U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINSTRATION
OCEAN PRODUCTS CENTER

TECHNICAL NOTE

A COMPARISON OF THE LFM, SPECTRAL, AND ECMWF NUMERICAL MODEL FORECASTS OF DEEPENING OCEANIC CYCLONES DURING ONE COOL SEASON

STEPHEN J. AUER

AUGUST 1986

THIS IS AN UNREVIEWED MANUSCRIPT, PRIMARILY INTENDED FOR INFORMAL EXCHANGE OF INFORMATION

OPC Contribution No. 6
NMC Office Note No. 312

OPC CONTRIBUTIONS

No. 1. Development of Forecast Guidance for Santa Ana Conditions. Lawrence D. Burroughs, 1986, 23 pp.

No. 2. Lake Erie Wave Height Forecasts Generated by Empirical and Dynmaical Methods - Comparison and Verification. William S. Richardson, David J. Schwab, Yung Y. Chao, and Darren M. Wright, 1986, 23 pp.

No. 3. Determination of Errors in LFM Forecasts of Surface Lows Over the Northwest Atlantic Ocean. Stephen J. Auer, 1986, 17 pp.

No. 4. A Method of Calculating the Total Flow From a Given Sea Surface Topography. Desiraju B. Rao, Steve D. Steinrod, and B. V. Sanchez.

No. 5. Compendium of Marine Meteorological and Oceanographic Products of Ocean Products Center. David M. Feit, 1986.

No. 6. A Comparison of the LFM, Spectral, and ECMWF Numerical Model Forecasts of Deepening Oceanic Cyclones During One Cool Season. Stephen J. Auer, 1986.

1. INTRODUCTION

This study compares the performances of the NMC Limited-Area Fine Mesh Model (LFM), the NMC Spectral Model (which is currently called the Global Aviation Model), and the European Center Medium Range Weather Forecast Model (ECMWF) in determining the surface intensities and positions of deepening oceanic cyclones over the LFM coverage regions of the Atlantic and Pacific Oceans. For all three models, the cyclone analyses and 24-h and 48-h forecasts are validated by the final NMC North American Surface Analysis (NASC) which is a hand analysis of surface station data. This report will discuss the formation of the oceanic cyclone data set and present gross model error statistics, model error correlation coefficients, and displacement error graphs to evaluate the models' performances with regard to the Atlantic and Pacific Ocean basin regions of coverage and to the "bomb" and "non-bomb" relative cyclone development rates.

2. DATA SET FORMATION

The data used was laboriously compiled by Scott Dennstaedt (1) who reviewed the NASC charts during the October 1, 1983, to March 31, 1984, cool season and selected those cyclone tracks within the LFM coverage region which experienced at least one deeping episode of 6 mb or more in any 12 hour period. He then included the corresponding cyclone central pressure (cp) and position from the LFM, the Spectral, and the ECMWF models analyses and (24-h and 48-h) forecasts. The ECMWF analysis lows in this data set were from initialized analyses; whereas, the other two models used noninitialzed analyses. The cyclones used in this study were located over the northwest Atlantic Ocean or the northeast Pacific Ocean or along those coastal boundaries.

3. METHOD

Cp and position errors were determined by using NASC data as "truth". The NASC values and the model errors were stratified by ocean region (Atlantic or Pacific) and by the "bomb" and "non-bomb" cases and statistically analyzed using SAS software (2). This report presents the results in statistical tabulation tables and plots.

The following brief descriptions of the different model analysis techniques, grid resolutions, and data collection schedules are valid for the model runs made during this study period. The analysis gridfield for the LFM was created by updating its first guess with data collected in a 2 hour dump time after the analysis time. All data observed within a 3 hour window were considered to be synoptic for the analysis time. The data were analyzed on the LFM gridspace (about 1.5° x 1.5° lat./long.) by using the Cressman successive-correction method (3). The analysis for the Spectral model was created by updating the first guess (the Global Data

Assimilation System forecast analysis) with data collected in a 3.75 hour dump time. The data were analyzed on the Spectral gridspace (about 2.5°x 2.5°lat./long.) using an optimum interpolation scheme as explained by Dey and Morone (4). The analysis for the ECMWF model was created by updating its first guess with data collected in a 9 hour dump time. The data were analyzed on the ECMWF gridspace (about 1.87°x 1.87°lat./long.) using an optimum interpolation scheme given in Bengtsson, et al. (5). The NASC was manually analyzed with data collected in a 0.75 hour dump time. A simple summary of these differences is given in Table 1 along with estimates of the percent of synoptic data available at these model data window times. These estimates were derived from the data counts (surface ships and data buoys) received over the Atlantic Ocean and Pacific Ocean LFM regions at NMC during October 19-28, 1985. Thus assumming that the transmission speed of the data was unchanged since 1983, NASC used about 35%, the LFM used about 75%, the Spectral used about 90%, and the ECMWF used about 99% of the synoptic marine observations.

To determine if NASC, with a shorter data dump time, was a valid comparison tool for the models, I randomly compared 42 data sample lows from NASC with the same lows on the Northern Hemispheric Surface Analysis which has a data dump time of 4.33 hours (comparable to the longer dump times of the models). The data sample results give NASC (mean, rms) differences from the Northern Hemispheric Surface Analysis of (+0.5 mb, 2.5 mb) for cp, (0.0 degrees, 0.6 degrees) for latitudinal position, (+0.1 degrees, 0.9 degrees) for longitudinal position, and (43 nmi, 51 nmi) for the magnitude of the position difference. In this data sample 60% of the compared low cases had the same cp and 33% of the low cases had the same position. Since the NASC lows were comparable to the Northern Hemispheric Surface Analysis lows, it appears that NASC was a reasonably good validation source for all three models.

In this study I have chosen to compare the models against NASC to judge how the models handle the "true" cyclone central pressure conditions at the ocean surface. In light of the different model characteristics, one could argue that a better evaluation would be to judge performances by verifying the model forecasts with its own analyses. This second approach, however, would not indicate the "true" magnitude of the forecast errors.

4. MODEL CYCLONE ERRORS IN OCEAN BASINS

Tables 2 and 3 contain the gross statistics for the NASC central pressures and the model central pressure errors and includes the resultant correlation coefficients between them for the Atlantic and Pacific Ocean lows. Note that each of the models are missing some associated NASC lows. This is not indicative of how many lows were missed by the models since most of those missing are due to logistical problems, such as charts which could not be "physically" located. Additionally, the ECMWF number are smaller as this model is only run once per day.

