NOAA Technical Memorandum NWS NHC 28

A STATISTICAL MODEL FOR THE PREDICTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONE MOTION (WPCLPR)

Yiming Xu
Shanghai Typhoon Institute
People's Republic of China

Charles J. Neumann
National Hurricane Center
Miami, Florida

National Hurricane Center
Miami, Florida
November 1985

UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
John V. Byrne, Administrator

National Weather Service
Richard E. Hallgren, Director

NOAA TECHNICAL MEMORANDA

NATIONAL WEATHER SERVICE, NATIONAL HURRICANE CENTER SUBSERIES

The National Weather Service National Hurricane Center (NHC) subseries provides an informal medium for the documentation and quick dissemination of results not appropriate, or not yet ready, for formal publication. The series is used to report on work in progress, to describe technical procedures and practices, or to relate progress to a limited audience and hence will not be widely distributed.

Technical Memoranda originated at the National Hurricane Center prior to the establishment of this series are listed below. They were published as ESSA Technical Memoranda, Southern Region (SRTM); ESSA Technical Memoranda, WBTM; or NOAA Technical Memoranda, NWS.

Beginning with WBTM SR 38, the papers are available from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22151. Price $2.75 per copy; $1.45 microfiche. Order by accession number shown in parenthesis at end of each entry.

ESSA Technical Memoranda

SRTM 28 The Weather Distribution with Upper Tropospheric Cold Lows in the Tropics. Neil L. Frank - September 1966

WBTM SR 38 Florida Hurricanes. Gordon E. Dunn and Staff NHC - November 1967 (PB 182 220)

WBTM SR 42 Memorable Hurricanes of the United States Since 1873. Arnold L. Sugg and Robert L. Carrodus - January 1969 (PB 182 228)

WBTM SR 44 Climatology of Atlantic Tropical Cyclones by Two and One-Half Degree Latitude-Longitude Boxes. John R. Hope and Charles J. Neumann - February 1969 (PB 183 308)

WBTM SR 45 On the Maximum Sustained Winds Occurring in Atlantic Hurricanes. Charles Holliday - May 1969 (PB 184 609)

WBTM SR 46 Hemispheric Circulation and Anomaly Patterns Observed When Tropical Storms Reach Hurricane Intensity. Paul J. Hebert, NHC and Banner I. Miller, NHRL - May 1969 (PB 184 610)

WBTM SR 47 Disturbances in the Tropical and Equatorial Atlantic. R. H. Simpson - June 1969 (PB 184 740)

WBTM SR 49 A Mean Storm Surge Profile. Arnold L. Sugg - December 1969 (PB 188 422)

WBTM SR 50 A Reassessment of the Hurricane Prediction Problem. Robert H. Simpson - February 1970 (PB 189 846)

WBTM SR 51 The Satellite Applications Section of the National Hurricane Center. R. H. Simpson and D. C. Gaby - September 1970 (COM 71 00005)

NOAA Technical Memoranda NWS

NWS SR 53 The Decision Process in Hurricane Forecasting. R. H. Simpson - January 1971 (COM 71 00336)

NWS SR 55 Digitized Atlantic Tropical Cyclone Tracks. John R. Hope and Charles J. Neumann - February 1971 (COM 71 00984)

NWS SR 56 Memorable Hurricanes of the United States Since 1873. Arnold Sugg, Leonard G. Pardue and Robert L. Carrodus - April 1971 (COM 71 00610)

NWS SR 58 Atlantic Hurricane Frequencies Along the U. S. Coastline. R. H. Simpson and Miles B. Lawrence - June 1971 (COM 71 00796)

NWS SR 62 An Alternate to the HURRAN (Hurricane Analog) Tropical Cyclone Forecast System. Charles J. Neumann - January 1972 (COM 72 10351)

NWS SR 63 A Statistical Method of Combining Synoptic and Empirical Tropical Cyclone Prediction Systems. Charles J. Neumann, John R. Hope and Banner I. Miller - May 1972 (COM 72 10553)

NWS SR 69 Statistical-Dynamical Prediction of Tropical Cyclone Motion. Charles J. Neumann and Miles B. Lawrence - April 1973 (COM 73 10728)

NWS SR 71 A Decision Procedure for Application in Predicting the Landfall of Hurricanes. R. H. Simpson and Brian R. Jarvinen - August 1973 (COM 73-11663/AS)

NWS SR 72 Objective Analysis of the Sea Surface Temperature. Brian R. Jarvinen - August 1973 (COM 73-11643)

NWS SR 81 The Effect of Initial Data Uncertainties on the Performance of Statistical Tropical Cyclone Prediction Models. Charles J. Neumann - March 1975 (COM 75-10483/AS)

NWS SR 82 A Statistical Study of Tropical Cyclone Positioning Errors with Economic Applications. Charles J. Neumann - March 1975 (COM 75-11362/AS)

NWS SR 83 A Satellite Classification Technique for Subtropical Cyclones. Paul J. Hebert and Kenneth O. Poteat - July 1975 (COM 75-11220/AS)

NWS NHC 1 Annual Data and Verification Tabulation of Atlantic Tropical Cyclones 1974. John R. Hope and Staff, NHC - January 1976 (PB285261/AS)

NWS NHC 2 Annual Data and Verification Tabulation - Atlantic Tropical Cyclones 1975. Paul J. Hebert and Staff, NHC - January 1977 (PB285263/AS)

NWS NHC 3 Intensification Criteria for Tropical Depressions in the Western North Atlantic. Paul J. Hebert - April 1977 (PB285415/AS)

NWS NHC 4 Annual Data and Verification Tabulation of Atlantic Tropical Cyclones 1976. Paul J. Hebert and Staff, NHC - May 1977 (PB285262/AS)

NWS NHC 5 Atlantic Tropical Cyclone Tracks by 5-, 10-, 15-, and 30-Day Periods. Brian J. Jarvinen and Charles J. Neumann - May 1978 (PB284009/AS)

CONTENTS

A STATISTICAL MODEL FOR THE PREDICTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONE MOTION (WPCLPR)

Yiming Xu[1]
Shanghai Typhoon Institute
People's Republic of China

and

Charles J. Neumann
National Hurricane Center
Coral Gables, Florida 33146

ABSTRACT

The derivation, implementation and operational utility of a new statistical model for the prediction of western North Pacific tropical cyclone motion is described. The model uses regression equations to forecast tropical cyclone motion through 72h and incorporates predictors derived from climatology, persistence, and storm intensity. It is patterned after models that were developed for most of the other tropical cyclone basins. In addition to its usefulness for operational prediction, the model provides a convenient threshold skill level for evaluating the performance of other, more sophisticated models.

Developmental data consisted of western Pacific tropical cyclone tracks and associated storm intensities for 1946 through 1980. The model was tested on independent data for 1981 and 1982 and on operational data for 1983 and 1984.

1. INTRODUCTION

This report documents a recently developed statistical model (WPCLPR) for the prediction of western North Pacific (WESPAC) tropical cyclone motion. The prediction scheme is based on a series of regression equations. The predictors are derived from climatology (the location of a storm and time of year), persistence (average storm motion over the past 12 and 24h) and storm intensity (maximum sustained surface wind). Predictors derived from analyzed fields of environmental data (winds or geopotential heights) have explicitly been omitted. Predictands are the meridional (north/south) and zonal (east/west) components of tropical cyclone motion in 12-h increments through 72h.

---

[1]Research accomplished while on temporary assignment to the National Hurricane Center.

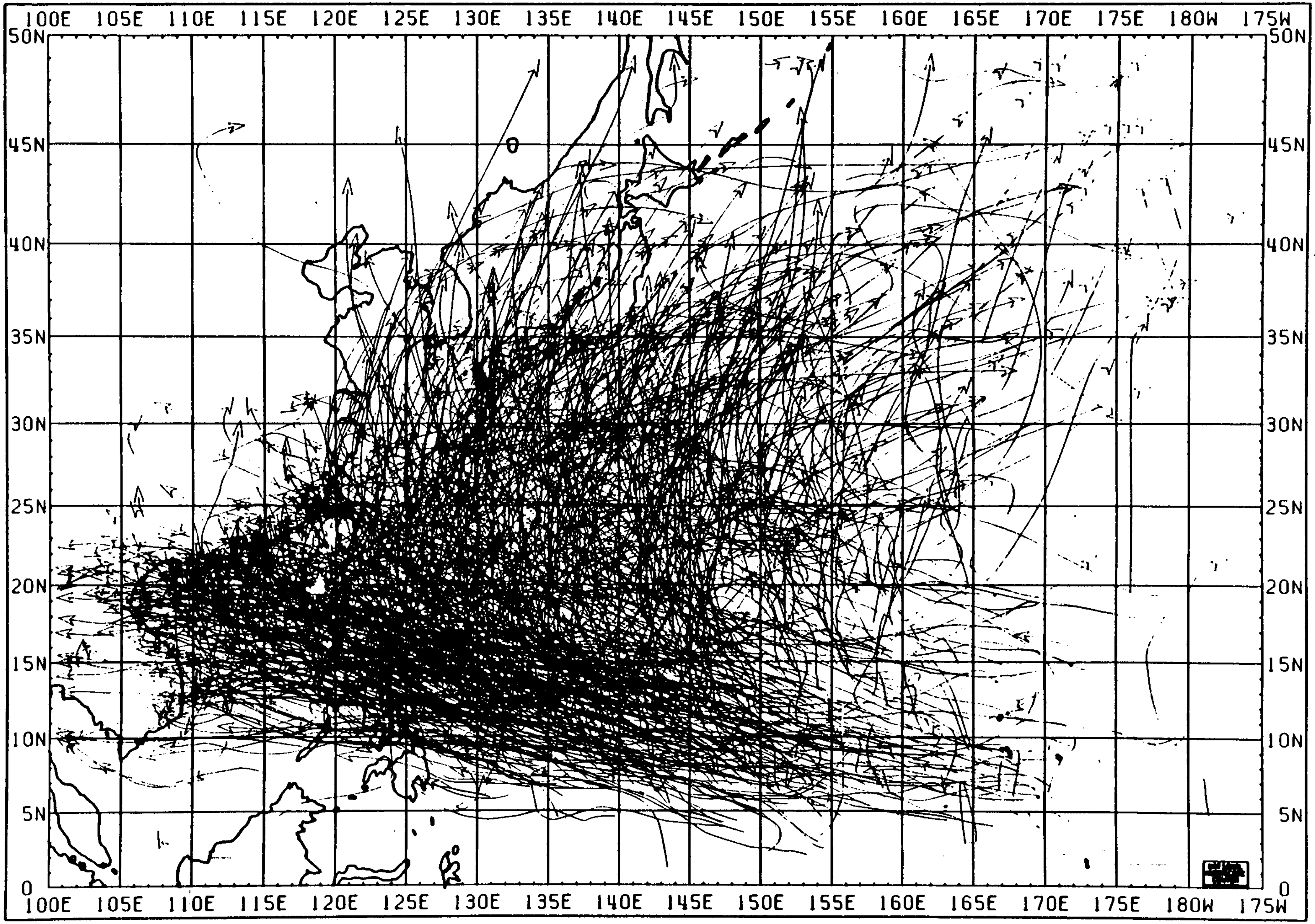

Figure 1. Tracks of the 873 western North Pacific tropical storms and typhoons, 1946-1980. These storms were used as dependent data.

This type of model, commonly referred to as a "CLIPER-class" model, has been used for several years in other basins and is well-documented in the literature. References to the other basins include: Neumann (1972) for the Atlantic; Neumann and Randrianarison (1976) for the southwest Indian Ocean; Neumann and Leftwich (1977) for the eastern North Pacific; and Neumann and Mandal (1978) for the North Indian Basin. Because of this rather extensive documentation, only those aspects of the model unique to WESPAC are described here.

2. DEVELOPMENTAL DATA

2.1 Historical Storm Tracks

Developmental data consist of the best tracks[2] of all recorded western North Pacific tropical cyclones over the 35-y period 1946-1980. This data set (through 1975) originally had been obtained from the NOAA National Climatic Center, Asheville, North Carolina (tropical cyclone deck 993). Included were storm positions for every 12h and maximum winds for most storms. This original data set was extensively supplemented by storm positions and maximum winds at 6-hourly intervals as obtained from WESPAC storm summaries that are published annually by the Joint Typhoon Warning Center on Guam (for example, Annual Tropical Cyclone Report, 1984). Also, some missing storm intensities for the earlier years were obtained from records maintained by the People's Republic of China (Central Meteorological Bureau, 1972). The final data set, beginning in 1946, consists of storm positions and intensities at 6-hourly intervals. Through 1980, 873 storms are documented; these are depicted in Figure 1. The latter plot of storm tracks led to spatial bounds of the model being set at 5°-35°N latitude and west of 150°E longitude.

