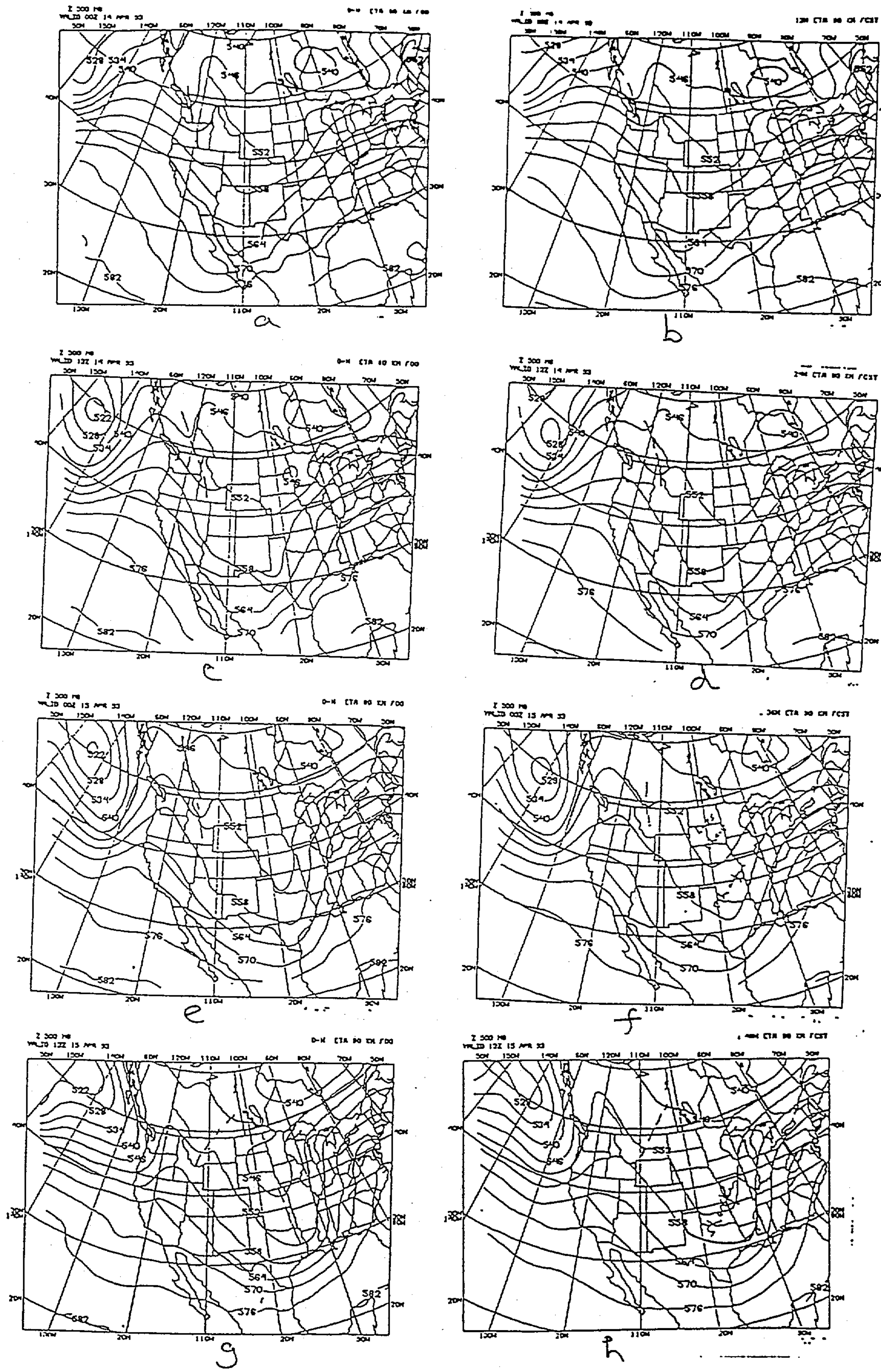

Fig. 3. Verifying and forecast height of 500 mb surface: (a) Analysis at 0000 UTC 14 April 1993, (b) 12 h forecast valid at 0000 UTC 14 April 1993, (c) analysis at 1200 UTC 14 April 1993, and (d) 24 h forecast valid at 1200 UTC 14 April 1993, (e) analysis at 0000 UTC 15 April 1993, (f) 36 h forecast valid at 0000 UTC 15 April 1993, (g) analysis at 1200 UTC 15 April 1993, and (h) 48 h forecast valid at 1200 UTC 15 April 1993. Units: tens of meters.

