Systematic Surface Anticyclone Errors in NMC's Limited Area Fine Mesh and Spectral Models during the Winter of 1981/82

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ABSTRACT

An examination is made of the current National Meteorological Center (NMC) operational models' ability to forecast surface anticyclones. A study of the 1981–82 cold season reveals systematic underprediction of the phenomenon on the part of both the Limited Area Fine Mesh (LFM) and spectral models. However, the LFM forecasts weaker anticyclones than does the spectral model. This difference is apparent in the region of eastern North America and the western Atlantic Ocean. The systematic underprediction found in this study is as great as Colucci and Bosart found for NMC's six-layer primitive equation model.

No overall systematic forecast bias is found for the 1000–500 mb mean temperatures over the surface anticyclones. However, excessively warm temperatures are forecast in the Pacific northwest region of both models, and the LFM forecasts erroneously cold temperatures in the western Atlantic basin south of 40°N. The spectral model shows a significant improvement over the LFM in this latter region.

The mean anticyclone displacement error for both models at 48-h range is about 500 km. There is also a tendency for both models to place anticyclones erroneously to the south and east of their observed positions, suggesting the models' translation of these anticyclones to be too fast. Colucci and Bosart also found a fast bias, but this study suggests an overall improvement in anticyclone placement.

Finally, a case of a recently poorly forecast anticyclone-cyclone complex illustrates the deleterious effects of those forecasts can have in the attempt to correctly forecast significant precipitation events. Our study shows an unforecasted precipitation event to have occurred in a lower troposphere warm advection region associated with a poorly forecasted surface anticyclone.

1. Introduction

The purpose of this paper is to assess recent operational numerical model performance in surface anticyclone forecasting. Several recent studies have focused upon operational model error statistics at 500 mb (e.g., see Bettge and Baumhefner, 1984; Bettge, 1983; Bengtsson, 1985). Other operational forecast verification studies have examined model surface cyclone behavior, such as those performed by Leary (1971) and Silberberg and Bosart (1982). These studies are useful for examining the meteorology of planetary-scale circulations or of the highly energetic cyclonic surface circulations. However, the surface anticyclone, which frequently dominates weather patterns, deserves equivalent scrutiny.

Recent literature has emphasized the importance of anticyclones, not only in daily temperature changes (Dallavalle and Bosart, 1975), but also to the energetics of the more robust cyclone (Boyle and Bosart, 1983). Colucci and Bosart (1979, hereafter referred to as CB), using 36-h National Meteorological Center (NMC) six-layer primitive equation (6-L PE) model (Shuman and Hovermale, 1968) output verifying at 1200 GMT each day from 1 October 1969 through 31 March 1970, have shown this model to generally underestimate surface anticyclone central pressures.

Our study will examine forecast anticyclone errors of position, central pressure, and 1000–500 mb thickness in both the Limited Area Fine Mesh (LFM, see Gerrity, 1977) and spectral (Sela, 1980) models. We will assess whether recent model anticyclone simulations have improved since the time of CB's study. We will compare results among the two models in this study and with the model studied by CB. To accomplish our assessment of recent operational model performance, we will examine whether systematic errors exist in the NMC's LFM and global spectral models. While NMC has introduced a new operational model this past year in the Regional Analysis and Forecast System (RAFS, see Hoke et al., 1985), it is important to document existing systematic errors in the LFM and

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spectral models for both research and operational considerations. Further, the LFM model will still be used in generating model output statistics for temperature and precipitation forecasting during the near future, so its forecasts will continue to have impact in the operational forecast environment. This paper places into sharper focus some of the current problems of anticyclone forecasting, with the hope that further research be spurred into this important process.

Section 2 describes the methodology, section 3 presents results of our anticyclone error analysis, and section 4 examines recent operational forecast anticyclone errors associated with a poorly forecasted precipitation event. The concluding discussion is presented in section 5.

