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Performance Test of the Movable-Area Fine-Mesh Model in the Western Pacific

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ABSTRACT

During the last six years at the National Meteorological Center (NMC), a project to develop a numerical model capable of forecasting hurricane (typhoon) movements has been underway. This project has been very successful and has resulted in the development and operational implementation of a primitive-equation, analysis-forecast system, the Movable-Area Fine-Mesh Model (MFM), capable of producing forecasts of either hurricane tracks or large-scale heavy precipitation. A performance test using the MFM was conducted on selected storms from the Western Pacific-1977 Typhoon Storm Season. The objective of the experiment was to evaluate the performance of the MFM in the Western Pacific where a sparsity of data and large storms exist. The initial analysis came from the Operational Spectral Analysis System. From this analysis a 48-hour Northern Hemisphere Six-Layer Primitive Equation Model forecast on a 381 km (true at 60° latitude) grid was generated to provide boundary conditions for the MFM. Forecast results are verified against the Joint Typhoon Warning Center provided typhoon positions.

I. INTRODUCTION

An experiment using the National Meteorological Center's Movable-Area Fine-Mesh Model (MFM) was conducted on selected storms from the Western Pacific-1977 Typhoon Storm Season. The cases used in this study were provided by the Joint Typhoon Warning Center (JTWC), Guam. Case selection was based on a storm intensity of 50 knots or greater and movement to include both straight and erratic movers.

The objective of the experiment was to evaluate the performance of the MFM in the Western Pacific, where a sparsity of data and large storms exist. Until the time of this test, experimental and operational runs of the MFM had been only conducted in the Atlantic and Gulf of Mexico areas.

II. THE NATIONAL METEOROLOGICAL CENTER'S MOVABLE-AREA FINE-MESH MODEL

During the last six years at NMC, a project to develop a numerical model capable of forecasting hurricane (typhoon) movements has been underway. This project has been very successful and has resulted in the "development and operational implementation of a primitive-equation, analysis-forecast system, the Movable-Area Fine-Mesh Model (MFM), capable of producing forecasts of either hurricane tracks or large-scale heavy precipitation" (Livezey and Hovermale, 1978b).

The MFM is a 10-layer Primitive Equation Model with a grid-mesh size of 60 km on a latitude-longitude grid of 3000 km on a side. Figure 1 shows the grid spacing and area of coverage of the MFM (i.e., HCN) as compared to the 6-layer Primitive Equation Model (hemispheric forecast area), Limited-Area Fine-Mesh Model (regional area), and the Very Fine-Mesh Model (VFM precipitation forecast).

The MFM is programmed such that it allows the grid not only to be centered on the storm at the start of the forecast, but moves with the storm, keeping it centered in the grid. Physical processes other than large-scale dynamics represented in the model are a comprehensive moisture cycle and horizontal and vertical subgrid scale fluxes of moisture, heat, and momentum.

The data required by the MFM to make a hurricane (typhoon) forecast is provided by the NMC operational data base. The standard Operational Hemispheric Analysis on a 65x65 grid provides the specification of the vertical (10 levels) and horizontal structure of the atmosphere. Boundary conditions are provided by the operational 7 or 6-layer Primitive Equation Forecast Model on a 65x65 grid. And finally, the storm's intial center (provided in this experiment by the JTWC) is the only information outside of the operational data base provided to the MFM.

The output from the model consists of 6-hourly storm center locations out to a 48-hour forecast. In general, even though winds are forecast by the model (on a 60 km grid spacing), they are non-representative. Center pressure is forecast but because of the 60 km grid spacing it is not very accurate. Storm direction and speed is forecast and is of good quality. Forecast center locations are the best products provided by the model. For the model to do its best, the storm should have a minimum wind speed of 50 knots or more. Forecasts are not made south of 15° N due to this area being too near the edge of the NMC operational forecast and analysis grid.

In order to save on computation time, the feedback of information from the MFM grid to the hemispheric grid is not accomplished. This saves a lot on computation time and has not been found by NMC to cause any significant negative impact on the MFM forecasts (Hovermale, et al, 1977).

One artificial approach used in the model is related to the internal structure of the storm being forecast. Since it is not possible to perform a real-time operational and detailed analysis of a storm's structure, a two-dimensional, axisymmetric balanced and well-behaved vortex is made by the model during its initialization. Generally, this approach works well except in cases of poorly organized storms (Livezey and Hovermale, 1978b).

III. THE EXPERIMENTAL STRUCTURE

The experiment was carried out in the following manner: The required Northern Hemisphere Operational Analysis fields were built from the NMC archived data base for the 1000, 850, 700, 500, 300, 250, 200, 150, 100, and 50 mb levels. These fields were produced by the Operational Spectral Analysis System (Flattery, 1970) for the NMC 65x65 Northern Hemisphere grid. This system uses a surface-fitting technique in which observations are fitted by the least squares method to surfaces described by a series of basic functions.

From this analysis a 48-hour Northern Hemisphere 6-layer Primitive Equation Model (Shuman and Hovermale, 1968) forecast on a 381 km (true at 60° latitude) grid was generated to provide boundary conditions for the MFM. This model was the operational forecast model at the NMC until 19 January 78, when it was replaced by a 7-layer version on a 190.5 km grid. The 1977 version of the 6-layer Primitive Equation Model was used in this experiment in order to keep the experiment consistent with the condition of the NMC operational data base in 1977.

Given the typhoon's center location (as provided by the JTWC in this experiment), the MFM then creates a symmetrical horizontal and vertical storm structure. Given this structure, the storm forecast is made out to 48-hours using the aforementioned analysis and forecast systems.

IV. FORECAST CASES

The forecast output of the model consists of the latitude and longitude of the storms center every six hours out to a 48-hour forecast. These forecasts were verified in this experiment against the JTWC provided positions (Figure 2 and 3). There was no removal of initial positioning error or any shifting of the forecast track to cause the forecast and best track to coincide. Figures 4 to 8 show the forecast (dots) and actual (typhoon symbols) for each 12-hours for each case. The forecast results are given below with longitude given as 0 to 360 degrees and latitude in degrees north. Storms are listed in chronological order:

CASE A. TYPHOON SARAH - 12Z/19 JULY 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	17.2/247.0	17.2/247.0	
06	17.2/247.4	17.4/247.6	
12	17.9/248.0	17.7/248.1	
18	18.7/248.9	18.5/248.7	
24	19.4/249.6	19.3/249.5	9.5
30	20.3/250.4	19.5/250.5	
36	21.2/251.2	20.2/251.5	58.9
42	22.1/252.0	20.6/252.8	
48	23.0/252.6	21.3/254.3	137.8

This forecast of Typhoon Sarah was quite accurate with a 9.5 NM error at 24 hours as the storm went ashore on Hainan Island. The slow movement of the storm over Hainan Island and its subsequent acceleration over the Gulf of Tonkin (Annual Typhoon Report--1977) was forecast fairly well at both the 36- and 48-hour times with a 48-hour error of only 138 NM over land as the storm was dissipating.

