**13A.3** TROPICAL CYCLONE WIND SPEED PROBABILITIES AND THEIR RELATIONSHIPS WITH COASTAL WATCHES AND WARNINGS ISSUED BY THE NATIONAL HURRICANE CENTER

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## 1. INTRODUCTION & BACKGROUND

In recognition of the increasing coastal population vulnerable to tropical cyclones and the inherent uncertainties in the National Hurricane Center (NHC) track forecasts, the National Weather Service (NWS) initiated a quantitative probability product (called Strike Probabilities) beginning with the forecast of Hurricane Alicia in August of 1983 (Sheets 1985). After consideration of a number of factors, the decision was made to supplement the NHC deterministic track, intensity and wind structure forecasts and the watches and warnings with these quantitative probabilities, rather than replace any of the existing products. It was felt that the familiar products were well suited for the general public, but the new, quantitative, strike probability products could be used by more sophisticated users (e.g., evacuation decision-makers).

The original Strike Probability product only considered track forecast uncertainties, where probabilities were estimated from bivariate normal distributions fitted to the recent history of NHC track errors. A tropical cyclone "strike" was defined as when the center of a tropical cyclone passed within 50 n mi to the right or 75 n mi to the left of a given location, and probabilities were provided at selected locations from 12 to 72 h (at the discrete lead times of the NHC deterministic forecast prior to 2003). Except for periodic updating of the track error statistics, the operational Strike Probability product changed very little from 1983 through the 2005 hurricane season.

The Strike Probabilities were utilized by many emergency managers and other decision-makers to account for tropical cyclone track forecast uncertainties. A significant limitation of those probabilities, however, was that the event to which they were tied (a "close" passage of a cyclone center) did not convey any information about specific hazards that could be experienced at a given location. Only conveying track forecast uncertainty, the strike probabilities did not account for uncertainties in the intensity or size of the tropical cyclone. Following some notable landfalling hurricanes (e.g., Charley 2004) that revealed shortcomings in the existing product suite for conveying forecast uncertainties, the NHC began to shift toward conveying uncertainties in specific tropical cyclone hazards, starting with the wind hazard.

A new probability product, called Tropical Cyclone Surface Wind Speed Probabilities, became operational at NHC in 2006, following an experimental phase during 2004-05 that was supported by the Joint Hurricane Testbed (JHT). The new version takes into account track, intensity and wind structure uncertainties (Gross et al 2004). Unlike the Strike Probabilities, the Wind Speed Probabilities provide information out to five days. These NHC products include text and graphical versions that are updated with every forecast cycle for each active tropical cyclone in the Atlantic and eastern North Pacific basins (the Central Pacific Hurricane Center in Honolulu provides the same products for cyclones in the Central Pacific basin). The wind speed probabilities are also being made available via the National Digital Forecast Database, and they are serving as input to text and graphical products issued by local NWS Weather Forecast Offices.

These new products provide users with information regarding the chances of experiencing winds of tropical storm force and hurricane force at specific locations within the five-day forecast period. They also indicate, in probabilistic terms, the range of possibilities regarding when these wind conditions could begin at specific locations (an important factor in the timing of evacuation orders). While these products are primarily intended for use by emergency managers (for decision-making) and the media (for communication of risk and uncertainty), the availability of the products via the NHC website makes it possible for anyone in the general public to use them for their own decision-making.

One of the significant challenges with the probabilities thus far has been relating them to coastal watches and warnings issued by the NHC. A hurricane watch is issued when hurricane conditions are possible within the watch area, generally within 36 hours. A hurricane warning is issued when hurricane conditions are expected within the warning area, generally within 24 hours (or less in some cases). Similar definitions are employed for tropical storm watches and warnings. The purpose of this paper is to explore the relationship between the wind speed probabilities and the timing and placement of hurricane watches and warnings. The intent of this research is to provide a *first-guess* to the hurricane forecasters as to when and where to issue hurricane watches and warnings.

## 2. METHODOLOGY

Tropical cyclone wind speed probabilities are computed using a Monte Carlo statistical approach, incorporating 1000 realizations determined by randomly sampling NHC track and intensity error distributions, and wind radii from a radii climate and persistence model and its error distributions. The wind radii are adjusted to represent the average extent of a certain wind speed in each quadrant, rather than the maximum extent of a wind

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speed in each quadrant. This adjustment causes the probabilities to better represent the chances of experiencing a particular wind speed at a given location, rather than the probability of falling within the wind radii. Probabilities are computed for three speed thresholds (34, 50, and 64 kt). The serial correlation of the track, intensity and wind structure forecasts is taken into account, and special procedures are employed for storms near land. These procedures ensure that the probabilities are just as reliable over land areas as over water, which is important for users preparing for the wind hazard in inland areas. A probability at a point results from counting the number of realizations passing within the (adjusted) wind radii of interest forecast by NHC (Gross et al. 2004). Short descriptions of the products and recent examples are available from http://rammb.cira.colostate.edu/ research/ tropical_cyclones/tc_wind_prob and from http://www.nhc. noaa.gov/aboutnhcprobs.shtml.

