An Analysis of NMC's Nested Grid Model Forecasts of Alberta Clippers

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ABSTRACT

Forecasts of Alberta Clipper–type cyclones, defined as cyclones that move southeastward from regions of western Canada into south-central Canada or the north-central United States before moving eastward to the coast of North America, were studied using the National Meteorological Center's Nested Grid Model (NGM). All available NGM forecasts between 1 January 1988 and 31 December 1992, excluding the months of June, July, and August, were analyzed. The 5-yr sample included 59 Alberta Clippers. For each case, the cyclone center position and central pressure were recorded for the NGM's initialization (0 h) and for 12-, 24-, 36-, and 48-h forecasts for each available run. Average cyclone position errors ranged from 140 km, with a standard deviation of 183 km at 12 h, to 339 km, with a standard deviation of 407 km at 48 h. Average central pressure errors ranged from 0.0 hPa, with a standard deviation of 2.5 hPa at 12 h, to 1.0 hPa, with a standard deviation of 5.7 hPa at 48 h. East of 84.0°W, cyclones verified farther east than forecast. West of 84.0°W, the NGM tended to forecast the cyclones farther north and slightly farther west than they were seen to verify. Positional and pressure forecast errors over and near the Great Lakes were found to be smaller than in other areas.

1. Introduction

Alberta Clippers are cyclones that are often associated with light-to-moderate precipitation. They generally occur between late fall and early spring and effect the northern United States and southern Canada. They can be defined as those cyclones that move southeast from regions of western Canada into south-central Canada or the north-central United States before moving eastward to the coast of North America. Alberta Clippers generally bring moderate snowfalls to areas up to a few hundred kilometers to the north of where they track and lighter snow or rain to areas to the south of where they track. By definition, the breeding grounds for clippers are east of the Canadian Rockies in Alberta, Canada, where, as several authors (Nielsen and Dole 1992; Whittaker and Horn 1981; Zishka and Smith 1980) have shown, there is a relative maximum in cyclogenesis.

The National Meteorological Center's (NMC) operational Nested Grid Model (NGM) (Hoke et al. 1989) is one of the primary tools used in forecasting tracks and intensities of Alberta Clippers. Numerous studies have examined verifications of NGM forecasts. It has been found that NGM forecasts have a bias toward overdeepening surface cyclones over land and underdeepening oceanic cyclones (Junker et al. 1989; Grumm and Siebers 1989; Smith and Mullen 1993). Further, the NGM has a tendency to forecast cyclones northwest of their verifying positions (Grumm and Siebers 1989), and this bias is locally largest in the lee of the Rockies and over the Atlantic Ocean (Smith and Mullen 1989). Also, the NGM has been shown, on average, to be too slow in forecasting cyclone movement (Junker et al. 1989).

During the 1991–1992 winter, the author was actively involved in forecasting weather for Albany, New York. He noticed that precipitation associated with Alberta Clippers was often poorly forecast by the NGM. On several occasions, the NGM forecasted a moderate snowfall of between 5 and 15 cm for Albany, whereas little precipitation was observed. It was hypothesized that this precipitation error might have arisen because the NGM was inadequate in predicting the location and intensity of Alberta Clippers crossing eastern North America in the vicinity of the Great Lakes. Petterssen and Calabrese (1959) showed that "the heat transfer from the (Great) Lakes to the air exerts a modifying influence on the motion systems and a dominating influence on the weather systems." Given that the Great Lakes are relatively poorly sampled in the NGM (Petersen and Hoke 1989), it is suggested that the NGM cyclone forecasts may be biased over and near the Great Lakes during the cooler part of the year when sensible and latent heat fluxes over the Great Lakes are maximized, thus warming the air and leading hydrostatically to lower pressures over the Great Lakes (Bluestein 1992). This may give the impression of a cyclone ac-

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celerating as it moves toward the lakes and decelerating as it moves away from the lakes (Petterssen 1956). Accordingly, this study compares the observed and NGM forecast positions of Alberta Clippers that frequently pass over or near the Great Lakes.

Although the initial intent of this study was to determine why Albany received less snowfall than was forecast, the results presented should be applicable to all forecasters who must predict weather associated with Alberta Clippers. NGM forecasts of clipper locations, surface central pressures, 500-hPa heights, and 1000–500-hPa thicknesses were examined, and results are presented for geographic areas along the cyclone tracks from Alberta through the northeastern United States.

2. Methodology

All available twice-daily NGM initializations and forecasts of mean sea level pressure and 500-hPa vorticity centers between 1 January 1988 and 31 December 1992, excluding the summer months of June, July, and August, were examined in search for Alberta Clippers. To be considered an Alberta Clipper, a disturbance had to meet the following criteria: 1) possession of at least one closed mean sea level pressure contour (with contour intervals at 4 hPa) *and/or* a distinct local minimum in pressure in a sea level pressure trough, and 2) association with a migratory upper-level 500-hPa vorticity center. The sample of available forecasts contained 59 Alberta Clippers. For each case, the cyclone center position was recorded to the nearest half degree of latitude and longitude from the NGM's initialization (0 h) and from 12-, 24-, 36-, and 48-h forecasts for each available run. Other variables recorded included 1) cyclone central pressure, 2) 500-hPa heights over the cyclone center, and 3) 1000–500-hPa thickness over the cyclone center. The NGM 0-h initialized analyses were used for verification purposes to ensure consistency with NGM forecasts. Unavailable forecasts were minimal and likely did not affect the results, except during the periods 25 September 1988 to 5 November 1988 (when one Clipper occurred) and 10 February 1989 to 28 February 1989 (when one Clipper occurred), during which times all forecast maps were either missing or illegible.