CASE B. TYPHOON THELMA - 12Z/22 JULY 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	16.9/234.6	16.9/234.6	
06	17.2/235.4	17.2/235.4	
12	17.8/236.4	17.7/236.2	
18	18.3/237.4	18.2/237.0	
24	18.6/238.2	18.7/237.8	24.8
30	19.2/238.7	19.1/238.6	
36	20.0/239.2	19.6/239.3	26.3
42	21.2/239.7	19.9/239.9	
48	22.4/239.9	20.4/240.3	118.6

CASE C. TYPHOON THELMA - 12Z/23 JULY 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	18.7/237.8	18.7/237.8	
06	18.8/238.0	19.1/238.6	
12	19.5/238.4	19.6/239.3	
18	20.3/239.1	19.9/239.9	
24	20.9/239.6	20.4/240.3	52.1
30	22.1/240.0	21.3/240.2	
36	23.3/240.3	22.2/239.9	70.9
42	24.5/240.5	23.8/239.8	
48	25.5/240.4	24.2/239.9	80.1

The above two cases for Typhoon Thelma were in good agreement with the observed track of the storm (Annual Typhoon Report--1977). During the 72 hours forecast in these two cases, the storm moved on a curved track to the northwest and then north with movement across southwestern Taiwan. Also, the storm intensity varied from less than, to more than, and back to less than typhoon strength during this forecast series. With 48-hour errors of only 119 and 80 NM the MFM made a good forecast considering the changing direction and intensity of the storm.

CASE D. TYPHOON VERA - 00Z/29 JULY 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	24.9/231.9	24.9/231.9	
06	24.8/232.7	24.6/232.7	
12	24.8/233.5	23.9/233.4	
18	25.0/234.2	23.4/234.0	
24	25.1/235.0	23.3/234.3	116.3
30	25.5/235.9	23.3/234.3	
36	25.9/236.7	23.5/235.1	116.3
42	26.4/237.1	24.0/235.7	
48	26.9/237.5	24.5/236.3	161.9

CASE E. TYPHOON VERA - 00Z/30 JULY 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	23.3/234.3	23.3/234.3	
06	22.9/236.3	23.3/234.6	
12	22.7/238.0	23.5/235.1	
18	21.7/239.8	24.0/235.7	
24	21.1/240.9	24.5/236.3	326.1
30	20.6/241.8	25.0/237.4	
36	20.5/242.5	24.9/238.6	340.9
42	20.8/242.9	24.8/239.8	
48	21.2/243.4	24.9/240.4	261.4

In Case D the first 48-hours forecast for Typhoon Vera did capture the general steering of the storm to the west-northwest (Annual Typhoon Report--1977) with a 48-hour error of 162 NM. However, as an anticyclone built to the north of the storm, the storm began a more westerly track with a decrease in speed and intensity. The initial building of the anticylone to the north of the storm was not reflected in the forecast storm track of Case E. The MFM pushed the storm well to the south and southwest of Taiwan with a 48-hour error in Case E of 261 NM.

CASE F. TYPHOON BABE - 12Z/07 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	18.5/232.1	18.5/232.1	
06	19.1/232.1	19.3/232.5	
12	20.5/231.9	20.6/232.7	
18	21.7/231.6	21.2/233.2	
24	23.9/231.4	22.9/233.2	117.1
30	24.3/231.0	22.6/232.5	
36	25.6/230.6	23.6/232.0	144.6
42	26.9/230.1	25.0/231.4	
48	28.2/229.8	26.9/231.2	107.1

CASE G. TYPHOON BABE - 00Z/09 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	23.6/232.0	23.6/232.0	
06	24.6/231.8	25.0/231.4	
12	25.9/231.3	26.9/231.2	
18	27.8/231.0	29.0/232.0	
24	29.6/231.1	30.3/233.9	152.2
30	31.5/230.9	30.9/235.7	
36	33.2/231.1	31.2/236.8	312.9
42	34.5/230.9	31.5/237.6	
48	35.3/230.0	31.8/238.6	477.6

The forecast for Case F for Typhoon Babe was very consistent and predicted well the northern movement of the storm while the storm was undergoing a rapid deepening (Annual Typhon Report--1977). The forecast error for this case at 48-hours was only 107 NM.

The forecast made for Case G for Typhoon Babe was a poor forecast with a 48-hour error of 478 NM. Missed completely was the steering of the storm toward Shanghai, China.

CASE H. TYPHOON DINAH - 00Z/15 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	19.5/235.1	19.5/235.1	
06	19.2/236.1	18.6/236.5	
12	19.2/237.2	18.2/237.6	
18	18.9/238.2	17.6/238.9	
24	18.8/239.1	17.3/240.0	104.3
30	18.9/239.9	17.1/240.9	
36	19.1/240.6	17.2/241.8	133.8
42	19.6/241.2	16.9/242.8	
48	20.1/241.8	17.0/243.4	207.5

CASE I. TYPHOON DINAH - 12Z/16 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	17.2/241.8	17.2/241.8	
06	17.2/241.9	16.9/242.8	
12	17.7/241.8	17.0/243.4	
18	18.5/241.7	17.2/243.7	
24	19.4/241.4	17.3/244.0	191.8
30	20.3/241.1	17.5/243.7	
36	21.2/240.7	17.9/243.2	243.3
42	22.2/240.1	18.4/242.7	
48	23.1/239.3	18.9/242.3	301.9

CASE J. TYPHOON DINAH - 12Z/18 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	18.9/242.3	18.9/242.3	
06	18.8/242.2	19.3/241.8	
12	19.9/241.8	19.6/241.5	
18	19.6/241.2	19.7/241.3	
24	20.4/240.9	19.9/241.2	30.9
30	21.2/240.7	20.0/240.9	
36	21.9/240.4	20.2/240.8	104.4
42	22.7/240.1	20.3/240.9	
48	23.5/239.6	20.3/241.1	207.9

CASE K. TYPHOON DINAH - 00Z/20 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	20.2/240.8	20.2/240.8	
06	19.8/241.2	20.3/240.9	
12	19.8/241.5	20.3/241.1	
18	19.8/241.9	20.1/241.3	
24	19.9/242.6	20.2/241.5	62.3
30	20.1/243.3	20.3/241.8	
36	20.4/244.2	20.0/242.7	85.3
42	20.8/244.9	19.4/243.5	
48	21.2/245.8	18.5/244.5	175.4

