The Effects of Climatological and Persistence Variables on the Intensities of Tropical Cyclones over the Eastern North Pacific Ocean

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ABSTRACT

The effects of 10 climatological and persistence variables (latitude, maximum wind speed, 12-h change of maximum wind speed, longitude, distance to land, Julian date, sea surface temperature, speed of movement, zonal component of motion, and meridional component of motion) on changes of intensities of tropical cyclones over the eastern North Pacific Ocean were examined for the periods 1982–87 and 1988–93. Backward multiple regressions were performed to relate these 10 variables to changes in maximum intensity (as determined by wind speed) over periods ranging from 12 to 72 h. Latitude, maximum wind speed, and the 12-h change of maximum wind speed were the most significant variables. Each of the 10 variables was statistically significant at the 95% level at one or more of the time periods. Speed of movement, the component of motion, and the meridional component of motion were the least significant factors. The statistical relationships were tested using independent data from 1994. The mean absolute forecast errors ranged from 3.0 m s^{-1} at 12 h to 13.2 m s^{-1} at 72 h using one of two sets of regression equations developed in this study.

1. Introduction

The intensity of a tropical cyclone is the result of complex interactions between processes occurring within the system and the influences of the external environment. The conversion of latent energy to internal energy (sensible heat) creates the warm core in the upper levels of the tropical cyclone and is the primary internal process that determines the intensity of the system. Rainbands that wrap around the center of the circulation and the development of concentric eyewalls as described by Willoughby et al. (1982) can generate significant fluctuations in the maximum sustained wind speeds. Strong vertical shear of the horizontal wind disrupts the circulation around a tropical cyclone and generally produces a reduction of the maximum sustained wind speed. Molinari and Vollaro (1989) relate eddy momentum fluxes in the outflow levels to the intensities of hurricanes. Emanuel (1988) and DeMaria and Kaplan (1994a) demonstrate the impact of sea surface temperatures (SSTs) on the maximum potential intensities of tropical cyclones.

While much is known about the factors affecting the intensity of a tropical cyclone, in an operational environment the forecaster generally has two primary sources of guidance. One source of guidance is provided from the analysis of satellite imagery using the Dvorak (1984) technique. This technique uses a set of rules and criteria to estimate the current intensity and a future intensity at 24 h through the analysis of features on the imagery. The other primary source of guidance is produced by statistical models, such as the Statistical Hurricane Intensity Prediction Scheme (SHIPS) developed by DeMaria and Kaplan (1994b) for the Atlantic Ocean. In some instances intensity guidance is also available from numerical models, such as the Geophysical Fluid Dynamics Laboratory Hurricane Prediction System (Kurihara et al. 1995). At the current time the guidance from the numerical models is generally less accurate than the statistical products due to limitations of resolution and initial data.

Much of the research into the factors affecting the intensity of a tropical cyclone has been conducted over the Atlantic basin. Far less work has been published about the causes of changes of intensities for tropical cyclones over the eastern North Pacific Ocean. Although a Statistical Hurricane Intensity Forecasting (SHIFOR) model is used by the National Hurricane Center (NHC) to provide guidance for storms over the eastern North Pacific, the documentation of the model was never published. The purposes of this research were to describe and to evaluate statistical relationships between climatological and persistence variables and intensity changes of tropical cyclones over the eastern North Pacific Ocean for the periods of 1982–87 and 1988–93. The statistically significant relationships were tested using an independent dataset from 1994. The results of forecasts

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TABLE 1. Climatological and persistence variables.

Variable	Contraction
Absolute value of Julian date—237	(JDATE)
Current maximum wind speed	(VMX)
Intensity change in the previous 12 h	(DVMX)
Initial lat (°N) of the storm center	(LAT)
Initial long (°W) of the storm center	(LONG)
Zonal component of the storm motion	(USM)
Meridional component of the storm motion	(VSM)
Translational speed of the storm center	(CSM)
Distance to land	(DTL)
Potential intensification	(POT)

made with the relationships developed in this study were compared with a homogeneous sample of official NHC and SHIFOR forecasts. The evaluation of the predictive capability of the statistical relationships may be useful to forecasters and researchers studying tropical cyclones in this region. The data used in the analyses are described in section 2 and the results of the statistical analyses are evaluated in section 3.