3. Results and analysis

a. Position errors

Figure 1 shows tracks of the 59 Alberta Clippers. The twice-daily positions of the cyclone in the NGM initialized (0 h) analyses were plotted and connected with straight lines to form a cyclone track for each case. A majority of the cyclones tracked southeastward toward or just north of the northern Great Lakes before moving into southeastern Canada or extreme northern New England. However, only five cyclones tracked south of the Great Lakes and well south of New York State and New England. In between there was a minimum in cyclones passing over much of the Northeast. In fact, during the study, no cyclones tracked over the northern half of Pennsylvania, central and southern New York State, or southern New England. This absence may have been associated with cyclones moving into western Pennsylvania and subsequently redeveloping off the east coast of the United States as they encountered the Appalachian Mountains, thus not fitting the definition for Alberta Clippers and not included in this study. Regardless of this, since the largest snowfalls are typically observed within a few hundred kilometers north of the cyclone track, this figure explains why Albany often did not receive significant precipitation from Alberta Clippers during the sample period.

Figure 2 shows scatter diagrams of error in 12-, 24-, 36-, and 48-h forecasts of NGM central surface cyclone positions for the entire sample. The center of the circle represents the position of verification of the cyclone, and the X's represent the position of each forecast relative to its respective verification; that is, a perfect positional forecast would result in an X at the center of the circle. A forecast that predicted the cyclone position farther north than the verifying position would result in an X directly up from the center of the circle, and so on. The 12-h forecasts show a high and rather random concentration around the center, indicating that the forecasts were generally within a few hundred kilometers of verification. At 24 h, the markers are less centralized but still quite random in their direction from the center. However, by 36 and 48 h, there was a tendency toward less centralization, and there was a slight bias with the NGM forecasting cyclones to be northwest of their verifying positions. The average scalar errors and standard deviations were, respectively, 140 and 183 km at 12 h, 199 and 252 km at 24 h, 257 and 316 km at 36 h, and 339 and 407 km at 48 h. The mean vector errors were 20 km to the northwest at 12 h, 42 km to the northwest at 24 h, 64 km to the north-northwest at 36 h, and 87 km to the north-northwest at 48 h.

Grumm et al. (1992, hereafter GOS) performed a study of NGM forecasts of all cyclones in the domain consisting of North America and surrounding oceans for each of the four seasons during the period December 1988 to November 1990. Their winter season (December, January, and February) results are somewhat applicable to this study, since most of the Alberta Clippers occurred during the winter season (69%). However, one must note that GOS defined a cyclone as a minimum in pressure with at least one closed 4-hPa isobar, which is slightly different from the definition of an Alberta Clipper used in this study, which also included distinct local minima in pressure in sea level pressure troughs. This may be important because the difference in the definitions allowed this study to analyze more diffuse cyclone centers than GOS analyzed, along with cyclones that would have been included in GOS's sam-

