NOAA Technical Memorandum NWS WR-169

# A STATISTICAL-DYNAMICAL MODEL FOR PREDICTION OF TROPICAL CYCLONE MOTION IN THE EASTERN NORTH PACIFIC OCEAN

Salt Lake City, Utah
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**U.S. DEPARTMENT OF COMMERCE** / National Oceanic and Atmospheric Administration / National Weather Service

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DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

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This publication has been reviewed and is approved for publication by Scientific Services Division, Western Region. We appreciate Mr. Leftwich and Mr. Newmann, of NMC, publishing this study in the Western Region Technical Memorandum Series.

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*ABSTRACT. A statistical-dynamical model, EPHC81, has been formulated to predict tropical cyclone motion in the Eastern North Pacific Ocean. Predictors utilized in its regression equations are obtained via a simulated analog model and numerical prognoses. Guidance from EPHC81 is transmitted directly to operational forecasters at the Eastern Pacific Hurricane Center (EPHC). This report documents the development and operational implementation of this model.*

## 1. INTRODUCTION

Responsibility for preparation and issuance of advisories concerning tropical cyclones in the Eastern North Pacific Ocean is assigned to the Eastern Pacific Hurricane Center (EPHC) located at the Weather Service Forecast Office (WSFO), San Francisco, California. As discussed by Neumann (1979a), various objective models provide guidance on the motion of these storms. Several of these objective models have been developed and/or operationally implemented by the National Hurricane Center (NHC) Research and Development Unit. Experience with tropical cyclones in the Atlantic basin has shown that the statistical-dynamical NHC73 model (Neumann and Lawrence, 1975) has exhibited the best overall skill among operational models during the period 1973-1979. This is depicted in Fig. 1. Particular improvements have been noted in recurvature situations. Recurvature is important in the Eastern North Pacific basin because such storms often affect coastal regions of Mexico and the southwestern United States. Accordingly, a statistical-dynamical model, hereafter referred to as EPHC81, has been developed to provide guidance on future motions of tropical cyclones in the Eastern North Pacific Ocean.

## 2. BACKGROUND

Recent studies at the NHC (Neumann, 1979b) suggested that objective predictions of tropical cyclone motion can be improved by use of predictors derived from pressure-weighted deep-layer mean geopotential heights rather than use of data at individual levels. Observations over the

[1]*Study partially supported by NOAA/ERL-AOML-National Hurricane Research Laboratory (NHRL).*

oceans at middle levels of the atmosphere have decreased substantially during the past several years. Consequently, analyses of geopotential heights (70 and 50 kPa) used in earlier statistically-based prediction models have become less reliable, particularly in the vicinity of tropical cyclones. In contrast, data at both higher levels (e.g., 30 kPa) and lower levels (e.g., 85 kPa) have increased, mainly due to satellite-derived winds. Many commercial aircraft also provide wind measurements at upper levels. Deep-layer means offer the advantage of incorporating information from levels that have experienced increases in data.

Several functions for computation of deep-layer means were tested. The function employed in the SANBAR barotropic tropical cyclone prediction model (Sanders and Burpee, 1968) was selected for use in the current model. For the purposes of this model, it is convenient to express this function in terms of a pressure-weighted departure of each level from normal. Jordan's (1958) mean September tropical geopotential heights were used as normals for each level. This weighting function is thus expressed as

$$d_m = (75d_1 + 150d_2 + 175d_3 + 150d_4 + 100d_5 + 75d_6 + 50d_7 + 50d_8 + 50d_9 + 25d_{10})/900, \tag{1}$$

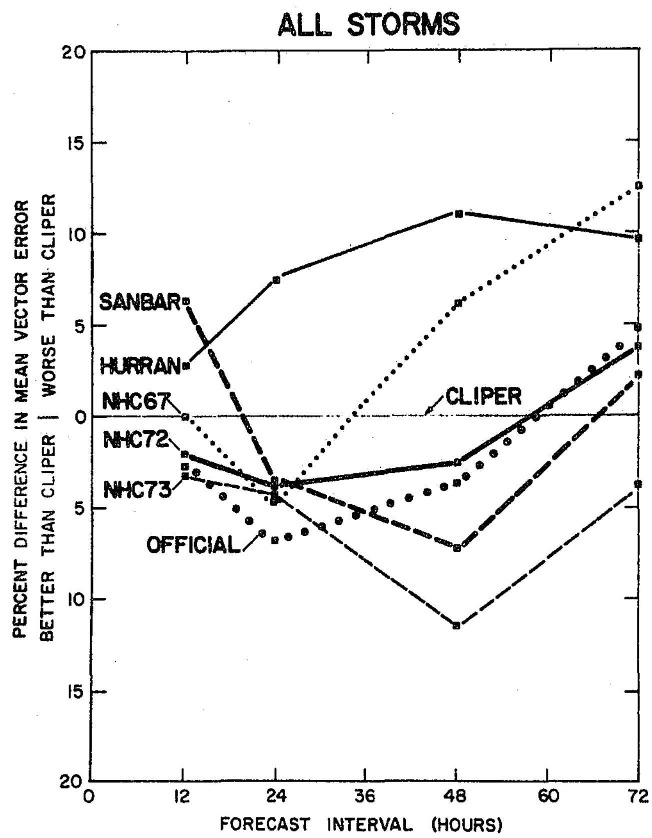


*Fig. 1. Performance of specified prediction system relative to the CLIPER model. Sample is homogeneous for all Atlantic storms during the period 1973-1979.*

where $d_m$ refers to the deep-layer mean and subscripts 1 through 10 refer to 100, 85, 70, 50, 40, 30, 25, 20, 15 and 10 kPa levels, respectively. Both analyzed and predicted synoptic patterns considered by this statistical-dynamical model as predictors of storm motion are represented by such deep-layer mean geopotential heights.

