13A.5 An Examination of the Logic within WFO Software Applications used to Generate Tropical Cyclone Impact Graphics

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1. INTRODUCTION

The National Weather Service (NWS) is committed to developing graphics which locally depict the potential negative impact for respective hazards associated with tropical cyclones that threaten the United States. Upon the issuance of either a tropical cyclone watch or warning within their defined areas of responsibility, a series of impact graphics is experimentally produced by select Weather Forecast Offices (WFOs) for hazards that include high wind, coastal flooding (storm surge and tide), inland flooding, and tornadoes. The graphics are updated shortly following each official advisory as issued by the National Hurricane Center (NHC), and then posted to WFO web pages for customer use in decision-making. The graphics are color-coded, making them easy to understand. They readily depict increasing levels of impact based on automated threat assessment techniques which account for the forecast magnitude of the hazard, along with the uncertainty of that forecast. Respective impact levels range from 0 to 5 (No Impact to Extreme Impact), with the worded definition for each level regionally described. In order to foster consistency among coastal WFOs and national centers, while also minimizing the need for significant manual editing, a set of software applications (e.g., SmartTools) is being coded by the Global Systems Division (GSD) of the National Oceanic and Atmospheric Administration (NOAA) and alpha tested by WFOs Melbourne, Miami, and Charleston. These SmartTools are able to quickly generate quality first-guess fields and then deliver them to the forecaster for limited fine-tuning. The SmartTools take advantage of both deterministic and probabilistic gridded input data, and are executed on a common Graphical Forecast Editor (GFE) platform. Afterwards, a script is run which produces web-ready versions of the graphics (in *.png format) and uploads them to the internet for display. Eventually, the SmartTools will be shared with other coastal WFOs for operational use. From start to finish, the associated workload becomes relatively small when using the tools.

With the growing popularity of impact graphics and their utility for supporting critical decision-making by a spectrum of users, the internal logic of these tools must possess reasonable integrity as to ensure a responsible approach relative to the applied science. More so, the information presented via the graphics must further enhance NOAA's one official message, as applied locally, by offering realistic interpretations of potential impact. In conjunction with NOAA's one message, during tropical cyclone events the impact graphics are produced using data from NHC, the Hydrometeorological Center (HPC), and the Storm Prediction Center (SPC). As such, the impact graphics uniquely harness the expertise from multiple national centers and WFOs to provide realistic interpretations of the wide-ranging impacts from tropical cyclones. The graphics must never be a source of confusion or contradiction. Rather, the intent is to clarify the situation with concise visual expressions which motivate people to take appropriate actions; actions which protect lives and property, but are also proportional to the level of threat. This point is cornerstone to the initiative. The paper will therefore examine the current and proposed logic for each of the hazard tools and offer corresponding examples of initial output. The operational availability of certain gridded input data will also be considered.

2. BACKGROUND

Initial concepts towards the development of WFO-scale hazard graphics to more effectively communicate threat information date back to a need identified in the post-storm review of the February 1998 Central Florida Killer Tornado Outbreak (NOAA, 1998). During the outbreak, 42 people lost their lives even though warnings were issued for all tornadoes with sufficient lead times. During post event studies, it was surmised that if a WFO could better communicate the anticipated magnitude, forecast confidence, and geographic distribution of an impending hazard, then communities would be well poised for critical decision-making before actual warnings were issued (Sharp, 2004). Later that year, the routine issuance of a prototype version began in Florida (Sharp et al, 2000). The effort offered a daily threat assessment of a variety of area weather hazards focusing on the Day 1 time frame (e.g., today and tonight). The graphics were designed to complement the textual Hazardous Weather Outlook (HWO) product by visually synthesizing complicated threat assessment information into graduated color-coded levels that corresponded to the words of the text. The graphics found early favor among internet users by furnishing emergency responders with at-a-glance information for resource management purposes, and by overcoming language and sophistication barriers among certain societal groups (e.g., demographics) when attempting to communicate the message. The effectiveness of the graphical HWO (gHWO) was greatly elevated once threat definitions were correlated to potential impact. Within a few years, variations of hazard graphics were being experimentally offered by several WFOs in Florida and elsewhere.

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Following the mass (record) evacuation in Florida prompted by Hurricane Floyd in 1999, a sister initiative was then pursued. The approach was similar to the gHWO, but provided hazard graphics that complemented the textual Hurricane Local Statement (HLS) instead. Since that time, upon the issuance of a tropical cyclone watch or warning, WFOs along Florida's Atlantic coast have provided graphics complementing the HLS; that is, have provided a gHLS for web users. The fundamental difference between the gHWO and gHLS, to date, is that the gHLS remains event driven (e.g., event triggered) and valid for the remainder of the tropical cyclone event, while the gHWO is schedule driven (e.g., clock triggered) and valid for the specified period. Development of the gHLS has been arduous but rewarding, especially when considering the combined experiences from the 2004-05 hurricane seasons. At the end of each season, experiences are shared at the annual NOAA Hurricane Conference, often prompting vigorous discussion. The gHLS initiative was formalized in 2005 with the formation of the NWS Tropical Cyclone Hazards Team. This team was specifically chartered to harness synergy among respective NWS regions (e.g., NWS Southern, Eastern, and Pacific Regions) in order to realize national coherency and promote seamlessness. Through its leadership, WFO participation has steadily grown, thereby increasing coastal and inland county coverage and widening feedback opportunities. For more information about the Tropical Cyclone Hazards Team and their previous work, see http://www.weather.gov/os/tropical/.

