JP1.3 EMPLOYING HURRICANE WIND PROBABILITIES TO CONVEY FORECAST UNCERTAINTY AND POTENTIAL IMPACT THROUGH NWS FIELD OFFICE FORECAST PRODUCTS

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1. INTRODUCTION

Since 2005, the National Hurricane Center (NHC) has produced gridded tropical cyclone wind speed probabilities for 34-, 50-, and 64-knot winds through 120 hours during operational forecast cycles for active systems in the Atlantic and Pacific Basins. The probabilities are centered about NHC's official track, intensity, and wind radii forecast, and incorporate average error statistics over recent years for those variables (Gross et al. 2004; Knaff and DeMaria 2005). Since probability information is often designed to answer specific questions, these probabilities are produced in several forms to include the *cumulative* (the probability that wind speeds will reach or exceed 34/50/64 knots between the 00 and HH hour forecast), *interval* (the probability that 34/50/64 knot winds or greater will begin during the 12 hour forecast period ending at hour HH), and *incremental* (the probability that 34/50/64 knot winds or greater will occur during the 12 hour period between forecast hours HH-12 and HH) forms for each successive period of the forecast. In an effort to improve the usefulness of wind speed information delivered during tropical cyclone events, the NWS Weather Forecast Offices (WFOs) at Miami and Melbourne have collaborated to examine the value of using the wind speed probabilities in conveying forecast uncertainty and potential impact within local forecast products. This paper presents an update on two such initiatives introduced at the 27th Conference on Hurricanes and Tropical Meteorology (Sharp et al. 2006). The first initiative involves a consistent method for providing coherent expressions of uncertainty within text forecast products, while the second initiative endeavors to graphically depict the potential impact due to the associated wind hazard.

In preparation for tropical cyclone events, decision-makers not only demand a meteorologist's best deterministic wind speed forecast, but they also require an accompanying expression of uncertainty. That requirement reveals the shortcoming of deterministic-only wind speed forecasts such as those found within the current Zone Forecast Product (ZFP) and Coastal Waters Forecast (CWF). To address the shortcoming, The Miami and Melbourne WFOs have developed a means by which the ***incremental probabilities*** (Figure 1) are employed to enhance the ZFP and CWF by introducing expressions of forecast error (e.g., uncertainty) within the body of the text. Experimentally, the enhancements have now been incorporated within the legacy (zone-based) versions, and also within the dynamic point-and-click versions found on the WFO Web sites. Together with hazard information (e.g., tropical storm/hurricane watches/warnings) and wind speed information, incremental probabilities of wind speed are used to trigger prescribed expressions through automated text formatters. The formatters weigh respective gridded inputs to determine the appropriate expression of uncertainty according to the situation. For each period of the 5-day forecast, they are able to then convey whether hurricane or tropical storm conditions are *IMMINENT/ONGOING*, *EXPECTED*, or *POSSIBLE*. Preliminary results have been positive and, if transitioned to official policy, stand to elevate the usefulness of the ZFP and CWF. It will foster a greater consistency between NHC and adjacent WFOs, while reducing the workload associated with manual post-editing. Similar improvements in the utility of tabular products, such as forecast matrices, can be easily accommodated, if desired.

In a parallel initiative, certain graphics which show the geographical distribution of potential impact associated with high winds during tropical cyclone situations have continued to evolve. Here, ***cumulative probabilities*** (Figure 2) for select wind speeds are used in combination with the deterministic wind speed forecasts to derive an automated first-guess of the local wind threat (e.g., threat assessment grids). Forecasters then have the opportunity to make final adjustments before translating the assessed threat into potential impact. The final output is a Web-ready High Wind Impact map which is updated with each advisory. In practice, the first-guess threat assessment is created by compositing the 10 percent probability for exceeding the 34-, 50-, and 64-knot wind thresholds, along with additional 64-knot probability variations for handling hurricanes of Category Two or greater on the Saffir-Simpson scale. Using the cumulative probabilities has promoted increased efficiency during product preparation. Synoptic considerations are now made quickly and consistently, freeing up more time for inherent mesoscale considerations. The initiative is part of a larger experimental project within the National Weather Service to provide impact graphics of all hazards associated with tropical cyclones. Additional information on this particular experiment can be found at http://www.weather.gov/os/tropical/.

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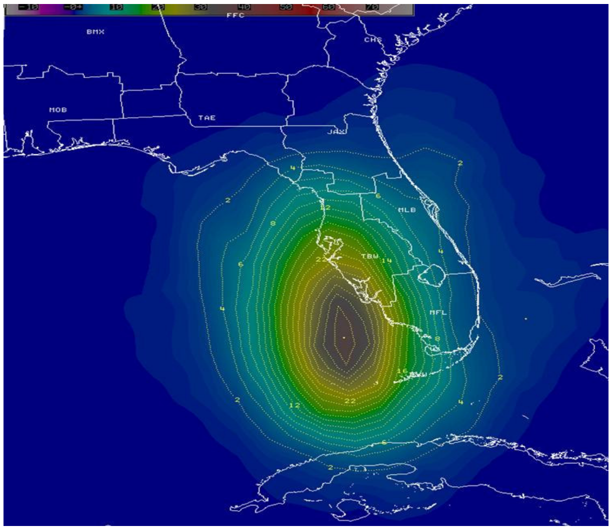

Figure 1. An example of the incremental 64-knot tropical cyclone wind probabilities valid for the 25 36-hours period for Hurricane Charley issued at 1200 UTC, 12 August 2004.

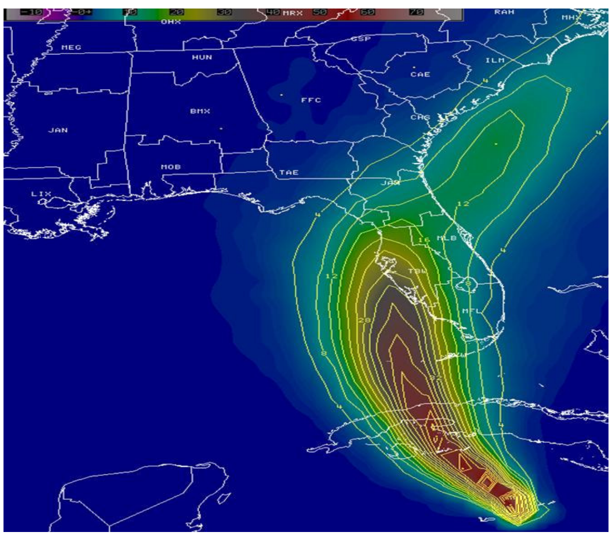

Figure 2. An example of the cumulative 64-knot tropical cyclone wind probabilities valid for the 0-120 hours period for Hurricane Charley issued at 1200 UTC, 12 August 2004.

2. BACKGROUND

As a significant finding indicated within the Hurricane Charley Service Assessment (NOAA 2006), post-event interviews revealed that many people tended to focus on the specific forecast track which showed the center of major Hurricane Charley making landfall near Tampa, FL, and not Punta Gorda, FL. Even though both cities were located within the Hurricane Warning area, residents in the vicinity of Punta Gorda stated that they had heard that Charley was going to hit Tampa and did not fully appreciate the associated uncertainty of the forecast. The same was true for the inland city of Orlando. This readily indicates a breakdown in communications when conveying the situational wind threat. Recent efforts to profile the average error cone have helped somewhat, especially within graphic depictions. However, confused or mixed messages are inevitable since the error cone does not take into account important parameters such as cyclone size, inherent uncertainties in the intensity forecast, or ill-behavior according to the projected track beyond that which is average. So, providing wind speed probabilities (for exceeding critical thresholds) seems the next logical step in the quest for a satisfactory solution. For sophisticated resource managers, direct users of the wind speed probabilities will be able to make responsible decisions by considering a reasonable tolerance according to their specific risk and vulnerability. This requires a genuine appreciation for the significance of probability values relative to rare but high impact events, even with each increasing temporal period of the forecast. However, for the benefit of the general public, the authors feel that it is useful for WFOs (especially until a comprehensive public education effort is performed) to operate as sophisticated first-users in order to harness the probabilities for improvements to current products:

a.) By inserting expressions of uncertainty within certain (official) text products,

b.) And by providing easy-to-understand (experimental) graphics which convey a component of uncertainty.

