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

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STATISTICAL GUIDANCE FOR THE PREDICTION OF EASTERN NORTH PACIFIC TROPICAL CYCLONE MOTION - Part 1

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ABSTRACT. This report documents the derivation, application and operational utility of an analog and simulated analog model for the prediction of tropical cyclone motion over the Eastern North Pacific tropical cyclone basin. These two models, together with an additional statistical-synoptic model (to be reported on separately), form the nucleus of a recently activated statistical prediction guidance package for use by the National Weather Service (NWS) Eastern Pacific Hurricane Center located at the Weather Service Forecast Office (WSFO), San Francisco, California. A similar statistical guidance package has been used on Atlantic tropical cyclones for a number of years.

Testing of the two models on 1976 operational data shows that both perform well on nonrecurving storms. However, the analog model shows an excessive left-of-track bias on recurving storms. The simulated analog model shows a similar but less severe bias.

The report also includes recommended procedures on initializing the models as well as a discussion on the operational utility of probability ellipses. Finally, the study concludes with a description of the communications and computer resources which are needed to run the package in its present configuration.

I. INTRODUCTION

Statistical models for the prediction of tropical cyclone motion are used as objective guidance at most tropical cyclone forecast centers throughout the world. These models can be grouped into two broad categories, i.e., those based on analogs and those based on statistical regression equations. The latter, in order of increasing sophistication, can be further categorized as a) those models which exclude predictors from current synoptic analyses, b) those models which include predictors selected or derived from current synoptic analyses and c) those models which include additional predictors selected from numerical prognoses. These latter models are often referred to as "statistical-dynamical" models while a and b are known respectively, as "simulated" analog models and "classical" models. The term "statistical-synoptic" has also been applied to models of type b.

This and a subsequent Technical Memorandum describe derivation and recent operational implementation of a tropical cyclone motion guidance package for use by the Eastern Pacific Hurricane Center (EPHC) located at the National Weather Service Forecast Office, San Francisco, California. The design of the package is similar to that which has been used by the National Hurricane Center (NHC) on Atlantic storms for a number of years and which is described by Neumann (1973). The notational relationship between the Atlantic and the Pacific package is given in Table 1.

Table 1. Atlantic operational statistical tropical cyclone models and their Eastern North Pacific counterparts.

TYPE OF MODEL	ATLANTIC PACKAGE	EASTERN NORTH PACIFIC PACKAGE
Analog	HURRAN (Hope & Neumann, 1970)	EPANLG (Jarrell, *et al*, 1975)
Simulated analog	CLIPER (Neumann, 1972)	EPCLPR (Described herein)
Statistical-synoptic	NHC72 (Neumann, *et al*, 1972)	EPHC77 (Leftwich & Neumann, 1977)

As noted in the table, the Pacific package consists of three models, EPANLG, EPCLPR and EPHC77. The package is completely automated with the applicable computer programs being stored in the National Oceanic and Atmospheric Administration (NOAA) 360/195 computer system. These are activated four times per day whenever a tropical cyclone is in progress over the EPHC area of forecast responsibility. An example of the guidance message generated by these programs is shown in Figure 1. The derivation, application, and operational evaluation of two of the models, EPANLG and EPCLPR, are the subject of the present Technical Memorandum. The remaining model, EPHC77, is treated separately by Leftwich and Neumann, 1977. Operational implementation of the three models, EPANLG, EPCLPR and EPHC77 occurred, respectively, on 15 July 1976, 24 August 1976 and 20 May 1977.

```
THIS IS A PRIORITY MESSAGE...RUSH...
TO  MIC WSFO SAN FRANCISCO CALIF.


        IVA                  IVA
DATE 1200Z 29 AUG 1976.
        ..INITIAL...     ...12 HRS...     ...24 HRS...
         8/29/76/12Z      8/30/76/00Z      8/30/76/12Z
         LAT    LON       LAT    LON       LAT    LON
EPHC77 19.6N 117.9W     20.2N 120.0W     20.9N 122.0W
EPANLG 19.6N 117.9W     20.1N 120.0W     20.7N 121.8W
EPCLPR 19.6N 117.9W     20.2N 120.2W     20.8N 122.3W


        ...36 HRS...     ...48 HRS...     ...72 HRS...
         8/31/76/00Z      8/31/76/12Z      9/01/76/12Z
         LAT    LON       LAT    LON       LAT    LON
EPHC77 21.3N 123.7W     21.5N 125.2W     21.6N 127.5W
EPANLG 21.2N 123.6W     21.8N 125.2W     22.9N 127.8W
EPCLPR 21.3N 124.3W     21.9N 126.0W     22.5N 128.9W


12HR OLD PSN 19.0N 115.2W 24HR OLD PSN 18.5N 113.5W
CMPTD MTN VECTORS..0012 283/13 R50..1224 287/08 R05
DIFF 1224-0012 276/05 R65..CNFDNC FCTR 1..WND 999KT

        50 PERCENT PROBABILITY ELLIPSE DATA
........EPHC77......    .............EPANLG.........
   MAJOR MINOR TILT          MAJOR MINOR TILT  NUMBER
HR  AXIS  AXIS ANGLE    HR  AXIS  AXIS ANGLE  CASES
12 -99.9 -99.9 -99.9    12 -99.9 -99.9 -99.9   126
24 -99.9 -99.9 -99.9    24   1.3   1.2   4.1   126
36 -99.9 -99.9 -99.9    36 -99.9 -99.9 -99.9   111
48 -99.9 -99.9 -99.9    48   3.0   2.5 -16.5    97
72 -99.9 -99.9 -99.9    72   4.5   3.7 -34.1    61
NOTES.....AXES DIMENSIONS ARE GIVEN IN DEGS OF LATD
TILT ANGLE GIVES ROTATION OF MAJOR AXIS FROM EAST.
...END... IVA
```

Example of KCRT and teletype message generated by program.

II. CLIMATOLOGICAL BACKGROUND

Insofar as the annual number of storms is concerned, the Eastern Pacific ranks as the second most active tropical cyclogenetical region in the world, being surpassed only by the Western North Pacific. Because of the remoteness of the Eastern Pacific basin and the small number of landfalling storms, this fact went unrecognized until the introduction of weather satellites. Satellite imagery was operationally introduced to the area in 1961 (Mull 1962). Subsequently, satellite utilization became more common but it was not until the 1966 season (Gustafson 1969) that full operational satellite coverage became a reality. Accordingly, a representative storm climatology is available only for the eleven-year period starting in 1966. Table 2, from Gunther (1977), gives the average monthly and annual frequencies during this latter period. For comparative purposes, Atlantic data have been appended to the table. It can be noted that the period of maximum storm frequency occurs earlier in the Eastern Pacific than in the Atlantic.

Table 2. Monthly and annual frequency of tropical storms and hurricanes for the Eastern North Pacific and Atlantic tropical cyclone basins.

	MAY	JUN	JUL	AUG	SEP	OCT	NOV	ANN
Eastern Pacific (1966-1976)	0.4	1.7	3.6	4.4	2.9	1.7	0.4	15.1
North Atlantic (1946-1976)	0.2	0.6	0.8	2.4	3.6	1.7	0.4	9.8

The areal extent of Eastern North Pacific tropical cyclones is relatively small and, as shown by Crutcher and Quayle (1974), the Eastern Pacific near 17N 110W is traversed by more tropical cyclones than any other region in the world. Figure 2, from Renard and Bowman (1976), outlines the areal extent of the basin. Further climatological discussion is beyond the scope of the paper. For additional background, the reader is referred to the above cited references as well as to Hansen (1972) and Baum and Rasch (1975).

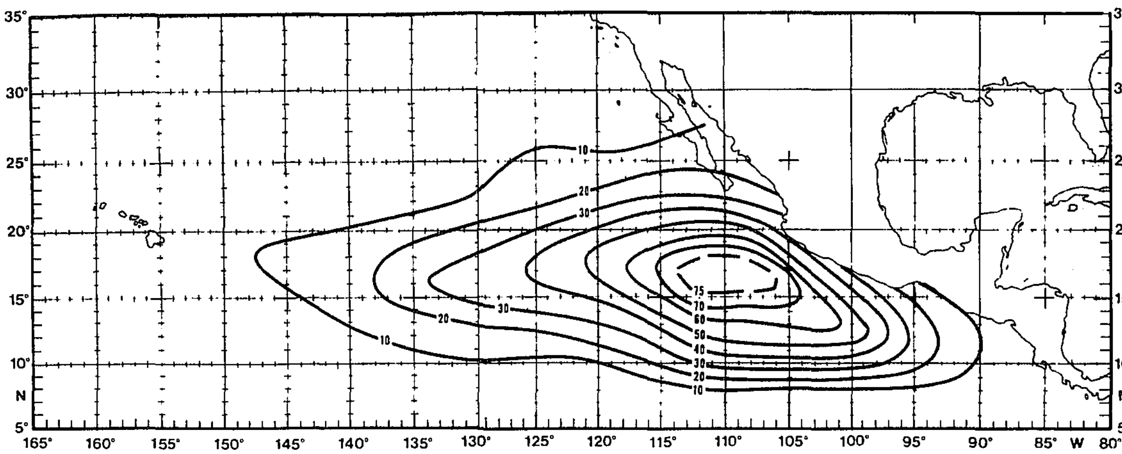

Figure 2. Number of individual tropical cyclone occurrences per 5-degree latitude-longitude box for the 10-year period 1965-1974. (From Renard and Bowman, 1976.)

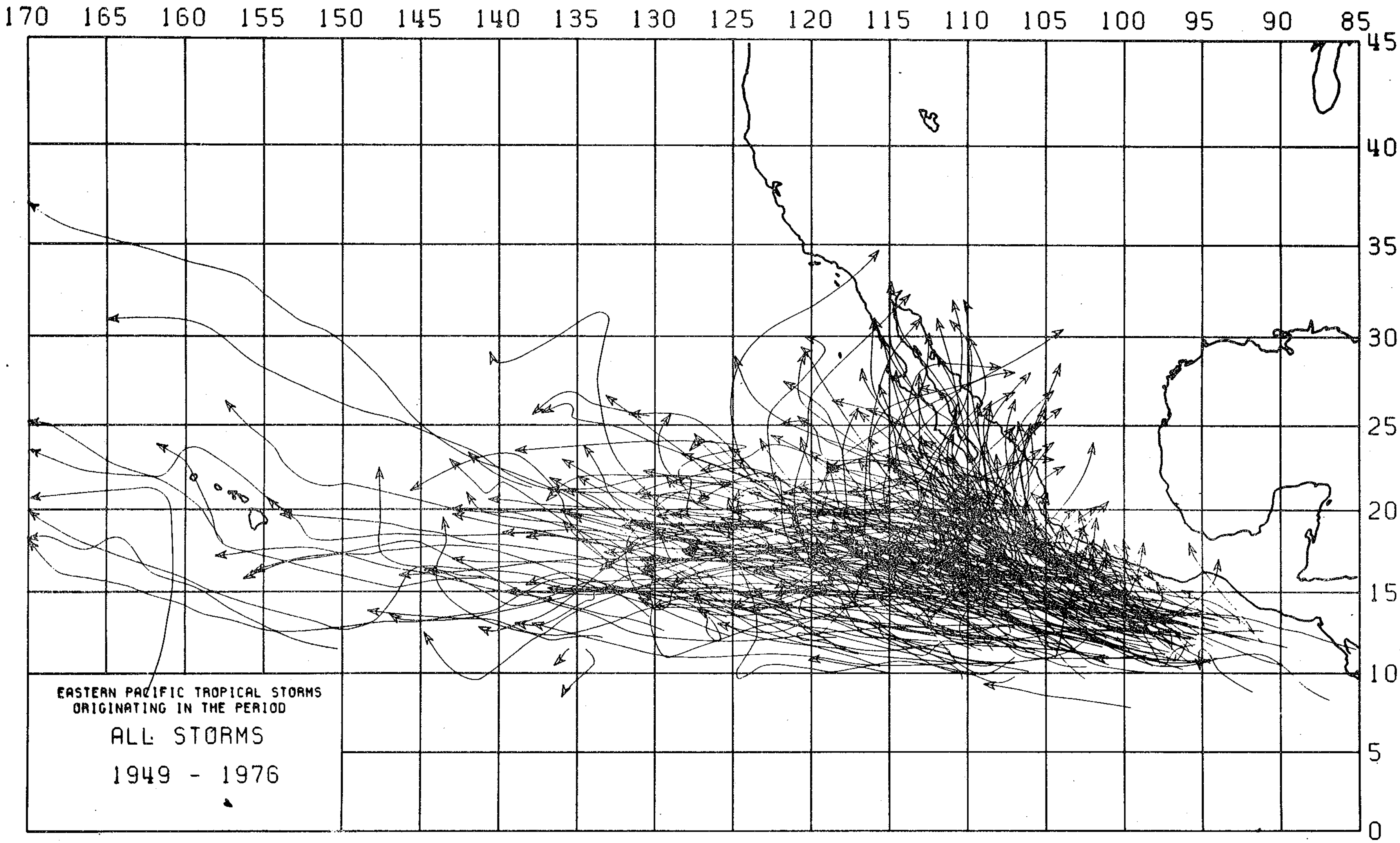

Fig. 3 Computer plot showing tracks of the 313 recorded Eastern North Pacific tropical cyclones, 1949-1976.

