

Windstorm Impact Reduction Program Biennial Progress Report for Fiscal Years 2005-2006

I. Background

The National Windstorm Impact Reduction Program (NWIRP) was established by Public Law 108-360, the National Windstorm Impact Reduction Act of 2004. As required by the legislation, an implementation plan¹ was developed by the Interagency Working Group (IWG) that provided guidance for participating agencies. The legislation also calls for a biennial report to Congress. This document is the biennial report for fiscal years 2005 and 2006.

A. The Significance of Wind Hazards

The 2005 hurricane season - the most costly in U.S. history - produced storms of unusual destruction, causing large-scale damage from wind and water across many states. Hurricanes Katrina, Rita and Wilma demonstrated in dramatic fashion how costly these events can be, both in lives lost and property destroyed. The expense of wind damage to the built environment from wind hazards have been increasing over the past decade, even when adjusted for inflation, as human development increases in the vulnerable coastal zones in hurricane-prone regions. These devastating events were only the most recent examples of the worldwide impact of windstorms.

According to a report published by RAND², windstorms caused almost two-thirds of the \$145 billion in uninsured losses in 2004. Florida alone suffered \$42 billion in uninsured losses from the damage brought by four hurricanes that year. The RAND report indicates that the destruction caused by high winds, storm surges and flooding hurricanes and tornadoes cause throughout the United States cost the nation an average of about \$6 billion per year.

Although economic losses have increased over the last decade, improvements in forecasts, preparation and mitigation have significantly reduced the number of lives lost during the last century. Before Hurricane Katrina, the nation averaged about 100 deaths and 1,250 injuries per year. Social vulnerability analysis indicates that demographic subpopulations, including those of lower socioeconomic status, are at higher levels of risk from wind events²⁶.

B. Objectives

Public Law 108-360, Title II, the National Windstorm Impact Reduction Act of 2004, which was signed into law by President Bush on October 25, 2004, is intended to measurably reduce the loss of life and property from windstorms. The law states that:

The objective is to be achieved through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector, aimed at improving the understanding of windstorms and their impacts and developing and encouraging implementation of cost-effective mitigation measures to reduce those impacts.

- *National Institute of Standards and Technology (NIST) shall support research and development to improve building codes and standards and practices for design and construction of buildings, structures, and lifelines.*
- *National Science Foundation (NSF) shall support research in engineering and the atmospheric sciences to improve the understanding of the behavior of windstorms and their impact on buildings, structures and lifelines.*
- *National Oceanic and Atmospheric Administration (NOAA) shall support atmospheric sciences research to improve the understanding of the behavior of windstorms and their impact on buildings, structures, and lifelines.*
- *Federal Emergency Management Agency (FEMA) shall support the development of risk assessment tools and the effective mitigation techniques, windstorm-related data collection and analysis, public outreach, information dissemination, and implementation of mitigation measures consistent with the Agency's all-hazards approach.*

C. The Interagency Working Group and Contributing Agencies

The National Windstorm Impact Reduction Act directed the Director of the President's Office of Science and Technology Policy to *"establish an Interagency Working Group consisting of representatives of NSF, NOAA, NIST, FEMA, and other Federal agencies as appropriate. The Interagency Working Group will be responsible for the planning, management, and coordination of the Program, including budget coordination."*

The Interagency Working Group was reconstituted after the delivery of the NWIRP implementation plan to Congress in April 2006. It consists of representatives from the agencies mentioned and, in addition, the Department of Transportation's Federal Highway Administration (FHWA) and the Department of Housing and Urban Development. The FHWA is the only agency not mentioned in the Act that contributes to this report.

D. The Intersection of Agency Missions with Wind Impact Reduction Objectives

The following agencies have contributed to this report in accordance with the objectives of the National Windstorm Reduction Act.

NSF: NSF supports basic research on the occurrence and effects of most natural hazards. This research includes studies of the temporal and special structure of hurricane winds, straight line winds and tornados and their effects on the built environment. Engineering studies include development of strategies and procedures for assessing and reducing impacts for all types of wind environments. Quantifying risk associated with wind loads and developing models for economic loss estimation and community impact are also important objectives. Another important objective of NSF is to study community preparedness and response to wind events in order to develop effective models for improving community resilience and hazard mitigation.

NOAA: Within NOAA's mission of understanding the environment, providing environmental stewardship, and predicting environmental changes, is the objective of saving lives and property. Wind is one of the many environmental parameters that NOAA strives to better understand and predict due to its often detrimental effect on lives and property. This includes potentially

damaging winds caused by tornadoes, hurricanes, and severe thunderstorms. The Hurricane Research Division of NOAA works with NOAA's National Hurricane Center to improve wind forecasts, for example, through the new hurricane wind probability products. The National Severe Storms Laboratory helps NOAA's Storm Prediction Center to improve forecasts of tornadic storms and of strong and damaging winds in severe thunderstorms. As part of the efforts leading to improved prediction, precise wind measurements are required, understanding of the processes producing such winds is improved, as is understanding of the nature (e.g., strength and duration) of strong wind events.

NIST: NIST has a long and effective history in fulfilling its mission of serving the measurement and standards needs of the building and fire safety industries through its Building and Fire Research Laboratory (BFRL). BFRL is a critical source of metrics, models and knowledge for predicting the extent of damage from natural and man-made hazards, mitigating their impact, and helping to prevent failures in communities and public infrastructure systems. NIST's mission in the area of wind engineering has historically been twofold: (1) to create the knowledge needed to improve code provisions and practices resulting in safer and more economical structures and (2) to develop effective tools for use in the prediction and investigation of losses due to wind.

