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

TECHNICAL NOTE

DETERMINATION OF ERRORS IN LFM FORECASTS OF SURFACE LOWS OVER THE NORTHWEST ATLANTIC OCEAN

STEPHEN J. AUER

JULY 1986

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

OPC Contribution No. 3
NMC Office Note No. 313

I. INTRODUCTION

Forecast low central pressure (cp) and position errors were determined for the National Weather Service's Limited-Area Fine Mesh Model (LFM) 12h forecast (F12), 24h forecast (F24), 36h forecast (F36), and 48h forecast (F48) from a 7 year (1/78 - 1/85) archive. LFM analyses were used to verify the forecasts. A regional pattern tracking program was developed to track and to verify the surface lows over the Northwest Atlantic Ocean using the LFM analysis and forecast sea level pressure (SLP) fields. An attempt was made to find regression equations to correct the LFM model's cp and position forecast errors, but independent data sample tests indicated that the regression equations could only slightly improve the forecasts. This study also found that a positive bias cp error results from the use of the biquadratic and the bilinear interpolation procedures for determining the low cp.

This report will present the 7 year LFM forecast errors in graphical plots and statistical summaries. This report will also describe the pattern tracking program (PTP), test the PTP performance, evaluate the standard cp interpolation methods, and discuss the attempts to find useful regression equations for the LFM forecast errors.

II. DESCRIPTION OF THE REGIONAL PATTERN TRACKING PROGRAM (PTP)

Since numerical models often use grid space in the analysis and forecasts, it is desirable to interpolate the intensities and positions of low centers from a gridded field and, to temporally and spatially track the movements and changes of the low centers with the successive analyses and forecasts. This section describes the PTP which is modified from a program developed by Richardson and Perotti (TDL Office Note 84, June 1984). The basic steps of the PTP are (1) read a series of LFM fields containing the analysis and the F12 - F48 forecast SLP fields, (2) find the low gridvalues within the SLP fields, (3) interpolate the lows cp's and positions, (4) track the lows within and between forecast runs by tagging them with unique names, (5) match the forecast lows with the valid analysis lows, (6) determine the forecast cp and position errors, and (7) archive the forecast lows. The archive format of predictors and predictands of each forecast low includes:

1. valid date and time of forecast low
2. low cp
3. low location (lat/long)
4. low gridpoint pressure gradient to the north
5. low gridpoint pressure gradient to the east
6. low gridpoint pressure gradient to the south
7. low gridpoint pressure gradient to the west
8. low cp change during the previous 12 hours
9. low speed during the previous 12 hours
10. low direction during the previous 12 hours
11. forecast low cp error

12. forecast low distance error
13. forecast low direction error
14. low location descriptor (land, ocean, or coast)

In this study, the oceanic lows consist of both ocean and coastal lows. The verifying analysis low positions were used to identify the forecast oceanic lows.

Figure 1 shows the LFM SLP gridfield used by the PTP and its geographical region of coverage. For each SLP field, the PTP checks to see if a time gap exists within the archive, finds all the relative low gridpoints (an interior low surrounded by 8 higher values or a boundary low surounded by 3-5 higher values) within each SLP field, and interpolates the synoptic low cp and positions (for interior lows only) from the surrounding SLP gridvalues using a biquadratic or a bilinear interplation scheme. The interior lows with cp greater than 1016.5 mb are dropped as are the boundary lows with cp greater than 1012.5 mb. The boundary lows are not interpolated, but are later used in the tracking process to help track lows out of the SLP grid region.

The PTP tracks a SLP field's synoptic lows by comparing them with the previous LFM run forecasts and analysis lows whose valid times are within + or -12 hours. The PTP then identifies the lows with unique names. This tracking procedure uses three tracking methods in a descending order of preference to assign each low a name. The synoptic lows are named by the track chosen at the highest order of preference. The first method called backward tracking tries to determine the names of the synoptic lows by backward tracking them with the lows from the last t-12 LFM run forecast or analysis. If any lows remain untracked, then a second method tries to match the synoptic lows (except F48) with the forecasts which have the same valid time. If any lows still remain untracked, then a third method called forward tracking tries to determine the names of the synoptic lows (except F36 and F48) by forward tracking them with the stored forecasts which are valid at t+12. Any remaining unnamed synoptic lows are then named as new lows. Refer to Table 1 for the tracking method order of the synoptic lows and the sequence calling order of the stored LFM run analysis and forecast lows.

The backward and forward tracking methods use the same criteria for tracking the synoptic lows which emphasizes the historically predominant northeastwardly track direction. The first step is to set up a matrix of possible low track matches in terms of cp change, speed of movement, and direction of movement. The empirical regionally defined preferred track has a speed of movement of less than 46 knots and a direction of movement toward the northeast. Thus a hierarchy of preferred directions and maximum speeds is used to pick the best low for each synoptic low. This is shown in Table 2. If a conflict evolves between two possible low matches at the same preferred direction of movement, then the low match whose low has the smallest cp is chosen (so the name of a split low will be carried by its most intense offspring).

The matching technique for tracking synoptic lows at the same valid time determines the distances between all the synoptic lows and all the lows of a previous LFM run forecast picks the low name that is nearest to the synoptic low. This matching is limited by a maximum distance limit which increases with the forecast period from 400 nm at F12, to 460 nm at F24, to 520 nm at F36, and to 580 nm at F48.

Synoptic lows are named by the low chosen in the highest tracking method order. Thus any subsequent tracking order choices are not considered for that low. When a low selects a track by the forward tracking or matching procedure, a check is made that the same track name is not being used by another synoptic low to ensure that the names are unique.

After the analysis lows have been tracked for each time period, they are then matched with all the valid forecasts (F12 - F48) of previous LFM runs to determine the forecast errors. Unfortunately, the assigned names are not unambiguous and additional checks are needed at this point in order to ensure a proper verification. The tracking procedure occassionally assigns two different names to the same low largely because the LFM run products overlap chronologically. Consider that the analysis and the 4 forecasts have been created by 5 different LFM runs whose initial conditions are different. Also the tracking method order process does not consider all the not yet valid stored forecast lows as input to the tracking selection process. For instance as seen in Table 1, the analysis lows are not tracked with the previous LFM run's F36 lows and F48 lows nor are they tracked with the second and third removed previous LFM runs' F48 lows. Therefore, if an extra low should occur between a forecast and its valid analysis the low naming sequence may be out of order. Also a low which dissipates then reappears during or between LFM runs will probably be assigned two different names. The tracking procedure operates best when the lows are well defined and persistent. To overcome the imperfections of the tracking process, a check is made before the verification of forecasts by the procedure detailed below.