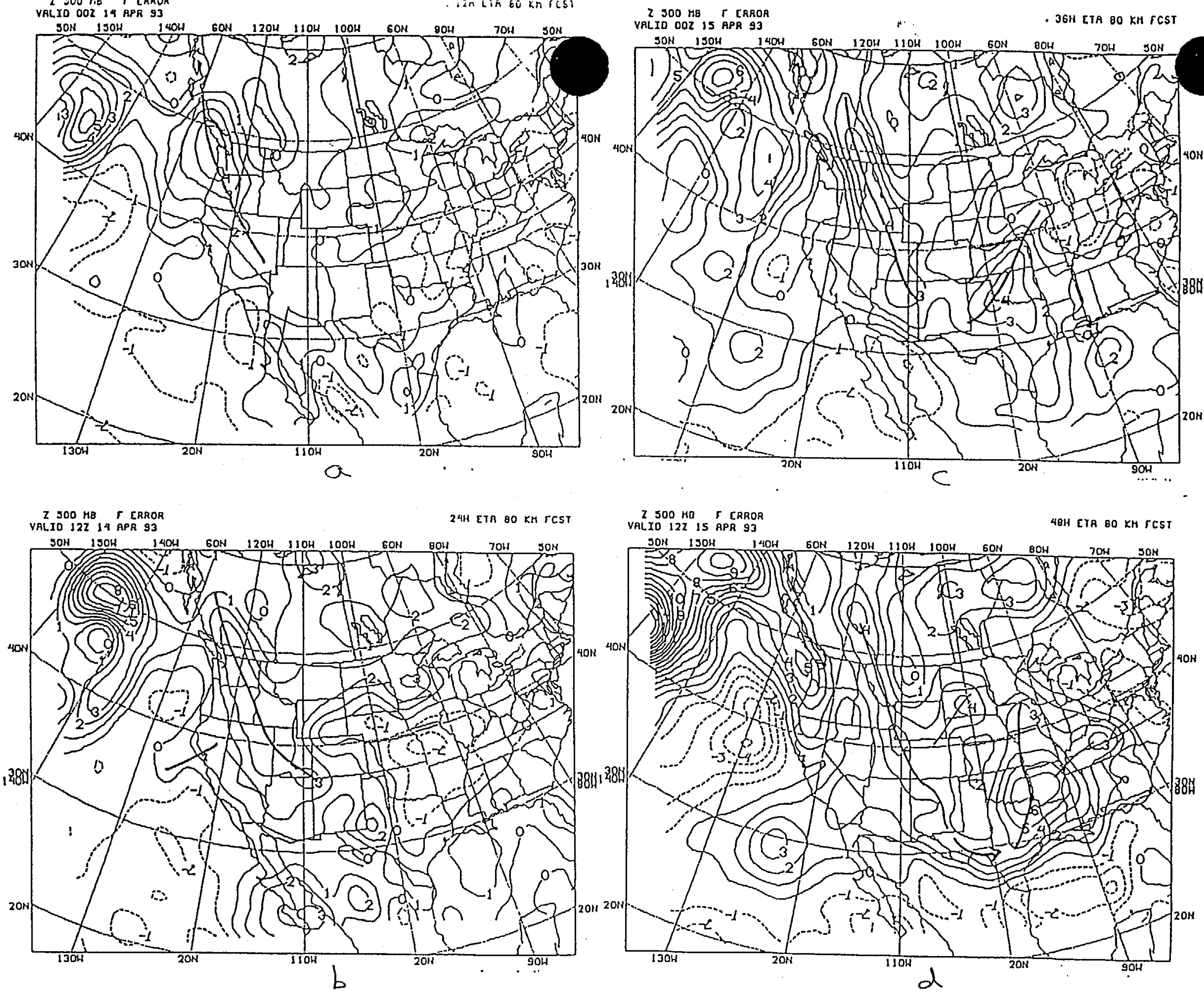

Fig. 4. Forecast errors in height of 500 mb surface at : (a) 12 h, (b) 24 h, (c) 36 h, and (d) 48h. Initial time 1200 UTC 13 April 1993. Units: tens of meters.