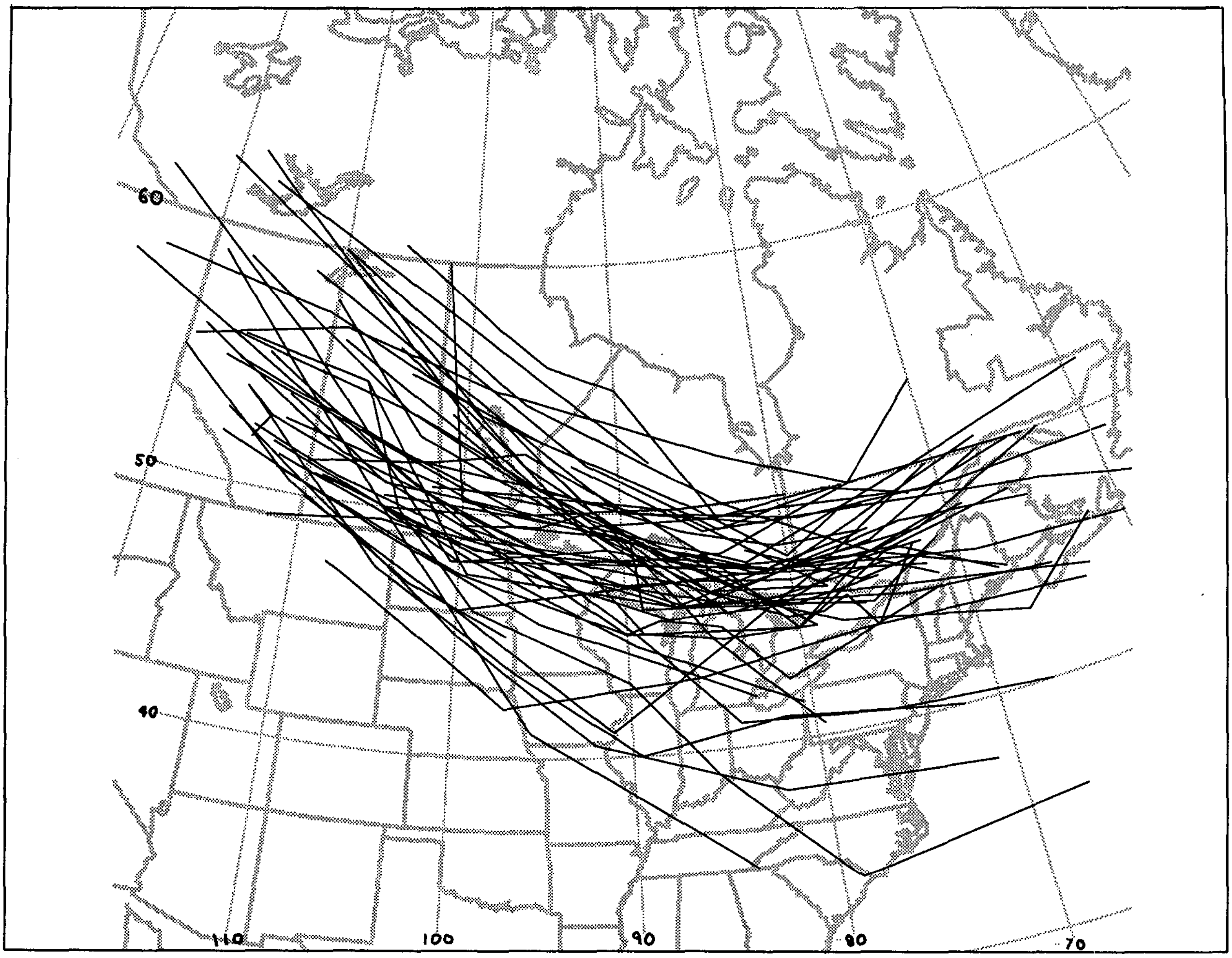

FIG. 1. Tracks of all Alberta Clippers during the study period, created by plotting twice-daily 0-h NGM forecast positions and connecting them with straight lines.

ple. GOS found average forecast displacement errors of 235 and 372 km at 24 and 48 h, respectively. Smith and Mullen (1993), using a very similar definition for a cyclone and a similar domain as GOS, found for two winter seasons (1987/88 and 1989/90) average forecast displacement errors of 263 km at 24 h and 376 km at 48 h. The errors found for Alberta Clippers are slightly smaller than this, which may be a result of the different definitions used, or it may indicate that the forecasts of the positions of Alberta Clippers were marginally better than the forecasts of the positions of all cyclones within the GOS and Smith and Mullen (1993) domains. GOS showed that the mean positional error in the NGM during their winter sample was consistently to the north-northwest of verification, with vectorial errors of 39 km at 24 h and 50 km at 48 h, while Smith and Mullen (1993) found vectorial errors to the northwest of verification by 27 km at 24 h and 49 km at 48 h. The mean vectorial errors of forecasts of Alberta Clippers are slightly larger than the GOS and Smith and Mullen (1993) results but consistent with the results from both studies of forecasts being northwest of verification.

In search for regional forecast biases, the analysis domain was divided into two geographic regions, the western region (WR) west of 84°W, and the eastern region (ER) east of 84°W. The 84°W meridian runs through western Ohio and eastern Michigan and divides the Great Lakes roughly in half. First, as shown in Fig. 3, in the ER, average scalar errors were 127, 145, 187, and 278 km at 12, 24, 36, and 48 h, respectively, and standard deviations ranged from 164 km at 12 h to 322 km at 48 h. Average vector errors were nearly due west at all hours, extending from 32 to 75 km. In the WR (Fig. 4), errors were larger than for the means of the study. The average scalar errors ranged from 149 km, with a standard deviation of 194 km at 12 h, to 380 km, with a standard deviation of 457 km at 48 h. The average vector errors were all just slightly west of north and ranged from 21 km at 12 h to 123