In the temporal sense, cases were excluded if they occurred before 15 May or after 15 December. As shown in Figure 2, this 8-month period comprises the bulk of the WESPAC season. Activating the program outside of these spatial and temporal bounds is not advised. Indeed, the recommended computer program to run the model (appendix) disallows running the program outside of these temporal bounds or if a storm is initially beyond 35°N latitude. The developmental data set also excluded all systems having maximum intensity of < 34 kt. Storms in existence for < 36h are also inherently excluded from the developmental data set in that there is a requirement for past positions through at least -24h and a future storm position through at least +12h.

Storms that occurred in 1981 and 1982 were reserved for testing of the model in an independent data mode and the model, developed early in 1983, was subsequently tested in an operational mode for 1983 and 1984. Storms that occurred during these latter 2-y periods are shown in Figures 3 and 4.

The 1946-1980 developmental data set is large enough (5,410 cases at 12h to 2,788 cases at 72h) that, even allowing for lost degrees of freedom through serial correlation, the classical significance testing exercise could probably

---

[2]The best track is the accepted track of a storm after a post-analysis of all available data.

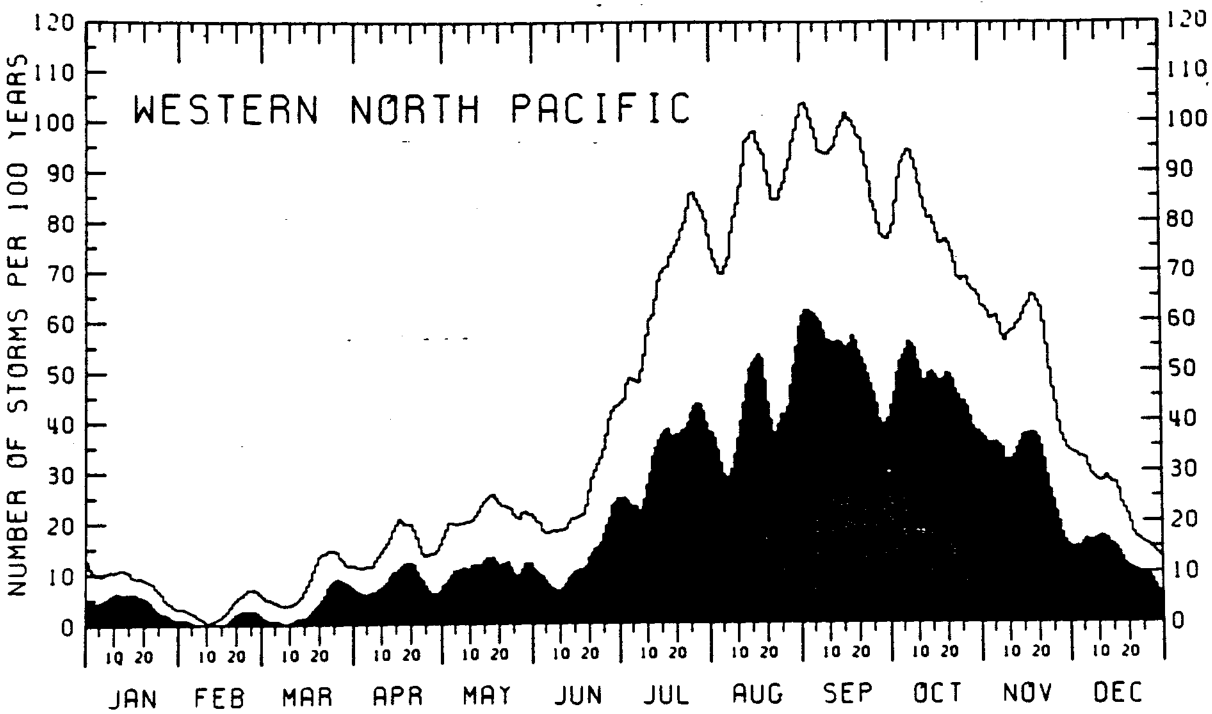

Figure 2. Daily frequency of typhoons (shaded area) and tropical storms and typhoons combined (nonshaded area) per 100 years based on the 39-year period 1946-1984. Data have been smoothed over 9-day period. Mean number of days per year with tropical storms or typhoons is 149.5. Mean number of days per year with typhoons alone is 79.9.

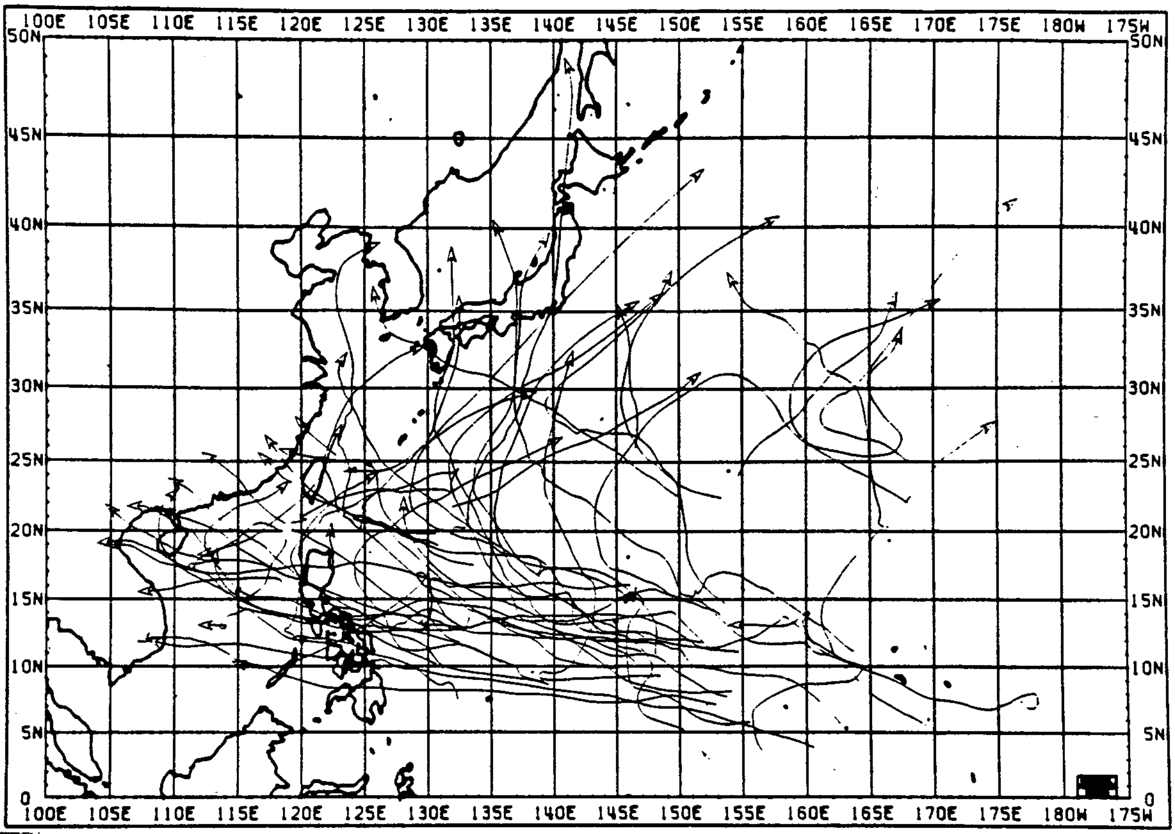

Figure 3. Tracks of the 54 western North Pacific tropical storms and typhoons, 1981-1982. These storms were used as independent data.

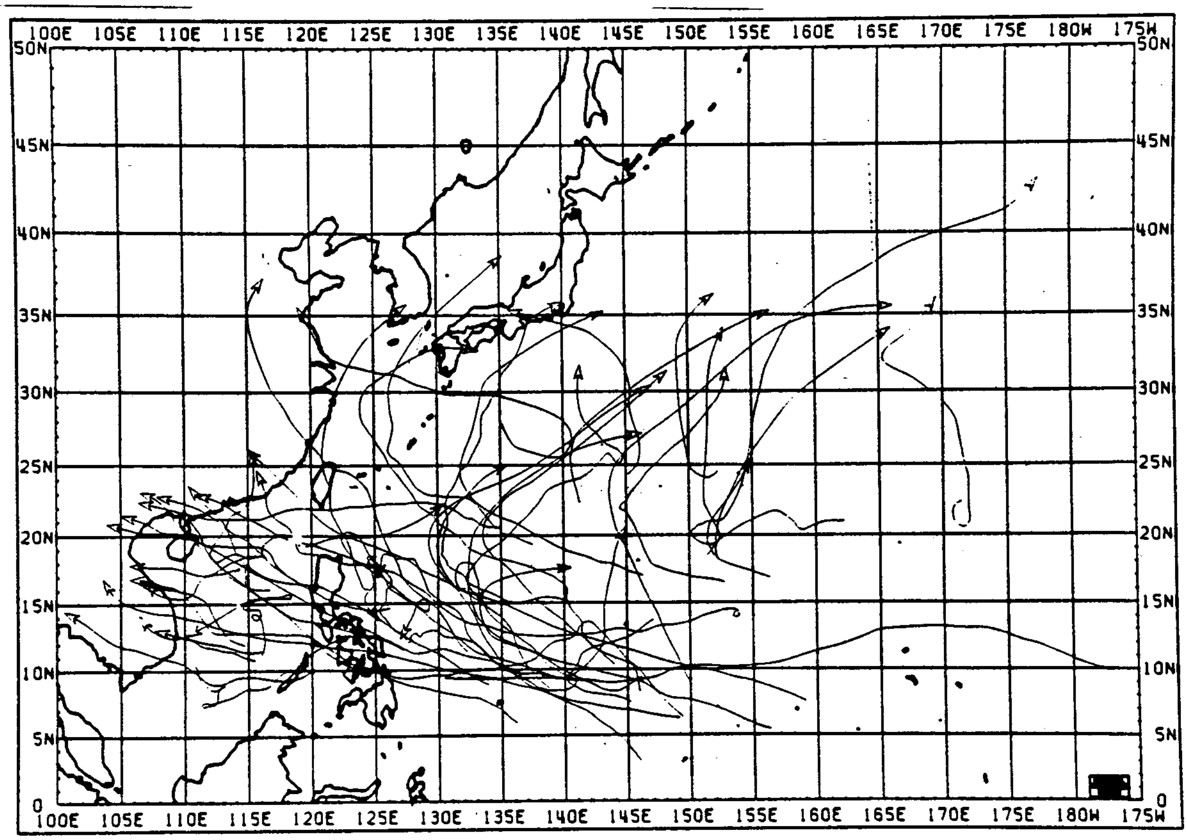

Figure 4. Tracks of the 50 western North Pacific tropical storms and typhoons, 1983-1984. These storms were used in operational testing of program.

have been omitted and the 1981 and 1982 storms profitably could have been added to the developmental data. This option was considered, but not adopted.

2.2 Definition of Predictors/Predictands

From the basic developmental data set, 8 first-order predictors can be defined. These are: initial storm latitude, initial storm longitude, time of year (Julian day number), average meridional translational speed over past 12h, average zonal speed over past 12h, average meridional storm translational speed over past 24h, average zonal storm translational speed over past 24h and initial storm intensity. The assumption is made that each of the orthogonal components of projected motion (Y_t) is a function of these 8 predictors,

$$Y_t = f(P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8). \quad (1)$$

When we developed CLIPER-class models for other basins, the above function was taken as a second- or third-order polynomial, with the order being determined by the size of the developmental data set and the geometric complexity of the basin. The very large data set available here and the parabolic nature of the tracks over WESPAC justify the use of a third-order polynomial. The number of possible predictors (excluding the "intercept" value) in the polynomial expansion of (1) is given by

$$T = (m+n)!/(m!n!) - 1, \quad (2)$$

where n is the order of the polynomial and m is the number of basic predictors. From (2), it follows that the third-order polynomial, including the intercept value, will contain 165 terms. Accordingly, a master data file was structured, and contained, for each case, the 12 predictands (storm meridional and zonal motion displacements for 12, 24, 36, 48, 60 and 72h) and the 164 potential predictors. The additional predictors, 9 through 164, can be generated by considering all possible products and cross products of the 8 basic predictors. These are identified in the FORTRAN program listing beginning on page 22. The predictor indexing, however, is somewhat different in the program from that just described.

