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STATISTICAL GUIDANCE ON THE PREDICTION OF EASTERN NORTH PACIFIC TROPICAL CYCLONE MOTION - PART 2

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National Weather Service Western Region
Salt Lake City, Utah
August 1977

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Preston W. Leftwich and Charles J. Neumann

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STATISTICAL GUIDANCE FOR THE PREDICTION OF EASTERN NORTH PACIFIC TROPICAL CYCLONE MOTION PART-2

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ABSTRACT. The EPHC77 system is one of three components of a statistical prediction package developed for the Eastern Pacific Hurricane Center (EPHC), San Francisco, California, to provide objective guidance for the forecasting of tropical cyclone motion over the Eastern North Pacific Ocean. EPHC77 forecasts are statistical combinations of forecasts made by a simulated analog model (EPCLPR) and forecasts made by predictors derived from synoptic data. This paper describes the formulation and application of the EPHC77 model.

I. INTRODUCTION

The EPHC77 prediction model is the third component of a statistical prediction package developed to provide objective guidance for forecasting tropical cyclone motion over the Eastern North Pacific Ocean. Description and discussion of two earlier components, an analog model (EPANLG) and a simulated analog model (EPCLPR), are contained in Part 1 of this Technical Memorandum (Neumann and Leftwich 1977).

EPHC77 is a statistical-synoptic model, that is, it utilizes both empirical and synoptic predictors to produce forecasts of tropical cyclone motion. Two sets of displacements are independently computed. One set is obtained from the EPCLPR model. A second set, hereafter referred to as the SYNOPTIC set, is obtained from regression equations using 500-mb geopotential heights as predictors. These two sets of displacements are then combined statistically to produce a final forecast. Development of regression equations for the EPHC77 system generally followed procedures discussed by Neumann, Hope, and Miller (1972).

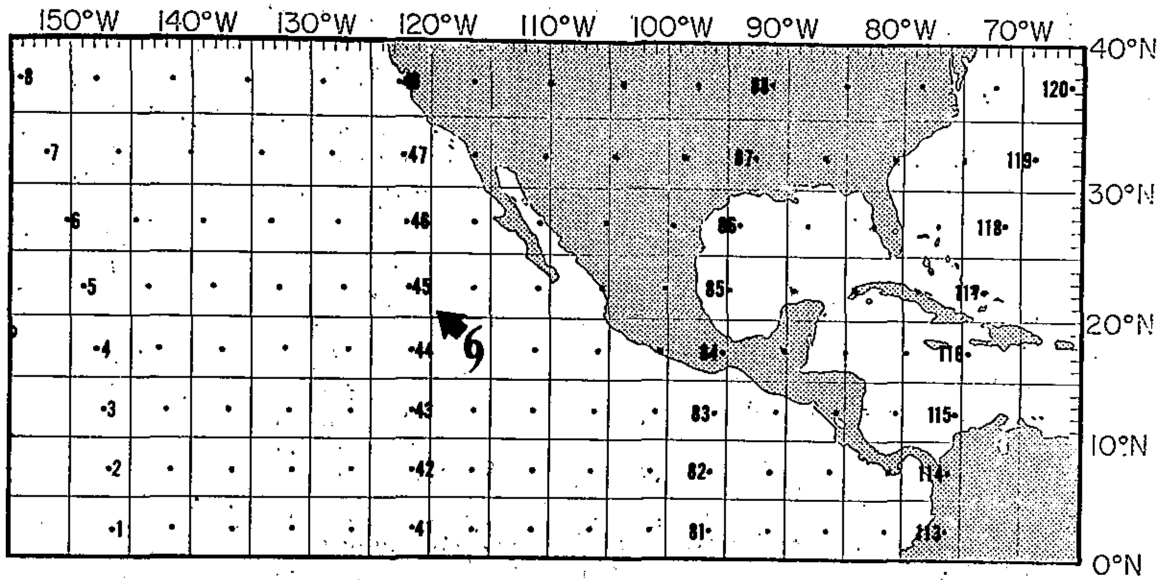

Figure 1. The grid system. Grid points are spaced at 300 n mi intervals. Grid moves with the storm.

II. DEPENDENT DATA

Dependent data for 2290 forecast situations during the period 1949-1976 are stored on magnetic tapes maintained at the National Hurricane Center (NHC), Miami, Florida. Data include 500-mb heights (current and 24 hours ago), best track storm positions at 12-hour intervals, and corresponding EPCLPR forecasts for periods of 12, 24, 36, 48, and 72 hours. Height fields are defined by a storm-centered, 8x15 grid system as illustrated in Figure 1. This grid is identical to that used in development of earlier statistical-synoptic prediction models for storms in the Atlantic basin.

III. PREDICTIONS BASED ON SYNOPTIC DATA

Potential synoptic predictors include current and 24-hour-old 500-mb heights at each of 120 grid points shown in Figure 1. Thus, 240 possible synoptic predictors are defined. Standard stepwise screening regression techniques, as discussed by Efroymson (1964) eliminate nonsignificant or redundant predictors.

During each screening regression run, linear correlation coefficients relating each synoptic data value to various storm displacements were computed. Fields of linear correlation coefficients for 24-hour meridional and zonal motions are shown in Figures 2a and 3a, respectively. For comparison, similar correlation coefficient fields obtained for the Atlantic region are shown in Figures 2b and 3b.

