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OBJECTIVE TROPICAL CYCLONE WARNING GUIDANCE USING MONTE CARLO WIND SPEED PROBABILITIES

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1. INTRODUCTION

The Monte Carlo wind speed probability (MWP) model estimates the probabilities of 34-, 50-, and 64-kt wind speeds occurring at a given point within the next 12, 24, 36, …, 120 h (DeMaria et al. 2009). For each tropical cyclone, the MWP generates 1,000 forecast realizations by sampling from track and intensity forecast errors from the last 5 years and determines the wind radii of each realization using radii-CLIPER. Wind speed probabilities are then derived at each point in the model domain by counting the number of realizations for which the point is within the radii of wind speed of interest relative to the total number of realizations.

There are current versions of the MWP for the Atlantic, N.E./Central and N.W. Pacific basins. The Atlantic and N.E. Pacific model versions of the model became operational NHC/TPC products (Tropical Cyclone Surface Wind Speed Probabilities Products) in 2006, replacing the Strike Probability Program. The operational products include both cumulative and interval probabilities in text and graphical forms.

As the example in Fig. 1 shows, there is clearly a relationship between wind speed probabilities and those areas put under watches and warnings by NHC. Quantifying this relationship, however, requires translating probability values into a deterministic watch or warning. A recent study looked at this relationship for cases from 2004-2006 and found that, on average, the 120-h, 64-kt probabilities at the endpoints of hurricane watches and warnings was 10%.

Building upon this idea of defining probability thresholds to use as guidance for putting up and taking down watches and warnings, this study seeks to expand upon the work of Mainelli et al. (2008) by 1) adding cases from 2007 and 2008 to the analysis, 2) investigating different methods of defining probability thresholds for NHC watches and warnings and 3) including tropical storm watches and warnings.

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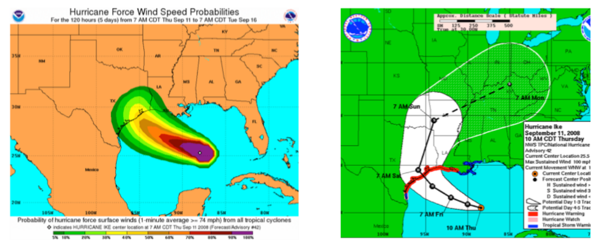

Figure 1. Hurricane Force Wind Speed Probabilities (left) and NHC warnings for Hurricane Ike on 11 Sep 2008, 7am CDT.

2. METHDOLOGY

From 2004-2008, 33 tropical cyclones either made landfall or came close enough to the U.S. mainland to prompt the issuance of hurricane and/or tropical storm watches/warning by the NHC. The MWP was run for each of these cases and 34- and 64-kt wind speed probabilities analyzed at each of 340 U.S. mainland breakpoints.

A previous analysis of U.S. hurricane watches and warnings showed that lead times for hurricane warnings (watches) are typically 34 h and 50 h, respectively (DeMaria and Franklin 2007). As such, hurricane (tropical storm) warnings were compared to 64 kt (34 kt) 48 h cumulative wind speed probabilities and hurricane (tropical storm) watches were compared to the 64 kt (34 kt) 60 h wind speed probabilities

Each type of NHC tropical cyclone warning was related to the most appropriate MWP available, so that hurricane warnings (watches) were compared to 64-kt, 48-h (60-h) cumulative wind speed probabilities and tropical storm warnings (watches) were compared to 34-kt, 48-h (60-h) cumulative probabilities.

3. RESULTS: PROBABILITY THRESHOLDS

Three methodologies for determining the best probability thresholds to use to relate wind speed probabilities to the four NHC TC warning types were tested; 1) averaging wind speed probabilities at watch/warning endpoints, 2) testing different probability thresholds until the threat score is maximized, and 3) maximizing the threat score while ensuring that no observed tropical storm/hurricane force wind observations are missed. The results of each of these methods are shown in Table 1. For this study, the main threshold of interest was the probability value for which a watch or warning is raised (p_{up}). As such, for every method the probability at which an existing watch or warning is dropped (p_{down}) is kept constant at 0%.

Table 1. Probability threshold results for each of the 3 methods tested.

*Values for p_{up}	1) Avg. WSP at warning endpoints	2) Maximize Threat Score (TS)	3) Max TS, no missed observations
Hurricane Warning	8	10	10
Hurricane Watch	8	8	8
TS Warning	31	38	21**
TS Watch	42	40	27

There is little difference in the probability thresholds for hurricane watches and warnings derived by the three different methods – all pup are between 8% and 10%. There is far more spread among the three method-derived thresholds for tropical storms. For tropical storm warnings, the three methods result in p_{up} values of 31, 38, and 21%, respectively and for tropical storm watches the resulting p_{up} values are 42, 40 and 27%. One possible reason for these differences may lie in the different levels of tolerance for misses inherent to each method. More work is needed to understand these differences fully. For the sake of brevity, Method #3 (Table 1) is used to define the wind speed probability-derived (WSP-derived) watch/warning scheme referred to in the remainder of this paper.

To evaluate the performance of the WSP-derived watch/warning guidance, total coastal distance and average lead times were calculated for each case in the sample set. The sample average values are shown in Figs. 2 and 3, and examples of individual storm hurricane warning distances are shown in Fig. 4. Figs. 2 and 3 show that both the WSP-derived hurricane watches and warnings have coastal distances and average lead times similar to NHC, on average. The individual storm values in Fig. 4 suggest that this is also true on a storm by storm basis. Distances and lead times of tropical storm watches and warnings, however, are overestimated by the WSP-derived watch/waring guidance scheme. Once again, this may be due to that the guidance scheme used here has no tolerance for missed observed 34-kt winds, which may be too strict.

