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for Wind Engineering

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November 2003



New Lessons for Wind Engineers (p. 10)

Congressional Briefing on HAZUS - a Natural Hazards Loss Estimation Methodology

A Congressional briefing on HAZUS (www.fema.gov/hazus) - a natural hazards loss estimation methodology developed by FEMA under a contract with the National Institute of Building Sciences was held on Capitol Hill on November 18, 2003. Appearing on behalf of FEMA were: Clifford Oliver, Special Assistant, Mitigation Division, Department of Homeland Security/Federal Emergency Management Agency (DHS/FEMA), and Ed Laatsch, Chief, Building Science & Technology, Mitigation Division, DHS/FEMA.

The briefing was organized by the office of Rep. Dennis Moore (KS), the cosponsor of H.R. 2020, the Hurricane, Tornado and Related Hazards Research Act, introduced in the U.S. House of Representatives, in May 2003. This legislation calls for significant increase in funding to provide for better coordination of the federal effort, prioritize research efforts, increase technology transfer programs and emphasize public education. The overall goal of this initiative is to achieve significant and measurable reduction in material wind damage and loss of life, over a period of ten years. This legislation has been developed through a bipartisan effort, with significant input by the members of the Wind Hazard Reduction Coalition (www.windhazards.org). AAWE is an active member of this coalition.

An abbreviated version of a paper illustrating application of HAZUS to estimate losses associated with forecasted landfall of Hurricane Isabel can be found on page 2.

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Jana Denning of Rep. Dennis Moore office introduces Clifford Oliver of FEMA (left) to Congressional staff and guests (upper right). Ed Laatsch of FEMA (lower right) addresses audience

FEMA Employs New State-of-the-art Technology to Predict Losses from Hurricane Isabel

Clifford Oliver, FEMA, DHS

Frank Lavelle, Applied Research Associates

Background

As Isabel threatened the east coast of the U.S., FEMA got a chance to test out the newest innovation in predicting losses from natural disasters. In mid-September, FEMA's Mitigation Division (MT) was performing acceptance testing on the latest version of HAZUS-MH[®] (Hazards-US-Multihazard), its state-of-the-art Geographic Information System (GIS) loss estimation software. HAZUS-MH is the latest in a series of HAZUS releases. Since FEMA was in possession of a fully operational version of HAZUS-MH, FEMA elected to utilize HAZUS-MH in preparing for the landfall of Hurricane Isabel.

FEMA successfully employed the HAZUS-MH Hurricane Wind Module to develop loss estimates based on the projected track and intensity of Hurricane Isabel. On Friday, September 13, 2003, the National Hurricane Center's models indicated that a Hurricane Isabel landfall along the east coast of the U.S. was quite possible. That same day, in response to this growing likelihood that a major hurricane would make landfall in the U.S., FEMA began mobilizing its response resources and consulting with its state emergency management counterparts. To get a sense of the potential impacts from such a major hurricane event, senior officials of FEMA's Response Division requested that MT begin assessing these potential impacts.

As Hurricane Isabel moved towards the east coast of the U.S., MT employed a number of approaches to estimating potential losses:

- For long-range estimates (>5 days before expected landfall), historic hurricane data, combined with data on today's built environment, were used to estimate potential losses today from these historical events;
- Application of mid-range (3-5 days before expected landfall) hurricane forecasts from the National Hurricane Center (NHC);
- Application of short-range (1-3 days before expected landfall) hurricane forecasts from the NHC;
- Application of real time (day of landfall) hurricane forecasts from the NHC.

As demonstrated in Figure 1, as Hurricane Isabel ap-

proached the North Carolina coast, the estimates of the intensity at landfall trended downward. The reduced intensity was incorporated in the HAZUS-MH meteorological input data and subsequent HAZUS-MH runs produced an expected reduction in estimated losses.

To support FEMA in providing loss estimate during this emergency, FEMA issued a task order to Applied Research Associates (ARA) of Raleigh, N.C. for modeling and technical support. ARA is the HAZUS-MH hurricane module developer and was therefore uniquely qualified to support FEMA during this event. ARA performed several important roles that included:

- Providing expert advice to FEMA on the proper meteorological input data for HAZUS hurricane scenarios;
- Conducting peer review of the HAZUS runs completed by FEMA, including duplicating the FEMA model runs to ensure the reliability of the output;
- Running a number of alternative wind field simulation models in an attempt to understand the range of possible outcomes and produce a best estimate of the on land wind field;
- Providing data sets for the overall performance evaluation of the HAZUS-MH hurricane module as part of the product acceptance testing.