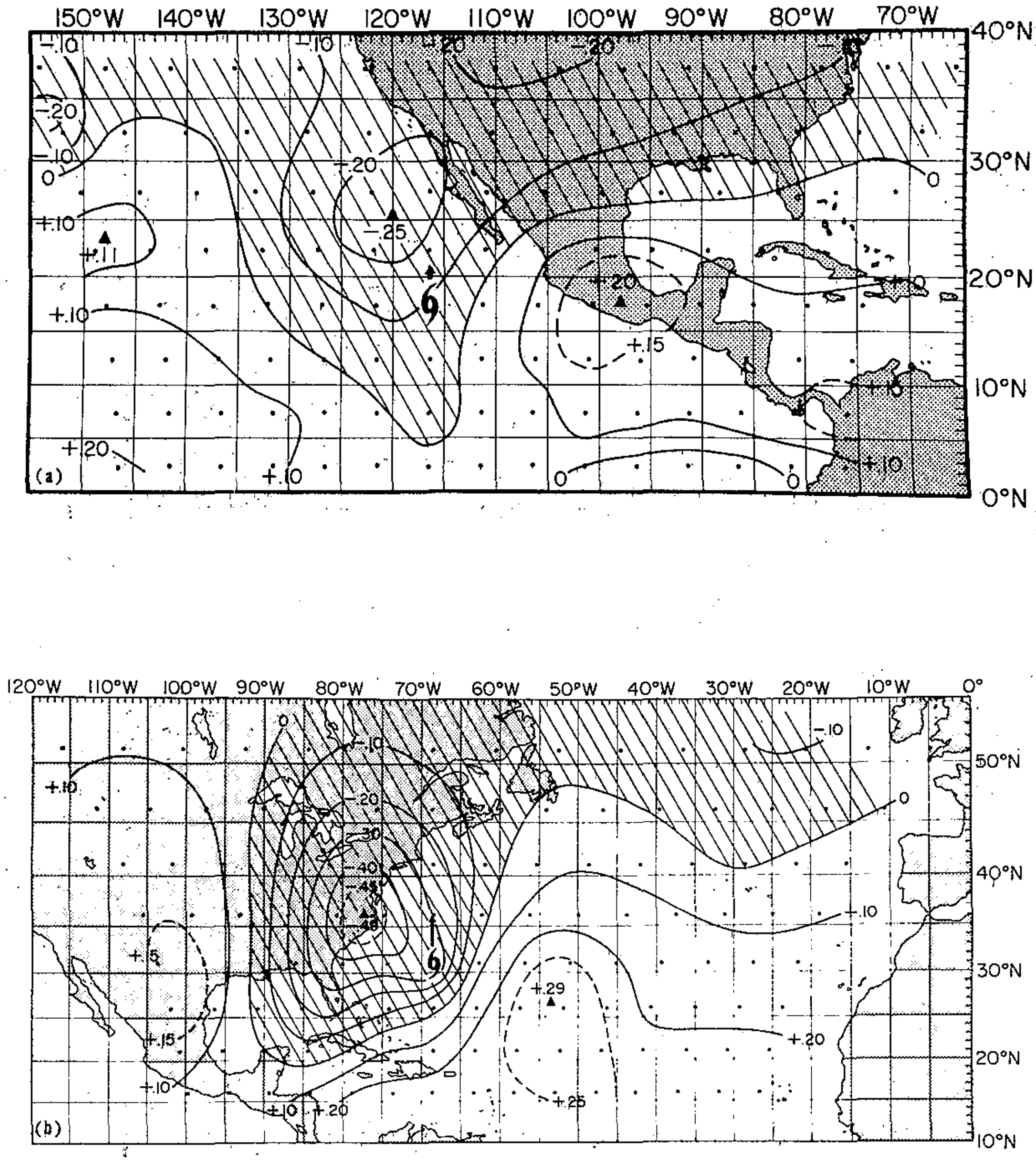

Figure 2. Linear correlation coefficient fields between 24-hour meridional tropical cyclone motion and 500-mb geopotential heights for (a) Eastern Pacific and (b) Atlantic regions.