The most important concept of statistical-dynamical models is use of predictors computed from numerical prognoses. In the current development, a "perfect-prog" approach was used. That is, analyses rather than actual numerical prognoses were used as developmental data. This was necessary due to the relatively few years of archived prognoses for tropical cyclone cases available at present. As archived data increase, development of a similar model based on the concepts of Model Output Statistics (MOS), such as discussed by Glahn and Lowry (1972), is anticipated.

Also, the success of the EPCLPR model (Neumann and Leftwich, 1977) in the Eastern North Pacific basin encouraged the inclusion of its guidance as predictors of future storm motion.

## 3. DEPENDENT DATA

Data for 755 storm cases during the period 1965-1977 were compiled and stored on a magnetic tape. Only cases for which tracks extended at least 72 h past the initial time were included. Basic data are storm positions every 12 h from -24 to +72 h, observed and predicted (EPCLPR) storm displacements, and deep-layer mean geopotential heights surrounding the storm at each time. Geopotential heights used to compute deep-layer means by (1) were extracted from National Meteorological Center (NMC) Northern Hemisphere analyses via a 120-point, 300 nmi, storm-centered grid. This grid, which has been used in the development of other statistical models, such as EPHC77 (Leftwich and Neumann, 1977), is shown below.

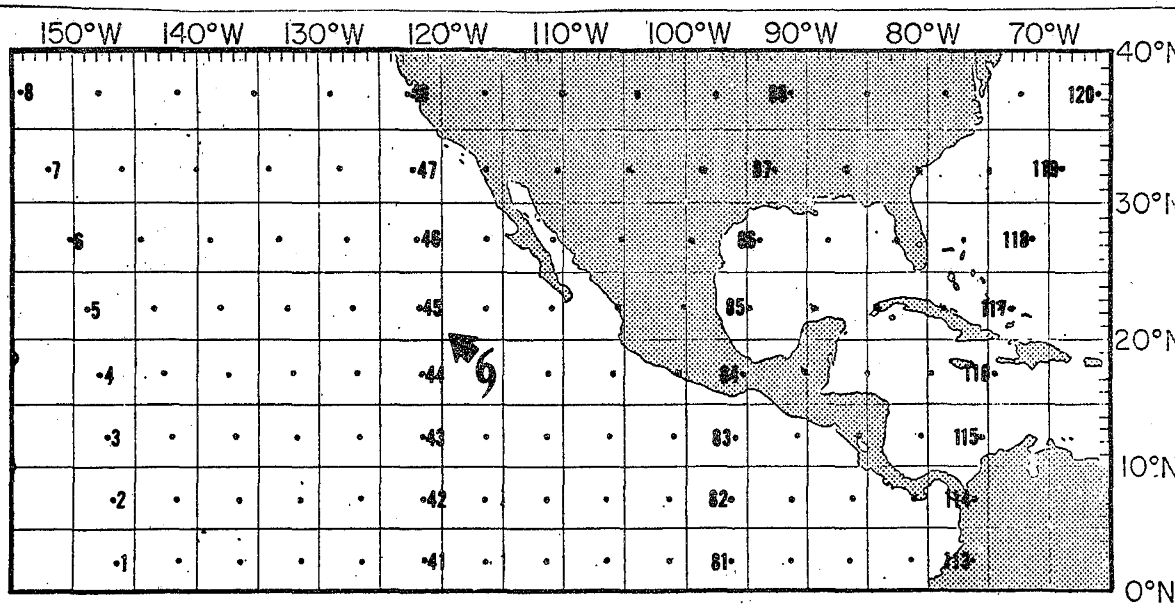


*Fig. 2. Mercator version of grid used to obtain geopotential height data. Storm center is always located at grid point 52. Arrow indicates mean storm motion from developmental cases.*

Examination of historical tropical cyclone tracks in the Eastern North Pacific basin (Leftwich and Brown, 1981) shows two preferred climatological paths. One extends from offshore Mexico and Central America west-northwestward toward Hawaii. The other leads from the same area of formation northward toward Baja California and southwestern California. In order to better model statistical characteristics of these regimes, dependent data were stratified according to the initial motion for each storm case. Cases having initial motion ranging from south to northwest (180°-315°) were included in one set. These cases comprised approximately 85% of the data. All other cases were included in a second data set. Stratification in this manner provided dependent data for formulation of two sets of prediction equations, hereafter referred to as EP81W and EP81N, respectively.

## 4. SELECTION OF PREDICTORS

Regression equations to predict tropical cyclone motion during periods of 12, 24, 36, 48 and 72 h were formulated for the two stratified data sets. A combination of subjective and objective steps was followed in selection of predictors to be retained in final regression equations. First, batchwise screening was done for various predictors computed from deep-layer mean geopotential heights surrounding the storm. Initial values, predicted values for each forecast time, averages over the various forecast periods, and predicted changes provided predictors of both meridional and zonal components of motion.

Because the grid used to extract these dependent data from analyses moves with the storm center, there are natural north-to-south variations in values of deep-layer means. In order to reduce such geographical variability in predictors, values were divided by standard deviations computed for 5° latitude-longitude zones. When a value fell within a zone, it was divided by the corresponding standard deviation shown in Fig. 3. These standard deviations were computed from 0-h values for the 755 storm cases in the dependent data. Because deep-layer means were expressed as departures from a climatological mean, division by standard deviations is similar to a standardization procedure described by Harris et al. (1963). Such standardized predictors were incorporated in regression equations for time periods of 36, 48 and 72 h.