3. PREDICTOR SELECTION

Experience from the development of other CLIPER-class models led to a modified procedure to determine which of the 164 potential predictors were to be retained in the final prediction equations. Typically, predictors are systematically selected until the incremental variance reduction drops below some preset value, often taken as 1 or 1/2%. The problem with this classical approach in the development of CLIPER-class models is that some predictors, which may be working in combination (as is often the case in nth-order polynomials), may be overlooked in the screening process. Another, even more serious, problem is that predictor selection from one period to another is done independently. This gives rise to the generation of meandering tracks that impart a certain degree of skepticism to the forecast.

To alleviate these problems, 20 "best" predictors were selected for each of the 12 regression equations (meridional and zonal components for each of six forecast periods). Trial-and-error screening runs suggested that this retention of 20 predictors was about optimal in assuring that all predictors acting in combination were selected. There were some differences here, depending upon projection or component, but, in the interest of simplicity, these differences were ignored. In this connection, the large sample size guarantees that if worthless predictors are included in the program, the partial correlations and, thus, the regression coefficients, will be near zero.

Next, we searched for predictors that were used at least once for any of the six meridional time periods, 12 through 72h. As a result, we obtained 32 of the 164 possible predictors. This sorting was also carried out for zonal motion and, coincidentally, 32 predictors (not necessarily the same ones) were identified. To avoid the meandering track problem referred to earlier, the program was structured about these 32 predictors.

The general form of the prediction equations is:

$$D = C_o + \sum_{i=1}^{i=32} C_i P_i, \tag{3}$$

where D is an orthogonal (zonal or meridional) displacement component at a given period, C_0 is the intercept value and C_i is the 32 regression coefficients corresponding to the 32 predictors P_i for that given forecast period and orthogonal component.

The specific predictors and regression coefficients can be identified from the data cards following the FORTRAN program listing given in the appendix (beginning on page 28). The predictand/predictor numbering convention in the program is:

P_1 and P_2 are the forecast meridional and zonal displacements in nautical miles (predictands) for each of the six projections, 12 through 72h.

P_3 is the initial storm latitude.

P_4 is the initial storm longitude.

P_5 is the current Julian day number.

P_6 is the average meridional speed (knots) over the past 12h.[3]

---

[3] It was intended that P_6 and P_7 be in knots. However, through oversight, the equations were derived using 1/2 of this amount. Compensation for this oversight is included in the program definition of P_6 and P_7 and is transparent to the user.

P_7 is the average zonal speed (knots) over the past 12h.

P_8 is the average meridional speed (knots) over the past 24h.

P_9 is the average zonal speed (knots) over the past 24h.

P_{10} is the storm intensity in knots.

P_{11} through P_{166} are additional predictors generated by the cubic products and cross products of P_3 through P_{10}.

It can be noted in the data cards that specify the predictors and regression coefficients that there are 12 nine-card sets of 32 predictor numbers and associated regression coefficients, each preceded by an intercept value. These 12 sets are in the order 12h meridional, 12h zonal, 24h meridional...72h zonal. For example, the intercept value for 12h meridional motion is 82.43, while the first predictor is number 29 and the associated regression coefficient is 0.1673843. As noted on page 25, predictor number 29 is defined as the product of P_4 and P_6 or the product of initial storm longitude and average meridional speed over the past 12h. These predictor/ regression coefficient sets are listed in the order that they were selected in the screening program. In the example under discussion, subsequent predictor numbers are 141, 154, 113, 133, etc.

For each of the 12 prediction equations, the first and most important predictor turned out to be a function of average motion over the past 12h. This characteristic points out the importance of the persistence factor in the prediction scheme and, as discussed in section 6, great care must be exercised in determing this motion.

4. PERFORMANCE ON DEPENDENT, INDEPENDENT, AND OPERATIONAL DATA

Tables 1 and 2 depict, respectively, the performance of the model on dependent and independent data. The dependent data forecast errors are somewhat greater for the short-term projections and somewhat less for the long-term projections than for the Atlantic counterpart of the model (Neumann, 1972). Comparison with still other basins shows that the WESPAC dependent data errors are higher for all periods. The explanation here is probably related to the degrees of forecast difficulty one encounters in going from one basin to another or to parts of the same basin. The concept is discussed by Pike (1985).

Comparison of Table 1 with Table 2 shows, for the most part, that the model performed better on the 2-y independent sample than on the 35-y developmental data set. Typically, the reverse is true. For example, in structuring a CLIPER-class model for the southwest Indian Ocean, Neumann and Randrianarison (1976) found about a 20% increase in forecast error when running the model on an independent sample. The explanation probably lies partially in that the data set used in developing WPCLPR was unusually large. Also, the sample of storms used to test the model for 1981 and 1982 (Figure 3) showed more adherence than normal to persistence and climatology.

Table 1. Performance of the model on best-track independent data. Period of record is 1946-1980. Errors are in n.mi. (km).

Forecast period (hours)	Component	Sample size	Multiple corr. coef.	Standard error	Forecast error
12	Meridional	5410	0.92	40.6 (78.9)	44.0 (85.5)
	Zonal		0.83	37.3 (72.5)	
24	Meridional	4894	0.90	88.8 (172.5)	97.5 (189.4)
	Zonal		0.78	80.5 (156.4)	
36	Meridional	4342	0.87	144.4 (280.5)	157.7 (306.3)
	Zonal		0.72	127.2 (247.1)	
48	Meridional	3784	0.83	205.5 (399.2)	219.7 (426.8)
	Zonal		0.65	172.1 (334.3)	
60	Meridional	3276	0.80	267.7 (520.0)	278.1 (540.2)
	Zonal		0.60	210.7 (409.3)	
72	Meridional	2788	0.76	328.2 (637.5)	334.9 (650.6)
	Zonal		0.56	244.9 (475.7)	

Table 2. Performance of the model on best-track independent data. Period of record is 1981-1982. Errors are in n.mi. (km).

Forecast period (hours)	Component	Sample size	Multiple corr. coef.	Standard error	Forecast error
12	Meridional	353	0.94	34.7 (67.4)	39.3 (76.3)
	Zonal		0.86	33.2 (64.5)	
24	Meridional	317	0.91	77.1 (149.8)	88.7 (172.3)
	Zonal		0.77	77.4 (150.4)	
36	Meridional	281	0.87	128.8 (250.2)	144.6 (280.9)
	Zonal		0.67	121.1 (235.2)	
48	Meridional	250	0.83	185.8 (360.9)	205.5 (399.2)
	Zonal		0.59	163.2 (317.0)	
60	Meridional	217	0.76	256.3 (497.9)	270.8 (526.0)
	Zonal		0.52	203.2 (394.7)	
72	Meridional	186	0.69	327.9 (637.0)	337.9 (656.4)
	Zonal		0.42	247.2 (480.2)	

Regardless of a model's performance on dependent or independent data, it must be tested on operational data where marked degradation over dependent or even independent data is not unusual. In the latter modes, initial input data is derived from the best track of the storm, whereas in an operational mode, a best-track scale of motion can only be estimated from warning time positions. As is noted in section 5, the model is particularly sensitive to uncertainties in the specification of the average motion over the past 12h.

During the last part of the 1983 season and throughout the 1984 season, the model was run operationally at JTWC. Verification statistics are presented in the Annual Typhoon Report, 1984 (JTWC, 1984). On page 164 of this report, it can be noted that the model's performance met expectations. That is, in comparison with other models, best performance was observed at the shorter range projections. At the more extended projections, models sensitive to environmental forcing were superior.

5. PERFORMANCE CHARACTERISTICS

In this section, examples of model performance under controlled initialization are presented. As stated, input data to the model consist of 8 predictors -- initial storm latitude, initial storm longitude, time of year, average meridional translational speed over past 12h, average zonal speed over past 12h, average meridional translational speed over past 24h, average zonal translational speed over past 24h, and maximum storm intensity. Speeds are computed within the program from current, 12h- and 24h-old warning time positions.

How sensitive is the model to inaccuracies in operational specification of these predictors? This question is best answered by holding certain predictors constant and varying others.

5.1 Time of Year

For a storm at a given location, which has a given intensity and for which past motion characteristics have been determined, the expected track, in the climatological sense, is a function of the time of year. This, of course, is merely a reflection of a normal climatological shift in the environmental steering forces. The model's ability to sense these average forces is demonstrated in Figure 5. Here, all input data were held constant, except for the Julian day number. The resultant shift in track is clearly noted. In accordance with climatological prediction, recurvature within 72h can be expected early and late in the season, but not during mid-season when the maximum westerly component occurs near mid-August.

5.2 Initial Latitude

In the climatological sense, storms initially in the deep tropics are more likely to remain embedded in the easterlies (move with a westward component of motion) through 72h than are storms initially at a more poleward location. Controlled WPCLPR forecasts, as illustrated in Figure 6, agree with this expectation. However, the model sensitivity to errors in initial

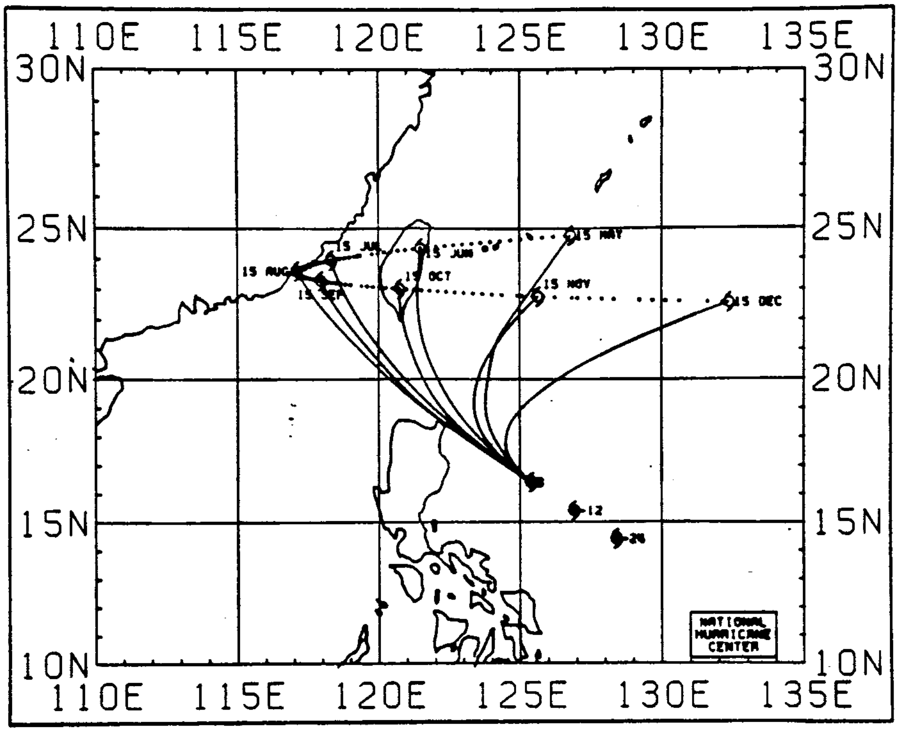

Figure 5. Sensitivity of WPCLPR to time of year. Shown are 72-h forecast tracks on fifteenth day of each month, May through December, with other predictors being held constant. Storm intensity was set at 100 kt.