2. Methodology

An anticyclone in this study is defined as a point of relatively high sea-level pressure, surrounded by at least one closed isobar (analyzed at 4-mb intervals) in the forecast or verification (LFM initial analysis) maps. Both the 0000 and 1200 GMT 48-h forecast runs were used for the period 1 December 1981 through 31 March 1982.

The LFM model, first used by NMC in 1972, was used in 1981–82 with 191 km horizontal grid spacing, valid at 60°W on a polar stereographic projection. Fourth-order differencing was used during the 1981–82 period and continues to be used on this 191 km mesh through the present. Seven layers are used in the model, with a 50-mb fixed depth planetary boundary layer and three tropospheric layers. Three additional layers above the tropopause extend to 50 mb. Complete details of the LFM model can be found in work by Gerrity (1977) and Newell and Deaven (1981). The LFM model currently continues to run operationally at NMC as part of the Early Analysis and Forecast System at NMC.

The global spectral model replaced NMC's seven-layer PE model as the primary operational hemispheric/global model in August 1980. A rhomboidal 12-layer 30 zonal wave version of the model was used during the 1981–82 cold season. Eight layers exist from the surface to 200 mb. The model was run with a data cutoff of approximately 3.5 h after the observation times of 0000 and 1200 GMT during 1981–82. This is about 1 h, 45 min after the LFM data cutoff time. Further details of the model may be found in Sela's (1980) work. This model currently continues to be run as part of NMC's Aviation Analysis and Forecast System.

The geographical area of study ranges from 25° to 70°N and approximately from 50° to 160°W, which encompasses most of North America, the eastern Pacific, and western Atlantic Oceans. The area was further subdivided into four distinct regions with the intersection point of the boundaries occurring at 45°N, 100°W.

These four regions are called Atlantic Northeast (AN), Atlantic Southeast (AS), Pacific Northwest (PN), and Pacific Southwest (PS). The elevated front range region of the United States is westward of 100°W, and the relatively warm waters of the Gulf of Mexico and Atlantic Gulf Stream are located in the Atlantic Southeast region. The detailed geographical area of study, showing these regions, is shown in Fig. 1.

For each 48-h forecast and verification, the following information was tabulated:

1) The latitude and longitude of the anticyclone center to the nearest half degree.

2) The anticyclone central pressure, as labeled or subjectively interpolated from the analyzed or forecasted isobars.

3) The 1000–500 mb thickness over the analyzed or forecasted anticyclone.

A total of 445 and 418 forecasted anticyclones were tabulated for the LFM and spectral models, respectively. However, illegible facsimile maps precluded estimates of thickness and/or pressure in less than 1% of the cases.

Errors in sea level pressure and thickness of the anticyclone are defined as forecast minus observed. Thus, a positive (negative) error in pressure corresponds to overforecasting (underforecasting). A negative (positive) error in the thickness corresponds to a forecast being too cold (warm).

Sea level pressure and thickness errors are tabulated in 5° by 5° latitude-longitude quadrangles corresponding to the anticyclone's verifying position, regardless of where the corresponding forecasted anticyclone occurred. The individual errors in each box are averaged to yield one error value, valid at the quad-

![Fig. 1. The geographical domain and the regions Atlantic Northeast (AN), Atlantic Southeast (AS), Pacific Northwest (PN), and Pacific Southwest (PS).](image-url)
range's center. Any anticyclone verifying on a box's boundary is classified as belonging to the north and/or west adjacent box. Leary (1971) introduced this analysis procedure in his study of systematic errors.

A case in which no anticyclone occurred, but was forecasted to occur, was tabulated as NOBS in the forecasted position. An anticyclone observed, but not forecasted, was recorded as NFCST in the observed position.

3. Results

Figure 2 shows a smoothed subjective analysis of the observed anticyclone geographical distribution. This sample was used in the LFM error analysis; the corresponding distribution used for the spectral model sample is nearly identical. High concentrations of anticyclones are found in the eastern United States, the Rocky Mountains, northwest Canada, and the southeastern Pacific Ocean. This pattern of anticyclone frequency is similar to that found by CB for 1969-70, except that a higher concentration of anticyclones existed in northwest Canada during 1981-82. This pattern is also qualitatively similar to the 28-year climatology of anticyclones presented by Zishka and Smith (1980). The large-scale flow pattern during this season was especially conducive to anomalously large numbers of surface anticyclones forming in this region (e.g., see Wagner, 1982). Clearly, once the upstream ridge was established, radiational cooling helped develop and maintain many of these anticyclones, as has long been known (e.g., Wexler, 1937).