At each step in the screening regression procedure, linear correlation coefficients relate predictors to the components of storm motion. Figs. 4 and 5 show linear correlation coefficients computed for deep-layer mean geopotential heights at the initial time and subsequent 24-h meridional and zonal components of motion, respectively. Positive (negative) values suggest that increasing (decreasing) values of the predictors are related to increasing values of northward or westward motion. When compared with linear correlations for 500-mb geopotential heights (Leftwich and Neumann, 1977), deep-layer means produced similar patterns with small increases in magnitudes of maxima and minima for both components of 24-h motion. Of importance for selection of predictors are the small variations seen in correlation coefficients in the two rows nearest the lower boundary of the grid. Constancy of values resulted from the method used to insert

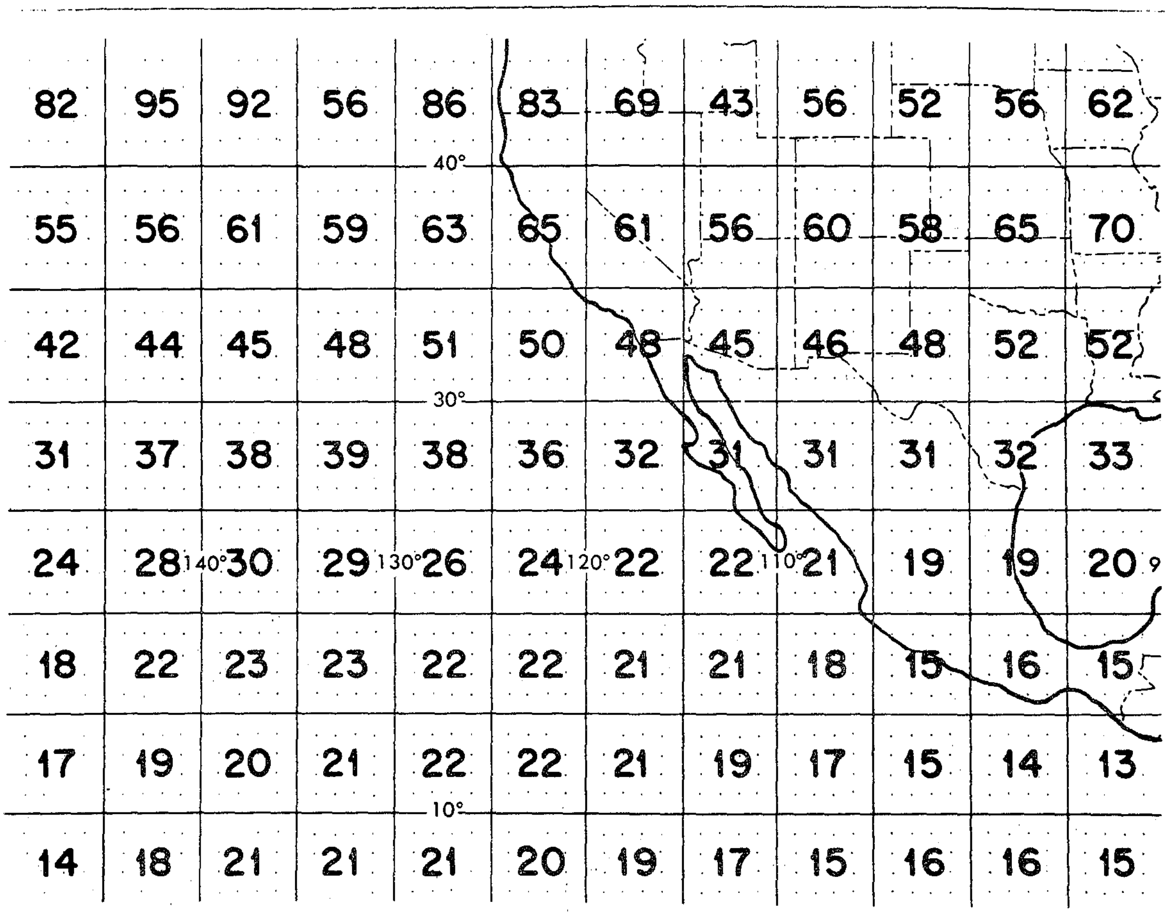


*Fig. 3. Standard deviations of deep-layer mean geopotential heights computed for 5° latitude-longitude zones. Values (m) are printed at the centers of the zones.*

values at grid locations for which deep-layer mean geopotential heights were missing in the originally compiled data. Because of this, restraint was exercised in retaining predictors from the southern two rows of the grid. Only one such predictor was retained, that being a predicted 36-h change at grid point 34.

In each screening regression procedure, both the number of available predictors and the independence of compiled cases were considered in determining the statistical significance of each selected predictor. The most significant predictors from each preliminary selection were then included as possible predictors in a final screening regression procedure. At this point, predictions from the EPCLPR model were offered as possible predictors at all time periods. No predictor was retained in the final set unless it contributed at least 1% to further reduction of variance. Inclusion of further predictors also ceased when the next predictor was subjectively judged to have little physical support, even though it contributed more than 1% to the reduction of variance.