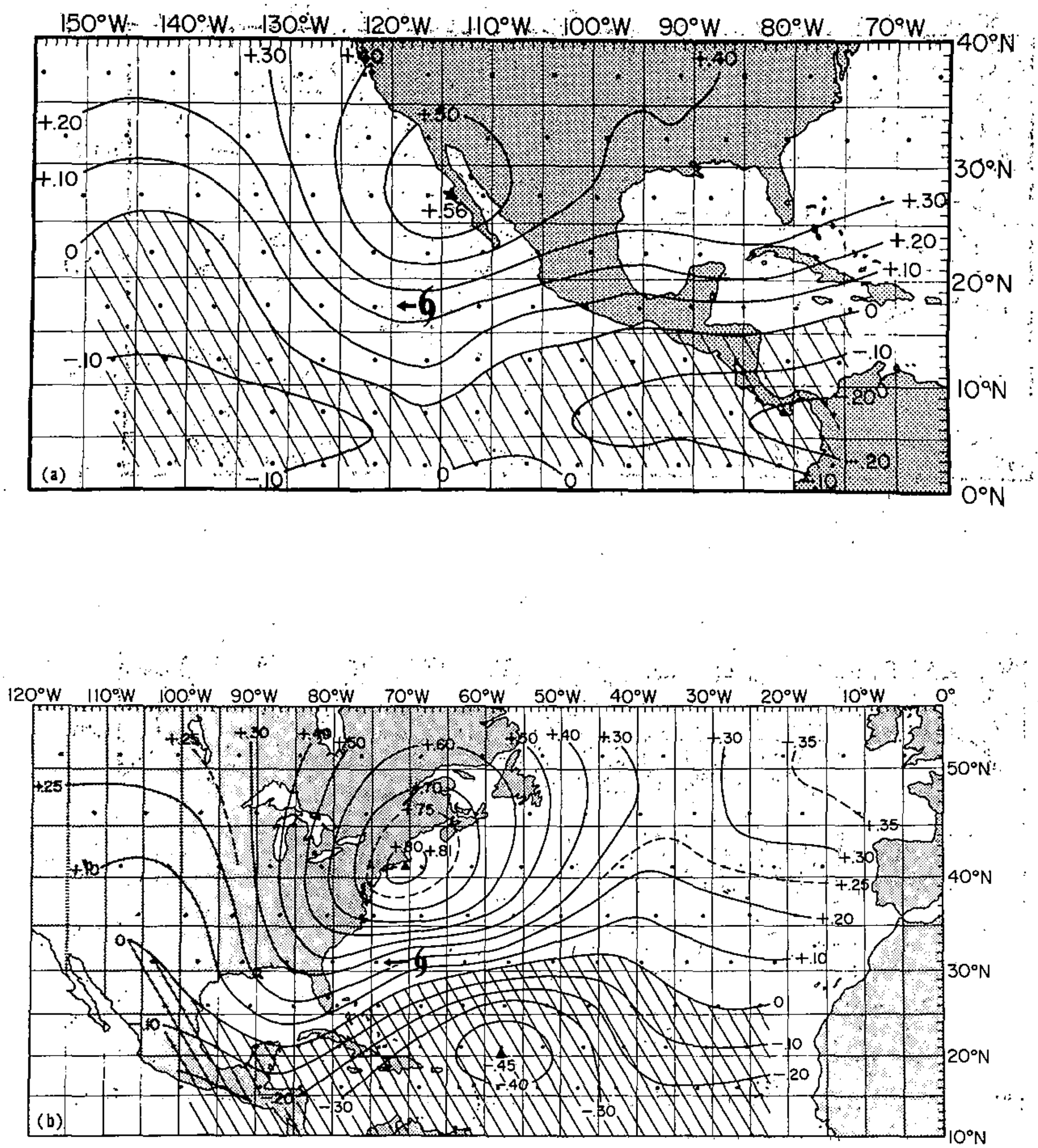

Figure 3. Linear correlation coefficient fields between 24-hour zonal tropical cyclone motion and 500-mb geopotential heights.

For both meridional and zonal motion, patterns of correlation coefficients relative to indicated storm centers for the Eastern North Pacific are similar to patterns for the Atlantic basin. These figures illustrate and confirm subjectively derived "steering" principles. Zonal motion is strongly influenced by geopotential heights north of the storm, while meridional motion is primarily controlled by heights northwest of the storm center. Thus, the 500-mb topography north through northwest of a storm is extremely important insofar as future motion is concerned. Reduced values of linear correlation coefficients found in the Eastern North Pacific as compared to the Atlantic can be at least partially attributed to poor 500-mb analyses over remote tropical oceanic regions, especially prior to the availability of satellite data.

At the completion of the screening regression procedure, separate sets of geopotential heights had been chosen as predictors for both meridional and zonal motion for periods of 12, 24, 36, 48, and 72 hours. This gave a total of 10 sets of predictors. Each individual predictor was then tested for statistical significance, and only significant predictors were retained. Also, some predictors were subjectively eliminated when that data point had been frequently assigned a climatological value. Final selection of predictors was made subjectively in order to retain a common set of predictors for a given motion component at all time periods. This procedure was followed because operational experience has shown that a common set of predictors produces smoother forecast storm tracks than predictor sets of variable size for different time periods. Selected predictors were thus included for time periods when they produced both small and large reductions of variance. For example predictor P3 for meridional motion contributed no incremental reduction of variance for the 12-hour period, but it was the first predictor selected for 72-hour meridional motion.

Grid-point locations of 500 mb geopotential heights retained as predictors of meridional and zonal motions are given in Figures 4 and 5, respectively. Six predictors were retained for meridional motion--five from the current analysis and one from the analysis made 24 hours prior to the current time. All four predictors retained for zonal motion are current 500-mb heights. Primary predictors for meridional motion are indicated by circles numbered 1 and 2 in Figure 4. Locations of less significant current heights are indicated by smaller circles, and the location of the height from the analysis made 24 hours ago is given by the square. Predictors for zonal motion are similarly noted in Figure 5. The two primary predictors were chosen first and second for all time periods by the screening regression procedure.

