14.7 Estimating the Likelihood of Rapid Intensification in the Atlantic and E. Pacific Basins using SHIPS Model Data

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1. Introduction

The National Hurricane Center/Tropical Prediction Center (NHC/TPC) has identified obtaining guidance on the timing and magnitude of episodes of rapid intensification as one of the highest operational tropical cyclone forecasting priorities. In an effort to provide a tool to aid in the forecasting of rapid intensification, Kaplan and DeMaria (2003) developed a simple index for estimating the probability of rapid intensification (RI) for the Atlantic basin as part of the NOAA Joint Hurricane Testbed (JHT). The original Atlantic RI index employed 5 large-scale predictors from the operational SHIPS (DeMaria et al. 2005) model to estimate the probability of rapid intensification for the 24-h period commencing at t=0 h. The index was provided in real-time to forecasters at the TPC from 2001-2003 and was made operational by the NHC/TPC commencing with the 2004 Hurricane Season. Since the original RI index was developed specifically for the Atlantic basin an RI index was also developed for the E. Pacific basin with support from the JHT. The E. Pacific RI index was very similar to that previously developed for the Atlantic basin except that it also included 2 satellite-derived inner-core predictors since sensitivity tests showed that the inclusion of this data improved the skill of the index. For consistency, the 2004 Atlantic version of the RI index also included these 2 satellite predictors.

Prior to the 2005 hurricane season a revised version of the rapid intensification index was developed for both the Atlantic and E. Pacific basins. The 2005 version of the rapid intensification index differed from that used in previous seasons in a few ways. First, the threshold for rapid intensification was reduced slightly from a maximum sustained wind increase threshold of $\geq$ 30 kt (35 kt) in 24-h for the Atlantic (E. Pacific) basins employed previously to a threshold of $\geq$ 25 kt in 24 h for both the Atlantic and E. Pacific basins. The 30 (35) kt threshold previously employed for the Atlantic (E. Pacific) basins represented approximately the 95% of over-water intensity changes, while the threshold of $\geq$ 25 kt represented approximately the 90th percentile of over-water intensity changes. Also, the methodology for deriving the index was modified so that that the contributions from each of the rapid intensification predictors represented a scaled value between 0 and 1 rather than simply a 0 or 1 as had been employed in the prior version of the index. The aforementioned changes were implemented since sensitivity tests showed that these modifications yielded increased forecast skill. The revised version of the rapid intensification index was run in real-time commencing in July of 2005 in both the Atlantic and E. Pacific basins and the output was provided to the NHC.

2. Methodology

The data employed in this study were obtained from the SHIPS and NHC HURDAT databases. The former contains synoptic and storm-scale predictors evaluated every 6 h for all tropical and subtropical cyclones in the Atlantic and Eastern Pacific basins. The SHIPS synoptic atmospheric predictors were evaluated using the t=0 h NCEP Aviation analysis fields while the synoptic oceanic predictors were evaluated using the most recent weekly Reynolds sea-surface temperature analysis. The storm-scale inner-core predictors were determined from GOES infrared imagery (Zehr 2000). The NHC HURDAT file, which contains tropical cyclone positions and intensities every 6 h from 1886 to the present

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was employed to evaluate the climatological and persistence predictors.

Previous versions of the RI index employed a threshold methodology (Kaplan and DeMaria 2003). The threshold methodology compares RI predictor magnitudes to previously determined RI thresholds for predictors for which statistically significant differences were found between RI and non-RI cases. The RI thresholds were obtained by computing the average magnitude of each of the RI predictors for the sample of cases that underwent RI. A predictor was satisfied if the predictor magnitude was above or below the threshold magnitude whichever previous statistical analysis had shown to be more conducive to RI. For example, Kaplan and DeMaria (2003) showed that RI was much more likely to occur when the sea-surface temperature exceeded 28.4°C. Thus, the RI threshold for sea-surface temperature was satisfied when the magnitude of the sea-surface temperature was $\geq$ 28.4° C.

While this simple technique showed skill when run in real-time during some seasons, it did not show skill during others. One of the reasons for this appeared to be the threshold technique itself. Specifically, each predictor was either assigned a value of 0 (threshold not met) or 1 (threshold met) Thus, if the magnitude of the sea-surface temperature was 28.3°C the sea-surface temperature threshold would not be satisfied and a weight of 0 would be assigned, while if the magnitude of the sea-surface temperature were 28.4 °C it would be assigned a weight of 1. Since there were some cases for which RI occurred when the sea-surface temperature was lower than the RI threshold, assigning a weight of 0 for such cases is problematic. Consequently, a scaling technique was employed to re-derive the RI index. Briefly, the maximum and minimum value of each of the 7 RI predictors were determined from the 1995-2003 SHIPS database. The predictors were the sea-surface temperature, the difference between the current and empirically derived maximum potential intensity, the 850-200 mb vertical shear and the 850-700 mb relative humidity both evaluated for the annulus between 200-800 km radius, and the previous 12-h intensity change. In addition, two inner-core predictors, the percentage of the area from 50-200 km radius with GOES infra-red brightness temperatures <-30° C and the standard deviation of the infra-red brightness temperatures from 100-300 km radius were also utilized. The magnitudes of the vertical shear, relative humidity, sea-surface temperature and the difference between the current and empirical maximum potential intensity were averaged over the 24-h period commencing at t=0 h, while both of the satellite predictors were evaluated at t=0 h.

