

## NMC NOTES

**Systematic Surface Cyclone Errors in NMC's Nested Grid Model  
November 1988–January 1989**

RICHARD H. GRUMM AND ANTHONY L. SIEBERS

*National Meteorological Center, World Weather Building, Washington, D.C.*

24 April 1989 and 1 May 1989

## ABSTRACT

Preliminary results from a study examining the performance of the nested grid model (NGM) in predicting cyclones covering a period from 13 November 1988 to 31 March 1989 reveal that the NGM tends to overdevelop surface cyclones over continental regimes and underdevelop surface cyclones in oceanic regimes. The results also indicate an overall cold bias in the model forecasts of thickness and 850 mb temperatures over the cyclone center. Displacement error data indicate that the NGM tends to move cyclones too slowly in the southern half of the forecast domain.

A semiautomated method has been developed at the National Meteorological Center (NMC) to track and verify sea level pressure features in the NGM. The method allows the user to interactively track a system, store its coordinates, and then retrieve information about the system from selected model forecast and analysis grids. This information can then be used to determine systematic forecast errors, compare past forecasts with the most recent forecast, and produce climatological tracks of forecast and observed systems.

**1. Introduction**

In March 1985, the National Meteorological Center (NMC) introduced the Regional Analysis and Forecast System (RAFS). The primary components of the RAFS are a hemispheric analysis, a normal mode initialization, and a forecast by the nested grid model (NGM). A description of the present RAFS configuration is given by Hoke et al. (1989). A central feature of the NGM is its two-way interactive nested grid, which consists of an outermost hemispheric grid (grid-A) and two successively nested interior grids (grid-B and grid-C), each having twice the resolution of the grid in which it is nested. This study examines the performance of the NGM surface cyclone forecasts on grid-C and portions of the surrounding grid-B, which spans all of North America and the adjacent oceans. The data in this study was displayed on the limited-area fine-mesh (LFM) model grid.

When initially introduced operationally, the NGM forecasts contained a cold bias in the lower levels of the model, but the forecasts offered improved positions of surface cyclones relative to the NMC LFM model. Since its introduction, the NGM and other RAFS components have been improved and upgraded. In addition to the performance of the NGM surface cyclone forecasts presented here, other NGM performance characteristics are described by Junker et al. (1989).

This note describes an interactive process developed

at NMC that defines systematic forecast errors, and presents some preliminary results of recent operational performance of the NGM in surface cyclone forecasting. Recent studies of operational model performance have focused on model error statistics at 500 mb (Hawes and Colucci 1986). Earlier model verification studies have examined the behavior of surface cyclones (Leary 1971; Silberberg and Bosart 1982), and anti-cyclones (Grumm and Gyakum 1986; Colucci and Bosart 1979). However, these studies were done by manually recording data from maps and then entering the data into a computer. The time required to accomplish these tasks often limited the scope of the study. With the new interactive approach described here, systems are tracked over the entire NGM grid-C and portions of the grid-B for all forecast times. The database includes all available analyses and forecasts.

**2. Method**

A cyclone in this study is defined as a point of relatively low sea-level pressure, surrounded by at least one closed isobar (analyzed at 4 mb intervals) in the NGM analysis or forecast. The NGM analyses were used to represent the verifying atmosphere. For the period from 0000 UTC 13 November 1988–1200 UTC 31 January 1989, data from the 0000 and 1200 UTC forecast cycles were used for all available 6, 12, 18, 24, 30, 36, 42, and 48 h forecasts. During this period no analysis or forecast cycles were missing and a total of 158 verification times were obtained (twice each day).

For each forecast and verification time, the following information was tabulated:

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*Corresponding author address:* Richard H. Grumm, National Meteorological Center, World Weather Building, W/NMC22, Room 204, Washington, D.C. 20233.

- 1) The valid time, including the month, day, and hour.
- 2) The forecast range (0, 6, 12, 18, 24, 30, 36, 42, and 48 hours).
- 3) The latitude and longitude of the cyclone center to the nearest hundredth of a degree.
- 4) The central pressure (mb) extracted from the gridded data fields.
- 5) The 1000–500 mb thickness (m) over the center of the analyzed cyclone extracted from the gridded data fields.
- 6) The 850 mb temperature (K) over the analyzed system extracted from the gridded data fields.
- 7) The system identification or tag number, assigned to all new systems for tracking purposes.
- 8) Remarks that were relevant to a particular system if necessary.