CASE L. TYPHOON DINAH - 00Z/21 SEPT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	20.2/241.5	20.2/241.5	
06	19.8/242.0	20.3/241.8	
12	19.9/242.5	20.0/242.7	
18	20.1/243.2	19.4/243.5	
24	20.3/244.0	18.5/244.5	109.8
30	20.6/244.9	17.8/245.1	
36	21.1/245.7	17.3/246.7	277.1
42	21.4/246.8	16.5/247.1	
48	21.6/247.6	15.5/248.0	366.4

Cases H, I, J, K, and L deal with Typhoon Dinah and its complicated maneuvering over the South China Sea (Annual Typhoon Report--1977). In Case H the storm moved southwesterly over the Island of Luzon. The MFM forecast a more westerly track but still had a reasonable error of 208 NM at 48 hours even though the storm had intensified, weakened over land, and reintensified during this forecast.

Case I dealt with a loop of the storm. This was not predicted by the MFM but the northward movement was forecast. The 48-hour forecast error was a high of 302 NM.

Case J found the storm decreasing and then increasing in intensity with a northern movement and the beginning of a turn back to the southwest. The northern movement was forecast but the turning was not. The forecast error at 48 hours was 208 NM.

Case K found Dinah again moving west and then southwest. The MFM forecast was west and then northwest. During this period the movement of the storm had slowed down. The 24- and 36-hour forecasts were less then 100 NM by the MFM and the 48-hour forecast was 175 NM.

Case L was the poorest forecast of the series on Dinah. The southwesterly movement was not captured but the forward speed was captured fairly well. Since the track was forecast northwest while the storm moved southwest, the error was a high of 366 NM at 48 hours.

Overall the forecast errors for five cases for Typhoon Dinah were 99.8 NM at 24 hours, 168.8 NM at 36 hours, and 251.9 NM at 48 hours. This reflects the difficulty of forecasting an erratic moving storm. The 48-hour error was 25-percent higher than the average error for all 15 cases. Interestingly enough, the 24- and 36-hour errors for Dinah were close to the average for all 15 cases (see Table 2).

CASE M. TYPHOON GILDA - 00Z/07 OCT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	26.3/212.0	26.3/212.0	
06	27.1/212.4	27.3/212.6	
12	28.1/212.0	28.4/212.9	
18	28.9/212.1	29.8/213.0	
24	29.6/211.7	31.0/212.7	98.9
30	30.1/211.3	32.3/211.8	
36	30.3/210.8	33.7/210.5	203.0
42	30.6/210.3	34.8/209.2	
48	30.9/210.0	35.9/208.1	312.5

In this case the 48-hour forecast error was over 300 NM. However, the 24-hour error was less than 100 NM. The recurvature of the storm was captured by the forecast model. During this forecast period the storm had decreased, then increased, and finally decreased in intensity.

CASE N. TYPHOON IVY - 00Z/24 OCT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	21.2/209.5	21.2/209.5	
06	22.0/208.9	22.2/208.2	
12	22.7/207.8	23.5/207.0	
18	23.8/206.8	24.6/206.1	
24	24.7/205.9	25.6/205.5	59.3
30	25.5/204.9	26.1/205.0	
36	26.3/203.7	27.4/204.6	82.2
42	27.2/202.5	28.2/204.1	
48	28.3/201.3	29.0/203.7	133.8

Typhoon Ivy was at typhoon strength during this forecast with a rather straight northeasterly movement. This forecast was handled well by the MFM with a 48-hour error of 133.8 NM as the forecast track moved the storm more easterly.

CASE O. TYPHOON JEAN - 00Z/29 OCT 77

Hour	Forecast Lat/Long	Fix Lat/Long	Vector Error in NM
00	20.3/203.9	20.2/203.9	
06	20.4/204.4	20.9/203.8	
12	20.7/204.7	21.5/203.4	
18	20.8/205.1	22.1/202.8	
24	21.1/205.3	22.7/202.5	183.3
30	21.5/205.7	23.2/202.5	
36	21.8/206.1	23.6/202.9	208.3
42	22.1/206.8	23.9/203.3	
48	22.4/207.7	24.1/203.8	238.4

This storm was of interest as it was a very weak storm (Annual Typhoon Report--1971) and established a record as the shortest-lived typhoon of the season (6 hours). The MFM did forecast the eventual movement of the storm to the west too early. As a result, the northeasterly movement of the storm was not forecast at all with a large error in the forecast track of 183 NM at 24 hours and 238 NM at 48 hours.

V. FORECAST SUMMARY

The forecast results for all 15 cases for comparison purposes are listed below:

TABLE 1

	CASE	STORM	Mean Vector Error (NM) 24	36	48 (Hours)
A.	12Z/19 JULY	SARAH	9.5	58.9	137.8
B.	12Z/22 JULY	THELMA	24.8	26.3	118.6
C.	12Z/23 JULY	THELMA	52.1	70.9	80.1
D.	00Z/29 JULY	VERA	116.3	168.2	161.9
E.	00Z/30 JULY	VERA	326.1	340.9	261.4
F.	12Z/07 SEPT	BABE	117.1	144.6	107.1
G.	00Z/09 SEPT	BABE	152.2	312.9	477.6
H.	00Z/15 SEPT	DINAH	104.3	133.8	207.5
I.	12Z/16 SEPT	DINAH	191.8	243.3	301.9
J.	12Z/18 SEPT	DINAH	30.9	104.4	207.9
K.	00Z/20 SEPT	DINAH	62.3	85.3	175.4
L.	00Z/21 SEPT	DINAH	109.8	277.1	366.4
M.	00Z/07 OCT	GILDA	98.9	203.0	312.5
N.	00Z/24 OCT	IVY	59.3	82.2	133.8
O.	00Z/29 OCT	JEAN	183.3	208.3	238.4

The average vector error for all of these cases is shown below:

TABLE 2

HOURS	Mean Vector Error in NM for 15 cases
24	109.2
36	164.0
48	219.2

When these results are compared with forecast verifications of storms in the Atlantic for rich and poor data cases using the MFM, the results are realistic as shown below (Hovermale, et al., 1977, and Livezey and Hovermale, 1978a):

TABLE 3

	Mean Vector Errors (NM)			
Hours	1976 Atlantic Sparse Data	1977 Pacific 15 Cases	1976 Atlantic All Cases	1977 Atlantic All Cases
24	135	109	126	95
36	250	164	143	118
48	365	219	201	126

VI. SUMMARY

A performance experiment on the MFM was run using the NMC Operational Analysis/Forecast Data Base.