III. ARCHIVED STORM TRACKS

Statistical models comprising the guidance package are based on tracks of all recorded tropical cyclones beginning with the year 1949. A computer plot showing tracks of the 313 recorded tropical cyclones 1949 through 1976 is given in Figure 3. The EPCLPR and EPHC77 models are based on the entire storm sample. The analog model, EPANLG, originally prepared in 1974, uses a data set through the 1973 season (257 storms). As discussed in a subsequent section, modification of the analog model incorporating a larger storm sample is desirable.

The magnetic tape containing the Eastern Pacific storm tracks was originally prepared at the NOAA Environmental Data Service (EDS) National Climatic Center (NCC) for use by the U. S. Navy. Because of an exclusive marine forecast requirement, many of the storms which eventually made landfall in Mexico were dropped from further consideration shortly before or after moving inland. Thus, there is an artificial constraint imposed on the tracks. This condition, together with the fact that many storms which move northward are rather abruptly terminated by cold sea-surface temperatures, introduces a left-of-track bias on recurving storms in analog models. Illustrations of the left-of-track bias on recurving storms are given in subsequent sections of this report. The present authors were aware of the bias and an attempt was made to at least partially alleviate the problem by extending some of the prematurely truncated storm tracks further inland. The tracks shown in Figure 3 include these extensions. However, in the majority of cases, there was insufficient evidence from the available surface and upper-air analyses to justify much track extension. Further research into the problem, perhaps using archived satellite data or collaboration with Mexican Meteorological Services (Serra 1971), is called for.

IV. THE ANALOG MODEL (EPANLG)

A. The Analog Concept.

Temporal and spatial analysis of tropical cyclone tracks show that certain tracks tend to be repetitive and to be associated with identifiable and likewise repetitive synoptic patterns. In Figure 3, for example, two broad classes of tropical cyclone tracks are identifiable, i.e., those storms which move westward and eventually dissipate at sea and those which recurve into Mexico. The latter group of storms are typically associated with a trough of low pressure to the northwest of the storm. On the other hand, those storms which continue westward are typically associated with ridging to the north of the storm. Other sub-patterns are also identifiable. Analog models capitalize on this ability to identify families of storm tracks. Through a series of computer algorithms, a current storm is identified with its parent track thus allowing statistical inferences to be made concerning the future behavior of the current storm.

Tropical cyclone forecasters have been using mentally founded analog principles throughout the history of tropical cyclone forecasting. Unfortunately, the large amount of data processing precluded routine objective use of the method. However, the gradual introduction of computer technology to offices having tropical cyclone forecast responsibility provided and continues to provide a means of rapidly archiving, retrieving, screening and processing large masses of historical storm tracks.

B. The U.S. Navy Analog Model.

The U. S. Navy and the National Hurricane Center have been using analog models for a number of years and operational analog models have been developed, principally by the U.S. Navy, for all of the world's tropical cyclone basins. Jarrell, et al (1975) describes the Navy model for the Eastern North Pacific. Rather than develop a separate model, the decision was made just prior to the 1976 hurricane season to adopt the Navy model for NOAA use. Accordingly, minor programming modifications were effected and the slightly modified Navy model, designated EPANLG, was put into NOAA operational use on 15 July 1976. Since the above cited reference to the Navy model is readily available to the interested meteorological community, only a brief description of the mechanics of the model will be presented here.

C. Selection of Analogs.

The logic of any analog model is centered about the analog selection process. In a typical analog model, a mass of archived storm tracks is computer scanned. Analogs are selected by considering certain temporal and spatial similarities between a current storm and an analog candidate. These criteria vary from one tropical cyclone basin to another. Specific criteria relevant to the EPANLG model are listed in Table 3. If, at least 10 analogs are selected, further processing is accomplished. This includes translating analog storms to the common origin given by the initial position of the current storm. Additionally, the individual tracks are adjusted (rotated) to allow for persistence. The amount of adjustment is a function of the forecaster confidence in the current storm position. A confidence factor of 1, 2, or 3 is assigned depending on whether the forecaster considers the current position to be respectively, excellent, average or fair.

Table 3. Criteria (screen settings) for selecting Eastern Pacific analogs. All screens must be passed. Distances (including zonal distances) are measured in degrees of latitude.

1. Candidate must pass within 1.5 degrees north or south of current storm latitude.
2. Candidate must pass within 72 degrees east or west of current storm longitude.
3. Candidate must have had past 12 h meridional motion within 0.6 degrees of past 12 h meridional motion of current storm.
4. Candidate must have had past 12 h zonal motion within 1.8 degrees of past 12 h zonal motion of current storm.
5. Date of analog candidate must be within 180 days from date of current storm.

Next, the adjusted analogs positions are weighted according to their individual conformity to the selection criteria specified in Table 3. Marginally accepted analogs are given little weight. Finally, the clusters of weighted analog positions at the various forecast projections are fitted to a bivariate normal distribution and the centroids (mean latitudes and longitudes) of the ellipses at each projection are taken as the most likely forecast track. The U. S. Navy analog model is designed to provide a forecast at 24-hour intervals through 96 hr. The modified NOAA model provides forecasts at 12, 24, 36, 48, and 72 hr. The foregoing discussion of the EPANLG rationale is considerably abbreviated. For a complete description, the reader is referred to Jarrell, et al (1975).

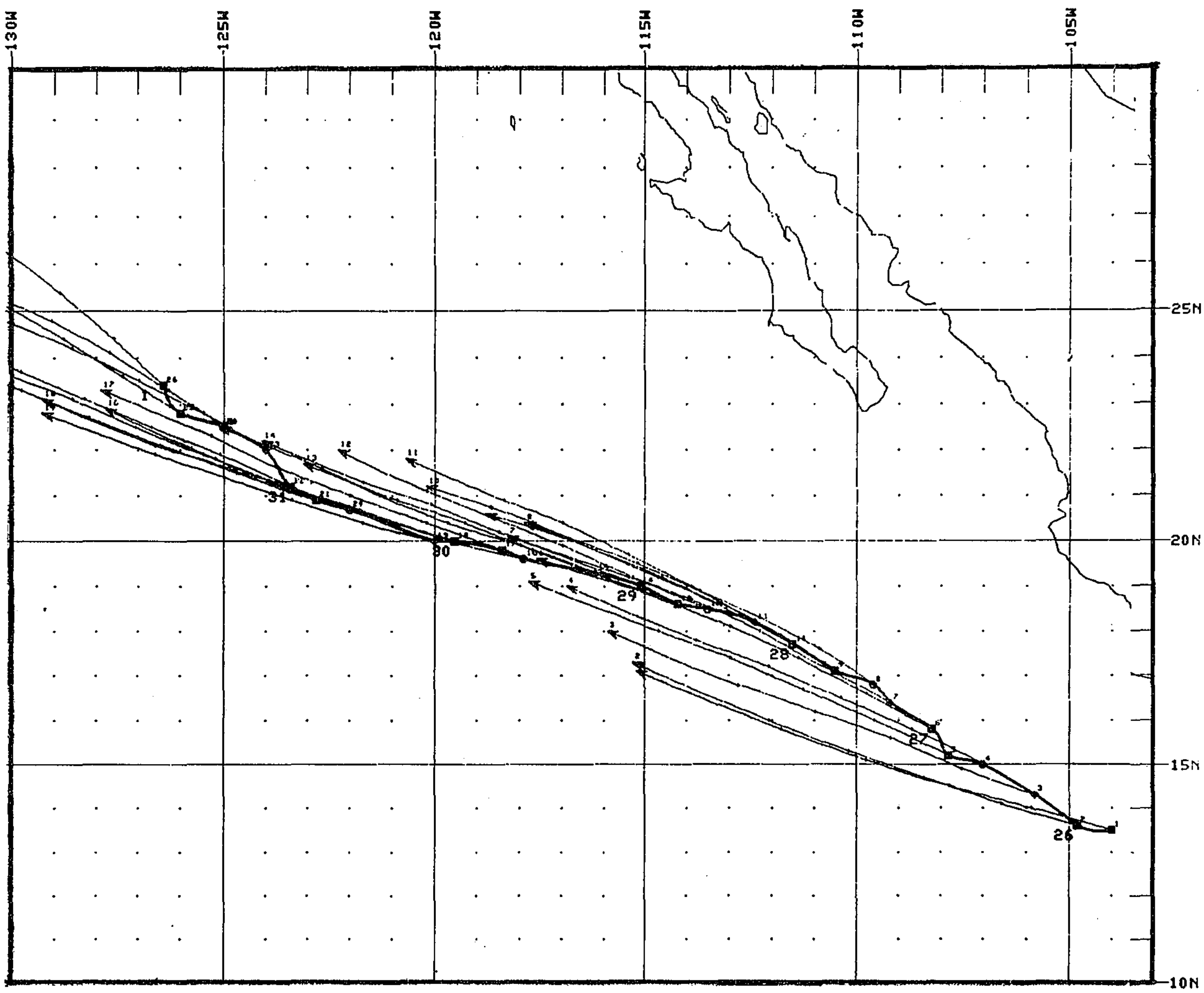

Figure 4. Computer plot showing EPANLG 72-hour forecasts on tropical cyclone IVA from 26 August to 1 September 1976. Forecasts are at 6-hourly intervals. Heavy line gives operational unsmoothed track of IVA. Forecast tracks without arrows extend west-northwestward beyond bounds of map.

If less than 10 analogs are selected, no attempt is made to provide a forecast. Such a condition can be expected under anomalous forecast situations. During 1976 on storms Celeste through Naomi, the analog model failed on 30 out of 197 72-hour forecasts, less on shorter range forecasts. However, 1976 was an anomalous storm season and the long-term failure rate should be much less than that observed during 1976 (see Jarrell, et al, 1975, Table 1). Nevertheless, failure of analog models to provide a forecast under anomalous weather situations is one of the principal shortcomings of the method.