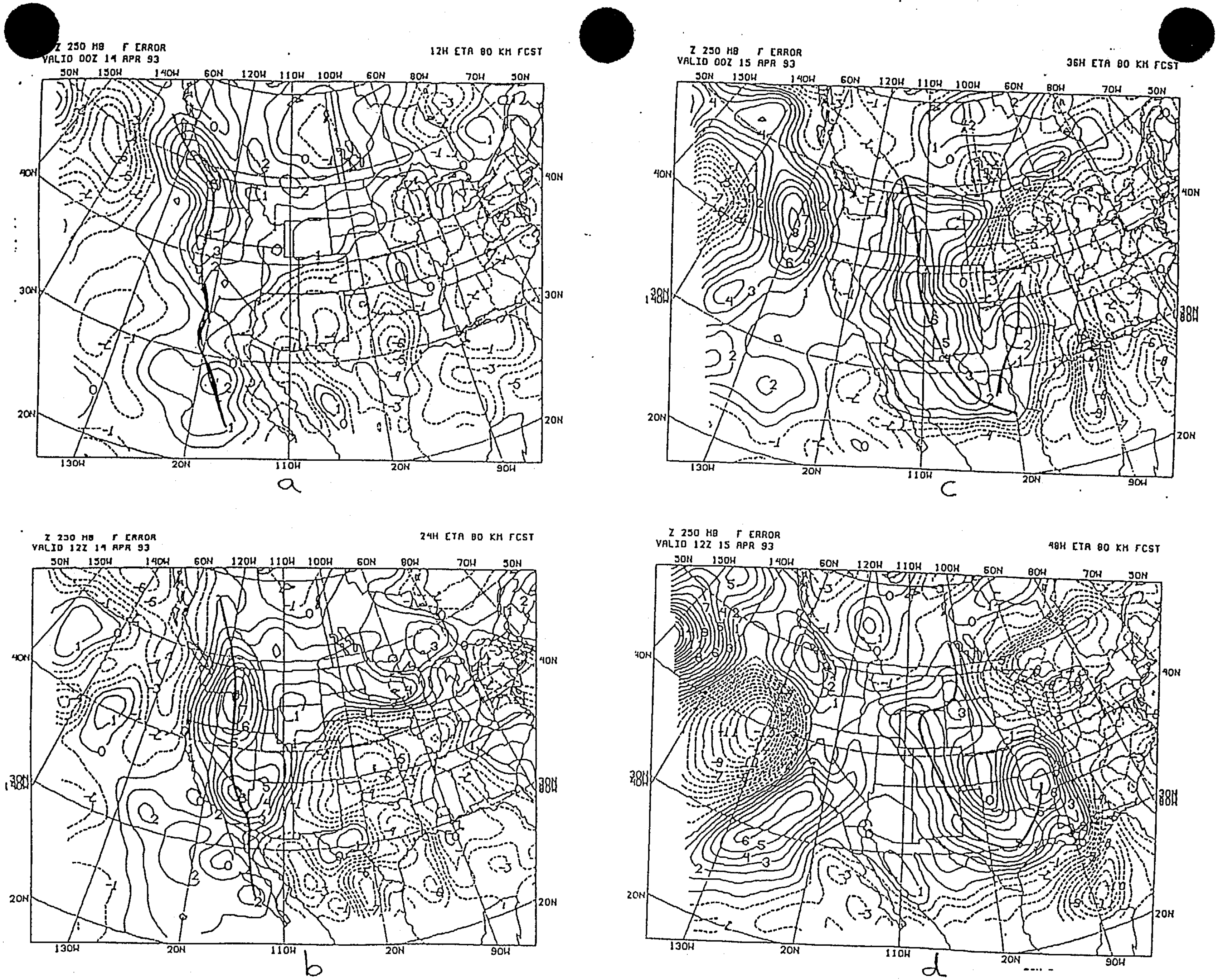

Fig. 5. Forecast errors in height of 250 mb surface at : (a) 12 h, (b) 24 h, (c) 36 h, and (d) 48h. Initial time 1200 UTC 13 April 1993. Units: tens of meters.

