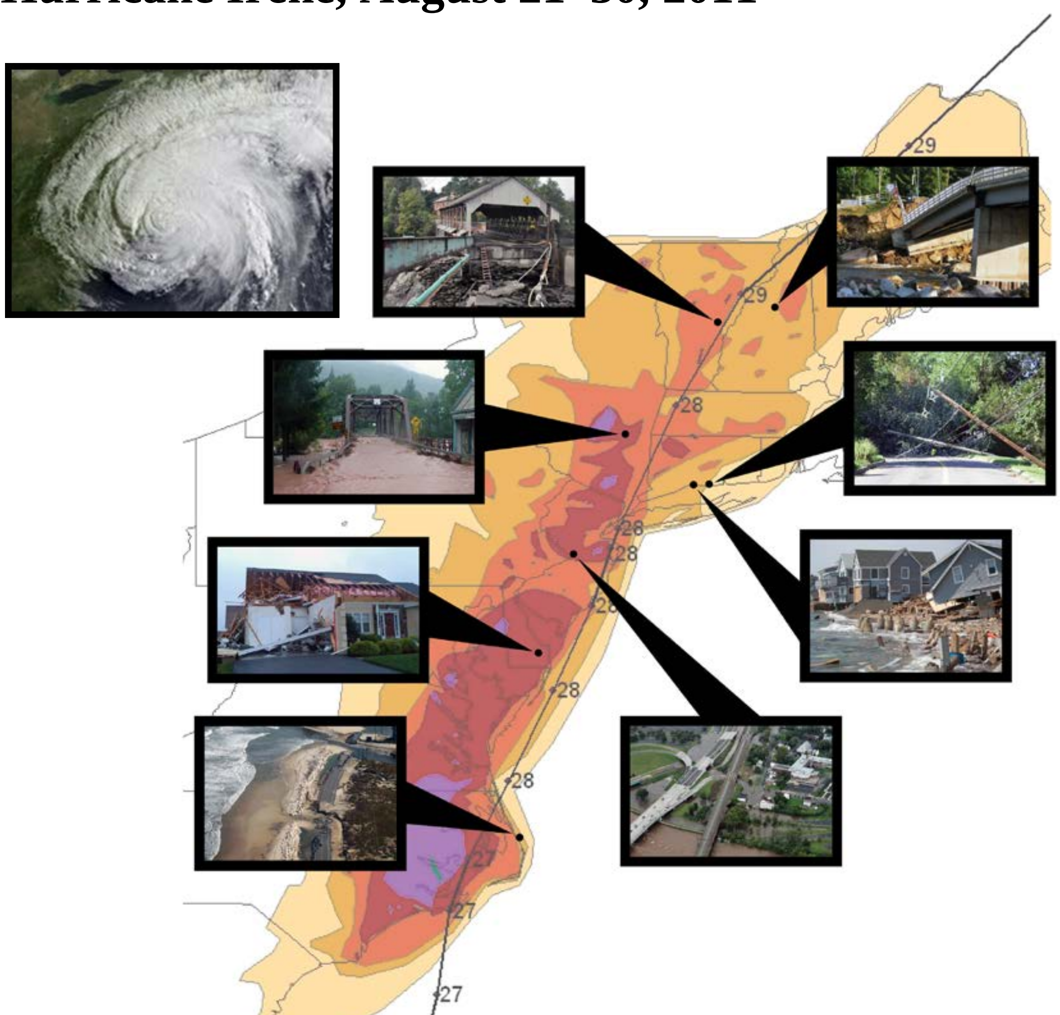
Service Assessment

Hurricane Irene, August 21–30, 2011



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover Photographs:

Top Left - NOAA GOES 13 visible image of Hurricane Irene taken at 12:32 UTC (8:32 a.m. EDT) on August 27, 2011, as it was moving northward along the east coast.