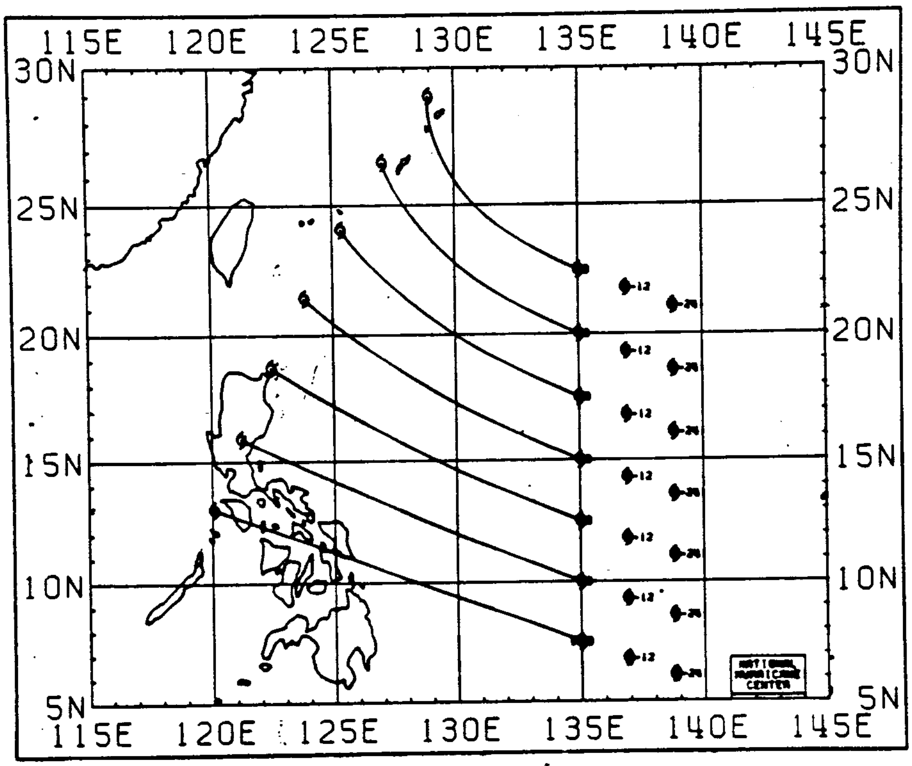

Figure 6. Sensitivity of WPCLPR model to initial latitude. Shown are 72-h forecast tracks with different initial latitudes and with other predictors being held constant. Date and storm intensity are set at 15 September and 100 kt, respectively.

latitude is rather small and, after a correction for this initial positioning error, the downstream effect of even a 1° or 2° error in latitude is not serious.

5.3 Initial Longitude

Figure 7 shows the effect of varying the initial longitude and holding constant the other seven input parameters. Here, the sensitivity is even less than for initial latitude, although there is some tendency for storms that are initially closer to the western edge of the basin to have a smaller northerly component in 72h.

5.4 Average Motion Over the Past 12h

Two predictors (average meridional and zonal speed over the past 12h) are involved here. The model computes these orthogonal components from the present and the 12h-old positions of the storm. As noted in Figure 8, there is much model sensitivity here, with errors in the 12h-old position having rather marked downstream effect. In this example, if the 12h-old position is to the north, the 72h forecast position will be to the south. Similarly, if the 12h-old position is to the south, the 72-h forecast position will be to the north. Further tests (not shown here), show even greater sensitivity to differences in present position. Accordingly (section 6), great care must be taken in specification of present and 12h-old warning time positions. Collectively, these two positions should reflect the forecaster's best estimate of average storm motion over the past 12h.

5.5 Average Motion Over the Past 24h

In contrast to model sensitivity to average motion over the past 12h, model sensitivity to average motion over the past 24h (as obtained from the present and the 24h-old positions) is considerably less. This is depicted in Figure 9. It can be noted that the downstream effects are rather small.

5.6 Storm Intensity

It can be shown dynamically that large storms have a larger poleward motion component than small storms. Although the WPCLPR does not directly address storm size, it does consider storm intensity and there is a weak positive statistical relationship between storm size (as measured by the outer closed surface isobar) and storm intensity (Merrill, 1982). Also, weak storms tend to be steered more by the lower troposphere and intense storms more by a deep layer throughout the troposphere (Simpson, 1971). The net result of these factors, and probably others, is that the more intense storms tend to have a larger poleward component than do the weaker storms. Also, there is slight increase in the westerly component with increasing storm intensity. The effect is illustrated in Figure 10.

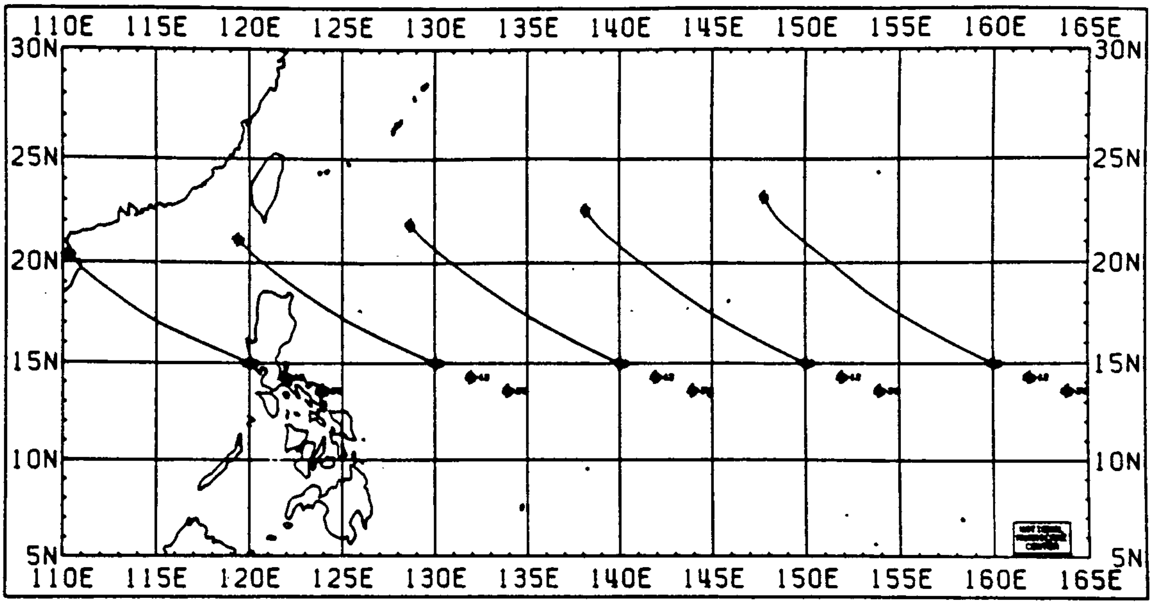

Figure 7. Sensitivity of WPCLPR model to initial longitude. Shown are 72-h forecast tracks with different initial longitudes and with other predictors being held constant. Date and storm intensity are set at 15 September and 100 kt, respectively.

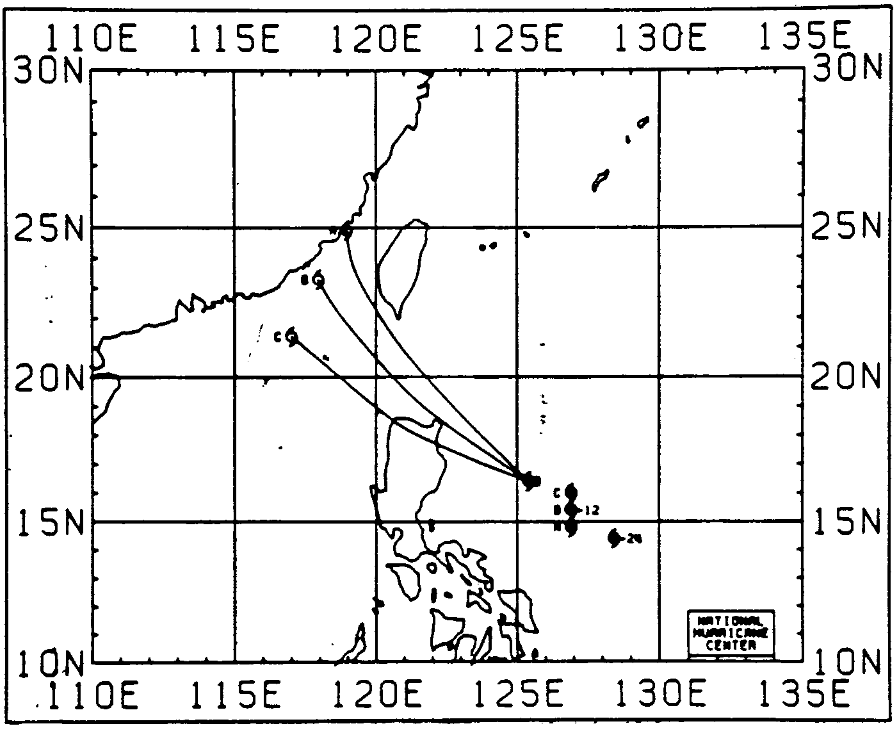

Figure 8. Sensitivity of WPCLPR model to 12h-old position. Shown are 72-h forecast tracks with three 12h-old positions and with other predictors being held constant. Date and storm intensity are set at 15 September and 100 kt, respectively.

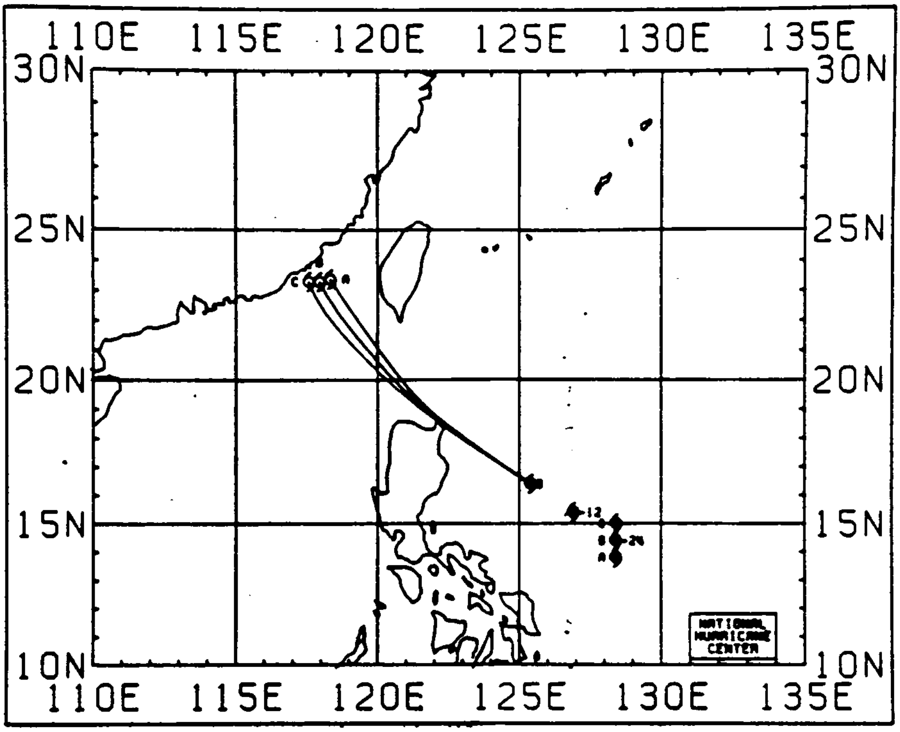

Figure 9. Sensitivity of WPCLPR model to 24h-old position. Shown are 72-h forecast tracks with different 24h-old positions with other predictors being held constant. Date and storm intensity are set at 15 September and 100 kt, respectively.

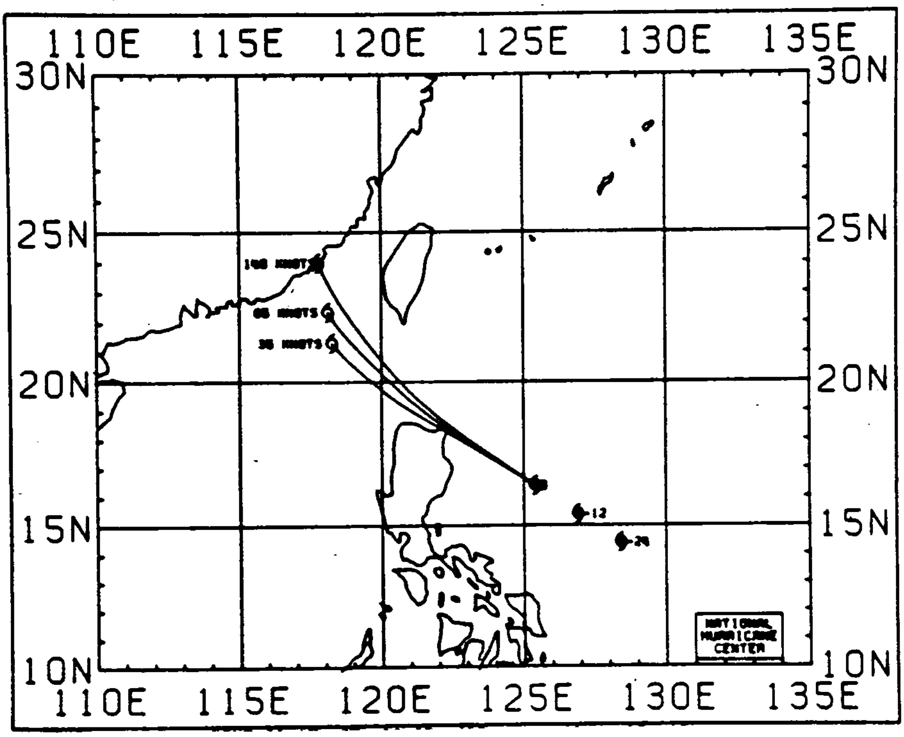

Figure 10. Sensitivity of WPCLPR model to initial storm intensity. Shown are 72-h forecast tracks with three initial intensities and with other predictors being held constant. Date has been set at 15 September.