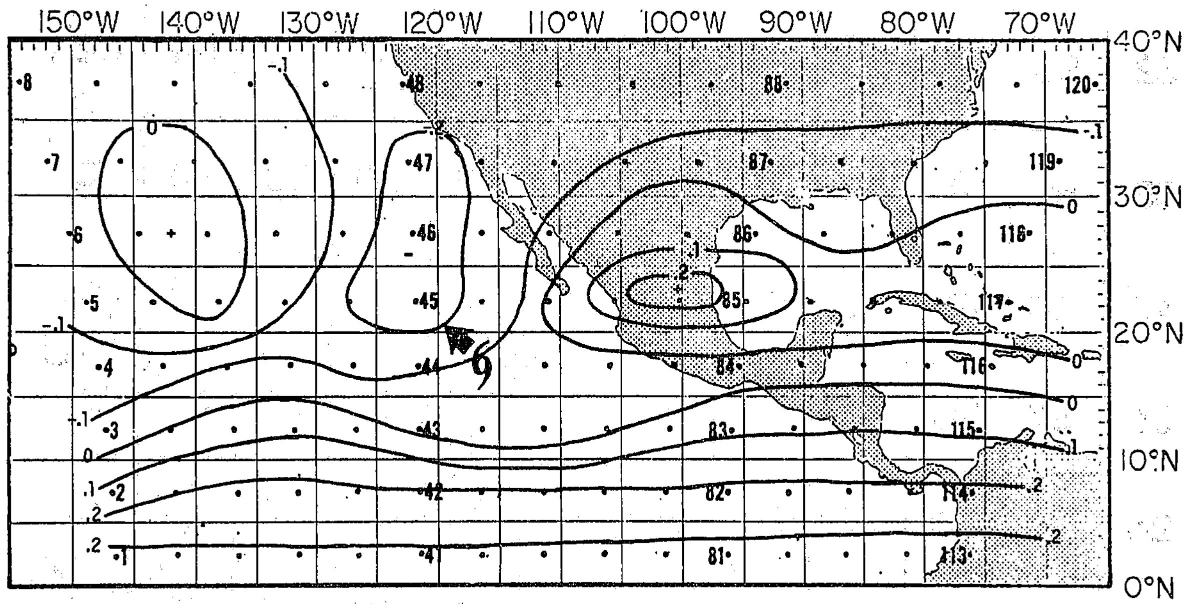


*Fig. 4. Linear correlation coefficient fields relating 24-h meridional tropical cyclone motion and initial deep-layer mean geopotential heights surrounding the storm. Background grid is the same as Fig. 2.*

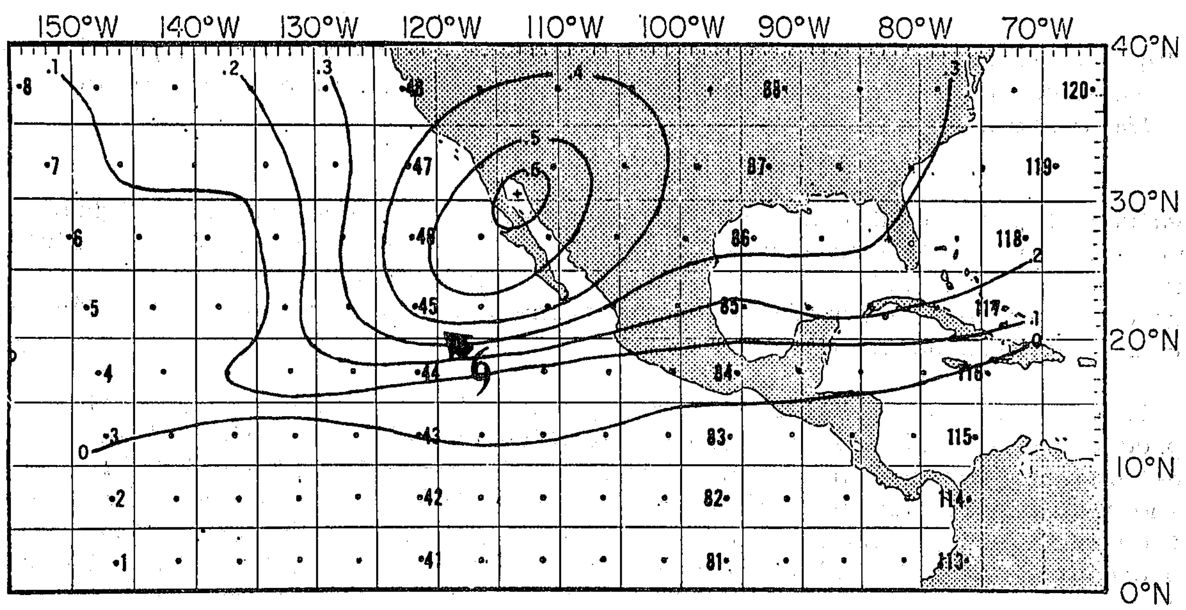


*Fig. 5. Same as Fig. 4, but for 24-h zonal tropical cyclone motion.*

Regression equations predict meridional ($y_j$) and zonal ($x_j$) displacements for each time period. Coefficients ($c_{i,j}$) were determined such that

$$y_j = c_{0j} + \Sigma c_{ij} \cdot p_{ij} \qquad i = 1, n_{ij};\ j = 1,5$$

$$\text{and} \qquad x_j = k_{0j} + \Sigma k_{ij} \cdot q_{ij} \qquad i = 1, m_{ij};\ j = 1,5. \tag{2}$$

Here, $c_{0j}$ ($k_{0j}$) are intercept values, $c_{ij}$ ($k_{ij}$) are regression coefficients, and $p_{ij}$ ($q_{ij}$) are retained predictors of meridional (zonal) displacements. Solutions of the above equations are given in nautical miles. Predicted displacements are then converted into predicted positions valid at the end of each forecast period. Table 1 lists predictors retained in each regression equation. An explanation of each of these predictors is given in the appendix.

## 5. TEST CASES

Two sets of cases were used to obtain comparisons of EPHC81 predictions with those of other objective models. First, preliminary tests were made with 24- and 72-h regression equations for cases from the 1979 season. Comparisons of mean prediction errors with those of EPCLPR for both westerly- (180°-315°) and northerly-moving storms are given in Table 2. For westerly-moving storms, mean 24-h errors were the same for both models. The mean for EPHC81 was lower at 72 h. Fewer cases were available for tests on northerly-moving storms. EPHC81 produced lower mean errors than EPCLPR for both periods. Although reductions of mean errors by 15% and 49% for 24 and 72 h, respectively, are substantial, one must view these carefully due to the small number of cases.

Table 3 contains mean prediction errors for EPCLPR, EPHC77 and EPHC81 for 30 cases from the 1980 tropical cyclone season. All of these cases had initial motions between 180° and 315°. EPHC81 showed noticeably lower errors at 12 and 72 h. There were small differences among values for the intermediate time periods. During past seasons, EPCLPR has performed well on cases such as these. Thus, long-term improvements (compared to EPCLPR) in 72-h mean prediction errors of around 10% would be the most expected on storms moving generally westward.

Fig. 6 shows predicted tracks from objective models and the observed track for Hurricane Kay from 0000 GMT, September 19, 1980. At this time, Kay was moving toward 280° at 16 knots with maximum sustained winds of 115 knots. Objective tracks from EPHC77, EPCLPR and EPHC81 are north of the best track after 72 h. EPHC81 had the best prediction of the zonal component of the storm's motion.