The maximum and minimum values were used as the boundary conditions for each predictor such that a weight of 0 was assigned if the magnitude of a predictor was less (or greater) than the lowest (highest) value at which RI was observed. The scaled magnitude of predictor values that were equal to the most favorable value was set to 1. To illustrate, the minimum sea-surface temperature at which RI was observed was 24.3 °C, and the maximum value was 30.3 °C. Thus, the scaled sea-surface temperature was set to 0 for values $\leq$ 24.3 °C and to 1 for values $\geq$ 30.3° C, since as noted previously higher sea-surface temperatures have been found to be more conducive for RI. A linear variation of the scaled values was assumed for all predictor magnitudes that fell within the range of observed sea-surface temperature RI values (e.g. 24.3 °C $\leq$ sea-surface temperature $\leq$ 30.3 °C). The same scaling technique was used for all of the RI predictors except for the previous 12-h intensity change. For this predictor, the scaled predictor magnitude was set equal to 1 for values that were equal to the mean of the RI cases since sensitivity tests showed that this yielded more skillful probability of RI estimates.

The scaled magnitudes of each of the 7 RI predictors were then summed for each of the cases. The total scaled RI index values (0 to 7) for each of the cases that comprised the 1995-2003 dependent samples were then binned to obtain probability of RI estimates for a given range of RI index values for both the Atlantic and E. Pacific dependent samples. The real-time probability of RI estimates were then estimated by linearly interpolating between the binned RI probabilities from the appropriate basin that had been determined previously utilizing the 1995-2003 developmental data.

3. Results

Since the RI index was not run in real-time until July of 2005, the index was re-run for the entire 2004 and 2005 Hurricane Seasons using the operational datasets from each season to estimate the skill of the index for independent data. The 2004 and 2005 forecasts were evaluated for the 24-h forecast period that commenced at t=0 h provided that a system remained either subtropical or tropical and over-water during that 24-h period. The forecast skill was assessed by comparing the 6-h probability of RI estimates to the climatological probability of RI of ~12% using a Brier skill score (Wilks 1995). The figure shows that the RI index was skillful for both the 2004 and 2005 Atlantic Hurricane seasons. The index was also very skillful for the 2004 E. Pacific Hurricane Season, however, it had essentially no skill relative to climatology during the 2005 season. For the combined two-year (2004+2005) independent sample the index showed skill of ~12% and 19% for the Atlantic and E. Pacific basins, respectively. Furthermore, as shown in Fig. 2 the skill was similar albeit lower than that found for the 1995-2003 dependent dataset. It is noteworthy that the skill of the RI index was larger for the E. Pacific basin than the Atlantic basin when run on both independent and dependent data.

As noted above, the RI index was run in real-time commencing in July of 2005. Fig. 3 shows the real-time performance of the RI index for the two most damaging hurricanes from the 2005 Atlantic hurricane season (Katrina and Wilma). The figure shows that the RI index performed fairly well for both of these systems. Specifically, the probability of RI exceeded 50% at the time at which Katrina underwent RI early on the 25th and 28th of August. For Hurricane Wilma, the index also performed fairly well showing a probability of RI near 60% at the start of the period over which Wilma underwent a period of extremely rapid intensification that commenced late on the 18th of October. However, the probability of RI also exceeded 50% early on the 16th during a period when Wilma intensified very slowly. It is noteworthy that the 95 kt intensity increase that Wilma experienced was ~50% larger than the greatest 24-h period of intensification previously found for the Atlantic basin by Kaplan and DeMaria (2003).

Figure 4 shows the performance of the RI index for two of the 2005 E. Pacific systems. The figure shows that the RI index was too aggressive in calling for rapid intensification for tropical storm Adrian with RI probabilities as high as 80% late on the 17th of May. Although Adrian did intensity by as much as 20 kt for two time periods, it did not undergo RI as defined in this study. Consequently, the Adrian RI forecasts reduced the skill of the RI index in the E. Pacific basin by ~10% for the entire 2005 Hurricane Season. In contrast to the results for Adrian, the RI index performed quite well for Hurricane Hilary with RI probabilities exceeding 80% at the time when Hilary commenced RI on the 19th of August.