FEMA: Within FEMA's National Earthquake Hazards Reduction Program legislative authority, the Earthquake Hazards Reduction Act of 1977, as amended, it is recognized in Section 2 Findings that earthquake mitigation activities provide collateral benefits to mitigate other natural hazards, including windstorm events. In addition, under the authority of the Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended, FEMA coordinates the National Hurricane Program which provides important information, products, and tools to state and local governments in hurricane-threatened areas of the country.

FWHA: The mission of the *Bridge Safety, Reliability, and Security Initiative* is to effectively deal with natural and manmade hazards to existing and new bridges as well as other highway structures. One of the objectives of the *Bridge Program Strategic Plan* is to ensure that highway structures provide a high level of safety and service under all conditions. Highway structures shall provide a high level of service under normal conditions and shall provide specified levels of reliability when subjected to natural and manmade hazards (extreme events).

E. Areas of Focus of the NWIRP implementation plan

As prescribed by Public Law 108-360, Title II, the National Windstorm Impact Reduction Act of 2004, the Interagency Working Group was established in 2004 and delivered the Windstorm Impact Reduction Implementation Plan¹ for the National Windstorm Impact Reduction Program (NWIRP) in 2005. The NWIRP implementation plan organized the body of wind hazard research into the following four major themes with sub-themes:

1. Understanding, predicting, and forecasting
 - a. Enhancing knowledge, information and data on severe winds
 - b. Improving prediction of hazardous wind events
 - c. Understanding and quantifying wind loading
 - d. Understanding the perception of wind hazard risk

- e. Mapping wind hazards
2. Assessing impacts
 - a. Investigating wind resistance of buildings, structures and critical infrastructure
 - b. Developing improved tools for component- and structure-level simulation and numerical modeling of wind effects
 - c. Developing improved tools for loss assessment of wind hazards
 - d. Assessing social costs
3. Reducing impacts
 - a. Assessing and communicating risk
 - b. Developing prototype structural requirements
 - c. Demonstration, education, training and outreach on improved codes and building guidelines
 - d. Guidance on retrofiting
 - e. Innovative technologies
 - f. Land use measures and cost effective construction practices
4. Preparedness and Enhancing Community Resilience
 - a. Developing tools for community preparedness to wind hazards
 - b. K-12 and college education needs
 - c. General public awareness and outreach
 - d. Evacuation planning
 - e. Enhancing disaster-resistance of building codes and standards
 - f. Building public and private partnerships
 - g. Conducting emergency response exercises

The progress in each sub-theme, if any and as appropriate within each agency's mission, is presented in the next section.

Within the four research themes, the NWIRP implementation plan identified eight high priority research topics to be addressed by agency programs:

- Assessing individual and community capability to respond to wind events, including vulnerability analyses, risk perception, risk communication, risk management, communication of wind warnings and public response, evacuation capability, and public knowledge of appropriate protective actions for wind events, especially among vulnerable populations
- Evaluating the response of the built environment and critical infrastructure to wind events by investigating aerodynamic response, load path, ultimate capacity and the performance of the building envelope
- Assessing the impact of wind and windborne debris or wind and water/ice/snow
- Examining the interaction between wind and storm surge to determine the impact on building foundations and critical infrastructure
- Exploring the near-ground and channeling/shielding effects of winds on buildings through testing and instrumentation
- Developing new technologies and ground, airborne and satellite based observing systems to improve knowledge and understanding of windstorms and the wind variability within those storms

- Measuring the response of bridges and other highway structures to wind events, including stability, serviceability and functionality leading up to and through extreme events
- Developing and implementing technologies for rapid repair and restoration of critical infrastructure and critical services.

II. Progress in Fiscal Years 2005 and 2006

A. Reports by Agency

National Science Foundation

NSF Program Directors receive unsolicited proposals for research on a broad range of topics related to hazard mitigation. The programs range from atmospheric sciences programs that are concerned with physics-based topics related to formation of hurricanes and thunder storms to engineering programs focused on improving the performance of structures against wind loads, to social science programs devoted to societal response to natural disasters. Although these proposals are selected through the peer review process under programs intended to advance research in myriad areas and not just hurricanes and winds, the NSF portfolio of projects have collectively made important progress in each of four focus areas and many of the sub-areas defined above.

Understanding, Predicting and Forecasting:

Over the past two years, research in atmospheric sciences was begun to develop a better understanding of atmospheric dynamics of straight-line winds and to improve understanding of fundamental physics that control hurricane intensity; wave dynamics during hurricanes; collaborative research on the impact of externally and internally modulated convection on tropical cyclone evolution

(<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0514199>). Understanding the hazard risk associated with extreme hurricane events is also being studied. Detecting synoptic-scale precursors of tornado outbreaks

(<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0527934>) is the objective of one investigation. Another project is studying tornadic storms with Doppler Polarimetric Radar (<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0532107>).

Assessing the impacts of wind hazards

Shortly after Hurricane Katrina struck the Gulf States, 29 small grants were awarded for reconnaissance studies aimed at documenting the effects and preserving highly perishable data. Two of these studies on the performance of the levee system were expanded in scope to include engineering analyses of failed sections of the levees and proposed repair and replacement strategies. Development of instrumentation for the observational studies of the effects of atmospheric winds on structures near the ground was also undertaken. Another of these projects investigated large coastal bridge performance in a hurricane environment. Collection of perishable data on wood-frame residential structures in the wake of Hurricane Katrina was also undertaken. Studies were conducted to better understand the response of typical bridges to hurricanes and to assessing risk for long-span bridges. The determination of storm surge effects

on levees and the simulation of non-linear water waves during hurricanes were the subjects of other investigations. In order to better understand the impacts of hurricane disasters, construction material requirements for rebuilding New Orleans are being investigated and documented. Improving glass performance during wind storms and the modeling response of tall buildings to straight line winds are important for understanding the impacts to wind hazards.