Figures 3a and 3b show the geographical distribution of pressure errors for the LFM and spectral models, respectively. Both models underforecast anticyclone intensities over large parts of the domain. This is especially true for eastern North America, with the LFM showing large systematic underpredictions in the northeastern United States. The mean pressure error for the entire domain is -2.2 and -1.6 mb for the LFM and spectral models, respectively. Overforecasted anticyclones occur systematically in both models in the western United States, but the area of overforecast high extends from the high plains eastward into the Ohio Valley only for the spectral model. An error pattern in the United States similar to the global spectral model was found by CB.

Figure 4 shows the anticyclone pressure error distributions of each model. Both distributions show a preponderance of cases of negative pressure errors signifying excessively weak anticyclone forecasts. The small skewness coefficients indicate the distributions

![Figure 2](image)
are centered close to the mean, as in a normal distribution. The kurtosis values show slightly enhanced peakedness over that of a normal distribution, whose kurtosis is three. A Student's t test of each distribution indicates that at the 99.9% confidence level, each distribution is significantly different from a corresponding
distribution with mean of zero. Thus, we may conclude that both operational models significantly underforecast surface anticyclones.

Table 1 summarizes the pressure error statistics by region. The underforecasting of anticyclones is especially apparent in the region east of 100°W in the LFM model. The Atlantic Southeast region spectral forecasts represent the only category in which we are not confident (at the 95% level) of a systematic forecasting bias.

A comparison of LFM and spectral anticyclone errors was made case by case, and the frequency distribution of the difference between the LFM and spectral errors is shown in Fig. 5. There is a suggestion that the LFM forecasts less intense anticyclones than does the spectral model. The t-test indicates that, at the 96% confidence level, the sample distribution shown in Fig. 5 is taken from a population with a nonzero mean. The regional statistics shown in Table 2 indicate that at the 99% confidence level, the relative underforecasting of anticyclones in the LFM compared with the spectral model is confined to the region east of 100°W.

Figure 6 shows the geographical distribution of observed, but unforecasted anticyclones in both models. Each model misses anticyclones in the southwestern United States, the southeastern Pacific Ocean, and the Yukon. The major difference between the models occurs in eastern North America, where the spectral model has little trouble forecasting anticyclones, and where the LFM otherwise failed to forecast several anticyclones. Colucci and Bosart found an unforecasted distribution similar to that of the LFM found in this study.

The forecasted, but not observed, anticyclones (Fig. 7) are located primarily in elevated regions of the western United States. The spectral model shows this error to occur in the Great Basin region, while the LFM has a more extensive concentration just east of the Continental Divide in the northern United States. The models also forecasted some phantom anticyclones in the Rio Grande and Mississippi River valleys, the western Gulf of Mexico, and in northwestern Canada.

Figure 8 shows the 1000–500 mb thickness error maps for both models. Strong regional differences are

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**Table 1.** LFM and spectral pressure error statistics. Significant departures at the 95% level from zero are indicated with an asterisk next to the t-value.

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>Mean (mb)</th>
<th>Standard deviation (mb)</th>
<th>t (mb)</th>
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<tbody>
<tr>
<td>LFM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>81</td>
<td>-4.42</td>
<td>5.56</td>
<td>-7.11*</td>
</tr>
<tr>
<td>AS</td>
<td>103</td>
<td>-2.35</td>
<td>5.36</td>
<td>-4.43*</td>
</tr>
<tr>
<td>PS</td>
<td>124</td>
<td>-1.10</td>
<td>4.84</td>
<td>-2.52*</td>
</tr>
<tr>
<td>PN</td>
<td>133</td>
<td>-1.87</td>
<td>5.76</td>
<td>-3.73*</td>
</tr>
<tr>
<td>all</td>
<td>441</td>
<td>-2.23</td>
<td>5.42</td>
<td>-8.63*</td>
</tr>
</tbody>
</table>

