J8.4: FROM THE "STATEMENT HEARD AROUND THE WORLD" TO HURRICANE THREATS AND IMPACTS: THE EVOLUTION OF COMMUNICATION POTENTIAL IMPACTS AND SAFETY MESSAGES SINCE KATRINA

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1. INTRODUCTION

On 28 August 2005, the National Weather Service (NWS) Forecast Office in New Orleans, LA, issued this compelling statement nearly 24h prior to the landfall of Hurricane Katrina. For many, the words that described a potential catastrophe, including potential impacts of harrowing proportions and the real possibility of "certain death" for persons left behind, were seen as very grave, having come from official federal government sources. "The Bulletin" (Goldsmith, 2006), as it came to be remembered, was credited with rousing many in the southeast Louisiana and southern Mississippi region to evacuate, with at least 90 percent of those in the danger zone seeking safety well inland (U.S. House of Representatives, 2006).

"The Bulletin" was issued based on the *deterministic* forecast of a land falling Category 5 wind speed (≥70 ms^{-1}). Storm surge inundation was not included in the worded impacts, even though the infrastructure and societal disruption largely occurred as predicted (The White House, 2006). Best estimates of 10m winds at land fall of Katrina were Saffir-Simpson Hurricane Wind Scale (SSHWS) Category 3 strength in southeast Louisiana (57 ms^{-1}) and Category 1 and 2 strength (33 to 49 ms^{-1}) in New Orleans, where the majority of deaths occurred due to flooding when the levees were overtopped by storm surge (Knabb, et. al., 2005).

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Based on the substantially lower wind speeds observed across the impact area, one can conclude that devastation from storm surge masked what might have been perceived as a false alarm based on the deterministic wind forecast alone. For this reason, as well as the growing need for weather and climate forecasts to be based on uncertainty (National Research Council, 2006), efforts began in 2005 to develop probabilistic wind forecasts for tropical cyclones. In the ten years since, probability forecasts of wind, storm surge inundation, rainfall flooding, and tornadoes have been further developed and included in a suite of experimental information to best capture reasonable worse-case scenarios, or safety margin forecasts. These forecasts help decision makers answer the core question: "When a hurricane threatens, to what extent should preparations be undertaken?" Most importantly, these forecasts address three pillars of decision support communication: Event (i.e. wind) and threat, or confidence, of occurrence; potential impact based on threat level; and suggested actions to mitigate against the event. Combined, these pillars provide risk assessment, based on a common definition of risk that combined threats with asset vulnerability for a given hazard (Renfroe and Smith, 2014)

2. HISTORY OF HURRICANE IMPACT COMMUNICATION

The use of words or actions to rouse a community to safety prior to a devastating natural disaster is nothing new. More than a century before "The Bulletin" became famous, Isaac Cline, the Chief of the U.S. Weather Bureau office in Galveston, TX, broke ranks with higher level officials to assume authority in the emergency and warn residents of the danger and recommend action to protect their lives and property (Cline, 1945). Though much of these recommendations were in near-real time as the hurricane was bearing down, Cline is generally regarded as a hero for directly or indirectly saving thousands of lives through efficient dissemination of warnings prior to the arrival of the hurricane's deadly wind and storm surge (U.S. Department of Agriculture Weather Bureau, 1900). Others in the Weather Enterprise would be remembered for similar communication efforts during the 20th Century. Richard Hagan, the Meteorologist in Charge of the Brownsville, TX NWS Office stated "May God Help Us" to implore residents in a highly religious population to evacuate as the SSHWS Category 5 storm was bearing down. Bryan Norcross, then Chief Meteorologist of WTVJ Channel 4 in Miami, became the trusted voice of Hurricane Andrew when he recalled a story from the 1926 Great Miami Hurricane where children were placed in a bathtub and covered with a mattress (Reardon, 1987) and calmly advised residents in the path of the Category 5 cyclone to do likewise.