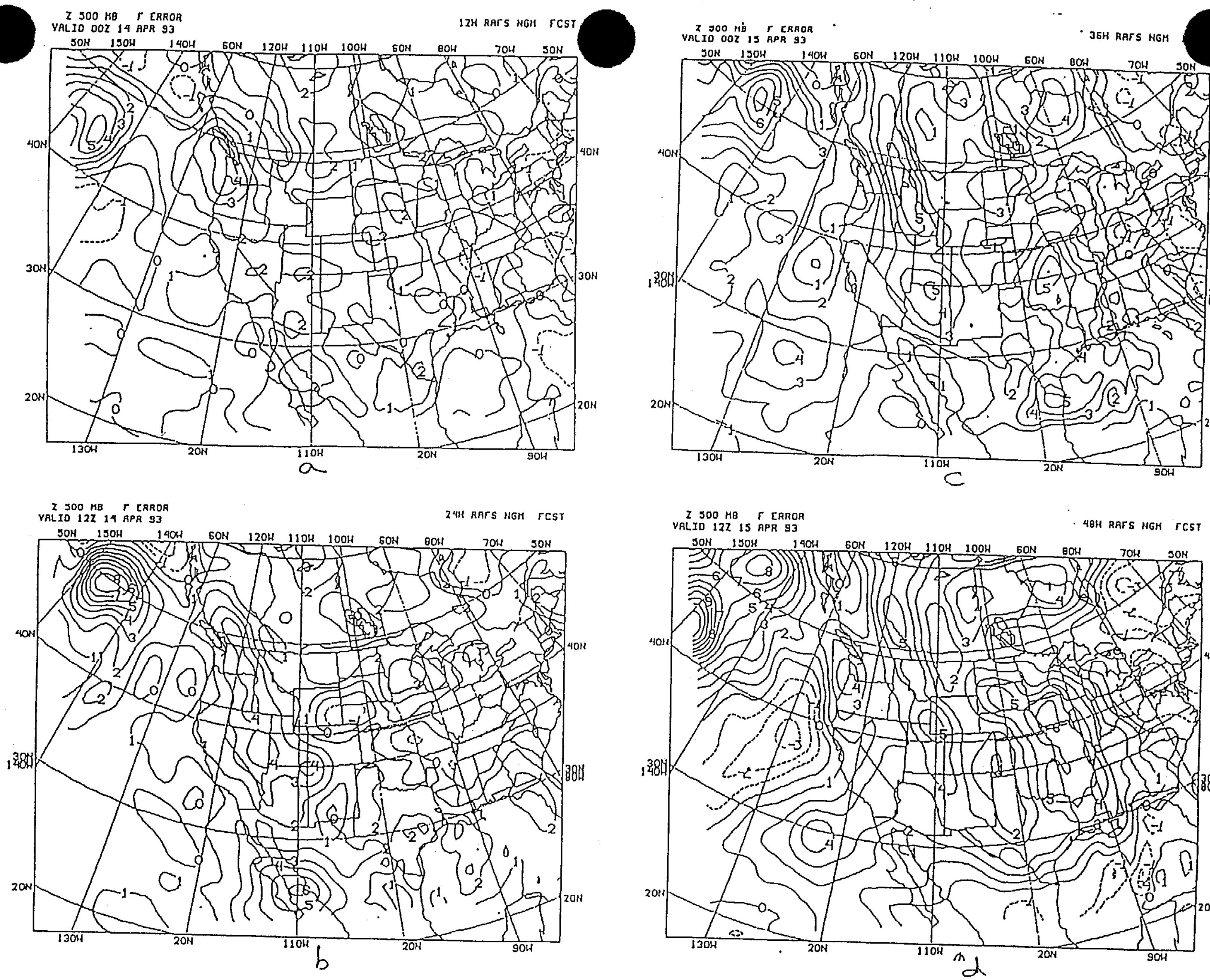

Fig. 6. Forecast errors in height of 500 mb surface in NGM at : (a) 12 h, (b) 24 h, (c) 36 h, and (d) 48h. Initial time 1200 UTC 