2. Data

In this study the intensity of the tropical cyclone is represented by the maximum sustained wind speed. Maximum sustained wind speeds at 6-h intervals for tropical storms and hurricanes over the eastern North Pacific Ocean are contained in the ‘‘best track’’ file compiled by the former Eastern Pacific Hurricane Center in Redwood City, California, and the NHC in Miami, Florida. The maximum sustained wind speeds in the best track file were usually estimated from satellite imagery, except in cases where aerial reconnaissance or ship reports were available. Gaby et al. (1980) reported an average absolute difference of 3.8 m s^{-1} and an average algebraic difference of -2.4 m s^{-1} between satellite estimates of maximum wind speed and best track data for the Atlantic during periods when aerial reconnaissance and other data were available. If those results are also applicable to tropical cyclones over the eastern North Pacific, then the maximum sustained winds may be slightly underestimated in that basin. Since this study examines changes of intensity rather than absolute intensity, a small systematic error in the intensity estimates should not significantly affect the results of the analyses.

The relationships between the 10 climatological and persistence variables listed in Table 1 and intensity changes were examined. The first eight variables in Table 1 are the same climatological and persistence predictors used by DeMaria and Kaplan (1994b) in the development of the SHIPS model for the Atlantic basin. Two of the variables listed as synoptic predictors by DeMaria and Kaplan (1994b) were also included in the analysis. Those variables were DTL and POT.

The best track file includes the date, the latitude of the storm center, the longitude of the storm center, the maximum sustained wind speed, and in some instances the minimum sea level pressure. These variables are available in 6-h intervals. Three of the variables, VMX, LAT, and LONG, were directly available. DVMX was computed by subtraction of the maximum sustained winds at 12 h prior to the current time from VMX. JDATE was computed from the date in the file. CSM, USM, and VSM were computed by calculating the movement of the center of the storm over the 12 h prior to the initial time. DTL was computed from the center of the storm using the method developed by Merrill (1987). The potential intensification represents the difference between an empirically derived maximum potential intensity and the current maximum sustained wind speed. The empirical maximum potential intensity was computed from the relationship developed by Whitney and Hobgood (1997), which was

$$\mathrm{EPMPI} = C_0 + C_1(\mathrm{SST}), \qquad (1)$$

where EPMPI is the eastern Pacific maximum potential intensity in meters per second, SST is in degrees Celsius, $C_0 = -79.17262$ m s^{-1}, and $C_1 = 5.361814$ m s^{-1} $°C^{-1}$. SST was taken from the climatological SSTs developed by Levitus (1982) that were used to develop (1). EPMPI was calculated for the initial position of the storm. This procedure was slightly different from the averaging of the maximum potential intensity along the track used by DeMaria and Kaplan (1994b). POT was then computed from

$$\mathrm{POT} = \mathrm{EPMPI} - \mathrm{VMX}. \qquad (2)$$

Since the computation of DVMX, USM, VSM, and CSM required an observation 12 h prior to the current time, the first two observations for each storm were eliminated from the analyses. In an attempt to maintain a geographically coherent dataset, all observations west of 140°W longitude were removed from the analyses. When the center of a storm crosses west of 140°W, it leaves the area of responsibility of the NHC and moves into the area monitored by the Central Pacific Hurricane Center. All observations when the storms’ centers were over land were also eliminated from the analyses. Since the mountainous terrain of western Mexico produces rapid dissipation of tropical cyclones, this decision eliminated only a few observations from the analyses.