Each is intended to complement the corresponding deterministic wind speed forecast (either textual or graphical). Fortunately, recent technological advances in forecast preparation procedures have created the ability for meteorologists to interface directly with gridded data fields. This is accomplished through the use of the Graphical Forecast Editor (GFE) software. The GFE offers WFO forecasters the efficient and effective means to interact with guidance data, to make essential value-added adjustments, to create derived fields through software tools (e.g., SmartTools), and to automatically produce a plethora of products from its database. These can be created in text, tabular, graphical, and gridded forms according to local input/output configurations within each respective product formatter. Therefore, the GFE provides the context for which the tropical cyclone wind probabilities will be used to enhance particular products. The grids that come out of GFE also provide the ability to extend this capability into the point-and-click web based forecasts.

3. ENHANCED TEXT PRODUCTS

Among the most used text forecast products are the Zone Forecast Product (ZFP) and the Coastal Waters Forecast (CWF). Traditionally, these have been flagship products for WFOs within the NWS, serving as primary supply vehicles for delivering valuable forecast information to a variety of users. There are two versions of the ZFP: zone and point-and-click (for more info on point-and-click the reader is referred to http://www.srh.weather.gov/srh/jetstream/webweather/pinpoint_max.htm). Currently (as of the date of this printing), there is only a zone version of the CWF but the point-and-click version is under development. The CWF has scheduled issuance times by 4:30 AM, 10:30 AM, 4:30 PM, and 10:30 PM (local time) each day. The zone version of the ZFP is scheduled for issuance by 4:00 AM and 4:00 PM (local time) each day. Amendments are issued as necessary any time throughout the day, which can be frequent during tropical cyclone situations. The point-and-click version of the ZFP updates anytime the forecast grids are updated in GFE and published. Importantly, wind speed information is of numeric form and rounded to the nearest 5 knots (CWF) or 5 mph (ZFP). The regular expression of wind speed continues to be deterministic-only in nature and is represented by either a single value or narrow range of values (e.g., 15 knots or 15-20 knots). Wind information is typically provided through 120 hours within the CWF and through 60 hours within the ZFP. One particular shortcoming is that contingents do not exist for expressing uncertainty whenever high magnitude wind events threaten the forecast area; this is the goal of our first initiative.

To explore possible mitigating techniques, the 34-knot (tropical storm) and 64-knot (hurricane) incremental wind speed probabilities were obtained for select tropical cyclones from the 2004-07 seasons which threatened portions of Central and South Florida as well as Northeast Texas and Southern Louisiana. Gridded versions were loaded into the GFE to be teamed with other wind-related data sets so that automated text formatters could then derive and express when hurricane or tropical storm conditions were *IMMIMENT* or *ONGOING* (for the first period only), *EXPECTED*, or *POSSIBLE* according to the temporal period of the forecast. This required the formulation of detailed and prioritized logic for proper coding of the text formatter. The purpose was to establish a set of rules for triggering enhanced wording by utilizing available hazards grids, wind grids, 64 knot probability grids, and 34 knot probability grids. The hazard grids include hurricane (tropical storm) Watch/Warning grids as issued for coastal counties by the TPC, for inland counties by the WFO, and for marine zones by the WFO. The wind grids represent the official TPC wind forecast with WFO value-added mesoscale adjustments for local effects (e.g., friction over land, exposure over lakes, terrain altitude (including windward, leeward, and valley effects), gap winds, etc.). Finally, the incremental 34-knot and 64-knot probabilities were used; the 50-knot probabilities were not (initially) needed. A hierarchy of priorities (Table 1) was established to account for official Watch/Warning sensitivity, official forecast sensitivity, and forecast error sensitivity. This hierarchy serves as the overarching governor, thereby ensuring a consistent and non-conflicting message within related NOAA/NWS products.

Hierarchy of Priorities for Sensitivity

Priority	Sensitivity	Grid Sets
1	**Official Warnings,** **Official Watches**	**Hazard Grids**
2	**Official Forecasts**	**Wind Grids**
3	**Forecast Error**	**64-knot Probability Grids,** **34-knot Probability Grids**

Table 1. The hierarchy of priorities for sensitivity as used by the enhanced ZFP and CWF tropical cyclone formatters. Its intent is to ensure a consistent and non-conflicting message within related NOAA/NWS products.

In determining the specific phraseology to be used as expressions of uncertainty, two particular notions regarding forecast accuracy were considered. The first notion was that deterministic wind speed information has decreasing value with increasing time, and the second was that probabilistic wind speed information has increasing value with increasing time. Thus, phrases were devised to accommodate three separate temporal categories with a separate set of phrases needed for the 00- to 12-hour period (e.g., situations where conditions could be imminent or ongoing, expected, or even possible and part of the warning period), for the 13- to 48-hour period (e.g., situations involving the approximate warning/watch periods where conditions could be expected or possible), and for the 49- to 120-hour period (e.g., situations involving the approximate balance of the 5-day forecast for which wind information is depicted within the ZFP and CWF and when conditions could be possible). For our purposes, the phrase *'HURRICANE CONDITIONS'* was defined as sustained winds greater than or equal to 64 knots, or sustained winds greater than or equal to 50 knots but gusting to 64 knots or greater provided certain probability thresholds were exceeded as a function of time. Similarly, the phrase *'TROPICAL STORM CONDITIONS'* was defined as sustained winds greater than or equal to 34 knots, or sustained winds greater than or equal to 25 knots but gusting to 34 knots or greater provided certain probability thresholds were exceeded as a function of time. Table 2 offers a simplified overview of baseline phraseology invoked by the enhanced ZFP and CWF tropical formatters.

Base Phrase	Qualifiers
HURRICANE CONDITIONS…	***Phrase Alone implies IMMINENT or ONGOING.***
	EXPECTED.
	POSSIBLE.
TROPICAL STORM CONDITIONS…	***Phrase Alone implies IMMINENT or ONGOING.***
	EXPECTED with HURRICANCE CONDITIONS POSSIBLE
	with HURRICANE CONDITIONS POSSIBLE.
	EXPECTED.
	POSSIBLE.
	POSSIBLE WITH HURRICANE CONDITIONS ALSO POSSIBLE.

Table 2. The baseline phraseology invoked by the enhanced ZFP and CWF tropical text formatters. The equivalent of '*IMMINENT*' or '*ONGOING*' may be used within the 00-12 hour period only; the word *'EXPECTED'* may be used during the 00-48 hours period only; and *'POSSIBLE'* may be used throughout the 120-hour forecast period. Certain situations require compound phrases.

Central to this initiative was determining the correct probability thresholds to trigger *POSSIBLE* hurricane or tropical storm conditions or even the *EXPECTED* qualifier when the sustained winds did not equal or exceed 34(64) knots but at least 50(25) knots for hurricane and tropical storm conditions, respectively, with warnings in effect. Empirically determined using distribution analyses, a series of preliminary values were used so that logic and code development could mature. During testing these threshold values have worked well.

Tables 3-5 illustrate the probability thresholds used so far during development as a function of time period along with the qualifiers used also as a function of time period. In the 00-12 hour period, you can have the phrase with no qualifier at all (implying *IMMINENT* or *ONGOING*), with the *EXPECTED* or *POSSIBLE* qualifiers, or no phrase at all (to allow for continuity from period to period through time even if a warning is in effect). In the 13-48 hours period you can have the phrase with the qualifiers *EXPECTED* or *POSSIBLE* or no phrase at all. And in the 49-120 hours period you can have the phrase with the qualifier *POSSIBLE* only or no phrase at all.

