NMC NOTES

Systematic Model Forecast Errors of Surface Cyclones in the NGM and AVN, January 1990

RICHARD H. GRUMM AND ANTHONY L. SIEBERS

Meteorological Operations Division, National Meteorological Center, Camp Springs, MD

26 June 1990 and 7 August 1990

ABSTRACT

Results from a study examining the performance of the nested grid model (NGM) and the aviation run of the global spectral model (AVN) in predicting surface cyclones during January 1990 revealed that the AVN slightly outperformed the NGM in forecasting cyclone central pressures and placement. Although both models performed better for deepening systems than filling systems, the AVN outperformed the NGM in predicting the characteristics of filling cyclones.

Overall, the NGM tended to overdeepen surface cyclones. A large part of the pressure error was due to the model's inability to properly fill cyclones and a tendency to forecast systems to deepen when they were observed to be filling.

The AVN tended to underdeepen surface cyclones with the deepening rate errors near 2 mb at 12 h and less than 1 mb by 48 h. The overall pressure errors for deepening cyclones appeared to be linked to a spin-up problem in the AVN and may have also been associated with the AVN cold bias in 1000- to 500-mb thickness forecasts.

1. Introduction

The operational forecaster is often faced with the job of interpreting different solutions from numerical guidance. The knowledge of systematic errors for the National Meteorological Center's (NMC) operational models allows the forecaster to decide which model solution may be applicable to a particular meteorological situation. In this paper, two operational models, the nested grid model (NGM) and the aviation run of the global spectral model (AVN), are compared. The NGM is a forecast component of the Regional Analysis and Forecast System (RAFS), described by Hoke et al. (1989). The AVN is the spectral model component (Sela 1980) of the NMC Global Data Assimilation and Forecast System, a description of which is given by Kanamitsu (1989).

Junker et al. (1989) offer a summary of the performance errors in NMC's regional models. The verification studies by Grumm and Siebers, (1989a, hereafter referred to as GS) have focused on the ability of the NGM to forecast surface cyclones and, in a later paper, anticyclones (Grumm and Siebers 1989b). In this study we expand upon our previous model verification studies on systematic errors in operational models. The results shown for the NGM in this note should be directly comparable to the results shown in GS (1989a) since there have been no significant changes to the RAFS since December 1988. A list of significant changes to the RAFS since March 1985 is presented by Rogers et al. (1990).

This study is unique for two reasons. *First, the NGM is directly compared to the AVN for the same forecast periods, geographical domain, and large scale circulation regime. Second, the systematic errors for both models are broken down into categories for deepening and filling cyclones.*

Model comparison studies are important in that they offer forecasters insight into systematic model errors which they confront on a day to day basis in their attempt to put out a forecast in the face of diverging numerical prognoses. Chen et al. (1987) examined 36-h surface cyclone and anticyclone forecasts in the Japan Meteorological Agency's Fine Mesh Limited Area Model (JFLM) and United States Navy's Operational Global Atmospheric Prediction System (NOGAPS). The JFLM is a 127-km resolution finite difference model with ten vertical levels. The NOGAPS is a 6-layer spectral model. Their results show that the JFLM had smaller cyclone position errors than the NOGAPS; and both models have a slow bias. Both models also tend to overforecast cyclone central pressures. Furthermore, they examined 36-h deepening rate errors and found that the JFLM properly predicts the sign of

Corresponding author address: Richard H. Grumm, NWS/MET Ops Dvn, W/NMC302, 5200 Auth Road, Camp Springs, MD 20746.

the deepening rate more often than the NOGAPS. Also, both models were able to forecast the 36-h pressure change in anticyclones better than cyclones.

Sanders (1987) examined the ability of the NGM and the AVN to forecast rapidly developing cyclones. He found that the NGM did a better job in detecting rapidly developing cyclones over the finer inner grid-C than in the transition zone between grid-C and grid-B. Sanders also found, for the period 12- to 24-h after model initialization, that the NGM tends to underpredict the 12-h deepening by 1 to 1.5 mb, depending on the location of the event. In the same study, the errors in the AVN were on the order of 3 to 6 mb.

Sanders and Auciello (1989) examined skill in the NGM and AVN in predicting rapidly developing cyclones over the western North Atlantic Ocean. They found that the NGM was better than the AVN at forecasting 12-h deepening in the 12- to 24-h forecast period. However, in the 36- to 48-h forecast period, the AVN was better than the NGM in forecasting 12-h deepening. They also note that both models had improved in their ability to forecast explosive cyclogenesis over the western North Atlantic Ocean in the 1987–88 cold season compared to the previous year.

This paper compares systematic surface cyclone errors in NMC's operational runs of the NGM and the AVN during January 1990. The model errors were further stratified to examine the characteristic errors for filling and deepening cyclones. Section 2 describes the methodology used in conducting the study. Section 3 provides an overview of the large scale circulation of January 1990. Section 4 describes the systematic errors in both the NGM and AVN. Section 5 describes the pressure change errors in the both the NGM and AVN. Section 6 discusses the results and explains some potential sources of the systematic errors in the NGM and AVN. The major strengths and weaknesses in surface cyclone forecasting in both the NGM and AVN are summarized in section 7, and avenues for further study are presented.

2. Methodology

A cyclone in this study is defined as a point of relatively low sea-level pressure (SLP), surrounded by at least one closed isobar (analyzed at 4-mb intervals) in the NGM or AVN analyses or forecasts. Cyclone tracking and data storage are described in GS. The corresponding NGM or AVN initialized analyses at 0000 and 1200 UTC were used to represent the verifying atmosphere for the period during January 1990. A total of 62 complete forecast cycles were available during this period.