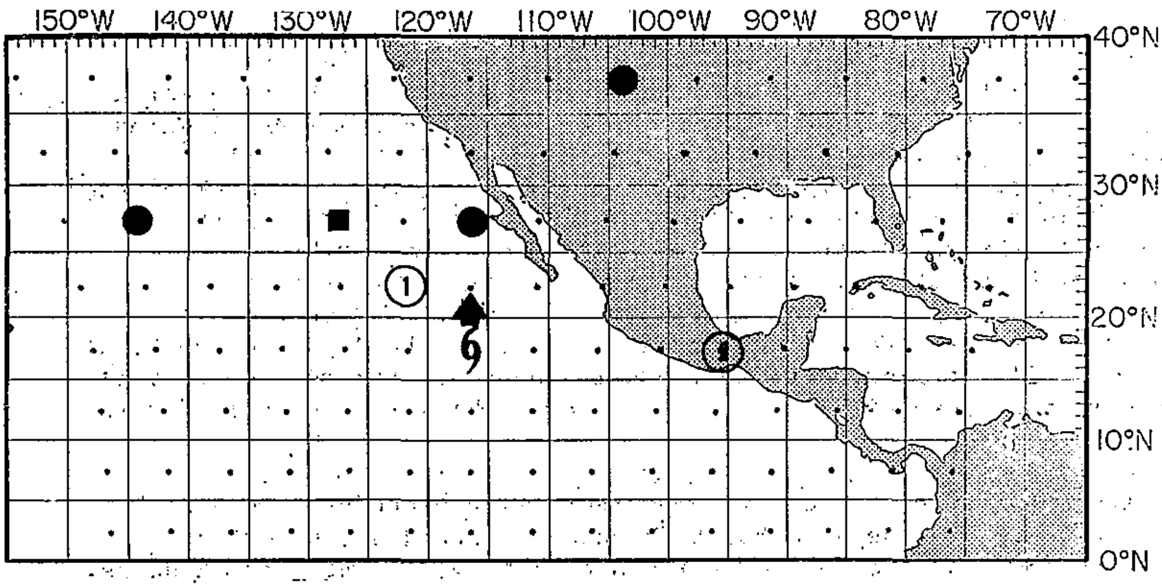

Figure 4. Location of 500-mb predictors of meridional tropical cyclone motion. Circles numbered 1 and 2 show principal predictors. Square indicates height value from 24 hours ago.

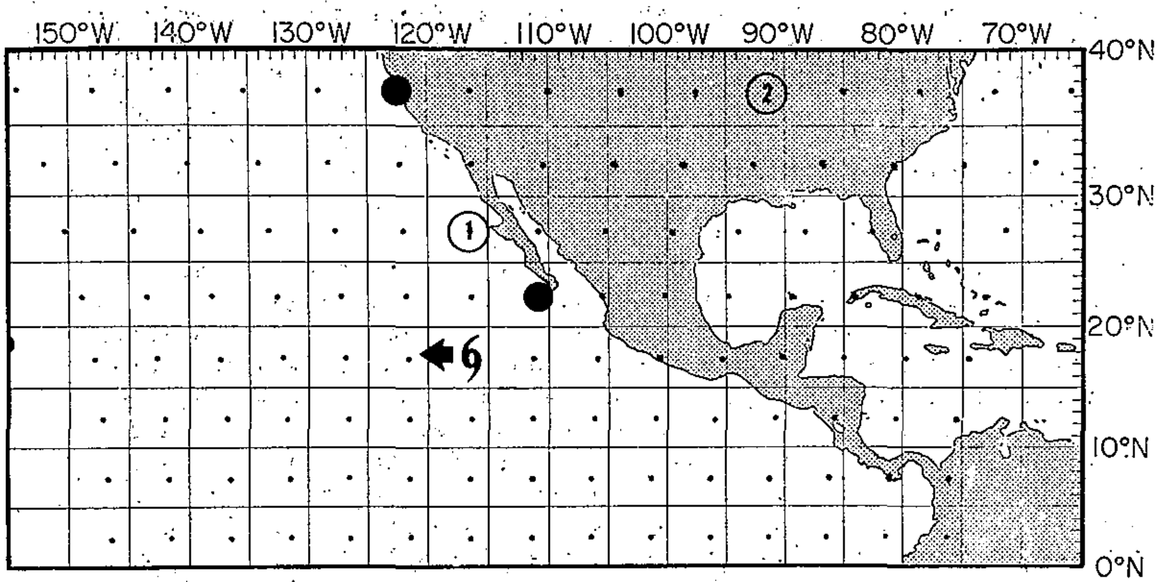

Figure 5. Same as Figure 4, but for zonal tropical cyclone motion. Here, all predictors are current 500-mb heights.

Selected predictors for each component of motion and associated reductions of variance (RV) are listed in Table 1. Predictors P1 through P5 for meridional motion and predictors R1 through R4 for zonal motion are current 500-mb heights. Predictor P6 for meridional motion is the 500-mb height from 24 hours ago.

Table 1. Variance analyses on meridional and zonal motions for SYNOPTIC forecasts.