Since its inception, the Tropical Cyclone Hazards Team has addressed a host of challenges from the forecaster's perspective and the user's perspective, alike. One of the target goals has been to deal with the array of misconceptions which surrounds the process of taking complex threat assessment information and translating it into simplified (location-centric) maps denoting potential impact. Indeed, a picture is worth a thousand words. However, the associated *thousand words* must be responsibly accommodated within logical and repeatable generation methods (issuance-to-issuance, forecaster-to-forecaster, WFO-to-WFO, and national center-to-WFO). The key is in the provision of a mutual set of GFE SmartTools, one for each hazard. The tools are written in meteorological jargon (e.g., functions applied to gridded numerical input), but output graphics are delivered in layman's terms which are relational in nature. In other words, a rigorous threat assessment is performed by executing the tools (e.g., the science perspective), while subsequent interpretation occurs once the graphics are actually posted to the web page next to carefully crafted definitions describing the relative impact (e.g., the social science perspective). In this way, the cause (e.g., the threat of a hazard) and the effect (e.g., the potential impact of a hazard) are both considered. Before the worded definitions can be exacted and finalized for an area, it is paramount to weigh the threat assessment logic contained within each of the tools.

3. LOGIC FOR THE HIGH WIND TOOL

The logic for performing a thorough threat assessment as the basis for generating the High Wind Impact graphic (Figure 1) is perhaps the most advanced of the initiative. Originally, the WFO forecaster manually performed the assessment process. First, the official wind forecast (e.g., radii and swath) from NHC was used to determine the maximum anticipated sustained (event) wind speed across the domain of interest. Local adjustments were then included to account for mesoscale contributions from boundaries, terrain altitude, gap winds, windward vs. leeward sides of mountains or islands, decreased friction across large inland lakes, etc.). Finally, subjective considerations regarding uncertainty were applied by utilizing the average error cone for track. Errors in storm size and intensity were factored in too, but with much more difficulty. The result was 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 assessment tended toward the deterministic solution. Contrastingly, the farther out in

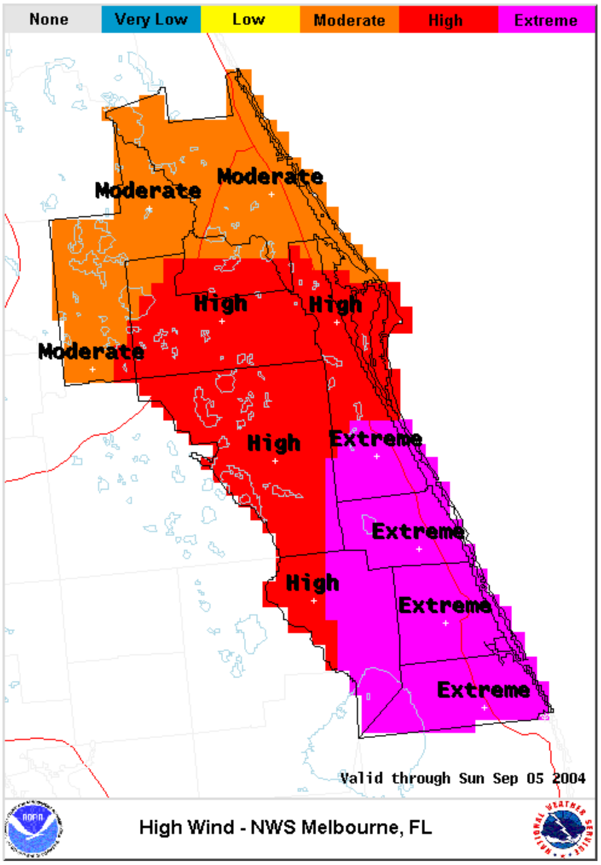


Figure 1. An example of the experimental Tropical Cyclone High Wind Impact graphic as generated for East Central Florida for Hurricane Frances (2004). This product is available to users whenever a tropical cyclone watch or warning is issued for the local area.

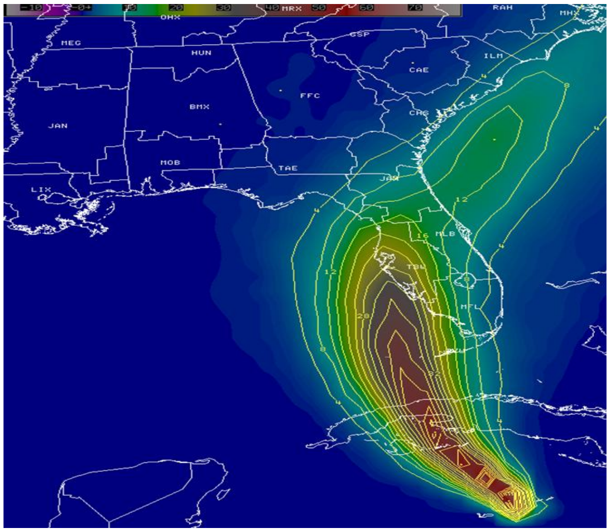


Figure 2. An AWIPS example of the cumulative-form 64-knot tropical cyclone wind probabilities valid through 120 hours for Hurricane Charley issued at 1200 UTC, 12 August 2004. The probabilities are also available for 34-knot and 50-knot wind speeds.