The decision on the time period for the analyses was one of the more difficult considerations. In order to capture a complete picture of the variability in tropical storm activity over the eastern North Pacific Ocean it was necessary to have a sufficiently long time period that includes one or more complete El Niño cycles. However, Whitney and Hobgood (1997) found a significant increase in the relative intensity of tropical cyclones in this region between 1988 and 1993. The relative intensity was computed as the ratio of VMX to EPMPI and was expressed as a percentage. The relative intensities exhibited little variation between 1973 and 1987. These results seemed to indicate that 1988 rep-

TABLE 2. Tropical cyclones over the eastern North Pacific Ocean from 1982 through 1993.

Year	Tropical storms	Hurricanes	Total
1982	8	11	19
1983	9	12	21
1984	6	12	18
1985	11	11	22
1986	9	8	17
1987	9	9	18
1988	8	7	15
1989	8	9	17
1990	4	16	20
1991	4	10	14
1992	10	14	24
1993	4	10	14

resented a discontinuity in the best track dataset. In 1988 the responsibility for monitoring tropical cyclone activity in this region was transferred from the Eastern Pacific Hurricane Center to the NHC. It was unclear if the increase in relative intensities was due to climatological factors or was the artifact of changes in the analysis procedures. It was decided to split the analyses into two periods. The first analysis period from 1988 to 1993 represented the first 6 yr of best track data compiled by the National Hurricane Center. The second period from 1982 to 1987 represented the final 6 yr of best track data compiled by the Eastern Pacific Hurricane Center. The best track data from 1994, which was the most recent active year in the eastern North Pacific, was kept for use as an independent test dataset.

3. Analyses

a. Exploratory analyses

The number of tropical cyclones over the eastern North Pacific for the two analysis periods are summarized in Table 2. The most active year was 1992, which produced 24 named tropical cyclones. There were also 20 or more named tropical cyclones in 1983, 1985, and 1990. The three least active years were 1988, 1991, and 1993. The summary statistics for the two periods chosen for the regression analyses are presented in Table 3. There were nearly two more named tropical cyclones per year between 1982 and 1987 than there were in the period from 1988 to 1993. However the mean of the maximum sustained winds was 2.2 m s^{-1} higher and the mean storm duration was 0.6 days longer during the latter period. These data indicate that the frequency of tropical cyclones was much more variable between 1988 and 1993, but the average storm was more likely to reach hurricane strength. The mean latitude and longitude shown in Table 3 indicates that between 1988 and 1993 tropical cyclones occurred farther north and west than during 1982–87. The movement of the storms during both time periods was close to the long-term climatological mean. The differences in the means of maximum sustained wind speeds, latitude, and longitude support the decision to analyze the two periods separately. The division into the two 6-yr periods produced two datasets with nearly equal numbers of observations.

TABLE 3. Summary statistics for the two analysis periods.

	1982–87	1988–93
Named storms yr^{-1}	19.2	17.3
Hurricanes yr^{-1}	10.5	11.0
Total observations	2890	2850
Mean storm duration (days)	6.3	6.9
Mean maximum wind speed (m s^{-1})	26.0	28.2
Mean lat (°N)	16.1	16.8
Mean long (°W)	114.7	116.2
Mean translation speed (m s^{-1})	4.6	4.4
Mean storm heading (°)	294	289

b. Regression analyses

Multiple linear regression analysis was chosen as the statistical procedure to relate the 10 variables mentioned in section 2 to the changes in the maximum wind speed. This is the same technique used by DeMaria and Kaplan (1994b) to develop the SHIPS model. The change in the maximum wind speed over a given time span ranging from 12 to 72 h is the dependent variable in each of the regression analyses. As stated by DeMaria and Kaplan (1994b), ‘‘The distribution of the intensity changes for a fixed time interval is approximately normal, with a mean close to zero.’’ While they were describing the data for the Atlantic Ocean, the exploratory analyses confirmed that the statement was also valid for the tropical cyclones over the eastern North Pacific Ocean. Thus, multiple linear regression is an appropriate technique for relating the 10 independent variables to the changes in maximum wind speed.