Cyclones were initially identified, numbered, and tracked in the NGM. Systems were then tracked in the AVN using the system track numbers from the NGM database whenever possible. Over the Pacific Basin, the AVN often captured the initial development of a cyclone before the NGM. In this case, the system numbers for the AVN were also used for the NGM. This allowed a direct comparison between the two models for the same geographic area and synoptic regimes.

Given our strict criteria of what constitutes a cyclone, the AVN had considerably fewer cyclones over North America than the NGM. In many instances, the AVN would depict a trough, without a closed circulation, as defined by our criteria.

Forecast errors in SLP, thickness, and 850-mb temperature of the cyclone are defined as forecast minus observed. A negative (positive) error in pressure corresponds to underprediction (overprediction) of the cyclone central pressure. Cyclone distance errors were also computed by comparing the forecast to the observed position, as in GS. Each model was compared against its own analysis for verification purposes.

Deepening and filling rate statistics were computed for 12-h periods. Both the 12-h deepening rate errors and the total pressure errors were examined. The 0–12-, 12–24-, 24–36-, and 36–48-h deepening rate errors were computed in each model forecast for all cyclones for which 12-h deepening verification data were available. For example, the 36–48-h deepening rate was computed by subtracting the 36-h forecast from the 48-h forecast; the actual 12-h deepening rates were then used to compute the 12-h deepening rate errors. These data were further stratified to assess errors for both deepening and filling surface cyclones. The categories are based on the forecast and analyzed pressure changes and are defined as follows: forecast to fill, observed to fill (FF); forecast to deepen, observed to fill (DF); forecast to fill, observed to deepen (FD); and forecast to deepen, observed to deepen (DD). Surface cyclones which maintained a constant pressure were classified as filling.

3. Overview of January 1990

The circulation of January 1990 was marked by a transition from the highly amplified pattern of December 1989, which was characterized by a large trough over eastern North America early in the month, to a broad region of zonal flow across most of the United States throughout the later part of the month. The Pacific North American (PNA) index (Wallace and Gutzler 1981) shifted from positive to negative in late December.

The storm tracks which were observed in the NGM for January 1990 are shown in Fig. 1. Based on the 28-year climatology of cyclones over North America and the adjacent oceans (Zishka and Smith 1980), January of 1990 had some deviations from the expected tracks of cyclones. There was an anomalously large number of cyclones which tracked into the Bering Sea, and the cyclone track across the southern Canadian Rockies was extremely active. The tracks of leeside cyclones in the southwestern United States and the tracks of east

NGM CYCLONE TRACKS

JANUARY 1990

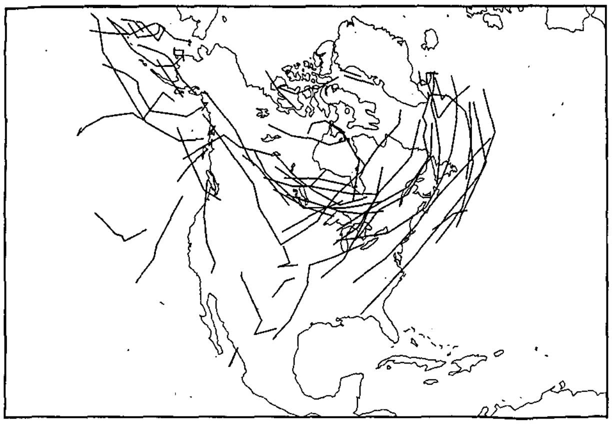

FIG. 1. Track of all cyclones from the NGM initialized analysis for January 1990.

coast cyclones were relatively inactive in January 1990. Cyclogenesis over the western Atlantic was shifted farther north and east, and cyclogenesis over North America was generally shifted farther north than normal.

The month of January 1990 was an anomalously warm month over the eastern half of the United States.[1] Many locations in the eastern United States were warmer than 90% of all previously recorded Januaries. This anomalous warmth was associated with a large 500-mb positive height anomaly during January 1990, which was located just off the coast of southern New England. This anomaly extended westward to 100W and eastward to 10W.

The anomalous circulation over North America during January 1990 may have affected the performance of the NGM and the AVN. Therefore, the results shown in this study may not be representative of all Januaries. Furthermore, when comparing the results presented here against results of previous studies, the differences in the general circulation patterns should be considered a potential source for some portion of the differences.

4. Overall comparisons between the NGM and AVN

Tables 1 and 2 show the overall errors for 12-, 24-, 36- and 48-h forecasts, for the NGM and AVN respectively. For each forecast time, the number of cases, mean and standard deviations of the pressure (mb), thickness (m), and distance (km) errors are shown.

The tables show that the NGM tended to underpredict (central pressure too low) and the AVN tended to overpredict (central pressure too high) surface cyclone central pressures. The standard deviation of the pressure errors were generally smaller in the AVN than in the NGM, especially at 48 h. At 48 h, the absolute pressure error in the NGM was 7.4 mb compared to only 4.6 mb in the AVN.

The thickness errors in Tables 1 and 2 show that the AVN had a distinct cold bias which decreased with forecast length. The cold bias over the cyclone center in the AVN was not found at 850 mb, 850-mb temperature errors (not shown) were positive with the exception of the 12-h forecast. In contrast to the AVN, the NGM tended to exhibit a warm bias in its thickness forecast over surface cyclone centers, with the exception of the 12-h forecast. The warm bias in the NGM increased with forecast length. Not unexpectedly, the standard deviation of the errors increased with time in both models. The NGM had a slightly smaller standard deviation than the AVN at all forecast periods.

The distance errors in Tables 1 and 2 indicate that the AVN was slightly superior to the NGM in forecasting the position of surface cyclones during all forecast lengths.