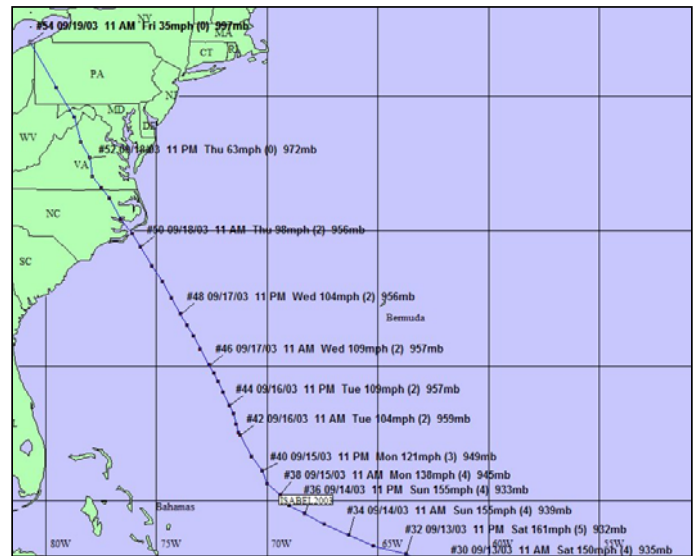


Figure 1. Hurricane Isabel Track Showing Advisory Number, Date, Time, Day, Max. Sustained Wind Speed, Saffir-Simpson Category (in parenthesis), and Central Pressure

Long-range Loss Estimation (>5 days before landfall)

The first discussions regarding the use of HAZUS-MH to support the Response Directorate began on Friday, September 13, 2003. At that time, Hurricane Isabel was

more than 5 days from making landfall and was a category 5 Hurricane. Although the NHC began issuing five-day forecasts for the first time during the 2003 hurricane season, the storm was still too far off shore to project either the intensity or the precise location of the storm at landfall. However, the projected five-day track indicated that Hurricane Isabel might make landfall near the border of South Carolina and North Carolina. Since landfall was beyond the limits of the NHC forecast, both in terms of track and intensity, FEMA looked to the historical hurricane library within HAZUS-MH, for hurricanes that might reasonably approximate the potential losses from Hurricane Isabel.

In reviewing the HAZUS historical hurricane library, it appeared that Hurricane Hazel (1954) and Hurricane Hugo (1989) presented characteristics similar to those that Hurricane Isabel might exhibit when it made landfall. Therefore, to produce the first estimates of potential losses from Isabel, the characteristics of Hurricanes Hazel and Hugo, including track, size, and intensity, and the present built environment in North Carolina and South Carolina (as defined in the national datasets in HAZUS-MH) were utilized to build the HAZUS run.

Based on Hurricane Hazel's track, size and intensity, HAZUS estimated several tens of billion of dollars in wind damage would occur given today's built environment and about 140,000 people would seek temporary public shelter as a result of wind damage to their residences. Based on Hurricane Hugo's track, size and intensity, HAZUS estimated approximately 5 billion dollars in direct economic losses from wind damage would occur and about 3,000 people would seek temporary public shelter as a result of wind damage to their residences.

Midrange Loss Estimation (3-5 days before landfall)

As the 5-day Isabel forecasted track projection reached the coast of the U.S., FEMA moved from using historic hurricanes to building hurricane scenarios based on forecast information provided by the NHC. The data required by HAZUS-MH to generate a hurricane scenario from an NHC Forecast/Advisory are the time, position, (latitude and longitude), maximum sustained wind speed (1-minute average), maximum radius to hurricane winds, and central pressure at each point along the predicted track.

Based on Advisory #37, issued at 0500 EDT on Monday, September 15, 2003, Hurricane Isabel was forecast to come ashore as a Category 3 hurricane with maximum peak wind gusts of 125-140 mph (see Figure 2). Based on Hurricane Isabel's forecasted track, size and intensity, HAZUS estimated 8 billion dollars in direct economic

losses from wind damage would occur and about 4,000 people would seek temporary public shelter as a result of wind damage to their residences. These estimates appeared reasonable considering the high peak gust wind speeds forecasted for the Norfolk area.

Short-range Loss Estimation (1-3 days before landfall)

As Isabel approached the coast, MT was able to further refine potential loss estimates for use by senior government officials who needed to gain an understanding of the potential scale of the event and take necessary actions to minimize deaths, injuries, and economic losses, as well as speed up the response and recovery process. During the 3-day period before Isabel made landfall, the predicted track did not vary significantly, but the loss estimates for Virginia did vary significantly, as the forecasted track moved towards or away from the heavily populated areas of Norfolk and Richmond. During Monday and Tuesday, however, the overall intensity of the storm weakened substantially, as the estimated maximum sustained wind speeds offshore decreased from 150 mph (Advisory #37) to 104 mph on (Advisory #42). This weakening was partially offset by an increase in the maximum radius to hurricane winds from 115 miles (Advisory #37) to 144 miles (Advisory #45).