Tracking was conducted on the VAS Data Utilization Center (VDUC) developed at the University of Wisconsin and transferred to NMC (Mostek and Siebers 1987). Tracking was done by creating an image on a computer graphics terminal from the NGM mean sea level pressure (MSL) grid and overlaying a contoured pressure analysis. For continuity purposes, current active tracks were plotted over an image of the model initial MSL analysis. Systems that were forecast to develop but did not appear in a subsequent analysis were plotted in a different color. A program was then run to track each system individually. The cursor was placed over the desired system and then the position of the pressure system was calculated. The program then advanced to the next forecast period and the new location was determined. Upon completion of a track, the Julian date, forecast cycle (0000 or 1200 UTC), forecast time (0, 6, 12, 18, . . . 48 hours), latitude, longitude, track number and any comments were stored. After all systems were tracked for a forecast period, a separate program extracted the central pressure, thickness, and 850 mb temperature over the system center from the model grids.

The database of model analyses and forecasts was, and still is, updated daily. Thus, systematic forecast errors in the NGM could easily be examined. We have examined errors in cyclone displacement, sea level pressure, 1000 to 500 mb thickness and 850 mb temperature over the cyclone center. Errors in sea level pressure, thickness, and 850 mb temperature of the cyclone are defined as forecast minus observed. Thus, a positive (negative) error in pressure corresponds to underdeepening (overdeepening) the central pressure. For example, if the cyclone pressure was forecast to be 996 mb, but verified as 994 mb, the error would be +2 mb. Similarly, a negative (positive) error in the thickness corresponds to a forecast being too cold (warm).

Cyclone displacement errors were computed by comparing the forecast to the observed position for each identically tagged cyclone. The vector displacement error consists of the distance error and a scatter

plot of directional error relative to the observed position.

For continuity purposes, the off-time or asynoptic forecasts (6, 18, 30, and 42 hours) were used and stored in the database. However, these data were not verified due to the lack of verifying analyses at the off times.

The frequency of events and the system error as a function of geography were determined by the  $5 \times 5$  lat and long box in which the verifying system occurred. The contour analysis objectively analyzed the data based on the center of the box. The mean error in each box was computed and then the data were filtered with a nine-point smoother. Charts showing the actual number of cases were not smoothed.

### 3. Results

The geographical distribution of cyclone central pressure errors for the four verifying forecast periods of 12, 24, 36, and 48 hours are shown in Figs. 1–4. The data were smoothed and objectively analyzed on a  $5 \times 5$  deg lat and long grid. On the 12-h forecast panel the primary cyclone tracks for each month are represented by the thick arrows, while thin arrows indicate secondary tracks. In November (Fig. 1a) the cyclones are primarily confined to higher latitudes. The Colorado and East Coast cyclone areas start to become active. By December (Fig. 1b) cyclone activity picks up along the eastern coast of North America. The eastern coast activity decreases by the seventeenth and the Colorado cyclone track dominates the later part of the month. The eastern coast cyclones tend to track through the Labrador Sea and the eastern coast of Greenland to the Greenland Sea where they dissipate. The Colorado lows track toward Hudson Bay and Baffin Bay, along the western coast of Greenland. Pacific cyclones enter the NGM study domain from the North Pacific and dissipate in the Gulf of Alaska. Early in January (Fig. 1c) cyclones begin to form over the Great Lakes and mid-Atlantic region and move toward the Labrador and Greenland seas. By the second week of January the Colorado cyclone track became active again, while cyclone activity in the Pacific remains well north in the Gulf of Alaska.

The geographical distribution of pressure errors with forecast time shows a preponderance of negative pressure errors over the North American continent, especially at the later forecast times, indicating that the NGM tends to overpredict cyclone deepening (Figs. 1–4). This overdeepening error is worse over western North America. The negative pressure error over the continent grows with forecast length (see Figs. 2–4). Along and off the eastern coast of North America, a large area of positive pressure errors occurs indicating that the NGM tends to underdevelop cyclones over the western Atlantic Ocean. This underdevelopment error, which also increases with forecast length, is, in part, related to the model's tendency to underpredict rapid cyclogenesis over the western Atlantic (Sanders 1987).

The pressure errors show some monthly variability.