4. Summary

A revised scaled rapid intensification index has been developed for estimating the probability of rapid intensification (defined as $\geq$ 25 kt increase in intensity in 24 h) as part of the Joint Hurricane Testbed (JHT). The RI index was developed for the Atlantic and E. Pacific basins using predictors from the 1995-2003 SHIPS database. The index was provided in real-time to the National Hurricane Center commencing in July of 2005. However, it was re-run for the entire 2004 and 2005 Hurricanes seasons using the operational datasets archived for both years to obtain a measure of its skill for independent data. The results showed that the revised version of the scaled RI index had skill relative to climatology for both seasons in the Atlantic and for the 2004 season in the E. Pacific. For the two-year (2004+2005) independent sample, the index had skill of about 12 and 19% for the Atlantic and E. Pacific basins, respectively. While these results are encouraging, further improvements to the index are planned. The most significant of these is the use of discriminant analysis to obtain weights for each of the 7 RI predictors that are currently weighted equally.

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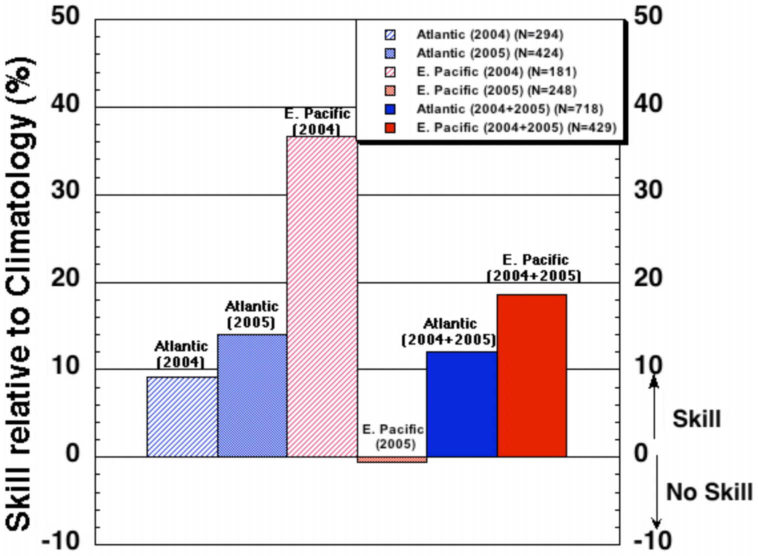

Fig. 1. Skill of the RI index for the Atlantic and E. Pacific independent samples. Results are shown for the 2004 and 2005 seasons individually and for the 2004+2005 seasons combined .

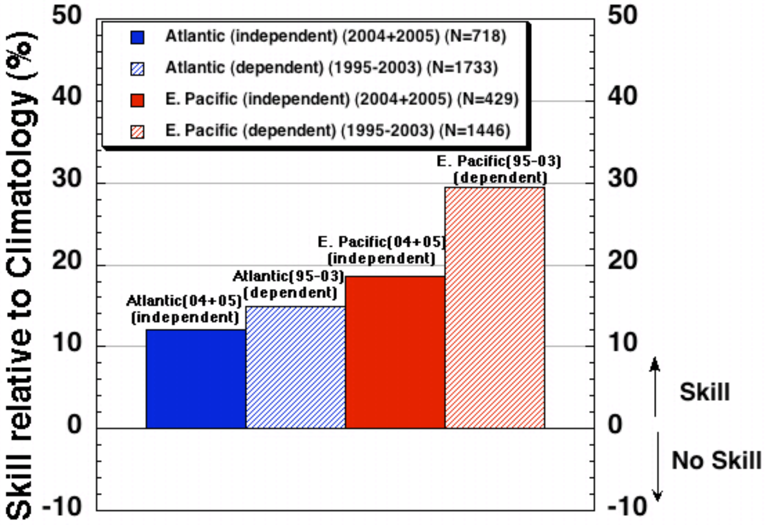

Fig. 2. Same as Fig. 1, except for the combined 2004+2005 independent and 1995-2003 dependent Atlantic and E. Pacific samples.