The geographical distribution of the 48-h pressure errors of surface cyclones in the NGM and AVN are shown in Figs. 2a and 3a, respectively. The NGM tended to underforecast cyclone pressures over most of North America. The largest underprediction errors occurred to the lee of the Canadian Rockies and over Alaska. Areas of overprediction occurred over the western Atlantic, eastern North America, and the east-

[1] See pages 19 and 43 of the Climatic Diagnostics Bulletin, January 1990. The Climatic Analysis Center, W/NMC52, NOAA/NWS/NMC, World Weather Building, Room 605, 5200 Auth Road, Washington, DC 20233.

TABLE 1. The mean pressure, thickness, and distance error by forecast hour (fcst) in NGM cyclones for January 1990. Data include the model, the number of cases, the mean pressure (mb), thickness (m) and distance (km) errors, and standard deviations.

NGM forecast errors								
			Pressure (mb)		Thickness (m)		Distance (km)	
Model	Fcst	Number	Mean	Std	Mean	Std	Mean	Std
NGM	12	256	−0.82	3.35	−0.90	32.60	133.18	118.60
NGM	24	235	−1.60	4.93	3.83	52.72	227.81	200.45
NGM	36	203	−2.45	6.25	8.92	58.58	299.47	262.49
NGM	48	165	−3.22	8.12	14.06	61.78	383.63	302.68

TABLE 2. As in Table 1 except for the AVN.

			AVN forecast errors					
			Pressure (mb)		Thickness (m)		Distance (km)	
Model	Fcst	Number	Mean	Std	Mean	Std	Mean	Std
AVN	12	223	1.27	2.79	−10.31	33.99	128.99	100.48
AVN	24	194	1.99	3.70	−5.36	44.41	206.23	229.52
AVN	36	172	2.02	4.77	−3.95	55.60	239.87	239.82
AVN	48	141	1.66	5.50	0.00	71.53	355.38	288.52

ern Pacific. In the AVN (Fig. 3a) overprediction errors dominated from the Rocky mountains of North America eastward over the western Atlantic and over most of the eastern Pacific. Underprediction errors in the AVN were confined to the elevated terrain of western North America and Alaska.

The geographical distribution of the 48-h 1000- to 500-mb thickness errors over surface cyclones in the NGM and AVN are shown in Figs. 2b and 3b, respectively. The NGM had a warm bias over most of North America and the adjacent oceans. The cold bias in the NGM was confined to the northern Rockies, western plains of Canada, the western Atlantic east of 60W, and portions of the eastern Pacific. In the AVN, the warm bias was confined to eastern North America from Texas, northeastward to Greenland, and from southern California northward to the Northwest Territories. The cold bias in the AVN occurred over the western Atlantic, eastern Pacific, and most of the plains of North America. A local maxima in the warm bias in both models occurred over the Great Lakes. A local minima in the cold bias in both models occurred over the plains of western Canada.

5. Pressure change errors

In this section, the 12-h pressure change errors in the models are reviewed. The data were divided into categories based on the forecast and analyzed pressure changes. These categories were described in the methodology section. The percent of occurrence for each category for the NGM and AVN are shown in Figs. 4a and 4b, respectively. The figures indicate that the models correctly forecast the cyclone 12-h SLP change 80 and 86% of the time in the NGM and AVN, respectively. The NGM deepened cyclones which were observed to be filling 15% of the time. The AVN forecast deepening for only 6% of filling cyclones. The NGM filled deepening systems only 5% of the time compared to 8% in the AVN. For clarity, this section is broken down into four subsections to examine the four pressure change categories.

a. Forecast to fill, observed to fill (FF)

In this category, all cyclones which were forecast to fill and were observed to fill are examined and shown

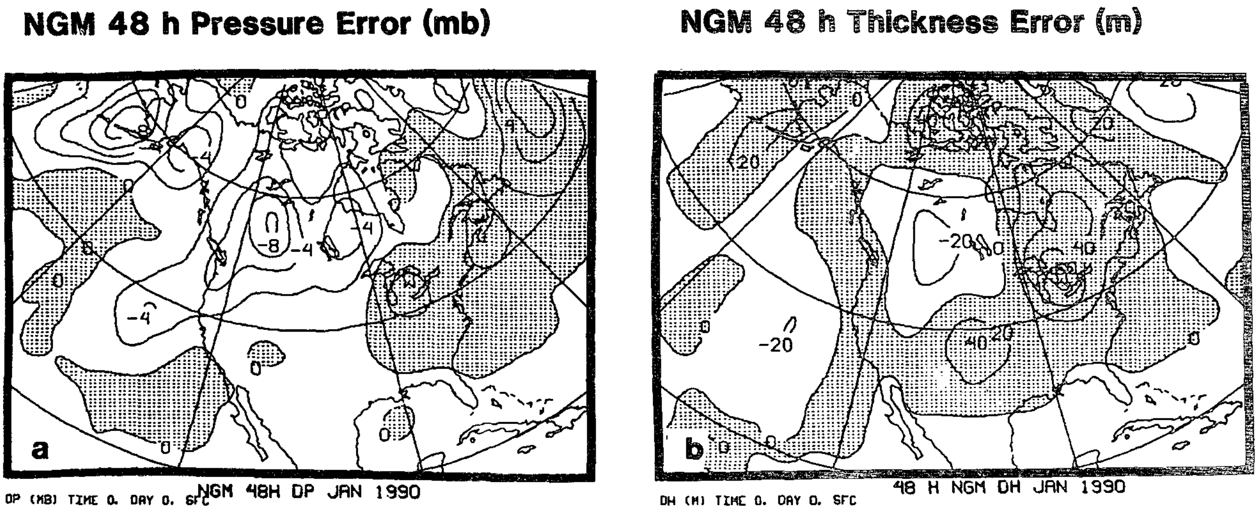

FIG. 2. The NGM mean cyclone forecast error at 48 h during January 1990 for (a) sea-level pressure (mb) and (b) 1000–500-mb thickness (m). Positive errors (overprediction) are denoted by shading. Contour interval is 2 mb for pressure and 10 m for 1000–500-mb thickness.