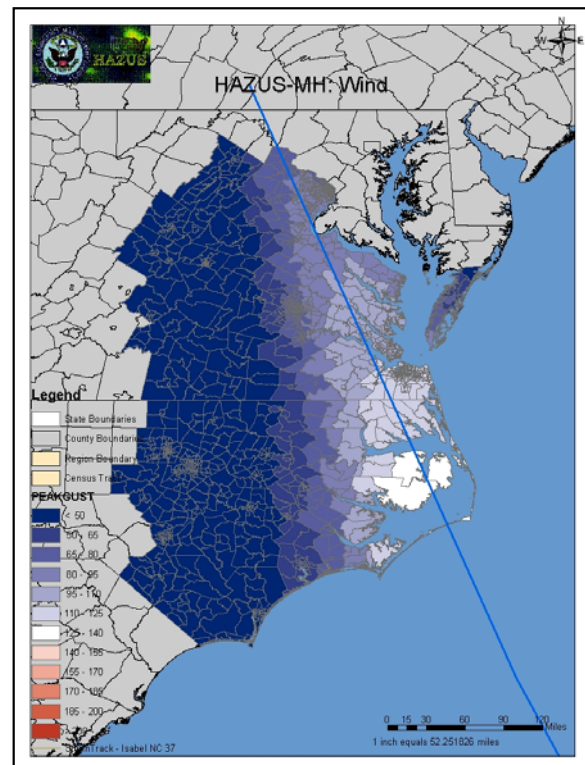


Figure 2. Forecasted Peak Gusts Wind Field for Hurricane Isabel, Based on NHC Advisory #37

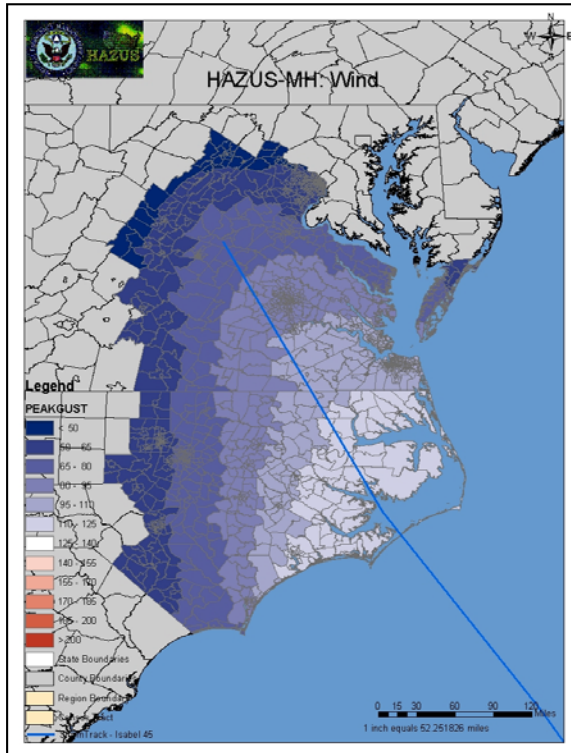


Figure 3. Forecasted Peak Gusts Wind Field for Hurricane Isabel, Based on NHC Advisory #45

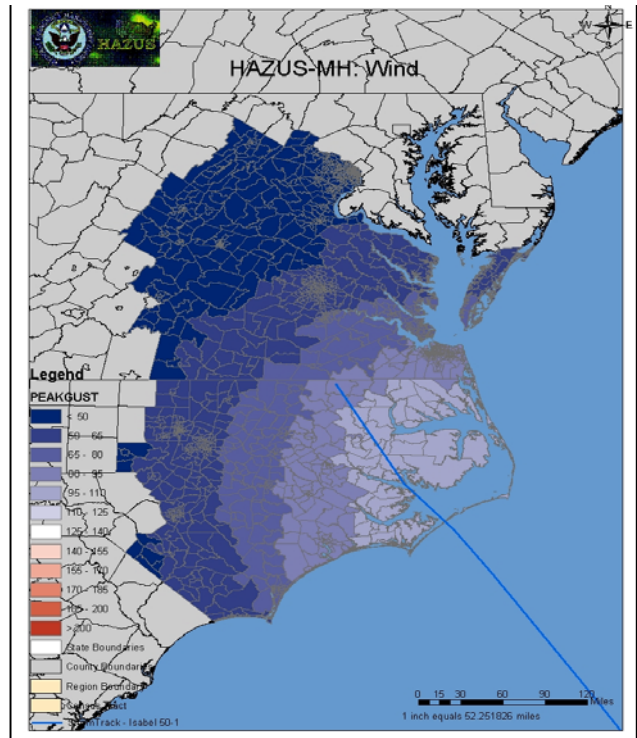


Figure 4. Forecasted Peak Gusts Wind Field For Hurricane Isabel, Based on NHC Advisories #50, 50A, and 50B

Based on Advisory #45, issued at 0500 EDT on Wednesday, September 17, 2003, Hurricane Isabel was forecast to come ashore as a Category 2 hurricane with maximum peak wind gusts of 110-125 mph (see Figure 3). Based on this forecast, HAZUS estimated 7 billion dollars in direct economic losses from wind damage would occur and about 4,000 people would seek temporary public shelter as a result of wind damage to their residences. This track still showed a significant impact of damaging winds in the southern portions of the greater Washington, D.C. metropolitan area.