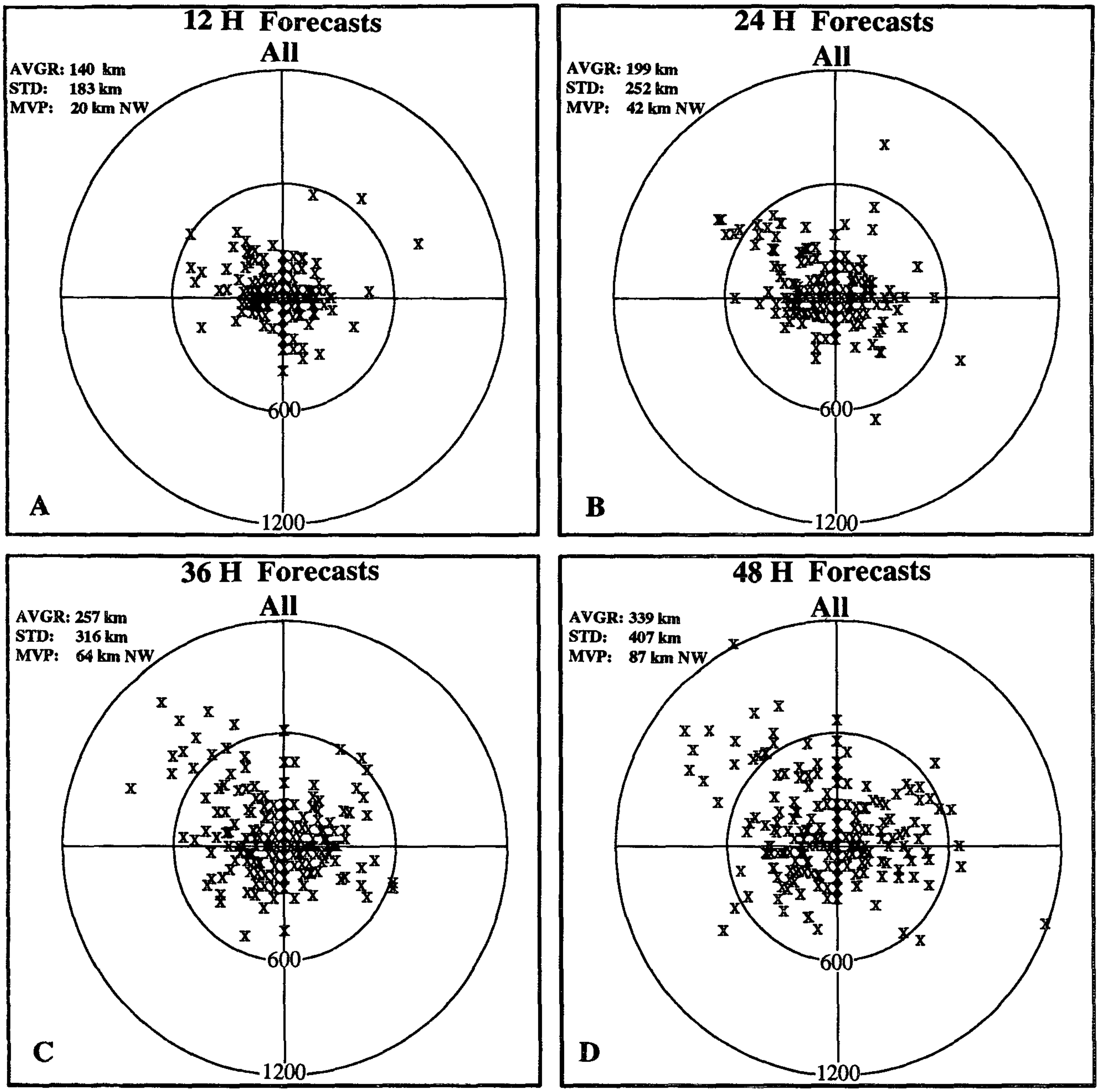

FIG. 2. Scatter diagrams of the error in (a) 12-, (b) 24-, (c) 36-, and (d) 48-h surface cyclone positions for all available forecasts of Alberta Clippers from 1 January 1988 to 31 December 1992. Each X represents a surface cyclone. An X directly north of the center indicates that the forecast position was north of the observed position. The inner and outer circles have radii of 600 and 1200 km, respectively. The average error (AVGR), standard deviation (STD), and mean vectorial point (MVP, with NW for northwest, SSE for south-southeast, etc.) are also shown.

km at 48 h. This is consistent with Mullen and Smith's (1990) and Smith and Mullen's (1993) results, which both showed that the NGM produced larger displacement errors in forecasting cyclone positions in the lee of the Rocky Mountains. One possible explanation for forecasts being somewhat better in the ER than the WR may be that Alberta Clippers tend to develop in northwesterly midtropospheric flow downstream of mountain barriers (see, e.g., Sanders 1988), and since the topography in the NGM is less than ideal, the model may have had difficulty positioning these cyclones in the lee of the Canadian Rocky Mountains, which would enhance the errors in the WR. Farther east, cyclone centers were generally more well defined; thus, it was easier to determine a central position for both the model and this researcher. Also, since the terrain in