Qualifier	Period	PWS64	PWS34
Imminent or Ongoing	00-12 hr	30%	70%

Table 3. Equivalent of the *IMMINENT/ONGOING* qualifier used with base phrases in Table 2 to create the expressions of uncertainty for the noted time period. PWS64 and PWS34 refer to the probability thresholds used for this qualifier and time period to determine the expression of uncertainty to use as explained in the text.

Qualifier	Period	PWS64	PWS34
Expected	00-12 hr	15%	50%
	13-24 hr	12%	40%
	25-36 hr	10%	35%
	37-48 hr	9%	30%

Table 4. *EXPECTED* qualifier used with base phrases in Table 2 to create the expressions of uncertainty for the noted time periods. PWS64 and PWS34 refer to the probability thresholds used for this qualifier and time periods to determine the expression of uncertainty to use as explained in the text.

Qualifier	Period	PWS64	PWS34
Possible	00-12 hr	15%	50%
	13-24 hr	12%	40%
	25-36 hr	10%	35%
	37-48 hr	9%	30%
	49-60 hr	8%	25%
	61-72 hr	7%	20%
	73-84 hr	6%	17.5%
	85-96 hr	5%	15%
	97-108 hr	4%	12.5%
	109-120 hr	3%	10%

Table 5. As in Table 4 but for the qualifier *POSSIBLE.*

The question then becomes how does the logic generate the proper expression of uncertainty (which is the combination of the base phrases and qualifiers in Table 2) using the combination of hazards, wind, and probabilistic information available? Using Tables 2-5 as reference, the algorithm logic used to determine the proper expression of uncertainty to use can be summarized as follows. First, consider the case of *IMMINENT* or *ONGOING* conditions (Table 3). It is reserved for the 00-12 hours period only. The phrase expressing *IMMINENT* or *ONGOING* conditions would get generated if a tropical storm (hurricane) warning is in effect and the maximum wind forecast is greater than or equal to 34 (64) knots and the 34 (64) knots incremental probability is greater than or equal to the PWS34 (PWS64) probability threshold in Table 3. Second, consider the case of the phrase with the *EXPECTED* qualifier. This combination is possible during the 00-48 hour time frame only. It is generated if a tropical storm (hurricane) warning is in effect and the maximum wind is greater than or equal to 34 (64) knots. *Or* it can also be generated if a tropical storm (hurricane) warning is in effect and the maximum wind is greater than or equal to 25 (50) knots and the incremental probability is greater than or equal to the PWS34 (PWS64) threshold according to forecast period in Table 4. *This allows the algorithm to express EXPECTED conditions beyond the radii of the 64 knots wind based on an objective quantification of the potential error associated with the forecast*. The phrase with the qualifier *POSSIBLE* can be triggered anytime during the 00-120 hours time frame. From a hazards perspective, *POSSIBLE* can be generated if 1) a tropical storm (hurricane) warning is in effect with maximum wind and/or probability criteria met but criteria for *IMMINENT* or *EXPECTED* not met (*so you can have a warning in effect but based on an objective estimate of the potential forecast error this allows the WFO to downscale and locally enhance NHC's forecast by not having to say EXPECTED everywhere just because there is a warning in effect*); or 2) a tropical storm (hurricane) watch to be in effect with maximum wind or probability criteria met. From a Wind perspective, tropical storm (hurricane) conditions *POSSIBLE* can also be generated if the maximum wind is greater than or equal to 25 (50) knots with a watch or warning in effect or if the wind is greater than or equal to 34 knots (64) knots but watches or warnings are not in effect. From the probability perspective, the use of tropical storm (hurricane) conditions *POSSIBLE* can also be generated if the 34 (64) knots incremental probability is greater than or equal to the PWS34 (PWS64) threshold according to forecast period shown in Table 5 regardless of whether there are watches or warnings in effect. In the extended portion of the forecast (hours 49-120), in addition to the probability threshold criteria, a minimum wind of 20 knots or greater is also required. This prevents the use of phrases over huge distances as the probabilities tend to fan out considerably with time.

Two important additional constraints imposed on the tropical version of the ZFP and CWF text formatters are: 1) in the zone version of the formatters ran within GFE, the forecasts are representative not of a point but a zone or zone combination, an area than can cover hundreds of square miles if not thousands. When this is the case, the formatters are programmed to use not the maximum wind anywhere across the area but rather a moderated max wind left after chopping off the top 15% highest wind grids. This prevents spurious high pixels from contaminating the analysis; 2) The wind phrases has been enhanced on both version of the formatters (zone and point-and-click) to use from 10 mph wind speed ranges (down from the moderated max wind) for weak tropical storms to 15 mph for strong tropical storms and 20 mph for hurricanes. This results in far better wind phrases and constitutes another way of handling uncertainty and the chaotic nature of the wind spectra associated with these high wind events.

During development, many cases were tested particularly from the 2004 and 2005 active seasons and experimentally in real time from the 2006 and 2007 seasons. Three examples are illustrated here. First is a hurricane Charley example using advisory number 17 from 1500 UTC 13 August 2004. Figure 3a shows a wind speed forecast valid early that afternoon using TPC guidance from the advisory in the GFE Wind grids. Figure 3b illustrates the corresponding incremental probability grid valid that afternoon from the 1500 UTC advisory. The entire West Florida Coast was under a hurricane warning at the time. In Figure 3a it is clear that the radii of 64 knots winds are kept away from Punta Gorda and brought up to Tampa. Yet the incremental probabilities in Figure 3b illustrate that the Port Charlotte and Punta Gorda area had a greater chance of experiencing the hurricane conditions. Figure 3c illustrates what a zone forecast from the NWS office in Tampa Bay would have looked like using the enhanced tropical version of the ZFP formatter. Despite being outside the 64 knots wind radii, the formatter is prompted to still express *EXPECTED* when weighting in the probability grid. Despite the fact that a hurricane warning remains in effect, the formatter only conveys tropical storm conditions EXPECTED for the early evening period. This is due to the fact that the 64 knots wind radii is by far north of the area by then and the corresponding probabilities dropped off fast as Charley was racing northeast by this time. Yet because there is still a hurricane warning in effect early in the evening, the possibility of hurricane conditions is still mentioned. This is an example of how the formatters make use of the hazards, wind, and probability grids together to downscale TPC's forecast in a responsible manner.

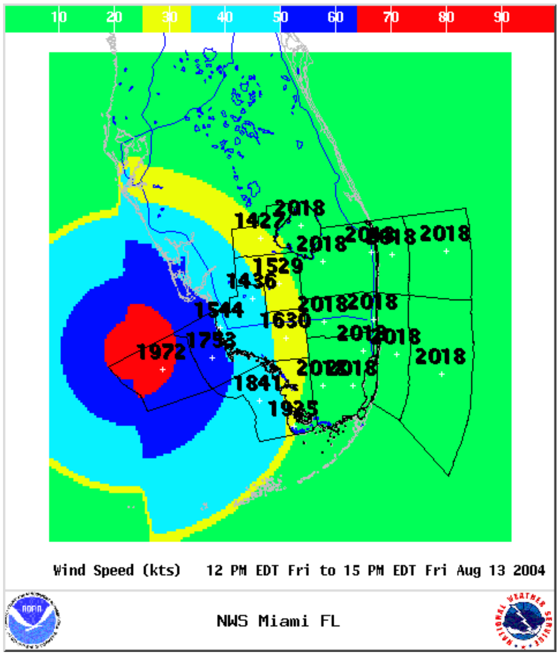

Figure 3a. Wind grids in GFE valid early afternoon on 13 August 2004. Outside the main core of the cyclone, a homogenous background field is shown here. These are not the actual wind grids from the event but the wind radii is from TPC's advisory. The graphic is colorized by categories for easier illustration. Areas in yellow show windy conditions, light blue winds of 34-50 knots, blue 50-64 knots, and red 64 knots or greater.