Map of total storm rainfall for Hurricane Irene (NCEP/HPC) overlaid with photos of Hurricane Irene's impacts. **Clockwise from top right:**

- Damage to bridge over the Pemigewasset River/East Branch in Lincoln, NH (NH DOT)
- Trees across road and utility lines in Guilford, CT (CT DEP)
- Damage to homes from storm surge at Cosey Beach, East Haven, CT (CT DEP)
- Flooding of Delaware River closes Rt. 29 in Trenton, NJ (State of New Jersey, Office of the Governor)
- Damage from storm surge on North Carolina's Outer Banks (USGS)
- Damage to home from an EF1 tornado in Lewes, DE (Sussex County, DE EOC)
- River flooding on Schoharie Creek near Lexington, NY (USGS)
- Flood damage to historic covered bridge and road in Quechee, VT (FEMA)

Service Assessment

Hurricane Irene, August 21–30, 2011

September 2012

National Oceanic and Atmospheric Administration
Dr. Jane Lubchenco, Administrator

National Weather Service
Laura Furgione, Acting Assistant Administrator for Weather Services

Preface

On August 21-29, 2011, Hurricane Irene left a devastating imprint on the Caribbean and U.S. East Coast. The storm took the lives of more than 40 people, caused an estimated $6.5 billion in damages, unleashed major flooding, downed trees and power lines, and forced road closures, evacuations, and major rescue efforts. The effects of Hurricane Irene were felt from the U.S. Virgin Islands and Puerto Rico to the Canadian Maritime Provinces, and as far west as the Catskill Mountains of New York. The storm produced widespread, devastating flooding in Vermont, New York, New Jersey, and parts of New Hampshire and damaging storm surge along the coasts of North Carolina and Connecticut. Hurricane Irene left 8 million people without power—some for as long as a week—and resulted in the closure of several major airports, the suspension of Amtrak train service, and the historic closure of the New York City mass transit system.

In response to the significant effects of the event, the National Oceanic and Atmospheric Administration formed a service assessment team to document and evaluate the performance and overall effectiveness of National Weather Service products and services, decision support, collaboration and communication, operational procedures, and preparedness activities. The NWS should thoroughly consider implementing the team’s recommendations as they are written; however, the organization may implement alternate solutions to resolve the findings and meet the intent of the service assessment team's recommendations. Alternate solutions may be implemented because they are, for example, more effective, more rapidly deployed, or less costly. The National Weather Service will use the findings and recommendations from this assessment to improve the quality of products and services, enhance awareness, and help guard the Nation against loss of life and property.

Kathryn D. Sullivan, Ph.D.
Assistant Secretary for Environmental
Observation and Prediction
Deputy Administrator
National Oceanic and Atmospheric Administration

September 2012

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Service Assessment Team

Dr. Kathryn Sullivan	Executive Sponsor, Assistant Secretary for Environmental Observation and Prediction, Deputy Administrator, NOAA
Dr. Frank Marks	Team Leader: NOAA Office of Oceanic and Atmospheric Research, Hurricane Research Division
Wes Browning	Technical Lead: Meteorologist in Charge, NWS Weather Forecast Office (WFO) St. Louis, MO
Dr. Vankita Brown	Social Scientist, NWS Office of Climate, Water, and Weather Services (OCWWS), Silver Spring, MD
Dr. Terri Adams-Fuller	Professor, Sociology, Howard University
Dr. Susan Jasko	Professor, Communication Studies, California University of Pennsylvania
Monica Allen	NOAA Public Affairs Specialist, Marine Fisheries
Sean Wink	NWS Systems Operations Division Chief, NWS Western Region Headquarters, Salt Lake City, UT
Aimee Fish	Meteorologist, Environmental and Scientific Services Div., NWS Alaska Region Headquarters, Anchorage, AK
John Gordon	Meteorologist in Charge, WFO Louisville, KY
Alan Haynes	Service Coordination Hydrologist, NWS California-Nevada River Forecast Center (RFC), Sacramento, CA
John Brost	Science and Operations Officer, WFO Tucson, AZ
Dr. William Hooke	Senior Policy Fellow and Director, American Meteorological Society, Washington, D.C.
Ray Tanabe	Meteorologist in Charge, WFO Honolulu, HI/Director, Central Pacific Hurricane Center, Honolulu, HI
Dr. Scott Lindsey	Service Coordination Hydrologist, Alaska-Pacific RFC, Anchorage, AK
Mike Clay	Chief Meteorologist, Bay News 9, Tampa, FL
Dr. John G.W. Kelley	Meteorologist, National Ocean Service/Coast Survey Development Lab, Durham, NH
John Winkelman	Coastal Engineer, U.S. Army Corps of Engineers
Rick Dittmann	Meteorologist in Charge, WFO Pocatello, ID