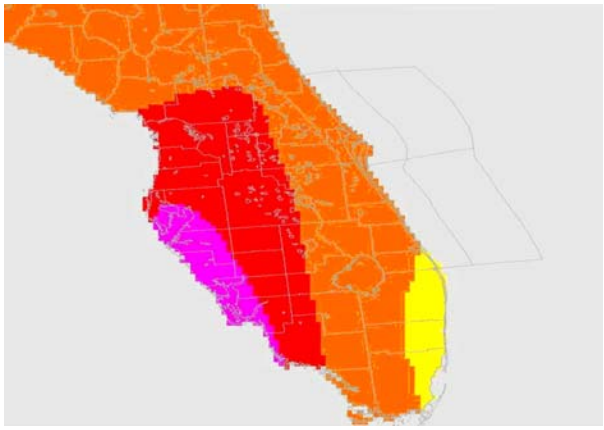
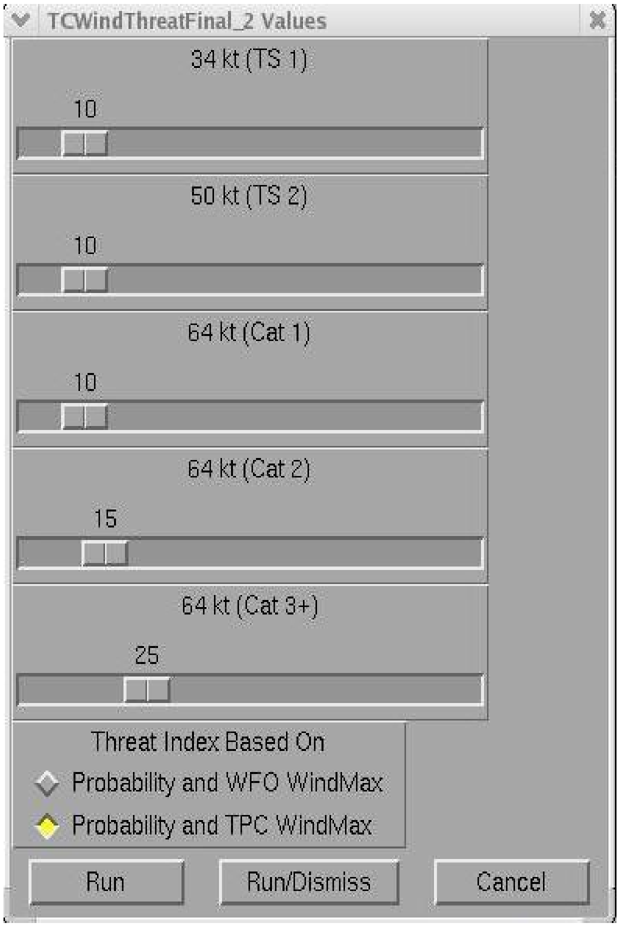


Figure 3. An example of a first-guess map for Hurricane Charley (2004) using wind speed probabilities such as those depicted in Figure 2. Through compositing techniques, an automated first-guess map can be generated depicting the tropical cyclone high wind impact.

Wind Speed Probability Thresholds Table

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 1. 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.



TCWindThreatFinal_2 Values

34 kt (TS 1): 10

50 kt (TS 2): 10

64 kt (Cat 1): 10

64 kt (Cat 2): 15

64 kt (Cat 3+): 25

Threat Index Based On
○ Probability and WFO WindMax
● Probability and TPC WindMax

Figure 4. Interface for the Graphical Forecast Editor (GFE) SmartTool which creates the first-guess field for the tropical cyclone high wind impact graphic.

time, the more important the contribution of forecast uncertainty was to the assessment. This method worked well for years, but relied heavily upon the auspices of the forecaster. Thus, two particular issues were identified which had to be attended. The first was to reduce the overall workload, which was daunting at times, and the second was to minimize the differences in assessment subjectivity among forecasters. As a result, a SmartTool was coded (Santos et al., 2008) using logic that loosely mimics the manual process, but makes creative use of the recently available cumulative-form wind speed probabilities (Knaff and DeMaria, 2005) to account for forecast uncertainty (instead of using the error cone). An example from Hurricane Charley (NOAA, 2006) is shown in Figure 2. The wind speed probabilities became available in 2006, providing a substantial forward integration of NHC probability guidance for WFO-scale threat assessments, and is especially useful as input for the high wind tool. Inherent uncertainties in track, intensity, and size are now routinely integrated without consternation. When executed, the tool smartly composites the 34-, 50-, and 64-knot probabilities to generate a first-guess field for forecaster inspection and fine-tuning (Figure 3). Automated compositing via the tool (Figure 4) highlights

Impact Levels	Description for High Wind – Peninsular Florida
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 2. The worded definition (as used for Peninsular Florida) for each impact level of the experimental Tropical Cyclone High Wind Impact graphic. The definitions are graduated and color-coded. Note: The *Very Low* category is optionally included according to each WFO's determination.

geo-spatial areas which exceed the 10 percent threshold for the specified wind speed for tropical storms and category one hurricanes as being very low, low, or moderate in level (Table 1). 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 the 64-knot probabilities to depict high or extreme levels (Table 1). This approach allows the tool to also distinguish between the strengths of hurricane-force winds of different wind speed categories (e.g., Saffir-Simpson Hurricane Scale). To account for localized wind maxima in the deterministic forecast, the first-guess field can be checked against the forecaster enhanced wind grids to ensure that the depicted levels are consistent with the definitions presented in Table 2.