As Hurricane Isabel approached the coast of North Carolina, another HAZUS run was completed. Based on Advisory #49, issued at 0500 EDT on Thursday, September 18, 2003, Hurricane Isabel was continuing to weaken. Although the forecast still resulted in peak gusts of 110-125 mph at the coast, the inland swath of strong winds was shrinking. Additionally, the storm track was forecast to move slightly more to the west, further moving the highest winds away from the Richmond and Norfolk metropolitan areas. Based on the more westerly track and reduced intensity, HAZUS estimated 2 billion dollars in direct economic losses from wind damage would occur, and about 500 people would seek temporary public shelter as a result of wind damage to their residences. This was a significant reduction from the forecast from Advisory #45, issued just 24 hours earlier.

As Hurricane Isabel made landfall, the final HAZUS run, based on NHC predicted track and intensity, was completed. Based on Advisories #50, 50A and 50B, issued at 0500, 1300, and 1500 EDT, respectively, on Thursday, September 18, 2003, the intensity of Hurricane Isabel was forecast to continue weakening to a Category 2 hurricane with maximum peak wind gusts of 95-110 mph (see Figures 4 and 5).

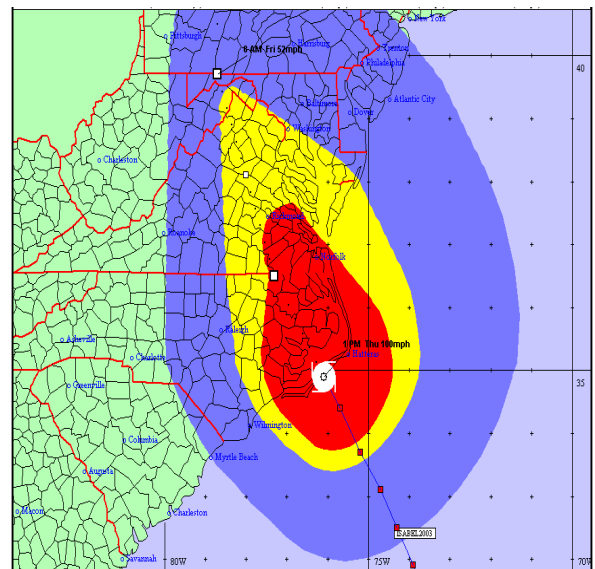


Figure 5. Estimated Wind Field from Hurrevac Software, Based on NHC Advisory #50

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Based on Hurricane Isabel's lessened forecasted intensity, HAZUS estimated 1.3 billion dollars in direct economic losses from wind damage would occur and about 200 people would seek temporary public shelter as a result of wind damage to their residences.

Real-time Loss Estimation

In addition to supporting FEMA's HAZUS runs based on the official NHC Advisories, the modeling team at ARA was concurrently collecting and analyzing additional sources of data to develop a best estimate of the entire hurricane windfield.

The best estimate tracks were defined using radius to maximum winds (R_{max}) and pressure profile parameter (B) instead of radius to hurricane winds and maximum sustained wind speed. R_{max} and B are fundamental inputs to the HAZUS hurricane windfield model, but they are not available in the official NHC Advisories. To estimate these parameters, the ARA team relied heavily on NHC's H*Wind product. H*Wind is an experimental product that uses flight level data, surface observations, dropsonde data, remote sensing inputs, and expert knowledge of hurricane windfield characteristics to develop a snapshot of the entire surface level windfield. Using the projected track coordinates from the NHC Advisories, together with estimates of R_{max} and B derived from NHC's H*Wind model and projections of inland central pressures based on the HAZUS inland decay model, the ARA team began generating best estimate loss projections in parallel with the purely advisory-based loss projections described in the previous sections. As Isabel crossed the Outer Banks, real-time anemometer readings from offshore buoys and several onshore locations were used to further refine the best estimate wind field. Figure 6 shows a sample comparison of the best estimate wind trace to observations recorded at the Cape Lookout C-MAN station.

Using the best estimate windfield, HAZUS estimated 1.0 billion dollars in direct economic losses from wind damage would occur and about 100 people would seek temporary public shelter as a result of wind damage to their residences.