In the current IBM 360/195 configuration at NMC, an MFM hurricane (typhoon) forecast out to 48 hours would operationally expect to be completed by 10 hours after data observation time. The through-put time of the MFM to generate a 48-hour storm forecast is approximately 100-minutes.

Overall, the statistical verification results of the model forecasts were good even with some very poor forecasts included in the sample. When these results are compared with forecast verifications of the storms in the Atlantic for rich and poor data cases, the results are realistic.

If all the NMC forecast samples up through 1978 are included for comparison (cases now number over 100), the mean vector error of the MFM averages 125 NM for 24 hours and 200 NM for 48 hours. The test results of the MFM in the Western Pacific compare favorably with these statistics.

In conclusion, the NMC Hurricane Model appears to perform as well in the Western Pacific (an area of sparse data for numerically structuring a storm) as it does in the Atlantic.

ACKNOWLEDGMENTS

Dr. Robert E. Livezey and Mr. Armand J. Desmarais provided invaluable assistance in setting up the computer programming structuring of the Movable-Area Fine-Mesh Model and the 6-Layer Primitive Equation Model.

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Shuman, Frederick G., and John B. Hovermale, 1968: An Operational Six-Layer Primitive Equation Model, Journal of Applied Meteorology, Vol. 4, pp. 525-547.

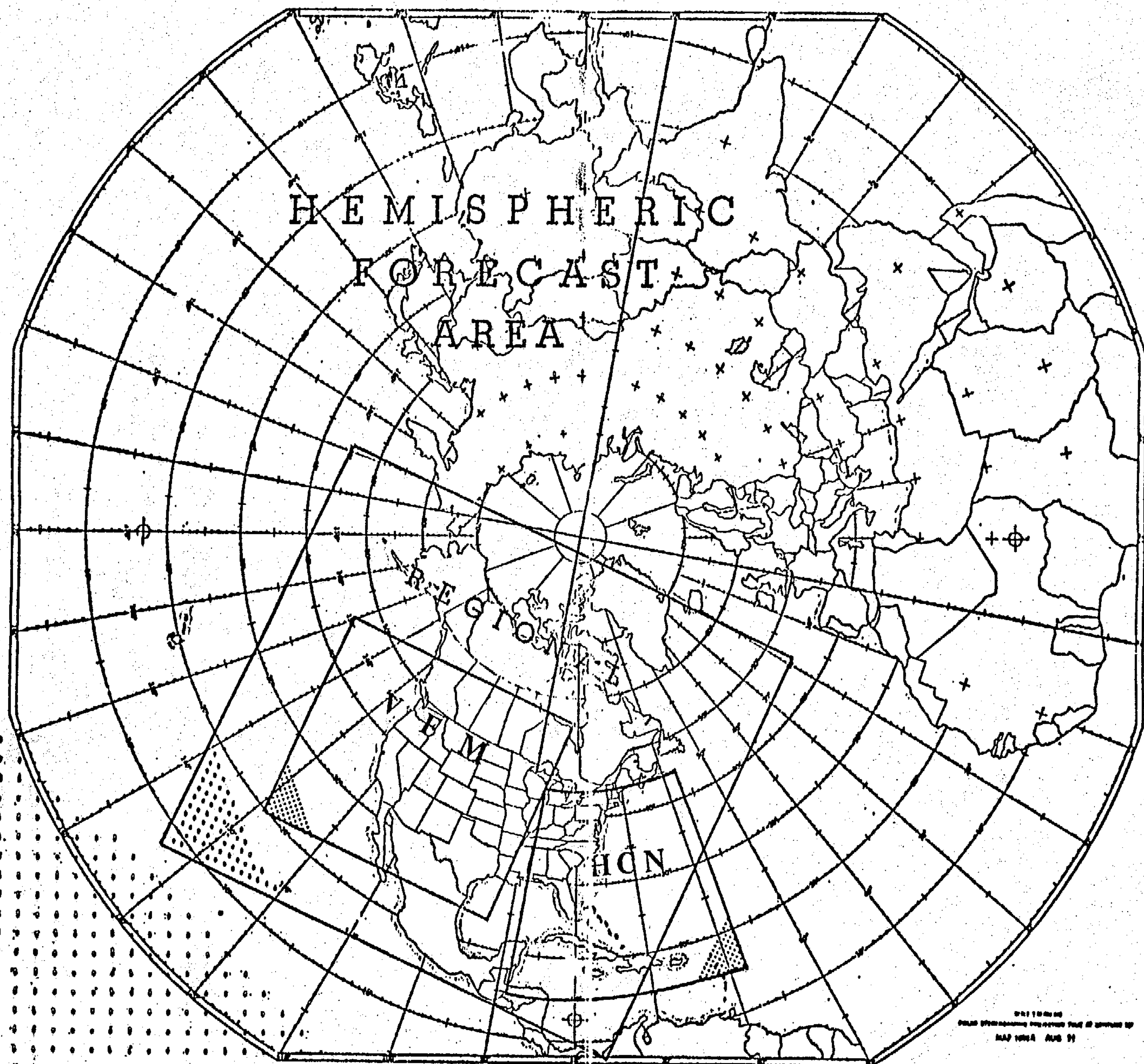

FIGURE 1. NMC Grids.