The checking procedure uses the following information as input, the assigned low name, the distance between possible low verifications, and the status of low names. The status of a low name is maintained by switches which are turned on when a name has been verified by an analysis/forecast match. An independent guess of the verification is accomplished by finding the closest analysis low for each forecast low. This guess is further limited by a maximum distance limit which increases with forecast time from 400 nm at F12 to 580 nm at F48. The checking procedure immediately accepts the case where the analysis low and its closest forecast low have the same assigned name and then verifies that forecast low. The checking decision process for the other conditions is detailed on the flow chart in Figure 2. Note the possible conditions that can result for each forecast low:

1. verified by an analysis low with the same name
2. verified by an analysis low with a different name (verification less certain)
3. unverified low (no verifying analysis low exists)

A list of analyses which have missing forecasts at the F12 through F48 valid times is also archived by the PTP.

III. PTP EVALUATION

A. Recognizing lows and forming low tracks

The PTP is tested in several ways to evaluate its performance. In Table 3, the ability of the PTP to recognize lows within the SLP is grossly evaluated by comparing the total number of lows found by the PTP with those found on the manual analyses during an 11 month period. The table shows that 94% of the manual anayses lows are also detected by the PTP -- thus 6% of PTP lows are missing. In all of these cases, the author reexamined the SLP and verified that it did not in fact have a low gridpoint. Generally the nondefined lows are weak lows or are subgridscale lows (on SLP). Often the undefined lows are located in a trough on the SLP. Occasionally an important low is not discernable in the SLP by the PTP, such as for 12Z on February 19, 1979, a 1006 mb low off Cape Charles, Virginia, which dumped the largest snowfall in the Washington, DC, area in the past 50 years. On the other hand, about 9% of the PTP analyzed lows are extra lows, that is, not defined by the manual analyses. In most cases, the extra PTP lows positions are located along a cold front or a stationary front in the manual analysis. In some cases the author believes that these are real lows which were not correctly manually analyzed. Thus the PTP recognizes lows reasonably well given the limitations of the SLP gridfield.

The author subjectively examined 15 months (9/1/77 - 10/23/77, 7/1/81 - 12/31/81, 4/1/82 - 6/30/82, and 1/1/83 - 2/10/83) of PTP low tracks and found that they compared well with the Daily Weather Map analyses for all the lows commonly defined by both. Thus the PTP appears to be tracking the lows well.

Figure 3 is a scatter diagram of the PTP determined low speeds of movement and directions of movement from 10 months (7/1/81 - 12/31/81, 4/1/82 - 6/30/82, and 1/1/83 - 2/10/83). The reference lines drawn on the diagram define the speed and direction criteria used by the PTP which are given in Table 2. The general lack of cases seen near the criteria boundaries on Figure 3 seems to imply that the criteria are valid for determining the low tracks.

B. Interpolation of low position

The PTP's biquadratic and bilinear interpolation of the analyzed SLP low positions were compared with 9 months (7/1/81 - 12/31/81 and 4/1/82 - 6/30/82) of low observations from the final North American surface analysis. The PTP mean low interpolated position error is 78.5 nm. Figure 4 is a scatter diagram plot of the PTP's distance errors and direction errors. The distance errors appear to be random with no discernible directional bias.

C. Interpolation of low cp

The PTP's biquadratic and bilinear interpolation of low cp were compared with 9 months (7/1/81 - 12/31/81 and 4/1/82 - 6/30/82) of lows from the final North American surface analysis. The mean interpolated cp error is +1.66 mb with a standard deviation of 2.5 mb for 231 lows. The maximum errors were -4 mb and +14 mb. This same method is used by the LFM model's postprocessor to determine low cp. The need of a better scheme for interpolating the low cp from a SLP gridfield is further pointed out by a statistical summary of the interpolation adjustments made by the PTP on the 7 year archive. The mean cp adjustment to the low gridpoint value via the biquadratic and bilinear interpolations is only -0.1 mb with a maximum adjustment of only -1.1 mb. Since all the adjustments are negative, the majority of the cp changes to the low gridpoint values are between 0.0 - 0.1 mb, very small corrections indeed. One would expect, given the large pressure gradients found around some intense lows and the length of the LFM model's grid spacing, that the maximum correction would be much larger.

IV. LOW CP AND POSITION LFM FORECAST ERROR RESULTS FOR 7 YEARS

A summary of the LFM forecast error results is presented in Table 4. The PTP looked at a 7 year period (1/78 - 1/85) containing 4880 LFM runs. A total of 296 LFM runs were missing in the archive (about 6%).

The total number of analyzed oceanic lows from this study compared to the number of LFM runs reveals that only about 24% of the analyses contained an oceanic low. This percentage reflects the small oceanic area covered in the LFM grid (see Fig. 1). The forecast performance values show that the forecasts degrade with forecast time, as expected. The total number of forecast lows over the 7 year period decreases from 970 at F12 to 693 at F48. The percentage of verified oceanic forecasts decreases from 66% at F12 to 47% at F48 or, put another way, the percentage of missing forecasts jumps from 34% at F12 to 53% at F48. The percentage of unverified forecasts (forecast lows which are not verified by analysis lows) increases slightly from 20% at F12 to 29% at F48. These missing or unverified forecasts are predominantly weak oceanic lows as reflected in Table 4 where less than 10% of them have cp's below 1000 mb. This is also indicated by the relatively high mean cp values of 1011 mb (not shown in Table 4) for the unverified forecasts.

The mean cp forecast error is 1.5 mb for F12 then jumps to and remains at about 2.5 mb for F24, F36, and F48. These values imply that the cp forecast error appears to be introduced in the model during the first 24 hour forecast period with little additional error in the next 24 hour period. A study by Silberberg and Bosart (MWR, April 1982) verfied the LFM runs during the 1978

-79 cool season and found larger mean cp forecast errors over the NW Atlantic Ocean region of roughly about 4 mb for F24 and 6 mb for F48. The distribution of all the forecast cp errors appears nearly even across the range of the forecast cp as seen in Figures 5-8. The small correlation values of forecast cp error and year for all forecast periods indicate that the LFM model improvements which were introduced over the study period (such as, the addition of an oceanic moisture flux and a cutback in sensible heat over the oceans in October 1981) appearently did not improve the forecast performance of oceanic low cp (except for F48). In fact, the correction value for F12 indicates a degradation. The mean oceanic low forecast position error increases linearly with forecast time from 106 nm to 190 nm. The small east and north mean vector position errors indicate that the LFM forecast position errors are nearly random with a small forecast bias toward the south and the west. The nearly random distribution of the forecast position errors are seen in Figures 9-12.