Other valuable contributors:

David B. Caldwell	Director, OCWWS, Silver Spring, MD
Douglas C. Young	Chief, OCWWS Performance Branch, Silver Spring, MD
Salvatore Romano	Evaluation Meteorologist, OCWWS Performance Branch
Melody Magnus	Technical Editor, ERT, Inc., OCWWS Performance Branch

Executive Summary

Hurricane Irene left a devastating imprint on the Caribbean and U.S. East Coast in late August 2011. The storm took the lives of more than 40 people, caused an estimated $6.5 billion in property damages, unleashed major flooding, downed trees and power lines, and forced road closures, evacuations, and major rescue efforts. The effects of Irene were felt from the U.S. Virgin Islands and Puerto Rico to the Canadian Maritime Provinces and as far west as the Catskill Mountains of New York. The storm produced widespread, devastating flooding in Vermont, New Hampshire, New York, and New Jersey and damaging storm surge along the coasts of North Carolina and Connecticut. It left 8 million people without power, some for as long as a week, resulted in the closure of several major airports, the suspension of Amtrak train service, and the historic closure of the New York City mass transit system.

Hurricane Irene tested the technical, human, and psychological resilience of citizens, emergency response organizations, decision makers, and the hydrometeorological capabilities of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) personnel. The National Hurricane Center forecasted the track, landfall, and progress of Irene accurately and worked successfully with federal, state, and local emergency management (EM) partners to warn and protect those in the storm's long path. NWS staff, in its coastal offices along Irene's track, worked in close partnership with emergency agencies to deliver accurate, clear, and compelling forecasts, watches, and warnings. The service assessment team found, however, that the threat of historic inland flooding, which resulted in the majority of fatalities with Irene, would have been more clearly conveyed had NWS forecasters used an impact-based warning approach to deliver the warning message. This service deficit has been noted in previous Service Assessments.

As part of the NWS mission to safeguard life and property through continuous improvement, NOAA formed a service assessment team to evaluate the strengths and weaknesses of NWS performance during this event. The service assessment team found performance excellence and innovation but also discovered:

- Gaps in technological capacity
- Potential for significant gaps in service
- Need for increased use of social and mobile forms of media
- Growing demand for geographical information system (GIS)-compatible products and services
- Issues working with broadcast media
- Need to improve partnerships with non-NOAA groups

Investments in outreach and partner relationships yielded meaningful payoffs by spurring responses to safeguard lives and property across a vast area of the Eastern Seaboard. Placing meteorologists in various EM operations centers gave responders timely, customized information and analysis. This information, in turn, enabled partners to make decisions with greater confidence, safeguarding lives and property. Hurricane Irene was one of the first natural disasters in which the NWS used social media extensively to communicate with the public, media, and others. In some cases, the NWS launched these communication tools to convey Irene's impacts. The public, media, and responders praised the timeliness of vital information disseminated in these creative ways, including on Twitter, Facebook, and in chat rooms (NWSChat).

As communications outlets grow more varied and complex and NWS's scientific and technological capability increases, the NWS adapted to best serve its users. An increasing number of public and private agencies and businesses rely on NWS expertise to prepare and mitigate weather impacts. The NWS Weather-Ready Nation initiative reflects the shift in scope and approach of NWS efforts needed to keep up with users' growing demands for its services. This shift will require the use and incorporation of both social science and social scientists because these changes should occur at all levels and across the entire organization.