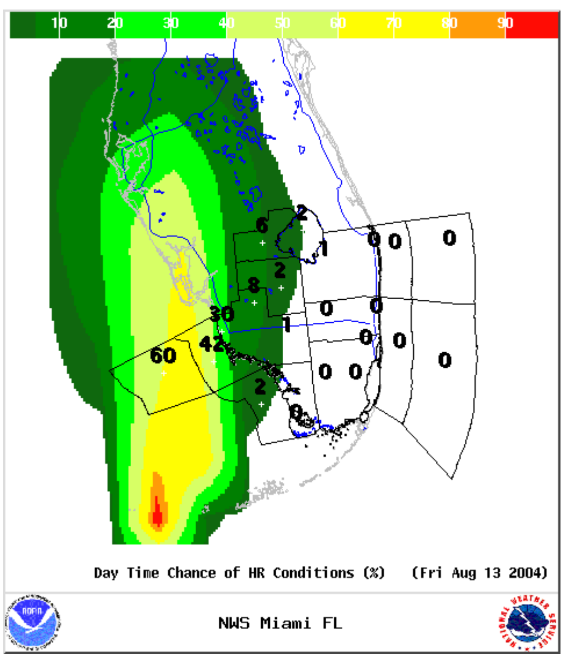

Figure 3b. 64 knots incremental wind speed probability grid valid for the afternoon of 13 August 2004 using TPC's 1500 UTC advisory data.

CHARLOTTE-LEE-
INCLUDING THE CITIES OF PORT CHARLOTTE
…PUINTA GORDA…AND FORT MYERS
1115 AM EDT FRI AUG 13 2004

…HURRICANE WARNING IN EFFECT…

.TODAY…HURRICANE CONDITIONS EXPECTED.
NEAR THE COAST…EAST WINDS 40 TO 45 MPH WITH GUSTS UP TO 60 MPH BECOMING SOUTH 50 TO 70 MPH WITH GUSTS UP TO 90 MPH IN THE AFTERNOON. INLAND…EAST WINDS 35 TO 40 MPH WITH GUSTS UP TO 55 MPH BECOMING SOUTHEAST 45 TO 55 MPH WITH GUSTS UP TO 65 MPH IN THE AFTERNOON.
.TONIGHT… TROPICAL STORM CONDITIONS EXPECTED WITH HURRICANE CONDITIONS POSSIBLE. SOUTH WINDS 45 TO 55 MPH WITH GUSTS UP TO 65 MPH BECOMING EAST AROUND 20 TO 25 MPH WITH GUSTS UP TO 30 MPH.
.SATURDAY…BREEZY…

Figure 3c. Example of what a zone forecast for Charlotte and Lee counties from WFO Tampa would have looked liked using the enhanced tropical ZFP GFE formatter. Only the expressions of uncertainty and wind phrase elements of the forecast are shown.

The second example is hurricane Frances from the advisory issued at 1500 UTC on 2 September 2004. Hurricane warnings were first issued at this time for the East Central and Southeast Florida coasts even when the official forecast did not have the hurricane affecting the area until late the third forecast period going on into the fourth. Therefore, this is a case of a very early warning. Figure 4a illustrates the sample output from the zone GFE version of the ZFP tropical formatter. Notice the enhanced wind phrases with proper spin up and spin down periods around the time of worst forecast conditions. It is also notable that in the first two periods, even when there was already a hurricane warning in effect, no uncertainty phrase was triggered. This is because neither the wind or probability grids reflected any reasonable chance of conditions beginning earlier than forecast. Again, this is an example of downscaling TPC's forecast to the WFO level in a manner where potential forecast errors are accounted for. Figure 4b illustrates the point-and-click forecast for the same Frances example shown in Figure 4a but for a point along the Northeast Palm Beach County coast. Notice the consistency with the forecast in Figure 4a. Also, even when hurricane conditions were no longer forecast by late Saturday night, the formatter still mentions the possibility which is also trended down into tropical storm conditions by Sunday. This is the result of the probabilities and their modulating effect as they remained above threshold levels into Sunday. The message here is the forecast error is such that even when the storm was forecast to

PALM BEACH EASTERN-
INCLUDING THE CITY OF...WEST PALM BEACH
1132 AM EDT THU SEP 2 2004

…HURRICANE WARNING IN EFFECT…

.REST OF TODAY...BREEZY. NORTHEAST WINDS 20 MPH WITH HIGHER GUSTS.
.TONIGHT...BREEZY. NORTHEAST WINDS 20 MPH AND GUSTY.
.FRIDAY...TROPICAL STORM CONDITIONS EXPECTED WITH HURRICANE CONDITIONS ALSO POSSIBLE. NORTHEAST WINDS 20 MPH WITH HIGHER GUSTS BECOMING NORTH 35 TO 40 MPH WITH GUSTS TO AROUND 60 MPH IN THE AFTERNOON. NEAR THE COAST...NORTHEAST WINDS 20 MPH WITH HIGHER GUSTS BECOMING NORTH 40 TO 50 MPH WITH GUSTS TO AROUND 70 MPH IN THE AFTERNOON.
.FRIDAY NIGHT...HURRICANE CONDITIONS EXPECTED. NORTH WINDS 45 TO 55 MPH WITH GUSTS TO AROUND 75 MPH BECOMING NORTHWEST AND BECOMING 55 TO 70 MPH WITH GUSTS TO AROUND 90 MPH AFTER MIDNIGHT. NEAR THE COAST...NORTH WINDS 45 TO 65 MPH WITH GUSTS TO AROUND 80 MPH BECOMING NORTHWEST AND BECOMING 65 TO 85 MPH WITH GUSTS TO AROUND 105 MPH AFTER MIDNIGHT.
.SATURDAY...HURRICANE CONDITIONS POSSIBLE. WEST WINDS 75 TO 95 MPH WITH GUSTS TO AROUND 120 MPH BECOMING SOUTHWEST AND DECREASING TO 65 TO 85 MPH WITH GUSTS TO AROUND 105 MPH IN THE AFTERNOON. NEAR THE COAST...WEST WINDS 90 TO 110 MPH WITH GUSTS TO AROUND 135 MPH BECOMING SOUTHWEST AND DECREASING TO 70 TO 90 MPH WITH GUSTS TO AROUND 115 MPH IN THE AFTERNOON.
.SATURDAY NIGHT...HURRICANE CONDITIONS POSSIBLE.
.SUNDAY...TROPICAL STORM CONDITIONS POSSIBLE.
.SUNDAY NIGHT...BREEZY.

Figure 4a. Example of what a zone forecast for Eastern Palm Beach County from WFO Miami would have looked liked using the enhanced ZFP GFE tropical formatter using advisory data for hurricane Frances from 1500 UTC 2 September 2004. Only the expressions of uncertainty and wind phrase elements of the forecast are shown. The background field used for this test was not representative of actual conditions. Only the inner core of the cyclone as represented in the GFE grids from TPC's advisory was used.

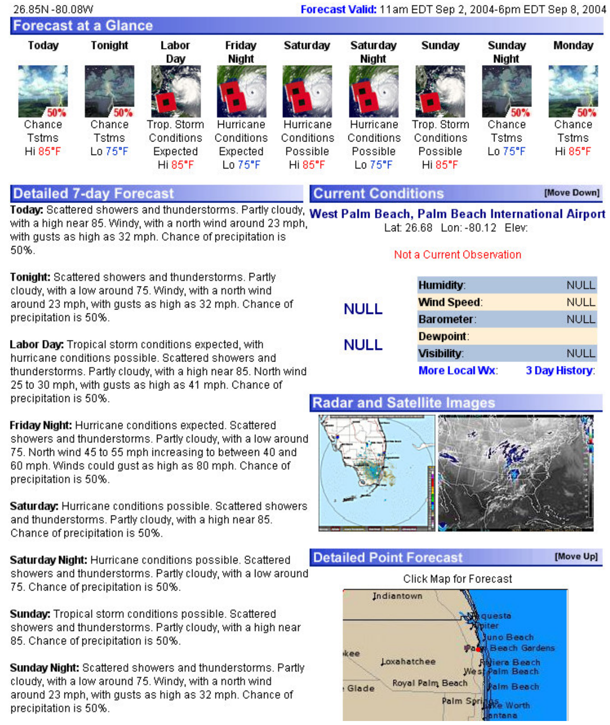

Figure 4b. Point-and-click version of forecast in Figure 4a but for a point along the Northeast Palm Beach County coast as shown by the red dot in the lower right corner of the figure. This was generated with test data with a background homogenous wind field. Only the wind data taken from TPC's advisory is real.

be away from the area by these periods, the potential error is such it still warrants mentioning the possibility that could result from a slower than expected movement, a larger than forecast storm, or a more intense than forecast system. These are the sources of errors accounted for by the wind speed probabilities.