The 21st Century development of potential impact wording used in The Bulletin began toward the end of the 20th Century. The lead author's desire to serve users of NWS information with potential impact and recommended life safety actions was crystallized after the 1995 Madison County Virginia Floods (Pontrelli, et. al, 1999), after his mentor, Mr. Andrew Stern, described his actions to alert the Virginia Department of Emergency Services in the middle of the night of the potential catastrophic flooding to come in a three-county area of Virginia's Shenandoah Valley (Madison, Greene, and Rappahannock). The alert and recommendation to bring resources to the area resulted in the deployment of National Guard aircraft and other emergency responders *ahead* of the storm; eighty-six persons were rescued from almost certain death (National Weather Service, 2015).

The lead author put these concepts into action a year later, prior to the arrival of Hurricane Fran's remnants to some of the same areas. Wording from a Flood Watch issued a day prior to the arrival of flooding rains and mudslides included "The heavy rains may result in catastrophic flooding in some locations, particularly the Virginia Piedmont and mountains of eastern West Virginia." In fact, the closure of schools across the Shenandoah Valley likely prevented disaster had school buses and other vehicles attempted to navigate flooded and washed-out roads (National Oceanic and Atmospheric Administration, 1997). Each event clarified the author's vision to offer descriptive impacts to infrastructure and society in order to achieve resonant life-saving messages.

The lead author combined existing wording from a National Weather Service Operations Manual Pacific Region supplement on structural impacts for increasing SSHWS Categories, with descriptive structural and impact phrases based on personal experience after traveling through destroyed residential areas of Miami-Dade County, FL, in February, 1993 - six months after Andrew, and the denuded/destroyed mixed pine and deciduous Francis Marion National Forest in coastal South Carolina two years after 1989's SSHWS Category 4 Hugo. The end result was pre-written statements for increasing level of wind impact.

3. THE STATEMENT HEARD AROUND THE WORLD

The pre-written statements were available for two text-based products, the Hurricane Local Statement (HLS) and the Inland Hurricane Wind Warning. On 28 August 2005, at 1011 AM CDT, The Bulletin was issued by the NWS Forecast Office in New Orleans using the Inland Hurricane Wind Warning; the pre-written statements were moved into the "Overview" section for maximum visibility. At the time, policies had been recently adjusted to allow local offices to provide impact language in tropical cyclone hazard communication, even though such information was provided for Florida's Hurricane Charley in 2004 (Goldsmith, 2006). Unlike Isaac Cline who broke with authority to get the life-saving message out to Galveston residents in 1900, Robert Ricks, the forecaster on duty on 28 August 2005, had the authority to use all available impact statements. Ricks, a native of New Orleans, combined his meteorological interpretation of the situation – a large Category 5 hurricane bearing down on the coast - with local knowledge of infrastructure and the community to select the impact statements reserved for the most catastrophic of outcomes. As an operational forecaster, Ricks had to reconcile the tendency to lean toward a "normal" distribution (a subjective assessment of uncertainty) with the dire situation at hand, which was an extreme outlier in the statistical analysis of tropical cyclones that came before. Using that understanding, Ricks' decision was easy. Thousands seeking safety during the final 24h prior to landfall that otherwise would have remained made him a modern-day hero, similar to Isaac Cline more than a century earlier.

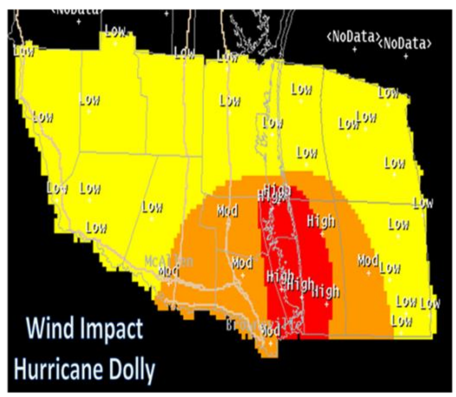
Figure 1. The "Statement Heard Around the World", as posted at the Newseum in Washington, DC, in 2010.

4. DEVELOPMENT OF TROPICAL THREAT AND IMPACT INFORMATION: 2005 TO 2011

While text continued to be the primary vehicle for the NWS to inform the nation on weather hazards, the rapid move toward simplifying image production, from internal operating systems such as the Advanced Weather Interactive Processing System (AWIPS) to personal computers, provided the opportunity for NWS offices to develop image-based hazardous weather information. As early as 2000, NWS offices in Miami and Melbourne, FL, and others, were providing graphical hazardous weather forecasts (Sharp, et. al., 2000). These forecasts, like most other core NWS information, were based largely on deterministic outcomes. That would begin to change by the middle of the decade, appropriately enough with the development of probabilistic tropical cyclone wind forecasts by the National Hurricane Center (NHC) by 2005. Those experimental forecasts, which became operational in 2006, were incorporated into text Expressions of Uncertainty for the legacy NWS Zone Forecast Product, as well as the first threat graphics (Fig. 2) (Sharp, et. al., 2006).