Slowness of statistical predictions for storms moving northwestward along the coast of Mexico was an initial motivation for consideration of prognostic data and stratification of cases. A 72-h prediction for such a case is shown in Fig. 7. At 1200 GMT on August 14, 1977, Tropical Storm Doreen was moving toward 300° at 5 knots and had maximum

*Table 1. Predictors retained in regression equations.*

| | Equation Set EP81W | | Equation Set EP81N | |
|---|---|---|---|---|
| | Meridional | Zonal | Meridional | Zonal |
| 12 h | 12MD | 24ZD | 12MD | 24ZD |
| | | 00VND080 | | |
| 24 h | 12MD | 24ZD | 36MD | 36ZD |
| | 24CND069 | 24VND053 | 24VND069 | 24VND013 |
| | | | 24MND045 | 24VND053 |
| | | | 24MND117 | 00VND078 |
| | | | | 00VND101 |
| 36 h | 36MD | 36ZD | 48MD | 48ZD |
| | 36VSD034 | 36VSD053 | 36CSD067 | 36VSD053 |
| | 36CSD068 | | | |
| | 36VSD096 | | | |
| 48 h | 48MD | 48ZD | 72MD | 48MSD045 |
| | 48CSD069 | 48MSD054 | 48VSD067 | 48MSD021 |
| | 48CSD055 | 48MSD006 | | |
| | | 48VSD084 | | |
| | | 48MSD053 | | |
| | | 48CSD084 | | |
| | | 48VSD080 | | |
| 72 h | 60MD | 72MSD053 | 48VSD069 | 72MSD062 |
| | 72MSD055 | 72MSD091 | 72MSD063 | 72MSD013 |
| | 72MSD014 | 00VSD014 | 72MSD006 | 48ZD |
| | 48CSD069 | 48VSD056 | 72MSD045 | |
| | 48CSD080 | | 00VSD055 | |
| 72 h from 1200 GMT | | | 72MD | 60MSD062 |
| | | | 60MSD076 | 60MSD045 |
| | | | 60MSD015 | 60MSD028 |
| | | | 60MSD045 | 60MSD084 |
| | | | 60MSD023 | 60MSD044 |

*Table 2. Mean prediction errors (nmi) from 1979 test cases.*

| | Westerly Storms | |
|---|---|---|
| Model | 24 h | 72 h |
| EPCLPR | 79 | 232 |
| EPHC81 | 79 | 192 |
| # Cases | 19 | 19 |
| | Northerly Storms | |
| Model | 24 h | 72 h |
| EPCLPR | 193 | 434 |
| EPHC81 | 163 | 221 |
| # Cases | 11 | 3 |

*Table 3. Mean prediction errors (nmi) from 1980 test cases. All values are for 30 cases.*

| Model | 12 h | 24 h | 36 h | 48 h | 72 h |
|---|---|---|---|---|---|
| EPCLPR | 50 | 98 | 134 | 172 | 262 |
| EPHC77 | 52 | 88 | 130 | 170 | 263 |
| EPHC81 | 42 | 91 | 132 | 166 | 241 |

sustained winds of 55 knots. Tracks predicted by EPHC77, EPANLG and EPCLPR as well as the observed track are also shown in Fig. 7. Here, the EPHC81 track followed the observed track more closely than the others after 24 h. In the future, EPHC81 is anticipated to show its maximum improvement in objective prediction skill for cases similar to this.

## 6. OPERATIONAL IMPLEMENTATION

EPHC81 will be run operationally with initial data from 0000 GMT and 1200 GMT. Initial data required will be the year, date, hour, storm name, positions 24 and 12 h ago, current position, current direction and speed of motion, and maximum sustained winds. All these data have been previously supplied by forecasters so no changes in procedure are necessary. The current direction of motion will be used to determine the appropriate set of prediction equations. EPCLPR predictions from this initial data will be computed internally. Initial and predicted geopotential heights needed to compute deep-layer means will be obtained from NMC operational files stored in the NWS computer system. Predicted geopotential fields will be those from the NMC operational spectral model.