A backward elimination procedure was used for each regression. The procedure began with all of the independent variables in the equation and then the variables were tested sequentially to see if they were eligible for removal. The test was based on the F statistic. Independent variables remained in the equation when the probability that the regression coefficient was not zero was greater than 95%. If an independent variable was removed from the equation, the procedure was repeated and the equations were recomputed until the remaining variables were all statistically significant at the 95% level. Six regressions were performed for each of the two time periods discussed in section 2. The dependent variables for the regressions were the changes in maximum wind speeds over 12, 24, 36, 48, 60, and 72 h, respectively, after the current time. In order to make the magnitudes of the regression coefficients easier to interpret and to be comparable to those published by DeMaria and Kaplan (1994b) the variables were normalized by subtraction of the mean and division by the standard deviation. This procedure was repeated for every variable prior to each regression.

The normalized regression coefficients for the re-

TABLE 4. Normalized regression coefficients for the period from 1988 through 1993. Coefficients in bold are statistically significant at the 95% level.

Time (h)	12	24	36	48	60	72
LAT	**−0.29**	**−0.34**	**−0.39**	**−0.37**	**−0.32**	**−0.28**
VMX	**−0.20**	**−0.25**	**−0.30**	**−0.32**	**−0.35**	**−0.39**
DVMX	**+0.52**	**+0.38**	**+0.25**	**+0.16**	**+0.11**	**+0.06**
JDATE	**−0.08**	**−0.11**	**−0.14**	**−0.16**	**−0.17**	**−0.19**
LONG	**+0.25**	**+0.22**	+0.12	−0.13	**−0.17**	**−0.29**
DTL	**−0.28**	**−0.26**	**−0.21**	**−0.12**	+0.01	−0.13
POT	+0.07	**+0.14**	**+0.13**	**+0.14**	+0.09	+0.12
USM	**−0.10**	**−0.12**	**−0.12**	**−0.12**	−0.11	+0.01
CSM	**−0.09**	**−0.10**	**−0.10**	−0.10	−0.10	+0.00
VSM	+0.01	−0.01	−0.03	**−0.05**	**−0.07**	**−0.10**
r^2	0.48	0.50	0.53	0.57	0.61	0.63
Cases	2646	2442	2238	2041	1848	1659

gressions for the period from 1988 through 1993 are presented in Table 4. The coefficients in bold type are statistically significant at the 95% level in the final regression equations. Latitude was the most significant variable when all six regressions are considered. The negative coefficients for LAT are consistent with physical reasoning. As a tropical cyclone in the eastern North Pacific moves northward, it is more likely to move over colder waters and to experience increasing vertical shearing of the horizontal winds. Both of these factors are linked to decreases of maximum sustained wind speeds of tropical cyclones. The magnitudes of the coefficients remain relatively consistent through all six equations.

The second most significant variable in the six equations was the current maximum sustained wind speed. The negative coefficients for VMX reflect the fact that intense tropical cyclones are more likely to undergo weakening than continued strengthening. Conversely, weak tropical cyclones in the best track file intensified sufficiently to reach tropical storm status. The average tropical cyclone existed for a period of slightly under seven days during these years. The coefficients for VMX reflect the fact that the early observations for each storm in the best track file generally represented a weak system that was intensifying. The maximum sustained wind speeds reached a peak after three or four days and then the tropical cyclone weakened over the next few days. Thus, VMX is negatively correlated with future intensity changes. The magnitudes of the regression coefficients become more negative with an increase in the time period for the intensity changes. This reflects the typical pattern described previously.