The third example highlights the fact that because of the differences in scales represented by the zone and point-and-click version of the forecasts, the zone version will always yield a forecast that in general is more pessimistic. To illustrate this, we consider tropical storm Noel advisory number 19 from 0900 UTC on 1 November 2007. A tropical storm warning was issued at the time for portions of the Southeast Florida coast (Figure 5). It is evident that the 34 knots wind speeds were not forecast to reach the coastal zones. So the question here is: were the wind speeds and incremental 34 knots wind speed probabilities high enough to mention *EXPECTED* or *POSSIBLE*?

Figure 6 illustrates the zone version of the ZFP for Coastal Miami Dade and Broward counties (6a) and the point-and-click version of the forecast for Biscayne Park (6b) and Miami Beach (6c). Notice that in the zone version generated within GFE, *TROPICAL STORM CONDITIONS POSSIBLE* is mentioned for all

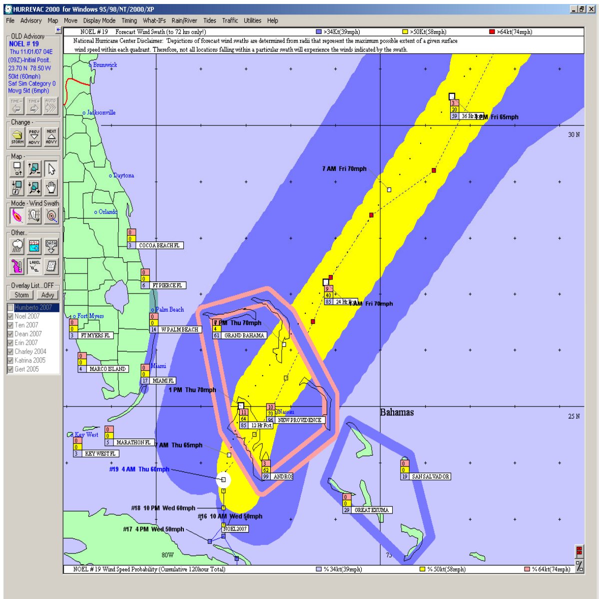

Figure 5. Hurrivac illustration of TPC's forecast from the 0900 UTC 1 November 2007 advisory. The blue swath illustrates the radii of the 34 knots wind speeds. The blue along the coast illustrates coastal zones under a tropical storm warning.

COASTAL BROWARD-COASTAL MIAMI DADE-
INCLUDING THE CITIES OF...FORT LAUDERDALE…
MIAMI BEACH...CORAL GABLES...CUTLER BAY…
HOMESTEAD
557 AM EDT THU NOV 1 2007

…TROPICAL STORM WARNING IN EFFECT…

.TODAY...TROPICAL STORM CONDITIONS POSSIBLE. NORTH WINDS 20 TO 25 MPH BECOMING 25 TO 30 MPH IN THE AFTERNOON. GUSTS UP TO 40 MPH.
.TONIGHT...WINDY. NORTH WINDS 20 TO 25 MPH DECREASING TO 15 TO 20 MPH AFTER MIDNIGHT. GUSTS UP TO 35 MPH.

Figure 6a. Forecast for Coastal Miami Dade and Broward counties using the enhanced ZFP GFE tropical formatter with Tropical Storm Noel TPC advisory data from 0900 UTC 1 November 2007. Only the expressions of uncertainty and wind phrase elements of the forecast are shown.

of the coastal counties even when the conditions are more likely for the immediate coastal sections. But in the point-and-click version, the possibility of such conditions is only mentioned along the immediate coast (Miami Beach) where the probabilities and winds are highest yet not high enough to mention *EXPECTED* even when a warning is in effect. This also illustrates nicely how the hazards, wind, and probability grids are used together by the tropical formatters to downscale TPC's forecast.

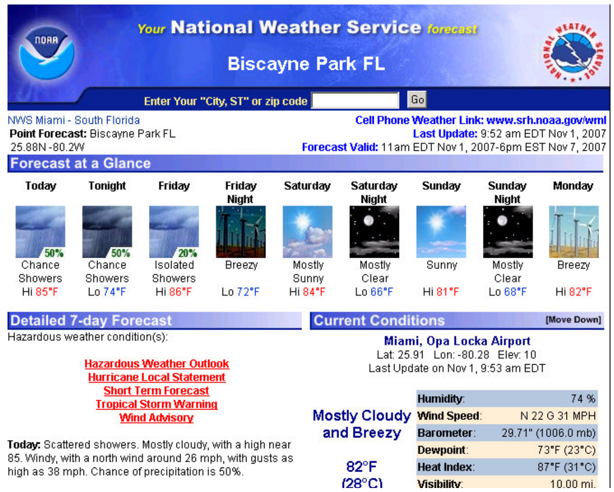

Figure 6b. Point-and-click forecast valid for Biscayne Park on the mainland (western) side of Biscayne Bay in Miami Dade County.

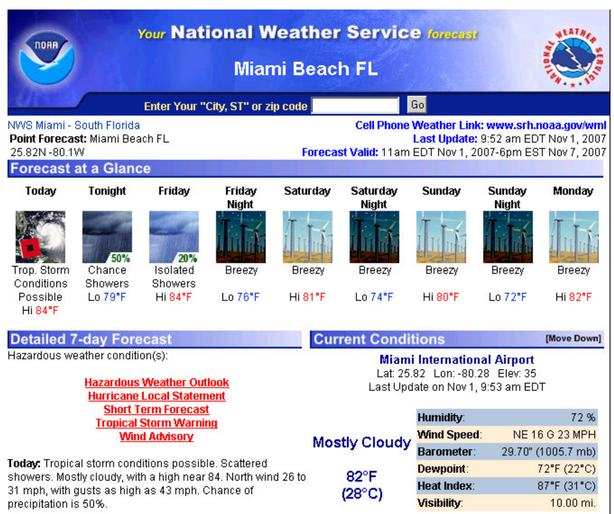

Figure 6c. Point-and-click forecast valid for Miami Beach on the eastern side of Biscayne Bay in Miami Dade County immediately adjacent to the Atlantic coastal waters.

All the while, these examples help illustrate that the probabilities operate as a safety net to minimize potential inconsistencies and negate the overemphasis of exact wind speeds forecast for exact time periods. However, it is necessary to test the experimental formatters on many different cases from various WFO/regional perspectives. Beyond the cases illustrated briefly here, test cases that have been evaluated from the 2004 season include Charley and Frances, and from the 2005 season Dennis, Katrina, Rita, and Wilma. For the 2006 season Ernesto has been evaluated and from the 2007 season Dean, Erin, Humberto and Noel have also been evaluated. Perspectives thus far have included South Florida (the WFO MFL perspective), East Central Florida (the WFO MLB perspective), West Central Florida (WFO Tampa), Southeast Texas (WFO Houston), and Southeast Louisiana (WFO New Orleans) using both the ZFP and CWF products. These will be expanded to other geographic areas and include other cyclones as the applied research continues and the experiment is expanded into the 2008 season when both version of these enhanced tropical formatters (Zone/GFE and point-and-click) will also be made available to the public if approved as of this writing.