This report identifies 24 best practices and 86 recommendations based on the service assessment team's findings. The NWS definitions along with a full list of the best practices, findings, and recommendations are in Appendix B. In particular, the team recommends key ways to address gaps in NWS workforce skills, infrastructure, communication modes, and technical capabilities to help NWS create a more Weather-Ready Nation. These recommendations are classified as **operational**, resolvable in the near-term. In addition, the team created **strategic** recommendations, which will likely require substantial time and resources to address. These strategic recommendations, based on experiences during the assessment, are an effort to assist the NWS in achieving its goals and vision as detailed in the Weather-Ready Nation, NWS Strategic Plan 2011 and the Weather-Ready Nation Roadmap. Overarching findings and recommendations that assist in achieving these NWS goals and vision are as follows:

1. **Inundation (Inland and Coastal):** Inland flooding has been and will continue to be a major and deadly impact of hurricanes yet, during Irene, NWS did not clearly convey the threat for historic flooding and its associated catastrophic impacts. In many cases during Irene's record-breaking floods in New England, the change in river levels was dramatic in both longevity and magnitude. The observed sudden and tremendous increases in river stages in the 2–3 hour timeframe were more characteristic of flash flooding in small streams than expected behavior from main stem rivers. NWS should improve how it communicates the risk of inland flooding and educate the public, media, and EMs on that risk. NWS should communicate storm surge information much more clearly and succinctly with a focus on impacts. Graphical depiction of inundation due to inland and coastal flooding is essential to addressing partner and user needs.

2. **Decision Support Services:** Decision support services were one of the most successful NWS activities during Irene. NWS staff embedded in emergency operations centers were *universally praised* for their consistent, authoritative, and neutral message. The effective communication of risk should extend not only to local authorities, but also to state and national levels of government and the public. Future products and services provided by the NWS should be interactive, Web-based, user-friendly, and contain societal impacts verbiage to articulate clearly the severity and urgency of the hazard. NWS should also develop a protocol for building, sustaining, and evaluating working relationships among NWS's embedded meteorologists/liaisons, Weather Forecast Offices, and River Forecast Centers. This protocol should include face-to-face visits to build trust and a clear understanding of the work demands and needs of each entity.

3. **Training/Hiring:** NWS should ensure those who brief government partners, especially those at the highest levels of government, have the necessary skill set and training to communicate effectively while operating in an Incident Command System setting. Working with the academic community, the NWS should focus recruitment and hiring efforts to ensure that the same skill set is present in its future workforce. Despite the significance of hurricane impacts, there is a lack of operational experience working tropical cyclone events. This is particularly true of forecasters at inland and coastal offices that have longer tropical cyclone return periods. Periodic training is essential to maintain needed tropical cyclone operational skills. NWS should fully fund a comprehensive Professional Development Series on tropical cyclones.

4. **Quality and Availability of Data:** NWS should operate and maintain a partnership with government agencies to ensure a mutually beneficial, technologically current, and resilient observational network. NWS should continuously enhance its numerical analysis and prediction modeling systems, including the improved use of observations, in collaboration with partners. NWS should also continuously increase its computational capacity to enable the development and operation of future forecast modeling systems. NWS will rely on all three components to empower forecasters with the necessary observations and forecast guidance, including estimates of uncertainty, needed to deliver impact-based weather services. NOAA and NWS should continue to support research and development in the areas of improved satellite observations of surface winds and experimental model guidance for impacts, such as those developed by the Hurricane Forecast Improvement Project and under the NOAA Storm Surge Roadmap.

5. **Resilience:** If the NWS cannot provide services when most needed, it fails as an organization. The NWS office backup plan is fragile during geographically large events. During Irene, all primary and secondary backup offices were impacted simultaneously while providing both expanded Decision Support Services and traditional services. OPSNet, the primary communications system for the NWS, has insufficient bandwidth to support NWS activities during a high-impact event.