Within 24 hours of landfall, the H*Wind research team at NHC, led by Dr. Mark Powell, also provided an estimate of the peak gust wind swath. Due to differences in inland decay models, the inland winds in the H*Wind swath were generally lower than the ARA best estimate windfield. Based on the H*Wind swaths, HAZUS estimated 460 million dollars in direct economic losses from wind damage would occur and less than 100 people would seek temporary public shelter as a result of wind damage to their residences. A subsequent update to the

H*Wind swath was issued by the NHC research team on September 23, 2003. Using the updated swath, HAZUS estimated 960 million dollars in direct economic losses from wind damage would occur and about 100 people would seek temporary public shelter as a result of wind damage to their residences.

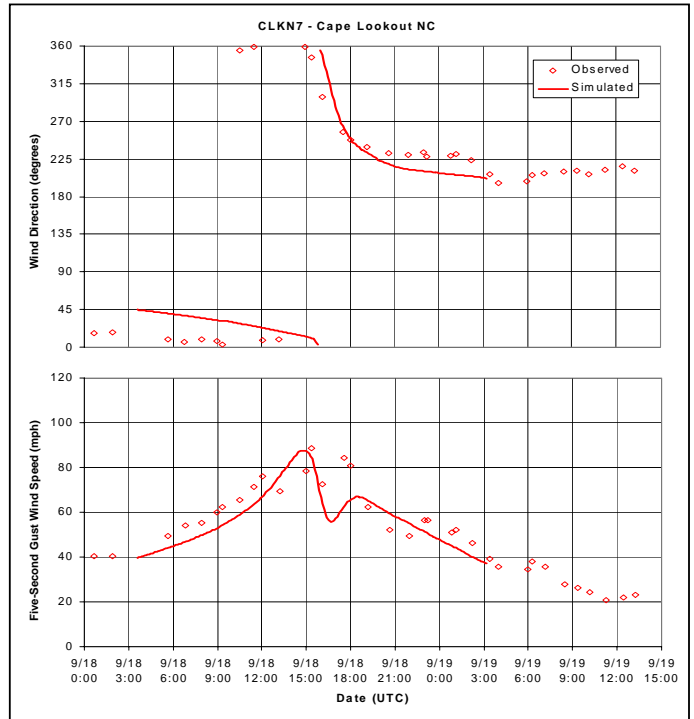


Figure 6. Comparison of Best Estimate Wind Trace with Observations Recorded at the Cape Lookout C-MAN Station.

Lessons Learned

Lessons learned from this first use of HAZUS include:

- Predicting potential losses prior to hurricane landfalling remains an imprecise science.
- Predicting potential losses from a landfalling hurricane more than 3 days, but less than 5 days before forecasted landfall, can provide a sense of the magnitude of the impending event. This information can be used to get a sense of the potential scale of the emergency response at the state or regional level.
- Predicting potential losses from a landfalling hurricane less than 3 days before forecasted landfall can provide valuable information to federal, state, and local emergency managers, including a sense of the magnitude of the impending event and where damages might be concentrated.
- Using HAZUS to predict loss from a landfalling hurricane requires expert skills in meteorology, wind and forensic engineering.

Deployment of the Clemson University/ University of Florida Wind Observation Team During Landfall of Hurricane Isabel

Tim Reinhold, Dept. of Civil Engineering, Clemson University, Clemson, North Carolina

A mobile wind tower observation program has been jointly established at Clemson University and the University of Florida to capture ground level winds during hurricane extreme wind events. Dr Tim Reinhold, Department of Civil Engineering at Clemson University directed the mobile wind tower design and construction, while Dr. Kurt Gurley at the University of Florida directed the data analysis and related time-data transmission efforts. The tower design and instrumentation efforts have been described in articles that are posted at <http://www.ce.ufl.edu/~fcmp/pubs/pubs.htm#Press>. A brief summary is as follows:

The towers are 10 meters (32.8 feet) tall when erected and are designed to remain stable under their dead weight in wind velocities up to 200 mph. In addition, earth screws are used to boost anchorage for particularly intense storms. The towers fold up so that they meet DOT requirements for transport as a conventional trailer. They are easily transportable and can be erected at a selected site in as little as 15 minutes, longer if optional satellite towers are also erected. On a couple of occasions, the towers have been erected in winds gusting to about 60 mph. The towers are instrumented for 3-degrees of freedom velocity measurements at elevations of 5 meters (16.4 feet) and 10 meters (32.8 feet) above the ground surface. Other instrumentation measures barometric pressure, relative humidity, temperature and rainfall. Representative views of towers are shown in Figures 1 through 4.