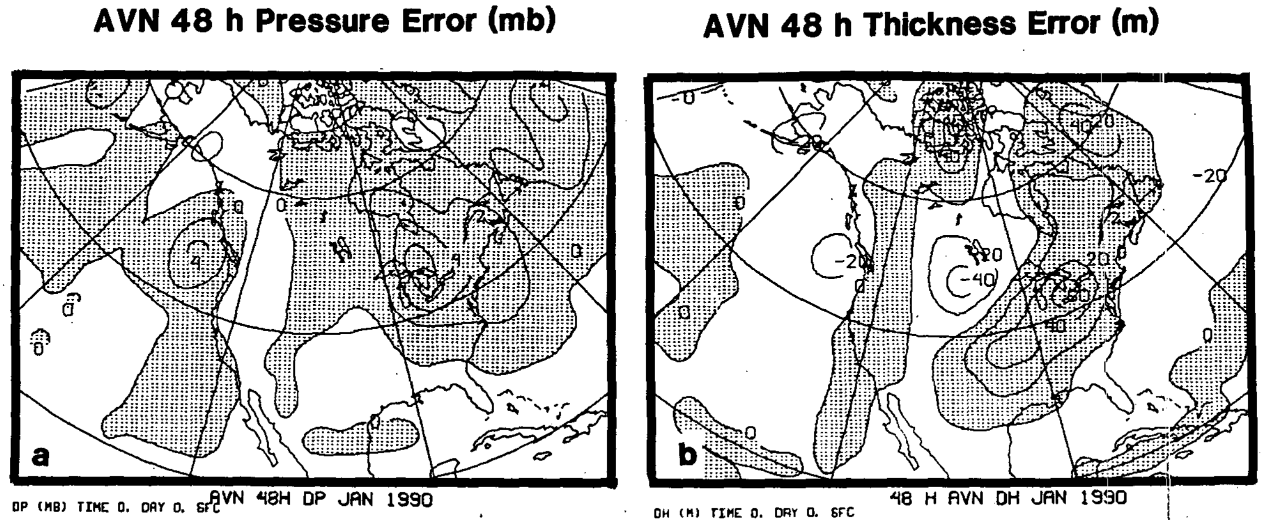

FIG. 3. As in Fig. 2. except for the AVN.

in Tables 3 and 4 for the NGM and AVN, respectively. Negative (positive) SLP change errors indicate that the 12-h SLP change forecast was too slow (fast) to fill the cyclone.

The NGM tended to be slow in filling cyclones for each period. The 12-h deepening rate error is approximately −1.5 mb at all forecast periods. The standard deviation of the SLP change errors grew slowly with time. There appears to be only a small time dependency on the deepening rate errors for filling systems in the NGM.

The overall distance, SLP, and thickness errors in the NGM for filling cyclones are also shown in Table 3. The overall SLP error was negative for all forecast periods, as expected given the SLP change errors. The thickness errors indicate an overall warm bias, with the exception of a slight cold bias at 12 h. The standard deviation of the error indicated only a slight time dependence of the error.

The distance errors for filling cyclones in the NGM (Table 3) are comparable to the NGM overall (Table 1) data set values. After 24 h, the FF cyclone positions had larger errors than the sample total. Both the mean and the standard deviation of the distance errors were larger for the FF category by 36 h. Displacement data (not shown) indicate that the NGM had no distinct bias in positioning FF cyclones because the data showed a large degree of scatter. For example, at 36 h, the mean NGM cyclone displacement was 35 km northwest (302 degrees) of the verifying position, while at 48 h it was 44 km to the northeast (45 degrees).

The AVN was also slow to fill FF cyclones, with the exception of the 12-h forecast period. The AVN forecasts of cyclone central pressure changes (Table 4) for FF cyclones were superior to the NGM's, with smaller errors and smaller standard deviations at all forecast length. In the AVN, the 12-h pressure change errors showed a sign change between the first 12-h and subsequent forecast periods which may be a result of spin-up problems in the AVN. The effect is so dramatic that the overall pressure errors do not become negative until the 48-h forecast period. This spin-up error is not evident in the NGM (Table 3) where the 12-h pressure change errors were near −1.5 mb for all forecast periods.

The thickness errors in the AVN for filling cyclones indicate that the AVN had a cold bias for FF cyclones. This bias appears to be independent of forecast length.

The AVN mean positions errors for FF cyclones were smaller than the mean positions errors for FF cyclones in the NGM at all forecast periods. Furthermore, forecast position errors of FF cyclones by the AVN were smaller than the total AVN sample. The 48-h forecast position error was 43 km smaller than the AVN sample total (Table 2).

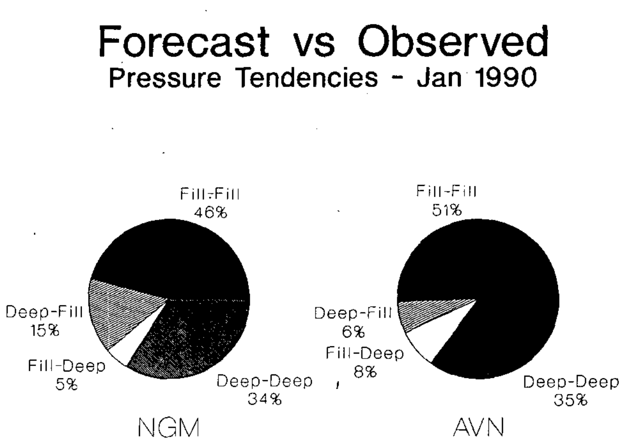

FIG. 4. Forecast vs. observed pressure tendencies in the NGM and AVN for January 1990. The percent occurrence of each category is shown. A description of the categories is given in the methodology section of the text.