As previously mentioned, future considerations for employing this method operationally will require a thorough objective examination in order to determine the best probability thresholds for triggering certain phrases. That is, full appreciation must be given to the diversity of tropical cyclone situations. The initial values as presented in Tables 3-5 were empirically established for use during the development phase and were used to trigger the wording contained in the examples provided in Figures 3-6. The method consisted of a distribution analysis of the incremental probabilities using four storms from the 2005 season, namely, Hurricanes Dennis, Katrina, Rita, and Wilma as they impacted South Florida. The analysis was conducted for each cyclone for both the 34-knot and 64-knot probabilities (separately) for specific individual regions/zones across South Florida. This approach is more revealing given that the probability sets already account for inland decay; separate information was yielded independently for marine, coastal, and inland areas. Ultimately, individual analyses (as carried out by zone, intensity threshold, and cyclone) were merged to create combined analyses. Figures 7a-e illustrate raw histogram plots of the 34-knot incremental wind speed probabilities for Hurricane Wilma for the warning, watch, Day-3, Day-4, and Day-5 periods (respectively). At first glance, and as expected, it is apparent that during the warning period the histogram is skewed toward the high end; in the watch period the distribution is spread out over a mid-range of values; and in the extended periods the distribution becomes more skewed toward the low end. It is evident, then, that the probability thresholds for triggering the mention of *POSSIBLE* or even *EXPECTED* hurricane or tropical storm conditions are a function of time, with lower values gaining more significance in the extended range of the forecast and vice versa.

In order to obtain confidence in the probability thresholds being used, or to identify any needed adjustments, a comprehensive verification analysis is currently underway in place of the distribution analysis done initially. This new more robust verification analysis uses Relative Operating Characteristic (ROC) diagrams as the method to help identify probability thresholds that differentiate between events and non-events (Knaff and DeMaria 2007). These will eventually be expanded to include more events across different coastal regions to gain confidence for choosing the final threshold values. At this time, it is unknown whether different probability thresholds will be needed for different geographic regions.

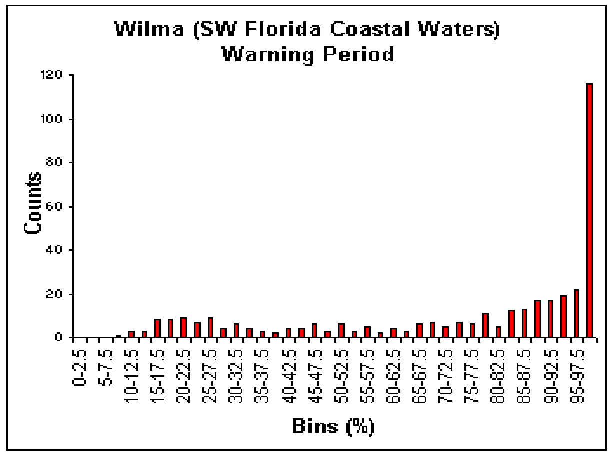

Figure 7a. A raw histogram plot of the 34-knot incremental wind speed probabilities for the SW Florida Coastal Waters (out 60 nautical miles from Naples, Florida) from Hurricane Wilma for the warning period (or 00-24 hours). Percentages are in bins of 2.5% plotted in the x axis with the raw counts plotted in the y axis.

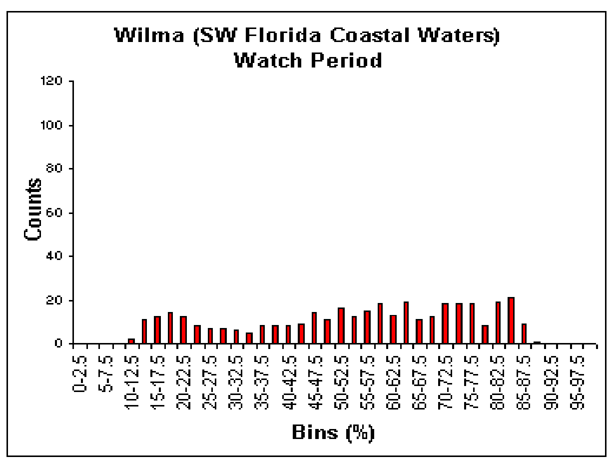

Figure 7b. The same as Figure 7a, except for the approximate watch period (25- to 48-hours).

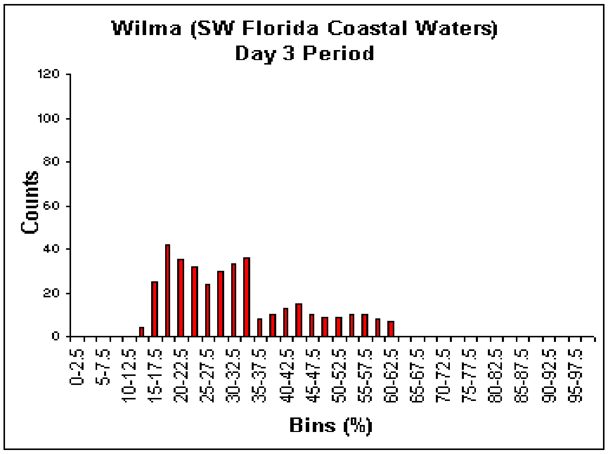

Figure 7c. The same as Figure 7a, except for the approximate Day-3 period (49- to 72-hours).

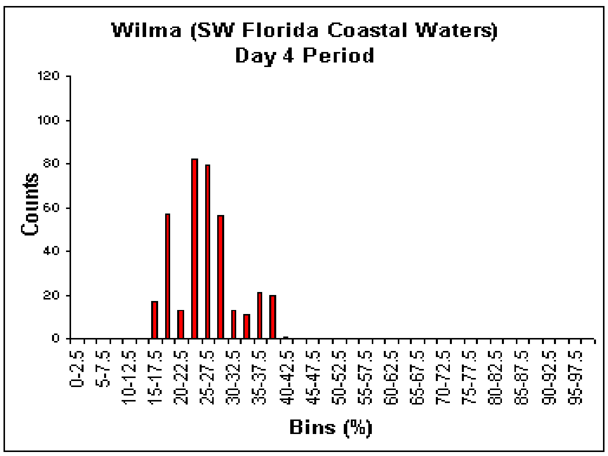

Figure 7d. The same as Figure 7a, except for the approximate Day-4 period (73- to 96-hours).

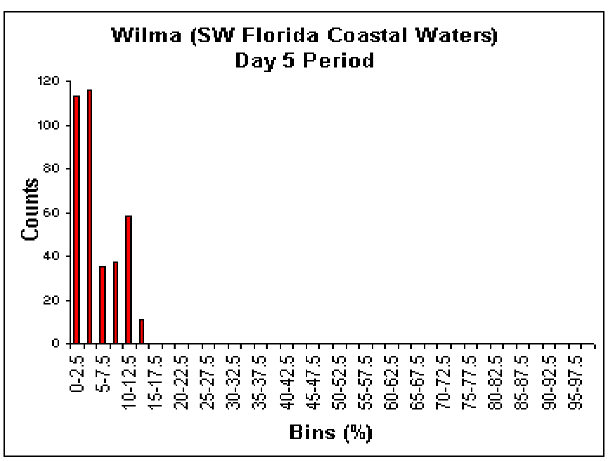

Figure 7e. The same as Figure 7a, except for the approximate Day-5 period (97- to 120-hours).