| Spectral |    |           |                         |       |
| AN       | 85 | -2.41     | 4.55                    | -4.85*|
| AS       | 103| -0.58     | 3.47                    | -1.69 |
| PS       | 104| -1.39     | 4.34                    | -3.25*|
| PN       | 125| -2.03     | 5.37                    | -4.21*|
| all      | 417| -1.59     | 4.58                    | -7.08*|

**Table 2.** LFM pressure error minus spectral pressure error statistics. Significant departures (at the 95% level) from zero are indicated with an asterisk next to the t-value.

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>Mean (mb)</th>
<th>Standard deviation (mb)</th>
<th>t (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>68</td>
<td>-2.02</td>
<td>4.79</td>
<td>-3.45*</td>
</tr>
<tr>
<td>AS</td>
<td>77</td>
<td>-0.00</td>
<td>4.37</td>
<td>-3.99*</td>
</tr>
<tr>
<td>PS</td>
<td>79</td>
<td>0.52</td>
<td>4.68</td>
<td>0.98</td>
</tr>
<tr>
<td>PN</td>
<td>104</td>
<td>0.51</td>
<td>5.60</td>
<td>0.92</td>
</tr>
<tr>
<td>all</td>
<td>328</td>
<td>-0.60</td>
<td>5.11</td>
<td>-2.13*</td>
</tr>
</tbody>
</table>
Fig. 6. The geographical distribution of nonforecasted anticyclones for (a) the LFM and (b) the spectral models. Contour interval is two events. Smoothing and analysis procedure is as for Fig. 2.

shown. A 60-m thickness error corresponds approximately to a mean virtual temperature error of 3°C. Both models forecast excessively cold anticyclones in the southeastern United States, the Mississippi River Valley, and in the Canadian Maritime Provinces. A warm bias exists for both models in the Great Lakes region. Negative thickness errors exist in northwestern Canada for both models. The area of excessively warm
LFM anticyclones in the northwestern United States is smaller and is shifted westward offshore in the spectral model. An extensive area of cold bias, which exists in the upper Mississippi River Valley for the LFM, is concentrated in eastern Texas for the spectral model. Colucci and Bosart's extensive area of excessively cold anticyclones in the western United States is opposite of that which we find in this region for the LFM. The area of warm bias in northern Alaska and northwestern Canada is the opposite of CB's cold bias in that region.
Though we do not find the overall cold thickness error found by CB, their concentration of negative thickness bias in the eastern United States and western Atlantic Ocean is similar to our result.

The anticyclone thickness error statistics are summarized in Table 3. Overall, we see a very small positive mean thickness error for each model, although we can attach no statistical significance to either bias. There
is, however, a strong suggestion of a warm bias in the Pacific Northwest region of both models. The Student’s t test for both samples shows that, at the 99.9% confidence level, these distributions come from a population whose mean thickness error is other than zero. Additionally, there is a suggestion of a cold bias (at the 96% significance level) in the LFM anticyclone forecasts in the Atlantic Southeast region. The sample thickness error distributions (not shown) overall are close to normal distributions, with skewness values of 0.05 and 0.15, and kurtosis values of 4.36 and 3.82 for the LFM and spectral models, respectively.

A case-by-case comparison of each model’s anticyclone thickness errors has been made, and the frequency distribution of the LFM-spectral differences is shown in Fig. 9. These overall data show the sample mean of −1.23 dam departs significantly from a population where the mean is zero. There is a slightly negative skewness, and the kurtosis shows peakedness somewhat greater than the normal distribution coefficient of three. Table 4 indicates that statistically significant differences in thickness error between the two models exist only in the regions east of 100°W, where the LFM forecasts colder anticyclones than does the spectral model. More specifically, the spectral model effectively eliminates the LFM’s significant cold bias in the Atlantic Southeast region (Table 3).