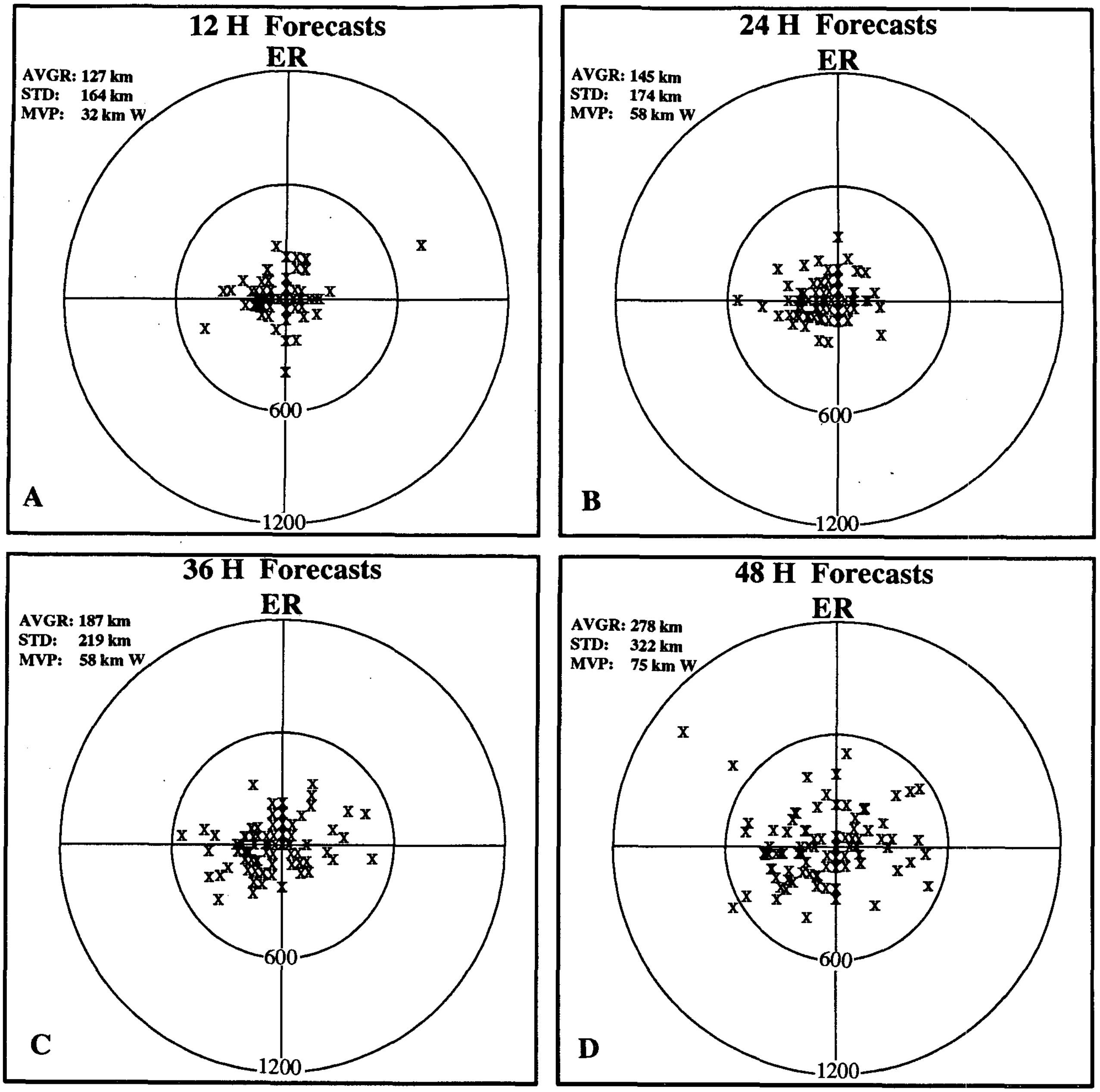

FIG. 3. As in Fig. 2 except for the ER.

the west is generally higher than that in the east, reduction of surface pressure to sea level pressure may have contributed to larger errors in the west. Contrary to the initial hypothesis, the geographical region 40°–52°N and 80°–90°W (Fig. 5), which encompasses the Great Lakes and is hereafter called the Great Lakes region (GLR), was a region in which the NGM did very well. Errors in this area ranged from 119 km, with a standard deviation of 161 km at 12 h, to 291 km, with a standard deviation of 343 km at 48 h. These errors are slightly smaller than Smith and Mullen (1993) found in their Great Lakes region (75°–85°E and 40°–50°N). The vectorial errors in the GLR were small and seemed rather random.

b. Central pressure errors

Table 1 shows the forecast errors of cyclone central pressure by geographic region. A negative (positive) value indicates that the cyclone was forecast too deep (not deep enough), that is, overforecast (underforecast). Values were placed in bold when,