V. FORECAST ERROR REGRESSION ANALYSIS TESTS

The effort to find suitable regression equations to correct for the forecast oceanic low cp and position errors was not fruitful. Table 5 provides the squared correlation (r^2) values (for both the dependent and independent data sets) determined for the best regression equations. The forecast data sets were split into dependent data sets and independent data sets whose sizes are shown in Table 5. A forward stepwise regression procedure operated on the dependent data sets and selected the best cp and position forecast error models from a list of possible predictors. The general forecast predictors include the forecast cp, low center position (latitude and longitude), the SLP low gridpoint pressure gradients (to the north, east, south, and west), and the season. Additional predictors for pre-existing lows include the low cp change, the low speed of movement, and the low direction of movement. The r^2 of the selected models are optimally about 0.25 for cp forecast error and 0.05 for forecast position error using the dependent data sets. The position error models were not tested with the independent data sets due to the small correlations derived from the dependent data sets. The #1 cp forecast error models selected predictors from the general predictor list. The #2 cp forecast error models selected from the general and the additional predictor lists. These additional predictors according to the increased r^2 values of the #2 cp models may contain slightly more information on the forecast cp error. However none of these models yield a good correlation when tested by the independent data sets as seen in Table 5. The seasonal variability of the forecast cp error is small as the seasonal predictor shows only small correlation values of 0.05 or less with the forecast cp errors.

VI. CONCLUSIONS

A regional PTP was developed for the NW Atlantic region to operate on the LFM SLP gridfield. Although the biquadratic and bilinear interpolation schemes are commonly used for determining the low cp from a SLP gridfield, these techniques apparently do not deepen the low cp enough (a mean error of 1.7 mb). The F12, F24, F36, and F48 errors for low cp and position were determined from a 7 year archive of LFM run SLP fields. The mean cp forecast errors increase with forecast time from 1.5 - 2.7 mb, but show little increase after 24 hours. The mean low position errors increase linearly with forecast period from 106 - 190 nm, but the overall position biases are small. The associated low predictors determined by the PTP from the 7 year data file apparently do not contain enough useful information on the model forecast error biases to significantly correct either the forecast low cp or position.

Table 1. Low tracking method order and the order of the stored forecast/analysis lows of LFM products (i = relative LFM run number). ANAL is the LFM analysis. F12, F24, F36, and F48 are the 12, 24, 36, and 48 hour forecasts.

	TRACKING METHOD ORDER		
LFM RUN PRODUCT	I. BACKWARD TRACKING	II. MATCHING	III. FORWARD TRACKING
ANAL (i)	ANAL (i-1)	a. F12 (i-1) b. F24 (i-2) c. F36 (i-3) d. F48 (i-4)	a. F36 (i-2) b. F48 (i-3)
F12 (i)	ANAL (i)	a. F24 (i-1) b. F36 (i-2) c. F48 (i-3)	a. F36 (i-1) b. F48 (i-2)
F24 (i)	F12 (i)	a. F36 (i-1) b. F48 (i-2)	F48 (i-1)
F36 (i)	F24 (i)	F48 (i-1)	none
F48 (i)	F36 (i)	none	none

Table 2. The NW Atlantic regional pattern tracking program's hierarchal order for the preferred low track direction and the maximum speed limit of movement.

ORDER #	DIRECTION	MAXIMUM SPEED
1	22.5° - 90.0°	46 knots
2	90.1° - 112.5°	46 knots
3	10.0° - 22.4°	40 knots
4	0.0° - 9.9°	30 knots
5	315.0° - 360.0° and 112.6° - 135.0°	23 knots
6	135.1° - 314.9°	23 knots

Table 3. A gross comparison of the number of lows defined by the regional pattern tracking program (PTP) with either the final North American surface analysis or the Daily Weather Map.

DATA PERIOD	# LOWS IN BOTH	# MISSING PTP LOWS	# EXTRA PTP LOWS
9/77 - 10/23/77	55	4	4
7/81 - 12/81, 4/82 - 6/82	208	15	24
1/83 - 2/10/83	42	2	3
TOTAL	305	21	31

Table 4. The results of the LFM forecast errors determined for the NW Atlantic Ocean region oceanic lows during the period 1/1/78 - 1/31/85.

missing LFM runs = 296
actual LFM runs in data set = 4880

	FORECAST PERIOD			
	F12	F24	F36	F48
# FCST LOWS	970	818	770	693
# VERIFIED FCST LOWS (%)	777 (.66)	659 (.58)	569 (.53)	495 (.47)
# MISSING FCST LOWS (%)	399 (.34)	483 (.42)	511 (.47)	554 (.53)
# MISSING BELOW 1000 mb (%)	28 (.07)	35 (.07)	42 (.08)	52 (.09)
# UNVERIFIED FCST LOWS (%)	193 (.20)	159 (.19)	201 (.26)	198 (.29)
# UNVER. BELOW 1000 mb (%)	10 (.05)	12 (.08)	10 (.05)	12 (.06)
MEAN (RMS) CP ERROR (in mb)	1.5 (3.4)	2.5 (4.8)	2.5 (5.2)	2.7 (6.2)
CORR. OF CP ERROR AND YEAR	.08	.02	.01	-.06
MEAN POSITION ERROR (nm)	106	141	168	190
MEAN EAST VECTOR ERROR (nm)	-19	-10	-12	2
MEAN NORTH VECTOR ERROR (nm)	-11	-2	-12	-19

Table 5. The squared correlations (r^2) of the best regression models with the low cp and position forecast errors of the dependent and independent data sets. The #1 cp error model selects from a general list of predictors. The #2 cp error model selects from additional predictors and only operates on pre-existing lows.