D. Adjustment of Screen Settings.

The failure rate described in the preceding subsection is a function of the screen settings and the size of the historical storm track file. Liberal screens provide for a large number of analogs but fail to discriminate between synoptic patterns. Such discrimination is crucial to the analog process. Conservative screen settings do well in discriminating between say, recurvers and nonrecurvers but lead to excessive failure rates. The operational screen settings should be a trade-off between these two extremes.

In developing the current analog model, a restricted sample of storm tracks (257 storms, 2,666 positions) dictated rather liberal screen settings. Indeed, it can be noted in Table 3 that criteria 2 and 5 are not screens at all but will pass all storms. A manifestation of these liberal screens is an almost constant analog forecast towards the west-northwest of 8 to 10 knots regardless of synoptic pattern. For "normal" storms which typically remain embedded in the easterlies and which are characteristic of this region, the model performs well. The performance on storm IVA of 1976, as shown in Figure 4, is indeed outstanding and the 72-hour forecast displacement[1] error was less than 150 n.mi. However, the performance on storms with a strong northerly component of motion, as typified by LIZA, is unsatisfactory. As shown by Figure 5, there is a strong forecast bias to the left-of-track. A similar bias was also noted on the other landfalling storms of 1976.

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[1]Displacement error is defined as the magnitude of the vector distance between observed and forecast storm positions after account has been taken of errors in the initial storm position.

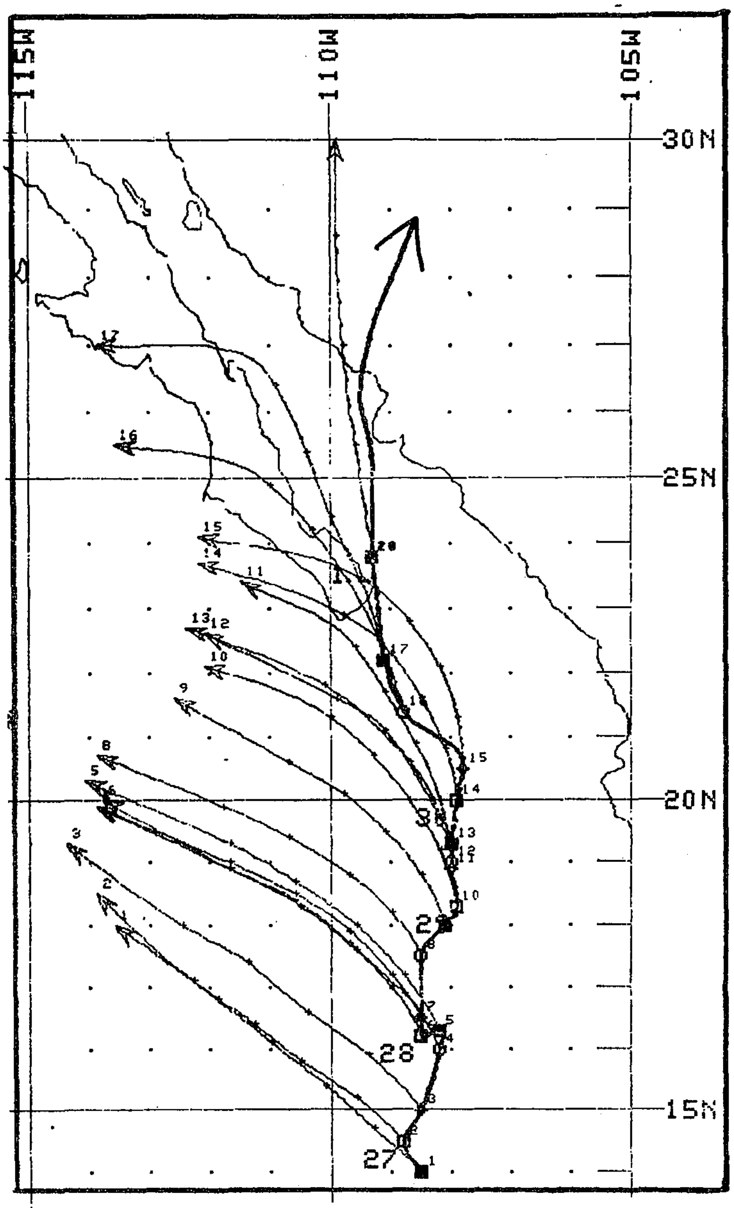


Figure 5. Computer plot showing EPANLG 72-hour forecasts on tropical cyclone LIZA from 27 to 30 September 1976. Forecasts are at 6-hourly intervals. Heavy line gives operational unsmoothed track of LIZA.

Adjustment of the analog screens to effect better discrimination on recurving and landfalling storms is desirable. However, this will also require real or artificial extension of prematurely terminated storm tracks (see Section III, paragraph 2) and an expanded data base through 1977 or 1978 storm seasons. In the interim, the analog model is not recommended as guidance on recurving storms. However, the model appears to give excellent guidance on the more typical west-northwestward moving storms of this tropical cyclone basin. Similar conclusions by Renard and Bowman (1976) are based on the performance of the model during 1975.

V. PROBABILITY ELLIPSES

A. Mathematical Background.

Analog forecasts are typically presented to the user with superimposed probability ellipses. These ellipses represent the projection of a three-dimensional bivariate normal surface onto a two-dimensional plane. Thus, the attributes of the univariate normal distribution are not applicable. In the univariate case, for example, 50% of the sample size should be included in the area 0.6745 standard deviations either side of the mean. However, in the bivariate normal distribution, 50% of the cases are included in 1.1774 standard deviations about the centroid. The number of vector standard deviations c needed to encompass P percent of the sample is given by,

$$c = \sqrt{-2 \log_e \{I - (P/100)\}} . \qquad (0 \leq P \leq 100) \qquad (1)$$

The foregoing is somewhat of a mathematical simplification but serves to illustrate the principles involved.

Relative to an x,y coordinate system, the bivariate normal distribution is defined by five parameters as given by the mean of the x displacements, the mean of the y displacements, the standard deviation of the x and the y displacements and the linear correlation coefficient between the x and the y displacements. For plotting a probability ellipse, it is convenient to define a) the length of one-half the major axis, b) the length of one-half the minor axis and c) the rotation of the major axis from an easterly direction. The rotations are stated in the mathematical sense thus, an ellipse oriented with the major axis northwest-southeast has a negative rotation angle. This rotation angle is the angle at which the correlation between the x and y displacements becomes zero. The standard deviations of the distributions are measured relative to these rotated axes. A complete mathematical treatment is beyond the scope of the present study. For futher details, the reader is referred to Hope and Neumann (1970).

B. Probability Ellipse Example.

Figure 1 illustrated the message format made available to the forecast center preparatory to the scheduled release of tropical cyclone advisories. The example is the 29 August 1976 guidance package on tropical cyclone IVA. The 50% EPANLG ellipse plotting parameters appear in the lower right hand corner of the message.

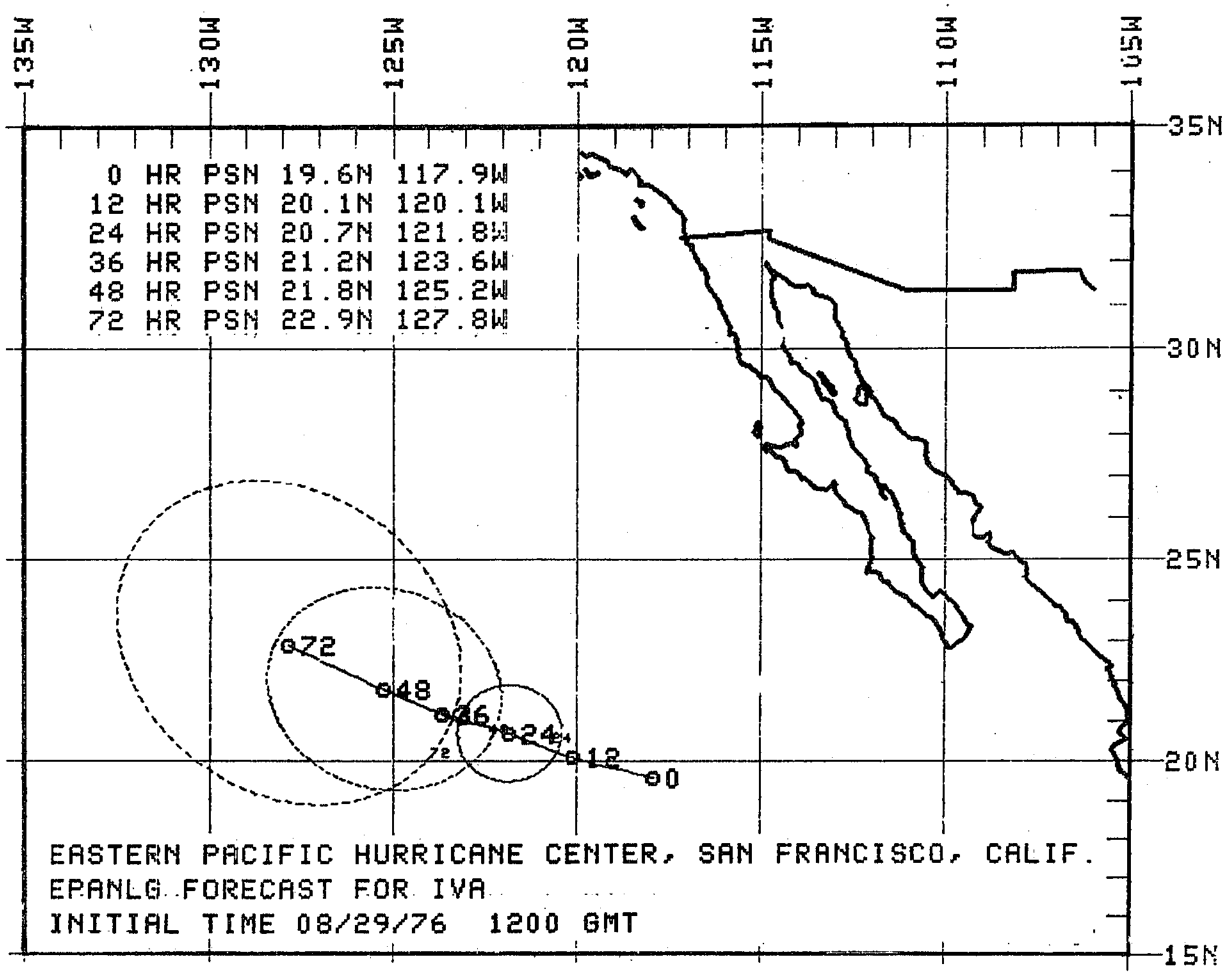


Figure 6. Computer plot showing 08/29/76 1200 GMT EPANLG forecast track with superimposed 24, 48, and 72 hour 50% probability ellipses for tropical cyclone IVA. Elliptical parameters are specified in Figure 1.

For 72-hour, for example, the semilengths of the major and minor axes are given as 4.5 and 3.7 degrees of latitude with an elliptical axis rotation angle of -34.1 degrees. Elsewhere in the message, the centroid of the ellipse is given as 22.9N 127.8W. An example of the ellipse plot together with the 50% ellipses for 24 and 48 hr is given in Figure 6. This example was plotted on the National Hurricane Center Varian computer system. Such computerized plots should be available to the Eastern Pacific Hurricane Center after AFOS installation. In the interim, manual plotting of the ellipses will be needed.

In the interest of brevity, only the 50% probability ellipses are specified in the message. The lengths of the axes for any probability (L_p) can be found from:

$$L_p = W \, L_{50} , \qquad (2)$$

where W is given by:

$$W = \sqrt{\frac{-\log_e (1 - p)}{0.8326}} \qquad (0 \leq p \leq 1) \qquad (3)$$

and L_{50} is the length of a given axis defining the 50% elliptical envelope. Solution to Eq. (3) for some common values of p are given in Table 4. Thus, in the example just cited, the semilengths of the major and minor axes defining the 72-hr 95% ellipse are given by 9.4 and 7.7 degrees of latitude, respectively.