Social science topics under investigation include evaluating preferences for rebuilding plans post-Katrina, assessing public health impacts of disasters, and decision making in displaced populations. In particular, one project is examining factors associated with compliance to Katrina mandatory hurricane evacuation orders in seven coastal Louisiana parishes.

Reducing Impacts of Wind Hazards

Resistance of existing wood roof structures and retrofit schemes is currently being studied to better understand how best to construct more resistant structures in the future. This type of damage accounts for a significant proportion of the damage caused by hurricanes and straight line winds each year. In addition, we also need to better understand the impact of hazard events on soils, infrastructure, and the submerged environment. A project entitled “The Effect of Katrina on Submerged Geotechnical Systems - Underwater Evaluation of Sediment-Structure-Storm Interaction” will provide important data on these important parts of the urban infrastructure. Another project that is vital to the energy supply is focusing on assessment of damage to underground tanks in New Orleans in the aftermath of Hurricane Katrina. Electric Utility Damage from Hurricane Katrina is also under investigation.

Preparedness and Enhancing Community Resilience

Instructional materials for K-12 are being developed to enhance preparedness among children. Also, information technologies are being developed to assist individuals in adapting to evacuation. Social networks are being studied to understand the role they might play in early warning strategies and subsequent compliance. Improving hurricane intensity forecasting is important to increase societal compliance and evacuation plans and orders, but the public must also be educated to understand risk and appropriate behavior to ensure their safety. Two studies are underway to better understand and improve evacuation procedures. Two projects have been funded for analyzing multi-organizational networks and their roles in hazard mitigation. Ten projects are underway that are investigating various tools that might be useful for building community resilience to wind hazards. One of these projects is examining how preferences for rebuilding plans are being made after Hurricane Katrina

(<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0554987>). Another one is studying “The Parallel Strengths and Weaknesses of the Civil Society and the State: The Example of Katrina Survivors”

(<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0555113>).

“Cyberinfrastructure Preparedness for Emergency Response and Relief: Learning the lessons from Hurricane Katrina” is the focus of another investigation

(<http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0638561>).

National Oceanic and Atmospheric Administration

NOAA activities and progress during the past two years can be divided into six categories: 1) development of plans, 2) provision of data of use for wind hazard reduction, 3) development of decision support tools and analyses of relevance to wind hazards, 4) understanding and predicting weather conditions producing wind damage, 5) creation of new facilities for improving our knowledge and prediction of wind hazards, and 6) education and outreach.

Development of plans:

NOAA developed a budget initiative for fiscal years 2009 to 2013 addressing the creation of resilient coastal communities of which resilience to wind hazards is a component. NIST and NOAA jointly developed a cooperative plan on Hazard-Resilient Communities. NOAA is represented on the U.S.-Japan Panel on Wind and Seismic Effects. This panel encourages exchange of information between the two countries and has initiated a joint project on bridge stay flutter. It proposes work on urban canopy wind modeling and verification and coupling of meteorological and computational fluid dynamic models to be used by wind structural engineers.

Providing data of use for wind hazard reduction:

During FY2004, several extreme turbulence (ET) probes^{3,4} were developed and successfully tested in actual hurricanes. These probes hold promise for very high spatial and temporal resolution measurements of winds on the immediate exterior of structures. In cooperation with NOAA, the Florida and South Carolina Sea Grant deployed portable towers measuring winds during Hurricanes Charley, Frances, Ivan, Katrina, and Rita. These data are useful for “nowcasts” of the winds and to duplicate wind tunnel measurements. The Shared Mobile Atmospheric Research and Teaching Radars (SMART-R), the result of a cooperative effort between the University of Oklahoma and NOAA, have been used in hurricane landfall deployments, and have been upgraded to deliver their data directly to forecast offices in real time^{5,6,7,8,9}. The stepped frequency microwave radiometer is now deployed on both research and operation aircraft for much improved surface wind and vertical wind profiles over water within hurricanes and they are now used in NOAA’s operational hurricane model and for real-time hurricane intensity analysis.

Decision support tools and analysis for wind hazards:

NOAA has been working with the state of Florida on a Public Hurricane Loss Projection Model to develop wind-dependent vulnerability functions for building retrofit guidance. The NOAA hurricane wind (H*WIND) analysis was used to validate this model. A stochastic model is being used to simulate 55,000 years of hurricane tracks for a wind demonstration project, conducted with NIST, to test wind and storm surge risk maps in a few selected coastal areas. The U.S. Army Corps of Engineers and NOAA completed a post-Hurricane Katrina, Charley, Frances, Ivan, and Jeanne 1-km resolution wind field analysis using the H*WIND product and data that were not available in real time. NOAA’s National Hurricane Center introduced its new experimental wind-speed probability forecast in time for the 2006 hurricane season to map out several predicted wind-speed thresholds.