	F12	F24	F36	F48
# LOWS DEP. DATA SET	528	447	394	339
r^2 OF #1 CP ERROR MODEL	.18	.26	.24	.25
r^2 OF #2 CP ERROR MODEL	.21	.29	.36	.34
r^2 OF EAST VECTOR ERROR MODEL	.07	.02	.03	.03
r^2 OF WEST VECTOR ERROR MODEL	.05	.06	.14	.08
# LOWS INDEP. DATA SET	249	212	175	156
r^2 OF #1 CP ERROR MODEL	.01	.07	.09	.10
r^2 OF #2 CP ERROR MODEL	.02	.11	.12	.07

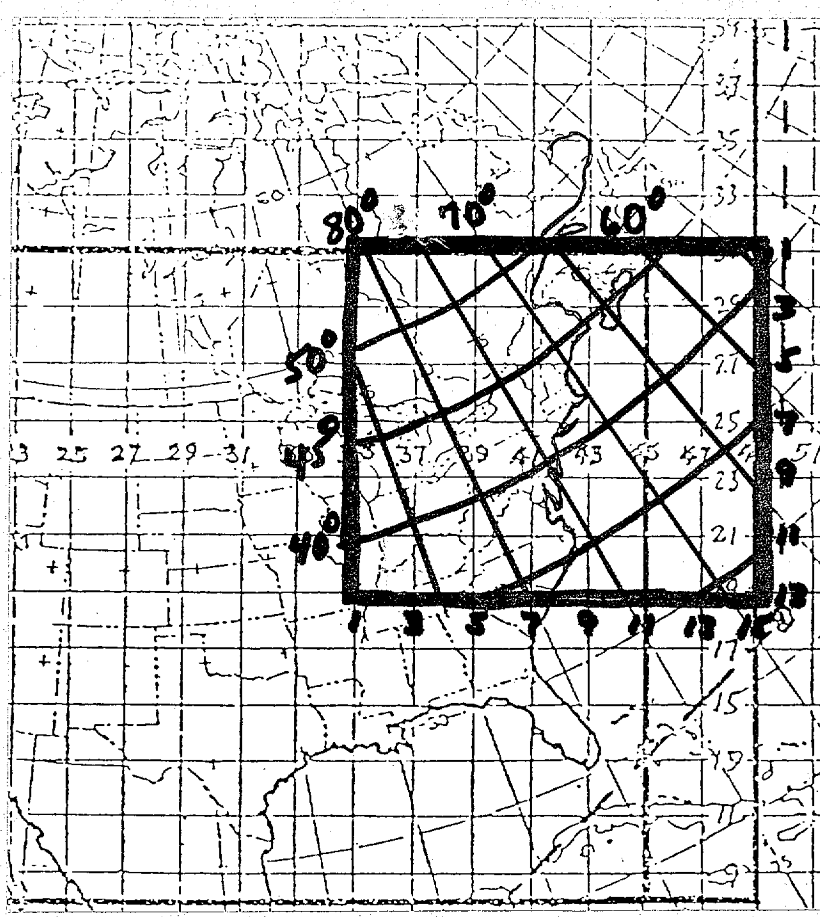
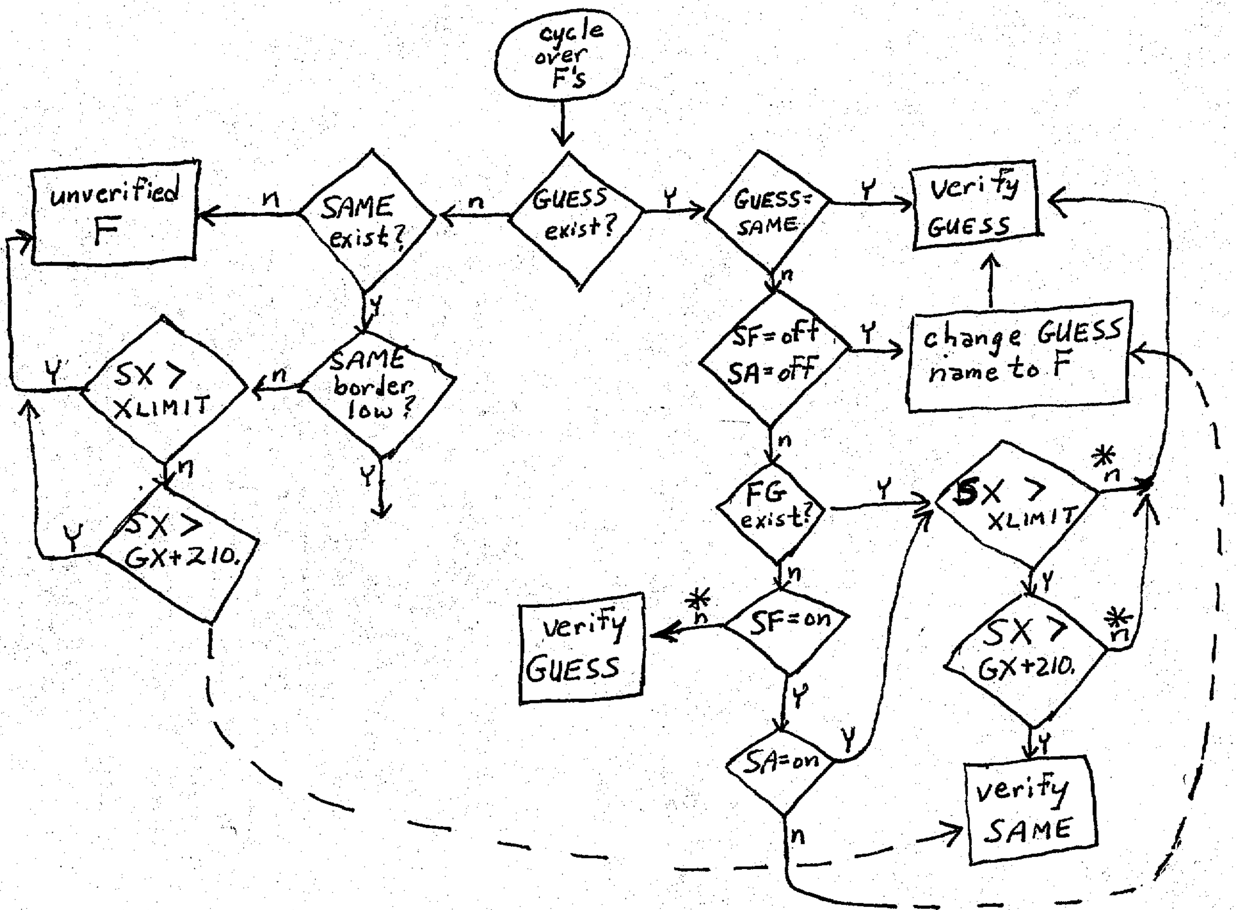


Figure 1. The gridfield (13 x 15 gridpoints) used by the regional pattern tracking program.

F2.



A = analysis low
F = forecast low (name)
GUESS = A closest to F, distance between them must be less than the forecast period's XLIMIT (400 - 580 nmi)
SAME = A with same F
GX = distance of GUESS and F
SX = distance of SAME and its closest forecast
FG = forecast low with same name as GUESS
SF = F switch } {on = name previously verified
SA = A (name) switch } {off = name not previously verified

Figure 2. A flow diagram of the forecast low verification process used in the regional pattern tracking program. An asterisk (*) indicates that the verified forecast and analysis low names are different.