4. LOGIC FOR THE COASTAL FLOODING TOOL

The effect of dangerous storm surge waters is still vivid in the minds of those who experienced the devastation and loss of life along the Louisiana and Mississippi gulf coast from Hurricane Katrina (2005). To motivate coastal populations to take early and responsible action whenever tropical cyclones threaten is a noble endeavor, but has yet to be wholly achieved. Until then, it remains incumbent upon NOAA/NWS to engage in applied research measures which go beyond the mere pursuit of increased forecast accuracy, but which also explore effective communication methods. These communication methods must be able to break through the information barrage to concisely interpret a tropical cyclone forecast into a meaningful message. That message should advocate protective actions which are proportional to the event and in a manner relative to a location. Unavoidably, for pre-event storm surge information to be trustworthy under such constraints requires increased complexity during the threat assessment process. That is, in order for the threat assessment to be responsible as to save lives, in situational context, it must introduce additional probabilistic complexities (thus becoming more substantial as to be appropriately thorough). Yet, these probabilistic complexities are being introduced coincident with the call for the public message to be simplified as to be more effective.

Prior to the 2008 hurricane season, WFO forecasters have had limited availability to real-time storm surge guidance specific to an event. Of course, valuable deterministic guidance has been available from iterative SLOSH (e.g., NOAA's Sea, Lake, and Overland Surges from Hurricanes computer model) runs to assess potential surge waters. For WFOs, the shortcomings of operational surge guidance have been that the guidance was deterministic-only (as based on the latest NHC forecast), furnished only within 24 hours of landfall, and displayable only on a platform separate from that which forecasters routinely use for operations. Consequently, the Hazards Team's efforts to create an elegant SmartTool actually began with the acquisition of essential input data to satisfy the need. Efforts are currently underway to port deterministic guidance onto the operational platform (e.g., AWIPS) for display and also for subsequent gridded ingest into GFE. This will be a major milestone. Another very important advancement is the operational realization of probabilistic surge guidance as developed by NOAA's Meteorological Development Laboratory (MDL). Essentially, this is an ensemble of SLOSH runs composited across a three-day period that accounts for errors in track, intensity, and size of the cyclone, which, in turn, affects the character of the associated storm surge (Taylor and Glahn, 2008). Probabilistic storm surge will also be ported over to the operational platform for WFO use this season. On AWIPS, the probabilistic storm surge guidance will be depicted in two distinct perspectives. The first perspective is simply the probability of the surge to exceed select heights (e.g., 2 feet, 3 feet, 4 feet, etc., up to 10 feet NGVD). This will be useful for forecasters to advise decision-makers regarding key decisions about the probability of a certain critical height at a particular location in question (within the resolution of the model). Nonetheless, it is the second perspective that is essential for SmartTool use. It is the 10 percent exceedance height (e.g., the height having a 10 percent chance to be exceeded) as shown in Figure 5. This is a powerful and useful data set since it generally appreciates most event variations except for extreme outlier cases.

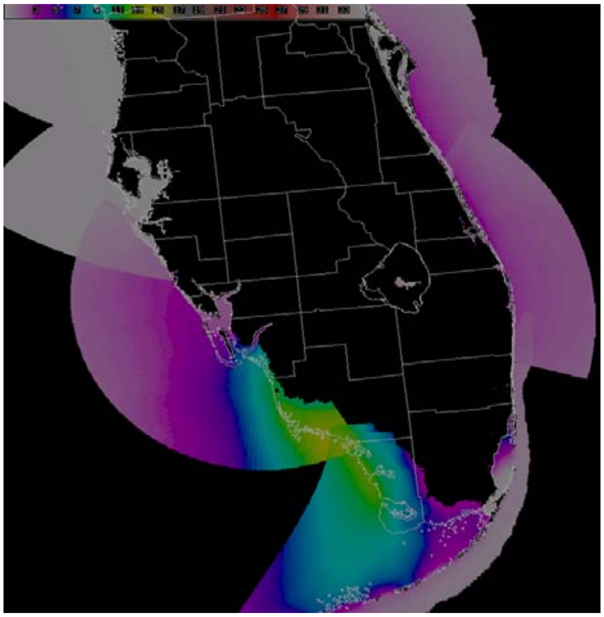
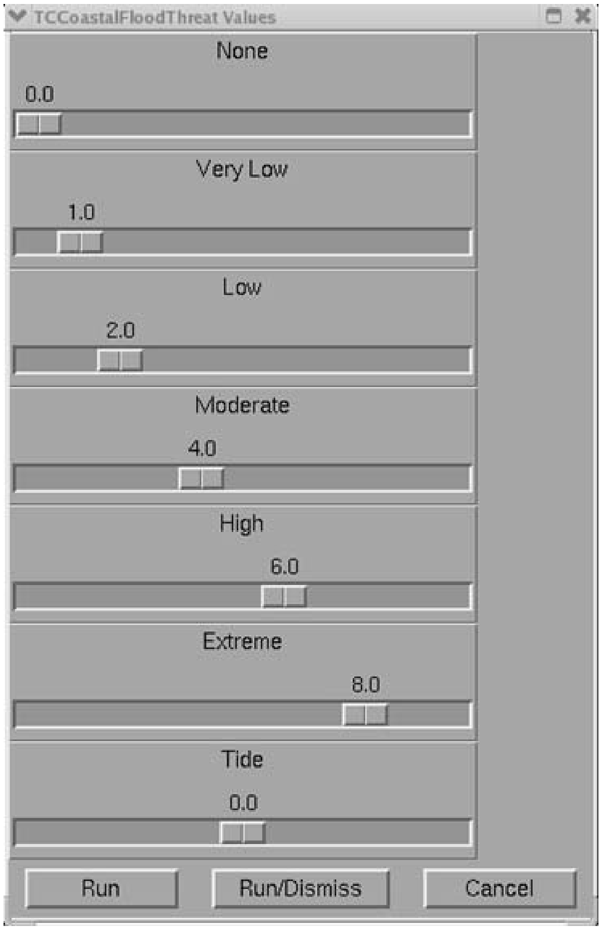