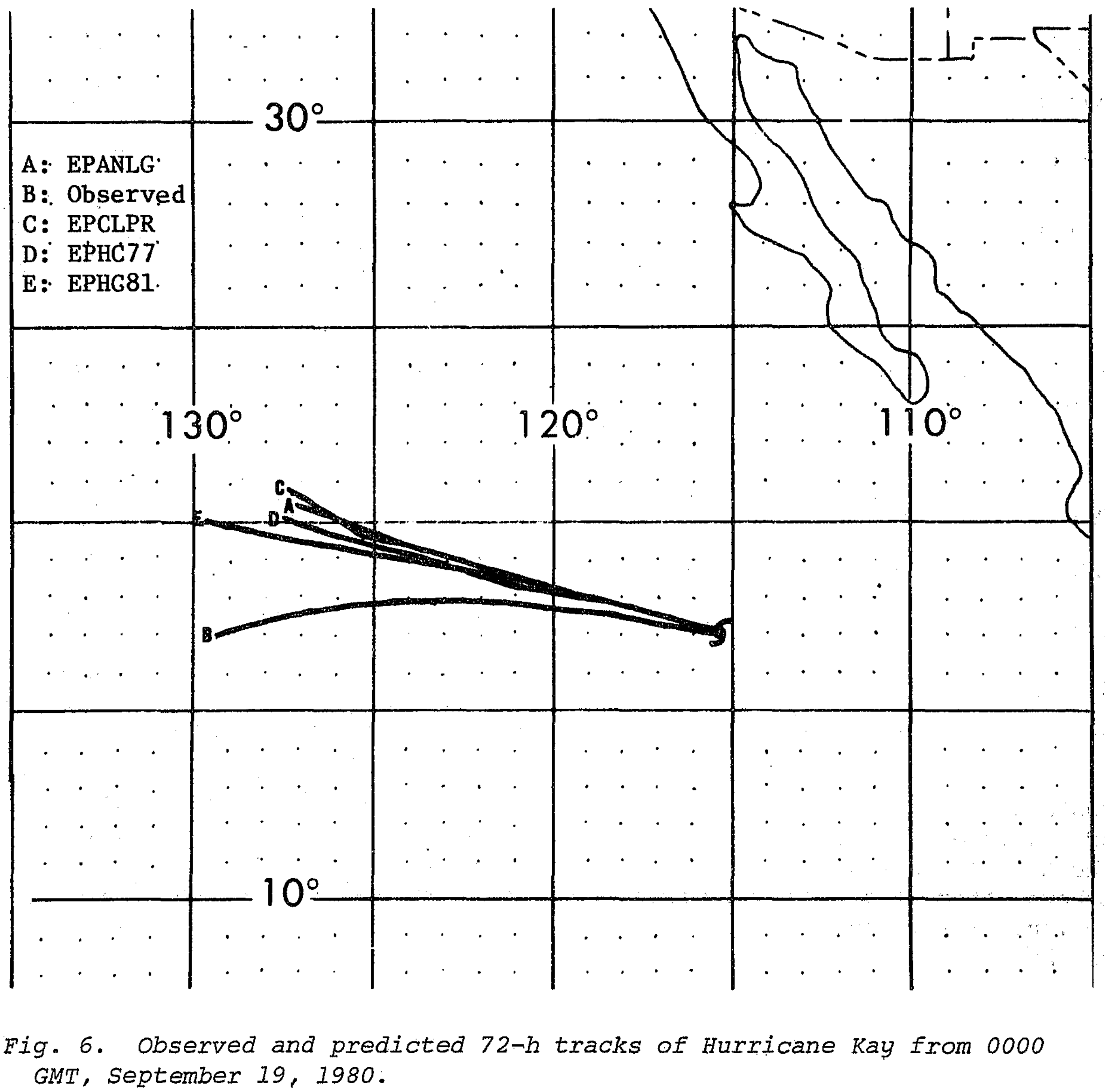


*Fig. 6. Observed and predicted 72-h tracks of Hurricane Kay from 0000 GMT, September 19, 1980.*

The operational computer program will run on the National Weather Service (NWS) IBM 360/195 computer system. Steps followed are depicted schematically in Fig. 8. First, EPCLPR predictions are made through combination of climatology and persistence. A detailed discussion of this model is given by Neumann and Leftwich (1977). Next, prognoses for ten levels of geopotential heights are collected. The initial motion is checked to determine which set of regression equations (EP81W or EP81N) should be used, and predictions are made for each forecast period.

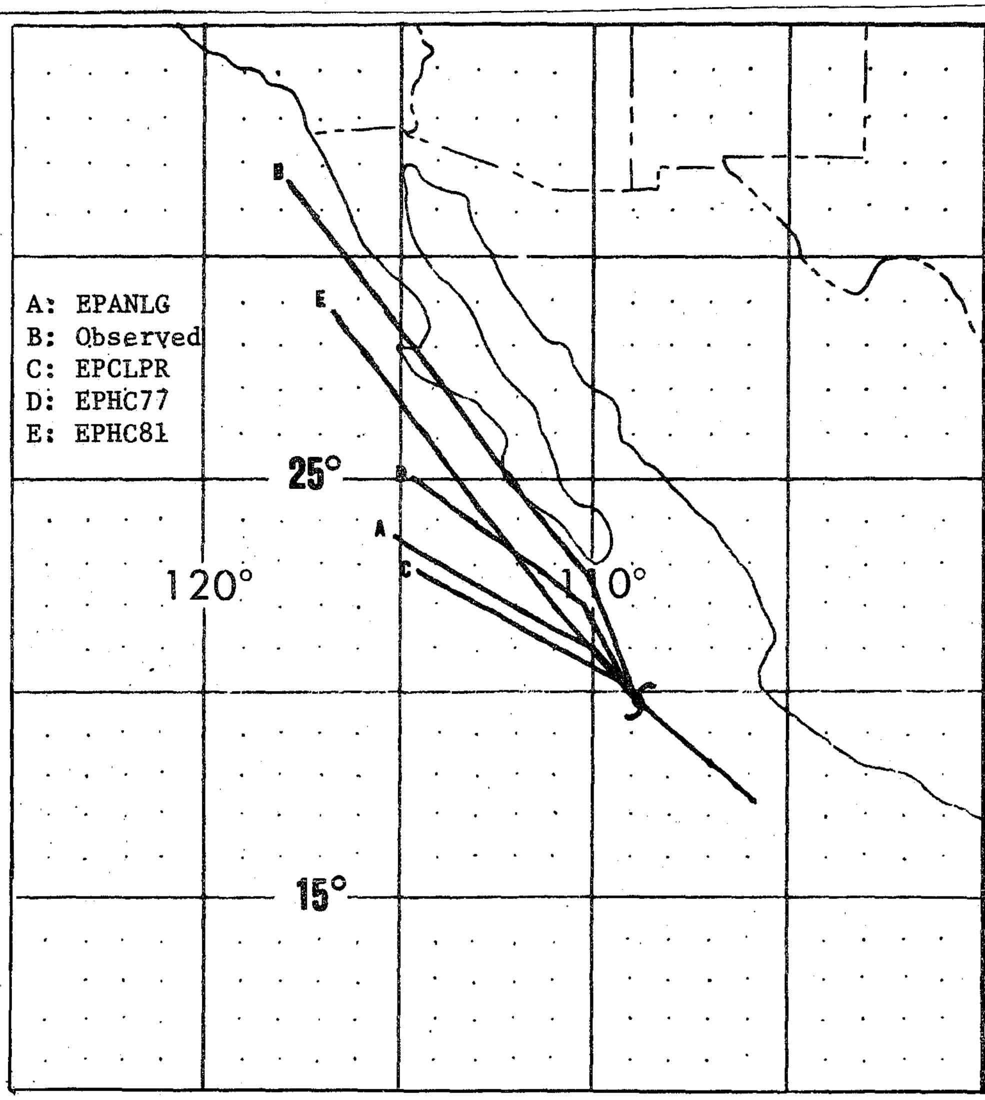


*Fig. 7. Observed and predicted 72-h tracks of Tropical Storm Doreen from 1200 GMT, August 14, 1977.*