Figure 1 is a bargraph comparing the model mean cp errors and standard deviations for both oceans. In general, the model mean cp error shows a linear increase with forecast time with a positive cp bias ranging from 1-10 mb. One cause of the error maybe the use of a biquadratic interpolation scheme to determine the cp from the surrounding sea level pressure gridvalues. A 9 month study by Auer (6) found that the interpolated cp values of LFM analysis lows over the northwest Atlantic Ocean were almost 2 mb too high as the biquadratic interpolation scheme only reduced the minimum gridvalues on average by 0.1 mb. The large analysis mean cp errors for the spectral and ECMWF may partly be due to their coarse grid resolutions which contrast with the LFM which has the finest grid resolution and also has the smallest analyzed mean cp errors for both oceans. Perhaps because of its reduced analysis error, the LFM forecast absolute mean cp errors also tend to be smaller. In contrast to this, the LFM shows the largest mean cp error increase from the analysis to the 48 hour forecast. In comparing the oceanic basins, all the Atlantic mean cp errors are less than their Pacific counterparts. The Spectral model appears to show the least mean cp error difference between the two oceans. The ECMWF model standard deviation values are smaller than the two other models for both oceans. This combined with its generally smaller mean cp error forecast degradation (from the analysis) indicates that the ECMWF may perhaps have the most stable model performance.

The statistical significance of the mean cp error differences can be determined by using a Student's t-distribution to test the null hypothesis that two population samples have the same population mean,

$$t_{n_x+n_y-2,\alpha} \approx \frac{\bar{X}-\bar{Y}}{\sqrt{n_x S_x^2+n_y S_y^2}} \sqrt{\frac{n_x n_y (n_x+n_y-2)}{n_x+n_y}} .$$

The equation variables are the limiting value, $t_{n_x+n_y-2,\alpha}$, defined in a statistical table by the number of degrees of freedom, n_x+n_y-2 , and the level of significance, α , the two sample population means, and , and the sample population standard deviations, $\bar{X}$ and $\bar{Y}$, and the number of observations, n_x and n_y . Tests conducted on the population samples given in Tables 2 and 3 at the 95% confidence level give the following impressions:

1. All three models have positive mean cp error biases for both their analyses and forecasts (significantly positive compared to NASC). The positive forecast biases are no doubt partly due to the initial underanalysis of the cp.

2. The analysis for the LFM is the best in both ocean areas (significantly smaller than the other two models). This is probably largely a result of the LFM's finer grid resolution.

3. A model's forecast cp error is due to more than just its analysis error. For most of the models, the mean cp error of the analysis is significantly smaller than the forecast errors (except for the ECMWF 24-h forecast in the Atlantic Ocean and the Spectral 48-h forecast and both ECMWF forecasts in the Pacific Ocean). The additional forecast error increase may be attributable to incomplete or incorrect model physics.

4. A 24-h forecast of cp is not significantly better than the 48-h forecast (except for the ECMWF in the Atlantic Ocean). A statistical independence between the forecast times might emerge with larger data samples (one intuitively expects to find a forecast degradation with time).

5. No model cp forecast is superior (significantly smaller cp error) at the 24-h or at the 48-h for either ocean.

6. All three models tend to handle cp better in the Atlantic Ocean than in the Pacific Ocean. The mean cp error is smaller for 8 of the 9 model products and the Atlantic mean cp errors are significantly smaller than their Pacific counterparts for 5 of these 8 products.

The bottom halves of Tables 2 and 3 contain the correlation coefficients found among NASC and the model cp errors. For the Atlantic Ocean lows, the model cp errors show some negative correlation with NASC, but they show a larger negative correlation for the Pacific Ocean lows, especially the LFM and Spectral models. Since the NASC cp mean and standard deviation for both oceans are about equal, this may indicate that the LFM and Spectral models have problems handling cyclogenesis for the Pacific Ocean. This possibility is illustrated in Figure 2 where a representative scatter diagram plot of NASC cp and the LFM 24-h forecast error shows a negative slope indicating that the model tends to overforecast the cp for lows above 1000 mb and to underforecast the cp for lows below 1000 mb. The correlations between the model cp errors are nearly all positive for both oceans indicating that the models tend to have somewhat similar successes and failures in handling the oceanic lows.

The model mean distance errors for both oceans are shown in the Figure 3 bargraph plot. The mean and the standard deviation of the distance errors increase with forecast time. The mean distance errors are roughly comparable among the models although the Spectral model errors tend to be slightly worse than the other two models. The mean distance errors also tend to be roughly comparable between the two oceans. It is mildly surprising that the models do not determine the low positions better in the data-rich Atlantic Ocean as they did for the cp errors. The average (all models and both oceans) distance error increases linearly with forecast time from about 80 nm for the analysis, to 150 nm for the 24-h forecast, and to about 220 nm for the

48-h forecast. These values compare favorably with the Silberberg and Bosart (7) LFM mean distance errors of 161 nm for the 24-h forecast and 233 nm for the 48-h forecast from all the cyclones over the LFM North American region (land cases too) during the 1978 - 79 cool season. Their study also contained geographical contour charts of the LFM 24-h and 48-h forecast mean cp error which by a rough comparison with this study seems to indicate that the more recent LFM version with improvements, such as the addition of a moisture flux over the ocean surface, may be handling the low cp determination slightly better in the Atlantic Ocean region.

Figures 4 and 5 are a collection of 18 compass graphs which show the model directional biases for both oceans. For each graph the numerical value in the center indicates the percentage of lows with a distance error less than 40 nm. The emphasized curve around the center indicates the percentage of low distance errors greater than 40 nm in the 8 principal compass directions (radii tic marks are at 5% increments). Overall, the percentage of small distance errors decreases with forecast time from about 25% for the analysis to about 5% for the 48-h forecast. For the Atlantic Ocean lows (Fig. 4), the LFM shows the least directional bias while the ECMWF shows a southwest bias indicating that it tends to move the lows too slowly. For the Pacific Ocean lows (Fig.5), the ECMWF shows a northeast forecast bias tending to move the lows too quickly (the opposite condition of its handling of the Atlantic lows). Meanwhile, the LFM and Spectral models show north directional forecast biases tending to move the lows to the left of the actual tracks. The study of Silberberg and Bosart (7) found that the LFM (over its entire continental and oceanic region) had little overall displacement bias, but it did show some seasonal bias (slow in the fall and fast in the spring).