Figure 1. Tower in Transit to Atlantic Beach, NC



Figure 2. Tower Deployed in Atlantic Beach, NC

Data is collected using two computer systems, a hardened rack mount computer that samples all channels at a rate of 100 Hz and a laptop computer with wireless cell phone connection that collects data from the main tower and associated environmental sensors at a rate of 10 Hz. Both systems collect data for 15 minute segments with at most 2 second gaps between consecutive segments. Backup power is provided by a generator that runs for about 12 hours before it runs out of fuel and a large capacity backup UPS that provides an additional operation time of about 15 hours. The laptop computer produces summary data for each 15 minute segment that includes the mean wind speed, mean wind direction, turbulence intensities and maximum wind speeds for a number of averaging times. The laptop then activates its cell phone connection every 15 minutes and uploads the summary data to a server at the University of Florida.



Figure 3. Deployment of Tower in Wilmington, NC



Figure 4. Tower in Transit to Frisco, NC



Figure 5. Area Around Outer Banks, Near Tower Site



Figure 6. Location of Tower in Elizabeth City, NC

Four towers were deployed in advance of Hurricane Isabel. The towers were erected near the Outer Banks at Elizabeth City, Wilmington, Atlantic Beach, and Frisco, NC, see Figures 1 through 5. Aerial photos showing the locations of the towers at Elizabeth City and Wilmington are shown in Figure 6 and 7.



Figure 7. Location of Tower in Wilmington, NC

Three fixed axis RM Young Gill anemometers are mounted on each tower at the 5 meter and 10 meter heights, in a nearly orthogonal array that is tilted 45 degrees from the horizontal plane. A RM Young Wind Monitor (prop vane instrument) is mounted at the 10 meter height and provides redundancy of horizontal velocity and direction measurements at that height. Impact resistant propellers are used and the wind monitor is set such that it has a sensitivity of 44.74 mph/volt. The Gill anemometers have a sensitivity of 38.48 mph/volt. The distance constant of the Gill anemometers is on the order of 5 meters (15 feet). No additional filtering other than that associated with the response characteristics of the anemometers is used in the system. The signals are acquired as analog signals and are then digitized using a 16 bit A/D converter. Typical resolution is on the order of 0.01 mph.

Data from each fixed array of Gill anemometers is resolved to produce three velocity components and incorporates an iterative solution algorithm that includes corrections for the non-cosine response of the fixed axis propellers to wind direction as published by RM Young. Sample (processed) records that have been obtained during Isabel's landfall are shown in Figures 8 and 9.