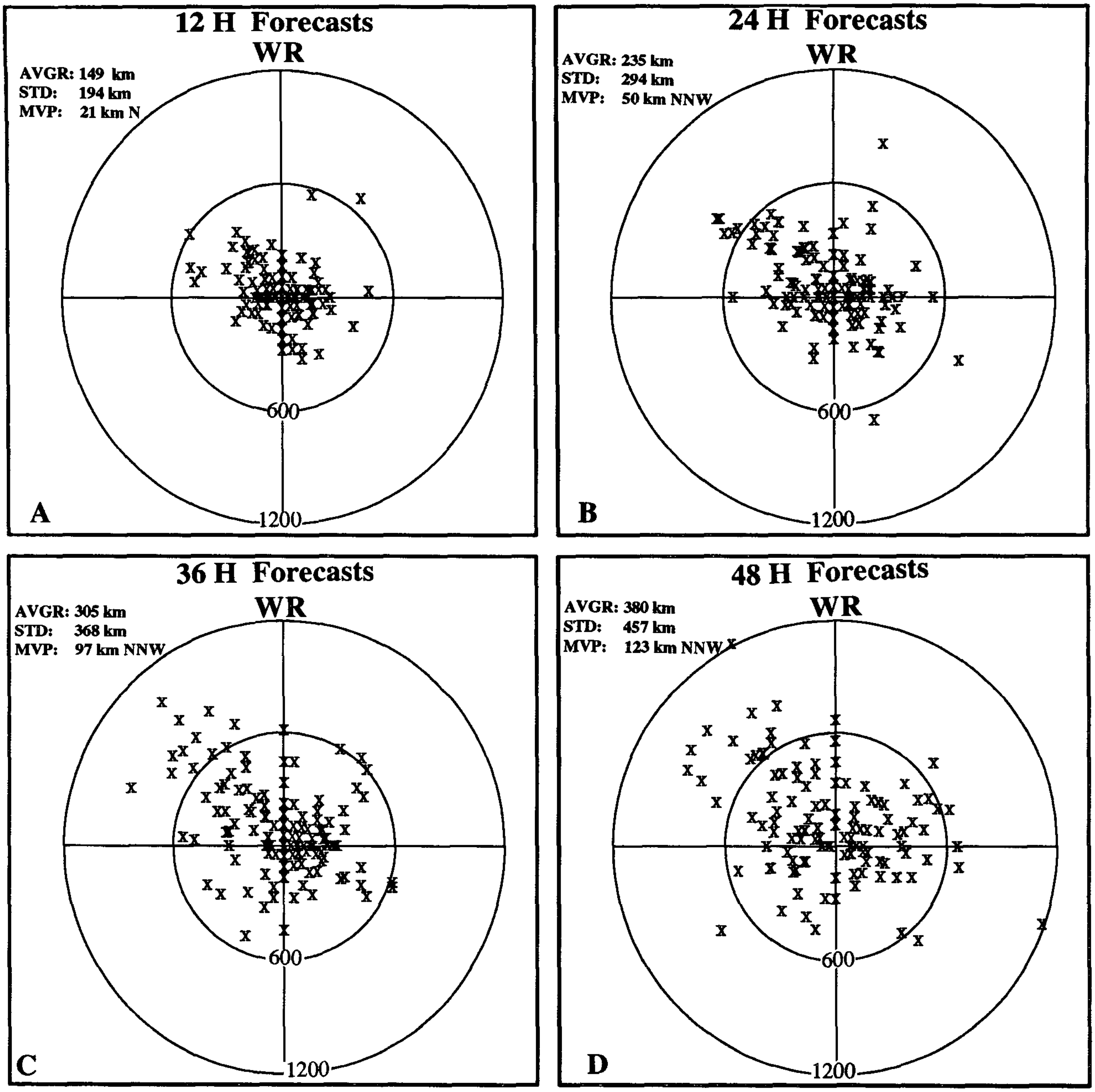

FIG. 4. As in Fig. 2 except for the WR.

according to a Student's t-test for comparing two population means (Mendenhall et al. 1990; Mullen and Smith 1990), they were significantly different (at a 95% confidence level) from the corresponding value in the region ALL. GOS, in the winter portion of their study, showed that the NGM tended to overforecast cyclone central pressure over all of interior North America. This characteristic error reversed very near the Atlantic coast and over the western Atlantic, where underprediction of central cyclone pressure was common. The results presented here show that the NGM tended to overforecast Alberta Clipper cyclones, consistent with the GOS results since the Alberta Clipper cyclones in this study were over land for most, if not all, of their life (Fig. 1). This central pressure error has been historically consistent in NMC forecast models since the advent of primitive equation models (see, e.g., Leary 1971; Silberberg and Bosart 1982; Grumm and Gyakum 1986; Grumm and Siebers 1989; Junker et al. 1989; Mullen and Smith 1990; Smith and Mullen 1993).

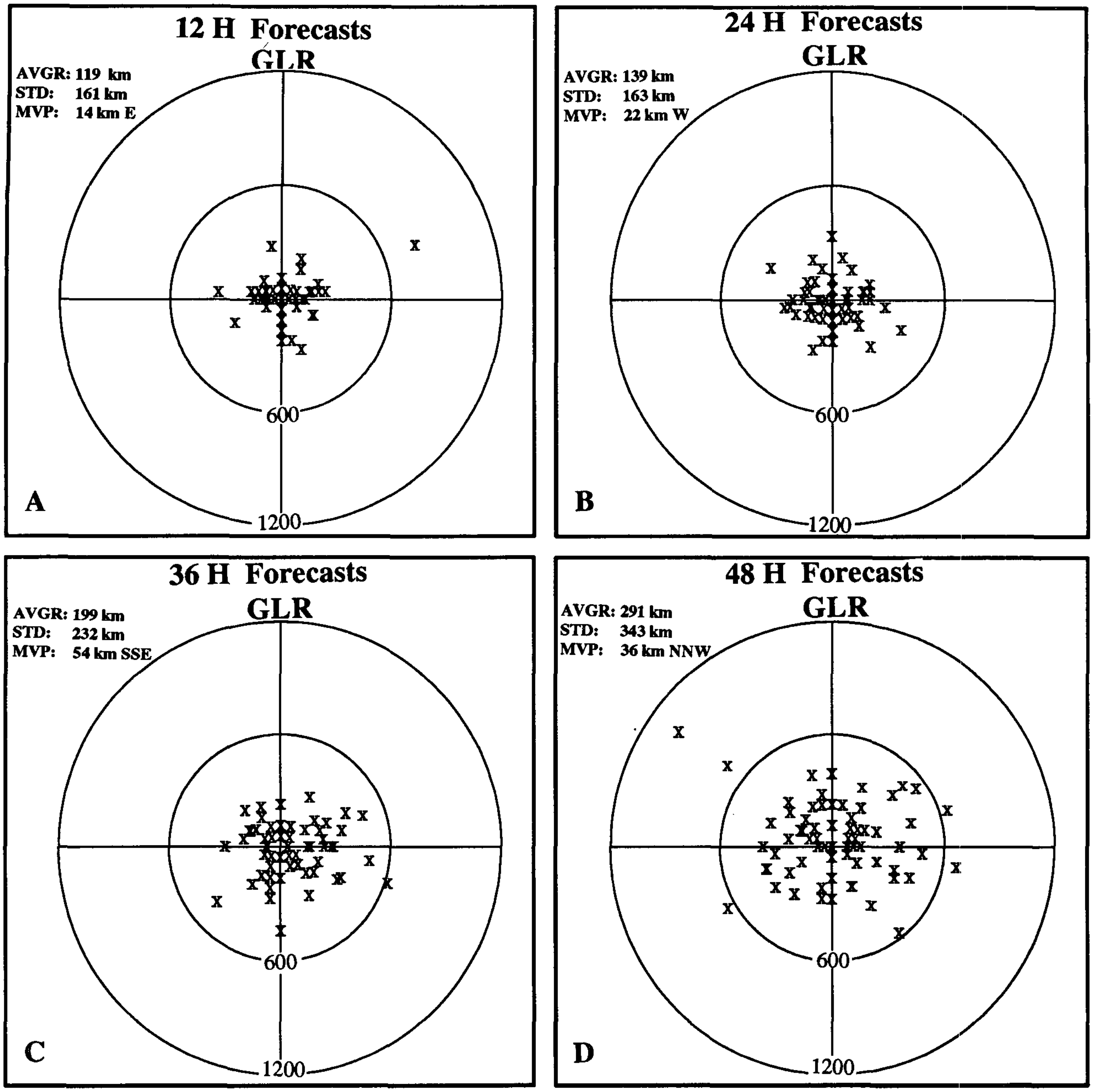

FIG. 5. As in Fig. 2 except for the GLR.