Figure 2. An example of the experimental Tropical Cyclone Wind Threat Index graphic for East-Central Florida during Hurricane Wilma (2005). This graphic, and the descriptive table that joins it, are available in Sharp, et. al., 2006.

As the decade progressed, wind probabilities were further refined (National Hurricane Center, 2014), and the data were used to enhance the wind threat graphics, including the provision of potential impacts based on a given threat level (Goldsmith and Ricks, 2008; Santos et. al., 2008). As these enhancements were underway, time and resources at NHC and the NWS Meteorological Development Laboratory were devoted to the development of probabilistic storm surge beginning in 2007, which became operational in 2008 (Taylor and Glahn, 2008). Baseline impact wording for storm surge inundation had been added to the HLS prior to the 2006 season by the lead author. Probabilistic forecasts of rainfall flooding and tornadoes were added to the tropical cyclone threat and impact depiction in time for the 2008 season, though the initial efforts were relatively crude when compared with wind and storm surge. Impact wording for inland (rainfall) flooding was left to the discretion of each office, and a generic set of tornado-related impacts was provided based on the increasing threat for the number and size of tornadoes for specific cases. The 2008 season provided the fledgling graphical tropical cyclone threats and impacts the opportunity to be tested by select NWS offices along the Atlantic and Gulf coast, with six United States land-falling events. The NWS office in Brownsville, TX, provided threat and potential impact graphics for each hazard (Figure 3, for wind). Damage to infrastructure (Figure 4) in the "high" region was a nearly identical match to the description.



High	**Threat** - A critical threat to life and property; the likelihood for sustained Category 1 Hurricane-force winds (74 to 95 mph) with frequent gusts to Category 2 (96 to 110 mph). **Minimum Action** - Prepare for major wind damage. **Potential Impact** - Life-threatening winds are possible. The majority of older mobile homes will be severely damaged or destroyed. Those that remain will be uninhabitable until repaired. Houses of poor to average construction will have major damage including partial wall collapse and roofs being lifted off. Many will be uninhabitable until repaired. Well constructed houses will incur minor to moderate damage of shingles, siding, and gutters, as well as blown out unprotected windows. Partial roof failure is expected in industrial parks, especially to those buildings with light weight steel and aluminum coverings. Older low-rising apartment roofs may also be torn off, as well as siding and shingle damage. Airborne debris will cause damage, injury, and possible death. Power outages will be widespread. Numerous lines will be pulled down, and a number of power poles will fall. All trees with rotting bases will uproot or snap. Nearly all large healthy branches will snap. Healthy trees will uproot, especially where ground is saturated. Major damage is expected to citrus orchards. Most newly planted crops will be damaged.

Figure 3: Map of wind impact (threat, top) and description of potential impact for the "High" threat for the Lower Texas coast (bottom), from forecast issued around sunrise on 23 July 2008, several hours before winds >45 ms^{-1} arrived.

Figure 4. Photo of damage to apartment complex in Port Isabel, TX, taken on 24 July 2008, one day following Hurricane Dolly. Descriptions in Figure 3 for apartment building damage were nearly identical to what's shown.

In 2009, the full suite of graphical tropical cyclone hazards was linked with text portions of the HLS, and became the first free-standing web page available to NWS Gulf of Mexico and Atlantic coastal offices from Brownsville, TX to Caribou, ME. The benefit of the text linkage was to provide users with information most critical to their area(s) of concern, rather than requiring users to sift through an entire HLS which, for multiple impacts that varied across an NWS service area, could end up being dozens of printed pages due to the combination of hazard separation into wind, storm surge flooding, inland (rainfall) flooding, and tornadoes and segmentation by zones (typically a county or sub-county) or zone groups with shared threats and potential impacts.