TABLE 3. The mean 12-h pressure change, distance, pressure and thickness errors by forecast hour (fcst) in NGM cyclones for January 1990. Data include the model, forecast length (h), cyclone pressure change category (explained in text), the number of cases, the mean 12-h pressure change (mb), distance (km), pressure (mb) and thickness (m) errors, and standard deviations.

NGM forecast errors: Forecast to fill, observed to fill

				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
NGM	12	FF	103	−1.57	2.55	140	132	−1.57	2.55	−2.14	30.52
NGM	24	FF	83	−1.47	3.17	201	202	−2.96	4.30	8.43	38.82
NGM	36	FF	75	−1.48	3.45	309	304	−4.56	5.43	14.88	61.13
NGM	48	FF	50	−1.58	3.86	396	324	−6.84	6.35	19.20	40.78

b. Forecast to deepen, observed to fill (DF)

In this category, all cyclones which were observed to fill, but forecast to deepen were examined. The results for this category are shown in Tables 5 and 6 for the NGM and AVN respectively. Due to the small sample size for the AVN, the results must be interpreted with caution.

The NGM had more of a tendency to forecast deepening of filling cyclones than the AVN, as seen by the number of cyclones in this category. In both models the 12-h deepening rate errors grew with time. The NGM had difficulty filling systems which resulted in large negative 12-h pressure change and total pressure errors. The AVN also had difficulty predicting filling systems, but the overall pressure errors were considerably smaller than in the NGM.

Thickness errors in the NGM showed an overall warm bias, with the mean thickness errors improving with time. The standard deviation and the RMS values (not shown) were extremely similar in value, both increasing with forecast length. The AVN had a distinct cold bias for cyclones in this category, with the exception of the 36-h forecast period where a warm bias occurred.

Distance errors indicated that the NGM did a better job forecasting the position of DF cyclones than FF cyclones. Both the mean and standard deviation of the distance errors were considerably less than the overall NGM sample mean distance error (Table 1) and the error for FF cyclones (Table 3). The AVN and the NGM were comparable in forecasting the positions of DF cyclones.

c. Forecast to fill, observed to deepen (FD)

In this category, all cyclones which were forecast to fill but were observed to deepen were examined. The results for this category are shown in Tables 7 and 8 for the NGM and AVN, respectively. Due to the small sample size for both models, the results should be interpreted with caution.

Deepening rate errors were comparable in both models.

The overall pressure errors were positive in both models with the exception of a negative pressure error at 36 h in the NGM. The thickness errors showed an overall cold bias in both models, with the exception of no bias in the NGM 12-h forecasts.

The NGM distance errors in this category were comparable to the overall NGM sample mean errors at all time periods. The NGM and AVN position errors were comparable for the 12- and 24-h forecast periods. However, the 36- and 48-h distance errors in the AVN for FD cyclones were larger than both the NGM errors and the overall AVN sample errors.

d. Forecast to deepen, observed to deepen (DD)

In this category, all cyclones which were forecast to deepen and were observed to deepen were examined. The results for this category are shown in Tables 9 and

TABLE 4. As in Table 3 except for the AVN cyclone category FF.

AVN forecast errors: Forecast to fill, observed to fill

				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
AVN	12	FF	96	0.59	2.41	130	100	0.59	2.41	−10.47	34.52
AVN	24	FF	74	−0.49	2.48	173	138	0.48	3.07	−6.22	31.72
AVN	36	FF	57	−1.16	2.71	237	175	0.60	4.44	−13.33	35.75
AVN	48	FF	52	−0.94	2.98	312	242	−0.08	5.00	−3.27	38.07

TABLE 5. As in Table 3 except for the NGM cyclone category DF.

NGM forecast errors: Forecast to deepen, observed to fill											
				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
NGM	12	DF	22	−3.63	2.04	141	78	−3.64	2.04	10.46	37.84
NGM	24	DF	26	−4.58	2.77	230	170	−3.77	3.57	10.00	39.90
NGM	36	DF	26	−5.34	3.26	272	207	−4.73	5.03	5.00	55.76
NGM	48	DF	29	−7.14	4.13	301	203	−7.27	6.90	2.07	54.42

10 for the NGM and AVN, respectively. Similar to category FF cyclones, there were a significant number of events in both models in the DD category.

The deepening rate errors in the NGM and AVN were positive at all forecast lengths. This indicates that while the models correctly forecast the pressure tendency, they underestimated the magnitude of the deepening. The NGM pressure change errors were smaller than the pressure change errors in the AVN, with the exception of the 36-h forecast. The standard deviation of the pressure errors were larger in the NGM at all forecast lengths. Similar to FF cyclones, the AVN had its largest 12-h pressure change errors in the first 12-h forecast period. Pressure change errors in the AVN decreased after the 12-h forecast period. The pressure change errors increased with forecast length in the NGM.

The verifying thickness errors indicate that both models forecast the thickness to be too high (warm bias) over DD cyclones at all but the 12-h forecasts. The error was slightly larger in the AVN based on the mean and standard deviation of the thickness errors.