Table 4. Multiplication factors (W) for selected values of p

p	0.25	0.50	0.75	0.90	0.95	0.99
W	0.64	1.00	1.41	1.82	2.08	2.58

C. Operational Utility of Ellipses.

Properly interpreted, probability ellipses afford the forecaster effective decision making capabilities. The centroid represents the most likely forecast position and, after a large number of similar forecast situations, the observed positions will, indeed, be clustered about the centroid. Forecasters should not be discouraged from forecasting other storm positions as they see fit but should be aware that, in doing so, they are going against climatology and persistence. Prudence suggests that any forecast outside the bounds of the 50% ellipse should be supported by synoptic or other reasoning.

The size and shape of the ellipses offer additional diagnostic information (Simpson 1971). Small ellipses suggest confidence in the analog forecast. Ellipses with the major axis oriented along the forecast track (as occurs in the 72-hr ellipse illustrated in Figure 6) suggest that the forecast problem is more related to speed than to direction. The exact spatial characteristics of the ellipses vary from one tropical cyclone basin to another and, among other factors, are a function of the screen settings already discussed in Section IV D. Specific utility of the elliptical concept must be developed from operational experience in a given basin.

As also pointed out in Section IV D, the use of analog guidance is currently not recommended in the case of recurving tropical cyclones. The associated elliptical guidance is similarly not recommended for this class of storms.

In the lower left hand corner of the message illustrated in Figure 1, it can be noted that provision is made for the specification of EPHC77 elliptical parameters. It is believed that these ellipses will offer more operational utility (including recurving storms) than the analog ellipses. As of the date of this report, the programming of this phase of the EPHC77 model is incomplete. However, these additional data should be available by the end of the 1977 hurricane season.

VI. THE SIMULATED ANALOG MODEL (EPCLPR)

As pointed out in subsection IV C, one of the principal shortcomings of any analog model is the failure to produce a forecast under anomalous weather situations. Such a condition is unacceptable when the model is used as input to a higher echelon model. Accordingly, Neumann (1972) introduced a regression equation model which has come to be known as a "simulated analog model". The model, as originally conceived, was intended to fill in the void when analog models failed. Experience with the model showed that on the average, its performance characteristics surpass those of the analog model even under normal weather situations. In addition to models for the Atlantic and Eastern North Pacific, simulated analog models have been developed by Neumann and Randrianarison (1976) for the South Indian Ocean and by Neumann and Mandal (1977) for the North Indian Ocean.

Another advantage of the model is its computational simplicity. The entire forecast takes but a few seconds of computer clock time. Analog models, on the other hand, require time to scan and process the large masses of historical storm tracks each time the program is run in an operational mode. Simulated analog models scan the historical files only during the developmental mode.

A. Development Data Set.

The EPCLPR model, as used for the 1976 hurricane season, was developed on all storms 1949 through 1975. At the end of the 1976 season, the prediction equations were revised and now include all storms 1949 through 1976. The latter data set also included some extensions into Mexico of some prematurely terminated storm tracks (see Section III, paragraph 2).

Storm positions on the magnetic tape are specified at 12-hour intervals. However, because of the requirements of the regression analysis, a minimum of four positions (P_t) at P_{+12}, P_0, P_{-12}, and P_{-24} are required for a 12-hour forecast. Thus all storms (a total of 15 storms) of less than 4 positions duration were eliminated from consideration for the development of the 12-hour prediction equations. Similarly, nine consecutive 12-hour positions P_{+72} through P_{-24} were required for generation of 72-hour prediction equations. Accordingly, a larger data set (2,214 cases on 298 storms) was used to develop the 12-hour prediction equations than was used (1,066 positions on 178 storms) to develop the prediction equations for 72-hour motion.

B. Predictands and Predictors.

The EPCLPR model is designed to predict the meridional (ΔY) and zonal (ΔX) displacement of tropical cyclones out through 72 hours.

Accordingly, 12 predictands, 6 for meridional motion and 6 for zonal motion, are required. These, along with their means and standard deviations are defined in Table 5.

Table 5. Means and standard deviations of the 12 predictands (nautical miles). Southward and westward motions are negative.

	Symbol	Mean	Standard Deviation
12 h meridional displacement	ΔY_1	39.6	48.3
24 h meridional displacement	ΔY_2	78.1	86.0
36 h meridional displacement	ΔY_3	114.0	118.8
48 h meridional displacement	ΔY_4	147.0	146.4
60 h meridional displacement	ΔY_5	176.3	169.3
72 h meridional displacement	ΔY_6	202.8	188.4
12 h zonal displacement	ΔX_1	-77.3	69.7
24 h zonal displacement	ΔX_2	-158.0	123.3
36 h zonal displacement	ΔX_3	-240.9	174.3
48 h zonal displacement	ΔX_4	-324.5	221.4
60 h zonal displacement	ΔX_5	-410.8	265.4
72 h zonal displacement	ΔX_6	-501.8	306.6

Analog models make use of storm selection criteria based on such factors as initial and past storm motion, initial storm position and time of year. To simulate these criteria by functional methods, seven predictors are introduced. These predictors, subsequently referred to as the seven primary predictors, are identified and quantified in Table 6. Since the number of cases diminishes with increasing forecast period, the means and standard deviations of the seven primary predictors vary with forecast period. The mean latitude and longitude of the 1,066 cases comprising the 72-hour data set (15.9N 115.2W) is seen to be upstream from the mean position (17.6N 116.3W) of the storms comprising the 12-hour data set. The explanation lies in the fact that the downstream storms are more likely to have been dropped from the data tape in 72 hours than are the upstream storms. Similar rationale can be used to explain other systematic differences noted in Table 6.

Table 6. Means and standard deviations of the seven primary predictors. Westward and southward motion is negative.

		MEANS						STANDARD DEVIATION					
		FORECAST PERIOD (h)											
PREDICTOR	SYMBOL	12	24	36	48	60	72	12	24	36	48	60	72
Day Number	P_1	231	231	231	231	231	231	39	38	38	37	37	37
Initial latitude (degs N)	P_2	17.6	17.2	16.8	16.5	16.2	15.9	3.7	3.5	3.3	3.1	3.0	2.9
Initial longitude (degs W)	P_3	116.3	116.1	115.8	115.6	115.4	115.2	11.1	11.0	11.1	11.2	11.3	11.3
Average meridional speed past 12 hours (kt)	P_4	3.3	3.2	3.0	2.9	2.8	2.7	3.6	3.4	3.2	3.1	2.9	2.9
Average zonal speed past 12 hours (kt)	P_5	-6.7	-7.0	-7.2	-7.3	-7.5	-7.7	5.1	4.9	4.7	4.6	4.5	4.4
Average meridional speed past 12 to 24 hours (kt)	P_6	3.2	3.1	3.0	2.8	2.7	2.6	3.2	3.1	2.9	2.8	2.7	2.6
Average zonal speed past 12 to 24 hours (kt)	P_7	-6.9	-7.1	-7.3	-7.5	-7.7	-7.8	4.7	4.5	4.3	4.2	4.1	4.0
Number of cases		2214	1936	1692	1465	1253	1066	2214	1936	1692	1465	1253	1066
Number of storms		298	272	246	226	204	178	298	272	246	226	204	178

Note: Day number 231 is August 19

C. Regression Analysis.

To apply standard regression analysis, the 12 predictands given in Table 5 are taken as functions of the seven primary predictors given in Table 6,

$$\Delta Y_j = f_j(P_1,P_2,P_3,P_4,P_5,P_6,P_7) \qquad j = 1,6 \tag{4}$$

$$\Delta X_j = g_j(P_1,P_2,P_3,P_4,P_5,P_6,P_7) \qquad j = 1,6 \tag{5}$$

where j refers to one of the six forecast periods, 12 through 72 hours.

Following the reasoning given by Neumann and Randrianarison (1976), functions (4) and (5) can be taken as second-order polynomials. Such a polynomial, containing all of the products and cross-products of the seven primary predictors expands to 36 terms (35 predictors and one intercept value). These additional predictors, P_8 through P_{35} are identified in Table 7. Accordingly, (4) and (5) can be defined,

Table 7. Additional predictors P_8 through P_{35} generated by a second-order polynomial with seven primary predictors. The meaning of P_1 through P_7 is given in Table 6.

$P_8 = P_1^2$	$P_{15} = P_4P_2$	$P_{22} = P_5^2$	$P_{29} = P_7P_1$
$P_9 = P_2P_1$	$P_{16} = P_4P_3$	$P_{23} = P_6P_1$	$P_{30} = P_7P_2$
$P_{10} = P_2^2$	$P_{17} = P_4^2$	$P_{24} = P_6P_2$	$P_{31} = P_7P_3$
$P_{11} = P_3P_1$	$P_{18} = P_5P_1$	$P_{25} = P_6P_3$	$P_{32} = P_7P_4$
$P_{12} = P_3P_2$	$P_{19} = P_5P_2$	$P_{26} = P_6P_4$	$P_{33} = P_7P_5$
$P_{13} = P_3^2$	$P_{20} = P_5P_3$	$P_{27} = P_6P_5$	$P_{34} = P_7P_6$
$P_{14} = P_4P_1$	$P_{21} = P_5P_4$	$P_{28} = P_6^2$	$P_{35} = P_7^2$

$$\Delta Y_j = C_{36,j} + \sum C_{i,j} P_i \tag{6}$$

$$i = 1,35$$
$$j = 1,6$$

$$\Delta X_j = Q_{36,j} + \sum Q_{i,j} P_i \tag{7}$$

$$i = 1,35$$
$$j = 1,6$$

where the arrays C and Q are constants. The array elements $C_{36,j}$ and $Q_{36,j}$ are defined as the intercept values. Determination of these constants require the solution of 36 "normal" equations using methods described in Neumann and Hope (1972). However, the scientific subroutine packages available through most large computer facilities normally contain statistical programs for this purpose. The list of constants so determined are given in Tables 8 and 9, the former being for meridional and the latter for zonal motion. The solutions to (6) and (7) are in units of nautical miles.

The method just described is a least-squares fit to each of the 36 terms of the polynomial. The question arises as to the wisdom of using this approach rather than the application of stepwise screening regression to reduce the number of predictors. The reasons for the rejection of the latter approach are based on the experience with the model in other tropical cyclone basins. These reasons, too lengthy to be included in the present documentation, can be summarized by stating that the model appears to give better operational performance using the least-squares rather than the stepwise screening regression approach.

Some insight into significance of the various predictors is afforded by Tables 10 and 11. The former gives the linear correlation coefficients between the seven primary predictors and the 12 predictands. The 99% significance level of the correlation coefficient is approximately .07. Thus, some of the relationships are quite significant, others are marginal. As expected, the best single predictor of meridional motion for any time period is the average v-component of motion over the past 12 hours. Similarly, for zonal motion, the best relationship is with the average u-component over the past 12 hours. The ranking of additional predictors is complicated by the inter-relationship between predictors as specified in Table 11. Note therein the high correlation (0.93) between P_4 and P_6.

Table 8. Regression coefficients C(I,J) for use with meridional motion prediction equations (6). Index I refers to predictor numbers as defined in Tables 6 and 7. Intercept is given by element C(36,J). Index J refers to forecast projection at 12 hourly intervals, 12 through 72 h.