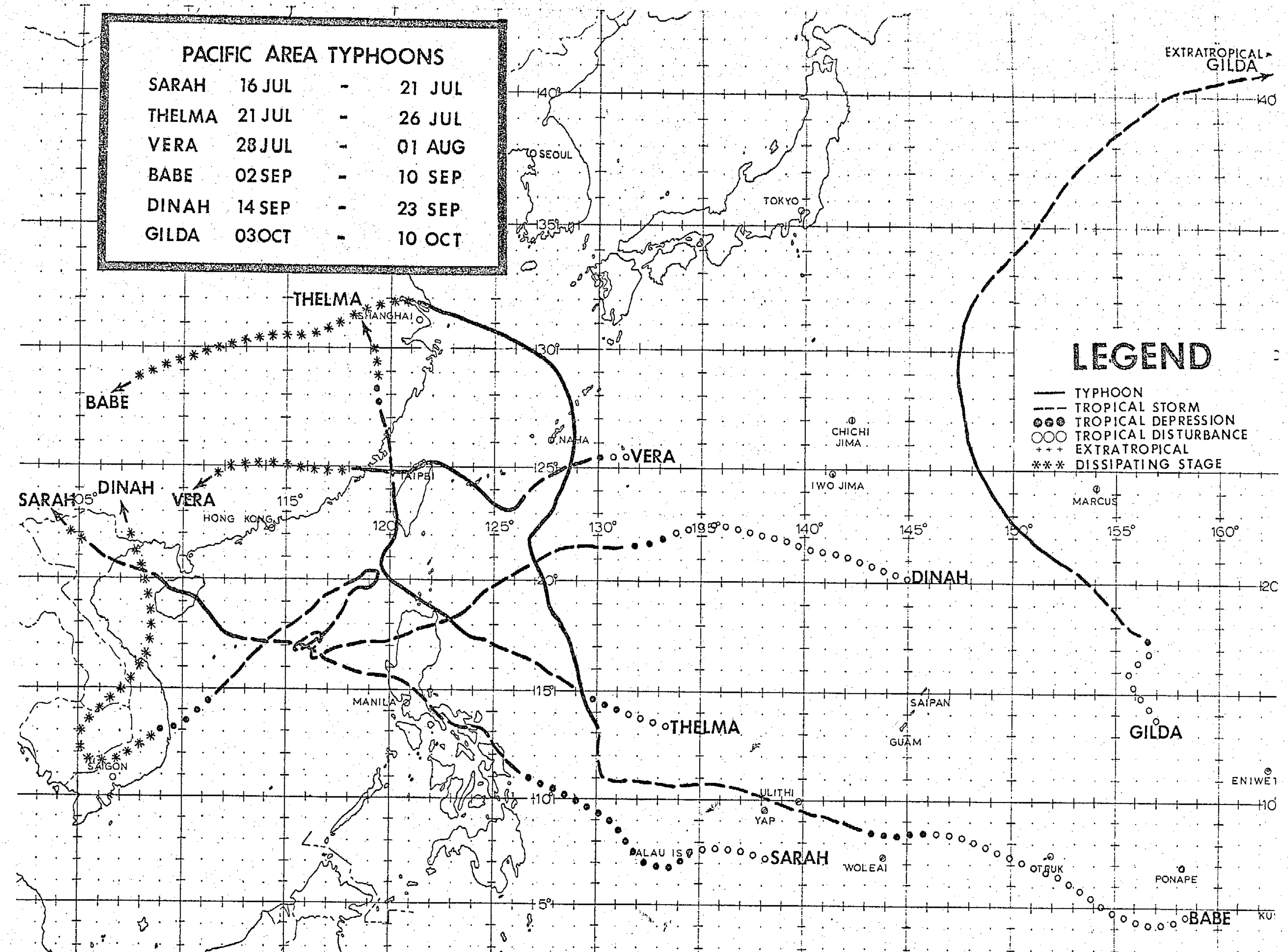

FIGURE 2. (reference page 16, Annual Typhoon Report - 1977)

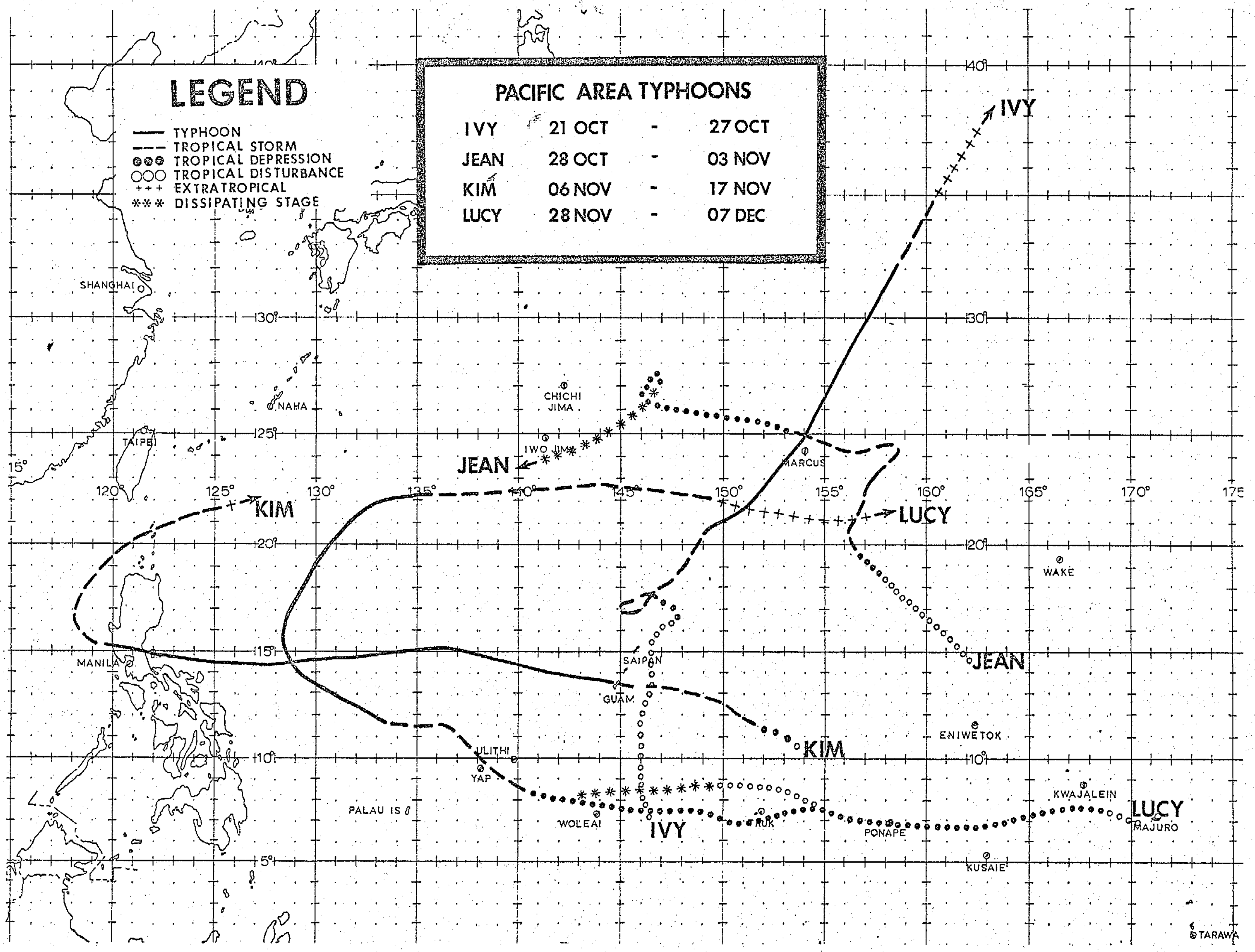

FIGURE 3. (reference page 17, Annual Typhoon Report - 1977)

