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BIASES IN NGM AND AVN CYCLONE FORECASTS OVER THE GREAT LAKES DURING THE 1989-90 COOL SEASON

Bruce B. Smith
National Weather Service Office
Lansing, Michigan

1. Introduction

The National Meteorological Center (NMC) currently employs three models used by operational forecasters for short-range (0 to 48 hour) forecasts: the Nested Grid Model (NGM), the Aviation (AVN) or Global Spectral Model, and the Limited-area Fine-mesh Model (LFM). Numerous verification studies document characteristic errors and biases for these models (Silberberg and Bosart, 1982; Sanders, 1987; Grumm and Siebers, 1989; Mullen and Smith, 1990; Grumm and Siebers, 1990; Smith and Mullen, 1991a; Smith and Mullen, 1991b). There are at least two reasons for performing such studies: 1) to provide operational forecasters with guidance for making adjustments to the models when confronted with the dilemma of choosing the "best" model, and 2) to inform those involved with the development of numerical forecast models of the nature of model errors.

In this study, cyclone prediction errors in NMC's NGM and AVN are examined. The primary goal is to document predicted sea-level cyclone central pressure, 1000/500 mb thickness, and position errors specifically over the Great Lakes region.

2. Analysis Procedures

Output from the NGM and AVN was analyzed for the 1989-90 cool season (1 October 1989 to 31 March 1990). All available 24 and 48 hour predicted surface maps were analyzed for the Great Lakes region, which was defined to be the area enclosed by 40N and 50N latitude, and 75W and 90W longitude. Errors in forecasted cyclone pressure, 1000/500 mb thickness, and position were computed.

A cyclone was included in the study if it possessed a closed isobar on either the 0 hour initialization, the 24 hour, or 48 hour forecast map of the NGM or AVN valid at the same time. The forecast error was defined to be the forecast quantity minus the observed one. For example, a positive (negative) central pressure error of two millibars corresponded to underdeepening (overdeepening), with the predicted pressure being two millibars higher (lower) than the observed pressure. Similarly, a positive (negative) 1000/500 mb thickness error corresponded to a warm (cool) bias. Vector displacement errors were computed relative to the position of the observed cyclone. For example, a northwest position error of 250 km corresponded to the predicted cyclone being positioned 250 km to the northwest of the observed location. For all error calculations, the NGM initialization panel was used as ground truth for verification.

3. Results

Table 1 shows mean pressure error (MPE), root-mean-square pressure error (RPE), mean 1000/500 mb thickness error (MTE), average absolute displacement error (ADE), and mean vector position error (MVE) as a function of model and forecast projection. Data for 87 cyclones in the Great Lakes region during the 1989-90 cool season were analyzed. It should be noted that cyclones which moved rapidly across the Great Lakes, but were not initialized within the area defined as the Great Lakes at either 0000 UTC or 1200 UTC were not included in the study.

TABLE 1. Mean pressure error (MPE), root-mean-square pressure error (RPE), mean 1000/500 mb thickness error (MTE), average absolute displacement error (ADE), and mean position vector errors (MVE) for 24 and 48 hour NGM and AVN forecasts in the Great Lakes region during the 1989-90 cool season.

	24 hr NGM	48 hr NGM	24 hr AVN	48 hr AVN
Mean pressure error (mb)	-0.7	-1.1	+2.6	+3.0
Root-mean-square pressure error (mb)	3.2	5.7	4.2	6.3
Mean 1000/500 mb thickness error (m)	+18	+19	+7	-6
Average absolute displacement error (km)	204	335	216	322
Mean position vector error magnitude (km)	85	40	96	129
Mean position vector error direction (degrees)	194	196	151	114

The MPE values shown in Table 1 reveal that the NGM tended to slightly overdeepen cyclones, while the AVN had a strong tendency to underdeepen systems near the Great Lakes. This should not come as a surprise to operational forecasters, as the NGM is typically observed to be more aggressive than the AVN in developing surface cyclones.