The change in the maximum sustained wind speed over the previous 12 h was the third variable that was statistically significant at all time intervals. DVMX was the most significant variable related to intensity changes at 12 and 24 h. The coefficients for DVMX were positive and decreased as the time interval for the intensity changes increased. The results are consistent with the fact that DVMX is a trend variable and functions somewhat as a surrogate for the synoptic environment surrounding the tropical cyclone. If the environment has produced an increase in the maximum sustained wind speeds over the previous 12 h, then it is likely that the conditions will persist in the shorter term and the wind speeds will continue to increase. The decreases of the coefficients at longer time intervals are indications that over those intervals the environmental conditions are less likely to remain consistent and persistence of a trend becomes less useful as a predictive variable. By 72 h DVMX is the least significant variable remaining in the final equation.

JDATE is the fourth and final variable that is statistically significant at all time intervals. JDATE is zero on 25 August, which is the climatological peak of the frequency of tropical cyclones over the eastern North Pacific. JDATE increases as the date is farther from 25 August and the environment becomes climatologically less favorable for the development of tropical cyclones. This relationship accounts for the negative coefficients for JDATE.

The coefficients for longitude change sign over the six equations. The coefficients for LONG are positive at 12 and 24 h and negative at 60 and 72 h. These coefficients are the result of the decision to normalize each variable prior to each regression. LONG is positive when the storm's center is to the west of the mean longitude of all of the observations. In those cases the tropical cyclone is likely to intensify in the first 24 h and then weaken. This is the result of movement over colder SSTs that are to the west of this area. These coefficients can also be partly explained by the typical east to west motion of these tropical cyclones. Systems generally develop in the eastern part of the region and then intensify as they move westward. Thus, during the intensifying phase increased longitude is correlated with increased maximum sustained wind speeds. DTL was included as one of the variables, because proximity to land often produces a reduction in the maximum sustained wind speeds due to entrainment of drier air into the circulation of the tropical cyclone. However, DTL was not as significant as the variables mentioned previously. Due to the orientation of the western coastline

TABLE 5. Normalized regression coefficients for the period from 1982 through 1987. Coefficients in bold are statistically significant at the 95% level.

Time (h)	12	24	36	48	60	72
LAT	−**0.18**	−**0.28**	−**0.47**	−**0.64**	−**0.73**	−**0.74**
VMX	−0.01	−0.06	−**0.18**	−**0.38**	−**0.57**	−**0.69**
DVMX	**+0.34**	**+0.28**	**+0.21**	**+0.18**	**+0.14**	**+0.11**
JDATE	−**0.12**	−**0.16**	−**0.20**	−**0.22**	−**0.25**	−**0.25**
LONG	−0.03	−0.02	+0.15	**+0.32**	**+0.39**	**+0.38**
DTL	+0.01	−**0.03**	−**0.25**	−**0.46**	−**0.57**	−**0.58**
POT	**+0.27**	**+0.29**	**+0.20**	+0.01	−**0.17**	−**0.28**
USM	+0.01	0.00	0.00	0.00	**+0.03**	**+0.07**
CSM	+0.01	+0.01	−0.01	−0.02	−0.02	+0.01
VSM	**+0.05**	+0.03	0.00	−**0.04**	−**0.08**	−**0.11**
r^2	0.35	0.44	0.51	0.56	0.60	0.62
Cases	2662	2434	2209	1992	1785	1587

of North America, DTL is positively correlated with LONG. DTL was negatively correlated with changes in the maximum sustained winds speeds up to 48 h. The negative coefficients for DTL are related to the decrease of SSTs experienced by storms moving away from the coast and result from variance not explained by LONG in the multiple regression procedure.