Understanding and predicting weather conditions producing wind damage:

NOAA continues to gather field data on hurricane inner core dynamics to better understand intensity changes. During the past two hurricane seasons, NOAA, with the Office of Naval Research, has been measuring the heat and momentum exchange between the atmosphere and

ocean within hurricanes to better parameterize this exchange in hurricane prediction models^{10, 11}. Preliminary testing of these new parameterizations in NOAA's operational hurricane model has improved hurricane intensity predictions. NOAA tested a new hurricane model during the 2006 hurricane season for operational application next season. It is coupled with an ocean model and has a nested and movable grid.

Creating new facilities for improving our knowledge and prediction of wind hazards:

The new National Weather Center in Norman, Oklahoma opened its doors during the summer of 2006. It consists of the South Research Campus of the University of Oklahoma, the NOAA Norman forecast office, the Storm Prediction Center, and the National Severe Storms Laboratory. This facility also features the Hazardous Weather Testbed, which performs research and development to improve prediction of hazardous winds. This year, Congress appropriated \$2M to NOAA to promote collaboration among the University of Alabama/Huntsville's Earth System Science Center, NASA's Short-Term Prediction Research and Transition Center, NOAA's National Severe Storms Laboratory, and the Hazardous Weather Testbed. This collaboration will lead to improved prediction and monitoring of severe storms and their associated hazardous winds.

Education and outreach:

- NOAA's Louisiana Sea Grant program has developed fact sheets that include information on building codes, where and how to rebuild, and how to determine if a contractor is following state and federal regulations. It has been distributed to parishes and is available on the Internet. The program has also sponsored seminars on storm preparedness and has provided information on building codes and zoning practices.
- NOAA's Texas Sea Grant Program (Texas A&M) has been evaluating the Texas Mitigation Plan, which includes construction codes.
- The North Carolina Sea Grant (North Carolina State in collaboration with Oregon State) developed a break-away wall design for 125-mph winds and 1.5-ft waves, which has been adopted by the American Society of Civil Engineers.
- The South Carolina Sea Grant (Clemson) has developed low-cost methods for reducing storm damage, including strengthening roofs and shutters which have been adopted by a Sun City developer.
- There is now a "hazards house" in Charleston, SC, that helps educate the public on hazard-resilient building and retrofitting techniques, including those that mitigate wind effects.
- NOAA has prepared material for a documentary on how to stay safe in high winds, including how to improve housing construction to resist damage and the appropriate design for safe rooms. The documentary will be featured on the Discovery Channel.
- NOAA held its first Weather Partners open house in Norman, OK, for approximately 1000 visitors. Wind risk to structures was a prominent theme for discussion.
- NOAA organized a training session at the National Hurricane Conference on hurricanes and public health. During the session, a representative from the Institute of Building and Home Safety delivered a presentation on the resilience of

public health facilities against structural hazards. Key structural components included window strength, exterior cladding, roof edging, and vulnerability of roof type and roof mountings. The participants then critically evaluated a simulated hurricane scenario.

National Institute for Standards and Technology

NIST research over the past two years has focused on two areas: (1) to gain an understanding of wind hazards to the built environment; and (2) to develop predictive technologies and mitigation strategies to enhance disaster resilience to wind hazards.

Understanding Wind Hazards to the Built Environment

Extreme Wind Databases: To facilitate use of Automated Surface Observing Station (ASOS) wind data for structural engineering purposes, NIST developed procedures and software for (a) extraction of peak gust wind data from archived ASOS weather reports, (b) extraction of thunderstorm observations from archived weather reports, (c) classification of wind data as thunderstorm or non-thunderstorm to enable separate statistical analyses of these distinct types of winds, and (d) construction of data sets separated by specified minimum time intervals to ensure statistical independence. Estimates showed that, at these stations, thunderstorm wind speeds dominate the extreme wind climate to the extent that non-thunderstorm wind speeds can be disregarded in the analysis¹². Using such records it is possible to obtain realistic probabilistic descriptions of the wind climate at stations where both types of wind occur. The software, data, and literature are available at www.nist.gov/wind.

Advanced Computational Tools for Determining Realistic Wind Loads in the Built Environment

NIST has developed software for analyzing wind effects on rigid, gable-roofed buildings, and flexible high-rise buildings using the database-assisted design methodology^{13, 14, 15, 16, 17, 18, 19}. Database-Assisted Design (DAD) is a unified framework for analysis and design of buildings for wind loads that makes direct use of pressure-time histories measured at a large number of pressure taps on wind tunnel models. Local climatological information can be used in conjunction with the measured pressures to obtain estimates of peak wind effects with specified return periods for use in structural design. DAD offers more accurate estimation of peak wind effects than simplified procedures that are now used, which paves the way for more risk-consistent designs. The software, data, and literature are available at www.nist.gov/wind.

Methodologies for Predicting Ultimate Structural Capacities and Estimating Safety Margins

The design of many low-rise metal buildings in the U.S. is based on the ASCE 7-93 Standard and the use of Allowable Stress Design (ASD). NIST used the nonlinear database-assisted design technique to assess the degree of safety of a typical low-rise portal frame industrial structure designed in accordance with ASCE 7-93 and ASD as compared to the provisions of the ASCE 7-02 Standard. We have found that the frame being considered satisfies all ASCE 7-02 requirements with respect to wind loading but that its safety level is relatively low and could be improved substantially at very low cost²⁰.

Assessing the Performance of Structures in Wind Disasters

NOAA's National Weather Service implemented the enhanced Fujita Tornado Intensity Scale on an operational basis in February 2007. The enhanced Fujita scale is based upon observations by

a NIST researcher as part of a reconnaissance team deployed following the 1997 Jarrell, TX tornado and subsequent technical work performed by Texas Tech University with funding and technical oversight by NIST. The more realistic wind speeds associated with the enhanced scale will allow the use of routine standard provisions for the safe design of buildings under most tornadoes occurring in the U.S.