The goal of segmentation was to reduce text to shorter, easily readable portions; unfortunately, users who made decisions for larger areas would need to read information for multiple segments, which could be time-consuming and even confusing. The Graphical HLS (gHLS) solved this issue by allowing users to roll their mouse or finger over the threat map graphic for each of the four hazards and have the particular text details, including event/threat, potential impact, and recommended action, appear in a small pop-up window (Figure 5). Few significant land falling tropical cyclones occurred from 2009 to 2010, which limited the ability to survey a significant number of users from which to determine the effectiveness of the gHLS. An informal survey of core Emergency Management partners across the Rio Grande Valley of Texas following the 2010 season, where two tropical cyclones - Alex and Hermine - made nearby landfall, indicated positive reviews for the combined graphic and text information.

With more offices coming online to the gHLS, consistency in message, particularly threat and potential impact, became a larger concern. Following Hurricane Ike and the use of terms such as "certain death" to convey the graveness of the potential storm surge flood ahead of the storm to a population much larger than what would ultimately be washed away (Morss and Hayden, 2010), a team was assembled to update both the wind and surge wording that had been in existence with the text HLS and a number of coastal offices' gHLS pages. The team, which comprised meteorologists, social scientists, and one wind engineer, modified some of the descriptive societal impact wording to remove some deterministic terms (such as "certain" and "will"), but the infrastructure impact wording was left largely intact.

5. MATURING THE PROCESS: FROM TROPICAL CYCLONE IMPACT GRAPHICS TO HURRICANE THREATS AND IMPACTS, 2012 to 2015

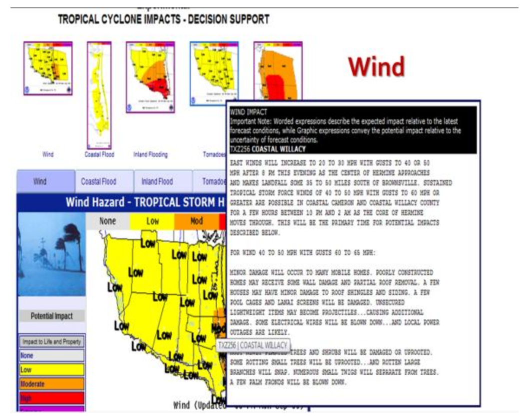


Figure 5. Example of wind forecast and potential wind impacts in a "pop-up" window when the user moves a mouse or finger (laptop) over an affected area. The impact statements were [raster? vector?] mapped to specific NWS zones, and would change automatically as the mouse or finger moved to a lower or higher category. Shown are threats from Tropical Storm Hermine in September, 2010, across the Rio Grande Valley of Texas.

Beginning in 2012, Tropical cyclone hazard threats and impacts continued to improve, both scientifically and technologically. Tropical Cyclone Impact Graphics (TCIG) was born, and would include a new focus on storm surge impacts based on *inundation* at the shoreline and points inland, rather than forecast surge values at the beachfront. Wind threat levels and impacts were fine-tuned to account for different types of natural and man-made structures between the Gulf of Mexico and Atlantic subtropics; for example, variations in hardiness and root systems of mesquite, live oak, southern pine, and palm trees of the subtropics compared with deciduous forests and northern evergreens from Virginia to Maine. For each case, including rainfall flooding, geographical resolution was increased.

Improvements were made to the web pages as well. With all coastal offices participating in the process, the graphics were ported to geospatial maps, including Google and ESRI Maps, which allowed users whose service areas are defined well beyond NWS County Warning Areas to view TCIG at a regional, state, or multi-state level (Figure 7a). The ability to use the gHLS text “mouseover” widget remained, but with TCIG, a user could save a map in keyhole markup language (KML) and view on an alternate platform, such as Google Earth. With just a tap on a mobile device or a click on a location, site-specific potential impacts would pop up.