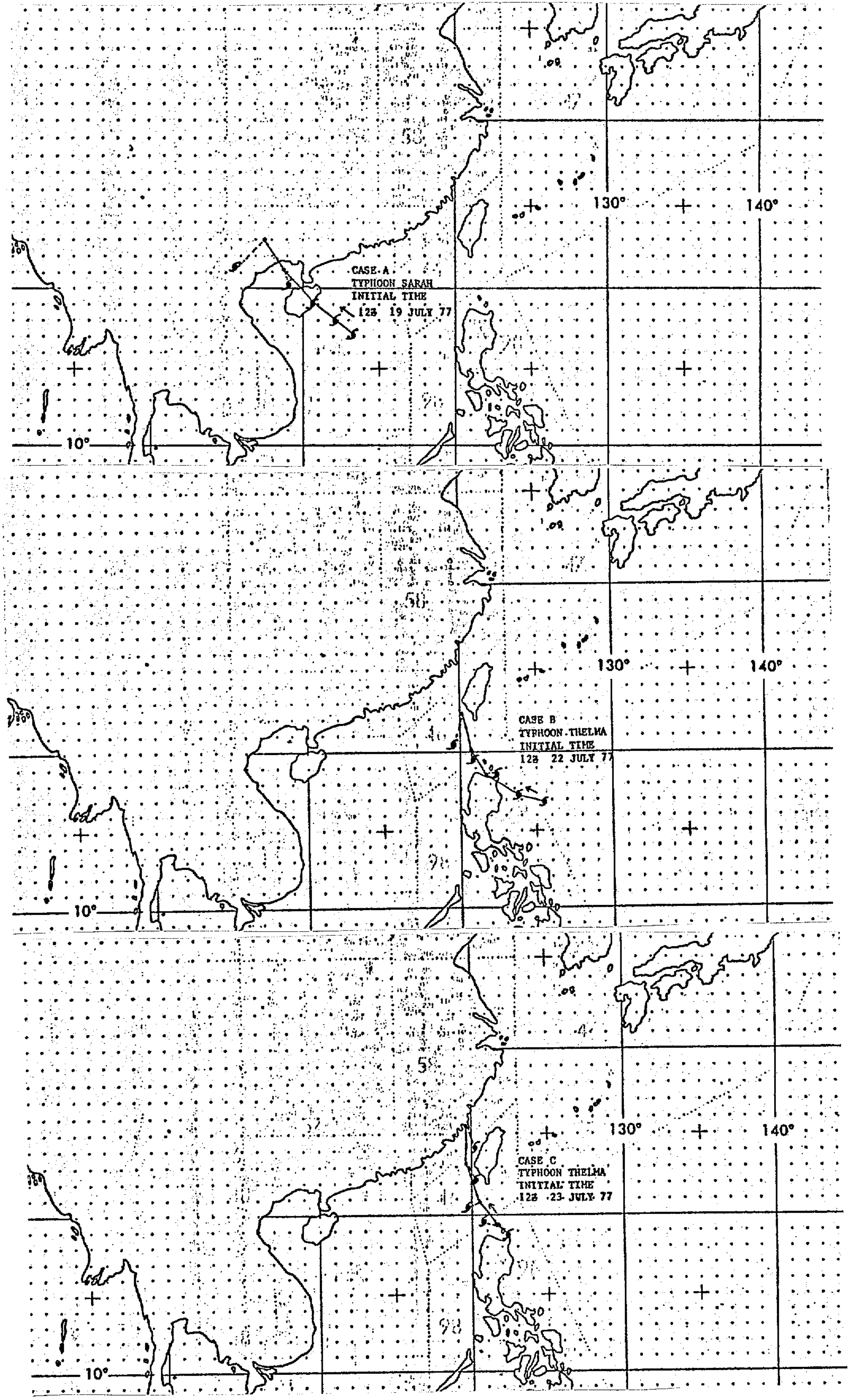

FIGURE 4. MFM - Forecasts (Dots) and Observed (Typhoon Symbols) for 12-hour positions.