Figure 5. An AWIPS example of the newly available probabilistic storm surge developed by NOAA's Meteorological Development Laboratory. This particular depiction represents the 10 percent exceedance height (feet) valid through 80 hours for Hurricane Wilma (2005) prior to landfall along the lower southwest Florida coast. The 10 percent exceedance height is a primary input for the coastal flooding SmartTool.

Critical Storm Surge Heights Table for Florida

Impact Level	10% Exceedance Height
Very Low	10% chance of exceeding 1 foot
Low	10% chance of exceeding 2 feet
Moderate	10% chance of exceeding 4 feet
High	10% chance of exceeding 6 feet
Extreme	10% chance of exceeding 8 feet

Table 3. The threshold values of storm surge height having a 10 percent chance of being exceeded. As shown, the values are calibrated for Peninsular Florida. The table serves as the primary logic for the SmartTool which generates the coastal flooding impact graphic.


TCCoastalFloodThreat Values

None
0.0

Very Low
1.0

Low
2.0

Moderate
4.0

High
6.0

Extreme
8.0

Tide
0.0

Figure 6. Interface for the Graphical Forecast Editor (GFE) SmartTool which creates the first-guess field for the tropical cyclone coastal flooding Impact graphic. Forecasters are able to make use of the slider bars to direct output according to regionally or locally determined critical heights. Here the slider bars are set to Peninsular Florida defaults. A slider bar for adding/subtracting tidal influences is also available.

The logic of the coastal flooding SmartTool requires the regional/local identification of critical storm surge heights according to historical experiences of impact. The critical heights for Peninsular Florida are indicated in Table 3. The tool first ingests the latest probabilistic guidance from the 10 percent exceedance height and remaps them according to the prescribed heights (e.g., impact levels) as selected via slider bars located on the tool's user interface (Figure 6). Then, if the cyclone is within 24 hours of landfall, it ingests the deterministic surge guidance as a consistency check. Performing a grid to grid comparison, the tool retains the greater of the two heights (deterministic vs. probabilistic) to ensure a responsible threat assessment (Figure 7). Through the tool, users may also add or subtract the effect of tide waters to gain a full expression of storm surge and tide.

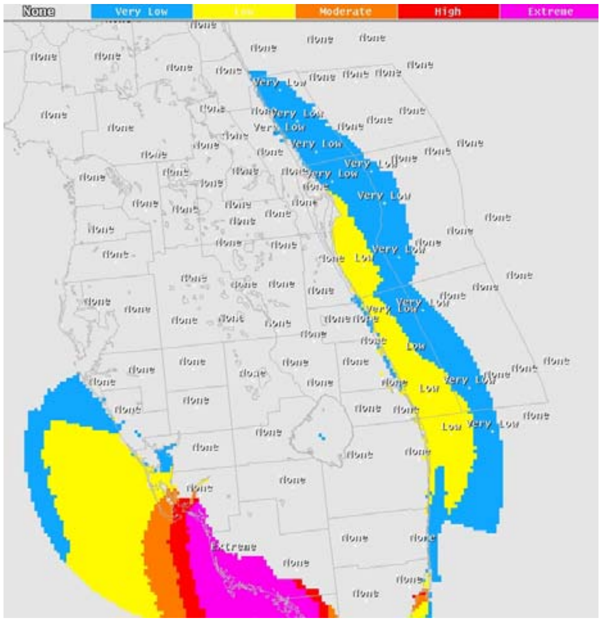


Figure 7. Making use of both deterministic and probabilistic storm surge information, the coastal flood threat tool is able to derive a quality assessment of the storm surge/tide hazard in context of the impending event. This example was generated using input data shown in Figure 5 for Hurricane Wilma (2005). The legend is calibrated according to Florida definitions as presented in Table 4. Lake Okeechobee data is not included here.