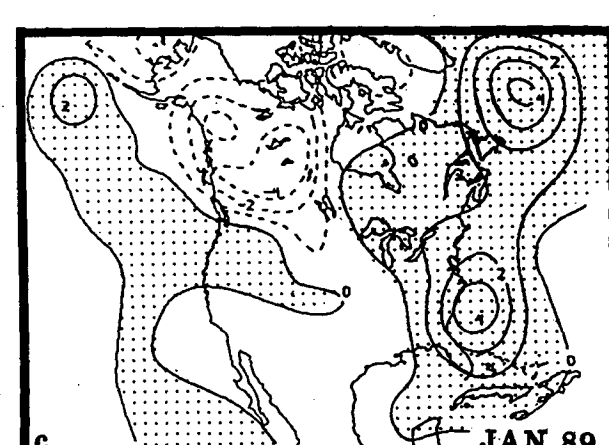
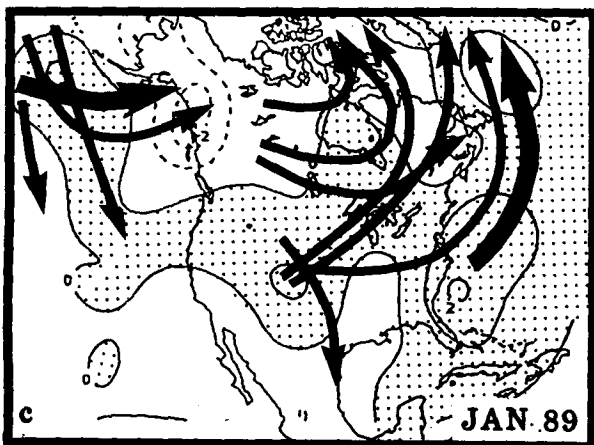
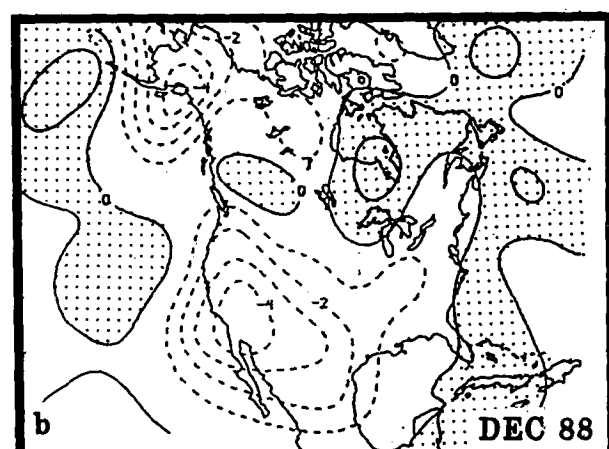
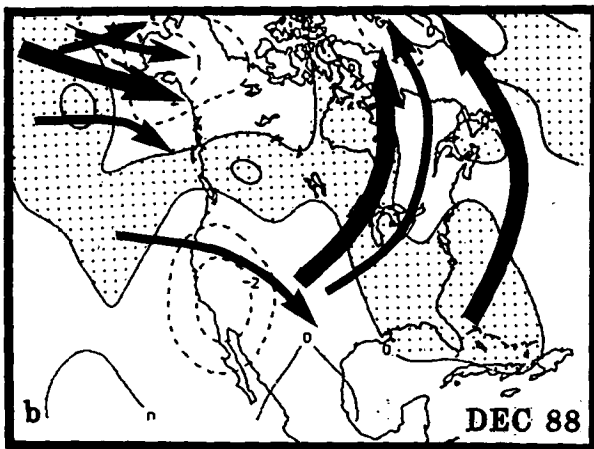
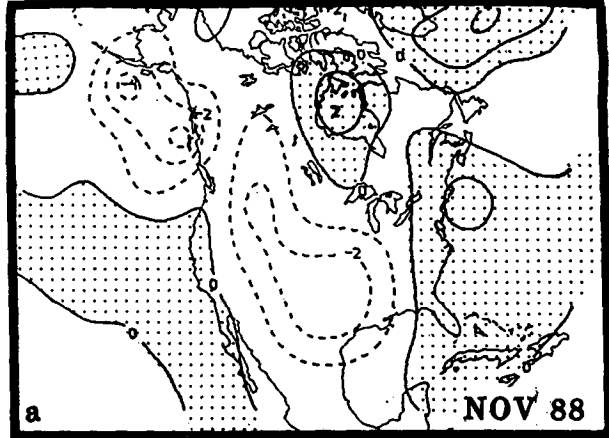
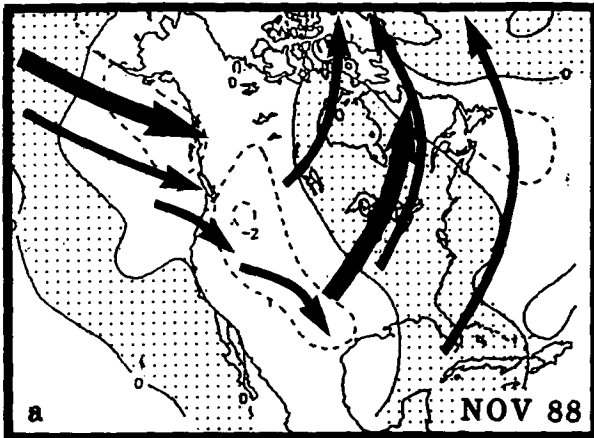