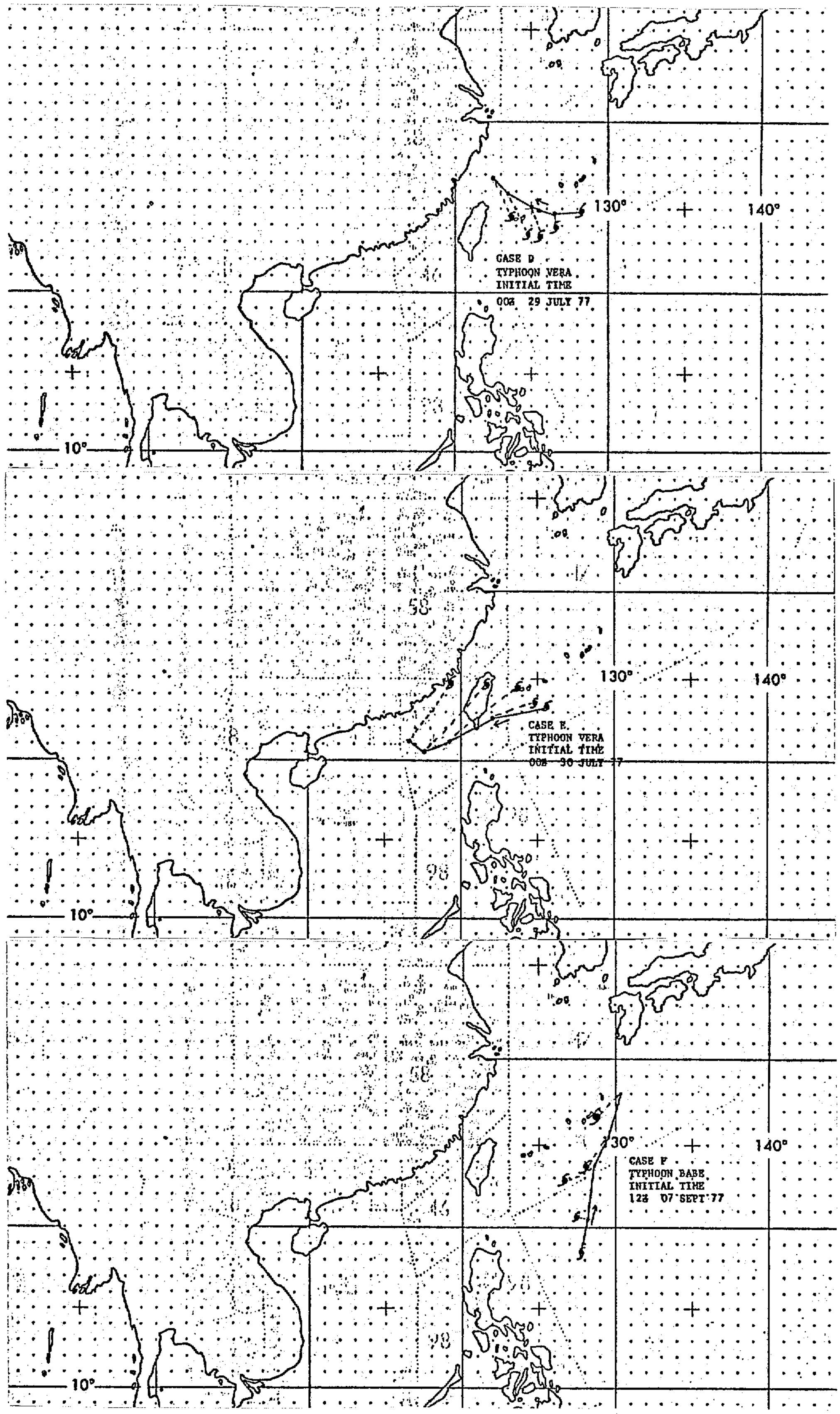

FIGURE 5. MFM - Forecasts (Dots) and Observed (Typhoon Symbols) for 12-hour positions.

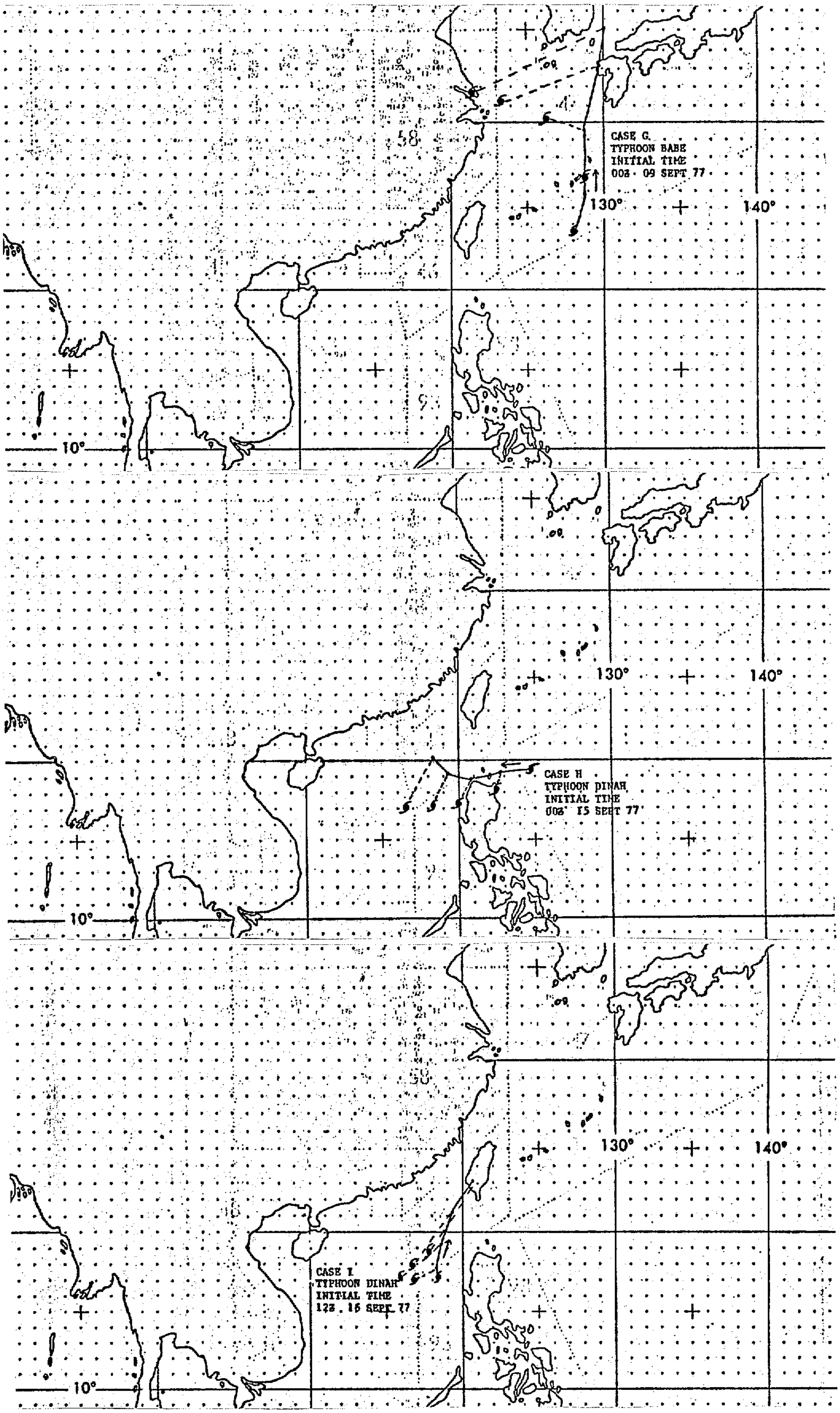

FIGURE 6. MFM - Forecasts (Dots) and Observed (Typhoon Symbols) for 12-hour positions.