5. MODEL "BOMB" and "NON-BOMB" OCEAN BASIN ERRORS

The mean cp and distance errors of "bombs" and "non-bombs" for both oceans are compared in the bargraphs given in Figures 6 and 7. In this study a "bomb" is an explosive deepening cyclone (as determined by NASC) with a 12 hour deepening rate at least as large as that defined by Sanders and Gyakum (8) where the critical rate is defined as a Bergeron, B, and varies by latitude, ϕ,

$$B = 12 \, (\sin\phi \, / \, \sin 60^\circ).$$

The Bergeron rate decreases toward the equator with a value of 12.0 at 60 N compared to 9.8 at 40 N. Of the 141 total oceanic cyclone cases in this study, 36 are determined to be "bombs". "Bomb" events occur more frequently in the Atlantic Ocean region (23 "bombs" out of 86 cyclone cases) than in the Pacific Ocean region (13 "bombs" out of 55 cyclone cases). In addition, the Atlantic "bomb" systems appear to deepen for a longer period as there are 5 double-event "bombs" (2 consecutive 12 hour explosive deepenings) and 1 quadruple-event "bomb" in which the cyclone cp dropped from 1015 mb to 948 mb in 48 hours. The Pacific Ocean region only had one double-event "bomb". On the other hand, the

NASC "bomb" mean cp are nearly the same at 982 mb for the Atlantic and 984 mb for the Pacific. Also, the NASC "bomb" deepening rates are comparable with a value of 1.53 Bergerons for the Atlantic and 1.61 Bergerons for the Pacific.

As one might expect, all the models have larger mean cp errors in both oceans for "bombs" than "non-bombs" (Fig. 6). All the models handle the Atlantic Ocean cp better than the Pacific Ocean cp for both "bombs" and "non-bombs". The comparison between the "Bombs" for the two oceans is fair as seen in the comparable NASC "bomb" mean cp and "bomb" deepening rates previously stated. The mean distance errors (Fig. 7) are roughly comparable between "bombs" and "non-bombs" and between the Atlantic and Pacific Oceans.

Figure 8 is a partial reproduction of a figure showing the "geographical distribution of bomb events for the Atlantic and Pacific basins in 1978-1979" given in the paper by Sanders and Gyakum (8) which is overlayed with emphasized X's showing the locations of "bomb" events found by this study. For both studies, the "bombs" are located at the initial 12-h deepening location. The heavy lines drawn on the figure indicate the LFM's coverage limit which is also the limit of this study. In Figure 8, the two studies appear to agree on the center of activity in the Atlantic LFM region. In the Pacific LFM region this study shows a center of activity to the south of Sanders and Gyakum's Gulf of Alaska epicenter, but this study shows no "bombs" corresponding to the second epicenter to the west whose existence is questionable according to Sanders (personal communication).

6. CONCLUSIONS

A survey of a single cool season data set containing deepening oceanic cyclone tracks over the Atlantic and Pacific Ocean LFM coverage regions compared the LFM, Spectral, and ECMWF model analyses and forecasts to the North American Surface Chart Analysis (manual). A comparison of the model cp errors indicates that all three numerical models have significant positive cp biases for both ocean regions. The LFM analyses in the two ocean regions is better than the Spectral analyses. A 24-h model forecast of cp is not significantly better than the 48-h forecast (except for the ECMWF in the Atlantic). None of the three model cp forecasts is significantly superior at 24-h or 48-h in either ocean region. All three models tend to handle cp better in the Atlantic Ocean region and for "non-bomb" cases. The oceanic low distance errors increase linearly with forecast time and are roughly comparable between the three models, between the two ocean regions, and between "bombs" and "non-bombs".

The results of this study should be treated with caution since the data collection is small and seasonal, the data selectively comprised deepening cyclone tracks, and the observational marine data available to the manual analysis and the model runs varies. One could speculate that if the database had included all cyclones during this cool season, that the mean cp errors might be slightly less.

REFERENCES

1. Scott Dennstaedt is a former co-op student at the National Meteorological Center. He now is employed by Booz-Allen & Hamilton Inc. of Bethesda, MD.

2. SAS Institute Inc. SAS User's Guide: Basics, 1982 Edition. Cary, NC. 923 pp.

3. Cressman, G., 1959. An Operational Objective Analysis Scheme. Mon. Wea. Rev., 87, 367-74.

4. Dey, D. and L. Morone, 1984. Evolution of the National Meteorological Center Global Data Assimilation System: January - December, 1983. Mon. Wea. Rev., 113, 304-18.

5. Bengtsson, L., M. Kanamitsu, P. Kallberg, and S. Uppala, 1982. FGGE 4-Dimensional Data Assimilation at ECMWF. Bull. Amer. Meteor. Soc., 63, 29-43.

6. Auer, S.J., 1986. A determination of errors in LFM forecasts of surface lows over the northwest Atlantic Ocean region. NMC Office Note 313, National Weather Service, NOAA, U.S. Department of Commerce, 18 pp.

7. Silberberg, S.R. and L.F. Bosart, 1982. An Analysis of Systematic Cyclone Errors in the NMC LFM-II Model During the 1978-79 Cool Season. Mon. Wea. Rev., 110, 254-71.

8. Sanders, F. and J.R. Gyakum, 1980. Synoptic-Dynamic Climatology of the "Bomb". Mon. Wea. Rev., 108, 1589-1606.

THIS PAGE IS
INTENTIONALLY BLANK

Table 1. Some general characteristics of the analyses compared in this paper. The percentage of marine observations available for the data dump times are estimated from the LFM marine region data counts received at NMC during October 19-28, 1985. The ECMWF analysis is in fact an initialized analysis.

ANALYSIS	DATA DUMP TIME	MARINE OBS. AVAILABLE (estimated)	GRID RESOLUTION
1. NASC	-- 0.6 hour --	35 % --	point
2. LFM	-- 2.0 hour --	75 % --	190 km
3. Spectral	-- 3.8 hour --	90 % --	278 km
4. ECMWF	-- 9.0 hour --	99 % --	278 km

Table 2. The top section shows the gross statistics of the NASC cp and the models' cp errors for the Atlantic Ocean lows. The bottom section contains the correlation coefficients for the same (values in parentheses are unreliable at the 95% confidence level).

CENTRAL PRESSURE ERROR STATISTICS FOR ATLANTIC OCEAN LOWS

Product	N	Mean (mb)	St. Dev. (mb)	Minimum (mb)	Maximum (mb)
NASC	86	988.8	15.7	948.	1015.
LFM Anal.	72	1.4	3.7	- 14.	13.
LFM 24-h	62	4.1	6.4	- 13.	27.
LFM 48-h	54	5.1	6.7	- 9.	25.
Spec. Anal.	78	4.4	3.8	- 3.	22.
Spec. 24-h	75	6.1	5.9	- 8.	24.
Spec. 48-h	72	6.8	8.1	- 12.	28.
ECMWF Anal	41	4.0	3.4	- 3.	14.
ECMWF 24-h	41	3.9	5.9	- 10.	20.
ECMWF 48-h	39	6.9	5.8	- 4.	20.