![Graph](image)

**FIG. 9.** As in Fig. 5 except for LFM minus spectral anticyclone thickness error distribution.

**TABLE 3.** LFM and spectral 1000–500 mb anticyclone thickness error statistics. Significant departures (at the 95% level) from zero are indicated with an asterisk next to the t-value.

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>Mean (dam)</th>
<th>Standard deviation (dam)</th>
<th>t (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LFM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>79</td>
<td>−0.68</td>
<td>9.59</td>
<td>−0.63</td>
</tr>
<tr>
<td>AS</td>
<td>102</td>
<td>−1.32</td>
<td>7.14</td>
<td>−2.14*</td>
</tr>
<tr>
<td>PS</td>
<td>122</td>
<td>0.21</td>
<td>6.14</td>
<td>0.37</td>
</tr>
<tr>
<td>PN</td>
<td>129</td>
<td>2.23</td>
<td>7.09</td>
<td>3.56*</td>
</tr>
<tr>
<td>all</td>
<td>432</td>
<td>0.24</td>
<td>7.52</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Spectral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>85</td>
<td>1.12</td>
<td>7.57</td>
<td>1.35</td>
</tr>
<tr>
<td>AS</td>
<td>103</td>
<td>−0.71</td>
<td>7.65</td>
<td>−0.94</td>
</tr>
<tr>
<td>PS</td>
<td>104</td>
<td>−0.45</td>
<td>5.95</td>
<td>−0.77</td>
</tr>
<tr>
<td>PN</td>
<td>124</td>
<td>2.36</td>
<td>7.22</td>
<td>3.62*</td>
</tr>
<tr>
<td>all</td>
<td>416</td>
<td>0.64</td>
<td>7.23</td>
<td>1.81</td>
</tr>
</tbody>
</table>

**TABLE 4.** LFM 1000–500 mb thickness error minus spectral thickness error statistics. Significant departures (at the 95% level) from zero are indicated with an asterisk next to the t-value.

<table>
<thead>
<tr>
<th>Region</th>
<th>N</th>
<th>Mean (dam)</th>
<th>Standard deviation (dam)</th>
<th>t (mb)</th>
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<tbody>
<tr>
<td></td>
<td>LFM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AN</td>
<td>67</td>
<td>−2.63</td>
<td>6.56</td>
<td>−3.25*</td>
</tr>
<tr>
<td>AS</td>
<td>75</td>
<td>−1.76</td>
<td>5.87</td>
<td>−2.58*</td>
</tr>
<tr>
<td>PS</td>
<td>78</td>
<td>0.75</td>
<td>6.59</td>
<td>1.00</td>
</tr>
<tr>
<td>PN</td>
<td>102</td>
<td>−1.41</td>
<td>7.98</td>
<td>−1.77</td>
</tr>
<tr>
<td>all</td>
<td>322</td>
<td>−1.23</td>
<td>7.00</td>
<td>−3.15*</td>
</tr>
</tbody>
</table>

Errors in the model anticyclone position are summarized in Fig. 10. Mean displacement errors for both models are about 500 km. The tabulations for the position errors are based upon the anticyclone’s verifying position. This compares favorably with CB’s finding of a 517 km displacement error, since their study examined 36-h forecasts. The LFM shows its largest mean position error (520 km) in the Atlantic Southeast region, where the spectral has its smallest position error (435 km). Directional errors were diagnosed for all cases forecasted at least 50 km (or approximately one-half degree latitude) from their observed positions. Figure 10 shows the percentage of cases with directional errors in each of eight 45° sectors with respect to the origin (observed anticyclone position). For example, if a forecasted anticyclone is located 20° clockwise from north of its observed position, then it would be categorized in the sector east of the segment connecting the origin and the word “North.” To determine whether directional biases exist in this sample, the “chi-square” (χ²) test was used. If we hypothesize that approximately an equal number of cases would be expected in each of the eight sectors, then we can test this by computing χ² (e.g., see Panofsky and Brier, 1968)