The coefficients for POT are positive, which is consistent with physical reasoning. POT represents the difference between the maximum sustained wind speed of the strongest tropical cyclone observed in the eastern North Pacific over the same SST as the current storm and VMX. Thus, POT represents an empirically based potential for further intensification based on the SST. The regression coefficients for POT are only statistically significant at 24, 36, and 48 h. This result is somewhat disappointing, since POT is partly a function of SST and is one of the more physically based variables in the regressions. However, in the eastern North Pacific Ocean SSTs are strongly correlated with latitude. As defined in (2) POT is a function of VMX and EPMPI, and in (1) EPMPI is a function of SST. Thus, when LAT and VMX emerged as the two most statistically significant variables, there was much less variance left to be explained by POT. Consideration was given to removing LAT or VMX and repeating the regressions, but a decision was made to allow the statistical procedure to identify the most significant variables. In future studies, it may be desirable to omit LAT and/or VMX from the analyses.

Although each of the variables related to the motion of the storm is statistically significant at three or more time intervals, USM, CSM, and VSM are the least significant of 10 ten variables in the regressions. This is a result of the consistent movement of most storms to the west-northwest at 4–5 $\mathrm{m\ s^{-1}}$. The regression coefficients for these three variables are negative. This reflects the fact that faster motion is often in conjunction with increased vertical shear of the horizontal wind and is associated with decreases in the maximum sustained wind speed. The negative coefficients with USM and VSM are also related to movement toward colder SSTs.

The amount of the variance explained by the final regression equation for each time interval is also presented in Table 4 in terms of the r^2. The variance explained increases from 48% at 12 h to 63% at 72 h. These percentages are higher than those achieved by DeMaria and Kaplan (1994b) during the development of the SHIPS model with synoptic predictors for the Atlantic Ocean. There are both physical and procedural reasons for the higher percentages in Table 4. As stated earlier, many tropical cyclones over the eastern North Pacific Ocean exhibit patterns of intensity and of motion that are very close to the long-term climatological means. Thus, the geographical variables, LAT and LONG, the intensity variables, VMX and DVMX, and the climatological surrogate variable, JDATE, are able to explain a high percentage of the variance. The maximum sustained wind speeds in the best track file are mostly the results of analyses of satellite images using the Dvorak (1984) technique, which is designed to produce temporally consistent estimates of intensity and intensity change. The increase in explained variance over increased time intervals was also found by DeMaria and Kaplan (1994b) and may be partially due to the reporting of maximum sustained wind speeds in increments of 2.6 $\mathrm{m\ s^{-1}}$ (5 kt). The use of these increments may have a greater impact on the ability to explain the variance at shorter time intervals when the changes in the maximum sustained wind speeds are generally less.

The normalized regression coefficients for the regression for the period from 1982 through 1987 are presented in Table 5. If the coefficients in Table 5 were the same as those for the period from 1988 through 1993, then it would be possible to state confidently that the regressions produced robust statistical relationships valid over the longer term. There are distinct similarities between the two sets of coefficients. LAT, VMX, DVMX, and JDATE are significant variables in both sets of equations. LAT was again the most significant variable when all six regressions were considered for the years from 1982 through 1987. DVMX was the most significant variable at shorter intervals, although at 12 and 24 h the coefficients were smaller than for the period from 1988 through 1993. The variables related to the movement of the tropical cyclone, CSM, USM, and VSM are the least significant variables in Tables 4 and 5. However, there are some significant differences between the two sets of coefficients. In Table 5 it can be seen that DTL is more significant than LONG at all time periods and that POT is more significant than it was for the period from 1988 through 1993. These differences may reflect changes in the atmospheric patterns over the eastern North Pacific or they may be related to changes in the analyses that may have occurred when the responsibility for this region was shifted from the Eastern Pacific Hurricane Center to the NHC.