CENTRAL PRESSURE ERROR CORRELATION COEFFICIENTS BETWEEN PRODUCTS

	NASC	L00	L24	L48	S00	S24	S48	E00	E24
L00	(.07)								
L24	(.03)	.47							
L48	-.43	.31	.44						
S00	-.25	.65	.63	.33					
S24	(.04)	.50	.70	.38	.71				
S48	(.14)	.50	.51	.59	.60	.79			
E00	-.23	.45	.50	(.35)	.75	.69	.54		
E24	(.17)	.38	.66	.42	.58	.80	.71	.68	
E48	(-.10)	(.22)	.64	.38	.62	.76	.74	.69	.83

Table 3. The top section shows the gross statistics of the NASC cp and the model cp errors for the Pacific Ocean lows. The bottom section contains the correlation coefficients for the same (values in parentheses are unreliable at the 95% confidence level).

CENTRAL PRESSURE ERROR STATISTICS FOR PACIFIC OCEAN LOWS

Product		N	Mean (mb)	St. Dev. (mb)	Minimum (mb)	Maximum (mb)
NASC		55	985.5	13.3	956.	1014.
LFM	Anal.	46	2.4	4.3	- 3.	16.
LFM	24-h	35	8.6	9.0	- 12.	23.
LFM	48-h	31	9.5	8.4	- 6.	27.
Spec	Anal.	49	5.6	5.0	- 8.	16.
Spec	24-h	36	8.8	7.7	- 15.	26.
Spec	48-h	41	6.8	11.1	- 27.	30.
ECMWF	Anal	22	8.8	4.2	3.	19.
ECMWF	24-h	19	10.6	5.7	- 1.	21.
ECMWF	48-h	16	9.5	6.1	1.	22.

CENTRAL PRESSURE ERROR CORRELATION COEFFICIENTS BETWEEN PRODUCTS

	NASC	L00	L24	L48	S00	S24	S48	E00	E24
L00	(-.26)								
L24	-.68	.64							
L48	-.53	(.04)	.40						
S00	-.48	.60	.75	.35					
S24	-.60	.37	.84	.41	.68				
S48	-.56	.23	.65	(.37)	.49	.45			
E00	(-.15)	(.33)	(.50)	(-.07)	.84	(.40)	(.25)		
E24	(-.16)	.53	(.42)	(.11)	.50	.74	(.20)	.53	
E48	(-.16)	(.17)	(.48)	(.37)	.68	.80	(.48)	.67	.75

THIS PAGE IS
INTENTIONALLY BLANK

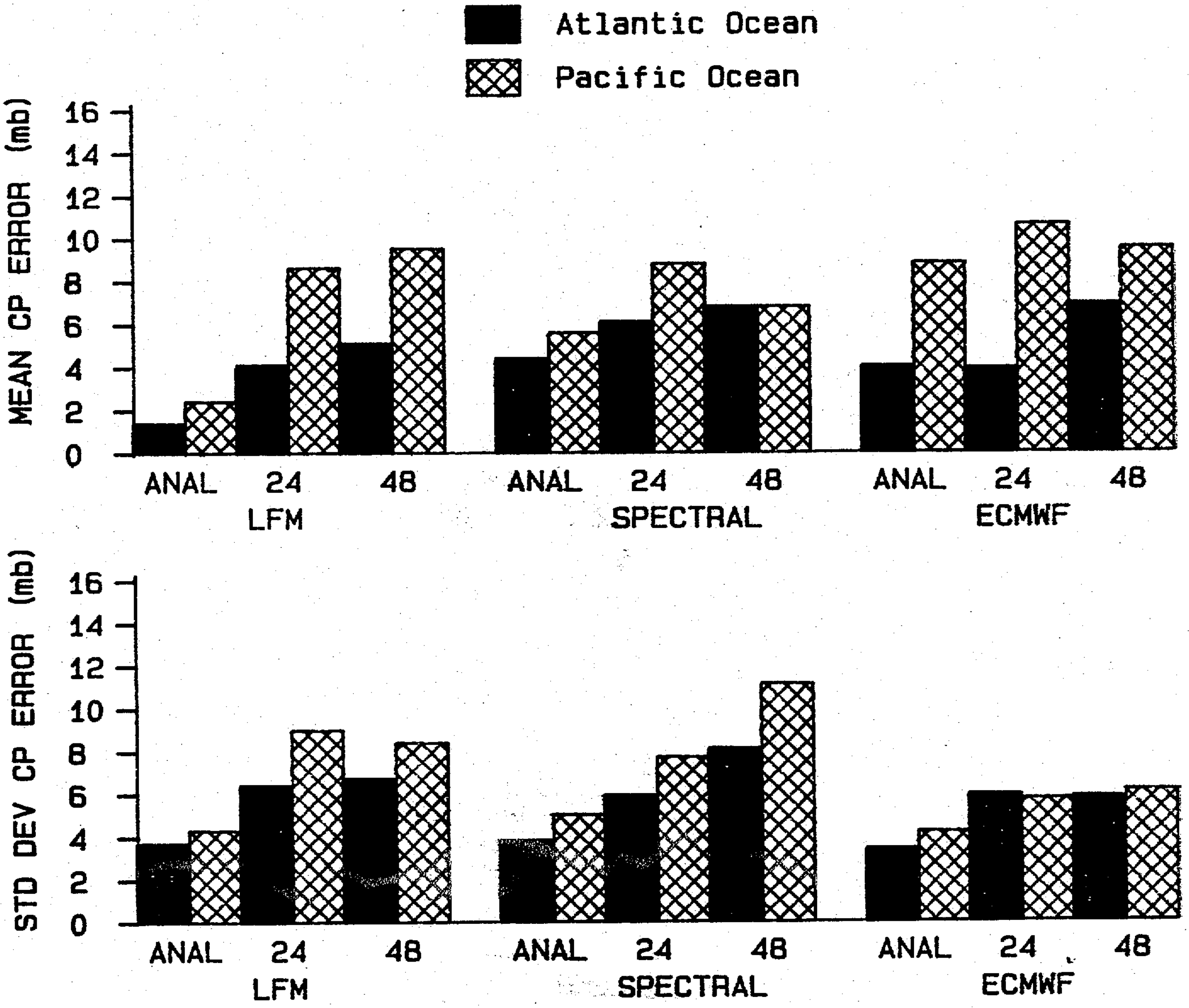

Figure 1. Means and standard deviations of the model cp errors for the Atlantic and Pacific Ocean lows.