FIG. 1. Mean 12-h cyclone sea-level central pressure error (mb) for (a) November 1988, (b) December 1988, and (c) January 1989. Solid contours and shading denote positive (underprediction) errors, dashed contours denote negative (overprediction) errors. The contour interval is 2 mb. Thick and thin arrows denote the primary and secondary cyclone tracks observed during the month.

FIG. 2. Mean 24-h cyclone sea-level central pressure error (mb) for (a) November 1988, (b) December 1988, and (c) January 1989. Solid contours and shading denote positive (underprediction) errors, dashed contours denote negative (overprediction) errors. The contour interval is 2 mb.

The negative pressure error over the Gulf of Alaska decreases from November to December and by January the western half of the Gulf of Alaska shows a positive forecast error. By February (not shown) the 48-h pres-

sure forecast error becomes positive over the entire Gulf of Alaska and adjacent North America. By the 24-h forecast period, along the eastern coast of North America and the adjacent western Atlantic Ocean the positive

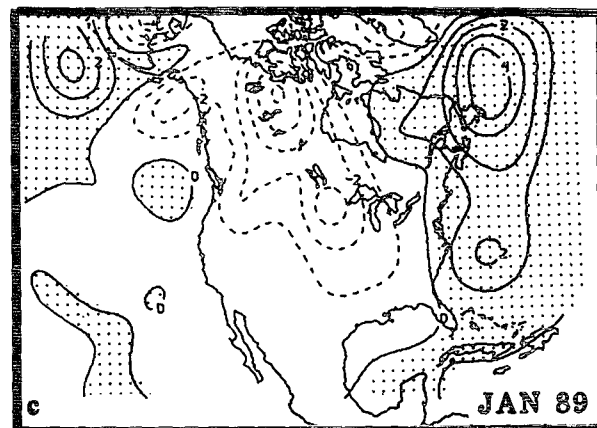
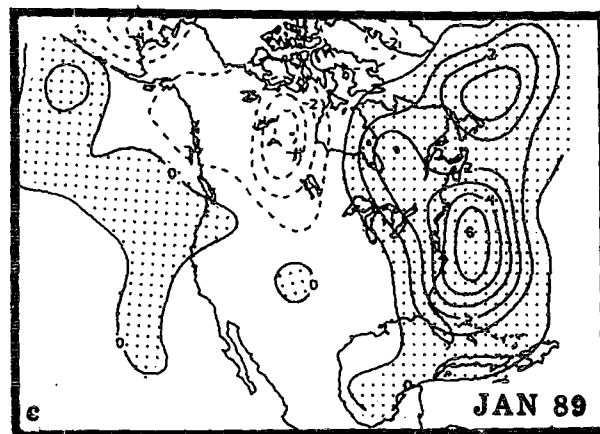
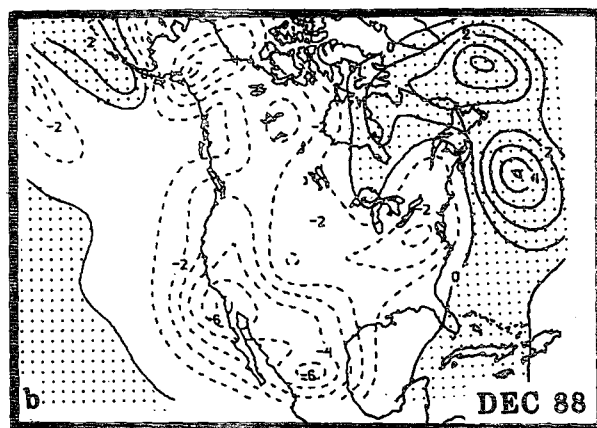
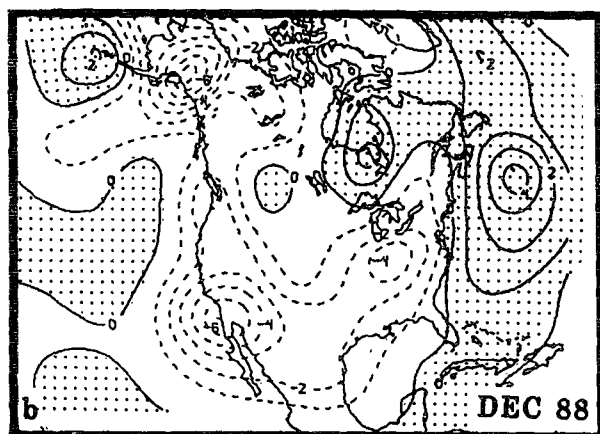
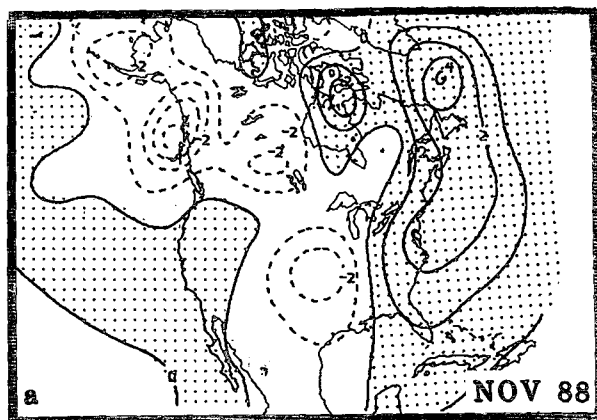
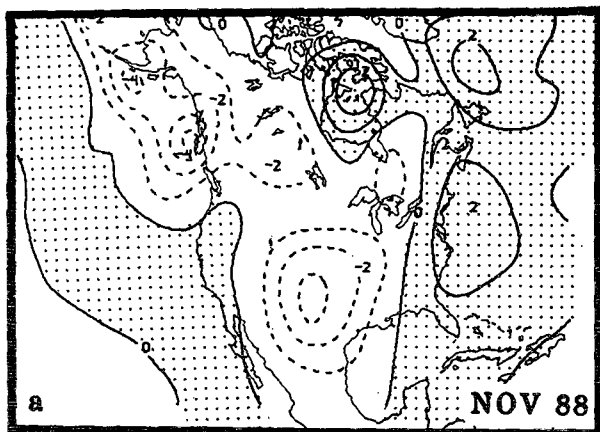