6. **Safety/Infrastructure:** NWS forecast offices are expected to remain operational during even the most extreme weather events. During Irene, forecast office staff operated in facilities neither designed for, nor adequately equipped to, shelter in place for 72 hours. In general, offices are not adequately prepared to provide staff a restful environment and food for 72 hours. In addition, the complexity of Irene's impacts nearly exceeded the capacity of the office workstation configuration. Several affected forecast offices did not have enough workstations to accommodate the increased staffing necessary for all critical functions.

1. Introduction

1.1. NWS Mission

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure that can be used by other governmental agencies, the private sector, the public, and the global community.

1.2. Purpose of Assessment

NWS envisions a Weather-Ready Nation (WRN) in which society is prepared for and responds to weather-dependent events as an integral part of national security. A new NWS Strategic Plan, published July 1, 2011, lays out anticipated service needs and requirements in science and technology, as well as setting meaningful goals and objectives that define a WRN. To achieve a WRN, the NWS is creating the *NWS Weather-Ready Nation Roadmap* that lays the foundation for future NWS services. This Roadmap creates a practical guide to making this vision a reality.

This long-term WRN goal is especially critical as America becomes increasingly vulnerable to high-impact events. As NWS looks to the future, assessment of its performance during high-impact events provides a key role to achieving these goals and objectives.

With this precept in mind, Dr. Kathryn Sullivan, NOAA Assistant Secretary for Environmental Observation and Prediction, commissioned a Service Assessment of NWS performance during Irene. This Service Assessment summarizes the event, documents operational best practices, and provides recommendations for improved services and support from multiple layers of NOAA and the NWS. Recommendations are classified as either **operational**, ones that may be resolvable in the near-term, or **strategic**, those that will likely require substantial time and resources to address. These strategic recommendations, based on experiences during the assessment, are an effort to assist the NWS achieve its goals and vision as detailed in the Weather-Ready Nation, NWS Strategic Plan 2011 and the Weather-Ready Nation Roadmap.

1.3. Methodology

The Hurricane Irene service assessment team assembled to evaluate NWS service on August 21-30, 2011. **Figure 1** depicts the 14 NWS Weather Forecast Offices (WFOs) and 3 River Forecast Centers (RFCs) covered by this Service Assessment. Because of the vast area requiring fieldwork, the team divided into five subteams:

- Team 1: New York (excluding New York City), Massachusetts, Rhode Island, New Hampshire, and Vermont
- Team 2: New York City, Connecticut, New Jersey, Delaware, and Pennsylvania

- Team 3: Virginia and North Carolina
- Team 4: Washington, D.C., Maryland, and Puerto Rico
- Team 5: National Hurricane Center (NHC)

The majority of the fieldwork occurred in one week. The team visited all affected WFOs except WFOs Gray and Caribou, ME; Binghamton, NY; and San Juan, PR. Staff members in those offices were interviewed by phone. The team also interviewed staff from the National Centers for Environmental Prediction (NCEP), including the Ocean Prediction Center (OPC), Environmental Modeling Center (EMC), NCEP Central Operations (NCO), Hydrometeorological Prediction Center (HPC), and National Hurricane Center (NHC); the Center Weather Service Unit (CWSU) in New York; NWS Eastern Region Headquarters (ERH); and NWS Headquarters (NWSHQ). The team interviewed local, state, and national governmental staff and Emergency Managers (EM), some of whom received direct decision support services through deployed meteorologists. In total, the team conducted more than 250 interviews.