\[
\chi^2 = \sum_{i=1}^{g} \frac{(O_i - H_i)^2}{H_i}
\]

where \(H_i\) is the hypothesized number of cases in the \(i\)th sector, and \(O_i\) is the observed number of cases in the \(i\)th sector. Thus, as the observed distribution increasingly departs from the hypothetical distribution, \(\chi^2\) becomes larger. The value of \(\chi^2\) beyond which we can reject the null hypothesis of equally distributed cases (at the 95% confidence level) is 14.1 (Panofsky and Brier, 1968). Thus, Fig. 10 indicates that both models overall show a distribution substantially different from the unbiased one with a preponderance of forecasted cases located south and east of the observed anticyclone position. This directional bias appears most pronounced in areas west of 100°W (Figs. 10d, e). No significant directional bias can be detected in the AN region for the LFM or the AS region for the spectral model. This tendency for the models to place surface anticyclones to the south and east of the observed position was also found by CB. Implicit in this finding is
Fig. 10. Summary of LFM and spectral displacement and directional error statistics for (a) all regions, (b) AN, (c) AS, (d) PS, and (e) PN regions. The numbers in each 45° sector are percentages of total number of cases forecasted more than 50 km from the observed position. LFM percentages are the top numbers; spectral percentages are shown in parentheses.

a corresponding enhanced anticyclone phase speed bias since most surface anticyclones in our sample move to the southeast. A recent case illustrating some of the model systematic errors will be discussed in the next section.

4. A poorly forecasted anticyclone

The purpose of this section is to examine a recent surface anticyclone case that contained representative central pressure and placement errors found in our study. The models discussed in this section have changed only slightly since our 1981–82 study period. One of the key changes in the global spectral model includes an enhancement in the horizontal resolution from 30 modes to 40, beginning in 1983. A primary change in the LFM occurred in January 1985 with a new surface stress formulation, which allows for this frictional effect to extend above the model’s 50-mb boundary layer into the lower troposphere. Previously, all of the frictional effect was contained within the lowest 50 mb. The objective in this change was to lessen the LFM’s tendency to deepen excessively lee cyclones. Small impact on overall forecast quality was found on the basis of internal comparisons at NMC. In spite of those small changes in the models, the following recent example of a poorly forecasted anticyclone illustrates some continuing forecast errors which are similar to those found in our 1981–82 forecast sample.

The LFM and spectral model sea-level pressure and 1000–500 mb thickness forecasts for 1200 GMT 10 February 1985, along with the corresponding verifi-
cation chart, are shown in Fig. 11. The LFM over-
forecasts the observed 1028 mb Nevada surface antici-
cyclone by 6 mb. Both models failed to capture the
intensity and placement of the observed 1032 mb sur-
face anticyclone located in northeastern Ohio. The
LFM's 1025 mb surface anticyclone in the western At-
lanic Ocean shows its tendency to place anticyclones
excessively far to the south and east of the observed
position. Although the spectral model does forecast the
surface ridge to be east of the observed 1032 mb Ohio
surface anticyclone, its position is more correctly placed
westward of the aforementioned LFM 1025 surface
high. The extensive cyclonic circulation seen in the
LFM forecast, extending from Mexico northward to
the Canadian border, and from eastern Kentucky
westward to the Continental Divide, is substantially
smaller and more concentrated in the verification. The
LFM's excessively low Oklahoma and Texas cyclone
central pressures of 1001 mb are good examples of the
model's systematic tendency to overforecast continen-
tal cyclones between the Rocky Mountains and the
Great Lakes (Silberberg and Bosart, 1982). The ob-
served inverted trough extending from a 1014 mb sur-
face low in southwestern Missouri is located between
the aforementioned Ohio anticyclone and a vigorous
1034 surface high in extreme southeastern Saskatch-
ewan. Both models failed to simulate the circulation
associated with this cyclone–anticyclone complex. The
LFM has essentially no surface ridge in the vicinity of
this Saskatchewan anticyclone. The spectral model,
however, does forecast a correctly placed, though
weaker-than-observed, surface ridge west of the in-
verted trough.

