FORECASTING TROPICAL CYCLONE INTENSITY CHANGE IN THE WEST PACIFIC

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1. INTRODUCTION

According to a National Disaster Survey Report on Hurricane Andrew (1993), hurricane intensity forecasts lack skill and scientists are urged to "redouble their efforts to develop models and operational techniques to forecast tropical cyclone intensity changes more effectively." In response, researchers are attempting to improve modelling techniques (Bender et al. 1993) and climatology statistical regression schemes (Landsea 1995; Chu 1994). Another regression scheme – the Statistical Hurricane Intensity Prediction Scheme (SHIPS) – incorporates Sea Surface Temperature (SST) and synoptic predictors in addition to climatology for the Atlantic Basin (DeMaria and Kaplan 1994).

This paper describes a recently developed regression scheme that is analogous to SHIPS for the West Pacific Basin. The new scheme is titled the Typhoon Intensity Prediction Scheme (TIPS), and includes digitized infrared satellite data as predictors – the first time such information has been included in a multiple regression forecast analysis. It is shown that satellite information improves intensity prediction, especially for storms which intensify quickly.

2. DATA and REGRESSION TECHNIQUE

Satellite data has been processed for 1983-1986, coinciding with reconnaissance flights before their termination in 1987. The regression equation is built on data for the years 1984-1986, since these years contain the most data compared to other three-year subsets. The accuracy of the empirical scheme is tested on independent data for 1983.

The sample consists of SST information, synoptic winds, satellite data, and climatology. The Joint Typhoon Warning Center (JTWC) Besttrack data is used for climatological input. The SST data is stored by year and month (Reynolds 1989). The synoptic data is obtained from the Australian Bureau of Meteorology Research Centre (BMRC) for 1984 to July 1986 (Davidson and McAvaney 1981). For 1983 and July-December 1986, synoptic data from European Centre for Medium-range Weather Forecasts (ECMWF) is used. Both synoptic data are on 2.5° grid spacing analyzed at 00 and 12 GMT.

The satellite source is 10 km resolution infrared "pixels" from the Geostationary Meteorological Satellite (GMS). The data is processed in radial areas with respect to the storm center (i.e., 0-1°, 0-2°, 0-4°, 0-6°, 0-8°, 1-2°, 2-4°, etc.). Then, the percentage of pixels colder than a specified brightness temperature (T_b) in the radial areas are computed.

For this empirical scheme, the future change of maximum wind (ΔV_{max}) is chosen as the dependent variable (consistent with SHIPS). In the development of a multiple regression model, it is desirable to pick the fewest number of significant predictors, as "overfitting" the sample data will lead to degradation of skill on the independent data (Aczel 1989). Therefore, stepwise regression is used to optimize the number of significant predictors. A total number of 116 variables are initially considered. These include Julian day, storm speed and direction, SST, latitude, longitude, wind shear, eddy fluxes (similar to SHIPS), 200 mb vorticity, and 200 mb vorticity advection. Furthermore, numerous linear and nonlinear pixel count thresholds/areas are examined as well as pixel count trends. The significance level of acceptance is 95%.

After this procedure, multicollinearity is examined. Multicollinearity occurs when two or more of the predictors are highly correlated with each other, and is undesirable (Aczel 1989). It is assumed that multicollinearity existed when the linear correlation coefficient is ≥ 0.5 between two predictors. This often occurs when several pixel count data or climatology variables are selected. Under these circumstances, the predictor chosen earliest in the stepwise procedure is used and the others rejected. Then the stepwise procedure is repeated on the remaining variables. Usually a few variables accepted in the initial stepwise process are then rejected in the second pass, leaving 6-8 final predictors.