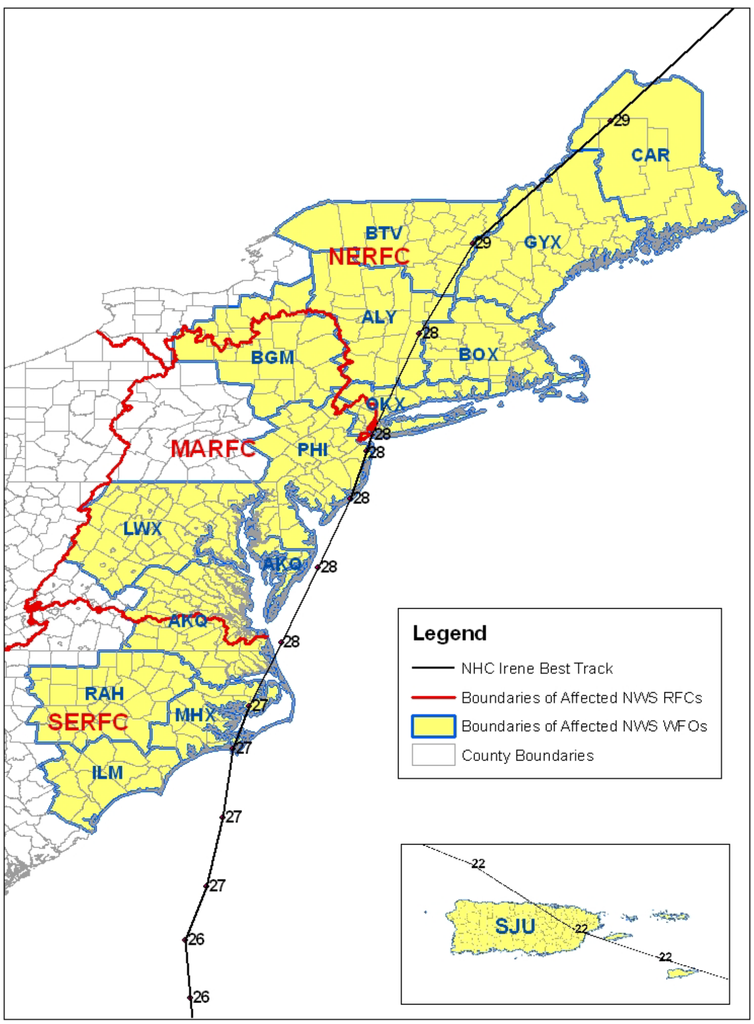

Figure 1: Irene track, affected WFOs (yellow shading), and approximate RFC boundaries (red outline)

1.4. Social Science and Communication Issues

Social scientists on this assessment team worked side-by-side with other team members, participating in a wide range of briefings, interviews, and site visits. Consequently, many recommendations in this report incorporate social science and meteorological perspectives.

This team brought a multidisciplinary perspective to every aspect of the assessment process, including the organization of subteams, analysis of information, group discussions, and composition and editing of this document.

As a result, issues that have risen to the top of the list generated by the team are broad and multifaceted, entailing changes in NWS and NOAA. This report examines concerns revolving around communication, the organizational climate, and the culture of NOAA and the NWS; the scope of WRN; and the financial, political, and social factors that influenced mission and operations.

2. Summary of Hydrometeorological Event

2.1. Antecedent Conditions

In the weeks before Irene, heavy rains in Puerto Rico and over the northeastern mainland United States resulted in high soil moisture content over much of the area. In Puerto Rico, Tropical Storm Emily produced up to 6 inches of rain on August 2–4, leaving the ground saturated. In New Jersey, observed rainfall from August 1–26 ranged between 8 inches and 16 inches, in a band from the southwest through the central part of the state. In the days preceding Irene, areas from New Jersey northward into Vermont had soil moisture ranking in the 90th percentile compared to long-term averages over the same period (**Figure 2**). In both Puerto Rico and the continental United States, these antecedent conditions set the stage for rapid runoff of heavy rain as Irene approached the region. Saturated soils also contributed to the large number of trees uprooted by Irene's winds, especially in New England.