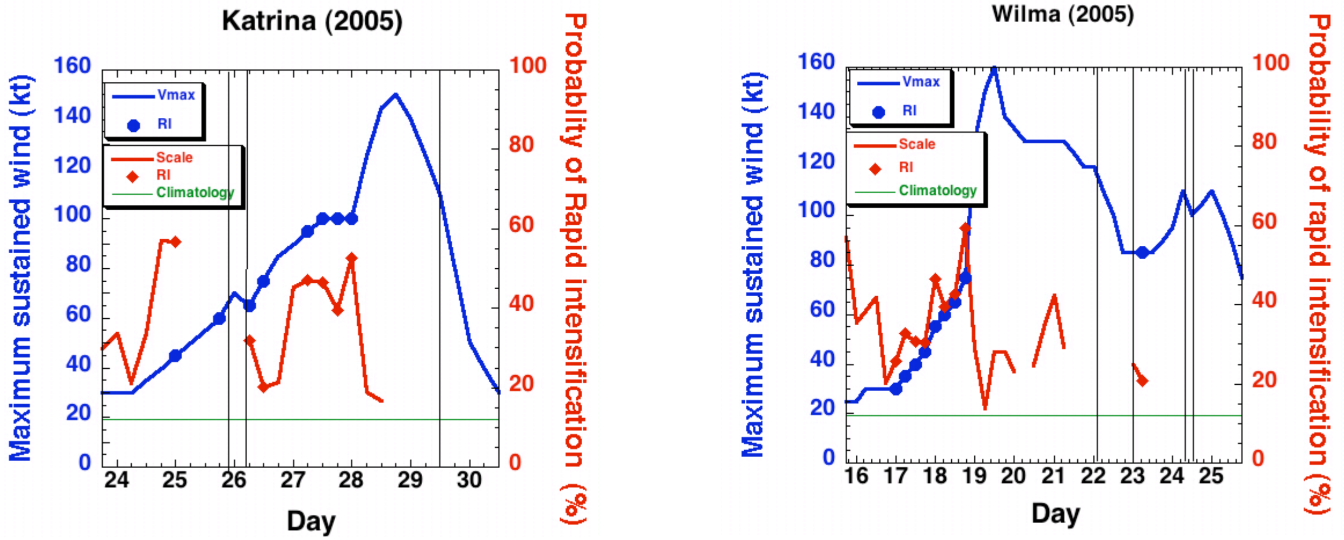

Fig. 3. Real-time performance of the scaled RI index for Hurricanes Katrina (2005) and Wilma (2005). The probability of RI (red) and NHC intensity (blue) estimates are provided every 6h. The start times of each 24-h period of RI are denoted by red diamonds and blue circles. The climatological probability of RI is shown in green. The times of landfall are denoted by vertical black lines.

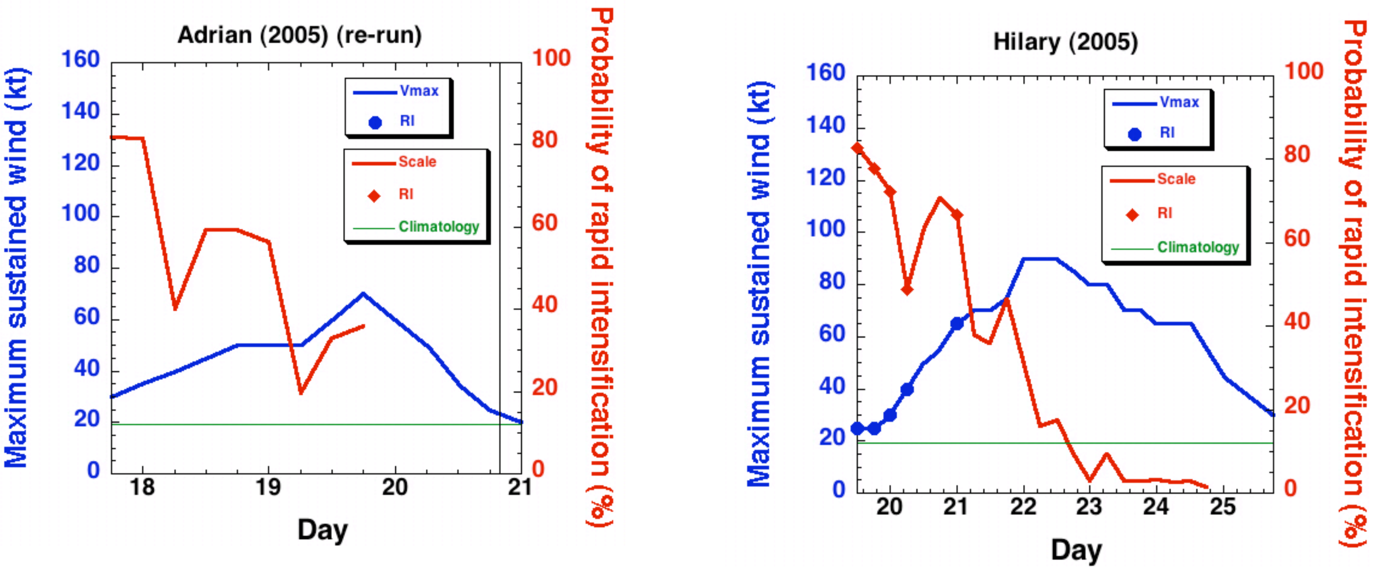

Fig. 4. Same as Fig. 3, except for the Adrian (2005) re-run and real-time Hilary (2005) forecasts.