An example of the website TCIG, for storm surge (Coastal Flooding) prior to the arrival of Hurricane Isaac in southeastern Louisiana in late August 2012, is shown in Figure 6. When made aware that this information was available prior to Isaac’s worst impacts, Plaquemines Parish President Billy Nungesser, who famously was quoted as asking how a Category 1 Hurricane could do so much damage, said, “If I had known about these graphics, my decisions to evacuate residents would have been much more proactive.” (Goldsmith, 2013)

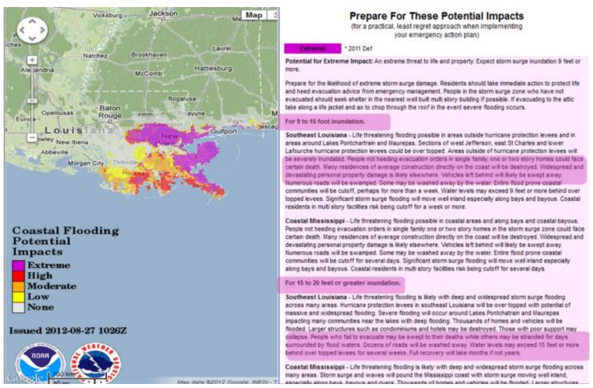


Figure 6. Threat and Potential Impact for Storm Surge (Coastal Flooding) Prior to Hurricane Isaac’s arrival along the southeast Louisiana coast. For the purple colored area, potential impacts for 9 to 15 feet of water depth (inundation) were realized.

Threat and potential impact wording, descriptors, and graphics were reviewed thoroughly by social scientists as TCIG transitioned to Hurricane Threats and Impacts (HTI) between 2013 and 2015 (Fauver, et. al., 2014). The effort to evolve a comprehensive suite of hurricane communication information from the gHLS through TCIG to HTI fit perfectly within the specification set forth in *When Weather Matters: Science and Services to Meet Critical Societal Needs* (National Research Council, 2010), described as a pressing need to improve scientific methods and address socioeconomic issues related to high-impact weather events. HTI, the culmination of efforts that began around the time of Katrina, is a clear example of a key component of the NWS Strategic Plan to build a Weather Ready Nation (National Weather Service, 2011) that meets each of the three components of “Ready, Responsive, and Resilient” through improved Impact-based Decision Support Services (IDSS).

HTI is specifically designed to answer this question: “When a hurricane threatens a coastal community, to what extent should preparations be undertaken?” From the scientific and statistical perspective, the attractive feature of HTI, and TCIG before, is the implicit inclusion of probabilistic forecasts into the final output. From the social science perspective, the simplified wording into everyday language and clearly defined categories for threats and potential impacts (Figure 7b). Decision makers can use the color coded graphics and associated threats and potential impacts text to prepare for a *reasonable, worse-case scenario* and use the information as a safety margin forecast.

Using a safety margin forecast helps to solve the dilemma of the extent to protect life and property proportional to a looming hurricane’s threat, without needless disrupting people’s routines or wasting valuable time and resource. Still, getting large numbers of decision makers, down to the level of an individual or head of household, to focus on a reasonable worse-case scenario over other options will take a continued education effort over years. One of the challenges includes the need for many to have a binary (i.e., shelter-in-place or evacuate) answer for a highly uncertain outcome at the time when such a decision has to be made. A second and more difficult challenge is overcoming human risk perception, which can be heavily weighted by socioeconomic characteristics and the psychological ability of the decision maker to process the information (Dash and Gladwin, 2007). This is particularly acute for those with limited or no experiential knowledge of a life and livelihood-altering event. HTI offers hope by addressing the reasonable, or plausible, worse-case scenario in a way that did not exist prior to Katrina.

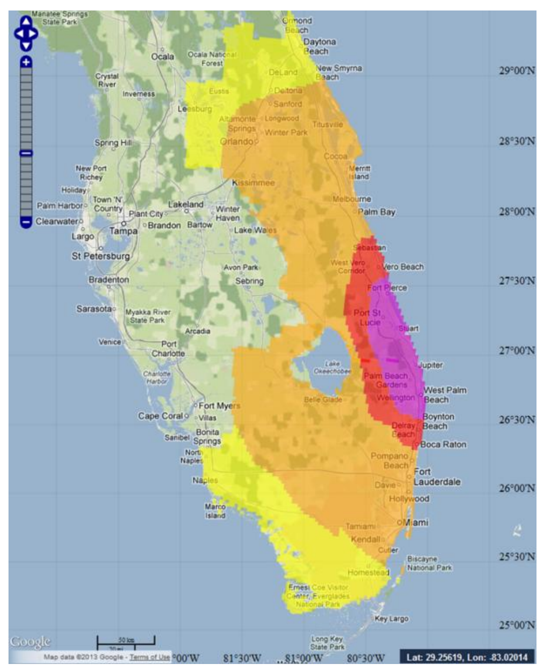


Figure 7a. Mosaic of HTI (wind) for east and south Florida which covered two NWS Weather Forecast Office areas of responsibility. Case was modeled based on Hurricane Jeanne in 2004.