The equations developed for the years from 1982 though 1987 explained 13% less variance at 12 h and 6% less variance at 24 h. The decrease in explained variance may be another manifestation of the transfer of forecast responsibility in 1988. NHC has a very systematic method for generating the best track files. It is possible that there was less smoothing of the best track data prior to 1988. This would be consistent with the smaller coefficients for DVMX at 12 and 24 h. Greater uncertainty in the location of the centers of tropical cyclones, which would affect LAT, LONG, DTL, and POT, might contribute to these results. The percentages of the variance explained by the two sets of equations are quite similar for the intervals from 36 through 72 h.

c. Independent tests

A further test of the robustness of the statistical relationships generated by the regression equations was performed with an evaluation of the final equations using independent data. The tropical cyclones over the eastern North Pacific Ocean during 1994 were chosen as the independent dataset. During 1994 there were 19 tropical cyclones over this region. There were nine hurricanes, eight tropical storms, and two systems that only reached tropical depression strength. The 17 named tropical cyclones were close to the 6-yr average from 1988 through 1993. However, the nearly equal occurrences of hurricanes and tropical storms was more similar to the data from 1982 through 1987. As noted by Pasch and Mayfield (1996), many of the tropical cyclones intensified in locations much farther westward than is normally seen in this region. Hurricanes Emilia, Gilma, Lane, and Olivia underwent periods of rapid intensification. The number and types of tropical cyclones in 1994 provided an excellent test of the statistical relationships developed in the previous section. The observations for all 19 tropical cyclones, including the two systems that did not reach tropical storm status, were used in the independent tests. In order to be consistent with the data used to develop the regression equations, observations when the center was west of 140°W longitude or over land were not used in the independent tests.

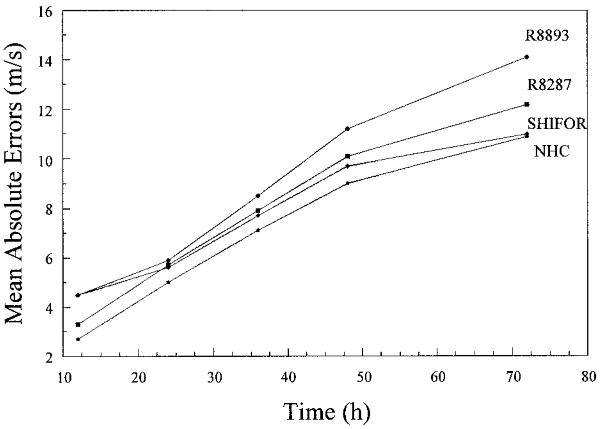

FIG. 1. Mean absolute forecast errors for the two sets of regression equations using operational data for 1994.

In making an operational prediction forecasters must often deal with uncertainties in the initial position and intensity of the tropical cyclone. An attempt is made to resolve as many of these uncertainties as possible in the production of the best track data that were used to generate the regression equations. In order to conduct a fair test the data available to the operational forecasters at the NHC in 1994 were used to perform a homogeneous comparison of the regression equations and the official forecasts. The results from a statistically based model run at the National Hurricane Center (SHIFOR) were also included in the homogeneous comparison.

The mean absolute errors for the homogeneous comparison are shown in Fig. 1. The official forecasts from the NHC had the lowest mean absolute errors at all time periods. SHIFOR generally exhibited lower mean absolute errors than the two sets of regression equations. The equations from 1982 to 1987 had the lower mean absolute errors of the two sets of regression equations. The mean absolute errors for the R8287 model ranged from 3.3 m s^{-1} at 12 h to 12.2 m s^{-1} at 72 h. At 12 h the mean absolute error of the R8287 model was 0.8 m s^{-1} less than SHIFOR. The mean absolute errors for the set of equations from 1988 to 1993 were higher than the other forecasts. They ranged from 4.5 m s^{-1} at 12 h to 14.1 m s^{-1} at 72 h. The mean forecast errors for the homogeneous comparison from 1994 are shown in Fig. 2. The R8287 model had the mean errors closest to zero when all time intervals were considered. The official forecasts from the NHC had a slight tendency to overpredict the maximum sustained wind speeds. The R8893 model underpredicted the intensity at 12 h and overpredicted at the longer intervals. These results indicate a probable bias of the R8893 model for the 1994 independent sample.