	J = 1	J = 2	J = 3	J = 4	J = 5	J = 6
I = 1	0.28183	1.18052	2.38256	3.58511	5.97668	8.56197
I = 2	4.54362	9.34165	14.13007	14.46563	16.85013	11.19234
I = 3	-1.42100	-3.42104	-6.36789	-9.25645	-9.91800	-9.18991
I = 4	-8.56360	4.48317	-3.71111	-7.51016	-31.14655	-41.40225
I = 5	5.71709	10.35844	17.69620	15.18651	0.44341	1.79082
I = 6	12.86888	5.87024	1.74920	-13.89104	-0.09895	-1.79274
I = 7	-6.01259	-10.03888	-14.15262	-10.82519	-1.69509	6.79229
I = 8	-0.00072	-0.00206	-0.00423	-0.00752	-0.01090	-0.01492
I = 9	0.00063	-0.01625	-0.04131	-0.05232	-0.08087	-0.14252
I = 10	0.06721	0.31212	0.56283	0.75825	0.65233	1.01402
I = 11	0.00031	0.00075	0.00406	0.01049	0.01027	0.01463
I = 12	-0.07295	-0.17033	-0.27114	-0.35747	-0.35492	-0.36397
I = 13	0.01014	0.02319	0.03542	0.04482	0.04810	0.03928
I = 14	0.02048	0.02328	0.06976	0.06327	0.04555	-0.00809
I = 15	-0.12879	-0.08382	0.98199	1.49706	2.64653	2.47840
I = 16	0.15884	0.13062	0.01637	0.07362	0.22316	0.45020
I = 17	-0.33551	-0.68624	-1.45030	-3.20021	-1.91375	-1.96895
I = 18	-0.00727	-0.04334	-0.03475	-0.09298	-0.07205	-0.12811
I = 19	-0.07209	0.20527	0.47377	0.87333	-0.34724	0.91126
I = 20	-0.02897	-0.04398	-0.15017	-0.06874	0.19187	0.22103
I = 21	-0.38261	-0.16919	-1.12399	-1.89451	-2.78150	-3.69923
I = 22	-0.33432	-0.24937	-0.38695	-0.35178	-1.11149	-1.73016
I = 23	-0.00643	0.02468	0.01177	0.04631	0.04412	0.14596
I = 24	0.21205	0.05579	-0.77006	-0.94017	-1.06854	-0.87386
I = 25	-0.14236	-0.14558	0.00474	0.04854	-0.12492	-0.37243
I = 26	0.42663	0.32494	1.03102	3.97111	1.03197	0.69980
I = 27	0.37864	0.32959	1.04663	1.74865	3.77791	3.04986
I = 28	-0.22564	0.16422	0.31629	-1.12289	0.40985	0.82163
I = 29	0.00583	0.05279	0.06682	0.14646	0.15913	0.24957
I = 30	-0.09063	-0.65893	-1.36515	-2.41965	-1.83110	-4.12507
I = 31	0.06227	0.10103	0.21472	0.19123	0.03990	0.01827
I = 32	0.38215	0.20131	1.03018	1.84901	2.99691	3.89398
I = 33	0.55811	0.24677	0.49862	0.19994	2.20824	3.86509
I = 34	-0.15284	0.14816	-0.33254	-0.77717	-2.89866	-2.04142
I = 35	-0.17689	0.13097	0.13402	0.57277	-0.36316	-1.26143
I = 36	51.54951	87.70613	191.45848	311.63135	122.90865	-49.45882

Table 9. Regression coefficients Q(I,J) for use with zonal motion prediction equation (7). Index J refers to predictor numbers as defined in Tables 6 and 7. Intercept is given by element Q(36,J). Index J refers to forecast projection at 12 hourly intervals, 12 through 72h.

	J = 1	J = 2	J = 3	J = 4	J = 5	J = 6
I = 1	-1.85455	-3.74638	-6.46342	-9.66092	-11.69466	-13.29456
I = 2	10.46346	21.86832	45.26634	70.99454	98.94820	137.46045
I = 3	1.45819	5.46016	7.89286	9.61258	19.26921	28.53558
I = 4	4.08746	7.87156	-10.19538	-49.06210	-38.47107	21.14783
I = 5	25.51109	12.02663	16.22977	11.31185	20.56873	33.27660
I = 6	-6.75084	-9.76737	-18.59772	4.63427	8.63129	-35.92805
I = 7	-17.30367	1.94166	7.22404	20.00237	10.30467	1.47229
I = 8	0.00331	0.00739	0.01291	0.01797	0.02353	0.02915
I = 9	-0.00704	-0.02194	-0.04063	-0.04398	-0.06271	-0.08834
I = 10	0.09916	0.30838	0.69502	0.81899	2.13888	2.48826
I = 11	0.00480	0.00776	0.01312	0.02258	0.02130	0.01642
I = 12	-0.09587	-0.21813	-0.48393	-0.70544	-1.28889	-1.63914
I = 13	-0.00401	-0.01402	-0.01306	-0.01543	-0.00684	-0.01311
I = 14	0.03287	-0.00091	0.06252	0.15327	0.14832	0.11112
I = 15	0.02140	0.41549	1.73121	0.91692	1.78905	1.27456
I = 16	-0.10892	-0.06777	-0.20891	0.06332	0.02972	-0.31684
I = 17	-0.03449	1.52858	0.08821	1.60376	2.42669	1.45771
I = 18	-0.02469	-0.04252	-0.04317	-0.08437	-0.03404	-0.12663
I = 19	0.93308	0.22601	0.68425	1.56295	0.84145	1.77174
I = 20	-0.21166	0.11558	0.12628	0.15139	0.14990	0.14701
I = 21	1.36879	-0.40859	-0.02464	-1.94950	-2.82517	-3.90791
I = 22	-1.07563	-0.36550	-0.60331	-0.70759	-1.64106	-2.68669
I = 23	-0.02778	0.03004	0.01623	-0.04308	-0.03849	-0.02593
I = 24	-0.17880	-0.61352	-2.38881	-2.00883	-3.91345	-3.82812
I = 25	0.13580	0.07664	0.39326	0.22906	0.27010	0.56483
I = 26	0.26839	-3.46122	-2.23628	-3.22331	-4.99370	-2.84130
I = 27	-2.48284	1.11385	0.35949	3.12168	3.57564	2.73703
I = 28	0.00029	1.83346	2.62705	2.45040	4.11566	3.59300
I = 29	0.03171	0.05635	0.06962	0.11245	0.04433	0.10238
I = 30	-0.97447	-0.46202	-1.20352	-2.24124	-2.48466	-3.67784
I = 31	0.22925	-0.06139	-0.07612	-0.09981	0.16656	0.30452
I = 32	-1.49676	0.65331	-0.33997	1.63690	4.13544	5.23015
I = 33	2.23501	1.73573	2.88805	3.01985	5.51485	7.56695
I = 34	2.42468	-1.45265	-0.29809	-3.43679	-5.39915	-4.68612
I = 35	-1.07444	-1.26156	-2.13891	-2.13442	-3.17083	-3.89801
I = 36	4.51569	-175.52870	-230.95285	-251.77850	-957.13672	-1752.63965

Table 10. Linear correlation coefficients between the seven primary predictors and tropical motion 12 through 72 hours. Southward and westward motion are negative.

		FORECAST PERIOD (h)											
		MERIDIONAL						ZONAL					
PREDICTOR	SYMBOL	12	24	36	48	60	72	12	24	36	48	60	72
Day number	P_1	.09	.10	.11	.11	.11	.12	.18	.20	.21	.21	.22	.22
Initial latitude	P_2	.24	.21	.16	.11	.06	.02	.29	.30	.28	.27	.26	.24
Initial longitude	P_3	-.23	-.24	-.24	-.23	-.21	-.19	-.13	-.14	-.11	-.08	-.06	-.04
Average v-comp past 12 h	P_4	.71	.62	.55	.48	.39	.29	.18	.19	.16	.16	.13	.11
Average u-comp past 12 h	P_5	.14	.17	.14	.11	.09	.09	.78	.76	.72	.66	.62	.57
Average v-comp past 12-24 h	P_6	.64	.56	.49	.41	.32	.23	.19	.20	.18	.16	.13	.11
Average u-comp past 12-24 h	P_7	.14	.17	.14	.11	.10	.09	.76	.74	.69	.63	.60	.55

Table 11. Correlation matrix between the seven primary predictors of 24 h motion. Symbols are identified in Table 6.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7
P_1	1.00	.22	.07	.07	.17	.07	.17
P_2		1.00	.19	.38	.26	.45	.27
P_3			1.00	-.20	-.15	-.20	-.17
P_4				1.00	.10	.93	.10
P_5					1.00	.11	.94
P_6						1.00	.10
P_7							1.00

Table 12. System performance on development data. Errors are given in nautical miles.

	Forecast period (h)					
	12	24	36	48	60	72
1. Number of cases	2214	1936	1692	1465	1253	1066
2. Number of storms	298	272	246	226	204	178
3. Meridional motion, reduction of variance (%)	53.8	44.6	37.4	31.3	25.9	21.5
4. Meridional motion, multiple correlation coefficient	.734	.668	.611	.560	.508	.464
5. Meridional motion, standard error	30.4	64.7	95.0	122.8	147.9	170.0
6. Mean absolute meridional motion error	22.6	46.7	71.0	93.6	112.2	128.3
7. Mean meridional motion error (y-bias)	0.0	0.0	0.0	0.0	0.0	0.0
8. Zonal motion, reduction of variance (%)	65.5	62.9	57.7	51.8	47.5	42.7
9. Zonal motion, multiple correlation coefficient	.809	.793	.759	.720	.689	.654
10. Zonal motion, standard error	37.2	75.8	114.6	155.6	195.0	236.0
11. Mean absolute zonal motion error	28.9	55.2	85.5	117.5	148.8	180.9
12. Mean zonal motion error (x-bias)	0.0	0.0	0.0	0.0	0.0	0.0
13. Mean displacement error	40.3	79.9	123.0	165.0	204.9	243.5

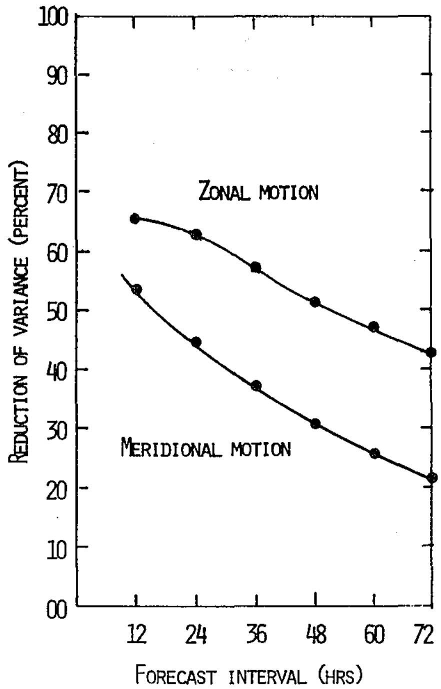


Figure 7. Total reduction of variance vs. forecast projection for meridional and zonal components of motion.

Thus, in the case of 24-hour meridional motion, the initial longitude (P_3) is selected as the second most significant predictor rather than P_6 as might be implied from Table 10.

Table 13. System performance on independent data. Errors are given in nautical miles. Numbered items correspond to similarly numbered items given in Table 11.