4. ENHANCED GRAPHIC PRODUCTS

Over the past six seasons, WFOs MLB and MFL have successfully generated hazard graphics depicting the current threat and corresponding potential impact for tropical cyclone situations affecting both East Central Florida and South Florida. Associated hazards include high wind, coastal flooding (e.g., storm surge and tide), inland flooding, and tornadoes. These experimental graphics are posted for live viewing on respective WFO websites to visually complement the official Hurricane Local Statement (HLS) text product. Development and testing has been arduous but rewarding, especially when considering the combined experiences from the 2004-05 seasons. Specifically, the High Wind Impact graphic (Figure 8) depicts wind hazard information from a location-centric perspective by responsibly translating the most relevant threat assessment information through descriptions of potential impact using a color-coded index scale ranging from 0 to 5, None to Extreme. This threat of impact assessment has specific definitions for different levels that have been regionally coordinated among WFOs (Table 6) in a manner that is consistent with the way the graphic is created. The product combines the forecasting expertise of the NHC and the local WFO by considering the larger-scale enhancements, while also accounting for inherent forecast uncertainties in track, intensity, and size of the tropical cyclone. Thus, it effectively employs both deterministic (e.g., wind speed) and probabilistic (e.g., uncertainty) components of the forecast for a more complete expression of the wind threat and corresponding impact. Product release is triggered by the issuance of a tropical cyclone Watch or Warning anywhere within the defined area with each successive update valid for the remainder of the event. Updates are provided shortly after each official advisory and are continued until tropical cyclone winds are no longer an immediate threat to local communities.

As stated, the High Wind Impact graphic uses an index scheme to distill an abundance of wind information into a single plan-view map that is easy-to-understand. It is useful for motivating less-sophisticated users to action regarding preparedness activities by helping overcome information paralysis. It also highlights the minimum recommended actions which should be taken according to generalized impact descriptions that are based on outcomes from past events. For more sophisticated users, this product serves as an excellent starting point for critical decision-making and is a coherent briefing tool. In gridded form, it can be ingested into Geographic Information Systems to address specific vulnerabilities, in context of the actual meteorological situation, for a more detailed assessment of the potential impact from high wind. As an example, upon the issuance of a tropical cyclone Watch or Warning a family might investigate the High Wind Impact graphic to determine the extent to which their personal interests are being

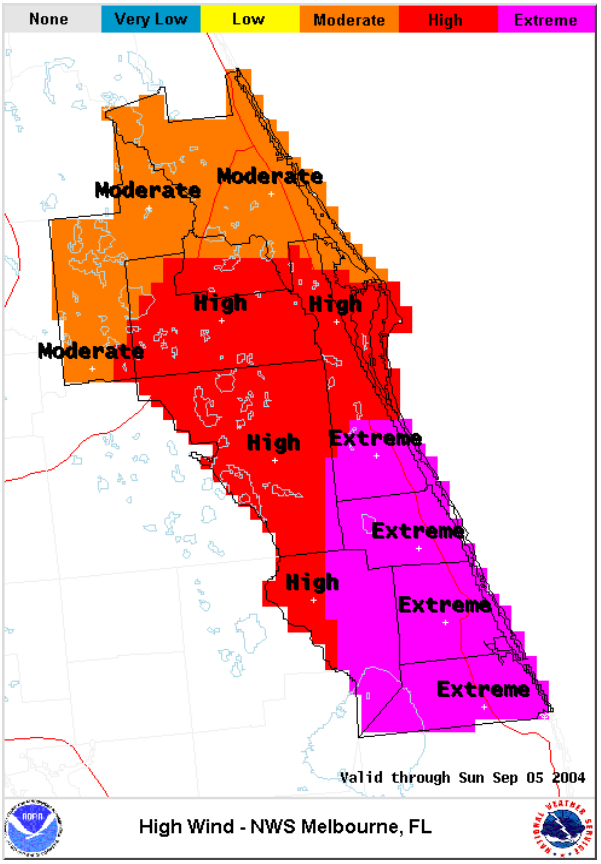

Figure 8. An example of the experimental Tropical Cyclone High Wind Impact graphic as generated for East Central Florida for Hurricane Frances (2004). This product is available to users whenever a tropical cyclone Watch or Warning is issued for the local area.

threatened by the description of potential impacts within their particular community. More so, government officials at all levels would have greater indication of extent to which certain locations are being threatened, as well as those areas in danger of being hardest hit. Response and recovery resources can better pre-positioned and managed, with other resources safely secured.

Originally, the WFO forecaster performed the threat assessment process manually by first using the official wind forecast (radii/wind swath) to determine the maximum forecast (event) wind speed across the forecast area, to include any mesoscale adjustments. Next, a forecaster would subjectively consider the inherent uncertainty by utilizing the average error cone for track. Errors in storm size and intensity were also factored in, but with more difficulty. The result is a broadening of the initial threat area to account for the situational spectrum of reasonable possibilities. The closer in time to landfall, the more the graphic tends toward the deterministic solution. Contrastingly, the farther out in time then the more important the contribution of forecast uncertainty. This method worked well for years, relying heavily upon forecaster expertise. However, two particular issues were realized. The first was to reduce the associated workload due to manual generation, and the second was to minimize the differences in subjectivity among forecasters. To mitigate these operational challenges, a SmartTool (e.g., GFE software application) was coded which makes creative use of the recently available cumulative-form wind speed probabilities (Knaff and DeMaria 2005). When executed, the tool smartly composites the 34-, 50-, and 64-knot probabilities to generate a first-guess field for forecaster review (Figure 9). Automated compositing (Figure 10) is largely based on highlighting areas which exceed the 10 percent threshold for the specified wind speed (Table 7) for tropical storms and category one hurricanes. This initialized impact levels are further checked against the wind grids to make sure the depicted impact levels are consistent with the definitions presented in Table 6. In order to initialize high and extreme areas, the tool checks to see if the cyclone is forecast to be category 2 or 3+ (major) as depicted in the wind grids. If it is, a higher percentage criterion is applied to depict high or extreme (Table 7). This approach allows the tool also to distinguish between the strengths of hurricane-force winds of different wind speed categories (e.g., Saffir-Simpson Hurricane Scale).

5. SUMMARY

It has been shown that critical decision-making during tropical cyclone events stands to realize significant gains through the availability of incremental-form and cumulative-form wind speed probabilities. Yet, it will still take some time before user-skill is acquired with these data sets. Serving as sophisticated first-users, and advocates of less-sophisticated users, WFOs can now offer information regarding the uncertainty of the wind speed forecast.

During events of high impact, requirements for this type of information can be as important as the deterministic forecast. Here, WFOs MFL and MLB have shown creative application of the incremental-form probability sets to enhance the wording of public and marine text products by introducing expressions of uncertainty via automated formatters that are coded to trigger on pre-selected probability thresholds. Rigorous testing will continue during the 2008 season and will be facilitated by the NOAA Tropical Cyclone Wind Team and by others who attend the annual NOAA Hurricane Conference. Upon revealing the trigger thresholds which can consistently offer the most responsible text wording, proper considerations will be made for operational implementation. This will take more hours of applied research, testing a variety of diverse situations. Too, it is hoped that other textual forecast products might be improved through a similar approach (e.g., fire weather forecast, tabular forecast products, etc.).