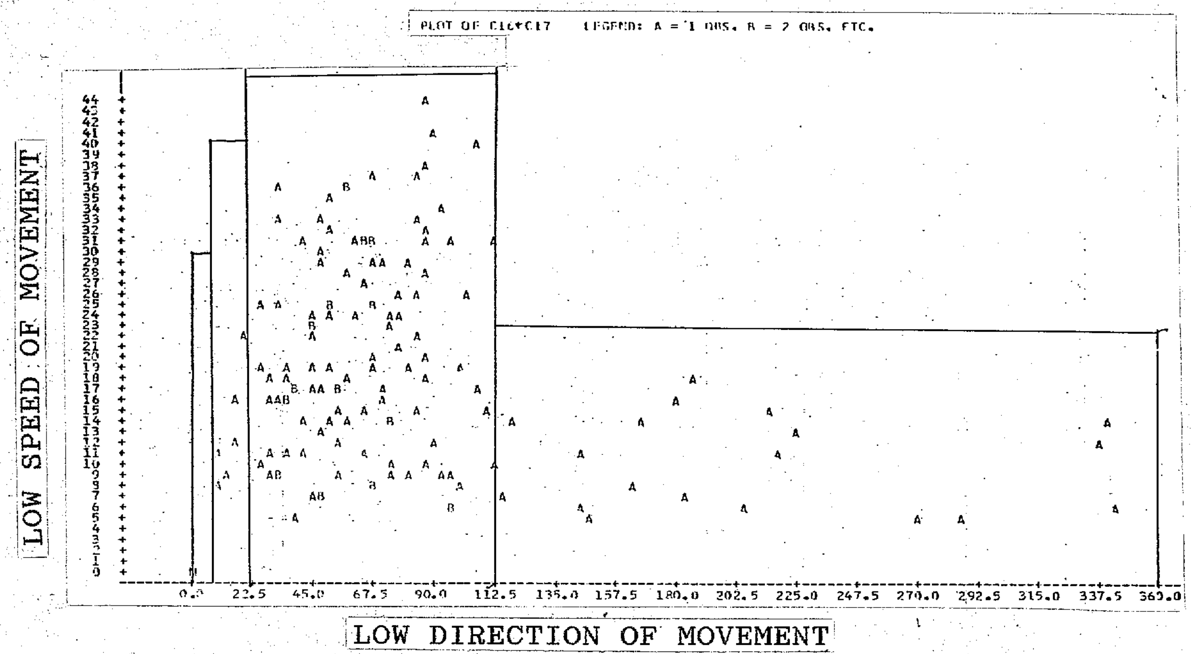


Figure 3. A scatter diagram plot of the low track movements (12 hour) for 10 months (7/81 - 12/81, 4/82 - 6/82, and 1/83) over the NW Atlantic Ocean using the regional pattern tracking program. The low speed of movement (knots) is shown along the ordinate and the low direction of movement is shown along the abscissa. The boxes around the plotted points define the hierarchal order criteria employed by the regional pattern tracking program for choosing the low tracks.

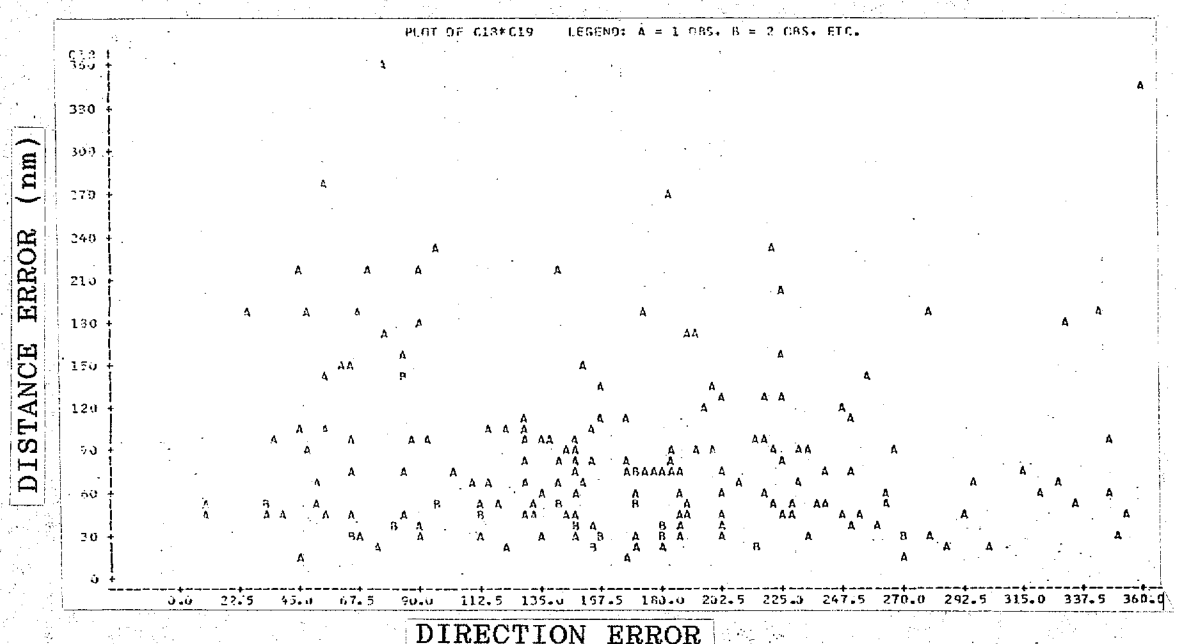


Figure 4. A scatter diagram plot of the low position errors of the pattern tracking program which are validated by the final North American surface analysis for 9 months of data (7/81 - 12/81 and 4/82 - 6/82). The distance errors (nm) are shown on the ordinate and the direction errors are given in degrees on the abscissa.