6. OPTIMIZING MODEL PERFORMANCE

6.1 Initial Motion Vectors

In the preceding section, it was noted that the model is very sensitive to the average motion vector over the past 12h as defined by the current and the 12h-old storm positions. The forecaster must make every effort to assure that these positions reflect a best-track scale of motion. The methodology to accomplish this varies from one forecast center to another. A pitfall is the unqualified use of storm positions that reflect small-scale, perhaps trochoidal, oscillations of the storm center, which are not really representative of the larger scale, more conservative motion of the entire storm envelope.

In this connection, the current position of a storm need not automatically be the 12h-old position of a storm 12h hence; similarly, the current 12h-old position of a storm need not automatically become the 24h-old position 12h hence. The three sets of positions (now, 12h and 24h ago) might require continuous adjustment so as to best reflect current motion trends.

6.2 Model Limitations

As stated, operational use of the model is limited to storms that are initially at 5°-35°N and westward from 150°E longitude through the Asian mainland. In the temporal sense, the model should not be activated on storms occurring before 15 May or after 15 December. Finally, the system must be of at least tropical storm intensity. Violation of these spatial, temporal, and wind restrictions will result in performance degradation. For example, Figure 11 illustrates a predicted 72-h track on a storm that is initially near the northern boundary of the dependent data set (35°N). The model is acutely biased toward storms that moved slowly; faster moving storms having been dropped from the master storm data file.

Activating the model on storms that were initially east of 150°E apparently does not have serious effects on the model performance. Figure 7 shows one such forecast on a storm, initially at 15°N, 160°E. The 72-h track does not appear to be out of line with the other tracks that are within the spatial bounds of the model.

7. FURTHER COMMENTS

The model described here is designed to make optimum use of climatology and persistence in WESPAC tropical cyclone prediction and provides a good first estimate of future storm motion. However, the third-order polynomial representation of the storm tracks does not allow for small local deviations from the large-scale climatology. Thus, track deviations as storms cross mountainous areas, such as Taiwan or the Philippine Islands (Brand and Blelloch, 1972, 1973) are not well-handled by the model. These areas would have to be modeled separately and blended into the larger scale patterns.

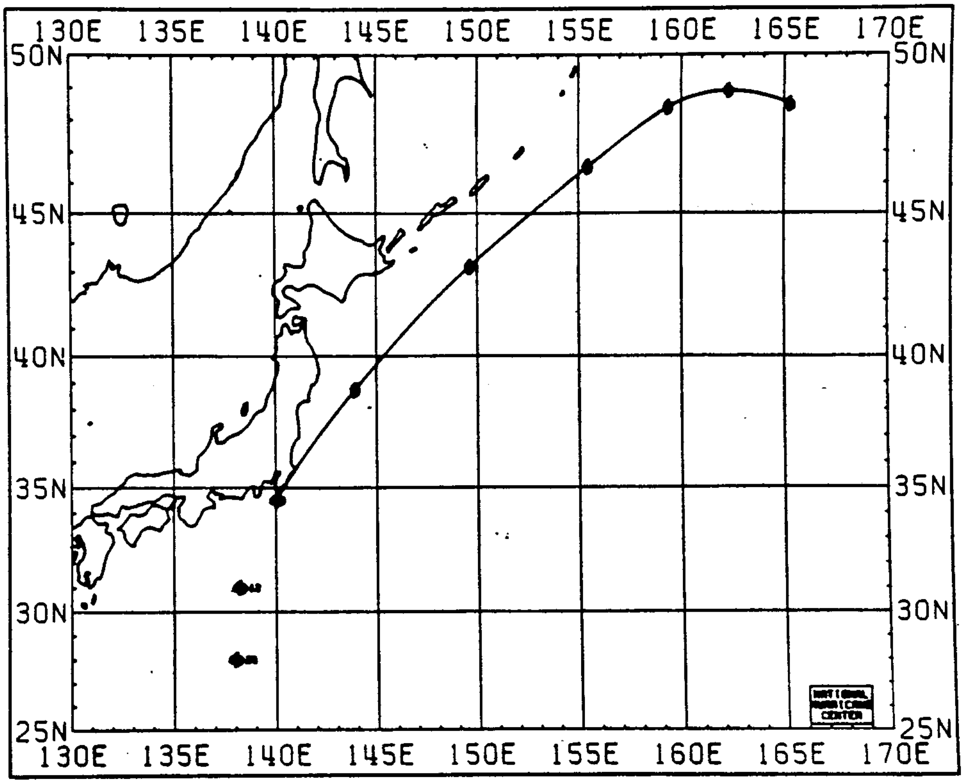

Figure 11. Example of WPCLPR model performance on a storm initially located near northern boundary of developmental (dependent) data set. Date and storm intensity were set at 15 September and 90 kt, respectively. Storm symbols give positions every 12h.

Through knowledge of current and future steering forces, it should be possible to refine model performance. Indeed, the model can be used as input to more sophisticated models that are sensitive to the existing environmental conditions. However, experience has shown that the model is subject to degradation if these synoptic steering forces are not known with sufficient precision (Neumann, 1980).

In addition to its use as a "first-guess" to the projected track, or as input to more sophisticated models, the WPCLPR model has other potential uses. Some of these are:

1) Establishment of a benchmark skill level with which to assess the real skill of more sophisticated models (Neumann and Pelissier, 1981).

2) Establishment of a "Forecast Difficulty Level," which can be used to assess long-term trends in tropical cyclone prediction (Neumann, 1981). When the model is run in this mode, best-track, rather than operational input, data are used.

3) Simulation studies that use Monte-Carlo techniques (Neumann, 1975; Jarrell et al., 1984).

4) Normalization of WESPAC tropical cyclone forecasts to those of other basins (Pike, 1985).

8. COMPUTER PROGRAM LISTING

Listing of a recommended FORTRAN IV computer program to run the program is given in the appendix. The program was written for an IBM 32-bit (4-byte) word-size machine and some of the statements may not be compatible with non-IBM compilers. Also, the job control language has been omitted; this must be user-supplied.

When the program is run, two sets of data cards are read in at execution time; the regression coefficient set and the storm data card set. The former consists of 110 cards, the first and last of which are dummies and read as such by the program. The 108 cards that contained the coefficients could probably be stored elsewhere or entered through a block data subroutine.

Following the regression coefficient cards are the storm data cards; there is no limit to the number of storms that can be run in a single job step. The program senses the last storm data card that goes through as end-of-file-marker; however, a "sentinel" card with 9999999 punched in columns 1 though 8 for the integer variable YMDH could alternately be incorporated with minor program modification. The specific formats (FORMAT statement 20 of the MAIN program) of the data card are:

Columns 1 through 8 -- Date/time in integer format (i.e., 85081706 represents August 17, 1985, 0600 GMT).

Columns 9 and 10 -- leave blank.

Columns 11 through 15 -- initial storm latitude.

Columns 16 through 20 -- initial storm longitude.

Columns 21 through 25 -- storm latitude 12h earlier.

Columns 26 through 30 -- storm longitude 12h earlier.

Columns 31 through 35 -- storm latitude 24h earlier.

Columns 36 through 40 -- storm longitude 24h earlier.

Note: Above latitudes and longitudes are in F5.1 format.

Column 41 -- leave blank.

Columns 42 through 44 -- wind in whole knots (integer format).

Note: If wind is < 100 kt, the two-digit entry must be right-adjusted.

Columns 45 through 56 -- storm name (Alphanumeric format).

Columns 57 through 80 -- leave blank.

Two sample storm data cards are included on the final page of the program. Program output generated by each data card is:

72H WPCLPR FORECAST ON STORM TEST STORM1
BEGINNING OF FORECAST PERIOD YR/MO/DA/HR (GMT) IS 85051500
MAXIMUM WIND IS 100 KNOTS
THIS IS RUN NUMBER 1

PROJECTION	LATD	LONG	DISPLACEMENT (NMI) N+/S-	E+/W-	MOTION (DIR/SPD) OVER LAST 12H
-24H	14.4N	128.4E	----	----	---/----
-12H	15.4N	126.9E	----	----	305/ 8.8 kts
0H	16.4N	125.4E	0	0	305/ 8.8 kts
+12H	17.5N	124.4E	68.7	-60.2	319/ 7.6 kts
+24H	18.8N	125.8E	144.2	-90.7	338/ 6.8 kts
+36H	20.2N	123.9E	226.2	-85.2	004/ 6.8 kts
+48H	21.7N	124.4E	315.8	-56.7	017/ 7.8 kts
+60H	23.2N	125.5E	405.1	7.5	035/ 9.1 kts
+72H	24.8N	126.8E	502.6	78.7	036/10.0 kts

and the second is:

72H WPCLPR FORECAST ON STORM TEST STORM2
BEGINNING OF FORECAST PERIOD YR/MO/DA/HR (GMT) IS 85091500
MAXIMUM WIND IS 100 KNOTS
THIS IS RUN NUMBER 2

PROJECTION	LATD	LONG	DISPLACEMENT (NMI) N+/S-	E+/W-	MOTION (DIR/SPD) OVER LAST 12H
-24H	14.4N	128.4E	----	----	---/----
-12H	15.4N	126.9E	----	----	305/ 8.8 KTS
0H	16.4N	125.4E	0	0	305/ 8.8 KTS
+12H	17.4N	123.8E	63.0	-91.5	305/ 9.3 KTS
+24H	18.5N	122.3E	128.4	-179.8	307/ 9.2 KTS
+36H	19.8N	120.8E	202.5	-261.6	312/ 6.8 KTS
+48H	21.0N	119.7E	277.2	-326.5	319/ 8.3 KTS
+60H	22.2N	118.7E	348.4	-382.0	322/ 7.5 KTS
+72H	23.3N	118.0E	413.9	-419.9	330/ 6.3 KTS

These forecast tracks (for 15 May and 15 September) were among those illustrated in Figure 5. It is recommended that the program be tested on these two cases.

9. ACKNOWLEDGMENTS

Operational testing of this program was accomplished through the cooperation of the Naval Environmental Research Facility and the Joint Typhoon Warning Center. This assistance is greatly appreciated. The lead author also expresses his gratitude to the National Weather Service and the National Hurricane Center for support received during his assignment to the center, November 1982 to November 1983. Finally, appreciation is directed to the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) Hurricane Research Division for editorial assistance and word processing services in preparing the manuscript for publication.

REFERENCES

Brand, S. and J. Blelloch, 1972: Changes in the characteristics of typhoons crossing the Philippines. Naval Environmental Prediction Research Facility Research Report TP 6-72, 38 pp.

Brand, S. and J. Blelloch, 1973: Changes in the characteristics of typhoons crossing the Island of Taiwan. Naval Environmental Prediction Research Facility Research Report TP 8-73, 21 pp.

Central Meteorological Bureau, 1972: Northwest Pacific typhoon track maps, 1949-1969, Peking, PRC, 378 pp. (in Chinese).

Jarrell, J. D., S. Brand and P. F. Krumpe, 1984: Tropical cyclone threat estimates: Where are we? Postprints, Fifteenth Conference on Hurricanes and Tropical Meteorology, January 9-13, 1984, Miami, Florida. American Meteorological Society, Boston, J29-J34.