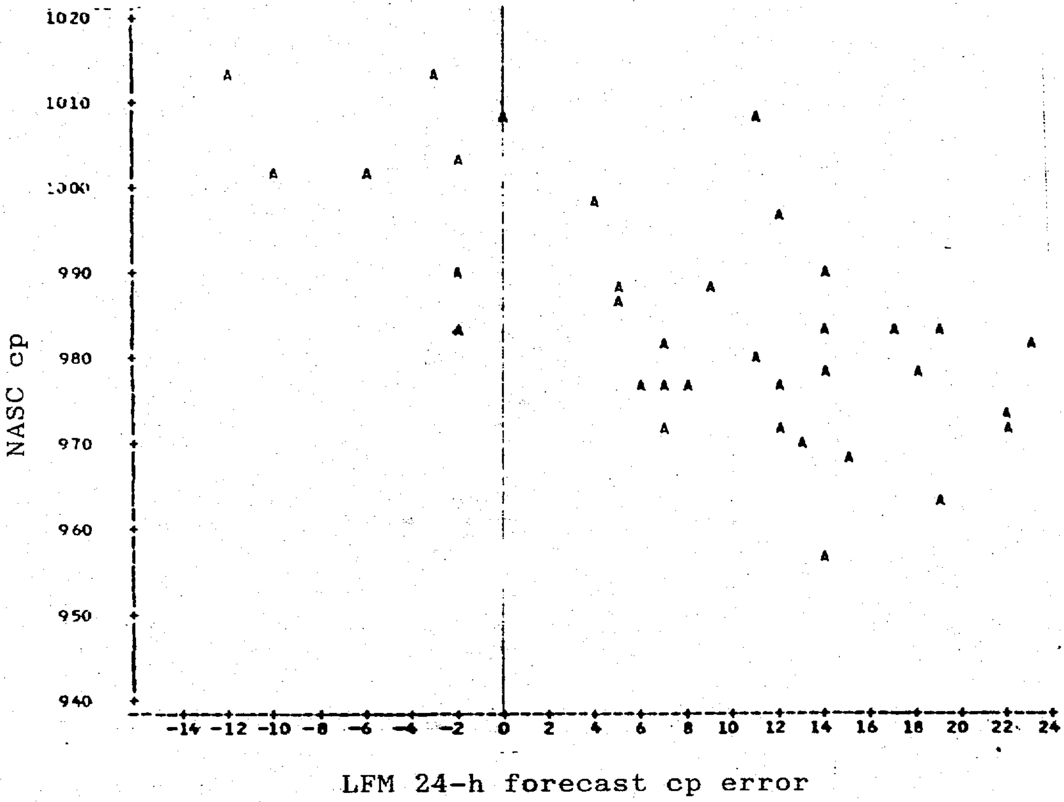

Figure 2. Manually analyzed NMC final North American Surface Analysis (NASC) central pressure (cp) versus the corresponding LFM 24-h forecast cp error (LP24) for the Pacific Ocean cyclones. All units are in mb and the number of cases for each point is given by the alphabetic letter (A=1, B=2, etc.).

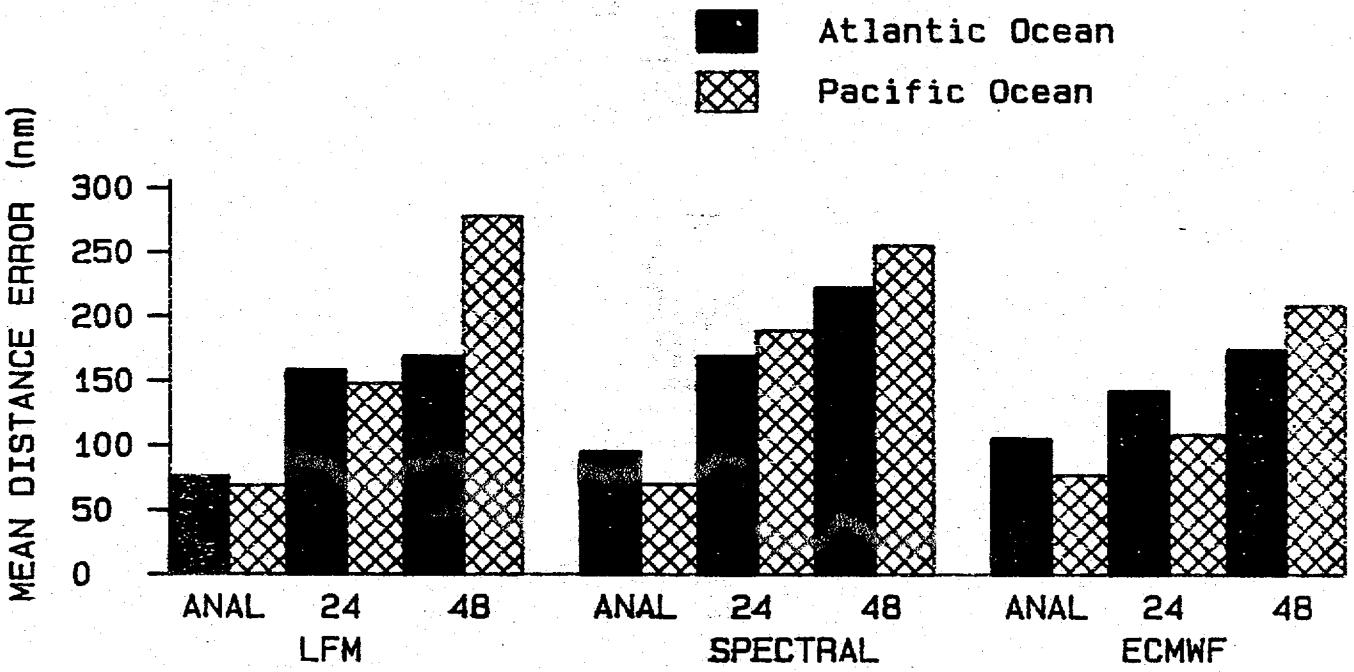

Figure 3. Comparison of model mean distance errors for the Atlantic and Pacific Ocean lows.