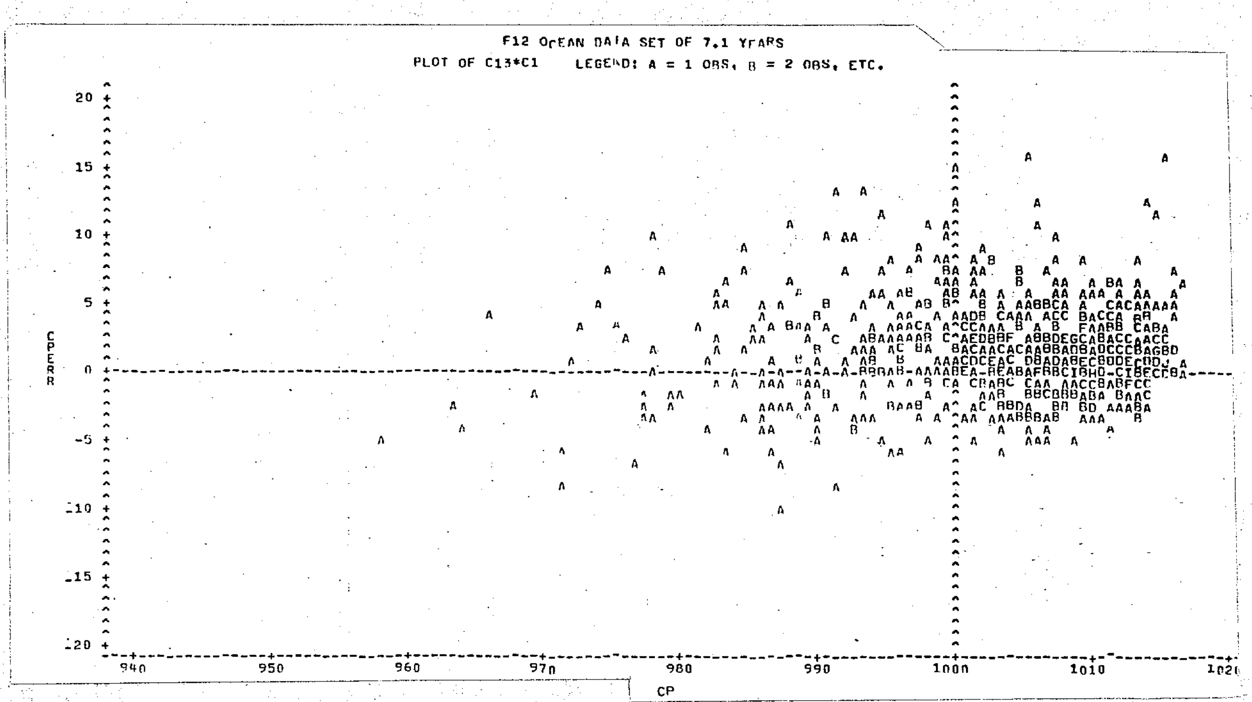


Figure 5. A scatter diagram of the LFM 12 hour forecast systematic low cp errors (along ordinate) and the forecast low cp (along abscissa) over the NW Atlantic Ocean region during 1/78 - 1/85. The units are in mb.

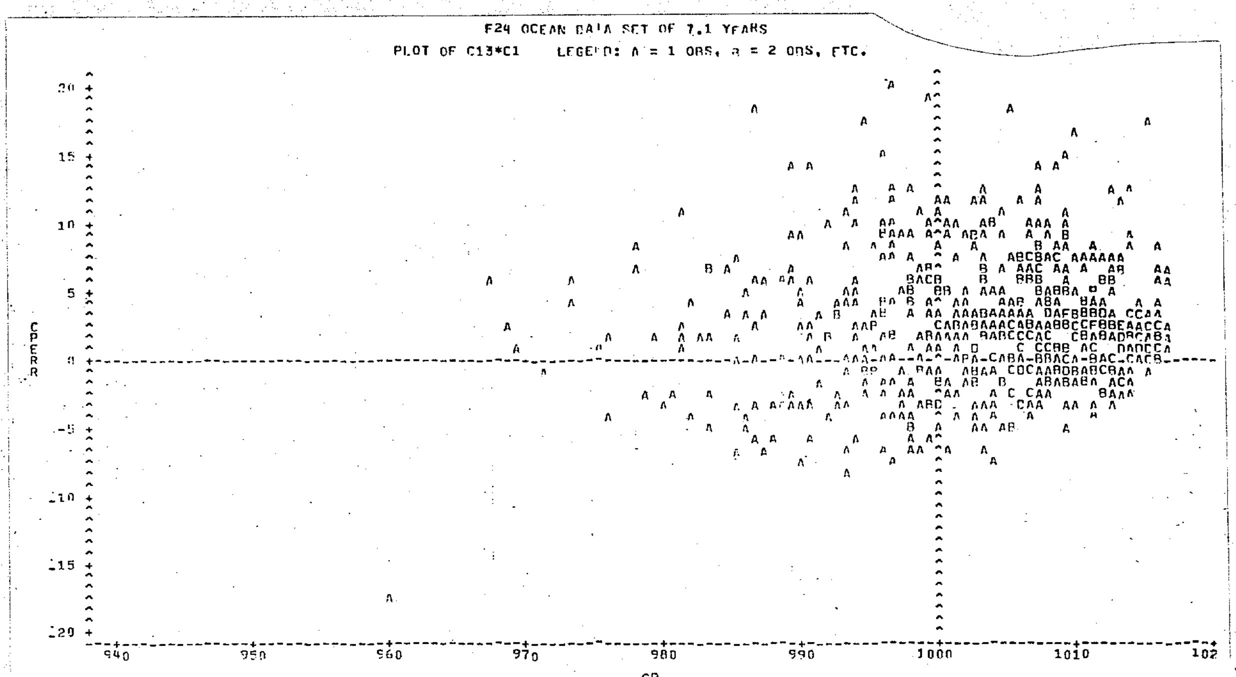


Figure 6. As in Fig. 5 except for the LFM 24 hour forecast low cp errors.