In the WR, cyclone central pressure of Alberta Clippers was underforecast by the NGM at 12 h, which is opposite from the characteristic errors for Alberta Clippers over the entire domain and was just slightly overforecast at 24 h (less than for all Alberta Clippers at 24 h). By 36 and 48 h, WR cyclones were overforecast. Consistent with the overall results, in the ER the NGM overforecast the central pressure of surface cyclones. At 12 and 24 h the overforecasting error was larger than the sample mean, while at 36 and 48 h the overforecasting error was smaller than the sample mean. In the GLR, underprediction is seen in the short range at 12 and 24 h, which is opposite to the characteristic NGM error for continental cyclones as shown in GOS, and for the subspecies of cyclones known as Alberta Clippers. By 36 and 48 h, there is a tendency for overprediction of cyclones in the GLR—however, to less of an extent than the model bias for continental cyclones (GOS).

TABLE 1. The NGM mean central pressure, thickness above the cyclone center, and height above the cyclone center errors by forecast hour (fcst hr) for Alberta Clippers for the period 1 January 1988 to 31 December 1992. Except for the region of ALL (all Alberta Clippers included), the data were stratified into the geographic regions as defined in the text. Data include the number of cases (verifications), the mean pressure error [average in hPa, with a negative (positive) value indicating overforecast (underforecast)], the mean 1000–500-hPa thickness (m) error, the mean 500-hPa height error, and the standard deviations (stdv) for each variable. Bold values indicate that the deviation was significantly (at the 95% confidence level) different from the corresponding value for the region ALL.

			Pressure (hPa)		Thickness (m)		Height (m)	
Region	fcst hr	Number	Mean	stdv	Mean	stdv	Mean	stdv
ALL	12	268	−0.01	2.51	−4.74	48.01	−2.50	57.88
ALL	24	244	−0.41	3.71	−6.60	56.21	−7.79	69.36
ALL	36	234	−0.52	4.76	−13.21	65.16	−12.99	81.60
ALL	48	214	−1.00	5.65	−14.11	74.68	−18.27	95.29
WR	12	170	**+0.49**	2.49	−4.06	49.07	+3.53	65.15
WR	24	149	−0.05	4.13	−11.88	60.00	−9.80	79.10
WR	36	140	−0.57	5.48	−21.78	71.66	−23.21	92.46
WR	48	128	−1.35	6.30	−26.17	81.64	**−36.64**	100.08
ER	12	104	**−0.86**	2.27	−5.67	45.21	**−12.88**	39.48
ER	24	101	−0.89	2.81	−2.97	48.31	−5.74	52.49
ER	36	99	−0.43	3.48	−1.52	51.41	+3.03	57.76
ER	48	89	−0.44	4.46	−4.16	58.23	+8.88	79.92
GLR	12	74	+0.20	1.70	−5.27	47.31	0.00	41.43
GLR	24	72	**+0.36**	2.88	−2.36	51.73	**+9.17**	60.32
GLR	36	70	−0.30	4.47	−0.86	62.65	−6.57	58.28
GLR	48	67	−0.66	5.07	−1.30	71.92	−9.70	86.95

c. Thickness and height errors

Table 1 also shows forecast errors of 1000–500-hPa thickness and 500-hPa height above cyclone centers stratified by region. A negative (positive) value indicates that the NGM forecast value was too low (high). Clearly, on average for the entire domain, the NGM tended to forecast thicknesses to be too low; that is, the NGM had a cold bias, which increased with increasing forecast hour. In the WR, the cold bias was smaller at 12 h but larger at 24, 36, and 48 h than the cold bias for the entire domain. In the ER, the cold bias was greater at 12 h but less at 24, 36, and 48 h than the cold bias for the entire domain. In fact, the ER cold bias was smaller at 36 h than it was at 12 and 24 h. The GLR showed similar trends but smaller values in biases than the ER.

GOS also found a cold bias in 1000–500-hPa thicknesses over cyclone centers. In the first winter of their two-year study, thickness errors ranged from −4.06 m at 12 h to −12.52 m at 48 h, while in the second year the errors were −2.73 m at 12 h and very near zero at 24, 36, and 48 h. Further, they also found a relatively large negative bias in the western part of North America and a smaller negative or slightly positive bias in eastern North America for 24- and 48-h NGM forecasts. Junker et al. (1989) found, for 48-h NGM forecasts of 850–500-hPa thicknesses, a cold bias west of about 95°W and a weaker warm bias east of that longitude.

Overall the mean 500-hPa height errors above cyclone centers were negative (low) and increased in magnitude with forecast hour. In the WR, height forecasts were too high at 12 h, but were too low and larger (in magnitude) than the means for the study between 24 and 48 h. In the ER, heights were forecast too low and larger (in magnitude) than for the entire domain at 12 h, but were forecast too low and smaller than for the entire domain at 24 h. By 36 and 48 h, heights were forecast too high in the ER. Errors in the GLR showed rather random fluctuations going from no bias at 12 h to a positive bias at 24 h to a negative bias at 36 and 48 h.