The distance errors indicate that both models were better able to predict the position of DD surface cyclones than other categories of cyclones. The AVN forecasts had smaller distance errors than the NGM at all forecast periods with the exception of the 12-h forecast. The standard deviation of the distance error was less in the AVN than the NGM at all forecast periods. When these data are compared to the sample totals in Tables 1 and 2, it is clear that both models had substantially better forecasts of the position of deepening cyclones than all cyclones. At 48 h, the NGM and AVN improvement in cyclone position as compared to their overall sample, was approximately 70 and 75 km, respectively.

6. Discussion

The results indicated that the NGM tended to underpredict the central pressure of surface cyclones while the AVN tended to overpredict the central pressure of surface cyclones. The errors in the NGM are similar to the errors found in GS (1989a). The errors were relatively constant with forecast length in the AVN. In the NGM, the errors grew with forecast length, with the largest negative pressure error of −3.22 mb occurring at 48 h. The mean and standard deviation of the errors indicated that the bias in the NGM increased with forecast length.

Surface cyclone mean central pressure and distance errors and the root mean square errors (RMS) for 24-, 36-, and 48-h model forecasts are shown in Tables 11 through 13, where the data from the JFLM and NOGAPS are derived from Chen and Wang (1987). These data were obtained during the months of May–July 1983. The study region included most of eastern Asia and the adjacent western Pacific Ocean. The data for the LFM-II are from Silberberg and Bosart (1982) for the month of January 1979, and their study area was the same general area used in this study. Of the five models, the NGM was the only one which system-

TABLE 6. As in Table 3 except for the AVN cyclone category DF.

AVN forecast errors: Forecast to deepen, observed to fill											
				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
AVN	12	DF	1	−2.00	0.00	78	0	−2.00	0.00	−20.00	0.00
AVN	24	DF	6	−4.50	3.59	147	122	0.17	1.86	−8.33	50.80
AVN	36	DF	16	−4.69	2.91	238	197	0.00	3.20	3.12	61.51
AVN	48	DF	12	−6.17	4.02	306	242	1.08	4.63	−6.67	45.90

TABLE 7. As in Table 3 except for the NGM cyclone category FD.

NGM forecast errors: Forecast to fill, observed to deepen

				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
NGM	12	FD	11	4.00	3.25	148	110	4.00	3.25	−5.46	25.00
NGM	24	FD	7	3.57	2.13	162	99	3.00	2.27	−7.14	23.12
NGM	36	FD	5	2.80	1.16	237	192	−1.60	4.50	−4.00	37.20
NGM	48	FD	10	5.00	2.79	402	307	4.90	9.26	6.00	74.46

atically overdeepened surface cyclones. The RMS for the 36-h forecasts indicated that the errors in the AVN, JFLM, and NOGAPS were very similar in magnitude and offered improved forecasts relative to the NGM. At 24 h, the NGM and AVN offered improved surface cyclone forecasts relative to the LFM-II (Silberberg and Bosart 1982). At 48 h, the AVN forecasts of surface cyclone central pressures were better than the NGM and LFM.

In these previous studies, no attempt has been made to account for the difference in the large scale circulation pattern between January 1979 and 1990 when comparing the LFM-II to the NGM and AVN. When comparing the NOGAPS and JFLM to the NGM and AVN, no attempt has been made to account for the geographical and seasonal differences which may account for some portion of the differences between the models.

The overdeepening error in the NGM was the result of two distinct problems. First, the NGM was unable to fill surface cyclones as rapidly as they actually filled. The inability to properly fill systems contributed negative pressure errors at all forecast lengths for filling cyclones (Table 3 and 5). The negative pressure errors were nearly double the overall sample pressure errors (Table 1) at all forecast lengths. Another contributing factor to the NGM's overdevelopment error was the tendency of the NGM to continue deepening surface cyclones which had begun to fill. The NGM continued to deepen filling systems 15% of the time as compared to only 6% for the AVN. The overall negative pressure errors for the DF cyclones were shown in Table 5.

Although the NGM had an overall tendency to overdevelop cyclones, it tended to underdevelop surface cyclones which were observed to deepen. The underdevelopment of DD and FD cyclones contributed positive pressure errors (Tables 8 and 10) to the overall pressure errors. However, the magnitude of the underdevelopment errors for DD and FF cyclones were smaller than the overdevelopment error for FD and DF cyclones and the effects could not be mitigated.

The AVN had an overall underdevelopment error (Table 2). The AVN performed significantly better than the NGM in forecasting the filling of cyclones which were observed to fill (Tables 3 and 4). Both the deepening rate errors and the overall pressure errors in the AVN (Table 4) were smaller than the errors in the NGM (Table 3). Similar to the NGM, the AVN had large overdevelopment errors for DF cyclones. But unlike the NGM, the AVN had no distinct tendency to deepen filling cyclones, limiting the impact of DF cyclones on the overall AVN errors.

A significant portion of the AVN underdevelopment error appeared to be linked to the AVN's inability to properly deepen cyclones which were observed to deepen (Table 10). This error was most noticeable in the first 24 h of the forecast cycle. The AVN appeared to have a spin-up problem in the first 12 h of the forecast period which introduced the +2-mb error in the surface pressure. This error decreased to less than +1 mb at the 36-h forecast period. The deepening rate errors decreased at each subsequent forecast period. By the 36-h forecast period, the AVN deepening rate errors were less than the error in the NGM, but the

TABLE 8. As in Table 3 except for the AVN cyclone category FD.

AVN forecast errors: Forecast to fill, observed to deepen

				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
AVN	12	FD	14	4.00	2.80	82	45	4.00	2.80	−12.86	17.90
AVN	24	FD	17	4.06	2.16	167	111	4.65	2.95	−21.76	54.48
AVN	36	FD	6	5.67	3.44	338	317	7.33	3.54	−8.33	65.68
AVN	48	FD	7	5.00	2.26	569	369	6.88	5.57	−22.86	93.77

TABLE 9. As in Table 3 except for the NGM cyclone category DD.