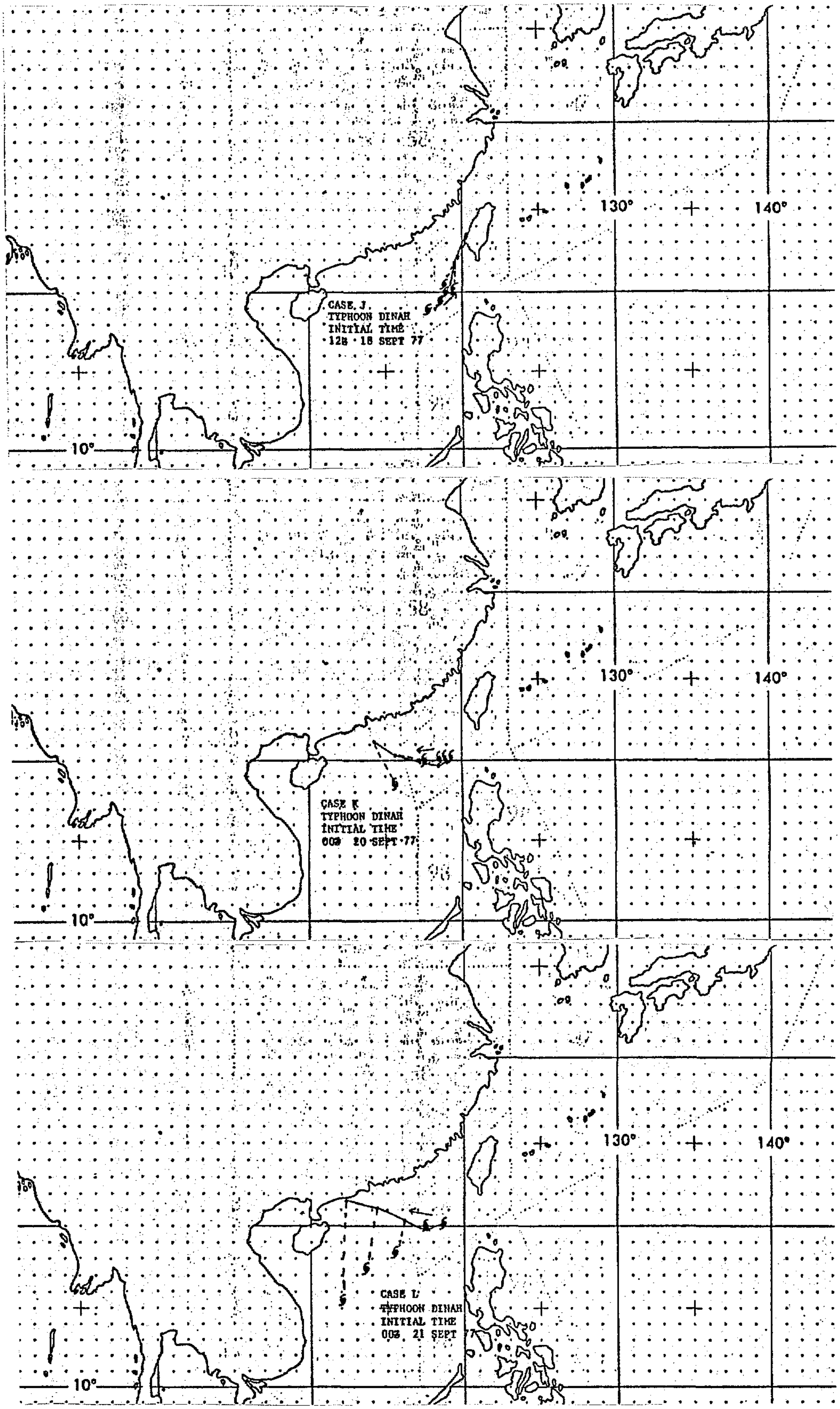

FIGURE 7. MFM - Forecasts (Dots) and Observed (Typhoon Symbols) for 12-hour positions.

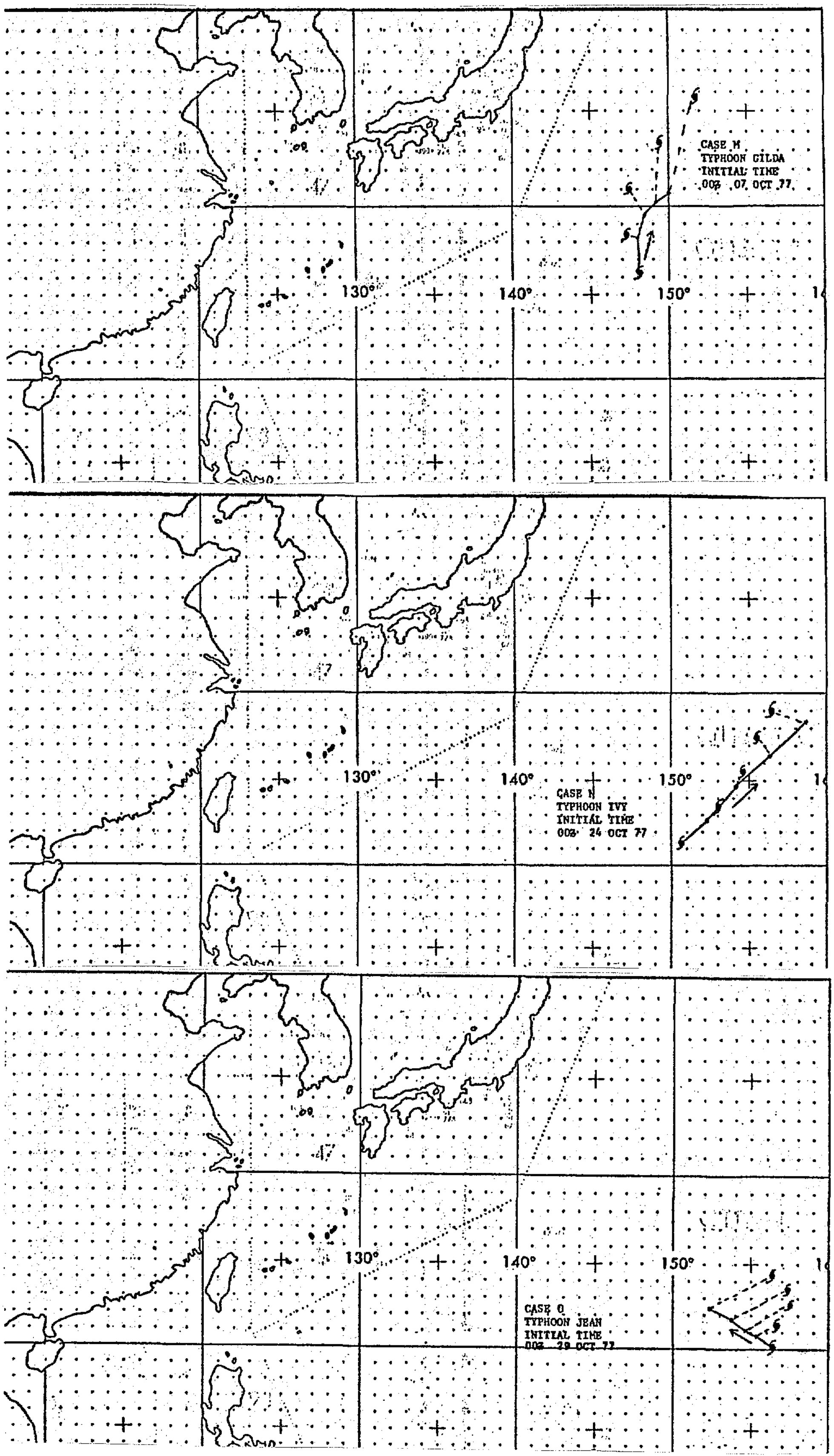

FIGURE 8. MFM - Forecasts (Dots) and Observed (Typhoon Symbols) for 12-hour positions.