	Forecast period (h)					
	12	24	36	48	60	72
1. Number of cases	76	71	58	51	47	39
2. Number of storms	76	71	58	51	47	39
6. Mean absolute meridional motion error	21.8	46.8	71.7	94.2	110.2	122.2
7. Mean meridional motion error (y-bias)	0.3	0.2	11.8	18.6	27.6	18.1
11. Mean absolute zonal motion error	28.9	57.2	95.7	115.9	161.0	182.5
12. Mean zonal motion error (x-bias)	1.9	8.8	11.0	-1.8	-17.7	-2.3
13. Mean displacement error	41.2	80.6	131.9	172.7	222.3	248.1

D. Performance on Dependent and Independent Data.

Data relating to the performance of Eqs. (6) and (7) on dependent (development) data are given in Table 12. Items 3 and 8 from this table are depicted graphically in Figure 7. In reference to this figure, the greater reduction of variance realized from the zonal motion equations is typical of any statistical prediction system in which the zonal and meridional components of motion are treated separately. Before making further interpretations of these results, it is well to consider the relationship between the reduction of variance (RV), the multiple correlation coefficient (r_m), the standard error (SE), and the standard deviation of the motion (SD). These relationships are:

$$SE = SD\sqrt{1 - r_m^2} \qquad (8)$$

$$RV = r_m2 \ .$$

Thus, even though Table 12 and Figure 7 indicate substantially greater reduction of variance for zonal motion, the greater standard deviations of zonal motion (see Table 5) provide, according to (8), for greater zonal standard errors. Similar results are noted in other tropical cyclone basins.

Consider now the performance of the model on independent data. For this purpose, every 30th case had been withheld from the master data set. The sample provides an independent test of Eqs. (6) and (7), the results of which are given in Table 13. The differences in performance between dependent and independent data can be obtained by comparison with Table 12. For convenience, a common numbering system has been used in both tables. Certain items were intentionally omitted from Table 13 since these are generally associated only with dependent (development) data.

Because of the large number of cases included in the development sample, the difference in performance of the model between the dependent and independent data modes is small. The x- and y- biases, always zero in the dependent data, are also seen to be quite small. These biases are typical and result from dependent and independent data having somewhat different statistical properties.

E. Significance Tests.

Serial correlations between individual predictor/predictand sets preclude direct use of the classical F-test. The presence of these correlations effectively inflates the degrees of freedom in the denominator of the F-variance ratio and can lead to acceptance of a regression equation at some confidence level when indeed, it should have been rejected. To offset this effect, an "effective" degrees of freedom can be introduced. Calculation of this quantity using methods suggested by Siegel (1956) and as applied by Enger, et al (1964), suggest reducing the sample size by a factor of 2.5 to account for serial correlations in the dependent data. Applying the modified F-test in this manner, still leads to acceptance of the regression equations at the 99% confidence level. Other tests as described by Neumann, et al (1977), also show that the equations are statistically sound.

Regardless of the outcome of any statistical test, a model's ultimate evaluation must be based on its performance in an operational environment. Such an evaluation is given in Section VIII.

F. Additional Comments.

The foregoing description of the derivation of the prediction equations for the EPCLPR model is considerably abbreviated. For a more thorough treatment, the reader is referred to Neumann and Randrianarison (1976) or Neumann and Mandal (1977). Adaptation of the model to the Eastern North Pacific was fairly straightforward, most of the applicable computer programs having been optimized on the other tropical cyclone basins.

The Atlantic version of the model (Neumann 1972) uses an additional predictor consisting of the maximum wind at the center of the tropical cyclone. This quantity does afford additional reduction of variance potential; however, scarcity of wind information in the archived data precluded its use over the Eastern Pacific basin.

VII. SENSITIVITY OF EPCLPR TO INITIALIZATION

As is typical with most prediction models, the operational performance is a function of the ability to specify the required input parameters under the constraints of an operational environment. The EPCLPR model is particularly sensitive to inaccuracies in these parameters (i.e., date, present and past storm positions). The EPANLG model, on the other hand, because of the liberal screen settings, is relatively insensitive to these operational uncertainties.

A. Examples of EPCLPR Sensitivity.

The EPCLPR model makes explicit use of climatology and persistence and accordingly, is sensitive to errors in these quantities. Some examples are provided by Figures 8, 9, and 10. Consider, for example, Figure 8. Here, a storm is initially positioned at 17N 115W with the 12-hour and the 24-hour storm positions as shown. The program was run seven times with the date varying from 15 May through 15 November. The resultant family of forecast tracks demonstrates the sensitivity to day number. It can be noted that the forecast maximum westward displacement corresponds with the climatological expectancy of deepest easterlies.

Figure 9 demonstrates sensitivity to 24-hour old positions. A storm is again positioned as in Figure 8. This time the date (September 15) and the 12-hour old position (16.2N 113.7W) are held constant and the 24-hour old position is allowed to vary as shown. The resultant forecast tracks are all towards the west-northwest. However, it can be noted that a more northerly location of the 24-hour old position results in a more northerly forecast track. In general, however, the model is relatively insensitive to the 24-hour old position.

Finally, consider Figure 10. Here, all parameters except for the 12-hour old position are held constant. The resultant tracks demonstrate that different 12-hour old storm positions have a profound effect on the forecast track. More northerly 12-hour old positions are seen to be associated with more southerly track forecasts. Similarly, variations in current storm positions (not illustrated) could be shown to effect even greater dispersion in forecast tracks.

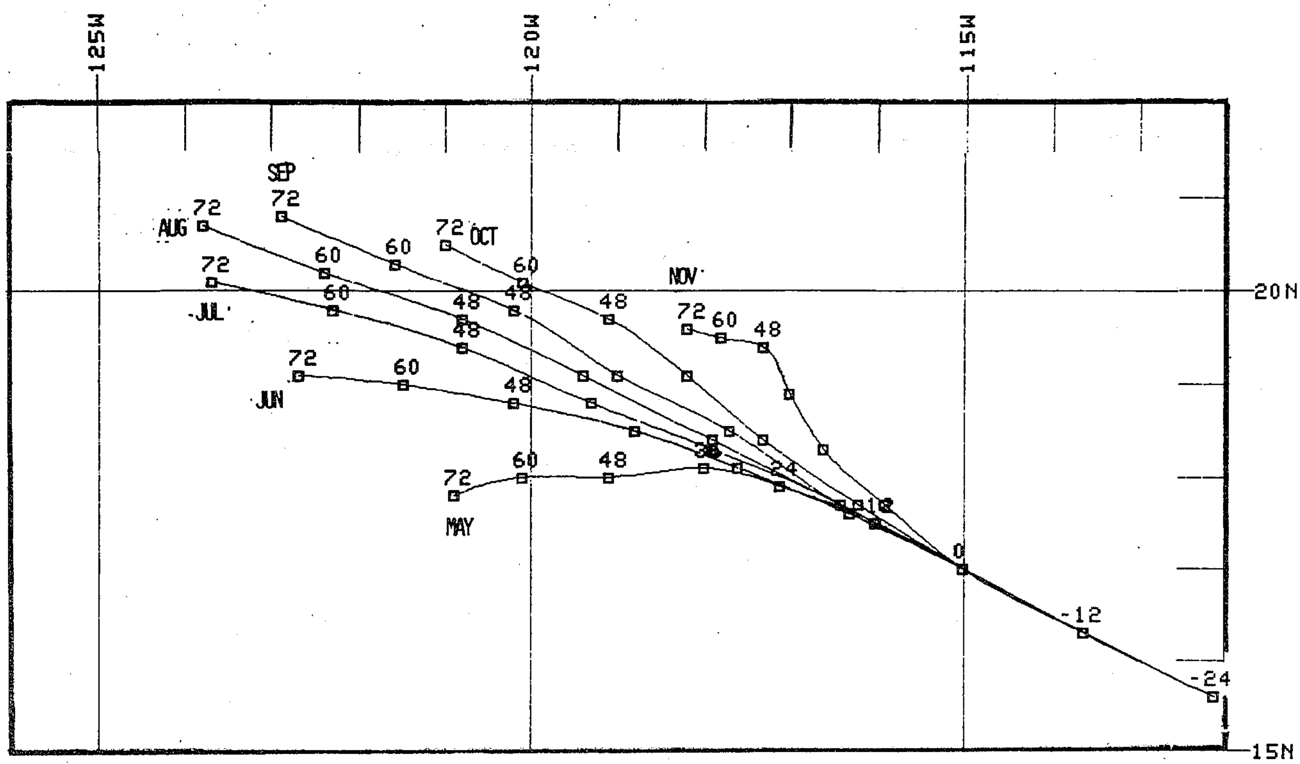


Figure 8. Seventy-two hour forecast tracks generated by EPCLPR model with predictors P_2 through P_7 (identified in Table 6) held constant and with predictor P_1 (date) ranging from 15 May through 15 November.

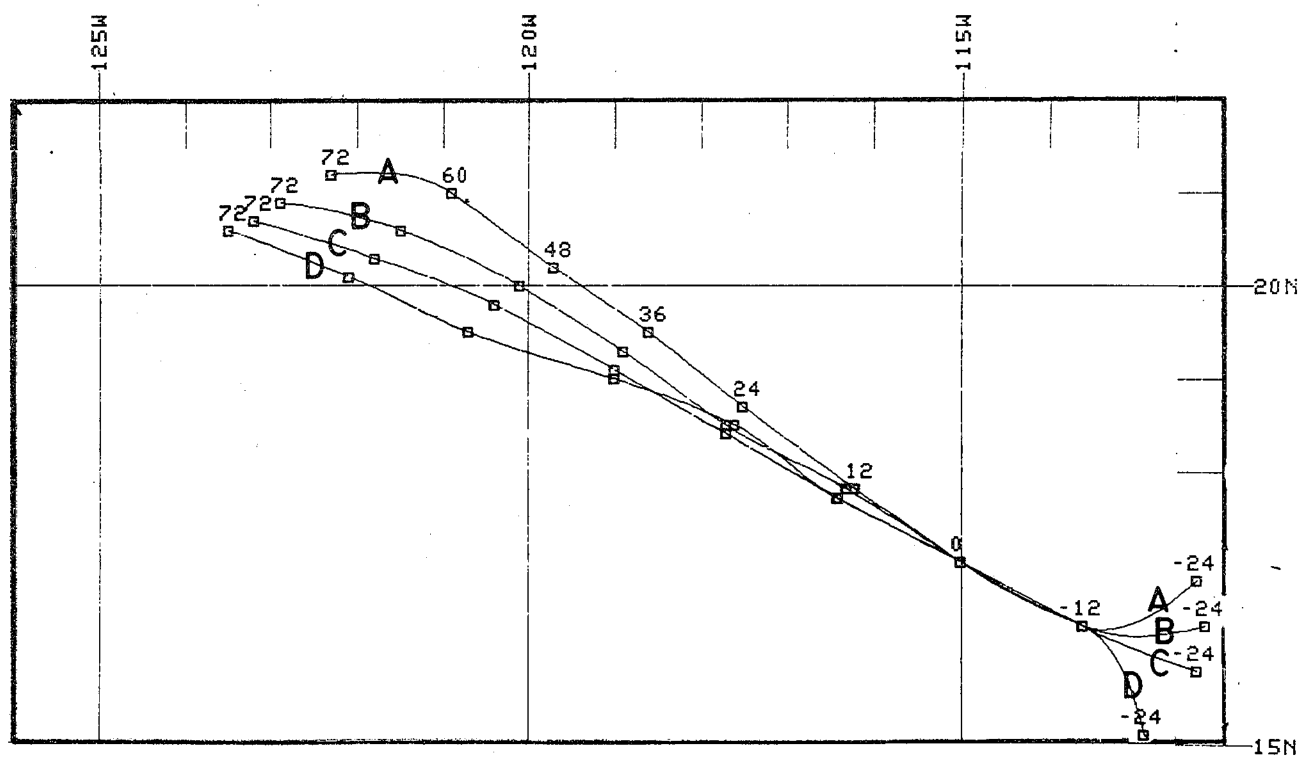


Figure 9. Similar to Figure 8, except predictors P_1 through P_5 held constant and predictors P_6 and P_7 ranging according to specified -24 hour storm positions.