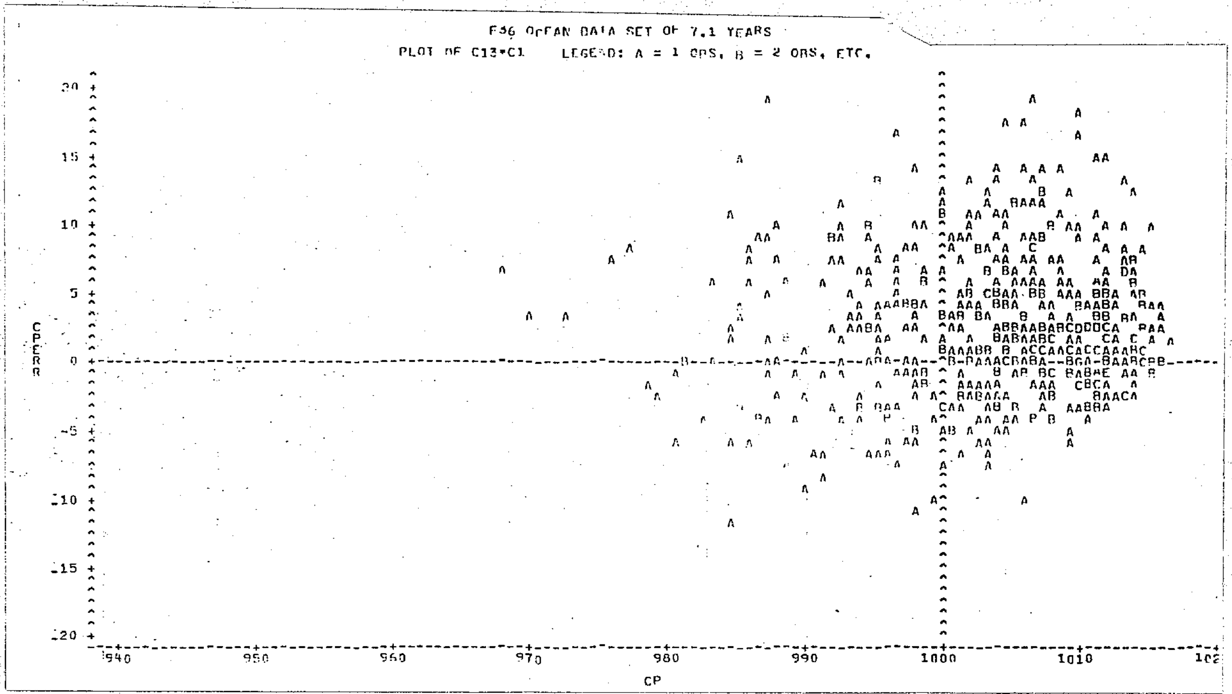


Figure 7. As in Fig. 5 except for the LFM 36 hour forecast low cp errors.

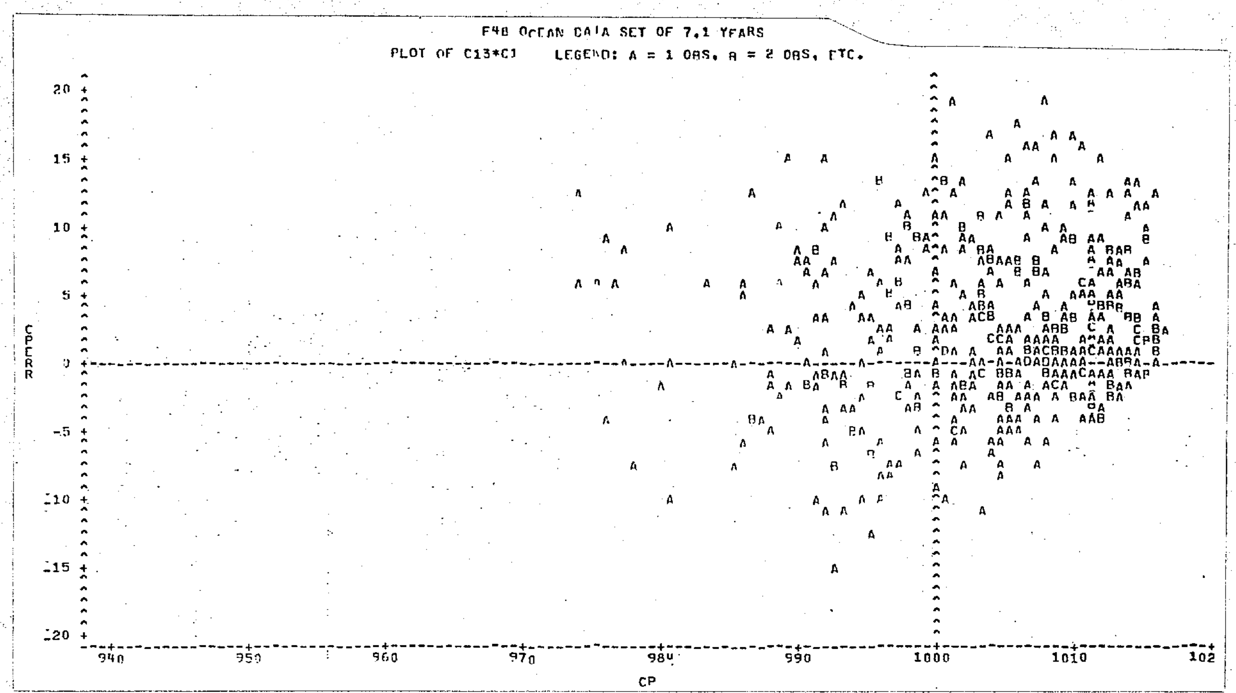


Figure 8. As in Fig. 5 except for the LFM 48 hour forecast low cp errors.

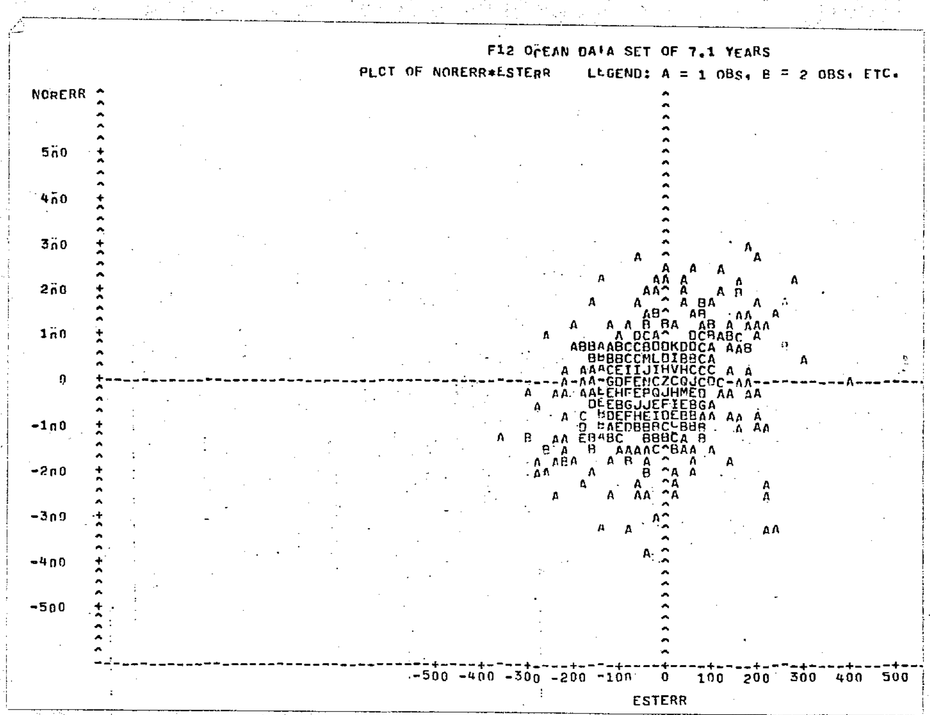


Figure 9. A plot of the LFM 12 hour forecast systematic position errors (nm) over the NW Atlantic Ocean region during 1/78-1/85.