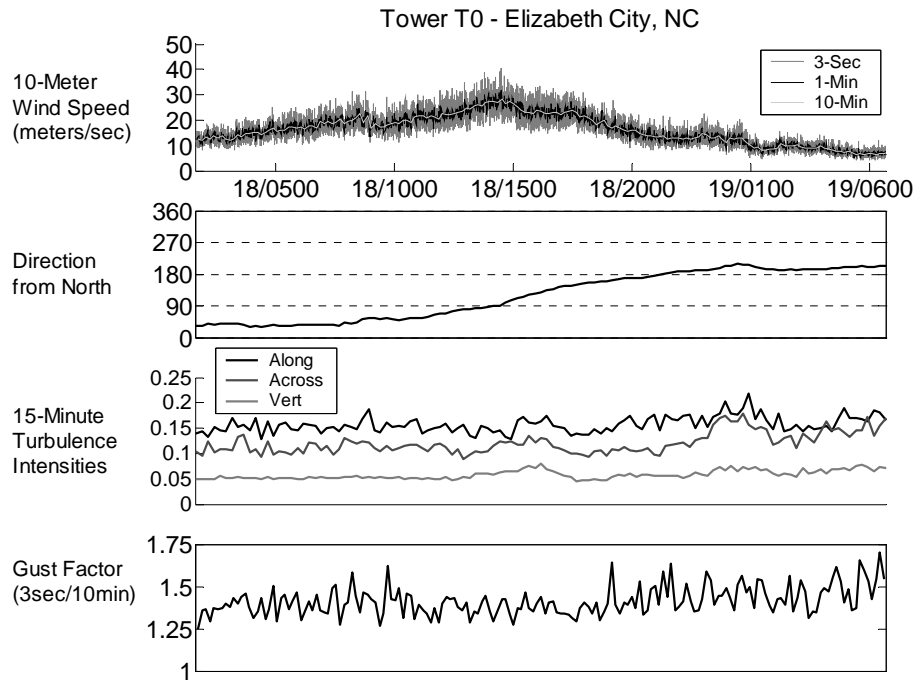


Figure 8. Wind Velocity Measured in Elizabeth City, NC

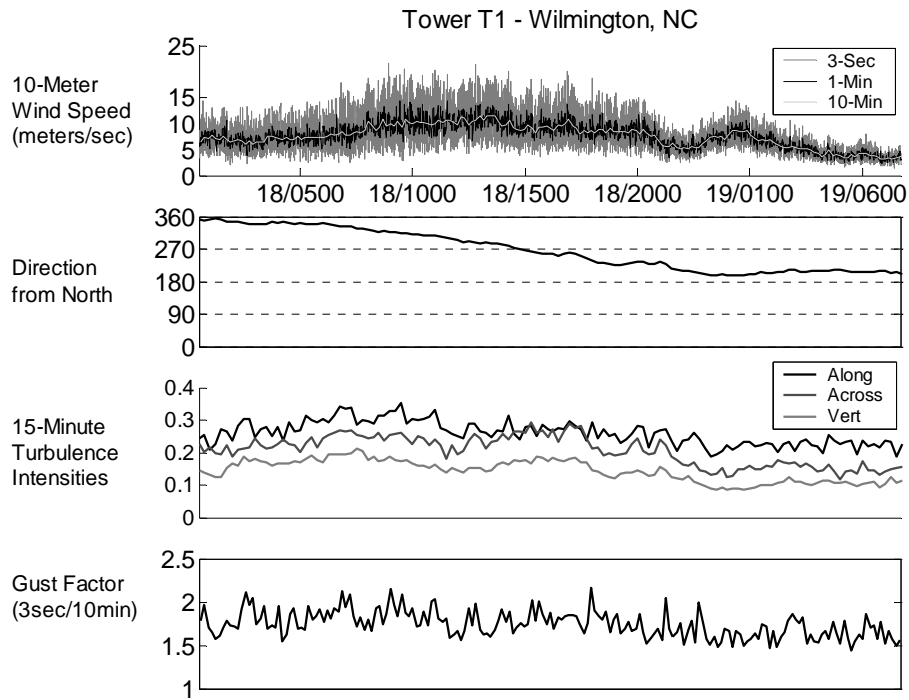


Figure 9. Wind Velocity Measured in Wilmington, NC

Hurricane Isabel at Landfall: A Significant Field Effort

John L. Schroeder, Wind Science and Engineering Research Center, Texas Tech University

Texas Tech University (TTU) sent 10 individuals on the 4000-mile roundtrip to collect data from Hurricane Isabel's landfall on the coastline of North Carolina. TTU transported five 10 m towers and coordinated with Oklahoma University (OU) to bring two Shared Mobile Atmospheric Research and Teaching (SMART) radars to the coast.

After coordination with the Clemson University and the University of Florida tower teams, TTU deployed one tower (WEMITE 1) at the Morehead City-Beaufort Airport, one tower at Atlantic Field (WEMITE 2), and a three-tower array, as well as the second SMART radar (SR-2), at the New Bern Airport. These positions represent locations along and to the left of Hurricane Isabel's final track. The first SMART Radar (SR-1) was deployed by OU at the airport in Washington, North Carolina. This position enabled the dual Doppler lobe of the SMART radars to completely cover the landfall location and inland track of Hurricane Isabel. Finally, through the National Severe Storms Laboratory, the position of TTU's Atlantic Field tower was relayed to the Center for Severe Weather Research, which deployed three additional mobile research radars near the tower deployment site.

The massive deployment effort led to the collection of an extensive dataset that can be leveraged to extend our current knowledge of hurricane planetary boundary layer (HPBL) wind flow. High-resolution wind speed data sets collected from the TTU towers locations are summarized in Table 1. Overall, the wind speeds were not that impressive at the TTU deployment locations, with a

maximum wind speed peak of 39 m/s collected at the Morehead City-Beaufort Airport location. While the New Bern and Morehead City-Beaufort Sites sites were located to the left of the storm center completely in the offshore flow, the Atlantic Field site took a direct hit from the northern eyewall of Isabel, as shown in Figure 1. However, the Atlantic Field site did not maintain an open exposure in all directions; hence, upstream forested areas effectively slowed the collected 1-minute mean wind speeds, which did not exceed more than 23 m/s at a 10 m height.

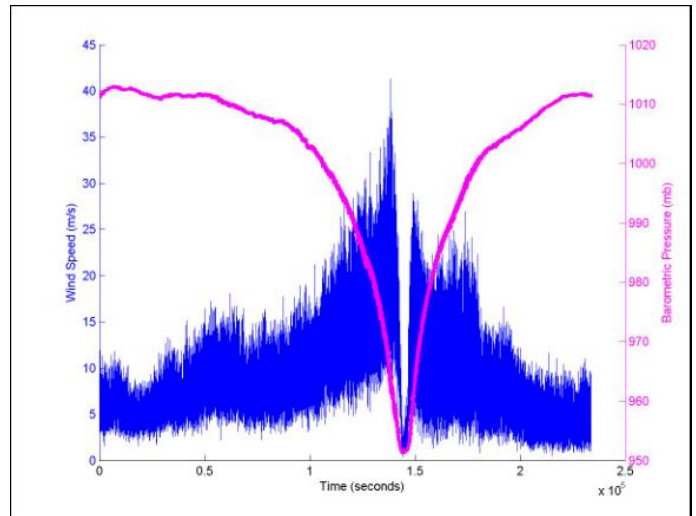


Figure 1. Original 10 Hz Wind Speed (15 m height) and Barometric Pressure Time History Collected at the Atlantic Field During the Passage of Hurricane Isabel