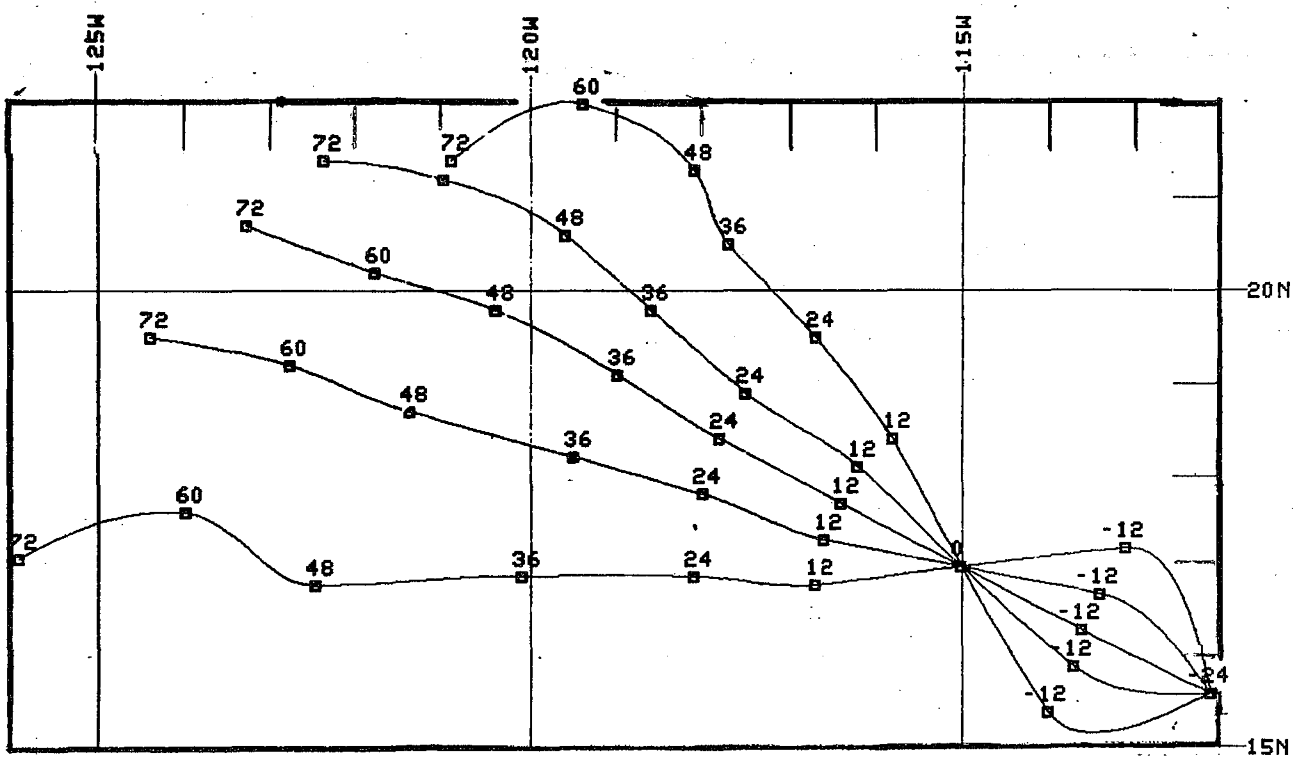


Figure 10. Similar to Figure 8, except predictors P_1, P_2, P_3 held constant and with remaining predictors ranging according to specified -12 hour storm positions.

B. The Concept of "Best Track".

The EPCLPR model was developed from best-track data. Accordingly, the operational input data should approximate a similar scale of motion. The actual track of the center of a tropical cyclone reflects the presence of two scales of motion. The smaller scale of motion, consisting of trochoidal oscillations 10 to 20 miles about some mean track, is generated by internal forces. Such motions have been documented by Lawrence and Mayfield (1977). The larger scale motion, typically quite conservative, reflects the influence of the environmental steering forces. In constructing a best-track, attempts are made to remove real as well as fictitious small-scale motions generated by positioning errors inherent in the standard observational platforms. This is a somewhat subjective process, and the end result is referred to as the best-track. This is the track that is archived and forms the basis of future prediction models.

C. Climatological Distribution of Motion Vectors.

Present, 12-hour old and 24-hour old storm positions are used by the model to generate a zero to -12 hour and a -12 hour to -24 hour average motion vector. The storms shown on Figure 3 contain 2,290 such motion vectors. Their statistical distribution is shown in Figure 11. The interpretation of Figure 11 is as follows. The most commonly observed motion vector is toward 296 degrees at 7.5 kts. This is the centroid of the distribution. Radially outward from this point, motion vectors are increasingly less observed. Ten percent of the vectors (nine percent in the outermost band) are expected in each annular band. In an average tropical cyclone season, only one percent (one out of a hundred forecast situations) should fall outside the 99% ring. An initial motion vector of, say, 360/18 is climatologically unlikely.

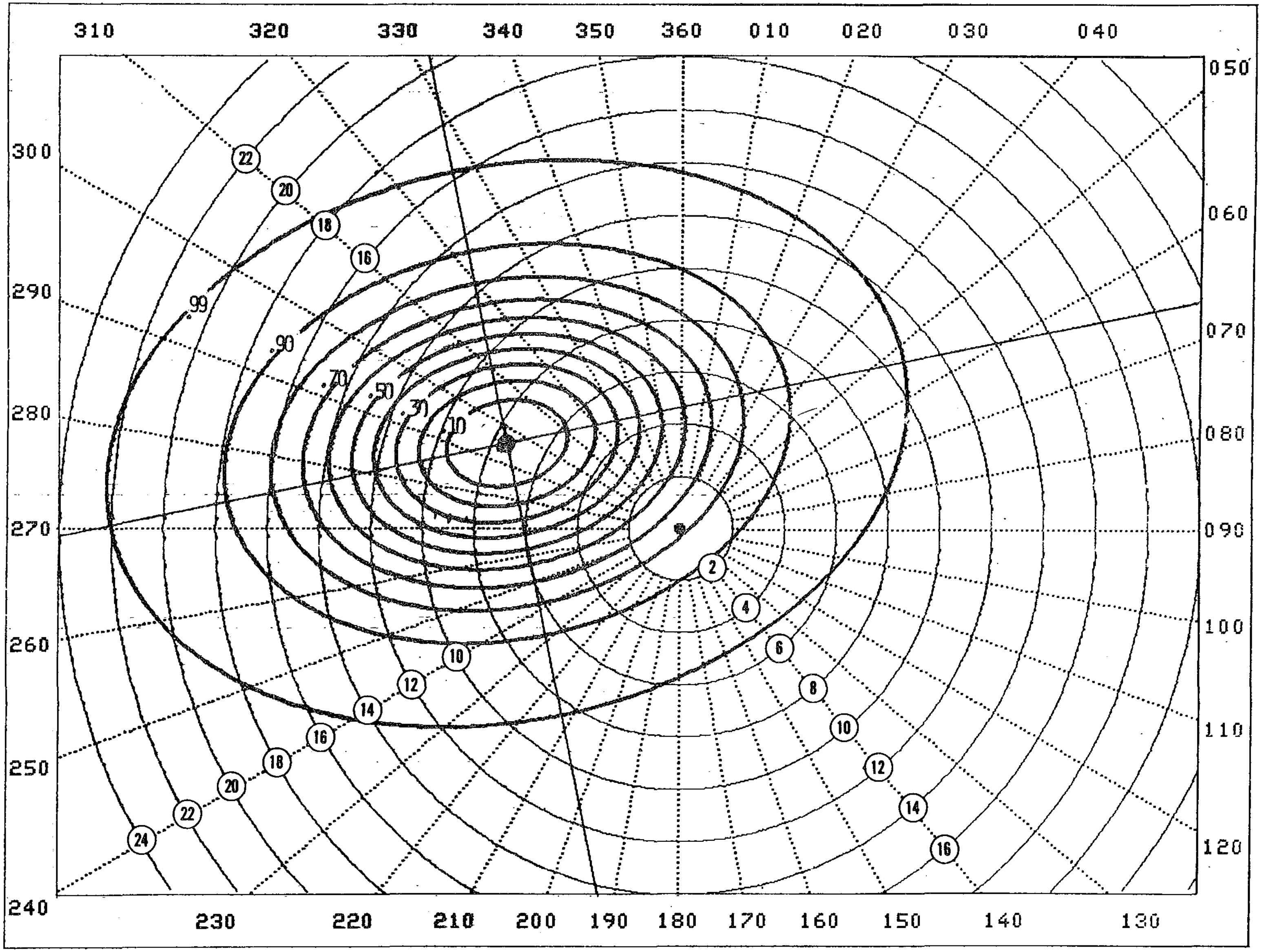


Figure 11. Initial 12-hourly motion vectors of Eastern North Pacific tropical cyclones fitted to a bivariate normal distribution. Radials give storm heading in degrees. Concentric circles give storm speed at 2-knot intervals. Period of record includes all recorded tropical cyclones 1949-1976 (2,290 cases).

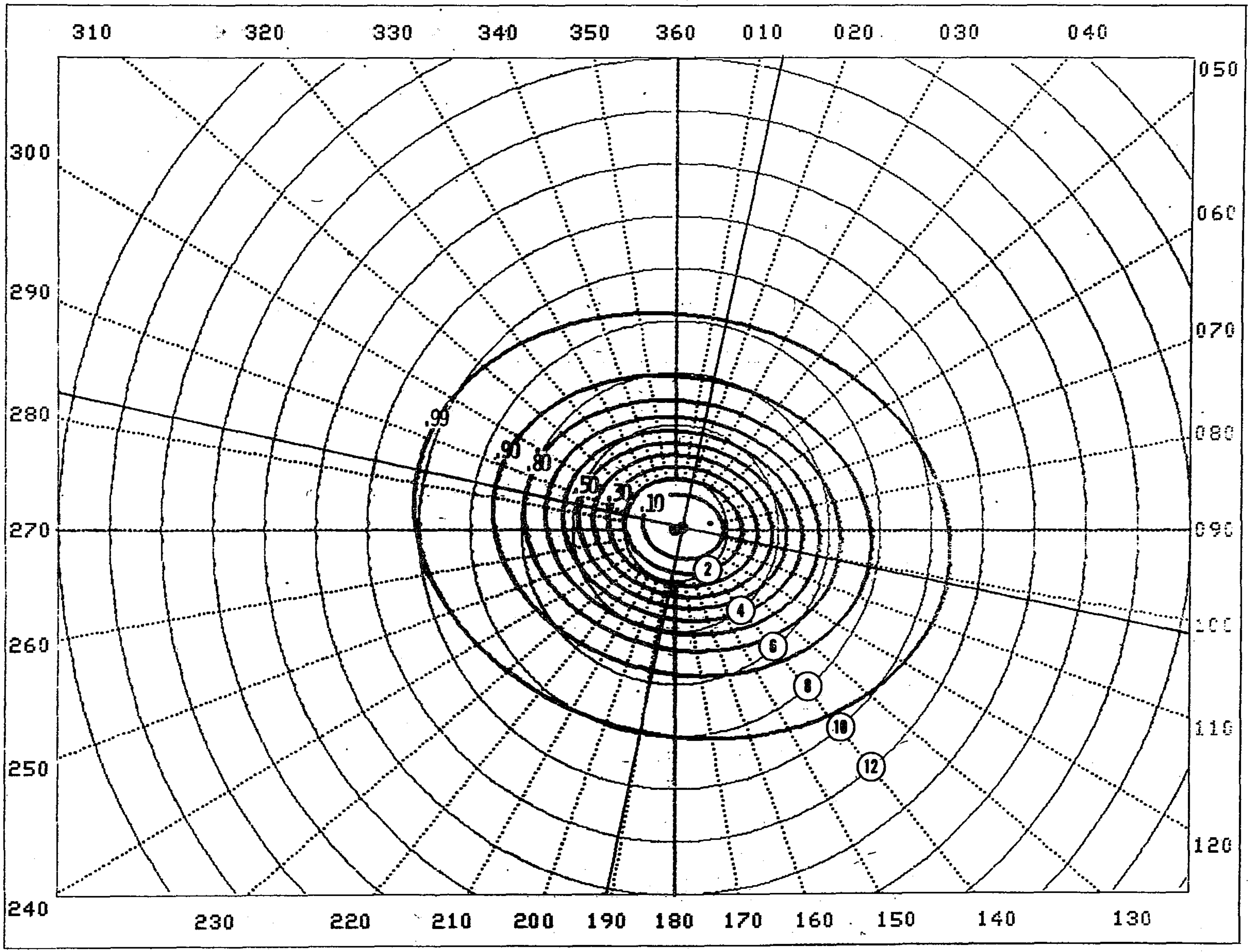


Figure 12. Same as Figure 11, except showing distribution of changes in two successive motion vectors.