NGM forecast errors: Forecast to deepen, observed to deepen											
				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
NGM	12	DD	73	0.22	3.24	112	115	0.22	3.24	−2.19	32.11
NGM	24	DD	63	0.73	4.00	199	164	0.83	4.45	3.65	47.02
NGM	36	DD	54	0.87	4.39	286	233	0.77	6.15	3.89	56.91
NGM	48	DD	40	1.33	4.87	314	226	1.30	6.69	19.25	51.98

overall pressure error was larger due to the poorly forecast deepening in the first 12-h forecast period.

Past studies have shown that the NGM and LFM typically underpredict cyclone central pressures (pressures too low) over North America and overpredict cyclone central pressures over the oceans (GS 1989a; Silberberg and Bosart 1982). The results here indicate that indiscriminate use of such geographical errors could be inappropriate. The results from this study suggest that over continental regions, central SLP for deepening cyclones will be forecast to be too high. Similarly, over the oceans, the central SLP of filling cyclones will be forecast to be too low. It is apparent that a large number of slowly filling cyclones over the continent and a large number of deepening cyclones over the oceans play a significant role in the geographical error distributions.

The overall statistics of 1000- to 500-mb thickness forecasts in the NGM for January 1990 (Table 1) show a warm bias over cyclone centers. This finding is opposite to that of GS (1989a). The AVN had a distinct cold bias in its 1000- to 500-mb thickness forecasts (Table 2). The cold bias in the AVN was expected, based on the overall pressure error in the AVN forecasts of cyclone central pressures. The warm bias in the NGM was related to the overall pressure error being forecast too low. As expected from the hydrostatic equation, the large negative pressure errors for FF and DF cyclones contribute to the NGM's warm bias. Surprisingly, a distinct cold bias is not found for DD cyclones in the NGM. Since a large portion of deepening cyclones occur over the oceans, the warm bias for DD cyclones may be related to diabatic effects.

The overall distance error statistics showed that the AVN produced better position forecasts of surface cyclones than the NGM for the 24- through 48-h forecasts. The NGM's mean surface cyclone position errors at 24 and 48 h were smaller than position errors found by Silberberg and Bosart (1982) in the LFM-II (Tables 11 and 13). The NGM has shown considerable improvement over the LFM in its ability to position surface cyclones. The AVN's 36-h position errors were smaller than the 36-h position errors of the JFLM and the NOGAPS (Table 12), as found by Chen and Wang (1987). The smaller position errors in the AVN, as compared to the other models, indicate that considerable progress has been made in recent years in forecasting the movement of surface cyclones by the global models.

The distance errors in the Tables 1, 3, 5, 7, and 9 show that the NGM was better able to forecast the position of surface cyclones which were forecast to deepen. When the NGM properly forecast the 12-h pressure change, the forecast for the position of deepening cyclones was always better than the forecast for the position of filling cyclones (Tables 3 and 9). The position of DF cyclones was better than FF cyclones at all but the 24-h forecast period. With the exception of the 48-h forecast period, the best position forecasts in the NGM were for FD cyclones. However, the limited sample size may play a significant role in this result. Examination of cyclone displacement statistics revealed

TABLE 10. As in Table 3 except for the AVN cyclone category DD.

AVN forecast errors: Forecast to deepen, observed to deepen											
				Pressure chg (mb)		Distance (km)		Pressure (mb)		Thickness (m)	
Model	Fcst	Cat	Number	Mean	Std	Mean	Std	Mean	Std	Mean	Std
AVN	12	DD	65	1.99	2.90	120	81	1.99	2.90	−8.31	37.70
AVN	24	DD	51	1.43	3.60	174	141	3.20	4.05	4.71	46.16
AVN	36	DD	45	0.76	2.86	233	211	3.06	4.10	13.56	60.69
AVN	48	DD	32	0.84	4.05	283	199	3.56	5.88	17.19	71.80

TABLE 11. Mean and root mean square errors for 24-h forecasts of cyclone central pressures and distances for the LFM-II, NGM, and AVN. The data for the LFM are from Silberberg and Bosart (1982) for the month of January 1979.

Model 24-h forecast errors					
		Pressure (mb)		Distance (km)	
Model	Fcst	Mean	RMS	Mean	RMS
LFM	24	1.97	6.44	354	—
NGM	24	−1.60	5.19	228	303
AVN	24	1.99	4.20	206	309

a large scatter for filling cyclones and a systematic slow bias in deepening cyclones.

The distance errors derived from the AVN revealed a potentially serious problem in the forecast position of FD cyclones during the later forecast periods. The 338-km error at 36 h was almost as large as the 355-km error for all cyclones at 48 h in the AVN (Table 2). The 569-km error at 48 h in the AVN for FD cyclones was the largest mean distance error found in the entire study. However, the limited sampling may be a contributing factor. At the 36- and 48-h time periods, the AVN was better able to forecast the position of DD cyclones. At 12 and 24 h, the position errors for DF cyclones were smaller than all other cyclone categories.

The NGM and AVN properly predicted the sign of the 12-h pressure change 80 and 86% of the time, respectively (Fig. 4). These percentages indicate that both models showed considerable skill in properly forecasting the direction of the 12-h pressure change. There was a tendency for the NGM to continue to deepen cyclones which were filling. This tendency was not present in the AVN.

7. Conclusions

A quantitative assessment has been made of the surface cyclone forecast errors found in both the operational NGM and AVN models of NMC for January 1990. The area of consideration was North America and the surrounding oceans.