FIG. 3. As in Fig. 2. except for 36-h forecast.

FIG. 4. As in Fig. 2. except for 48-h forecast.

forecast error dominates every month (Figs. 2–4). The locus of the maximum pressure error, which is between 4 and 6 mb each month in the 48-h forecasts, (Fig. 4) shifts southward from the Labrador Sea in November (Figs. 1a–4a), to the western mid-Atlantic in December (Figs. 1b–4b). In January (Figs. 1c–4c) the error maxima shifts back to the Labrador Sea with a secondary maxima in the western Atlantic. Over North America, the generally negative pressure error (overdeepening)

dominates. The locus of maximum error shifts to regions where cyclogenesis was a maximum.

For the 48-h forecast over the entire study period, Figs. 5a–d show the mean forecast errors of sea level pressure, 1000–500 mb thickness, and 850 mb temperature as well as the number of systems used in this study. Figure 5a again shows how the NGM tends to overdevelop cyclones over North America, especially to the lee of the Rocky Mountains, underdevelops cy-

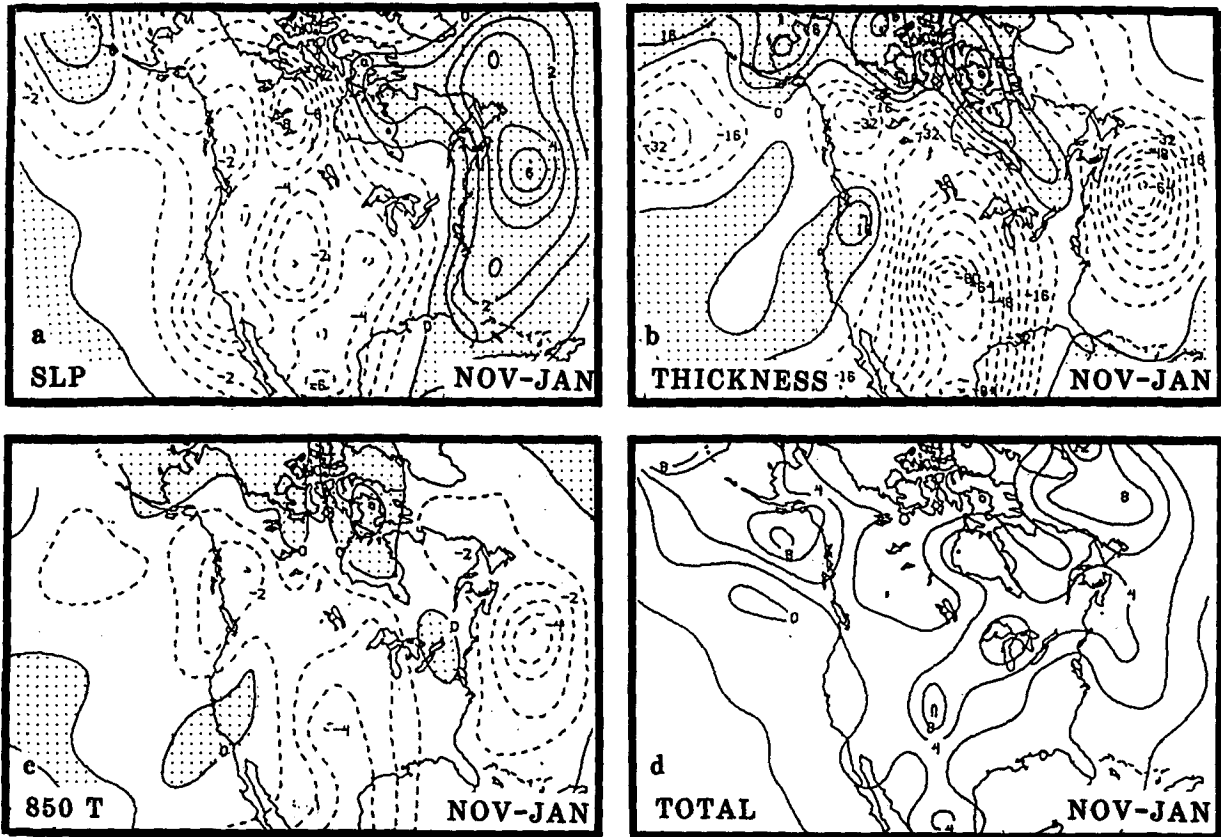


FIG. 5. The NGM mean cyclone forecast error at 48 hours during the period 13 November 1988–January 31 1989 for (a) central sea-level pressure (mb), (b) 1000–500 mb thickness (m), (c) 850 mb temperature (K), and (d) total number of cyclone cases in study sample.

clones over the eastern coast of North America and the adjacent Atlantic, overdevelops cyclones in the eastern Gulf of Alaska, and underdevelops cyclones in the western Gulf of Alaska.