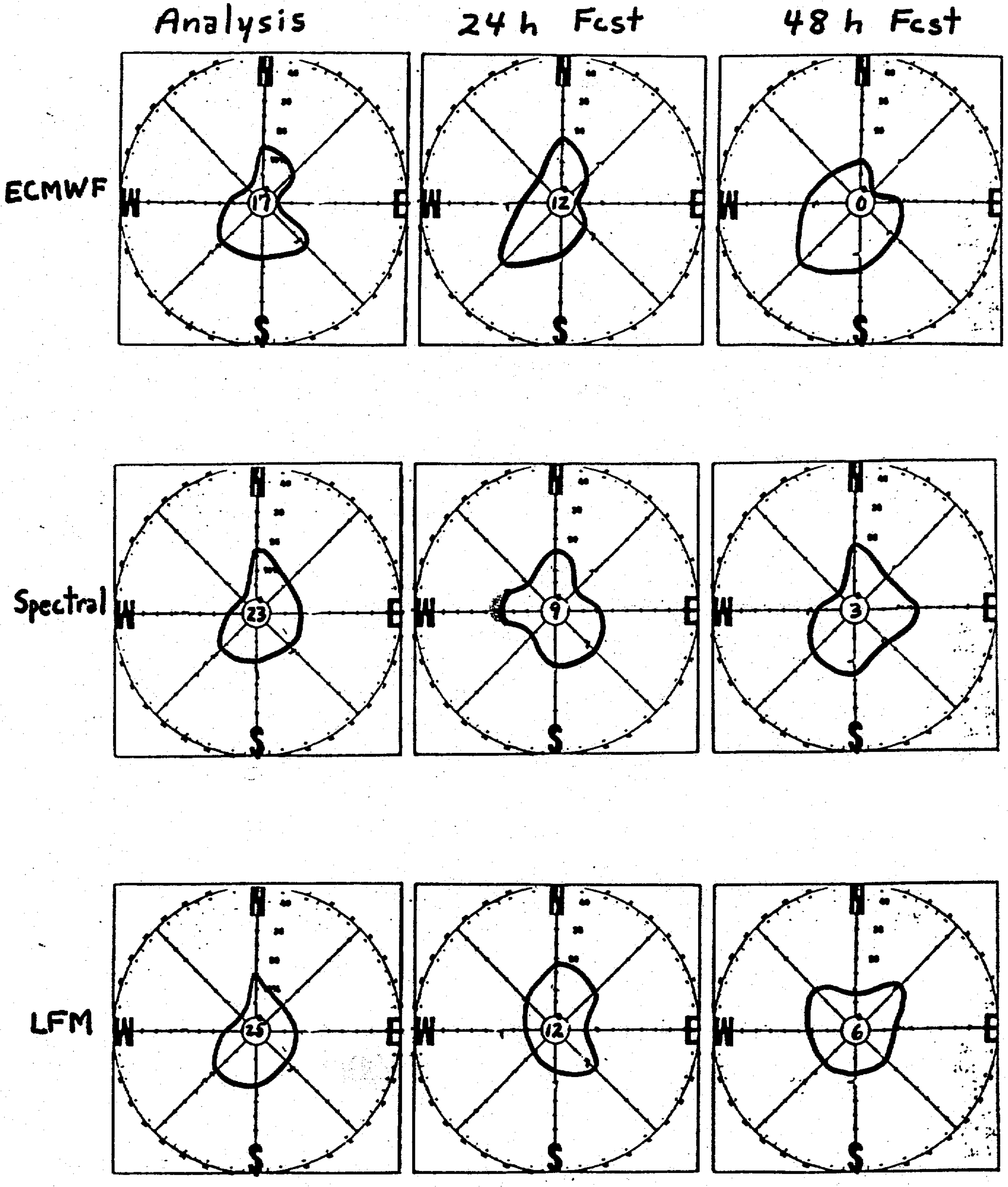

Figure 4. Model direction errors for the Atlantic Ocean. The heavy line shows the % of cases having large displacement errors (> 40 nm) in the 8 principal directions. Tic marks along the radii are at 5% increments. The center value is the % of cases of small displacement errors.