The corresponding 500-mb forecasts and analyses
(Fig. 12) show the LFM forecast to have missed the
essence of the observed meridionally oriented ridge
through central Ohio. Both models excessively de-
veloped the 500 mb trough upstream of this Great Lakes
ridge. The LFM forecast shows a ridge and associated
anticyclonic vorticity advection confined erroneously
to the western Great Lakes. The spectral model does
forecast a 500-mb ridge in the east, but its amplitude
is slightly weaker than observed, and its location is
about 300 km east of the observed ridge. Upstream of
where the observed 1034 mb Saskatchewan surface
ridge exists is a 500-mb ridge north of Montana. The
LFM forecast, however, shows a weak trough in this
region, which extends southeastward into a spurious
cyclonic vorticity maximum in South Dakota. The
spectral model does feature a 500-mb ridge, which is
most intense in southeastern Montana. However, this
feature is displaced southeastward of the corresponding
observed ridge.

An important consequence of the LFM's missed
Ohio surface anticyclone forecast is the associated
weaker-than-observed surface geostrophic warm ad-
vection, which is especially strong in the region ex-
tending from the observed surface trough in south-
western Missouri northeastward into eastern Indiana.

Fig. 11. (a) LFM 48-h forecast of sea level pressure (mb, solid)
and 1000–500 mb thickness (dam, dashed) for 1200 GMT 10 Feb-
uary 1985; (b) as in (a) except for spectral model 48-h forecast; and
(c) LFM analysis of sea level pressure and thickness for 1200 GMT
10 February 1985.
and western Michigan. Thus, quasi-geostrophically, one would expect ascent and precipitation in this region, whereas the LFM 48-h forecast was mainly devoid of any precipitation here. The Model Output Statistics (see Berlowitz, 1975) measurable precipitation probabilities ranged from 15% in Wisconsin to about 20% in Indiana and Illinois. In fact, an extensive area of precipitation had covered Missouri, Illinois, Indiana, and Wisconsin by 1200 GMT 10 February 1985, with 12-h amounts ranging up to 5 mm.

Other factors associated with the precipitation probabilities being excessively minimized included a forecast of mean tropospheric relative humidities of less than 50% in the affected regions, whereas the corresponding verifications were about 80%. Additionally, the LFM forecasted weak subsidence in much of Illinois, Indiana, and Wisconsin. Our kinematic calculations, in fact, show ascent in these regions to have exceeded 4 μb s⁻¹. Both of these factors were closely related quasi-geostrophically to the poorly forecasted warm advection associated with the poorly forecasted cyclone–anticyclone couplet.

The radar summary chart (Fig. 13) for 1135 GMT 10 February shows an extensive area of light, occasionally moderate, rain, snow, and freezing rain extending from southwestern Missouri into eastern Indiana and Wisconsin. This area corresponds closely to the previously described warm advection region. As pointed out earlier, measurable precipitation had covered all of Illinois, Indiana, and southern Wisconsin by this time, and the LFM missed all of this precipitation in its 48-h forecast.

The surface sectional map for this time (Fig. 14) clearly shows a wind shift from a southeasterly direction to northeasterly, westward across the inverted trough. The northerly and east-southeasterly flows associated with, respectively, the Saskatchewan and Ohio anticyclones are also seen. No suggestion of a surface front is seen on this chart, as no prominent temperature contrast discontinuities are indicated. The areas of precipitation in Indiana, Illinois, and Wisconsin are located several hundred kilometers away from the weak surface cyclone in southwestern Missouri. Substantial lower tropospheric warm advection and associated quasi-geostrophic ascent (not shown) have also been calculated and are found to have been concentrated in the southern Illinois and Indiana precipitation regions. This precipitation pattern is a strong reminder of the significance of the surface anticyclone in organizing precipitation.