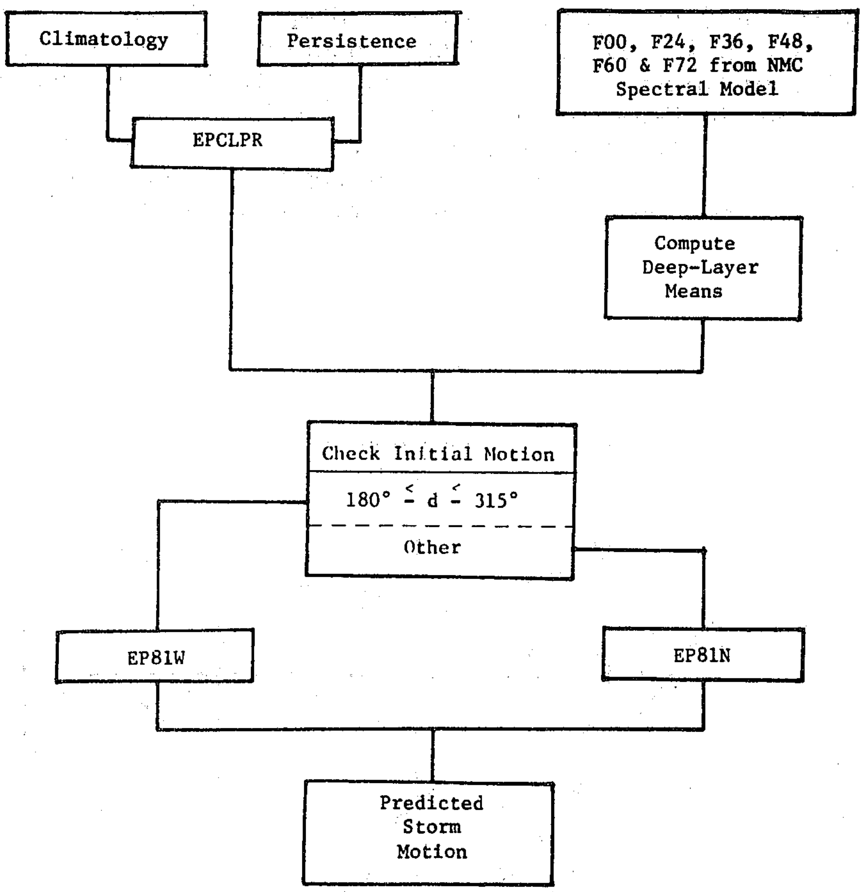


*Fig. 8. Schematic of EPHC81 operational procedure.*

Predicted tracks are disseminated via NWS teletypewriter, KCRT, and Automated Field Operations System (AFOS) communication systems. An example of the message format is given in Fig. 9. These messages include initial and predicted positions for periods up to 72h, current direction and speed of motion, and current maximum sustained winds.

Because operational files of geopotential heights do not contain ten levels of data for +72 h from 1200 GMT, values from +60 h prognoses are used. Regression tests with both +60 h and +72 h deep-layer means allowed replacement of +72 h values by +60 h values in the original regression equations for storms using the EP81W set. Entirely new regression equations were formulated for EP81N 72 h predictions from 1200 GMT.

A question which arises in operational implementation is the location of the storm-centered data grid at forecast times. In this model, the EPCLPR position for each forecast time is used to center the grid. Although this location will be in error, it will always be available and location errors, even at 72 h, will typically be less than one grid length.

THIS IS A PRIORITY MESSAGE...RUSH...
TO MIC WSFO SAN FRANCISCO CALIF.
EPHC81 TROPICAL CYCLONE FORECAST

TESTTESTTEST

DATE 0000Z 20 JUN 1981
FOR WSFO SAN FRANCISCO USE ONLY

| | LAT | LON | VALID AT |
|---|---|---|---|
| INITIAL | 14.0N | 108.4W | 6/20/0000Z |
| 12 HOUR | 14.1N | 109.8W | 6/20/1200Z |
| 24 HOUR | 14.2N | 111.2W | 6/21/0000Z |
| 36 HOUR | 14.8N | 113.3W | 6/21/1200Z |
| 48 HOUR | 16.8N | 114.3W | 6/22/0000Z |
| 72 HOUR | 18.8N | 110.0W | 6/23/0000Z |

CURRENT MAX WIND 35KTS. INIT MOTION 270/10

*Fig. 9. Example of KCRT and teletype message format for EPHC81 predictions.*

Any errors in predicted geopotential heights or changes in statistical characteristics of fields from those of dependent data will lessen the predictive skill of EPHC81. Preliminary tests have been satisfactory, but performance of the model must be observed over a lengthy period before either positive or negative effects of the NMC spectral model on EPHC81 can be determined.

Stratification according to initial motion is helpful in better modeling of statistical characteristics of the two subsets. However, changeover from one set of equations to another can lead to sudden changes in predicted storm track when successive initial motions fall in different classifications. An example of such a case is shown in Fig. 10 for Hurricane Dolores on July 20, 1979. At 0000 GMT, initial motion was 295° at 7 knots and at 1200 GMT, the initial motion was 320° at 8 knots. A turn to a more northerly track was predicted by EPHC81 in both cases while EPCLPR predicted a more westerly track. In this case EPHC81 produced a better forecast track. When the initial motion is north of 315°, EPHC81 will characteristically move the storm more to the north at an increased speed. If the storm is increasingly influenced by the westerlies, this model characteristic is advantageous, otherwise it may not be. If motion is close to 315°, a small error in determination of initial motion may lead to use of the less desirable set of equations. This emphasizes the need for careful estimation of the initial motion given as input to this model.

Because EPHC81 must await the completion of 72-h predictions from the operational spectral model, guidance from EPHC81 will not be available to the operational forecaster until approximately seven hours after the time of initial data. This is a disadvantage operationally. Hopefully, this will be offset by advantages discussed earlier. Future work considering use of data from the previous data cycle is anticipated.