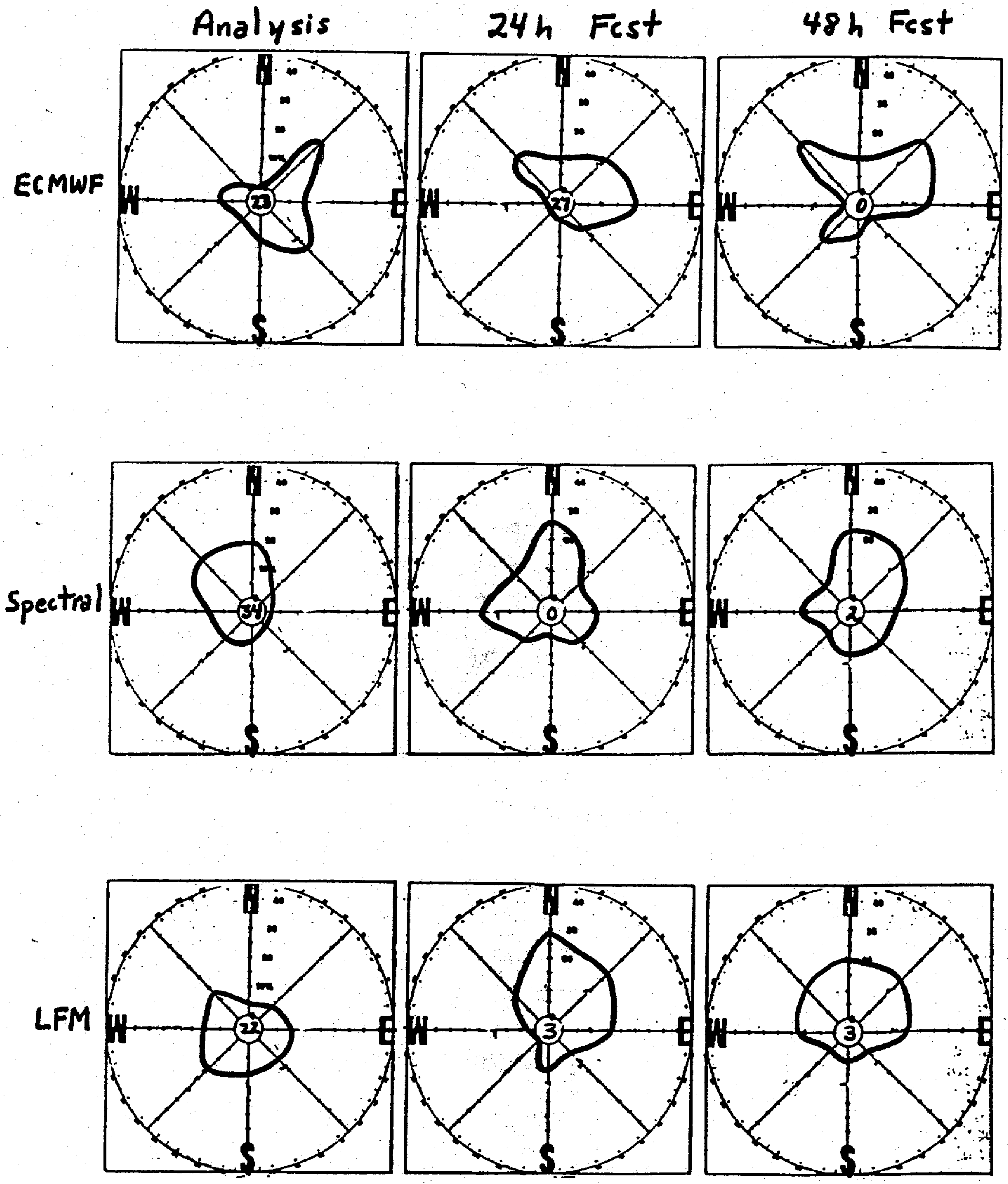

Figure 5. Same as Fig. 4, except for the Pacific Ocean lows.

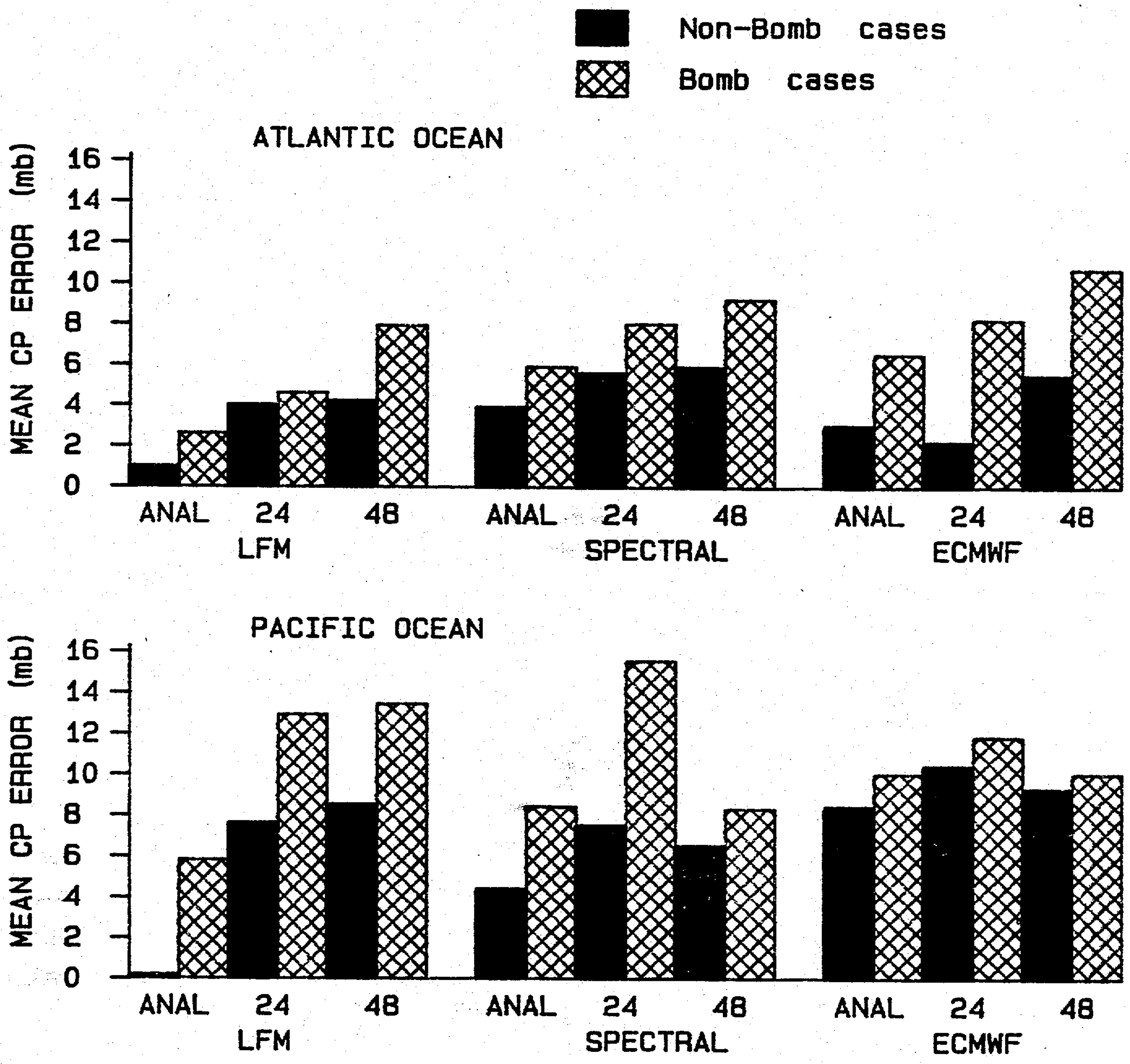

Figure 6. Comparison of the model mean cp errors of "bombs" and "non-bombs" for the Atlantic and Pacific Oceans.