The NGM MPE near the Great Lakes is not significantly different than the average of those over all of North America. The AVN MPE, however, is approximately one half millibar larger near the Great Lakes than the AVN MPE over all of North America. This indicates that the AVN is, on average, underdeveloping cyclones over the Great Lakes somewhat more than over other portions of North America. This may suggest that the AVN is not properly simulating the unfrozen waters of Great Lakes, and therefore the role latent heating plays in cyclone development strength.

Variability among individual NGM and AVN forecasts is indicated by the RPE values shown in Table 1. Forecast variability increases for both models as forecast projection increases from 24 to 48 hours. This is not unexpected, as initialization errors and uncertainties tend to be amplified as forecast models are run farther out in time. Note that at both 24 and 48 hours, NGM RPE values are smaller than those of the AVN.

When assessing the operational value of using the MPE to make systematic adjustments to individual model cyclone forecasts, it is of interest to compare the size of the MPE to the corresponding RPE. The ratio of the MPE to the RPE provides a measure of the "signal to noise" ratio. This ratio varies from approximately .20 for the NGM, to around .50 for the AVN. The square of this ratio gives the fraction of the total error variance accounted for by the systematic error (approximately .04 for the NGM, and .25 for the AVN). These ratios suggest that while adjusting NGM central pressure forecasts would not result in a substantial improvement, skill improvement may be obtained by adjusting AVN central pressure forecasts. In other words, consistently subtracting 3 millibars from AVN central pressure forecasts over the Great Lakes would likely be more beneficial in the long run than adding 1 millibar to NGM central pressure forecasts.

Table 1 reveals that NGM thicknesses are approximately 20 meters too high over Great Lake cyclone centers at both 24 and 48 hours. NGM overdevelopment partially accounts for this warm bias; the 1000 mb pressure surface would be predicted too low, causing the 1000/500 mb thickness to be larger and consequently warmer. However, NGM MPE magnitudes of around 1 millibar are not large enough to account for the nearly 20 meter warm bias (assuming 1 millibar to equal approximately 8 vertical meters). Therefore, the warm NGM thickness bias over the center of cyclones appears to be present, on average, whether the mean pressure error is removed or not.

AVN MTE's are smaller in magnitude than those of the NGM, and range from 6 meters too small (cool) at 48 hours, to 7 meters too large (warm) at 24 hours. It can be argued that a MTE of less than 10 meters is not resolvable operationally, given a typical thickness gradient near a moderately strong cyclone of 60 meters per 150 horizontal miles. However, note that if the AVN's MPE is accounted for, and 3 millibars are systematically subtracted from AVN central pressure forecasts, a 20 to 30 meter warm bias is revealed. Needless to say, such thickness biases in the NGM and AVN could easily affect the predicted position of the rain/snow line in the vicinity of cyclones passing over the Great Lakes.

It is revealed by Table 1 that the NGM performs slightly better than the AVN at 24 hours in reducing the magnitude of the ADE (the average distance that a cyclone prediction is in error, regardless of direction). The opposite is true at 48 hours, with the AVN performing slightly better. Differences between the NGM and AVN are quite small, however. Of greater operational importance are the ADE magnitudes, which for both models exceed 200 km at 24 hours, and 300 km at 48 hours. To better understand the operational impact of these large ADE's, it is of interest to examine forecast model confidence bounds (computed using cumulative frequency distributions of 24 and 48 hour ADE's). To achieve a 90% confidence level for 24 hour cyclone position forecasts, operational forecasters must accept an uncertainty of approximately 450 km. At 48 hours, this uncertainty exceeds 550 km. In other words, 48 hour NGM and AVN forecasts will be in error by at least 550 km approximately 10% of the time! Clearly, in order to achieve a level of confidence that is operationally desirable, large potential error bounds must be accepted with NGM/AVN cyclone position forecasts near the Great Lakes.

The MVE values shown in Table 1 indicate that the NGM tends to position Great Lake cyclones to the south southwest of where they verify. The AVN, on the other hand, has a tendency to forecast cyclones to the southeast of their verifying position. Surprisingly, the size of the 24 hour NGM mean vector is larger than the 48 hour NGM mean vector (85 km vs 40 km). Vector magnitudes are larger for the AVN, and range from 96 km at 24 hours, to 129 km at 48 hours.