After Hurricane Katrina and Hurricane Rita, NIST assembled a team of experts to conduct a reconnaissance of the status of buildings, physical infrastructure, and residential structures in the New Orleans area, coastal Mississippi, and Southeast Texas. NIST documented its findings on the environmental conditions (e.g., wind speeds, storm surge elevations, and flooding) and on the performance of structures in the study areas in its final report issued in June 2006. The report includes 23 recommendations in three groups: 1) immediate impact on practice for rebuilding, 2) standards, codes, and practices, and 3) further study of specific structures or research and development²¹.

Technical Basis for Improved Codes and Standards

Estimates of the World Trade Center (WTC) towers' response to wind by two North American wind engineering laboratories differed from each other by almost 50 percent. A recent NIST investigation indicated that those differences reflected discrepancies between the respective estimates of the wind speeds and the respective modeling of directional interaction between wind speeds and aerodynamic/dynamic response of the building^{22, 23}.

NIST analyzed the role of risk-consistent probabilistic definitions of peak wind effects in developing safety margins for inclusion in codes and standards.

U.S.-Japan Panel on Wind and Seismic Effects

NIST chairs the US-Japan Joint Panel on Wind and Seismic Effects and NIST staff actively participates in the Panel and its wind engineering task committee. The Panel provides an effective mechanism for the exchange of technical data and information, the exchange of researchers, and the coordination of joint research on topics of mutual interest to the US and Japan.

Federal Emergency Management Agency

FEMA activities and progress during the past two years can be organized in the following categories: 1) risk assessment; 2) windstorm-related data collection and analysis; 3) public outreach; 4) implementation of mitigation measures consistent with the Agency's all-hazards approach; and 5) hurricane program coordination.

Risk Assessment

Hazards US – Multi-Hazard, or HAZUS-MH, is a risk assessment program developed by FEMA for analyzing potential losses from floods, hurricane winds and earthquakes. In HAZUS-MH, current scientific and engineering knowledge is coupled with the latest GIS technology to produce estimates of hazard-related damage before, or after, a disaster. HAZUS-MH estimates include: physical damage to buildings and infrastructure; economic loss, including lost jobs, business interruptions, repair and reconstruction costs; and social impacts, including shelter requirements, displaced households, and population exposed to the disaster. HAZUS-MH MR2, the second maintenance release of the HAZUS-MH software program, became available from

FEMA in April 2006. HAZUS-MH MR2 produces loss estimates based on state-of-the-art scientific and engineering knowledge and software architecture. These estimates are essential for decision-making at all levels of government, and are a basis for developing mitigation plans and policies, emergency preparedness, scenarios used to conduct exercises, and response and recovery planning.

Windstorm-related data collection and analysis

FEMA conducts Mitigation Assessment Team (MAT) studies of building performance after hurricanes. During the year since the catastrophic devastation of Hurricane Katrina, the Mitigation Division has made significant strides in helping the residents of the Gulf Coast rebuild by providing unprecedented levels of support and resources. After Katrina, FEMA deployed a MAT to evaluate and assess damage from that storm and provide observations on the performance of structures impacted by flood and wind forces along with recommendations for improved disaster resistant construction. The team released a comprehensive report earlier this year. Key findings from the report include: 1) Lack of adequate building codes in the affected states greatly compounded the effect of Hurricane Katrina on building performance; 2) Storm surge and wave crest elevations from Hurricane Katrina exceeded the mapped base flood elevations in many coastal areas of Alabama, Louisiana, and Mississippi and flood damage was severe in these areas; and 3) Hurricane Katrina was less than a design-level storm for wind in most areas; however, wind damage was widespread and was severe in some areas. Buildings that experienced substantial structural damage typically were built before wind effects were adequately considered in building design and construction.

Implementation of mitigation measures consistent with the Agency's all-hazards approach

As part of the MAT effort, the team developed first-of- its- kind construction guidance that provides coastal residents with engineering guidance and complete foundation solutions for rebuilding in the Gulf. In great demand, the MAT experts have delivered nearly 40 briefings and presentations on Katrina to local, regional, state and national audiences. By using better building practices now, Gulf Coast communities will be strengthened and more resilient when the next hazardous storm occurs. *FEMA 550 Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* provides homeowners, builders and design professionals with prescriptive, pre-engineered foundation solutions, cost information and guidance on choosing and constructing disaster-resistant foundations. Another publication receiving widespread dissemination and usage is FEMA 499 Homebuilders Guide to Coastal Construction - Technical Fact Sheet Series. This publication is a series of 31 colorful and graphic fact sheets that detail critical components of successful coastal building construction. To date, over 20,000 copies have been ordered and provided.

Public Outreach

The FEMA web site, www.fema.gov, serves as the nation's portal to emergency and disaster information. During the month that followed Hurricane Katrina's landfall along the Gulf Coast, more than 14 million visits and 400 million hits were logged on the Web site.

Hurricane Program Coordination

FEMA and NOAA worked together to improve evacuation planning for hurricanes. Improved hurricane intensity predictions resulting from NOAA's research are used to improve evacuation

decision-making and limit evacuations to only those who absolutely need to evacuate, thereby reducing congestion on the highways.

Over the past two years, FEMA has worked in coordination with NOAA to improve planning based on improved data and Sea, Lake and Overland Surges from Hurricanes (SLOSH) modeling parameters. The NOAA SLOSH hurricane storm surge model is used nationwide to predict the storm surge magnitude for all categories of storms along the coastal regions. Since Hurricane Isabel, NOAA has conducted reviews and examinations of the SLOSH data and has made adjustments to the model for future real time predictions.