Figure 5b shows the geographical distribution of 1000–500 mb thickness errors in the NGM 48-h forecasts. The model generally underpredicts the thickness (cold bias) over the cyclone center from the Rocky Mountains to the Atlantic Coast. The model tends to underpredict the thickness (cold bias) over the cyclone center over the western Atlantic and most the Gulf of Alaska. Areas of overprediction are limited and confined to extreme northern portions of North America, the southern Gulf of Mexico, the Caribbean, and the eastern Pacific.

The 850 mb temperature errors (Fig. 5c) show the same general pattern as the thickness errors. It is noteworthy that a strong cold bias occurs in the western Atlantic with rapidly intensifying cyclones. The negative thickness errors over the western Atlantic are what one might expect based on the geographical distribution of the positive pressure errors (underprediction) shown in Fig. 5a.

Figure 5d shows a smoothed subjective analysis of the observed geographical frequency of the cyclones used in the NGM error analysis. High concentrations

of cyclones are found over the Gulf of Alaska, in the lee of the Rocky Mountains and from the Labrador Sea northeastward up the east coast of Greenland. Secondary maxima occur along the East Coast of North America and over the Great lakes. This pattern is similar to the 28-yr climatology for cyclones presented by Zishka and Smith (1980), and Whittaker and Horn's (1981) study. The high concentration of cyclones in the Gulf of Alaska corresponds well with Fig. 1 in the study by Gyakum et al (1989) on North Pacific cold season cyclones.