Wind Threat	Potential Wind Impacts
EXTREME Threat for wind greater than 110 mph	**DEVASTATING TO CATASTROPHIC** To be safe, aggressively prepare for the potential of devastating to catastrophic wind impacts from major hurricane force wind of equivalent Category 3, 4, or 5 intensity.
HIGH Threat for wind 74-110 mph	**EXTENSIVE** To be safe, aggressively prepare for the potential of extensive wind impacts from hurricane force wind of equivalent Category 1 or 2 intensity.
MODERATE Threat for wind 58-73 mph	**SIGNIFICANT** To be safe, earnestly prepare for the potential of significant wind impacts from strong tropical storm force wind.
ELEVATED Threat for wind 39-57 mph	**LIMITED** To be safe, prepare for the potential of limited wind impacts from tropical storm force wind.
LITTLE TO NONE Wind less than 39 mph	**LITTLE TO NONE** No immediate preparations needed; little to no wind impacts.

Figure 7b. **T**able showing simple (regional) definitions for threat and impact used in HTI. Note the clear differentiation between threat levels (extreme, high, etc.) and impact descriptions (devastating, extensive, etc.). Local impact descriptions in the right column will be highly detailed to specific locations under threat, similar to those shown in Fig. 6.

A great example of how HTI would be used to inform a preparation decision based on wind is shown in Figure 8. The top image shows the forecast peak wind for increasing level of wind based on the *deterministic* track and radii forecast for Hurricane Wilma, approximately 36h prior to landfall in southwest Florida. The bottom image indicates the forecast peak wind threat based on the 10 percent probability that winds could reach a given threshold – a reasonable worse-case scenario. A decision maker in heavily populated Miami-Dade or Broward County (circled area) preparing for the deterministic outcome would likely make a minimal effort, with an inherent knowledge that tropical storm force winds occur once every other year and that natural and man-made infrastructure is built to absorb the nuisance impacts that come with such winds. If, on the other hand, the decision maker understood the errors in track *and* intensity 36h out and chose to prepare wisely for the reasonable worse-case scenario (rightmost circled area, bottom image), he/she might choose maximum effort to prepare for hurricane force winds or even major hurricane force winds. In reality, Hurricane Wilma grew in size and accelerated, increasing the area of hurricane force wind and strength of the wind to the right of the track, and even tracked a bit farther south than forecast at this time. In reality, more than $21 billion in damage, the vast majority in Miami-Dade and Broward County, from sustained winds that ranged from 46 to 49 ms^{-1}, just shy of major (49.6 ms^{-1}) (Pasch, et. al., 2006)