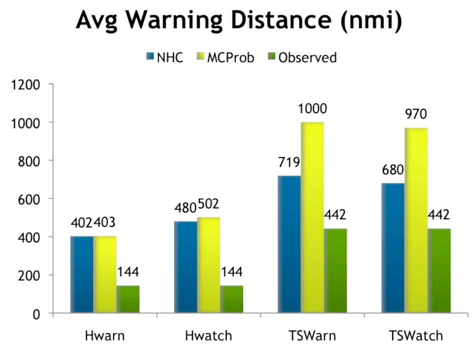

Figure 2. Storm-total watch/warning coastal distances, averaged over the 2004-2008 sample.

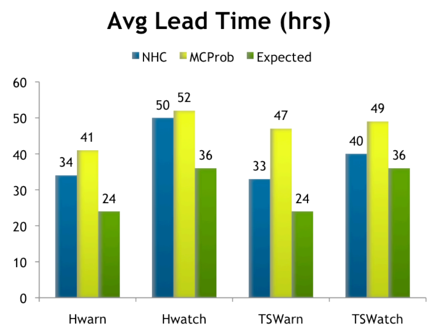

Figure 3. Storm-average lead times, averaged over the 2004-2008 sample.

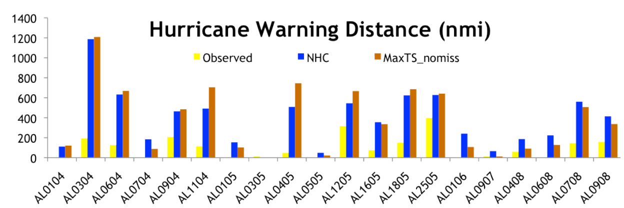

Figure 4. Individual hurricane warning distances, 2004-2008.

4. TROPICAL CYCLONE CONDITIONS OF READINESS

In lieu of watches and warnings, Department of Defense installations use Tropical Cyclone Conditions of Readiness (TCCOR) to indicate the time at which the onset of damaging (50-kt) winds are anticipated or expected. TCCOR range from 1 to 4, where 1 (4) indicates the onset of 50-kt winds is expected (anticipated) within 24 (72) hours.

Tropical cyclone conditions of readiness (TCCOR) are used by Department of Defense installations. TCCOR values range from 1 to 4, each corresponding to a time when the onset of 50-kt winds is expected. Each TCCOR also corresponds to a set of actions to be taken by the installation.

TCCOR data was collected from 10 different Dept. of Defense installations for 42 tropical cyclones between 1997-2009. For this analysis, the 50-kt cumulative 12-, 24-, 48- and 72-h wind speed probabilities were generated for comparison with TCCOR levels 1, 2, 3, and 4, respectively. Unlike NHC watches and warnings, TCCOR data was available at single points (e.g., an Air Force base). Hence, wind speed probabilities did not need to match coastal distances but rather had to be related to the timing of TCCOR issuance alone.

As preliminary look at the TCCOR data suggests the following wind speed probability; 1 = 9%, 2 = 12%, 3 = 15%, 4 = 13% (Table 2). The lead time between probability-derived TCCOR and actual TCCOR were computed for each case in the sample and, on average, the probability-derived TCCOR are issued prior to and within 12 hours of actual TCCOR for each level (Table 2). Future efforts will focus on refining thresholds and evaluating performance on case by case basis.

Table 2. Probability thresholds corresponding average lead times for TCCOR 1-4.

	TCCOR 1	TCCOR 2	TCCOR 3	TCCOR 4
P_{up} (%)	9	12	15	13
Lead (hr)	10	6	6	1

5. SOCIOECONOMIC APPLICATION

The methodology of the MWP uses forecast errors from the past 5 years. Combined with the WSP-derived hurricane warning guidance scheme derived here, this property allows for the unique opportunity to artificially reduce forecast errors over the last 5 years and see what impacts improved forecasts may have on hurricane warnings.

For this experiment, forecast track and intensity errors were artificially reduced by 20% and 50% and the resulting reduction in coastal distance overwarned (under a hurricane warning but never experience 64-kt winds) was calculated. For the 2004-2008 sample, a 20% (50%) reduction in forecast track and intensity errors resulted in an 11% (33%) reduction in the coastal distance overwarned.

6. CONCLUSIONS

Methods for relating Monte Carlo wind speeds probabilities to deterministic tropical cyclone watches and warnings were examined. Objective wind speed probability-derived schemes were developed for Atlantic hurricane and tropical storm watches and warnings. The average WSP-derived watch and warning properties (coastal distance, lead time) are similar to NHC for hurricanes, but the tropical storm watch and warning schemes seem to overestimate both distance and length. Further refinements of the tropical storm guidance schemes, likely involving the relaxation of the criteria that no missed observed 34-kt winds, are needed.

A similar methodology was applied to Tropical Cyclone Conditions of Readiness (TCCOR), resulting in preliminary probability thresholds for TCCOR 1-4 objective guidance. Overall, the timing of the objective TCCOR are similar to those in the sample set, but more data and wind speed observations would be helpful in improving this guidance. Finally, a socioeconomic application of the hurricane warning guidance scheme was presented. This application provides a framework for relating future forecast improvements (i.e., reductions in forecast track and intensity errors) to reductions in coastal distance overwarned. Results of this analysis suggest that 20% (50%) reductions in both track and intensity forecast errors should result in an approximate 11% (33%) reduction in warning false alarms. The application, in combination with socioeconomic research on the cost of warning false alarms, could be used to estimate one sources of socioeconomic benefits of hurricane forecast improvements.

7. REFERENCES

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