Impact Levels	Description
Extreme	• **Threat** - An extreme threat to life and property; the likelihood for major hurricane-force winds (greater than 110 mph) of Category 3, 4, or 5 intensity. • **Minimum Action** - Prepare for the likelihood of extreme to catastrophic wind damage. • **Potential Impact** – An extreme impact to communities within the specified area. Winds capable of causing structural damage to buildings, some with complete wall and roof failures. Complete destruction of mobile homes. Numerous large signs and trees blown down. Many roads impassible due to large debris. Widespread power outages. Damage is consistent with that realized by winds of Category 3, 4, or 5 strength on the Saffir-Simpson Scale.
High	• **Threat** - A critical threat to life and property; the likelihood for strong hurricane-force winds (96 to 110 mph) of Category 2 intensity. • **Minimum Action** - Prepare for the likelihood of major wind damage. • **Potential Impact** – A high impact to communities within the specified area. Winds capable of causing significant damage to roofing material, doors, fences, and windows of buildings, but with some occurrences of structural damage. Considerable damage to mobile homes. Many large signs and trees blown down with further damage to standing trees. Some roads impassible due to large debris. Widespread power outages. Damage is consistent with that realized by winds of Category 2 strength on the Saffir-Simpson Scale.
Moderate	• **Threat** - A significant threat to life and property; the likelihood for hurricane-force winds (74 to 95 mph) of Category 1 intensity. • **Minimum Action** - Prepare for the likelihood of moderate wind damage. • **Potential Impact** – A moderate impact to communities within the specified area. Winds capable of causing significant damage to mobile homes, especially if unanchored. Some damage to roofing material, doors, fences, and windows of buildings. Several large signs and trees blown down, especially shallow-rooted and diseased trees. A few roads impassible due to large debris. Scattered power outages, but widespread in areas with above ground lines. Damage is consistent with that realized by winds of Category 1 strength on the Saffir-Simpson Scale.
Low	• **Threat** - An elevated threat to life and property; the likelihood for strong tropical storm-force winds (58 to 73 mph). • **Minimum Action** - Prepare for the likelihood of minor to locally moderate wind damage. • **Potential Impact** – A low impact to communities in the specified area. Winds capable of causing damage to unanchored mobile homes, porches, carports, awnings, pool enclosures and with some shingles blown from roofs. Large branches break off trees, but several shallow-rooted and diseased trees blown down. Loose objects are easily blown about and become dangerous projectiles. Winds dangerous on bridges and causeways, especially for high profile vehicles. Scattered power outages, especially in areas with above ground lines.
Very Low	• **Threat** - A limited threat to life and property; the likelihood for tropical storm-force winds (39 to 57 mph). • **Minimum Action** - Prepare for the likelihood of minor wind damage. • **Potential Impact** – A very low impact to communities within the specified area. Winds capable of causing damage to carports, awnings, and pool enclosures. Some damage to unanchored mobile homes. Small branches break off trees and loose objects are blown about. Winds becoming dangerous on bridges and causeways, especially for high profile vehicles. Isolated to widely scattered power outages, especially in areas with above ground lines.
None	• **Threat** - No discernable threat to life and property; winds to remain below tropical storm-force, but windy conditions may still be present. • **Minimum Action** - Evaluate personal and community disaster plans and ensure seasonal preparedness activities are complete. • **Potential Impact** – Wind damage is not expected; impact should be negligible.

Table 6. The table shows the definition of each impact level for the experimental Tropical Cyclone High Wind Impact graphic. The definitions are graduated and color-coded. They are also Florida centric in this case.

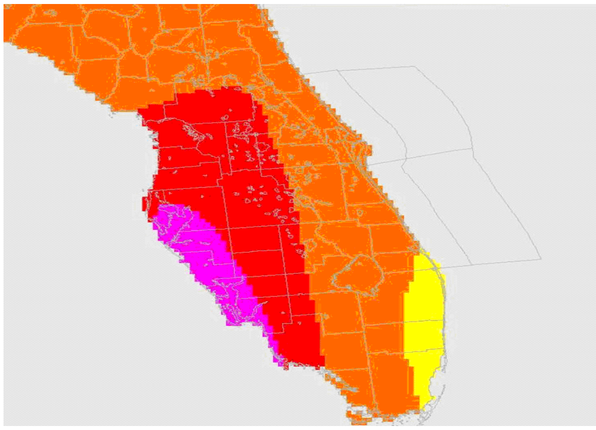

Figure 9. Through compositing techniques using the cumulative-form tropical cyclone wind probabilities, a first-guess map can be generated depicting the Tropical Cyclone High Wind Impact. Shown is an example of a first-guess map for Hurricane Charley (2004).

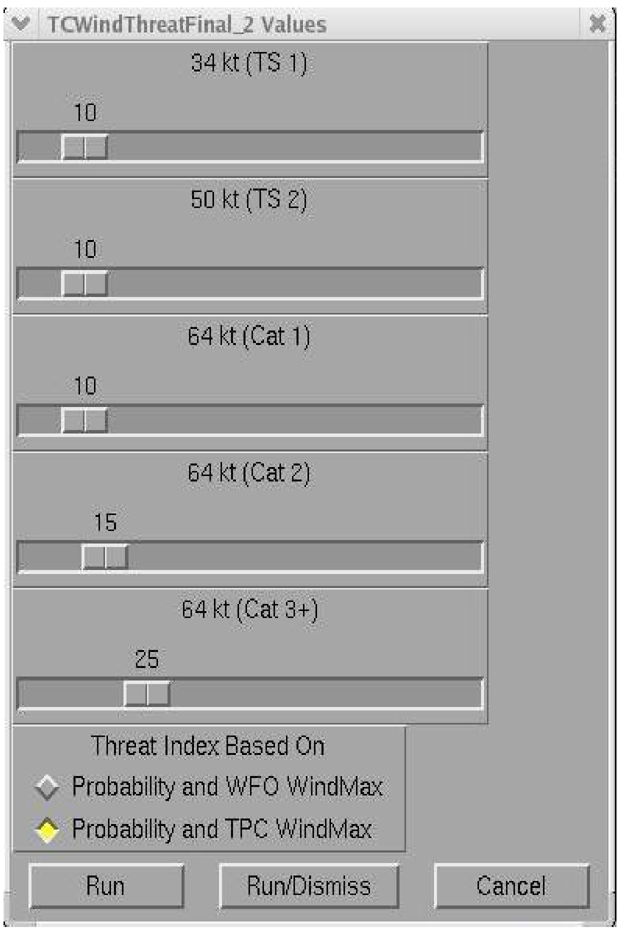

Figure 10. Interface for the Graphical Forecast Editor (GFE) SmartTool which creates the first guess field for the Tropical Cyclone High Wind Impact graphic.

Probability Thresholds Table - Preliminary

Impact Level	Probability Threshold
Very Low	> 10% for 34-knot wind
Low	> 10% for 50-knot wind
Moderate	> 10% for 64-knot wind
High	> 15% for 64-knot wind (if Cat. 2)
Extreme	> 25% for 64-knot wind (if Cat. 3+)

Table 7. The table shows the preliminary threshold values of the cumulative-form probabilities for approximating each of the Tropical Cyclone High Wind Impact levels. By incorporating this logic within a SmartTool, reasonable first-guess fields can be generated and provided to forecasters.

Opportunity has also been shown to exist for improving (experimental) graphic products by employing the cumulative-form probabilities. Workload and subjectivity can be reduced when performing tropical cyclone wind threat assessments. Graphics which distill an abundance of sophisticated decision-making information into an easy-to-understand depiction is the lofty desire of less-sophisticated users. Undoubtedly, probabilities for exceeding certain critical thresholds are main ingredients for such graphics. This would also have value for sophisticated users if related information was additionally available in gridded format. With an advanced geographic information system (GIS), a user would be able to answer questions (with more detail) regarding potential impact whenever tropical cyclones threaten.

6. ACKNOWLEDGEMENTS

The authors wish to recognize participants of the NOAA Hurricane Conference (2005-2007) for insightful discussion and debate. This recognition is extended to the members of the Tropical Cyclone Wind Team, and in particular, to Scott Kiser (NWS Tropical Program Office) for his invaluable role as a facilitator allowing this project to move forward. Sincere gratitude is expressed to Tracy Hansen of the NOAA Global Systems Division, Matthew Belk (Forecaster WFO Boston), and Mark Mitchell (ITO WFO Pleasant Hill) for expert programming assistance with the text formatters. Also Matt Moreland (Forecaster WFO Houston) for excellent feedback during the Texas storms of 2007. We would like to thank James Gross and Richard Knabb of the NOAA Tropical Prediction Center for their collaborative spirit and help, as well as Mark DeMaria of the NOAA National Environmental Satellite Data and Information Service for responding to cited needs from the field. Shirley Leslie is also commended for providing grammatical review. Lastly, the authors would like to thank the operational meteorologists of WFOs Miami and Melbourne for their collective and progressive commitment to protecting lives.

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