Federal Highway Administration^{24, 25}

Understanding, Predicting and Forecasting Wind Hazards

The FHWA Office of Infrastructure R&D continuously monitors winds at the sites of three major long-span, cable-supported bridges to establish and characterize site-specific wind conditions and the responses of the bridges. All sites are relatively near the coastline with one in Louisiana, another in Delaware, and the third in Maine. The engineering data collected at these sites provides valuable input into design of new structures.

Assessing the Impact of Wind Hazards

The FHWA Office of Infrastructure R&D has continuously monitored the wind environment and detailed response of three major long-span, cable-supported bridge structures to evaluate their wind performance and wind resistance. The Computational Fluid Dynamics (CFD) model UABRIM is being enhanced by implementation of unstructured and adaptive grids for use in simulating the interaction between wind and structures such as large bridges. Tests have been completed in our small wind tunnel using evolving Particle Image Velocimetry (PIV) technology to study wind flow fields around and compute wind forces on several representative bridge deck sections.

The FHWA Office of Operations continued activities under the Road Weather Management Program, which seeks to develop and promote effective tools for observing and predicting the impacts of weather on the roads, and to alleviate these weather impacts. As part of the program, the Claris Initiative has continued to conduct activities to develop and demonstrate an integrated surface transportation weather observing, forecasting and data management system, and to establish a partnership to create a Nationwide Surface Transportation Weather Observing and Forecasting System. The Initiative Coordinating Committee (ICC) held its annual meeting in August 2006.

Reducing the Impact of Wind Hazards

The FHWA Office of Infrastructure R&D has initiated research to prepare a synthesis report on Wind Load Criteria for Cable Supported Structures. Complementary research has also been initiated to prepare a synthesis report on User Comfort and Serviceability Criteria for Wind Loading. Research has continued on the issue of wind- and wind/rain-induced vibration of bridge stay cables. A draft guidelines document is under development for the aerodynamic design of bridge stay cables.

Preparedness and Enhancing Community Resilience

The FHWA Office of Infrastructure R&D, together with the Missouri Department of Transportation, organized and held the 2nd National Workshop on Wind-Induced Vibration of Cable-Stayed Bridges in April 2006. This workshop served to disseminate the latest information on the mitigation of wind-induced vibrations to state bridge engineers and design consultants.

B. Table of Agency Progress (FY2005 and FY2006) in the Four Implementation Themes

	NIST	NSF	NOAA	FEMA	FHWA
1. Understanding, Predicting and Forecasting					
Enhancing knowledge, information and data on severe winds	Developed procedures and software for extraction of peak gust wind data and thunderstorm observations from archived ASOS weather reports; classification of wind data as thunderstorm or non-thunderstorm; and construction of data sets separated by specified minimum time intervals to ensure statistical independence.	Better understanding of atmospheric dynamics of straight-line winds; modeling and measuring of rotor effects	<p>Developed extreme turbulence probe. Deployed portable towers in hurricanes at landfall. Deployed stepped frequency microwave anemometer. Improvements in mobile radars.</p> <p>These instruments provide much improved and robust wind measurements near the ground and, therefore, improved understanding of the forces experienced by structures in actual hurricanes.</p>	Conducted Mitigation Assessment Team (MAT) evaluations following Hurricanes Charlie and Ivan in 2004 and Hurricane Katrina in 2005	Monitor/Characterize wind conditions at 3 bridge sites
Improving prediction of hazardous wind events	Developed procedure for statistical estimation of extreme wind speeds in mixed non-thunderstorm/ thunderstorm wind climates.	Tornado genesis and tornadic vortex structure	<p>Studied hurricane inner core dynamics. Improved air-sea exchange parameterizations. Tested improved hurricane model for operational use. Established new National Weather Center in Norman, Oklahoma to improve research and development related to the prediction of hazardous winds.</p>		
Understanding and quantifying wind loading	<p>Developed methods for utilizing database, assisted design for rigid and flexible buildings and implemented the methods in software. The database assisted design method uses pressure-time histories measured at a large number of pressure taps on wind tunnel models.</p> <p>Evaluated the procedure for estimating extreme wind effects by the directional sector-by-sector approach.</p>	Improved understanding of fundamental physics that control hurricane intensity; wave dynamics during hurricanes; effects of convection on cyclones		Conducted MAT evaluations (see above) and worked with the International Code Council (ICC) to develop a Wind Shelter Standard	
Understanding the perception of wind hazard risk		Anticipation of extreme hurricane winds		Conducted MAT evaluations (see above) and worked with the International Code Council (ICC) to develop a Wind Shelter Standard	