Feedback to date on these preparedness products indicates that they provide an excellent tool for decision-making, especially for local and state emergency managers. In addition, television meteorologists are increasingly using these products to convey simple messages regarding forecast uncertainties to the public. NHC continues to aggressively promote these products and educate its partners in emergency management and the media on how to interpret and best utilize these products.

## 3. PROBABILITIES VS. WATCHES/WARNINGS

Comparisons of the wind speed probabilities among various cases during 2005-07 reveal that the magnitudes of the probabilities vary considerably, both within individual watch and warning areas, and from one cyclone to the next. For example, hurricane-force probabilities along the coast in a hurricane watch area are usually much greater for a large, major hurricane than for a smaller, less intense cyclone. These variations present challenges for NHC in conveying a clear and consistent message to areas under a watch or warning. The variations are realistic, however, as verification of the probabilities shows that they are reliable (i.e., over a large number of cases, a 10% probability actually corresponds to the stated event occurring about 10% of the time).

A previous analysis of U.S. hurricane watches and warnings from 2000-2006 showed an average storm-total watch length of 489 miles and an average storm-total warning length of 417 miles. Relating these watches and warnings to the length of coastline that actually received hurricane winds (as determined from the NHC best track and wind radii estimates) resulted in an average probability of 20% for individual points under a hurricane watch and a value of 25% for points under a hurricane warning.

In the current study, the relationship between the watches and warnings and the wind speed probabilities is examined in greater detail. The study was restricted to evaluating tropical cyclones in the Atlantic basin where coastal hurricane watches and/or warnings were issued for any portion of the continental United States during the 2004-2006 seasons. For those three hurricane seasons, the approach or landfall of fifteen tropical cyclones warranted the issuance of a hurricane watch, a hurricane warning, or both. The average lead time for the watch prior to actual landfall of the circulation center was 50 hours, and lead time for the warning prior to actual landfall was 32 hours. These averages included two landfalls each for Katrina (2005) and Ernesto (2006) and took into account the extended lead times for both Frances (2004) and Ophelia (2005).

The analysis of 64-kt probabilities versus the hurricane watches/warnings had three components. First, the probabilities were averaged at the watch or warning end points, at the time of first issuance of the watch or warning. Second, the probabilities were averaged among all points within the watch or warning area at the time of first issuance. Third, the probabilities were averaged, at the time of first issuance of a watch or warning, at locations that ultimately experienced hurricane-force winds (as estimated by NHC best track wind radii).

## 4. PROBABILITY RESULTS

Over the three-year period, the fifteen tropical cyclones were evaluated both individually and collectively with respect to the three components above. The collective results are shown in Table 1 and indicate that, at the end points of the watches and warnings, the cumulative, 120-hour, 64-kt probabilities averaged about 10%, and increased toward the coastal points in the interior of the watch or warning areas. As expected, the highest probabilities were, on average, at the coastal points that eventually received hurricane-force winds. These results are very close to a previous study conducted by Knaff and DeMaria (2006).

*Table 1. Summary of relationships between 2004-2006 U.S. coastal hurricane watch/warning areas and hurricane-force wind speed probabilities at first issuance.*

| ALL STORMS | Watch % | Warning % |
|---|---|---|
| Average probability at points that received 64-kt winds | 23 | 32 |
| Average probability at all points within watch or warning area | 14 | 17 |
| Average probability at watch or warning end points | 10 | 11 |

The fifteen tropical cyclones were also investigated individually. While most of the cyclones resulted in the issuance of both a hurricane watch and warning, Alex (2004) and Alberto (2006) had only hurricane warnings issued, and Ernesto (2006) resulted only in hurricane watches. Figures 1 and 2 provide an overview of the results. There is considerable storm-to-storm variability in the probabilities for both the watches and warnings. Also, even for the locations that eventually receive hurricane-force winds, the probability values (at the time of first watch or warning issuance) are not very large (all less than 45%). This result is consistent with a previous analysis conducted by Knaff and DeMaria (2006) of the coastline lengths included in watches and warnings and the coastline lengths that received hurricane-force winds.

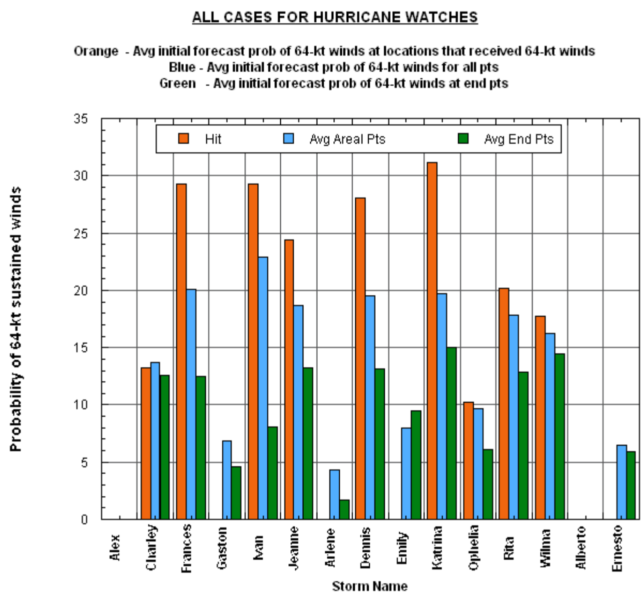


*Figure 1. Average 120-h cumulative 64-kt probabilities for hurricane watches for individual tropical cyclones from 2004-2006.*