13 April 1993. Units: tens of meters.

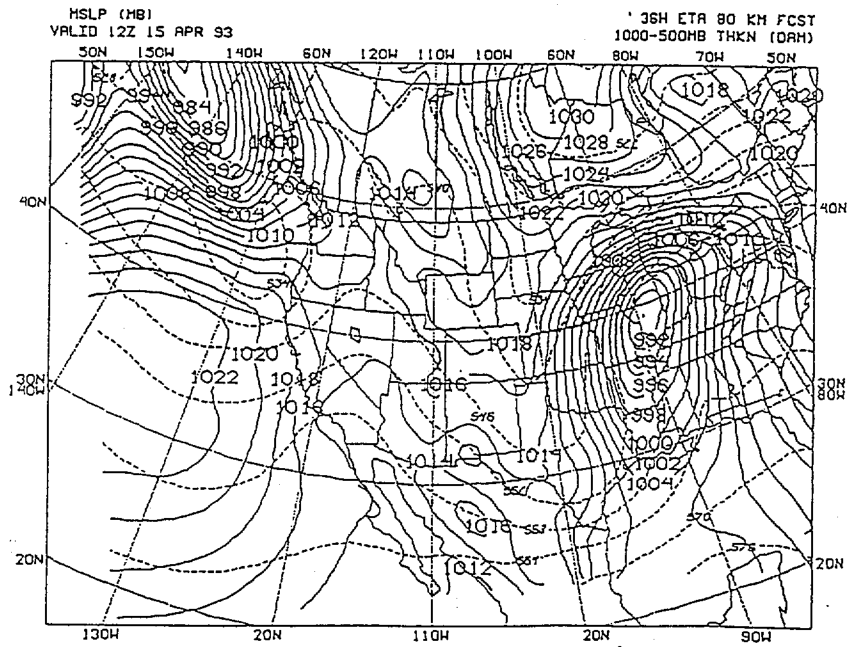

Fig. 7. Forecast mean sea level pressure at 36 h from 0000 UTC 14 April 1993. Units: mb.