5. Concluding discussion

A quantitative assessment has been made of surface anticyclone forecast errors found in both the operational LFM and spectral models employed by the National Meteorological Center. Our consideration of cases encompasses North America and the eastern Pacific and western Atlantic Oceans for December 1981 through March 1982.
We have found that, averaged over all cases considered, both models underforecasted surface anticyclone central pressure to the degree found by Colucci and Bosart (1979). However, strong regional differences are seen in both models. The LFM and spectral forecasts show especially negative anticyclone pressure error in the eastern section of our domain, while there is a suggestion of the spectral model forecasting excessively strong anticyclones primarily in the Mississippi Valley region of the United States. Additionally, there is a statistically significant finding that the LFM forecasts weaker anticyclones east of 100°W than does the global spectral model. This suggests that the spectral model typically predicts anticyclone central pressures more accurately in this region, since both models systematically underestimate these central pressures.

We find no overall anticyclone 1000–500 mb thickness bias in either model, although both models forecast excessively warm anticyclones northwest of 45°N, 100°W. Apparently, the overall cold bias found by CB has been eliminated in these more recent models. However, the LFM does forecast excessively cold anticyclones along the Atlantic Coast. This bias is not seen in the spectral forecasts.

The data also show that both models generally place surface anticyclones south and east of their observed position. Implicit in this finding is the suggestion of a model fast bias in the anticyclone tracks. We also find that the spectral model provides improved anticyclone position forecasts in areas east of 100°W.

Since the LFM anticyclone central pressure and temperature errors are comparable to those found by CB, a consideration of the model changes since their study is justified. The horizontal computational resolution of the six-layer (6-L) PE model (about 381 km, at 60°W) has been enhanced to 190.5 km, with fourth-order differencing, in the current LFM. However, as in the 6-L PE, the LFM still has only four tropospheric layers. Above the 50 mb planetary boundary layer, each of the additional tropospheric layers is about 240 mb thick. The 12-layer spectral model has eight layers from the ground to 200 mb, and the thickness of the lower tropospheric layers is at most 150 mb. Thus, the LFM's continued problems with anticyclone pressure and temperature may be related to its coarse vertical resolution.

Anticyclone intensity can be changed substantially by static stability and diabatic processes, according to quasi-geostrophic theory. It is quite possible that excessive model oceanic sensible heat flux is contributing to an excessive loss of pressure hydrostatically in model oceanic anticyclones, which verify upstream over the continent. The statistically significant excessive pressure loss in LFM surface anticyclones relative to spec-
tral model surface highs in the eastern United States—western Atlantic regions is possibly related to differences in model planetary boundary layer and friction parameterizations. These processes are all crucial to surface pressure tendencies and are especially important over the relatively warm waters of the western Atlantic Gulf Stream current. Further, coarse vertical resolution could be a factor in producing excessively warm and unstable lower tropospheric air which could combine to produce an excessive loss in surface pressure. The details of the model planetary boundary layer, along with surface friction and radiation, may be crucial to this surface pressure change. Clearly, these physical causes are speculative, but our data do suggest that a model with improved vertical resolution will produce more realistic prognoses of anticyclones in the cold stable air often seen in these anticyclones. Only a thorough test of this hypothesis against other modeling sensitivity studies involving radiation, surface frictional and planetary boundary layer parameterizations will show the relative importance of these processes in anticyclogenesis.

We have shown a recent case illustrating many of these cold-season systematic anticyclone forecasting errors in both models. As a consequence of the models simulating the observed anticyclone-cyclone complex incorrectly, errors also were made in the location of significant precipitation events. This was especially true in the failure of the models to predict the light-to-moderate snowfall in Indiana, Illinois, and Wisconsin. Much of this is likely due to the model failure to predict the strong surface warm advection between the Mississippi Valley inverted trough and the Ohio anticyclone (Fig. 11). Thus, while anticyclones not only play key roles in providing cold, subsiding air to middle latitudes (Dallavalle and Bosart, 1975) and in providing energy for synoptic-scale cyclones (Boyle and Bosart, 1983), anticyclones also play important roles in defining synoptic-scale precipitation areas.

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