Assuming cyclone movement from west to east, the NGM MVE values suggest a tendency to: 1) move cyclones a little too slow, and 2) position cyclones too far into the warm air. This is particularly true for 24 hour NGM forecasts, noting that the magnitude of the MVE is nearly half of the corresponding ADE (85 km vs 204 km). It was previously hypothesized that the NGM's warm thickness bias was partially due to it's tendency to overdeepen central pressures. NGM MVE's suggest that this warm bias may also be due to cyclones being systematically forecast too far to the south (into larger 500 mb heights).

For the AVN, MVE's suggest a tendency to: 1) move cyclones too quickly, and 2) position cyclones too far into the warm air. Again, this assumes cyclone movement from west to east. It is hypothesized that the AVN's MVE may be related to it's previously noted tendency to underdevelop cyclone central pressure. To show this, envision a weak area of low pressure over the mid Mississippi valley which begins to deepen and move to the north-east. Since the AVN tends to underdevelop cyclones, it's central pressure forecast for this system would likely be too high (i.e. the AVN would resist deepening). Experience, as well as knowledge of synoptic and dynamic meteorology, tells us that developing cyclones tend to be located on the warm side of their corresponding jet, while occluded (vertically stacked) cyclones tend to be positioned on the cold side. A surface cyclone which is not predicted to deepen through upper-level dynamics, therefore, will also tend to remain on the warm side of the jet. Consequently, in a southwest to northeast upper-level flow situation, an AVN central pressure forecast for a developing cyclone that is too weak will also tend to be positioned too far to the south and east.

4. Summary and Conclusions

An analysis of errors in NGM and AVN 24 and 48 hour predictions of sea-level cyclones during the 1989-90 cool season over the Great Lakes region has been completed. The primary findings of this study are as follows:

- Mean pressure errors reveal that the NGM tends to over-deepen cyclones slightly. The AVN has a strong tendency to underdeepen cyclones. Central pressure forecasts produced by the AVN can be adjusted with more confidence than those of the NGM.

- Root-mean-square pressure errors indicate that for both models, forecast variability becomes larger as forecast projection increases.

- The NGM possesses a warm bias in the 1000/500 mb thickness over cyclone centers. The AVN's thickness bias over cyclone centers is negligible.

- Average absolute displacement errors for both models exceed 200 km on 24 hour forecasts, and 300 km on 48 hour forecasts. In order to achieve a 90% confidence level for NGM and AVN cyclone position forecasts, operational forecasters must accept an uncertainty of approximately 450 km on 24 hour forecasts, and 550 km on 48 hour forecasts.

- On average, NGM cyclone position forecasts are too far to the south southwest. Mean vector position errors for the AVN are larger in magnitude than those of the NGM, and are directed to the southeast.

The results presented in this study should not be used indiscriminately by operational forecasters to make routine, systematic adjustments to NGM and AVN cyclone predictions near the Great Lakes. The large root-mean-square pressure errors, and the broad 90% confidence intervals for position forecasts point to the danger in doing so. Rather, these findings should only provide insight as to the type of errors that may occur in the vicinity of the Great Lakes. It is hoped that by being aware of the potential errors, forecasters will be able to recognize when closer examination of the meteorological situation and the corresponding model output is warranted.

Lastly, it is important to recognize that because changes are continuously being made in the operational models, it is possible that the error tendencies reported here may differ from those of the current NGM and AVN. It is believed that the changes implemented in RAFS since the 1989-90 winter (Petersen et al. 1991) are so minor that the results presented here are still applicable for the current NGM. On the other hand, because during 1991 the AVN had it's horizontal resolution increased by approximately 50% (Kanamitsu et al. 1991, Kalnay et al. 1991) and it's analysis and initialization scheme changed (Derber et al. 1991), the AVN T80 statistics for the 1989-90 cool season may differ significantly from those of the current AVN T126 version. With the increase in horizontal resolution, it is hypothesized that some of the AVN's systematic error characteristics will now bear more resemblance to the NGM's characteristics. Clearly, the behavior of the current AVN is an area that warrants additional research.

5. Acknowledgments

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