The forecaster should always consider this statistical distribution whenever he is faced with the problem of initializing the models with the current,-12 hour and -24 hour storm positions. To assist in this practice, the guidance message (Figure 1) gives the exact 00/-12 hour and -12/-24 hour motion vectors. The guidance message also gives the point-probability location (from equations defining Figure 11) of the end-points of these two vectors. As an example, consider the forecast situation on storm IVA in Figure 1. The storm was initially located 19.6N 117.9W. Twelve and 24 hour old positions are given, respectively, as 19.0N 114.2W and 18.5N 113.5W. As specified in Figure 1, this corresponds to a 00/-12 hour motion vector of 283/13 kts and a -12/-24 hour motion vector of 287/08 kt. The end-points of these vectors, plotted onto Figure 11, would reach, respectively, to the 0.50 and the 0.05 annular rings. These point probabilities, designated R50 and R05 appear in Figure 1 immediately following the specific motion vector.

Any initial motion vector falling beyond the 0.75 ring (R75) should be suspect and the forecaster should verify that this is indeed the information he wishes to convey to the model. If not, suitable adjustments should be made in the storm positions to reflect the storm motion he feels is representative. Only in this way can the full variance reducing potential of the model be realized.

D. Climatological Distribution of Changes in Motion Vectors.

Large differences in two successive motion vectors taken from best-track data are unlikely. This is tantamount to stating that rapid changes in the environmental steering forces are unlikely. Figure 12 shows the climatological statistical distribution of the vector difference between two successive motion vectors as derived from the same best track data source as Figure 11. Interpretation of the figure is similar to interpretation of Figure 11. It can be noted that the most likely condition is to have little or no change in two successive motion vectors.

The guidance message illustrated in Figure 1 also contains information relative to Figure 12. In the sample given the difference between the -12/-24 hour and the 00/-12 hour motion vector is given as 286/05 kt. The point probability of this change is given as R65. Thus, the difference in speed from 8 to 13 knots is somewhat excessive when compared to best-track data. The forecaster should verify that accelerations conveyed to the program are consistent with his thinking. Thus, in the example cited, if the forecaster thought that the storm was indeed exhibiting steady-state motion, then some adjustment in at least one of three storm positions supplied to the program would have been called for.

VIII. COMPARATIVE PERFORMANCE OF EPANLG AND EPCLPR

The EPANLG model became operational on 15 July 1976 and the EPCLPR model approximately 5 weeks later, on August 24. Missing EPCLPR forecasts for the period prior to 24 August were obtained by running the model on exactly the same operational input data as supplied the analog model. Accordingly, a complete homogenous sample of the two models is available for the 12 storms, Celeste through Naomi, of 1976. The sample size varies from 156 12-hour forecasts to 72 72-hour forecasts. Five of the storms, G, K, L, M, and N were classified as recurvers and the remaining seven storms as nonrecurvers. A separate verification was compiled for both classes of storms as well as for the entire sample. These comparisons are shown in Figure 13.

In the case of nonrecurving storms, little or no difference can be noted in the performance of the two models. However, in the case of recurving storms, the displacement errors of EPCLPR were significantly less than EPANLG. The marked westward bias of the analog model (see Figure 5) is largely responsible for the difference. Although the EPCLPR model also showed the bias, it was confined to the latter portion of the forecast period. For the entire storm sample, shown by the center panel of Figure 13, the poorer performance of the analog model on the recurving storms is reflected in the overall statistics.

In both models, the error on recurving storms is excessive. As additional operational data are collected, efforts will be made to improve on the performance of both models on this important class of storms over the Eastern Pacific basin.

IX. COMPUTER ACCESS

The analog model and the simulated analog model can be run on virtually any computer system, the only restriction being that input/output requirements of the analog model are excessive for some older model computer systems. The EPHC77 model (to be discussed separately) requires fields of upper-air data available through the NOAA 360/195 system. Accordingly, it is convenient to run the entire package through the NOAA facility. The Eastern Pacific Hurricane Center (EPHC) located at the San Francisco WSFO does not have access to the 360/195 system. Accordingly, a relay system through the National Hurricane Center has been established. The system is shown schematically in Figure 14.

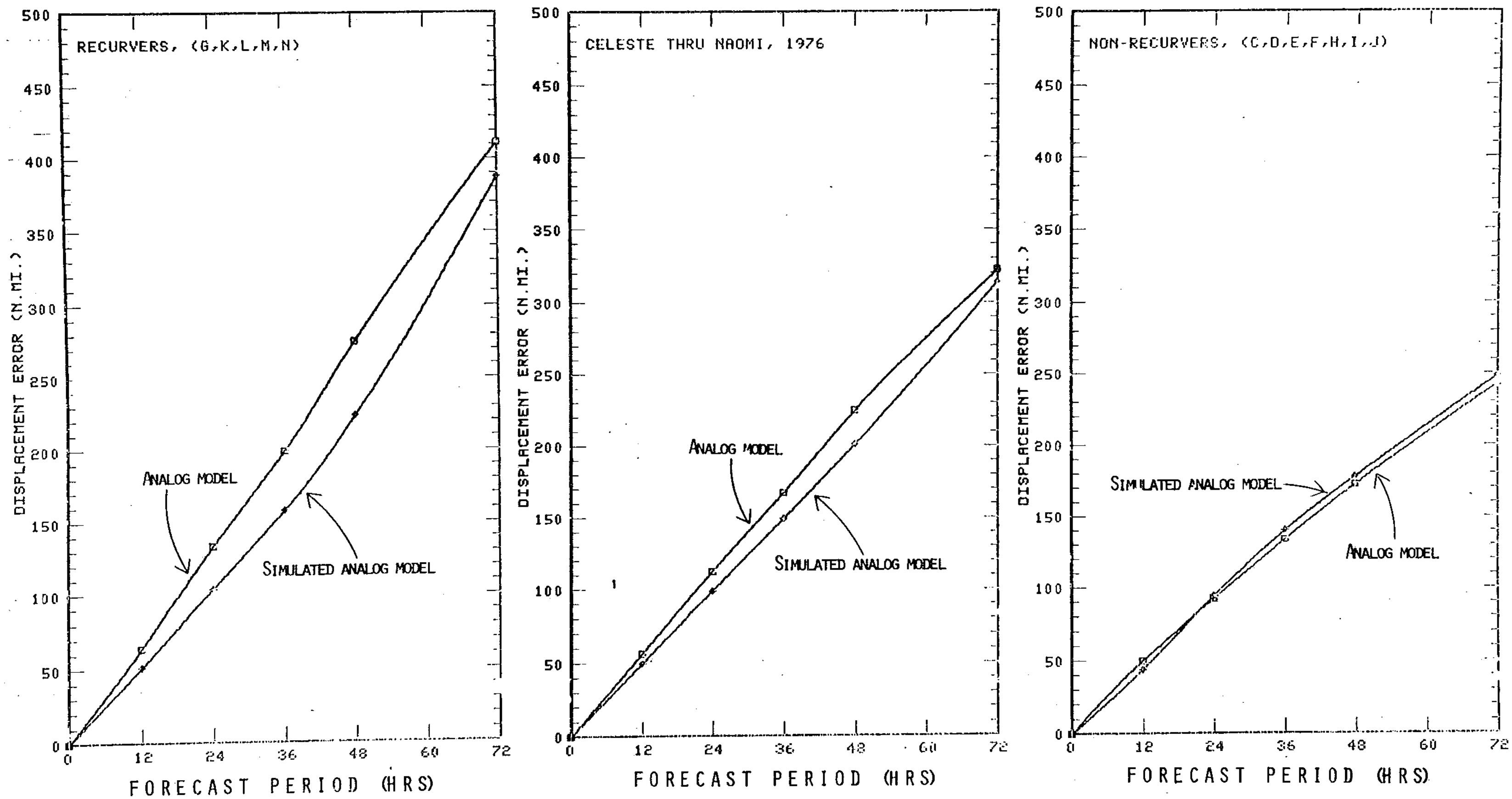
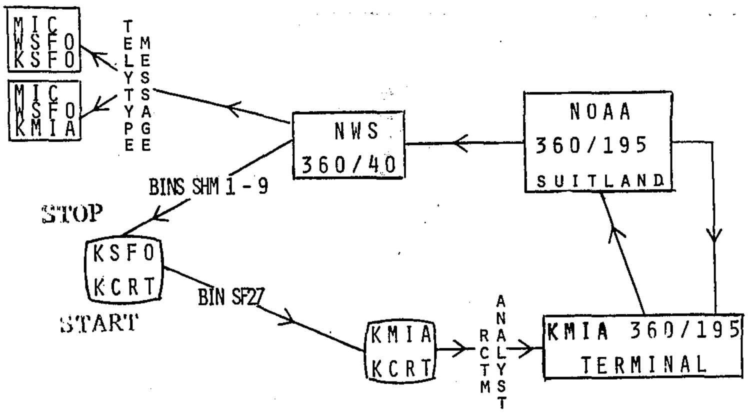


Figure 13. Displacement error vs. forecast projection on storms Celeste through Naomi, 1976.



~~Figure 14.~~ EPHC ~~statistical forecast package~~ communications linkages

The process is activated when the EPHC forecaster enters the required storm parameters into the KCRT system. The data are read off the scope by an analyst attached to the WMO Regional Center for Tropical Meteorology (RCTM), collocated with the National Hurricane Center in Miami, Florida. A single data card is prepared and transmitted to the 360/195 complex through the computer terminal available to NHC. After the program has been run, a teletype and KCRT message (see Figure 1) are automatically generated and made available to both Miami and San Francisco. Additionally, a hard copy computer printout is received at NHC. Provision is also made for multiple storm occurrences, common over the Eastern Pacific tropical cyclone basin. The clock time required for the complete circuit depicted in Figure 14 is about 15 to 20 minutes.

X. SUMMARY

This study has documented the development of a portion of a recently activated statistical forecasting package for use by the Eastern Pacific Hurricane Center, located at the WSFO, San Francisco, California. The prediction models comprising the package, like any other prediction model must be continually monitored and revised on the basis of their performance in an operational environment. Only in this way can optimized performance be expected. The use of at least a portion of the package for much of the 1976 hurricane season has already highlighted certain deficiencies. These relate primarily to poor performance of the models and an inadequate data set on recurving storms. Since this class of storms is important in this tropical cyclone basin, modifications to effect better performance are called for. It is expected that these modifications will gradually be accomplished and suitably documented over the next few hurricane seasons.

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