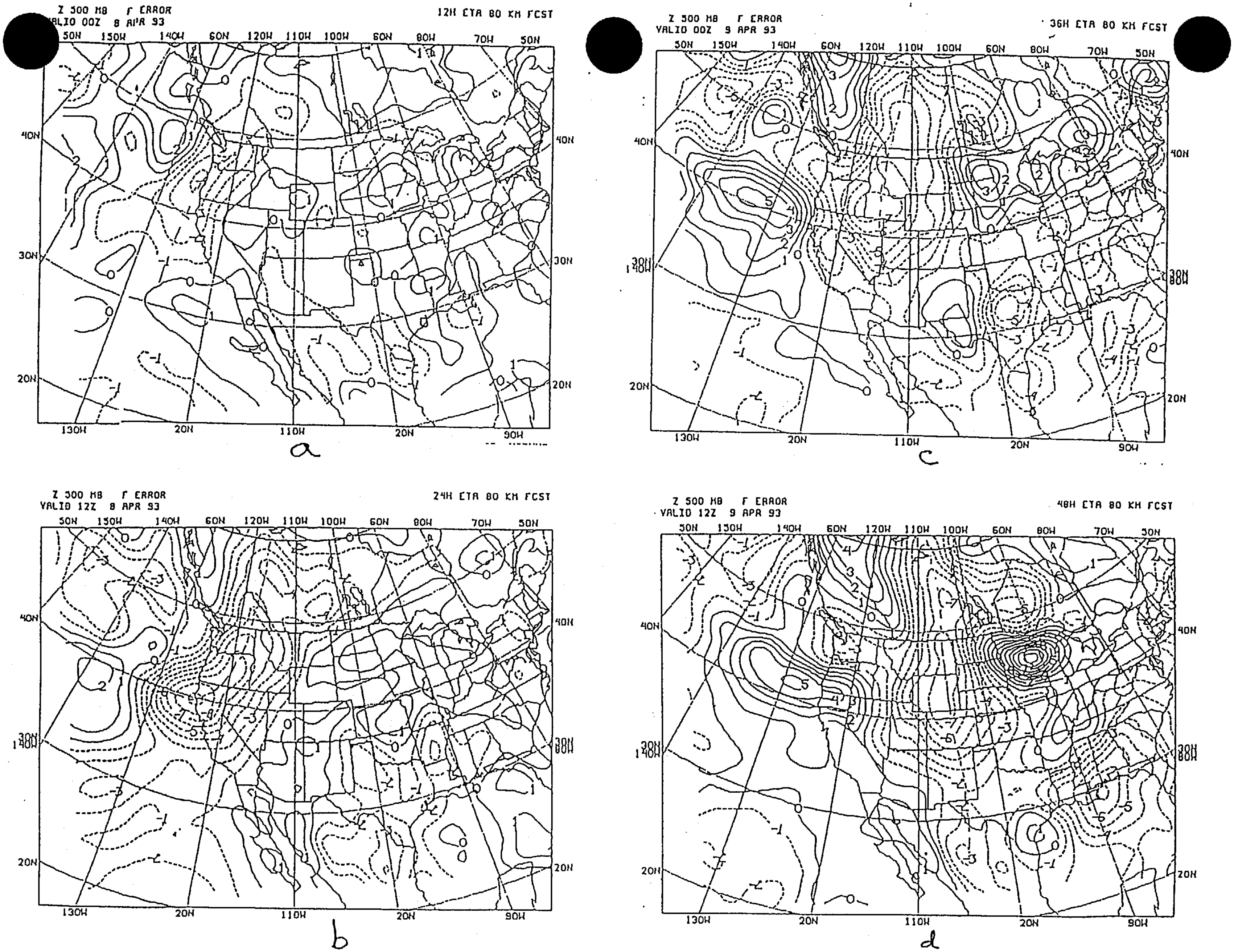

Fig. 8. Forecast errors in height of 500 mb surface at : (a) 12 h, (b) 24 h, (c) 36 h, and (d) 48h. Initial time 1200 UTC 7 April 1993. Units: tens of meters.