3. REGRESSION RESULTS

Although analysis is applied to 12, 24, 36, and 48 h intensity change, only the 24 h scheme will be discussed here. Table 1 lists the chosen predictors, and are schematically shown in Fig. 1. POT measures intensification potential based on the difference between an empirically derived Maximum Potential Intensity (MPI) from SST and the current storm intensity (DeMaria and Kaplan, 1994). SHEAR is computed over a 5.0° circle by:

$$\mathrm{SHEAR} = \sqrt{(\overline{\Delta u})^2 + (\overline{\Delta v})^2} \qquad (1)$$

where $\Delta u = u_{200} - u_{850}$ at a radius r and circle angle ϕ. Denoting $r = 2.5°$ & $5.0°$ with $i = 1$ & 2, and $\phi = 0$, 90, 180, & 270 deg with $j = 1$ to 4, $\overline{\Delta u}$ is computed as

$$\overline{\Delta u} = \frac{1}{9}\left[\Delta u(r=0) + \sum_{i=1}^{2}\sum_{j=1}^{4}\Delta u_{i,j}\right] \qquad (2)$$

and likewise for $\overline{\Delta v}$. It was found that slightly more variance was explained using 5.0° areal SHEAR than 2.5° or "single point" shear at $r = 0$. SHIPS produced

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Table 1: 24 h regression predictors. A perfect forecast of the storm track and shear are assumed.

1) POT	Maximum Possible Intensity (MPI) minus initial intensity (V_{max}). MPI is averaged over the forecast track (ms^{-1}).
2) SHEAR	Magnitude of 200–850 mb vertical shear averaged over a 5° circle and averaged over the forecast track (ms^{-1}).
3) TREND	Indicator variable that parameterizes the existence of a well-formed, contracting eye. If $V_{max} \geq 55$ kts and $\Delta V_{max} > 0$ the past 12 h, TREND = 1; otherwise, TREND = 0.
4) PIX	Percent of pixels for $T_b < -55°C$ in a 0–4° circular area.
5) DPIX	12 h change of pixels (%) for $T_b < -70°C$ in a 0–1° circular area.
6) VSM	Northward component of storm motion vector (ms^{-1}).
7) LONG	Initial storm longitude (deg E).

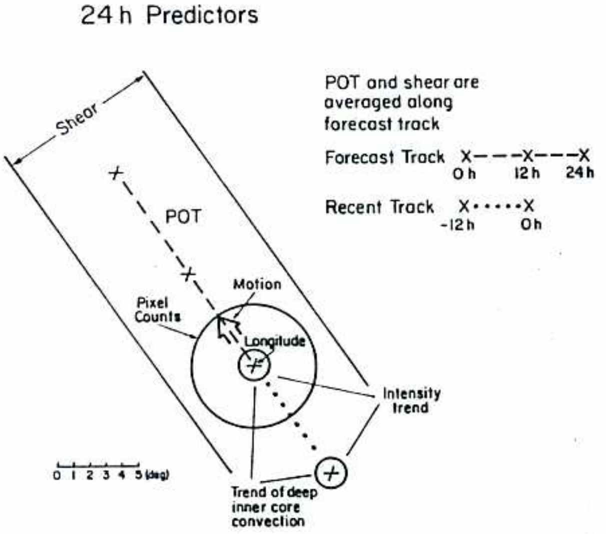

Figure 1: General schematic of chosen predictors, which are defined in Table 1.

similar conclusions (M. DeMaria, personal communication). Both MPI (for POT) and SHEAR are averaged over the forecast track.

TREND combines two intensification characteristics: persistence and eye formation. Quickly intensifying storms are associated with eye subsidence (generally when $V_{max} \geq 55$ kts) and eyewall contraction (generally when $\Delta V_{max} > 0$). Climatology shows that W. Pacific storms generally intensify preceding recurvature and when they are east of 130° (Mundell, 1990) – hence, the stepwise routine selected the two predictors VSM and LONG.

Two satellite values were chosen. PIX is a measure of two favorable intensification features. First, it is a measure of cloud symmetry in a 0-4° areal circle – asymmetric clouds or lack of clouds are signs of a unhealthy storm. Second, eyewall convection (which is in a 0-2° area) is included in PIX. The other satellite predictor is DPIX, which is a persistence value. Since DPIX's components are the 12 h tendency of $T_b < -70°C$ in a 0-1° area, it is a measure of deep inner core convective change.

Denoting σ as the standard deviation of a variable, $y = \Delta V_{max}$, and $\overline{x}$ as the variable mean, a number k predictors are normalized by the following regression:

$$(y - \overline{y})/\sigma_y = \sum_{i=1}^{k} c_i(x_i - \overline{x}_i)/\sigma_i \qquad (3)$$

The advantage of this approach is that the importance of a predictor may be assessed by the regression coefficient c_i between different variables and different forecast intervals (DeMaria and Kaplan 1994), and that the y-intercept is zero. Table 2 shows values for c_i and x_i at 24 h.