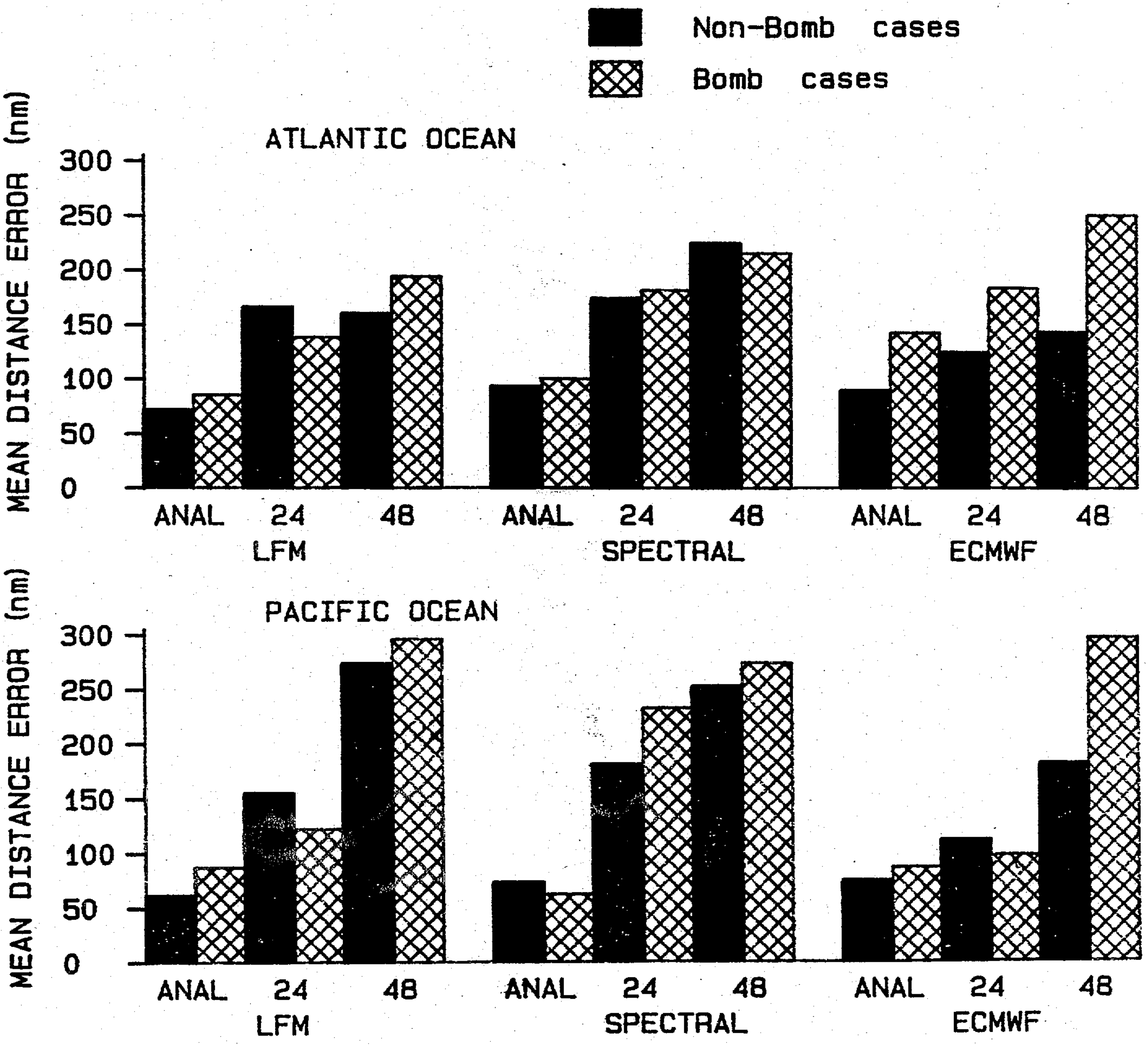

Figure 7. Comparison of the model mean distance errors of "bombs" and "non-bombs" for the Atlantic and Pacific Oceans.

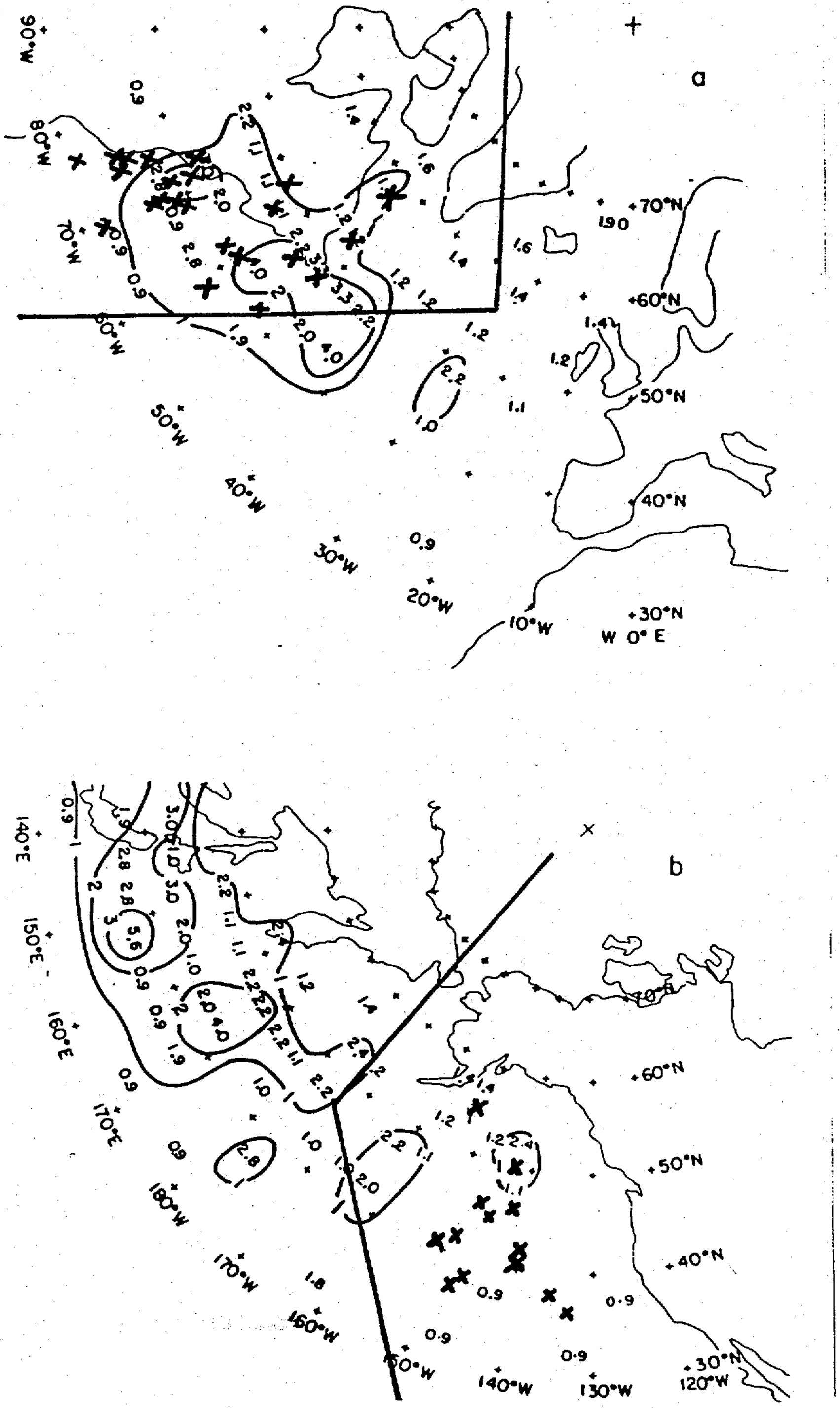

Figure 8. A geographical comparison between the initial location of "bomb" events between the Sanders and Gyakum (9) study whose figure is reproduced here and this study (shown by the emphasized X's). The lines drawn through the oceans show the LFM's coverage limit which is also the limit of this study.