VARIANCE ANALYSIS ON MERIDIONAL MOTION

PREDICTOR SELECTION	12 HOUR FCST		24 HOUR FCST		36 HOUR FCST		48 HOUR FCST		72 HOUR FCST	
ORDER	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV
I=1	P4	.048	P2	.050	P3	.045	P3	.065	P3	.039
2	P5	.032	P5	.058	P5	.047	P5	.039	P6	.033
3	P2	.031	P6	.017	P1	.018	P1	.029	P1	.032
4	P6	.015	P1	.011	P6	.013	P6	.016	P5	.012
5	P1	.008	P4	.015	P2	.014	P4	.010	P4	.008
6	P3	.000	P3	.001	P4	.010	P2	.010	P2	.002
TOTAL REDUCTION	(J=1)	.134	(J=2)	.151	(J=3)	.147	(J=4)	.149	(J=5)	.126

VARIANCE ANALYSIS ON ZONAL MOTION

PREDICTOR SELECTION	12 HOUR FCST		24 HOUR FCST		36 HOUR FCST		48 HOUR FCST		72 HOUR FCST	
ORDER	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV	PREDICTOR	RV
I=1	R1	.256	R1	.302	R1	.285	R1	.255	R1	.222
2	R3	.034	R3	.043	R3	.053	R3	.062	R3	.072
3	R2	.008	R4	.011	R4	.020	R4	.024	R4	.023
4	R4	.008	R2	.014	R2	.015	R2	.015	R2	.010
TOTAL REDUCTION	(J=1)	.306	(J=2)	.370	(J=3)	.373	(J=4)	.356	(J=5)	.327

In the formulation of desired prediction equations, meridional (ΔY_j) and zonal (ΔX_j) displacements are taken as linear functions, f , of selected synoptic predictors such that

$$\Delta Y_j = f_j(P1,P2,P3,P4,P5,P6) \qquad j=1,5 \qquad (2)$$

and

$$\Delta X_j = g_j(R1,R2,R3,R4) \qquad j=1,5 \qquad (3)$$

where j refers to the five forecast periods of 12, 24, 36, 48, and 72 hours. Regression coefficients determined by a least-squares fit of the linear functions are given in Appendix I. Then, (2) and (3) are defined by

$$\Delta Y_j = C_{0,j} + \Sigma(C_{i,j} \cdot P_i) \qquad \begin{matrix} i=1,6 \\ j=1,5 \end{matrix} \qquad (4)$$

and

$$\Delta X_j = Q_{0,j} + \Sigma(C_{i,j} \cdot R_i) \qquad \begin{matrix} i=1,4 \\ j=1,5 \end{matrix} \qquad (5)$$

Here, $C_{0,j}(Q_{0,j})$ are intercept values, $C_{i,j}(Q_{i,j})$ are regression coefficients, and $P_{i,j}(R_{i,j})$ are predictors for meridional (zonal) displacement. As a complete example, predicted 72-hour meridional displacement is given by

$$\Delta Y_{72} = -17001.6 + 1.17 \cdot P1 - 0.49 \cdot P2 - 1.11 \cdot P3 - 0.29 \cdot P4 + 1.27 \cdot P5 + 2.39 \cdot P6. \qquad (6)$$

Solutions of the above equations are given in nautical miles. These equations thus provide an estimate of tropical cyclone motion based entirely on predictors derived from synoptic data.

IV. EPHC77

Once predictions have been made utilizing synoptic data alone, two sets of forecasts exist--one set from the simulated analog model (EPCLPR) and one set from the synoptic predictors (SYNOPTIC). As discussed in Thompson (1977), error variances of final forecasts appear capable of being reduced by the optimum combination of two or more independent predictions. An analogous procedure by which EPHC77 statistically combines the separate EPCLPR and SYNOPTIC forecasts is illustrated schematically in Figure 6.

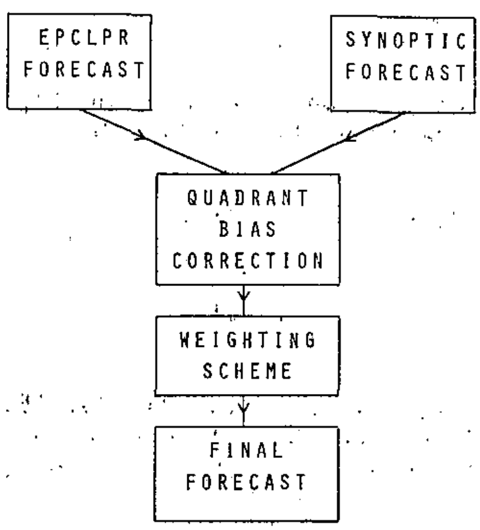

Figure 6. Schematic of EPHC77 prediction algorithm.

As demonstrated by Neumann and Hope (1972), any weighting factors used in this combination must be both time and space dependent. Also, it was found that results can be improved by stratification of data according to initial motion. In the current development, forecast cases were stratified according to the mean motion over the past 12 hours. A bivariate normal distribution fitted to these motions is shown in Figure 7.