More importantly, the active coordination between radar and tower teams led to an organized effort to investigate the dynamics and surface reflection of HPBL rolls. SR-2, shown in Figure 2, was operated using an alternating scanning strategy. Dual Doppler coverage of mesoscale kinematic and precipitation structure was operated intermittently with focused high-temporal (< 30 second

Table 1. Maximum Peak and Mean Wind Speeds (at 10 m) Collected by TTU During the Passage of Hurricane Isabel.

Site	Latitude	Longitude	Maximum Peak Wind Speed (m/s)	Maximum 1-Minute Sustained Wind Speed (m/s)
New Bern Airport	35.070806°	77.045111°	30	21
Atlantic Field	34.889028°	76.355056°	38	23
Morehead City-Beaufort Airport	34.729737°	76.658671°	39	29

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Figure 2. SMART Radar (SR-2) Deployed at the New Bern Airport During the Passage of Hurricane Isabel

revisit times) and high-spatial (~66 m gate spacing) resolution 90° sector scans over the three-tower array located at the New Bern Airport. Coordination with the Center for Severe Weather Research lead to the collection of a high-resolution dual Doppler data set with minimal gate spacing (10 m) and revisit times of approximately 15 seconds centered over the TTU tower deployment site in Atlantic Field. Assimilation of the tower and radar datasets will provide the best opportunity to date to resolve the HPBL rolls and determine if there is a surface reflection in the wind field.

Hurricane Isabel – New Lessons for Wind Engineers

Mike Gaus

Hurricane Isabel has provided some new lessons for wind engineers and emergency management persons. At one point early in its growth Isabel was listed as a category 5 storm. Fortunately as it progressed across the Atlantic it became more disorganized and the rated intensity dropped. However the hurricane was still rated as a category 3 event as it approached land along the US coast on Sept. 17, 2003. As the storm came ashore, with the eye in the Cape Hatteras area on Sept. 18, there was further decrease in wind velocities.

At one point Hurricane Isabel reached the highest level in the Saffir-Simpson scale, a Category 5 hurricane. At its peak, it had a central sea-level pressure of 920 millibars; the lower the pressure, the more intense the hurricane, and 920 mbs is quite low! On one aircraft reconnaissance flight an eyewall dropsonde measured a wind of 183 knots just above the surface. Luckily, it was far out to sea when it was at this dangerous level. However, even though the storm continued to weaken as it

approached shore, it still required close watching for everyone near its path.

Although the maximum winds in most areas swept by the hurricane including North Carolina, Virginia, Maryland, Pennsylvania, New Jersey and Delaware were reduced from the maximum intensity over open water, a number of factors resulted in large amounts of loss and damage. Although the overall wind velocities were below the ASCE 7 recommendations, the damage that resulted was not of a type that might have been expected for the average winds that seem to have occurred and in fact there was relatively little direct structural damage directly attributed to high wind velocities. It does not appear that wind velocities even reached ASCE 7 design values in most areas. The largest sources of damage were from storm surge, wave action, flooding, and tree failures. Tree failure resulted in massive loss of electrical and communication infrastructures and shortly after passage of the hurricane millions of persons were without power and in many cases also without communications, whether they were land-line or wireless. There also was a large amount of structural damage resulting from falling trees striking structures. The amount of effort and cost related to repairing tree-generated damage and in removing fallen trees was very substantial.

An interesting phenomena related to tree damage was noticed. As you would progress through an area there would be places of substantial damage and then there would be adjacent areas where there was very little damage, even though the density and character of the vegetation was the same. Clearly there was a significant amount of embedded disturbances in the form of downbursts or tornadoes or unusual turbulence to account for the extreme variations. There were probably a number of reasons for the extreme level of tree failure. Among these was the passage of a substantial amount of time since there was an event with strong winds that continued for extended periods of time and that allowed failure of trees of great heights, and there had been a period of drought followed by extremely wet weather so the soil had reduced holding power.

The types of failures and damage that occurred in Isabel indicate that there is a whole new area of research that should be pursued by wind engineers. This would involve taking a broader view and including items that have not been previously considered in wind studies. Wind damage can obviously involve more than wind pressures on buildings. A workshop should be held to discuss the most effective way to document post disaster studies including the failure of trees and other non-conventional structures.

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