Figure 6 shows the directional or vector displacement errors computed as in Grumm and Gyakum (1986). The center of the plot represents where the verifying cyclone occurred and each "plus" represents the forecast position. The figure shows the errors in each forecast period for the region bounded by  $45^\circ$  north, and  $100^\circ$  west, and to the southern and eastern boundaries of the NGM study domain. This area is called the "Atlantic Southeast" (AS). Figure 6a depicts the 12-h forecast displacement errors, which show a slight tendency to place cyclones north and west of the verifying position. From 24 to 48 hours (Figs. 6b–d), the north and west forecast bias continues to grow such that by 48 hours almost every system occurs either north or west of the observed position.

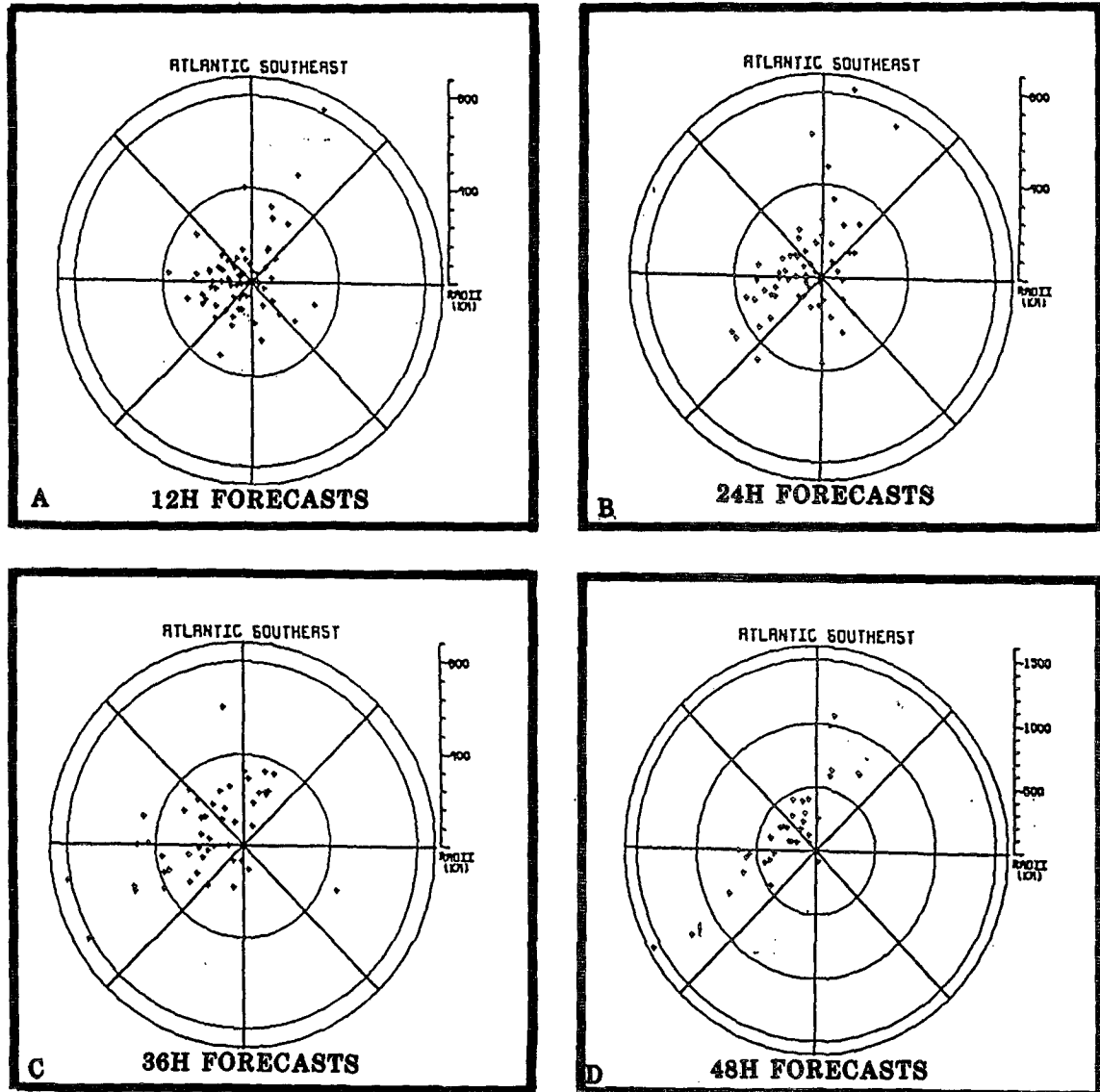


FIG. 6. Depiction of NGM cyclone forecast vector displacement errors for the Atlantic Southeast region for (a) 12 hours, (b) 24 hours, (c) 36 hours, and (d) 48 hours. The center represents the verifying position and the "plus" represents the forecast position. Concentric circles are spaced according to the range markers (kilometers), specified to the right of each plot.