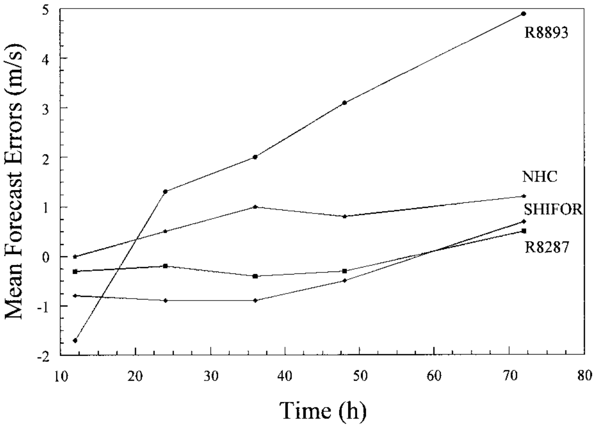

FIG. 2. Mean forecast errors for the two sets of regression equations using operational data for 1994.

4. Discussion and conclusions

The analyses presented in section 3 described the statistical relationships between climatological and persistence variables and intensity changes of tropical cyclones over the eastern North Pacific Ocean for the periods 1982–87 and 1988–93. Latitude was the most significant predictor during both periods. As tropical cyclones move northward in this region, they are more likely to encounter colder SSTs and increased vertical shear of the horizontal winds. Both of these factors contribute to a reduction of the maximum sustained wind speeds. Persistence of the current rate of change of maximum sustained winds speeds was the best predictor over 12 and 24 h. This variable acts as a surrogate for the current environmental conditions and is most highly correlated with short-term intensity changes. Persistence of a trend becomes much less useful as a predictor as the time interval increases and the environment around a system changes more substantially. The current maximum wind speed, the Julian date, and the longitude were less significant predictors. Distance to land and potential intensification were correlated with other more significant predictors, and the three variables related to the movement of the storm were the least significant predictors.

The percentage of variance explained by the final equations for the years 1988 through 1993 ranged from 48% at 12 h to 63% at 72 h. These percentages are higher than those reported by DeMaria and Kaplan (1994b) for the SHIPS model for the Atlantic Ocean that included synoptic predictors. These percentages indicate that the intensity changes over the eastern North Pacific are more predictable than those occurring in tropical cyclones over the Atlantic. Most tropical cyclones over the eastern North Pacific travel similar paths and follow similar cycles of intensification and dissipation. These facts allow variables related to location and previous changes of intensity to predict future changes of intensity. The general absence of aircraft reconnaissance over the eastern North Pacific and the use of the Dvorak (1984) technique enhances the significance of persistence of the current trend for intensity change as a predictor at 12 and 24 h.

There were some differences in the normalized regression coefficients from the two periods. The change of maximum sustained wind speeds over the previous 12 h was much less significant at 12 and 24 h for 1982–87. The final regression equations explained 13% less variance at 12 h and 6% less variance at 24 h for 1982–87. These results may indicate that there was less smoothing of the best track data prior to 1988 when the NHC assumed forecast responsibility for the eastern North Pacific. Users of the best track data for this region should be aware of possible changes to the procedures used to generate those data, which may have occurred in 1988.

An independent test of the final regression equations was conducted with data from 1994. The predicted intensities were compared with the official forecasts from the NHC and forecasts from an operational statistical model, SHIFOR. The official forecasts from the NHC had the lowest mean absolute forecast errors at all time periods. The R8287 model had a mean absolute error that was 0.8 m s^{-1} less than SHIFOR at 12 h, but SHIFOR outperformed the final regression equations over all other intervals. The regression equations were unable to improve on the operational statistical model despite the incorporation of SST into the potential intensification variable. These results seem to confirm that although SST, as a surrogate for the energy available in the mixed layer of the ocean, acts as an upper bound on intensity, other environmental factors control the observed intensity of a tropical cyclone. More research is needed to identify and to quantify the effects of synoptic predictors, such as wind shear, on the intensity of tropical cyclones over the eastern North Pacific Ocean.

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