Table 2: Normalized regression coefficients c_i and mean predictor values $\overline{x}_i$ for TIPS at 24 h. Variance=53.5%, and the sample size for 1984-1986 is 538.

Variable	c_i	$\overline{x}_i$
1) POT	+0.59	38.6
2) SHEAR	-0.25	8.5
3) TREND	+0.29	0.39
4) PIX	+0.26	25.4
5) DPIX	+0.07	0.0
6) VSM	+0.15	2.0
7) LONG	+0.08	135.9

From this table, it is apparent that POT is the strongest predictor, followed (in order) by TREND, PIX, SHEAR, VSM, LONG, and DPIX. Normalization analysis also allows one to infer threshold values for predicting intensification or weakening of a storm. For example, POT > 38.6 ms^{-1}, PIX > 25.4%, and SHEAR < 8.5 ms^{-1} all contribute to intensification. But a typhoon west of 135.9 E might be expected, in general, to weaken the next 24 h.

Another feature that can be studied is how a predictor contributes to different magnitudes of ΔV_{max}. Figure 2 shows average PIX values for different classes of intensity change ($\overline{\text{PIX}}$), and Fig. 3 shows $\overline{\text{POT}}$ in a similar fashion. Note that $\overline{\text{PIX}}$ contributes strongly to quickly intensifying storms ($\Delta V_{max} > 20$ kts) with a normalized standard deviation ($[x - \overline{x}]/\sigma$) of 0.72 but does not contribute significantly to moderately intensifying storms ($20 \geq \Delta V_{max} \geq 10$ kts). However, while $\overline{\text{POT}}$, is a positive contributor to both intensification classes, it is not distinctly different in these two regimes. $\overline{\text{DPIX}}$ and $\overline{\text{TREND}}$ share $\overline{\text{PIX}}$'s characteristic of strongly contributing to the $\Delta V_{max} > 20$ kts class but not to the $20 \geq \Delta V_{max} \geq 10$ kts class (not shown). Meanwhile $\overline{\text{SHEAR}}$ is similar to $\overline{\text{POT}}$ and is not different in the two intensifying classes (not shown). Hence, the satellite data plays a crucial role in differentiating storms which will intensify quickly and those that will intensify moderately. On the other hand, $\overline{\text{POT}}$ differentiates between moderately weakening storms and quickly weakening storms, while $\overline{\text{PIX}}$ does not.

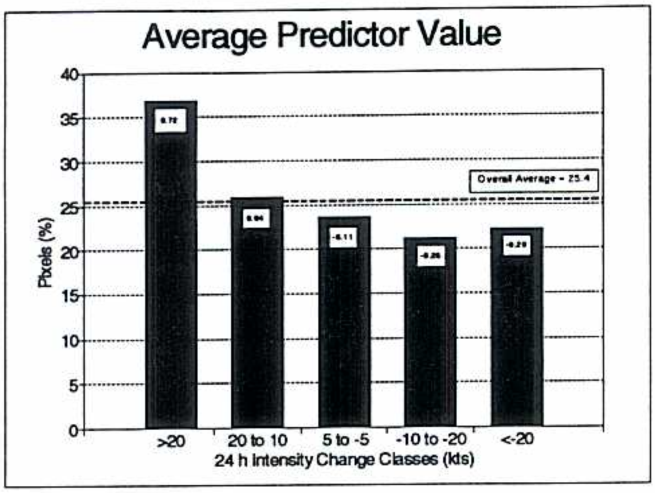

Figure 2: Average PIX values for different ΔV_{max} classes. Numbers on the bars are normalized standard deviations defined by $(x - \overline{x})/\sigma$. The overall average from Table 2 (denoted by the dashed line) is shown for comparison.