Mapping wind hazards			<p>Provided surface wind analysis for Florida building retrofit guidance.</p> <p>Provided hurricane track statistics for wind and storm surge risk maps.</p> <p>Assisted Army Corps of Engineers with high resolution wind maps of recent significant hurricanes.</p>		
2. Assessing Impacts					
Investigating wind resistance of buildings, structures and critical infrastructure	<p>NOAA's NWS implemented the enhanced Fujita Tornado Intensity Scale operationally in February 2007. The enhanced Fujita scale is based upon observations by a NIST researcher following the 1997 Jarrell, TX tornado and technical work performed by Texas Tech University with funding and technical oversight by NIST.</p> <p>NIST led a reconnaissance of the performance of buildings, physical infrastructure, and residential structures affected by Hurricanes Katrina and Rita.</p>	<p>Development of instrumentation for the observational study of atmospheric winds; Bridge response to hurricanes; documentation of wind effects; workshop on wind effects; performance of tanks and industrial facilities during Katrina (2 projects); performance of underground structures during Katrina; response of submerged geotechnical systems and buried infrastructure (3 projects) reconnaissance studies(12 projects)</p>		Conducted MAT evaluations (see above)	Measure wind/structure interaction of 3 bridges
Developing improved tools for component- and structure-level simulation and numerical modeling of wind effects	<p>Developed wind engineering software, data, and literature, which is described at www.nist.gov/wind .</p>	<p>Improving glass performance; response of tall buildings to straight line winds, response and repair of levee systems for Katrina</p>			<p>Enhance CFD bridge model</p> <p>Perform wind/bridge flow visualization tests using PIV in wind tunnel</p>
Developing improved tools for loss assessment of wind hazards		<p>Assessing risk for long-span bridges; determination of storm surge on levees; simulation of non-linear water waves during hurricanes; construction material requirements for rebuilding New Orleans</p>	<p>Developed low-cost methods for reducing storm damage, including strengthening roofs and shutters, from NOAA Sea Grant.</p>	<p>Completed development and release of HAZUS-MH MR 1 and MR 2 updates for Hurricane Winds and methodology for Hurricane Storm Surge Model</p>	<p>Continue road weather management program</p>
Assessing social costs		<p>Evaluating preferences for rebuilding plans post-Katrina; assessing public health impacts; decision making in displaced populations; Electric utility damage from Katrina; impact of Katrina and storm surge on human and built environment</p>		<p>Completed a major study through the National Institutes of Building Sciences (NIBS) on the Benefits of mitigation which determined a 4:1 return on mitigation investment</p>	

3. Reducing Impacts					
Assessing and communicating risk		Improving hurricane intensity forecasting	Introduction of experimental wind speed probability product.	Completed HAZUS-MH MR 1 and MR 2 releases; Ongoing Hurricane Evacuation Studies and Planning; conducted over 50 briefings on the results of the Hurricane Katrina MAT	
Developing prototype structural requirements		Resistance of wood roof structures		Participated in standards development committees: ASCE 7 Wind Loads Task Committee; the ICC Wind Shelter Standard; and the NFPA Manufactured Housing Foundations Standard	Initiate research on wind load criteria, Initiate research on comfort and serviceability criteria
Demonstration, education, training and outreach on improved codes and building guidelines	Participated in the ASCE 7 Standard Committee on Wind Loads; trained future wind engineers (post-doctoral researchers, graduate and under-graduate students).			Conducted over 50 Hurricane Katrina MAT briefings; HAZUS Hurricane Module training to over 500 people; numerous presentations and speeches at conferences	Draft design guidelines for stay cables
Guidance on retrofiting				Developing an electronic tool assessment and retrofit for wind, flood and earthquake for residences	
Innovative technologies			Developed breakaway wall design for 125 mph winds and 1.5 ft waves from NOAA Sea Grant.		
Land use measures and cost effective construction practices				Ongoing evacuation planning studies with the US Corps of Engineers and coastal States in hurricane-prone regions	
4. Preparedness and Enhancing Community Resilience					
Developing tools for community preparedness to wind hazards		Developing tools for preparedness for hurricanes and wind storms (8 projects); response of Texas school systems to Katrina; emergency preparedness planning and on-line evacuation of large buildings;	"Hazards house" in Charleston, SC, developed by NOAA Sea Grant.	Ongoing efforts to improve and develop tools for effective State and local evacuation and sheltering plans	
K-12 and college education needs	Trained future wind engineers (post-doctoral researchers, graduate and undergraduate students).	Development of instructional materials on disaster preparedness; Tracking Katrina: algebra project instructional materials using stories by displaced New Orleans students		Delivered hurricane mitigation training to University professors thru the MBDSI Summer Institute and thru presentations to conferences where educators are present	

General public awareness and outreach	Conducted initial series of briefings to state and local building officials and emergency managers on the findings and recommendations of the Hurricane Katrina and Hurricane Rita reconnaissance.	Development of social networks for early warning	Developed fact sheets on building codes, rebuilding, and contractor issues from NOAA Sea Grant in Louisiana. Held session at National Hurricane Conference on public health facility resilience to winds. Prepared material for Discovery Channel program on wind safety and Weather Partners open house.	Delivered hurricane mitigation training to University professors thru the MBDSI Summer Institute and thru presentations to conferences where educators are present	
Evacuation Planning		Study on adapting to evacuation: information technology; Evacuation studies (2 projects)		Ongoing activity and improvements information, products, and tools for effective State and local hurricane evacuation and sheltering plans	
Enhancing disaster-resistance of Building Codes and Standards	Determined that differences in estimates of the World Trade Center (WTC) towers' response to wind by two North American wind engineering laboratories were due to discrepancies between the respective estimates of the wind speeds and the respective modeling of directional interaction between wind speeds and the response of the building. Analyzed the role of risk-consistent probabilistic definitions of peak wind effects in developing safety margins for inclusion in codes and standards.	Code analysis and studies of enforcement		Participated in ASCE 7 Wind Loads Task Committee; ICC Wind Shelter Design Standard development; Proposed successful code changes to improve wind resistance of national model buildings codes	Held workshop on wind-induced cable vibration
Building public and private partnerships				Working cooperatively with US Dept of Housing and Urban Development (HUD); American Society of Civil Engineers (ASCE); US Corps of Engineers and others	
Conducting emergency response exercises		Analyzing emergent multi-organizational networks (2 projects)		Conducted major catastrophic planning activity for a hurricane exercise in New Orleans and began planning for a Cat 5 Miami hurricane exercise	