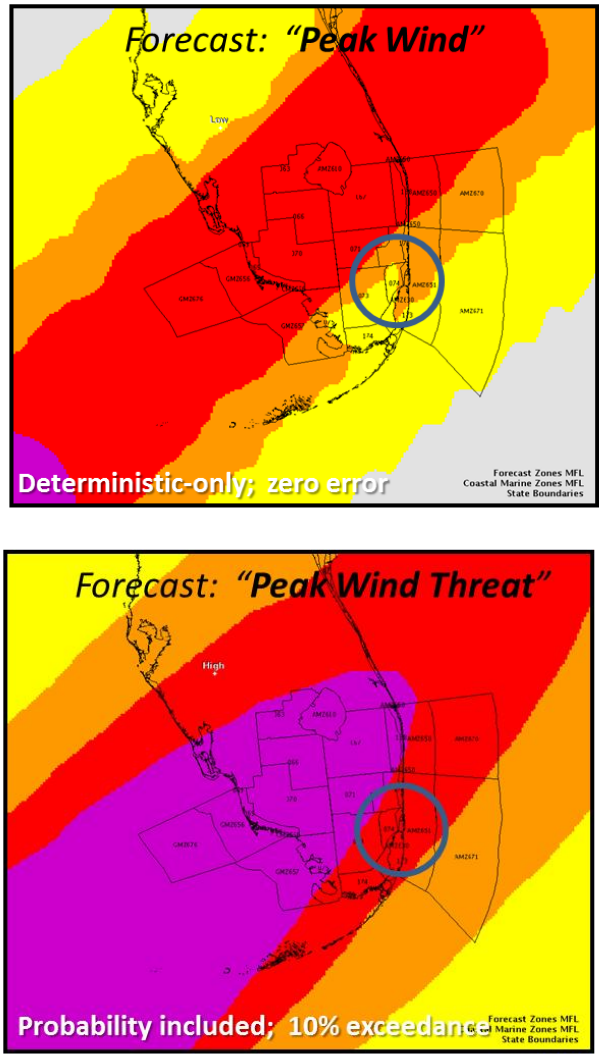


Figure 8. Example of a peak wind forecast (top) and a peak wind threat forecast at 10 percent exceedance (bottom) based on Hurricane Wilma (October, 2005). Forecast depicts the onset of the warning period, or around 36 hours to impact in southwest Florida.

Similar comparisons were created for storm surge, and can be produced for rainfall flooding and tornadoes. HTI will provide the reasonable worse-case scenarios for each hazard. Similar to the gHLS and TCIG web pages, a tab system will allow decision makers to quickly view the different level of threats and potential impacts to allow them to focus on those that are most dangerous to coastal and inland communities.

6. FUTURE DEVELOPMENTS

The most important evolutionary step in the HTI process was the fusion of text information from enhanced legacy NWS Weather Forecast Office text products, the HLS and a new, highly detailed and automated hazard (threat), potential impact, and recommended action product that includes Valid Time

Event Code (VTEC) and is paired with the HLS. Based on a finding from the Hurricane Irene Service Assessment in 2012 (National Oceanic and Atmospheric Administration, 2012), which stated: "The HLS is inefficient and ineffective. NWS should consider both a short-term (operational) and long-term (strategic) solution", the HLS reverted back to a summary product that removed the VTEC and dramatically shortened the information without losing sight of the broader hazard/threat, potential impact, and recommended action message for local NWS service areas (Sharp and Enyedi, 2015). The paired product, known Tropical Cyclone VTEC (TCV) is provided per zone and includes local details of hazard (threat), potential impact, and recommended action relevant to each zone, with information details down to the community level where possible. For example, for a coastal zone, potential impacts for storm surge inundation might include a range of water depth on impacted beaches, towns, and highways; for a zone outside of storm surge impact, no surge inundation information would be provided.

Prior to HTI, NWS local office staff produced legacy text products and graphical information such as gHLS and TCIG on separate tracks. In cases where wording differed for threats and potential impacts, confusing messages could have resulted. HTI development was done in parallel with the new HLS and TCV, which ensured that words associated with HTI *and* HLS/TCV matched, based on shared dictionaries through AWIPS.

Future steps include a modernized, device-adaptable web site (Fig. 9) that will be a one-stop shop for HTI, but also any local and national tropical cyclone information stream, including storm surge inundation graphics and storm surge watch and warning graphics and text information. Beyond these steps, there is a real possibility that traditional local "all text" hurricane information will cease to exist as advances in HTI and Geographic Information Systems capabilities provide the ability for decision makers to evaluate their threat at the neighborhood or even home/business level. Detailed mapping of land elevation, home construction, natural elements such as wooded areas and flora types, infrastructure, even pre-cursor conditions such as prior rainfall and absorption could help inform the potential impacts based on the level of threat for each hazard.

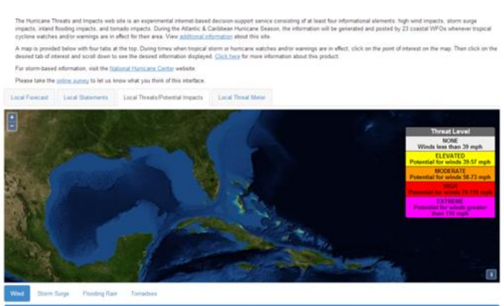


Figure 9. Example of experimental prototype HTI web page. Tabs on top (forecasts/impacts) and bottom (individual hazards) ease ability for users to quickly assess threats and potential impacts.

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