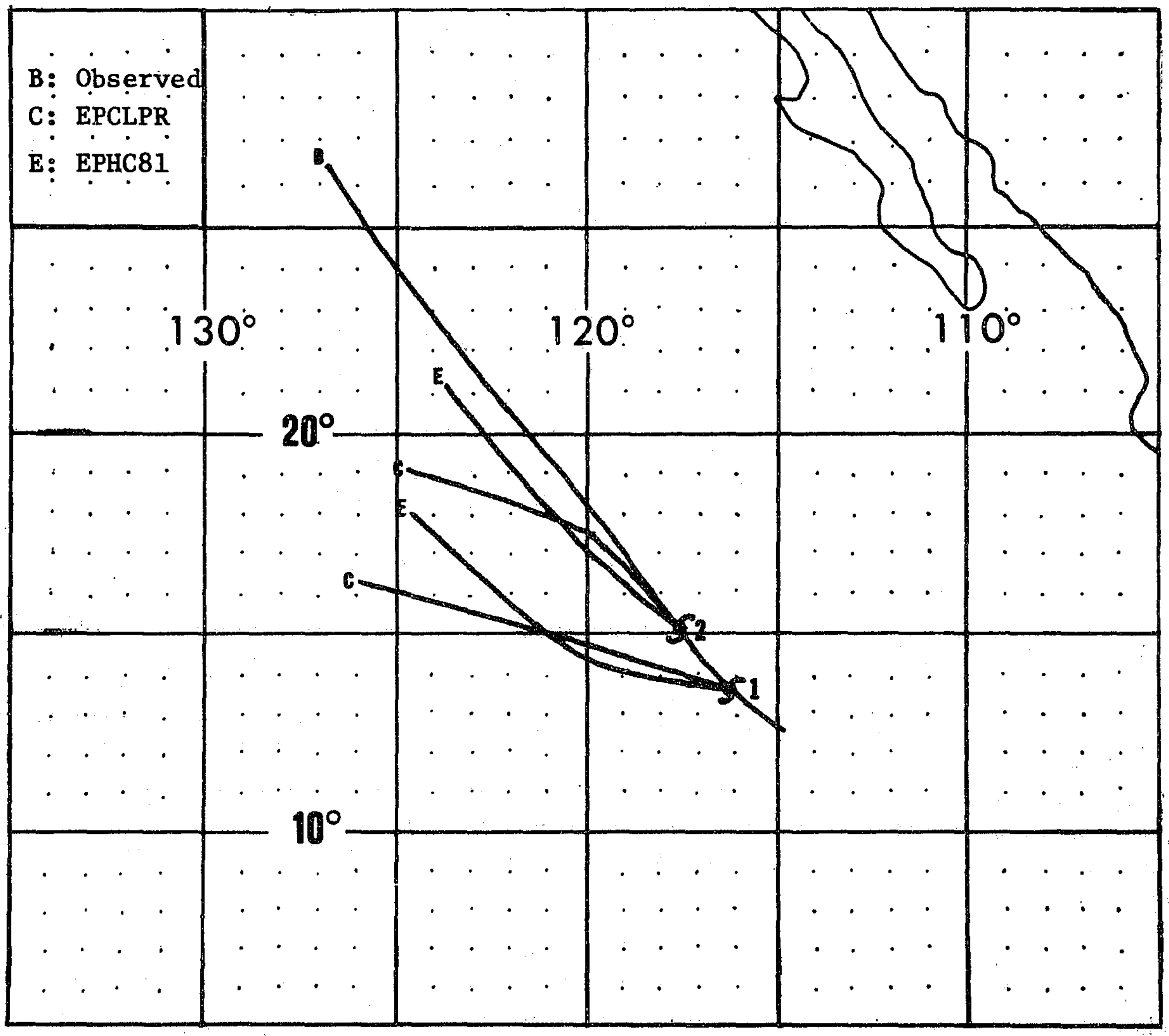


*Fig. 10. Comparative 72-h tracks predicted by EPCLPR (C) and EPHC81 (E) for Hurricane Dolores from 0000 GMT (1) and 1200 GMT (2), July 20, 1979. Observed track is denoted by B.*

## 7. SUMMARY AND FINAL COMMENTS

A statistical-dynamical model has been developed to provide guidance to the operational forecaster concerned with prediction of tropical cyclone motion in the Eastern North Pacific Ocean. This model provides the initial use of deep-layer mean geopotential heights as predictors of tropical cyclone motion.

Predictions of motion for periods up to 72 h are obtained via regression equations. Selection of an appropriate set of prediction equations is determined from the specified initial direction of motion of the storm. After predictions are made they are transmitted to both the EPHC and the NHC.

Performance of this model will be monitored during the current tropical cyclone season. Any needed modifications will be made. Verification will be utilized in future refinements of this model.


## ACKNOWLEDGMENTS

The author thanks Charles J. Neumann, Chief, NHC R&D Unit for guidance during this project. Barry Damiano performed computer programming for both development and operational implementation of the model. Judy Kraus provided technical assistance for production of this report.


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## APPENDIX I. EXPLANATION OF PREDICTORS

Table 1 contains coded predictors retained in the regression equations of EPHC81. The codes shown for both sets of equations, EP81W and EP81N, follow the general formats described below.

A. Predictors from EPCLPR forecasts:

hhdd

hh: length of forecast period in hours

dd: MD = meridional displacement
ZD = zonal displacement

Ex: 48ZD is the +48 h zonal displacement from EPCLPR.

B. Predictors derived from deep-layer mean geopotential heights.

hhabcxxx

hh: length of forecast period in hours; 00 refers to initial time

a: M = mean predicted value over forecast period
C = predicted change over forecast period
V = value valid at end of forecast period

b: S = standardized (see text)
N = nonstandardized

c: D = departure from climatological mean
A = actual value

xxx: grid point number from 120-point data grid (Fig. 2)

Ex: 60MSD045 is the mean standardized departure of predicted deep-layer mean over the 60-h forecast period at grid point 45.

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