**4. Discussion**

The 1000 to 500 mb thickness and 850 mb temperature error statistics indicate that the NGM has an overall cold bias over cyclone centers. This bias is present in the model at the beginning of the forecast cycle and grows slowly with time (not shown). Assuming the model provides an unbiased 500 mb height forecast, a positive (negative) pressure error should have caused a cold (warm) bias in the thickness forecasts over the cyclone center. Comparing Figs. 5a and 5b, this expectation generally holds over the oceans where occurrences of underdevelopment correspond with areas of low (underforecasted) thickness (cold bias). Over the continents the expectation is contradicted as a cold

bias exists where the pressure error indicates overdeepening. Therefore, the cold bias over North America must be due to the forecast 500 mb heights over the cyclone center being too low. Furthermore, this 500 mb height error must be greater than the 1000 mb height error implied by the error in sea-level pressure error. Hence, overdeepening of surface cyclones over the continent may be related to overdeepening of 500 mb lows.

The underprediction of rapid cyclogenesis over the oceans may be related to a lack of data over the oceans and the NGM's inability to properly simulate the physics of explosive cyclogenesis. It should be noted that system 141 in the database was the extraordinary, rapidly deepening cyclone that occurred during the

ERICA project (Hadlock and Kreitzberg 1988). This cyclone was well forecast by the NGM when scored against the NGM analysis, whereby the 12-h forecast error was 0 mb. However, manual analysis and the ERICA datasets indicate that the central pressure of this system was actually 937 mb, 10 mb lower than forecast or analyzed in the NGM. The overall result of underpredicting cyclogenesis over oceanic regimes, especially in the longer range forecasts, is consistent with Sanders' (1987) finding that the critical success index decreases as forecast length increases.

The NGM's cold bias and its difficulty in simulating rapid cyclogenesis may be interrelated. The cold bias may create higher static stability in the model atmosphere due to the lower levels being too cold. This could reduce the ability of the model to simulate ascent in the environment around the developing cyclone.

The displacement error statistics indicate that some progress has been made in the ability of numerical models to position surface cyclone centers. The overall 24- and 48-h forecast distance errors were 256 and 417 km compared to 299 and 432 km in the LFM-II as shown by Silberberg and Bosart (1982). Another interesting finding was the slight north and west displacement error indicating that the NGM tends moves cyclones too slowly. This is similar to the results found by Silberberg and Bosart (1982) in the LFM-II during the 1978-79 cold season. In October and November they found a distinct slow bias that weakened during December and January and was almost totally gone in February, indicating a seasonality in model displacement errors.

## 5. Conclusions

A quantitative assessment has been made of the surface cyclone forecast errors found in the operational NGM model of NMC. The area of consideration encompassed North America and the adjacent oceans for November 1988 through January 1989.

The NGM tends to overpredict surface cyclone pressure over the oceans and underpredict surface cyclone pressure over the North American continent. The pressure error is already present by 12 hours and grows as the length of the forecast increases. Thickness errors over the cyclone center indicate an overall cold bias. This error, like the pressure error, has some geographical variability. The error is generally negative (cold bias) over the North American continent and the adjacent oceans. This overall cold bias may play a role in the model's inability to properly simulate rapid cyclogenesis.

The data suggest that the model generally places surface cyclones too far north and west of the verifying position. This error is most significant in the two southern regions, especially in the Atlantic Southeast. More data will have to be compiled in order to determine if a statistically significant displacement error exists for each forecast period and season.

Recent cases of rapid cyclogenesis over the North

American continent, not presented in this study, indicate that similar errors occur over land as over the oceans in rapidly developing cyclones. The fact that very few rapidly developing cyclones occurred over North America during the study period may have skewed the results presented here. As our dataset grows, a comparison will be made of rapidly intensifying cyclones over land and oceans.

Further research will be pursued to determine how the NGM simulates anticyclone as well as cyclone development during a forecast cycle. Geographical maps will be produced to show pressure, thickness, 850 mb temperature errors, and the locations of where the NGM fails to forecast observed cyclones, and where the NGM forecasts cyclones which are not observed at each forecast period. A similar study should be conducted on the aviation model to examine similar errors in the medium range forecast time periods.

*Acknowledgments.* The authors would like to thank Robert "Bud" Hanson for his graphics-programming support and Kenneth E. Mitchell for editing assistance.

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