TABLE 12. Mean and root mean square errors for 36-h forecasts of cyclone central pressures and distances for the JFLM, NOGAPS, NGM, and AVN. The data for the JFLM and NOGAPS are from Chen and Wang (1987) for the months of May, June, and July 1983.

Model 36-h forecast errors					
		Pressure (mb)		Distance (km)	
Model	Fcst	Mean	RMS	Mean	RMS
JFLM	36	1.9	5.3	333	456
NOGAPS	36	0.2	5.2	369	450
NGM	36	−2.5	6.7	299	398
AVN	36	2.0	5.1	257	351

TABLE 13. As in Table 11 except for 48-h forecasts.

Model 48-h forecast errors					
		Pressure (mb)		Distance (km)	
Model	Fcst	Mean	RMS	Mean	RMS
LFM	48	2.33	8.55	480	—
NGM	48	−3.22	8.74	384	488
AVN	48	1.66	5.74	355	457

The results indicate that the NGM tended to underpredict (central SLP too low) the central pressure of surface cyclones and overpredict the thickness (warm bias) over surface cyclones. The overall warm bias in the NGM was opposite to what GS found for the previous winter; possibly the result of the effects of the different large-scale circulation characteristics on the model forecasts.

With both models available in an operational forecast environment, the following rules may be derived from this study:

1. The NGM overdeveloped surface cyclones.
   a. The NGM was too slow to fill filling cyclones.
   b. The NGM was too slow to deepen deepening cyclones.
   c. The NGM had a tendency to deepen filling cyclones.
2. The AVN tended to underdevelop surface cyclones.
   a. The AVN was too slow to deepen deepening cyclones, especially in the first 12-h forecast period.
   b. The AVN was better able to simulate filling cyclones than the NGM.
3. The NGM forecast the 1000–500-mb thickness to be too high (warm bias) over surface cyclones.
4. The AVN forecast the 1000–500-mb thickness to be too low (cold bias) over surface cyclones.
5. The AVN had smaller position errors than the NGM.
   a. The AVN was better able to forecast the position of cyclones which were both observed and forecast to deepen or fill.
   b. The AVN had difficulty positioning surface cyclones which were deepening but forecast to fill.
6. The NGM had its smallest position errors for surface cyclones which were deepening and forecast to continue deepening.

Further research on model forecasts of cyclone filling and deepening rates will have to be pursued in order to further quantify and substantiate the above findings. We plan to look at similar data for anticyclones in the AVN and NGM during January of 1990. Nine months of NGM cyclone and anticyclone track data have been collected over the study area, with 13 months of AVN data collected over the Pacific Basin. These data will allow us to examine pressure change statistics for each model.

The results of this study compared to GS (1989a) indicate that the effects of the large scale circulation on model errors and skill is an area where further research is needed. Long term research related to the examination of model systematic errors and circulation indices may eventually yield model confidence indices which can be used to produce more accurate forecasts.

Acknowledgements. The authors would like to thank Keith Ward for graphics programming support, Wei Zhong Li for database programming support, and Louis Uccellini and Paul Kocin for editorial assistance.

REFERENCES

Chen, G. T. J., and Y. J. Wang, 1987: Evaluation of the surface prognoses of cyclones and anticyclones of the JMA and FNOC model over East Asia and the Western Pacific during the 1983 Mei-Yu season. *Mon. Wea. Rev.,* **115,** 235–250.

Grumm, R. H., and A. L. Siebers, 1989a: Systematic surface cyclone errors in NMC's nested grid model: November 1988–January 1989. *Wea. Forecasting,* **4,** 246–252.

——, and ——, 1989b: Systematic surface anticyclone errors nested grid model run at NMC: December 1988–August 1989. *Wea. Forecasting,* **4,** 556–561.

Hoke, J. E., N. A. Phillips, G. J. DiMego, J. J. Tuccillo and J. G. Sela, 1989: The regional analysis and forecast system of the National Meteorological Center. *Wea. Forecasting,* **4,** 323–34.

Junker, W. N., J. E. Hoke and R. H. Grumm, 1989: Performance of NMC's regional models. *Wea. Forecasting,* **4,** 368–390.

Kanamiatsu, M., 1989: Description of the NMC Global Data Assimilation and Forecast System. *Wea. Forecasting,* **4,** 335–342.

Rogers, E., G. J. DiMego, J. P. Gerrity, R. A. Peterson, B. B. Schmidt and D. M. Kann, 1990: Preliminary experiments using gale observations at the National Meteorological Center. *Bull. Amer. Meteor. Soc.,* **71,** 319–333.

Sanders, F., 1987: Skill of NMC Operational dynamical models in prediction of explosive cyclogenesis. *Wea. Forecasting,* **2,** 322–336.

——, and E. Auciello, 1989: Skill in prediction of explosive cyclogenesis over the western North Atlantic Ocean, 1987–1988: A forecast checklist and NMC dynamical models. *Wea. Forecasting,* **4,** 322–336.

Sela, J. G., 1980: Spectral modeling at NMC. *Mon. Wea. Rev.,* **108,** 1279–1292.

Silberberg, S. R., and L. F. Bosart, 1982: An analysis of systematic cyclone errors in the NMC LFM-II model during the 1978–79 cold season. *Mon. Wea. Rev.,* **109,** 784–811.

Wallace, J. M., and D. S. Gutzler, 1981: Teleconnection in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev.,* **109,** 784–811.

Zishka, K. M., and P. J. Smith, 1980: The climatology of cyclones and anticyclones over North America and the surrounding ocean environs for January and July 1950–77. *Mon. Wea. Rev.,* **108,** 387–401.