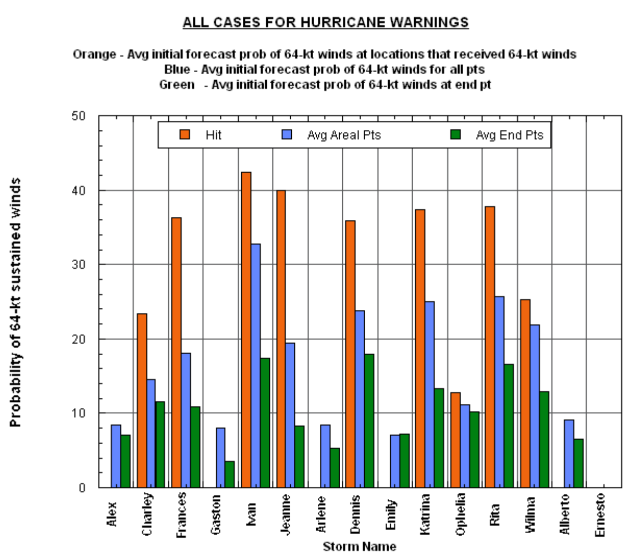


*Figure 2. Average 120-h cumulative 64-kt probabilities for hurricane warnings for individual tropical cyclones from 2004-2006.*

Much of the storm-to-storm variability in Figs. 1 and 2 is unavoidable and is due to differences in the storm characteristics (intensity and size). It might be possible, however, to reduce some of the variability by developing objective guidance (first guesses) for issuing watches and warnings based on the probability values, as described in the next section.

## 5. OBJECTIVE WATCH/WARNING GUIDANCE

The results from Figs. 1 and 2 and additional analysis are being used to develop objective guidance for the placement of NHC hurricane watch and warning areas. The probability threshold should not be any smaller than the lowest probability value at the locations that actually received hurricane-force winds. Therefore, the starting point is to include any points where the 64-kt wind probability is 10% or higher, which is close to the average value at the end points of the watch/warning areas as listed in Table 1. The hurricane warnings are nominally issued 24 h in advance and the watches 36 h in advance of the onset of hurricane conditions. A recent analysis (DeMaria and Franklin 2007) shows, however, that the lead times of the warnings and watches for the continental U.S. are closer to 34 and 50 h, respectively. For this reason, the initial objective guidance for placement of a warning and watch will be based on the cumulative 64-kt wind probabilities at 48 and 72 h, respectively. As part of the analysis of the probabilities, results showed that the probabilities when the watches and warnings were lowered had much smaller values than when they were issued. Thus, time continuity will also be imposed so that any point that was previously included in a watch or warning will continue to be included unless the probability value drops below 1%. The analysis also showed that, except near the edge of where the U.S. watches/warnings are issued (Brownsville, Texas; Eastport, Maine; and the end of the Florida Keys), the length of U.S. watches and warnings along the coastline include at least a few breakpoints. This minimum size constraint (of having a least a few breakpoints included in the initial issuance of a watch/warning) will also be included in the objective guidance.

Another potential consideration is to evaluate the 34-kt wind speed probabilities with respect to the possible times of arrival of 34-kt winds within the proposed watch or warning area, to provide guidance on *when* to issue a hurricane watch or warning. The cumulative, 120-h, 64-kt probabilities could then still be used to determine where to place the watch or warning. This could be useful since, in practice, hurricane watches and warnings are often issued about 36 or 24 hours, respectively, in advance of the arrival of 34-kt winds. This practice is reflected in the results showing that average lead times for hurricane watches and warnings were 50 and 34 h, respectively, during 2000-2006.

The program to implement and evaluate the above rules to provide objective watch and warning guidance is currently under development. Preliminary examples will be presented at the conference.

## 6. CONCLUSIONS

To date, the wind speed probabilities text and graphical products have proven to be useful tools for decision-makers, primarily local and state emergency managers. In addition, television broadcasters are increasingly making use of these products to help the public understand their risk and the uncertainties in each tropical cyclone forecast. Not only can a risk analysis of potential wind hazards be assessed along the coast, but the potential extent of winds inland can also now be evaluated.

In addressing the need to relate the wind speed probabilities to the timing and placement of hurricane watches and warning issuances by NHC, a study was conducted using the 2004 through 2006 hurricane seasons. Preliminary results show that, on average, the 64-kt wind speed probabilities are around 10% at the end points of a hurricane watch or warning at first issuance. In order for this information to be used operationally at NHC, however, objective guidance for when and where to issue the hurricane watches and warnings need to be provided to the forecasters. Development is currently underway with the intent to provide the hurricane forecasters a *first-guess* of watches and warnings during the 2008 hurricane season. If the objective guidance proves to be useful, the study will be expanded to include tropical storm watches and warnings based upon information derived from the 34-kt wind speed probabilities.

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