III. Summary

One of the primary goals of the National Windstorm Impact Reduction Program is to increase the effectiveness of existing program efforts through better coordination among agencies. Improved coordination can frequently produce improvements in existing research with little or no additional expense. During fiscal years 2005 and 2006, NWIRP agencies improved communications and collaborations among Federal programs in the following ways:

- Enhanced knowledge, collected data and shared information on severe winds
- Investigated wind resistance of buildings and structures (in particular, bridge structures)
- Developed improved tools for assessment of losses from wind hazards
- Increased general public awareness and outreach on specific wind-related topics
- Assisted in the development of evacuation planning and guidance

In addition, improved communication revealed several research areas in the Windstorm Impact Reduction Implementation Plan that deserve further attention or development:

- Understanding the perception of wind hazard risk
- Mapping wind hazards
- Assessing and communicating risk
- Developing prototype structural requirements
- Guidance on retrofitting
- Innovative technologies for assessment and mitigation
- Land use measures and cost effective construction practices
- Building public and private partnerships
- Conducting emergency response exercises

These areas of research will be re-examined during subsequent discussions and planning, and will be factored into subsequent prioritization of research needs.

In some sectors of wind research, the delivery of existing research results to users would provide high value for resources invested, and this will be emphasized during the next year. Interagency coordination is improving through the work of the Interagency Working Group. Strong interagency coordination and collaboration allows for more efficient use and leveraging of existing resources. Under the auspices of the National Science and Technology Council, the NWIRP Interagency Working Group will continue to perform gap analyses, which will provide more detailed guidance on where resources are needed to accomplish the goals of the implementation plan.

One of the focusing events of the historic 2005 U.S. hurricane season was the landfall and resulting unprecedented disaster caused by Hurricane Katrina. Although dozens of Federal agencies responded to the massive damage caused by this hurricane and the subsequent breach of the New Orleans levees, the science agencies of the National Windstorm Impact Reduction Program used this destructive storm as an opportunity to expand our knowledge of hurricanes and the effects of high winds on buildings, bridges, and natural systems. The following list is a

partial summary of science activities in the NWIRP agencies, some conducted individually, some conducted collaboratively:

NIST

- Led a reconnaissance of the performance of buildings, physical infrastructure, and residential structures affected by Hurricanes Katrina and Rita.
- Conducted initial series of briefings to state and local building officials and emergency managers on the findings and recommendations of the Hurricane Katrina and Hurricane Rita reconnaissance.

NSF

- Development of instrumentation for the observational study of atmospheric winds; Bridge response to hurricanes; documentation of wind effects; workshop on wind effects; performance of tanks and industrial facilities during Katrina (2 projects); performance of underground structures during Katrina; response of submerged geotechnical systems and buried infrastructure (3 projects) reconnaissance studies (12 projects)
- Improving glass performance; response of tall buildings to straight line winds, response and repair of levee systems for Katrina
- Assessing risk for long-span bridges; determination of storm surge on levees; simulation of non-linear water waves during hurricanes; construction material requirements for rebuilding New Orleans
- Evaluating preferences for rebuilding plans post-Katrina; assessing public health impacts; decision making in displaced populations; Electric utility damage from Katrina; impact of Katrina and storm surge on human and built environment
- Developing tools for preparedness for hurricanes and wind storms (8 projects); response of Texas school systems to Katrina; emergency preparedness planning and on-line evacuation of large buildings;
- Development of instructional materials on disaster preparedness; Tracking Katrina: algebra project instructional materials using stories by displaced New Orleans students

NOAA

Although NOAA's role in Katrina was largely operational, many of its activities informed subsequent scientific investigations by other agencies.

- NOAA National Climatic Data Center provided storm meteorological data (rain, wind, and pressure) and social and economic impact data.
- Aircraft missions into Katrina, satellite images from various sources, tropical cyclone surface wind field analyses, radar data from aircraft and land-based stations.
- National Ocean Service provided water levels for Hurricane Katrina, including observed versus predicted water levels.
- The U.S. Army Corps of Engineers and NOAA completed a post-Hurricane Katrina, Charley, Frances, Ivan, and Jeanne 1-km resolution wind field analysis using the H*WIND product and data that were not available in real time.

- NOAA's Louisiana Sea Grant program has developed fact sheets that include information on building codes, where and how to rebuild, and how to determine if a contractor is following state and federal regulations. It has been distributed to parishes and is available on the Internet. The program has also sponsored seminars on storm preparedness and has provided information on building codes and zoning practices.

FEMA

- Conducted Mitigation Assessment Team (MAT) evaluations following Hurricanes Charlie and Ivan in 2004 and Hurricane Katrina in 2005
- Completed HAZUS-MH MR 1 and MR 2 releases; Ongoing Hurricane Evacuation Studies and Planning; conducted over 50 briefings on the results of the Hurricane Katrina MAT
- HAZUS Hurricane Module training to over 500 people; numerous presentations and speeches at conferences

Although the tragic toll of human life and property damage resulting from Hurricane Katrina and associated events is indisputable, it reveals the importance of collecting perishable scientific data in a timely manner. Expert observations and data collection during and immediately after such an event informs the research that is intended to reduce our vulnerability to wind-related hazards. The National Windstorm Impact Reduction Program agencies responded quickly and well to this scientific opportunity.

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