4. Discussion

Positional and central pressure errors of NGM forecasts of Alberta Clippers in the entire domain were found to be consistent with overall NGM forecast errors shown for land cyclones by GOS. However, positional and central pressure forecast errors in the GLR were found to be smaller than the GOS results for land cyclones. Since the Great Lakes remain mostly ice free in most winters [with the exception of Lake Erie (Niziol 1987)], and given that the overlying air mass is generally colder than the lakes in winter, surface moisture and heat fluxes would be expected from the Great Lakes. By contrast, during most of the sample period, due to the method used to determine the initial conditions for ice cover in the Great Lakes, the lakes were generally considered ice covered when the land areas surrounding them were snow covered (Petersen and Hoke 1989). Given that the Great Lakes are poorly represented in the NGM in terms of surface moisture and heat fluxes (Petersen and Hoke 1989) and that these fluxes are conducive to atmospheric warming, moistening, and destabilization, one would expect the NGM to show an aberration from its overall continental bias of overforecasting sea level pressure toward a smaller bias of overforecasting or a bias of underforecasting sea level pressure over and near the Great Lakes. Historically, primitive equation models run by NMC have shown a tendency to underforecast the intensity of oceanic cyclones (Leary 1971; Silberberg and Bosart 1982; Grumm and Gyakum 1986; Grumm and Siebers 1989; GOS; Mullen and Smith 1990; Smith and Mullen 1993). Similarly, this study showed a tendency of the NGM to lean toward underforecasting or less overforecasting (relative to land cyclones) in the GLR; that is, pressure errors in the GLR were between those errors for all land cyclones and those for all oceanic cyclones. Further, the GLR was also found to be an area of low thickness errors. As discussed above, one would expect warming of the lower atmosphere near the Great Lakes. Thus, it is likely that the overall cold bias of the NGM was somewhat offset by warming near the lakes.

The positional errors were such that in the ER (Fig. 3) there was a tendency of the points to be scattered with an axis of forecast positions from the west or west-southwest to the east or east-northeast of verification. In the WR (Fig. 4) at all forecast hours there was a tendency of the points to be scattered such that there was an axis of forecast positions from the northwest to southeast of verification. In the GLR the axis of forecast positions tended to be aligned along a line due west to due east of verification. Since the direction of cyclone travel (Fig. 1) was primarily from the northwest in most of the WR, generally from the west in the GLR, and primarily from the west or west-southwest in the ER, it appears that the NGM may have had difficulty predicting the speed at which these cyclones progressed. Furthermore, cyclones were more often forecast too slow than too fast, with errors in the WR concentrated more northwest than southeast of verification and errors in the ER concentrated more west than east of verification. This is consistent with the Mullen and Smith (1990) and the Smith and Mullen (1993) results, which both showed that the NGM had a tendency to forecast cyclones more often too slow than too fast.

Mullen and Smith (1993) examined NGM forecasts of cyclones for two different upper-level large-scale flow patterns over two winter seasons (1987/88 and 1989/90). One of which allowed for a 500-hPa ridge in the western United States and a 500-hPa trough in the eastern United States. They showed that one of the primary storm tracks that develops in this pattern is coincident with storm tracks of Alberta Clippers. Their results (their Fig. 7) suggest that NGM cyclone vector positional errors are large and northwest of the verifying position in the lee of the Canadian Rockies, while errors in the GLR are relatively small. This is consistent with the results found in this study. However, in their Great Lakes region, Mullen and Smith found cyclones to be overforecast in the short range (−0.39 hPa at 24 h) and underforecast in the longer range (+1.18 hPa at 48 h), contradicting the results presented here.

The period for which this study encompasses was bound by an anomalous pattern with a strong upper-level ridge in the eastern United States. Over the 45 months for which the study took place, average monthly 500-hPa heights were above normal in 22 of the months, near normal in 11 of the months, and below normal in 12 of the months (Kousky 1988–1992). Thus, it is possible that the results presented here may have been slightly different had there been a "normal" upper-level flow pattern.

5. Conclusions

A 5-yr sample of NGM forecasts of Alberta Clippers was analyzed. The tracks of Alberta Clippers presented here show that they tended to track over the northern part or just north of the Great Lakes. In general, the NGM forecast Alberta Clippers too far to the north and west, consistent with the Grumm et al. (1992) results for all winter cyclones in their domain. NGM forecasts of Alberta Clippers were shown to be better east than west of 84°W. Forecasts in the Great Lakes region were better than in other regions. Thus, contrary to the initial hypothesis, the NGM's poor forecasts of snowfall in Albany associated with Clippers were not the result of inadequacy in predicting the location and intensity of Alberta Clippers in the vicinity of the Great Lakes. Positional forecast errors tended to be aligned along the direction of travel of the cyclones, indicating that the NGM had difficulty diagnosing the speed of these cyclones. Overall, central pressures of Alberta Clippers were overforecast, consistent with the Grumm et al. (1992) winter results. The Great Lakes region showed less error than other regions. Forecasts of 1000–500-hPa thicknesses over cyclone centers were much better east of than west of 84°W. Once again, near the Great Lakes, thickness forecasts were better than in other regions. The smaller positional, surface central pressure and thickness errors near the Great Lakes may have been associated with a deviation from the NGM's systemic errors as a result of the partial representation of surface sensible and latent heat fluxes near the Great Lakes.

Since forecast tracks and central pressures of Alberta Clippers east of 84°W were relatively good, it is possible that NGM upper-level wind forecast errors, unresolved mesoscale structure in NGM forecasts, or other atmospheric features misrepresented by the NGM were responsible for poor precipitation forecasts associated with Alberta Clippers for Albany.

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