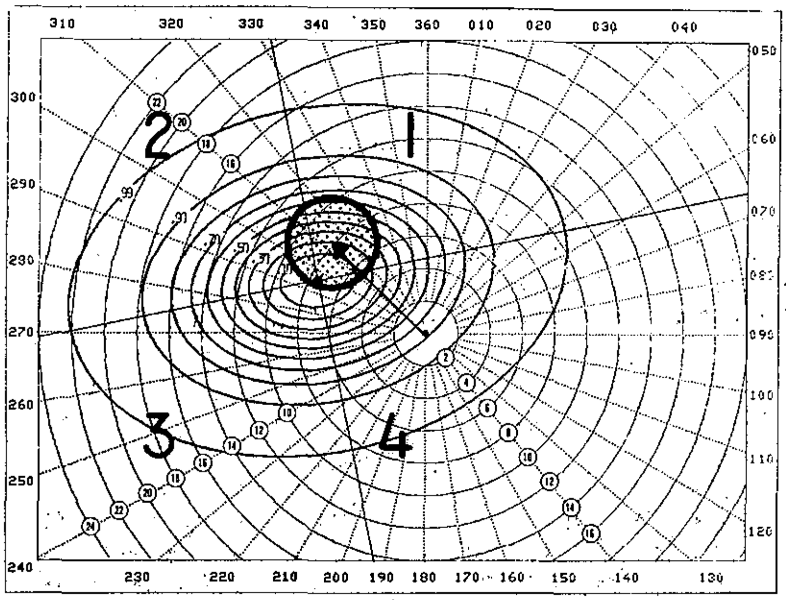

Figure 7. Bivariate normal distribution fitted to 12-hourly motion vectors for tropical cyclones in the Eastern Pacific. Radials give heading in degrees. Concentric circles give storm speed. Dotted circle used in weighting of forecasts.

Four sets of regression equations were formulated using cases with motions lying in each quadrant of the given distribution. The form of equations used to combine EPCLPR(CF) and SYNOPTIC (SF) forecasts is

$$NF = f(SF,CF) \qquad (7)$$

where NF is the displacement forecast and f is a quadratic function. Regression coefficients for these equations are listed in Appendix II. At each forecast time four forecasts are made with these sets of equations. These four separate forecasts are then weighted for combination into one forecast.

Weight assigned to each of the four forecasts is the proportion of the area of the dotted circle shown in Figure 7 lying within the associated quadrant of the fitted bivariate normal distribution. The center of this circle is located at the tip of the initial motion vector. Experience with the NHC-72 model indicates that such a procedure eliminates undesirably large changes in successively predicted storm tracks. The radius of the dotted circle was chosen as the mean distance between the origin and the 30% probability ellipse.

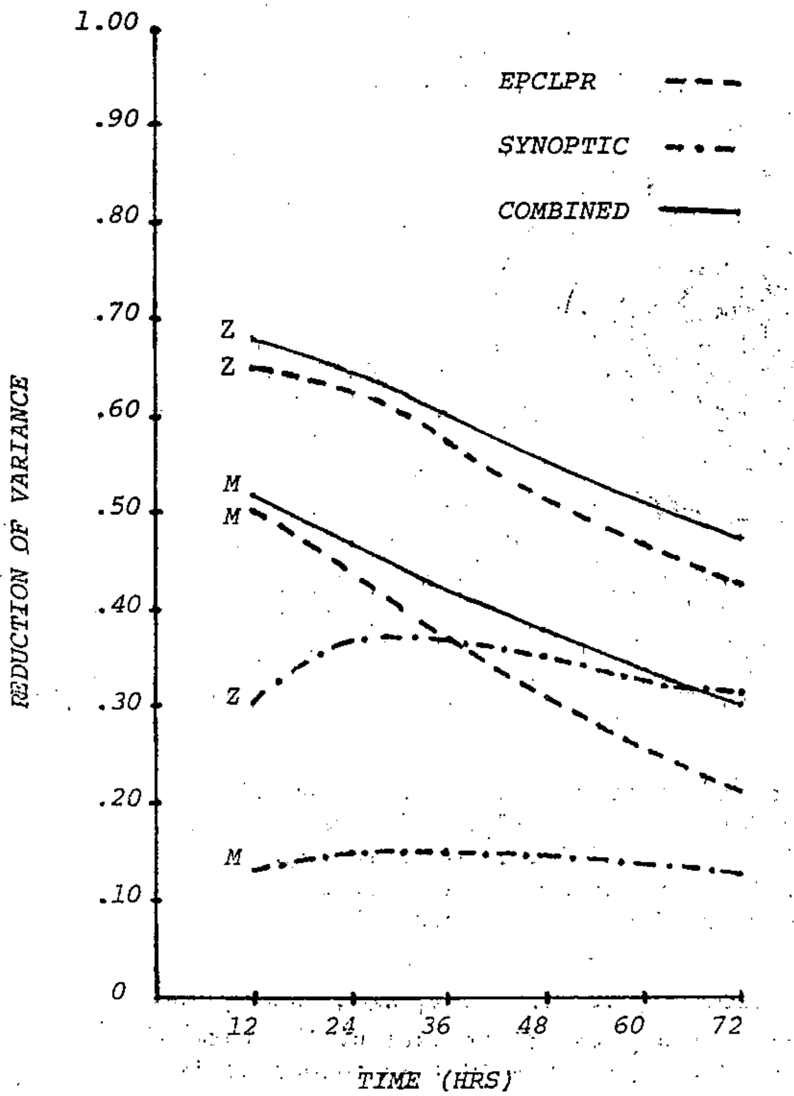

Figure 8. Total reduction of variance of meridional (M) and zonal (Z) components of EPCLPR, SYNOPTIC, and combined (EPHC77) systems.