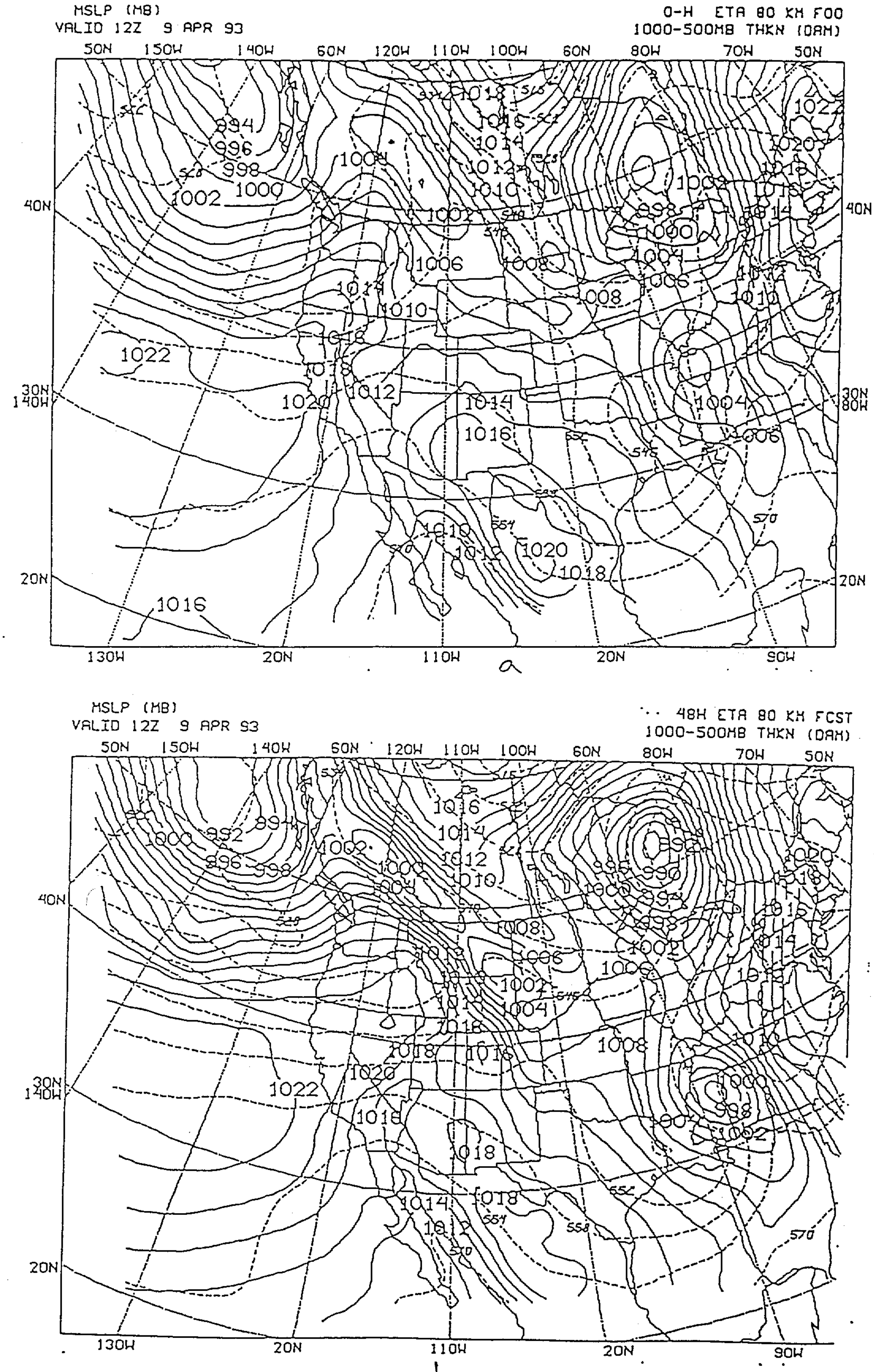

Fig. 9. Verifying and forecast Mean sea level pressure fields: (a) Analysis at 1200 UTC 9 April 1993, (b) 48 h forecast valid at 1200 UTC 9 April 1993. Units: mb.