Certainly, there are additional issues to confront with regard to the coastal flooding impact graphic. Even so, significant strides have been achieved, bringing excitement to the project. One of the issues revolves around data resolution as finer scale surge data are projected onto a more coarse resolution grid (e.g., 2.5 x 2.5 km) on GFE. As a result, the project team will need to decide whether to apply land and/or water masks or whether to employ the use of predefined edit areas. The current design is not for the coastal flooding impact graphic to serve as an exact inundation map, but rather as a vehicle which motivates coastal communities to relative action. More work is needed here. Another issue is how to deal with inland lakes such as Lake Okeechobee. The deterministic SLOSH runs deliver

Impact Levels	Description for Coastal Flooding – Peninsular Florida
Extreme	• **Threat:** An extreme threat to life and property; the likelihood for storm surge and storm tide waters of 8 feet or higher. • **Minimum Action:** Prepare for the likelihood of extreme to catastrophic coastal flood damage. • **Potential Impact:** An extreme impact to communities in the specified area. Coastal flooding capable of causing widespread inundation of the surge zone by sea water, possibly reaching several miles inland for low-lying areas. Extreme beach erosion with several new inland cuts likely created. Many large sections of near-shore roads washed out and/or low-lying escape routes roads flooded. Powerful scouring surge waters and intense battering wind waves breaching dunes and seawalls in widespread locations to result in structural damage to numerous shoreline buildings, with several washing into the sea. Damage accentuated from considerable floating debris. Extensive damage to marinas, docks, and piers. Numerous small craft broken away from moorings.
High	• **Threat:** A critical threat to life and property; the likelihood for storm surge and storm tide waters of 6 to 8 feet. • **Minimum Action:** Prepare for the likelihood of major storm surge damage. • **Potential Impact**: A high impact to communities in the specified area. Coastal flood waters capable of causing partial inundation of the surge zone by sea water, especially for low-lying areas. Severe beach erosion. Several sections of near-shore roads washed out and/or low-lying escape roads flooded. Scouring surge waters and battering wind waves breaching dunes and seawalls in scattered locations to result in structural damage to several shoreline buildings, with a few washing into the sea. Damage accentuated by floating debris. Damage to marinas, docks, and piers. Several small craft broken away from moorings, especially in unprotected anchorages.
Moderate	• **Threat:** A significant threat to life and property; the likelihood for storm surge and storm tide waters of 4 to 6 feet. • **Minimum Action:** Prepare for the likelihood of moderate storm surge damage. • **Potential Impact**: A moderate impact to communities in the specified area. Coastal flood waters capable of causing major beach erosion. A few sections of near-shore escape roads weakened or washed out, especially in historically vulnerable low spots. Surge waters and wind waves breaching dunes and seawalls in scattered locations to result in structural damage to a few shoreline buildings, mainly in historically vulnerable spots. Minor damage to marinas, docks, and piers. A few small craft broken away from moorings, especially in unprotected anchorages.
Low	• **Threat:** An elevated threat to life and property; the likelihood for storm surge and storm tide waters of 2 to 4 feet. • **Minimum Action:** Prepare for the likelihood of minor storm surge damage. • **Potential Impact**: A low impact to communities in the specified area. Coastal flood waters capable of causing moderate to locally major beach erosion. Very heavy surf breaching dunes in isolated locations, mainly in historically vulnerable spots.
Very Low	• **Threat:** A limited threat to life and property; the likelihood for storm surge and storm tide waters of 2 feet or less. • **Minimum Action:** Prepare for the likelihood of minor storm surge damage. • **Potential Impact**: A very low impact to communities in the specified area. Coastal flood waters capable of causing heavy surf and moderate beach erosion.
None	• **Threat:** No discernable threat to life and property; no surge waters expected. • **Minimum Action:** Evaluate personal and community disaster plans and ensure seasonal preparedness activities are complete. • **Potential Impact:** Coastal flooding is not expected; impact should be negligible. Surf conditions may still be rough with minor beach erosion.

Table 4. The worded definition (as used for Peninsular Florida) for each impact level of the experimental Tropical Cyclone Coastal Flooding Impact graphic. The definitions are graduated and color-coded. Note: The *Very Low* category is optionally included according to each WFO's determination.

water heights with respect to the vertical datum (NAVD88) that are basically relative to sea level, while the probabilistic guidance for the lake is relative to the current lake level (e.g., the initial lake level is subtracted out to get surge above lake level). An enhanced version of the tool has been coded for WFOs Miami and Melbourne to adequately handle Lake Okeechobee. Too, specific worded definitions of potential impact will need to be crafted separately for Lake Okeechobee and the Hoover Dyke.

5. LOGIC FOR THE INLAND FLOODING TOOL

Performing an automated, yet thorough, threat assessment for inland flooding has proven to be difficult. There are important matters related to the effects of torrential rain which must be dealt with either directly or indirectly. For instance, should river flooding be incorporated into the assessment scheme? Certainly, the negative impacts of river flooding can be overwhelming, especially when considering the longer term duration potential. In fact, the worst river flooding may occur after the tropical cyclone has exited the area as flood waters crest downstream. Because of this, it was decided not to include river flooding within the tool. Potential impacts from this hazard are more appropriately addressed through the AHPS (Advanced Hydrologic Prediction Service) web sites maintained by NWS River Forecast Centers.