Figure 8 depicts reduction of variance on dependent data for the EPCLPR, SYNOPTIC, and final EPHC77 components of the model. Although reduction of variance attributed solely to the SYNOPTIC system is relatively low, inclusion of this component does lead to increased reduction of variance for the combination forecasts. At all times and for each component, there was a larger reduction of variance for zonal motion than for meridional motion. Effects of the SYNOPTIC system are greatest for longer time periods. This result is consistent with decreasing importance of empirical predictors found in development of the NHC-72 statistical model for Atlantic storms (Neumann and Hope 1972).

V. OPERATIONAL IMPLEMENTATION

The EPHC77 model was programmed in Fortran IV computer language and included in the Eastern Pacific Statistical Prediction Package catalogued in the National Oceanic and Atmospheric Administration (NOAA) IBM 360/195 computer system at Suitland, Maryland. Access to this computer system is through the user terminal located at NHC, Miami. A description of the operational procedure may be found in Part 1 of this Technical Memorandum (Neumann and Leftwich 1977).

Synoptic data required in the program are retrieved from current NMC data files routinely stored in the computer system at Suitland. At present, NMC analyses and prognoses made from data at 0000 GMT and/or 1200 GMT are utilized. For tropical storm forecasts made from 0000 GMT (1200 GMT), the RADAT analysis provides current heights, and the previous final NMC analysis for 0000 GMT (1200 GMT) provides data from 24 hours ago. When forecasts are made at 0600 GMT (1800 GMT), current heights are obtained from the 6-hour NMC PE forecast from 0000 GMT (1200 GMT), and heights for 24 hours ago are mean values of final NMC analyses made 18 and 30 hours prior to the forecast run. An example indicating data sources is given in Table 2.

Table 2. Sources of synoptic data used in EPHC77 system. Example shown is for 15 August.[1]

Initial Time (GMT)	Current Data	Data for 24-hour ago
8/15/00	8/15/00 RADAT Analysis	8/14/00 NMC Final Analysis
8/15/06	Six-hour PE Forecast from 8/15/00	Mean of Final Analyses for 8/14/00 and 8/14/12
8/15/12	8/15/12 RADAT Analysis	8/14/12 NMC Final Analysis
8/15/18	Six-hour PE Forecast from 8/15/12	Mean of Final Analyses for 8/14/12 and 8/15/00

[1] Proposed procedural changes at NMC may require revisions of data sources given in Table 2.

Forecasts produced by an operational run are transmitted via National Weather Service teletypewriter and CRT circuits to EPHC, San Francisco, and NHC, Miami. Computer printout that includes diagnostic information in addition to predicted storm tracks is also received at NHC, Miami. Content of transmitted messages is discussed in Part 1 of this Technical Memorandum (Neumann and Leftwich 1977).

VI. FUTURE REFINEMENTS

Operational experience in the Atlantic and Pacific tropical cyclone basins has confirmed the utility of probability ellipses associated with predicted storm tracks. Accordingly, production of such probability ellipses (similar to those accompanying EPANLG forecasts) will be included in the EPHC77 system.

Performance of EPHC77 will be evaluated during its initial season of operational usage, and any needed modification will be made. Possible refinements include (1) change the statistical procedure used to combine EPCLPR and SYNOPTIC forecasts, (2) change the weighting scheme that combines four quadrant forecasts into a final forecast, and (3) include numerically predicted data as predictors.

Examination of characteristics of the current NMC spectral objective analyses has indicated that tropical storms which have been "bogused" at either 300 mb or 1000 mb are often inadequately reflected in the 500-mb height field. This occurrence will have detrimental effects on the performance of EPHC77. Also, investigations at NHC during the 1976 Eastern Pacific storm season indicated considerable predictive potential in mean layer values of winds and geopotential heights. Accordingly, further studies are being made of possible utilization of mean layer values as predictors rather than 500-mb heights.

VII. SUMMARY

This paper discussed development of the EPHC77 statistical-synoptic prediction model. In the forecast procedure, two separate forecasts are combined statistically to produce final predictions of tropical cyclone motion. Synoptic data are acquired from current NMC data files at the beginning of each forecast run. After each run is completed, predicted storm tracks for periods up to 72 hours are transmitted to both EPHC, San Francisco, and NHC, Miami.

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APPENDIX I

REGRESSION COEFFICIENTS FOR EQUATIONS THAT PRODUCE SYNOPTIC FORECASTS. DY AND DX REPRESENT MERIDIONAL AND ZONAL DISPLACEMENTS, RESPECTIVELY.

	PREDICTAND				
PREDICTOR	DY12	DY24	DY36	DY48	DY72
INTERCEPT	2634.1900	4637.1110	-8003.9550	14260.5000	-17001.6400
(P1)	0.1147	0.3041	0.5774	1.1006	1.1676
(P2)	-0.3327	-0.6988	-0.7796	-0.6151	-0.4919
(P3)	0.2275	-0.0899	-0.2970	-0.8124	-1.1063
(P4)	-0.0871	-0.1379	-0.1937	-0.2967	-0.2900
(P5)	0.4213	0.8830	1.1163	1.3530	1.2670
(P6)	0.3372	0.5488	0.9151	1.7351	2.3925

	PREDICTAND				
PREDICTOR	DX12	DX24	DX36	DX48	DX72
INTERCEPT	-6794.0540	-13746.8000	-20438.8800	-26213.3200	-30138.1100
(R1)	0.5109	0.9934	1.3215	1.5860	1.8547
(R2)	0.4128	0.8074	1.2320	1.5654	1.5929
(R3)	0.1523	0.3122	0.5039	0.7174	0.9625
(R4)	0.0946	0.2558	0.4654	0.6517	0.7931

APPENDIX II

Regression coefficients which combine SYNOPTIC and EPCLPR forecasts of (a) meridional and (b) zonal displacements. Quadrant is determined by position of motion vector in bivariate normal distribution shown in Figure 7.