Joint Typhoon Warning Center, 1985: Annual Typhoon Report, 1984. Joint Typhoon Warning center (JTWC), Guam, Mariana Islands, 222 pp.

Merrill, R. T., 1982: A comparison of large and small tropical cyclones. University of Colorado, Department of Atmospheric Science Paper No. 352, Ft. Collins, 75 pp.

Neumann, C. J., 1972: An alternate to the HURRAN tropical cyclone forecast system. NOAA Technical Memorandum NWS SR-62, Miami, Florida, 25 pp.

Neumann, C. J., 1975: A statistical study of tropical cyclone positioning errors with economic applications. NOAA Technical Memorandum NWS SR-62, Miami, Florida, 21 pp.

Neumann, C. J., 1980: The prediction of tropical cyclone motion - An overview. Selected Papers, Thirteenth Technical Conference on Hurricanes and Tropical Meteorology, Miami Beach, Florida, December 1-5, 1980. American Meteorological Society, Boston, 68-78.

Neumann, C. J. and P. W. Leftwich, 1977: Statistical guidance for the prediction of eastern North Pacific tropical cyclone motion - Part 1. NOAA Technical Memorandum NWS WR-124, Miami, Florida.

Neumann, C. J. and G. S. Mandal, 1978: Statistical prediction of tropical cyclone motion over the Bay of Bengal and Arabian Sea. Indian Journal of Meteorology, Hydrology, and Geophysics, 29, 487-500.

Neumann, C. J. and J. M. Pellissier, 1981: An analysis of Atlantic tropical cyclone forecast errors, 1970-1979. Monthly Weather Review, 109, 1248-1266.

Neumann, C. J. and E. A. Randrianarison, 1976: Statistical prediction of tropical cyclone motion over the southwest Indian Ocean. Monthly Weather Review, 104, 76-85.

Pike, A. C., 1985: The variation of track forecast difficulty among tropical cyclone basins. Extended Abstracts, Sixteenth Conference on Hurricanes and Tropical Meteorology, May 14-17, 1985, Houston, Texas. American Meteorological Society, Boston, 76-77.

Simpson, R. L., 1971: The decision process in hurricane forecasting. NOAA Technical Memorandum NWS SR-63, Miami, Florida, 35 pp.

APPENDIX: FORTRAN Computer Program and Associated Data Needed for WPCLPR model

```
C THIS IS MAIN PROGRAM
      INTEGER YMDH.WIND
      REAL LAO.LOO.LAM12.LOM12.LAM24.LOM24
      DIMENSION CI(12).M(32.12).COF(32.12).DISP(2.6).FP(2.6)
      DIMENSION IDIR(3.8).SPD(8)
      NRUNS=0
C
C READ IN REGRESSION COEFFICIENTS AND CORRESPONDING PREDICTOR NUMBERS
C
      CALL READRC(COF.M.CI)
   10 READ(5.20.END=50) YMDH.LAO.LOO.LAM12.LOM12.LAM24.LOM24.WIND
     $            .NAME1.NAME2.NAME3
   20 FORMAT(I8.2X.6F5.1.1X.I3.3A4)
      NRUNS=NRUNS+1
C
C PREPARE FORECAST
C
      CALL WPCLIP (YMDH.LAO.LOO.LAM12.LOM12.LAM24.LOM24.WIND.CI.M.COF.
     $DISP.FP)
C
C OBTAIN PAST AND FORECAST MOTIONS
C
      CALL DIRSPD(LAO.LOO.LAM12.LOM12.LAM24.LOM24.FP.IDIR.SPD)
C
C WRITE OUTPUT TO PRINTER
C
      WRITE(6.23)
   23 FORMAT(//////5X.61(1H*))
      WRITE(6.25)NAME1.NAME2.NAME3.YMDH.WIND.NRUNS
   25 FORMAT(5X.'72H WPCLPR FORECAST ON STORM '.3A4/5X.'BEGINNING OF FOR
     $ECAST PERIOD YR/MO/DA/HR (GMT) IS 'I8/5X.'MAXIMUM WIND IS 'I3.
     $' KNOTS'/5X.'THIS IS RUN NUMBER '.I4/)
      WRITE(6.26)
   26 FORMAT(1H0.29X.'DISPLACEMENT (NMI)  MOTION (DIR/SPD)'/
     $5X.'PROJECTION  LATD    LONG     N+/S-     E+/W-      OVER LAST 12H')
      WRITE(6.27)LAM24.LOM24
   27 FORMAT(8X.'-24H'.4X.F4.1.1HN.F6.1.'E      ---        ---        ---/--
     $--')
      WRITE(6.28)LAM12.LOM12.IDIR(1.1).IDIR(2.1).IDIR(3.1).SPD(1)
   28 FORMAT(8X.'-12H'.4X.F4.1.1HN.F6.1.'E      ---        ---'.7X.3I1.
     $1H/.F4.1.' KTS')
      WRITE(6.29)LAO.LOO.IDIR(1.2).IDIR(2.2).IDIR(3.2).SPD(2)
   29 FORMAT(8X.'  0H'.4X.F4.1.1HN.F6.1.'E       0          0'.8X.3I1.
     $1H/.F4.1.' KTS')
      DO 35 J=1.6
      KHRS=12*J
      WRITE(6.30)KHRS.FP(1.J).FP(2.J).DISP(1.J).DISP(2.J).
     $IDIR(1.J+2).IDIR(2.J+2).IDIR(3.J+2).SPD(J+2)
   30 FORMAT(8X.1H+.I2.1HH.4X.F4.1.1HN.F6.1.1HE.2F9.1.6X.3I1.1H/.
     $F4.1.' KTS')
   35 CONTINUE
```

```
      WRITE(6.38)
   38 FORMAT(5X.61(1H*))
      GO TO 10
   50 CONTINUE
      STOP
      END
C*****************************************************************************
      SUBROUTINE READRC(COF.M.CI)
      DIMENSION COF(32.12).M(32.12).CI(12).RDUMY(4).IDUMY(4)
C READ 108 CARDS CONTAINING REGRESSION COEFFICIENTS. THERE ARE 12 SETS
C OF 9 CARDS EACH. FIRST SET IS FOR 12H MERIDIONAL MOTION. SECOND SET IS
C FOR 12H ZONAL MOTION. THIRD SET IS FOR 24H MERIDIONAL MOTION. ETC.
C ARRAY COF HOLDS REGRESSION COEFFICIENTS. 32 COEFFICIENTS PER SET
C ARRAY M HOLDS CORRESPONDING PREDICTOR NUMBER
C ARRAY CI IS INTERCEPT VALUES. ONE PER SET. THIS IS PUNCHED ON FIRST
C CARD. CARDS 2 THRU 6 OF EACH SET HOLD PREDICTOR NUMBER AND REGRESSION
C COEFFICIENTS.
C CARDS ARE SELF INDEXING....THEY CAN BE OUT OF ORDER
C
      READ(5.6)DUMMY
    6 FORMAT(A4)
      DO 30 I=1.108
      READ(5.10)INDEX.(IDUMY(J).RDUMY(J).J=1.4)
   10 FORMAT(I3.1X.4(I4.E15.7))
      J=(INDEX+8)/9
      IF(MOD(INDEX-1.9).EQ.0)GO TO 25
      INIT=(INDEX-9*(J-1))*4-7
      LAST=INIT+3
      N=0
      DO 20 L=INIT.LAST
      N=N+1
      M(L.J)=IDUMY(N)
   20 COF(L.J)=RDUMY(N)
      GO TO 30
   25 CI(J)=RDUMY(1)
   30 CONTINUE
      READ(5.6)DUMMY
      RETURN
      END
C*****************************************************************************
      SUBROUTINE DIRSPD(LAO.LOO.LAM12.LOM12.LAM24.LOM24.FP.IDIR.SPD)
C COMPUTE APPROXIMATE HEADING AND SPEED AVERAGED OVER 12H INTERVALS
      REAL LAO.LOO.LAM12.LOM12.LAM24.LOM24
      DIMENSION FP(2.6).Q(2.9).IDIR(3.8).SPD(8).LDIR(8)
      DO 5 I=1.2
      DO 4 J=1.6
    4 Q(I.J+3)=FP(I.J)
    5 CONTINUE
      Q(1.1)=LAM24
      Q(2.1)=LOM24
      Q(1.2)=LAM12
      Q(2.2)=LOM12
```

```
      Q(1.3)=LAO
      Q(2.3)=LOO
      T=.0087266
      DO 20 J=1.8
      DY=Q(1.J+1)-Q(1.J)
      DX=(Q(2.J+1)-Q(2.J))*COS((Q(1.J+1)+Q(1.J))*T)
      SPD(J)=SQRT(DY*DY+DX*DX)*5.
      IF(SPD(J).EQ.0.0)GO TO 10
      DIR=ATAN2(DX.DY)*57.29578
      IF(DIR.LT.0.0)DIR=DIR+360.
      LDIR(J)=DIR+.5
      IF(LDIR(J).EQ.0)LDIR(J)=360
      GO TO 20
   10 LDIR(J)=0
   20 CONTINUE
      DO 30 J=1.8
      IDIR(1.J)=LDIR(J)/100
      IDIR(2.J)=(LDIR(J)-IDIR(1.J)*100)/10
   30 IDIR(3.J)=LDIR(J)-IDIR(1.J)*100-IDIR(2.J)*10
      RETURN
      END
C*****************************************************************************
      SUBROUTINE WPCLIP(YMDH.LAO.LOO.LAM12.LOM12.LAM24.LOM24.WIND.
     $                  CI.M.COF.DISP.FP)
      INTEGER YMDH.WIND
      REAL LAO.LOO.LAM12.LOM12.LAM24.LOM24
      DIMENSION CI(12).M(32.12).COF(32.12).DISP(2.6).FP(2.6)
C
C        A WEST PACIFIC CLIMATOLOGY-PERSISTENCE METHOD
C        FOR FORECASTING STORM DISPLACEMENTS THROUGH 72H AT 12 HRLY
C        INCREMENTS.  VALID FROM 15 MAY THRU 15 DECEMBER ONLY AND FOR
C        STORMS INITIALLY AT OR SOUTH OF 35N LATITUDE AND WEST OF 150E.
C
C        ARGUMENTS:
C
C        ON INPUT
C        YMDH--DATE(YEAR.MONTH.DAY.HOUR). I8. (6/1/83.00Z-83060100)
C        LAO--INITIAL LATITUDE. DEGREES
C        LOO--INITIAL LONGITUDE. DEGREES
C        LAM12--LATITUDE AT -12 HOURS
C        LOM12--LONGITUDE AT -12 HOURS
C        LAM24--LATITUDE AT -24 HOURS
C        LOM24--LONGITUDE AT -24 HOURS
C        WIND--INITIAL MAXIMUM WIND. KNOTS
C        CI--REGRESSION INTERCEPTS
C        M--REGRESSION VARIABLE NUMBERS
C        COF--REGRESSION COEFFICIENTS
C
C        ON OUTPUT
C        DISP--DISPLACMENTS 12Z.. 12M.. 24Z.. 24M.. 36Z.. 36M.. 48Z..
C                           48M..60Z..60M..72Z..72M..           NM
C                           Z.-- E TO W NEG.
```

```
C                                M.-- S TO N POS.
C         FP--FORECAST POSITIONS            DEGREES
      DIMENSION P(166)
C POTENTIAL PREDICTORS ARE NUMBERED 3 THRU 166.  ONLY 32 OF THESE ARE
C USED FOR EACH OF THE 12 REGRESSION EQUATIONS.
      P(3)=LAO
      IF(LAO.GT.35.)GO TO 2
      GO TO 4
    2 WRITE(6.3)LAO
    3 FORMAT(//5X.'CURRENT LATITUDE OF 'F4.1.' IS NORTH OF 35.0. PROGRAM
     $ BEING TERMINATED'//)
      STOP
    4 P(4)=LOO
      IY=YMDH/1000000
      IM=YMDH/10000-IY*100
      ID=YMDH/100-IM*100-IY*10000
      IH=YMDH-IY*1000000-IM*10000-ID*100
      P(5)=3055*(IM+2)/100-(IM+10)/13*2-91+ID
      IF(P(5).LT.134..OR.P(5).GT.350.)GO TO 5
      GO TO 7
    5 WRITE(6.6)YMDH
    6 FORMAT(//5X.'PROGRAM RESULTS NOT VALID BEFORE 15 MAY OR AFTER 15 D
     $ECEMBER.  CURRENT DATETIME IS'.I10/1X.'PROGRAM BEING TERMINATED'/)
      STOP
    7 P(6)=(LAO-LAM12)*2.5
      P(7)=(LOO-LOM12)*2.5*COS((LAO+LAM12)*0.0087267)
C                                              UNIT      NM/30 MINS
      P(8)=(LAO-LAM24)*2.5
      P(9)=(LOO-LOM24)*2.5*COS((LAO+LAM24)*0.0087267)
C                                              UNIT      KNOT
      P(10)=WIND
      P(11)=P(3)*P(3)
      P(12)=P(3)*P(3)*P(3)
      P(13)=P(3)*P(4)
      P(14)=P(3)*P(3)*P(4)
      P(15)=P(4)*P(4)
      P(16)=P(3)*P(4)*P(4)
      P(17)=P(4)*P(4)*P(4)
      P(18)=P(3)*P(5)
      P(19)=P(3)*P(3)*P(5)
      P(20)=P(4)*P(5)
      P(21)=P(3)*P(4)*P(5)
      P(22)=P(4)*P(4)*P(5)
      P(23)=P(5)*P(5)
      P(24)=P(3)*P(5)*P(5)
      P(25)=P(4)*P(5)*P(5)
      P(26)=P(5)*P(5)*P(5)
      P(27)=P(3)*P(6)
      P(28)=P(3)*P(3)*P(6)
      P(29)=P(4)*P(6)
      P(30)=P(3)*P(4)*P(6)
      P(31)=P(4)*P(4)*P(6)
```

```
P(32):=P(5)*P(6)
P(33):=P(3)*P(5)*P(6)
P(34):=P(4)*P(5)*P(6)
P(35):=P(5)*P(5)*P(6)
P(36):=P(6)*P(6)
P(37):=P(3)*P(6)*P(6)
P(38):=P(4)*P(6)*P(6)
P(39):=P(5)*P(6)*P(6)
P(40):=P(6)*P(6)*P(6)
P(41):=P(3)*P(7)
P(42):=P(3)*P(3)*P(7)
P(43):=P(4)*P(7)
P(44):=P(3)*P(4)*P(7)
P(45):=P(4)*P(4)*P(7)
P(46):=P(5)*P(7)
P(47):=P(3)*P(5)*P(7)
P(48):=P(4)*P(5)*P(7)
P(49):=P(5)*P(5)*P(7)
P(50):=P(6)*P(7)
P(51):=P(3)*P(6)*P(7)
P(52):=P(4)*P(6)*P(7)
P(53):=P(5)*P(6)*P(7)
P(54):=P(6)*P(6)*P(7)
P(55):=P(7)*P(7)
P(56):=P(3)*P(7)*P(7)
P(57):=P(4)*P(7)*P(7)
P(58):=P(5)*P(7)*P(7)
P(59):=P(6)*P(7)*P(7)
P(60):=P(7)*P(7)*P(7)
P(61):=P(3)*P(8)
P(62):=P(3)*P(3)*P(8)
P(63):=P(4)*P(8)
P(64):=P(3)*P(4)*P(8)
P(65):=P(4)*P(4)*P(8)
P(66):=P(5)*P(8)
P(67):=P(3)*P(5)*P(8)
P(68):=P(4)*P(5)*P(8)
P(69):=P(5)*P(5)*P(8)
P(70):=P(6)*P(8)
P(71):=P(3)*P(6)*P(8)
P(72):=P(4)*P(6)*P(8)
P(73):=P(5)*P(6)*P(8)
P(74):=P(6)*P(6)*P(8)
P(75):=P(7)*P(8)
P(76):=P(3)*P(7)*P(8)
P(77):=P(4)*P(7)*P(8)
P(78):=P(5)*P(7)*P(8)
P(79):=P(6)*P(7)*P(8)
P(80):=P(7)*P(7)*P(8)
P(81):=P(8)*P(8)
P(82):=P(3)*P(8)*P(8)
P(83):=P(4)*P(8)*P(8)
```

```
P(84)=P(5)*P(8)*P(8)
P(85)=P(6)*P(8)*P(8)
P(86)=P(7)*P(8)*P(8)
P(87)=P(8)*P(8)*P(8)
P(88)=P(3)*P(9)
P(89)=P(3)*P(3)*P(9)
P(90)=P(4)*P(9)
P(91)=P(3)*P(4)*P(9)
P(92)=P(4)*P(4)*P(9)
P(93)=P(5)*P(9)
P(94)=P(3)*P(5)*P(9)
P(95)=P(4)*P(5)*P(9)
P(96)=P(5)*P(5)*P(9)
P(97)=P(6)*P(9)
P(98)=P(3)*P(6)*P(9)
P(99)=P(4)*P(6)*P(9)
P(100)=P(5)*P(6)*P(9)
P(101)=P(6)*P(6)*P(9)
P(102)=P(7)*P(9)
P(103)=P(3)*P(7)*P(9)
P(104)=P(4)*P(7)*P(9)
P(105)=P(5)*P(7)*P(9)
P(106)=P(6)*P(7)*P(9)
P(107)=P(7)*P(7)*P(9)
P(108)=P(8)*P(9)
P(109)=P(3)*P(8)*P(9)
P(110)=P(4)*P(8)*P(9)
P(111)=P(5)*P(8)*P(9)
P(112)=P(6)*P(8)*P(9)
P(113)=P(7)*P(8)*P(9)
P(114)=P(8)*P(8)*P(9)
P(115)=P(9)*P(9)
P(116)=P(3)*P(9)*P(9)
P(117)=P(4)*P(9)*P(9)
P(118)=P(5)*P(9)*P(9)
P(119)=P(6)*P(9)*P(9)
P(120)=P(7)*P(9)*P(9)
P(121)=P(8)*P(9)*P(9)
P(122)=P(9)*P(9)*P(9)
P(123)=P(3)*P(10)
P(124)=P(3)*P(3)*P(10)
P(125)=P(4)*P(10)
P(126)=P(3)*P(4)*P(10)
P(127)=P(4)*P(4)*P(10)
P(128)=P(5)*P(10)
P(129)=P(3)*P(5)*P(10)
P(130)=P(4)*P(5)*P(10)
P(131)=P(5)*P(5)*P(10)
P(132)=P(6)*P(10)
P(133)=P(3)*P(6)*P(10)
P(134)=P(4)*P(6)*P(10)
P(135)=P(5)*P(6)*P(10)
```

```
      P(136)=P(6)*P(6)*P(10)
      P(137)=P(7)*P(10)
      P(138)=P(3)*P(7)*P(10)
      P(139)=P(4)*P(7)*P(10)
      P(140)=P(5)*P(7)*P(10)
      P(141)=P(6)*P(7)*P(10)
      P(142)=P(7)*P(7)*P(10)
      P(143)=P(8)*P(10)
      P(144)=P(3)*P(8)*P(10)
      P(145)=P(4)*P(8)*P(10)
      P(146)=P(5)*P(8)*P(10)
      P(147)=P(6)*P(8)*P(10)
      P(148)=P(7)*P(8)*P(10)
      P(149)=P(8)*P(8)*P(10)
      P(150)=P(9)*P(10)
      P(151)=P(3)*P(9)*P(10)
      P(152)=P(4)*P(9)*P(10)
      P(153)=P(5)*P(9)*P(10)
      P(154)=P(6)*P(9)*P(10)
      P(155)=P(7)*P(9)*P(10)
      P(156)=P(8)*P(9)*P(10)
      P(157)=P(9)*P(9)*P(10)
      P(158)=P(10)*P(10)
      P(159)=P(3)*P(10)*P(10)
      P(160)=P(4)*P(10)*P(10)
      P(161)=P(5)*P(10)*P(10)
      P(162)=P(6)*P(10)*P(10)
      P(163)=P(7)*P(10)*P(10)
      P(164)=P(8)*P(10)*P(10)
      P(165)=P(9)*P(10)*P(10)
      P(166)=P(10)*P(10)*P(10)
C     WRITE(6.9)     (P(I).I=3.166)
    9 FORMAT(25HOLIST OF PREDICTORS----   .8E12.4/10(E12.4))
      DO 30 K=1.6
      DO 20 J=1.2
      KJ=(K-1)*2+J
      DISP(J.K)=CI(KJ)
      DO 10 I=1.32
      L=M(I.KJ)
   10 DISP(J.K)=DISP(J.K)+P(L)*COF(I.KJ)
   20 CONTINUE
      FP(1.K)=DISP(1.K)/60.0+P(3)
      FP(2.K)=DISP(2.K)/60.0/COS((FP(1.K)+P(3))*0.0087266)+P(4)
   30 CONTINUE
      RETURN
      END
```

```
PERMANENT DATA CARDS (THIS CARD IS CONSIDERED PART OF SET)
  1         0.8243047E 02
  2    29   0.1673843E 00 141   0.2086875E-01 154 -0.3422998E-02 113 -0.3635096E-02
  3   133   0.2699498E-02  65 -0.9927880E-04 148 -0.5865134E-02  47  0.1775683E-03
```