Initial Logic Table for the Inland Flooding Tool

ERP	QPF/FFG Ratio			
	0 - .74	.75 - .99	1.0 - 1.99	≥ 2.0
0 - 4%	None	Vry Low	Low	Mod
5 - 9%	Vry Low	Low	Mod	High
10 - 4%	Low	Mod	High	Extrm
15 - 100%	Mod	High	Extrm	Extrm

Table 5. The initial logic for the inland flooding tool for tropical cyclones. Values across the top represent the ratio of the WFO quantitative precipitation forecast to flash flood guidance. Values down the left side represent excessive rainfall probabilities as provided by the HPC.

The inland flooding tool focuses on flooding that is more rapid in nature from the shorter-term effects of intense tropical rain. To execute, the tool requires gridded inputs characterizing the atmosphere's ability to produce excessive rainfall and how the ground terrain will handle it if realized. It is fortunate that the HPC is now releasing excessive rainfall potential (ERP) outlooks in probabilistic form for the CONUS. The outlooks are probability products which express the risk of excessive rain. They are temporally and spatially coarse in resolution, but provide an optimum starting place. On contoured maps, a slight risk is indicated whenever probabilities are between 5 to 10 percent. Likewise, a moderate risk is indicated whenever probabilities are between 10 to 15 percent, while a high risk is yielded with probabilities greater than 15 percent. Probabilities less than 5 percent may be noteworthy for isolated flood problems with users referred to elaboration in the text. If there is a chance that the accumulated rainfall may exceed 5 inches, then the area is hatched. The ERP is now flowing across the AWIPS product stream and is available in gridded form for GFE use.

Another important input to the tool is the WFO-based quantitative precipitation forecast (QPF) as compared to the flash flood guidance (FFG). This ratio provides an estimate of the magnitude of the situational flooding potential. Although heavy rain may still occur, a non-event is indicated whenever the QPF/FFG ratio is less than 0.75. Values of 0.75 to 1.0, 1.0 to 1.5, 1.5 to 2.0, and > 2.0 indicate the flooding potential becoming a concern, minor, moderate, and major, respectively. These ratios may be empirically adjusted and locally tuned as more experience is gained. Of course, of concern is the current nature of FFG since it is not readily available in gridded form and must be derived from the county-based tabular product. The availability of true gridded FFG is being addressed for a variety of applications and initiatives, with hopes by the Tropical Cyclone Hazards Team that it will eventually become available for this application too. However, FFG values are subject to change as the heavy rain begins to fall. For any singular six-hour period that matches the corresponding QPF window, the ratios seem to perform well. But for longer periods of rain that extend well beyond a six-hour window, the ratios may suffer from cumulative effects as the FFG values decrease to unknown numbers. This is further compounded by events that last longer than one day.

The logic of the inland flooding tool is the least mature of the hazard tools for the 2008 season and will require forecaster attention and feedback during operational testing. The initial version uses the look-up table as shown in Figure 5 with over-emphasis on Day 1. It is important that forecasters understand this. Manual modifications will be necessary until a more mature version can be fielded.

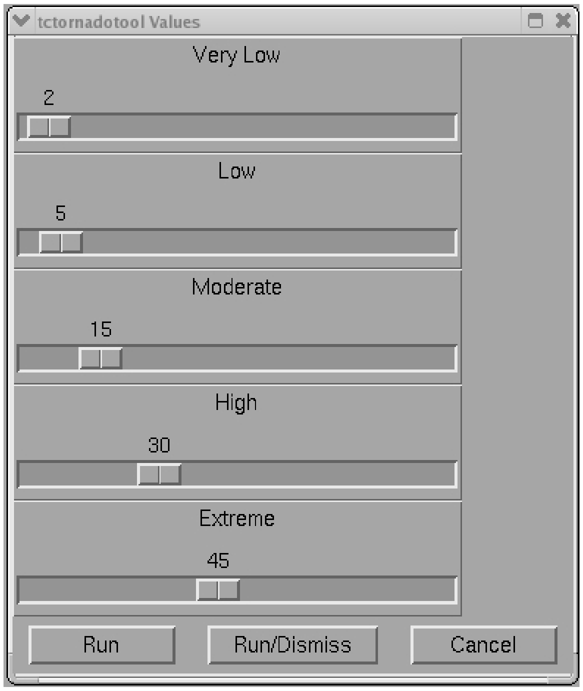
6. LOGIC FOR THE TORNADO TOOL

Although there are obvious contingents of the associated tornado threat relative to innate forecast errors with a tropical cyclone, it is important that expressions of threat (and potential impact) be similar to other tornado situations. The threat assessment approach for tornadoes associated with a passing outer rainband from a tropical cyclone shouldn't be altogether different from that with a passing squall line associated with a mid-latitude cyclone. WFO-based climatologies and statistics can be very helpful in the assessment process. Yet, it is the buoyancy and shear characteristics of the local atmosphere which dictate the tornado potential (McCaul, 1991; Spratt et al., 1997; Edwards and Pietrycha, 2006). The ability for a tropical cyclone to be a tornado-producer is

Initial Logic Table for the Tornado Tool

Probability	Tornado	
	Non-significant	Significant
< 2%	None	---
2 to 4%	Very Low	---
5 to 14%	Low	---
15 to 29%	Moderate	---
30 to 44%	---	High
≥45 %	---	Extreme

Table 6. The initial logic for the tornado tool for tropical cyclones. Threshold values are similar to those used by the SPC to foster consistency.