(a)

		PREDICTAND				
	PREDICTOR	DY12	DY24	DY36	DY48	DY72
QUADRANT 1	INTERCEPT	-19.5417	-50.8075	-99.8179	-187.2854	-14.7286
	(CF)	0.9634	1.0854	1.0852	1.6190	0.3638
	(SF)	0.7409	0.7671	1.0589	1.0245	0.2957
	(CF)(CF)	-0.0003	-0.0008	-0.0016	-0.0033	-0.0002
	(SF)(SF)	-0.0047	-0.0008	-0.0031	-0.0027	-0.0006
	(CF)(SF)	0.0004	-0.0005	0.0025	0.0035	0.0025
QUADRANT 2	INTERCEPT	21.2031	88.1648	87.1321	46.4062	3.8169
	(CF)	0.8291	0.2246	0.1504	0.7745	1.3435
	(SF)	-1.0439	-1.7010	-0.9996	-1.1335	-1.2917
	(CF)(CF)	-0.0007	0.0003	0.0018	-0.0006	-0.0017
	(SF)(SF)	0.0142	0.0084	0.0056	0.0045	0.0047
	(CF)(SF)	0.0034	0.0081	0.0019	0.0029	0.0017
QUADRANT 3	INTERCEPT	-12.3663	-22.5307	-43.3790	-61.4366	-16.9915
	(CF)	1.0769	1.0443	1.0307	1.3086	0.9828
	(SF)	0.3127	-0.0183	0.2171	0.1046	0.5801
	(CF)(CF)	0.0055	0.0032	0.0018	0.0010	0.0005
	(SF)(SF)	-0.0019	0.0032	0.0012	0.0023	-0.0035
	(CF)(SF)	-0.0024	-0.0019	-0.0015	-0.0039	-0.0003
QUADRANT 4	INTERCEPT	-16.9915	-34.5868	-56.1177	-87.3978	-50.4654
	(CF)	0.9828	0.9559	1.1053	0.6903	0.4489
	(SF)	0.5841	0.5609	0.4720	1.0729	0.5780
	(CF)(CF)	0.0005	0.0011	0.0010	0.0012	0.0017
	(SF)(SF)	-0.0035	-0.0014	0.0006	-0.0021	0.0006
	(CF)(SF)	-0.0003	-0.0008	-0.0025	-0.0001	-0.0012

(b)

		PREDICTAND				
	PREDICTOR	DX12	DX24	DX36	DX48	DX72
QUADRANT 1	INTERCEPT	-22.1646	-46.8825	-84.4167	-123.7997	-163.6609
	(CF)	0.5246	0.4669	0.4826	0.7969	0.9696
	(SF)	0.5308	0.7117	0.7481	0.3731	0.0317
	(CF)(CF)	0.0014	0.0017	0.0021	0.0023	0.0017
	(SF)(SF)	-0.0016	-0.0010	-0.0001	0.0015	0.0018
	(CF)(SF)	0.0038	0.0003	-0.0012	-0.0030	-0.0029
QUADRANT 2	INTERCEPT	-8.4627	-48.0992	-165.8327	-135.2563	-545.1581
	(CF)	1.5796	1.3666	2.2852	1.7428	2.2032
	(SF)	-0.4368	0.0638	-0.3466	-0.1106	0.6291
	(CF)(CF)	-0.0062	-0.0015	-0.0034	-0.0019	-0.0013
	(SF)(SF)	-0.0018	-0.0003	-0.0005	-0.0002	-0.0003
	(CF)(SF)	0.0080	0.0011	0.0028	0.0016	0.0002
QUADRANT 3	INTERCEPT	-4.6973	111.0324	68.8516	96.5753	-171.3972
	(CF)	1.0552	0.2387	0.7339	0.8479	0.6892
	(SF)	0.2709	-0.2021	0.0458	-0.0614	1.0863
	(CF)(CF)	-0.0015	0.0004	-0.0004	-0.0007	0.0000
	(SF)(SF)	-0.0012	-0.0003	-0.0004	-0.0004	-0.0007
	(CF)(SF)	0.0005	0.0021	0.0009	0.0012	0.0001
QUADRANT 4	INTERCEPT	-10.7962	-35.9077	-61.4194	-85.2630	-142.4015
	(CF)	0.8942	0.8929	0.8169	0.7205	0.4509
	(SF)	0.1276	0.1654	0.2356	0.2820	0.4238
	(CF)(CF)	0.0014	0.0017	0.0013	0.0011	0.0017
	(SF)(SF)	0.0003	-0.0001	0.0000	0.0000	0.0003
	(CF)(SF)	-0.0006	-0.0002	-0.0003	-0.0002	-0.0011

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