4	5	-0.4999201E 00	20	0.2700687E-02	33	0.1438122E-02	40	-0.6320661E-01
5	153	-0.6018809E-04	163	0.1673713E-03	12	-0.3845890E-03	7	0.2286027E 01
6	37	0.2333808E-01	31	-0.4772958E-03	144	-0.2076029E-02	56	-0.4434004E-02
7	146	0.1320566E-03	84	-0.2983983E-03	135	-0.2515721E-03	134	0.4485503E-03
8	4	-0.2090873E 00	46	-0.4572004E-02	92	-0.1706305E-04	85	0.2506665E-02
9	123	0.1779330E-01	126	-0.1372335E-03	18	0.4651449E-03	131	0.7627250E-07
10		-0.7274435E 02						
11	7	0.3444308E 01	67	0.6443840E-03	65	-0.2021452E-03	55	0.1816658E 00
12	94	0.1220374E-03	138	0.1236677E-02	151	-0.3542996E-03	60	-0.2548988E 00
13	101	-0.4025444E-01	51	0.1947947E-01	107	0.2317467E 00	5	-0.3123049E 00
14	69	0.1631727E-04	24	0.2076455E-03	18	-0.9038967E-01	3	0.9873206E 01
15	100	-0.1912876E-02	50	0.1113659E 01	120	-0.5292714E-01	91	-0.8169997E-03
16	44	0.1044284E-02	135	-0.4174725E-04	70	0.2064505E 00	40	-0.1809160E-01
17	19	0.1243634E-03	17	-0.3273220E-04	4	0.1318529E 01	22	0.4694369E-05
18	98	-0.3580001E-02	157	0.4959767E-04	45	-0.1010245E-02	43	0.2646374E 00
19		0.2489156E 03						
20	29	0.1700943E 00	7	0.8978351E 01	133	0.3507804E-02	92	-0.4143245E-04
21	144	-0.2603549E-02	141	0.6853032E-01	154	-0.1987820E-01	148	-0.1717164E-01
22	113	-0.2648072E-01	85	-0.3888343E-01	5	-0.1491605E 01	33	0.3334465E-02
23	131	0.1996335E-05	20	0.7599130E-02	18	0.4191808E-02	46	-0.3758204E-01
24	84	0.4155543E-03	4	-0.7392796E 00	47	0.9272879E-03	163	0.4049011E-03
25	12	-0.1352994E-02	37	0.5155999E-01	65	-0.2045497E-03	40	-0.9431607E-01
26	153	-0.7771955E-04	134	0.7513005E-03	56	-0.4073039E-02	123	0.4733110E-01
27	126	-0.3429537E-03	135	-0.2059647E-03	146	0.6084653E-04	31	-0.6504587E-04
28		0.2223004E 02						
29	7	0.1194606E 02	67	0.1335611E-02	65	-0.5685668E-03	120	-0.6427991E-01
30	55	0.3251997E 00	91	-0.2551002E-02	44	0.4644394E-02	101	-0.8324653E-01
31	51	-0.4293872E-01	60	-0.4286121E 00	69	0.6524181E-04	5	-0.1161908E 01
32	24	0.6120715E-03	18	-0.2589714E 00	3	0.2757455E 02	138	0.4483256E-02
33	100	-0.7047493E-02	50	0.5297915E 01	94	0.6836692E-03	70	0.9826621E 00
34	40	-0.1018223E 00	19	0.4714034E-03	107	0.3417803E 00	17	-0.6994254E-04
35	22	0.2124114E-04	43	0.3614590E 00	151	-0.1331816E-02	4	0.1714292E 01
36	98	-0.9823222E-02	45	-0.1655797E-02	135	-0.1847712E-04	157	0.1516053E-03
37		0.5401133E 03						
38	29	0.1500874E 00	7	0.7761415E 01	92	0.7268143E-04	133	0.5656216E-02
39	85	-0.2617476E-01	37	0.1117029E 00	113	-0.6192457E-01	47	0.1639675E-02
40	84	0.7281310E-03	5	-0.3185656E 01	131	0.2206964E-05	33	0.6248180E-02
41	144	-0.6947838E-02	46	-0.4137528E-01	20	0.1864345E-01	12	-0.2953369E-02
42	4	-0.2323362E 01	163	0.1150065E-02	153	-0.2317171E-03	123	0.9330589E-01
43	154	-0.3383111E-01	141	0.9067208E-01	148	-0.2221274E-01	40	-0.3846226E 00
44	134	0.1699561E-02	126	-0.5587398E-03	18	0.6707959E-02	65	-0.4418660E-03
45	135	-0.9510636E-03	146	0.4035267E-03	56	0.6355673E-02	31	0.3931348E-03
46		0.3100667E 03						
47	7	-0.2403130E 02	67	0.1950011E-02	65	-0.8820281E-03	101	-0.1938653E 00
48	51	-0.3152274E 00	98	0.6957471E-01	60	-0.6029782E 00	40	-0.3214965E 00
49	70	0.2465692E 01	24	0.1245809E-02	5	-0.2642607E 01	18	-0.5156037E 00
50	3	0.5310783E 02	69	0.1225598E-03	19	0.1057535E-02	50	0.1442510E 02
51	100	-0.1926617E-01	138	0.8992221E-02	151	-0.3066611E-02	107	0.3948497E 00
52	94	0.1995778E-02	17	-0.1238049E-03	22	0.5343799E-04	45	-0.4917126E-02
53	55	0.3230032E 00	91	-0.5892359E-02	44	0.9430107E-02	120	-0.4385853E-01
54	43	0.1091300E 01	157	0.3790313E-03	4	0.1314850E 01	135	-0.8274055E-05
55		0.8928682E 03						