Very Low
2

Low
5

Moderate
15

High
30

Extreme
45

Figure 8. Interface for the Graphical Forecast Editor (GFE) SmartTool which creates the first-guess field for the tropical cyclone tornado impact graphic. Forecasters are able to make use of the slider bars to direct output according to critical probability thresholds. Default values are similar to those used by the Storm Prediction Center.

assessed as to whether there is potential for isolated vs. multiple tornadoes and whether a realized vortex in contact with the ground can become significant in its classification (e.g., an EF2 or greater on the Enhanced Fujita scale). Of course, this is a challenging task.

Since a mantra of the Tropical Cyclone Hazards Team is to use probabilistic guidance where it already exists, it seemed prudent to develop tool logic which starts by incorporating the probabilistic guidance provided by the SPC. Although somewhat coarse in temporal and spatial resolution, the SPC tornado probabilities do offer an initial assessment that is also graduated based on the likelihood of tornado occurrence. There is a bit of a dilemma, however, when attempting to account for magnitude such as the automated deciphering of SPC hatched areas where at least a 10 percent chance of a significant tornado exists. As it stands now in its initial release, the tornado tool (Figure 8) simply ingests the tornado probabilities (as configured in gridded form) and returns a first-guess assessment to the WFO forecaster for final tweaking. Table 6 outlines the basis of this (early) logic. As the tool matures, it will need to adequately appreciate both Day 1 and Day 2 probabilistic outlooks to fully cover the temporal aspect of the event.

7. SUMMARY

Associated logic has been presented for four separate SmartTools which, when executed, provide an automated threat assessment for tropical cyclone high winds, coastal flooding, inland flooding, and tornadoes that is consistent and coherent. The presented logic represents Version 1.x of each of the tools, with future enhancements likely to come about as situational experience necessitates and guides their maturity. Using these tools will minimize the manual workload when performing threat assessments toward the provision of (experimental) tropical cyclone impact graphics.

These graphics speak effectively to users of varying sophistication. They are useful for motivating less-sophisticated users to action regarding preparedness activities by helping to overcome information paralysis. They also highlight 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 an exceptional 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 a particular hazard. For 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 and community interests are being threatened. More so, government officials at all levels would have greater indication of the extent to which their jurisdictions are being threatened, as well as those areas in danger of being hardest hit. Response and recovery resources can be better positioned and managed, with other resources safely secured. Interestingly, the provision of impact graphics is consistent with the vision of the WAS*IS working group to change the weather enterprise by comprehensively and sustainably integrating social science into meteorological research and practice. For more information about WAS*IS, see http://www.sip.ucar.edu/wasis/objectives.jsp.

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9. REFERENCES

Edwards R., and A. E., Pietrycha, 2006: Archetypes for surface baroclinic boundaries influencing tropical cyclone tornado occurrence. Preprints, *23rd Conference on Severe Local Storms*, St. Louis, MO, Amer. Meteor. Soc.

Knaff, J. A., and M. DeMaria, 2005: Improvements in deterministic and probabilistic tropical cyclone surface wind predictions. *Final Report, Joint NOAA/Navy/NASA Hurricane Testbed, United States Weather Research Program* [Available from NOAA/Tropical Prediction Center*,* 11691 SW 17th Street, Miami, FL, 33165.]

McCaul, E. W., Jr., 1991: Buoyancy and shear characteristics of hurricane-tornado environments. *Mon. Wea. Rev*., 119, 1954-1978.

National Oceanic and Atmospheric Administration, 1998: Service Assessment, Central Florida Tornado Outbreak February 22-23, 1998.

National Oceanic and Atmospheric Administration, 2006: Service Assessment, Hurricane Charley, August 9-15, 2004.

Santos, P., D. Sharp, M. Volkmer, and G. Rader, 2008: Employing hurricane wind probabilities to convey forecast uncertainty and potential impact through NWS field office forecast products. Preprints, *Tropical Meteorology Special Symposium, 88th Annual Conference,* New Orleans, LA, Amer. Meteor. Soc.

Sharp, D. W., D. L. Jacobs, J. C. Pendergrast, S. M. Spratt, P. F. Blottman, and B. C. Hagemeyer, 2000: Graphically depicting east-central Florida hazardous weather forecasts. *NOAA Tech. Attach*, SR/SSD 2000-27.

Sharp, D. W., 2004: Leveraging the combined strengths of local mesoscale modeling and local forecaster intelligence to refine convective threat assessments. Preprints, *22nd Conf. on Severe Local Storms,* Hyannis, MA, Amer. Meteor. Soc.

Spratt, S.M., D.W. Sharp, P. Welsh, A.C., Sandrik, F. Alsheimer, and C. Paxton, 1997: A WSR-88D assessment of tropical cyclone outer rainband tornadoes. *Wea. Forecasting*, **12**, 479-501.

Taylor, A., and Glahn, B., 2008: Probabilistic guidance for hurricane storm surge. Preprints, *19th Conference on Probability and Statistics*, New Orleans, LA, Amer. Meteor. Soc.