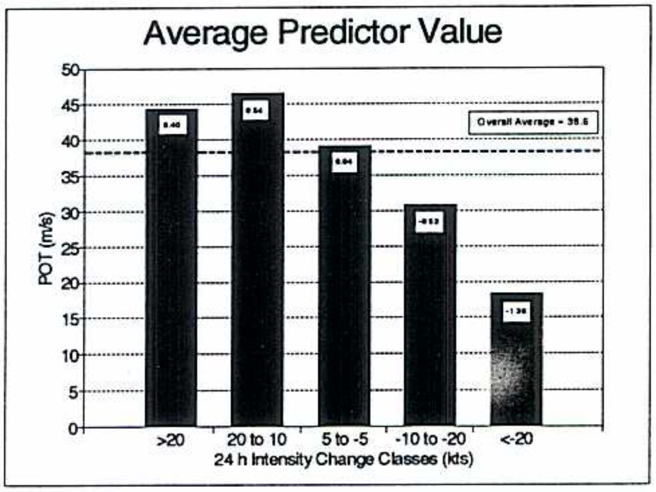

Figure 3: As in Fig. 2, but for POT.

4. FORECAST RESULTS

Absolute errors from TIPS for 24 h are computed for the independent data set (1983) and compared to JTWC's 1983 forecast (Fig. 4). In general, the regression errors are fairly high, but constitute a 19% improvement on average compared to JTWC, and 25-30% improvements for quickly changing ΔV_{max}. The error reductions are higher at 48 h, where the average improvement is 26%; furthermore, there is 40-50% less error for $\Delta V_{max} > 40$ kts or < -40 kts in 48 h (not shown).

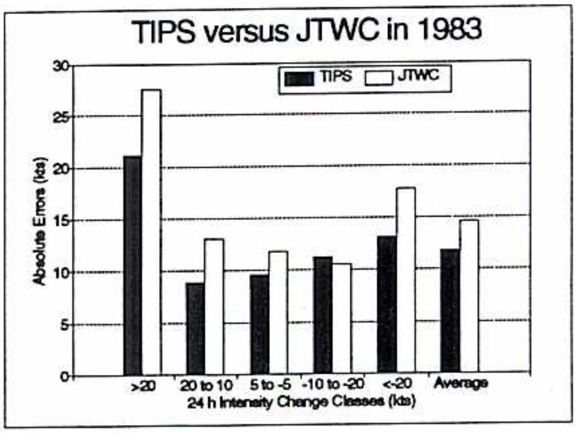

Figure 4: Absolute 24 h errors for TIPS and JTWC on the independent data set (1983).

Since the variance explained by TIPS ranges from 50% to 60%, there is still much room for improvement in tropical cyclone intensity forecasting. However, the utilization of quantitative satellite data seems promising.

5. ACKNOWLEDGMENTS

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REFERENCES

Aczel, A. D., 1989. Complete Business Statistics. Richard D. Irwin, Inc., 1056 pp.

Bender, M. A., R. J. Ross, R. E. Tuleya, and Y. Kurihara, 1993: Improvements in tropical cyclone track and intensity forecasts using the GFDL initialization system. *Mon. Wea. Rev.*, 121, 2046-2061.

Chu, J., 1994: A regression model for the western North Pacific tropical cyclone intensity forecast. Tech. Report NRL/MR/7541–94–7215, Naval Research Laboratory, Monterey, CA 93943, 33 pp.

Davidson, N. E., and B. J. McAvaney, 1981: The ANMRC tropical analysis scheme. *Aust. Met.*, 29, 155-168.

DeMaria, M., and J. Kaplan, 1994: A Statistical Hurricane Intensity Prediction Scheme (SHIPS) for the Atlantic Basin. *Wea. Forecasting*, 9, 209-220.

Landsea, C., 1995: SHIFOR94 – Atlantic tropical cyclone intensity forecasting. Preprints, *21st Conf. on Hurricanes and Tropical Meteorology*, Miami, FL, Amer. Meteor. Soc., see table of contents.

Mundell, D. B., 1990: Prediction of tropical cyclone rapid intensification events. M. S. Thesis, Colorado State University, Fort Collins, CO, 80523, 186 pp.

National Disaster Survey Report, 1993: Hurricane Andrew: South Florida and Louisiana, August 23-26, 1992. NOAA Tech. Report, Silver Spring, MD 12345, 131 pp.

Reynolds, R. W., 1988: A real-time global sea surface temperature analysis. *J. Climate*, 1, 75-86.