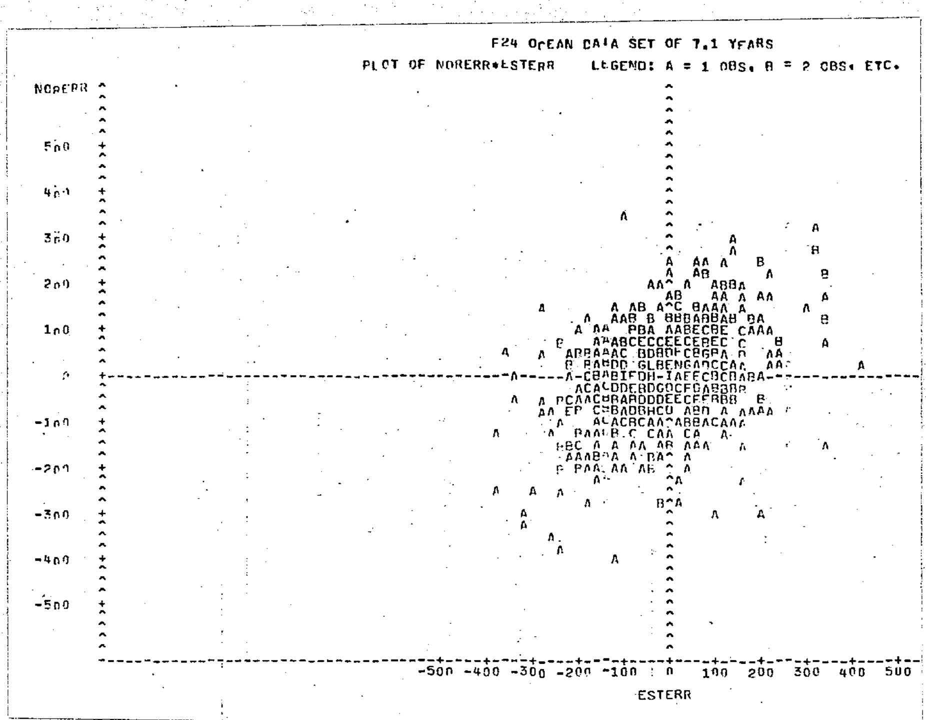


Figure 10. As in Fig. 9 except for the LFM 24 hour forecast position errors.

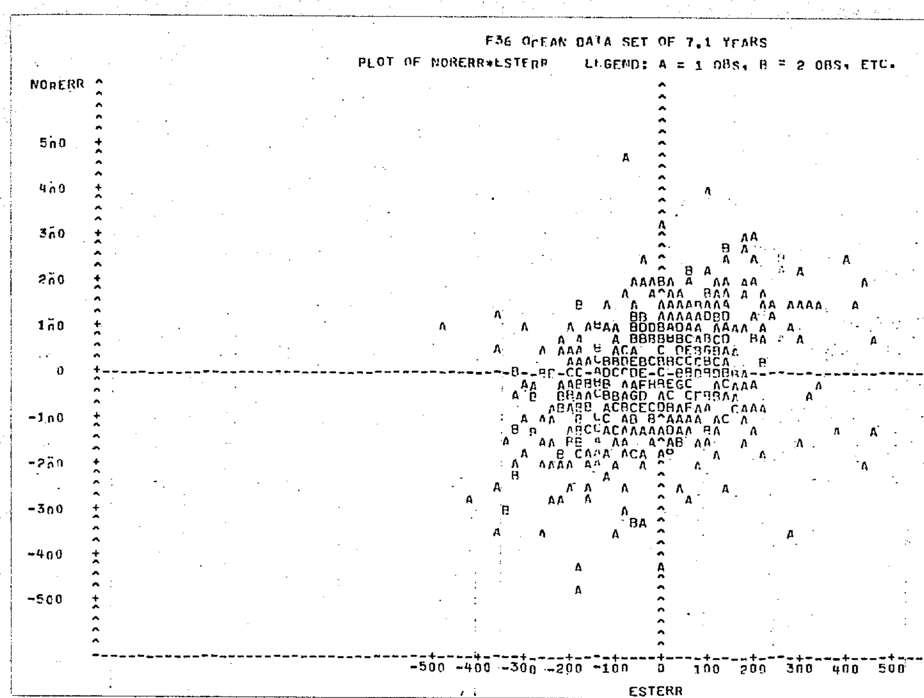


Figure 11. As in Fig. 9 except for the LFM 36 hour forecast position errors.

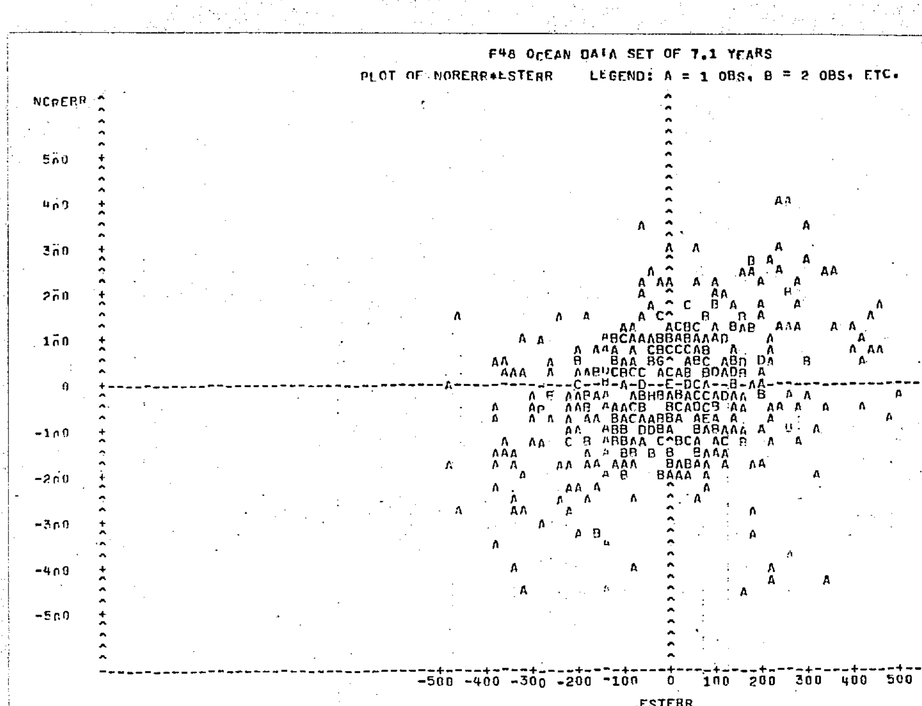


Figure 12. As in Fig. 9 except for the LFM 48 hour forecast position errors.