56	29	0.4984372E-01	7	0.9466640E 01	126	-0.9195774E-03	92	0.1422788E-03
57	85	-0.5339801E-01	133	0.4315995E-02	84	0.1586292E-02	5	-0.5175555E 01
58	144	-0.1052923E-01	131	0.4122331E-05	33	0.1029949E-01	20	0.3082294E-01
59	12	-0.4820015E-02	4	-0.4121036E 01	163	0.1774920E-02	153	-0.3377146E-03
60	154	-0.4528344E-01	141	0.8610046E-01	113	-0.6368273E-01	123	0.1621369E 00
61	148	-0.1540766E-01	47	0.2351495E-02	46	-0.5561870E-01	18	0.9735085E-02
62	40	-0.4327580E 00	37	0.1083534E 00	134	0.2952944E-02	135	-0.1440395E-02
63	146	0.5335121E-03	56	0.7292505E-02	65	-0.1317292E-03	31	-0.2794338E-05
64		0.4801357E 03						
65	7	-0.2391514E 03	67	0.2307272E-02	94	0.1752103E-02	65	-0.1087733E-02
66	101	-0.3508924E 00	51	-0.5850123E 00	40	-0.5115929E 00	22	0.9420360E-04
67	69	0.1973974E-03	24	0.1972680E-02	5	-0.4531600E 01	18	-0.8082932E 00
68	3	0.8245955E 02	44	0.1079658E-01	17	-0.2429102E-03	19	0.1710244E-02
69	50	0.2251128E 02	100	-0.2868167E-01	70	0.3151261E 01	45	-0.1869880E-01
70	138	0.1348644E-01	151	-0.2281587E-02	157	0.3738598E-02	43	0.4594197E 01
71	98	0.1336988E 00	135	0.2020500E-03	91	-0.6983630E-02	60	-0.8020301E 00
72	107	0.5052091E 00	4	0.3285592E 01	55	-0.2141741E 00	120	-0.3377817E-01
73		0.1070405E 04						
74	29	0.1585412E 00	126	-0.1266842E-02	47	0.1865536E-02	40	-0.6368155E 00
75	92	0.2318663E-03	7	0.7787856E 01	12	-0.7067483E-02	5	-0.6708192E 01
76	33	0.1426759E-01	20	0.3929519E-01	4	-0.4460957E 01	131	0.6467513E-05
77	163	0.1963431E-02	153	-0.3980743E-03	154	-0.4871838E-01	141	0.6862462E-01
78	123	0.2165112E 00	144	-0.1045722E-01	84	0.2797279E-02	134	0.4809570E-02
79	113	-0.4149419E-01	18	0.1515382E-01	46	-0.4402407E-01	135	-0.2590124E-02
80	146	0.9472435E-03	65	-0.7366973E-03	85	0.2865400E-01	37	0.2626506E-01
81	133	-0.4466332E-02	31	-0.4161224E-03	148	-0.1505543E-02	56	0.2455192E-02
82		0.6585605E 03						
83	7	-0.4070564E 03	67	0.3226322E-02	94	0.9927768E-03	17	-0.3613045E-03
84	24	0.2840996E-02	5	-0.6543036E 01	18	-0.1164495E 01	3	0.1216047E 03
85	101	-0.6059824E 00	51	-0.5853522E 00	70	0.2449144E 01	22	0.1484775E-03
86	19	0.2063197E-02	100	-0.2828110E-01	50	0.2411407E 02	40	-0.5863789E 00
87	138	0.8881852E-02	135	0.6271652E-03	65	-0.1259519E-02	69	0.2335963E-03
88	157	0.9130541E-02	45	-0.2869136E-01	43	0.7279905E 01	120	-0.1447690E 00
89	60	-0.1698784E 01	55	-0.1119654E 01	91	-0.1070156E-01	44	0.1429705E-01
90	107	0.1224539E 01	98	0.1121298E 00	151	0.4748836E-02	4	0.4786591E 01
91		0.1227649E 04						
92	134	0.5315151E-02	46	-0.5306449E-01	4	-0.4715615E 01	29	0.7092304E 00
93	31	-0.4714649E-02	153	-0.4246614E-03	12	-0.1065860E-01	5	-0.8510695E 01
94	20	0.4844772E-01	163	0.2085041E-02	18	0.3572815E-01	131	0.1123452E-04
95	40	-0.4290173E 00	33	0.1273538E-01	154	-0.5434983E-01	47	0.3082309E-02
96	141	0.6222808E-01	7	0.1034117E 02	144	-0.8771151E-02	84	0.4368767E-02
97	123	0.2687349E 00	126	-0.1671656E-02	135	-0.2234948E-02	113	-0.3654267E-01
98	146	0.5971477E-03	65	-0.5225483E-03	133	-0.6916974E-02	92	0.1508313E-03
99	37	-0.4163603E-01	148	0.4399456E-02	56	0.7542375E-02	85	0.4912918E-03
100		0.1009912E 04						
101	7	-0.6465908E 03	67	0.3588817E-02	94	-0.3876986E-03	17	-0.4624140E-03
102	40	-0.5615302E 00	19	0.2003934E-02	135	0.1165639E-02	138	0.3531024E-01
103	5	-0.8648671E 01	24	0.3629969E-02	18	-0.1472466E 01	3	0.1582075E 03
104	101	-0.6459741E 00	22	0.2087192E-03	157	0.1485109E-01	65	-0.1360313E-02
105	55	-0.2531728E 01	50	0.2311008E 02	100	-0.2338113E-01	44	0.2408564E-03
106	51	-0.5105714E 00	45	-0.4381987E-01	43	0.1115743E 02	69	0.2404939E-03
107	120	-0.7225931E-01	60	-0.1858356E 01	91	-0.4631437E-02	70	0.1690327E 01
108	107	0.1184354E 01	4	0.4417151E 01	151	-0.2811498E-02	98	0.1303708E-01

END PERMANENT DATA CARDS. (THIS CARD IS PART OF SET). STORM CARDS FOLLOW

85051500 16.4125.4 15.4126.9 14.4128.4 100 TEST STORM1

85091500 16.4125.4 15.4126.9 14.4128.4 100 TEST STORM2

NWS NHC 6 A Tropical Cyclone Data Tape for the North Atlantic Basin, 1886-1977: Contents, Limitations, and Uses. Brian R. Jarvinen and Eduardo L. Caso - June 1978 (PB285504/AS)

NWS NHC 7 The Deadliest, Costliest, and Most Intense United States Hurricanes of the Century (and Other Frequently Requested Hurricane Facts). Paul J. Hebert and Glenn Taylor - August 1978 (PB 286753/AS)

NWS NHC 8 Annual Data and Verification Tabulation of Atlantic Tropical Cyclones 1977. Miles B. Lawrence, Paul J. Hebert and Staff, NHC - March 1979 (PB295702)

NWS NHC 9 Annual Data and Verification Tabulation of Atlantic Tropical Cyclones 1978. Paul J. Hebert and Staff, NHC - April 1979 (PB296323)

NWS NHC 10 Statistical Forecasts of Tropical Cyclone Intensity for the North Atlantic Basin. Brian R. Jarvinen and Charles J. Neumann - April 1979 (PB297185)

NWS NHC 11 A Guide to Atlantic and Eastern Pacific Models for the Prediction of Tropical Cyclone Motion. Charles J. Neumann - April 1979 (PB297141/AS)

NWS NHC 12 Modification of NMC Analyses and Prognoses for Use in Statistical Tropical Cyclone Prediction Models. Preston W. Leftwich, Jr. - May 1979 (PB297190)

NWS NHC 13 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1979. Paul J. Hebert and Staff, NHC - June 1980

NWS NHC 14 A Statistical Tropical Cyclone Motion Forecasting System for the Gulf of Mexico, Robert T. Merrill - August 1980

NWS NHC 15 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1980. Glenn Taylor and Staff, NHC - June 1981

NWS NHC 16 A Compilation of Eastern and Central North Pacific Tropical Cyclone Data. Gail M. Brown and Preston W. Leftwich, Jr. - August 1982 (PB83115444)

NWS NHC 17 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1981. Staff, NHC - November 1982

NWS NHC 18 The Deadliest, Costliest, and Most Intense United States Hurricanes of this Century (and Other Frequently Requested Hurricane Facts), Paul J. Hebert and Glenn Taylor, NHC - January 1983 (PB83-163527)

NWS NHC 19 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1982. Gilbert B. Clark and Staff, NHC - February 1983 (PB83184077)

NWS NHC 20 The Miss/Hit Ratio - An Estimate of Reliability for Tropical Cyclone Track Predictions, Preston W. Leftwich, Jr. - April 1983

NWS NHC 21 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1983. Gilbert B. Clark and Staff, NHC - January 1984.

NWS NHC 22 A Tropical Cyclone Data Tape for the North Atlantic Basin, 1886-1983: Contents, Limitations, and Uses. Brian R. Jarvinen, Charles J. Neumann, and Mary A. S. Davis - March 1984

NWS NHC 23 Frequency and Motion of Western North Pacific Tropical Cyclones. Zongyuan Xue and Charles J. Neumann - May 1984 (PB85106466)

NWS NHC 24 Hurricane Experience Levels of Coastal County Populations - Texas to Maine - June 1984 (PB85111383)

NWS NHC 25 A Tropical Cyclone Data Tape for the Eastern and Central North Pacific Basins, 1949-1983: Contents, Limitations, and Uses - September 1984 (PB85110054)

NWS NHC 26 Annual Data and Verification Tabulation Atlantic Tropical Cyclones 1984. Gilbert B. Clark and Robert A. Case, NHC - February 1985.

NWS NHC 27 A Storm Surge Atlas for Corpus Christi, Texas. Brian R. Jarvinen, A. Barry Damiano, and Gloria J.D. Lockett - August 1985

NWS NHC 28 A Statistical Model for the Prediction of Western North Pacific Tropical Cyclone Motion (WPCLPR). Yiming Xu and Charles J. Neumann - November 1985