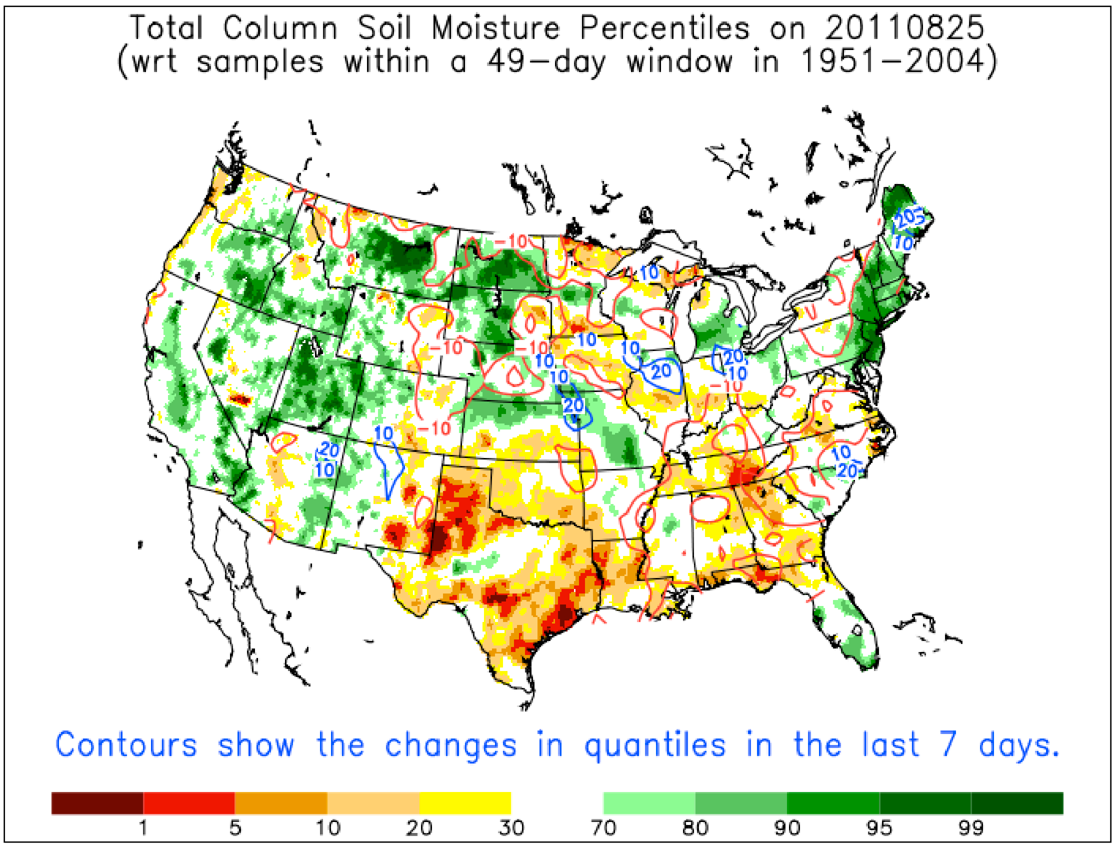

Figure 2: Shown above are Total Soil Moisture percentiles as of August 25, 2011. Note very moist area from New Jersey into Maine. (Courtesy of Princeton University Land Surface Hydrology Research Group)

2.2. Track and Intensity

A post-storm analysis of Irene's track and intensity is shown in **Figure 3**. At 7 p.m. Eastern Daylight Time[1] on August 21, an Air Force Reserve Hurricane Hunter aircraft investigating a tropical wave east of the Lesser Antilles found tropical storm force winds. The wave became Irene. Over the next week, Irene made four landfalls: Puerto Rico, North Carolina, New Jersey, and New York. Only the North Carolina landfall was a hurricane landfall; the other three landfalls were as a tropical storm. Irene reached peak intensity of 115 mph, Category 3, on August 24, as the storm tracked through the Bahamas. Winds weakened as the storm approached North Carolina, where it made landfall at 7:30 a.m. on August 27 near Cape Lookout, NC, as a Category 1 hurricane. Maximum winds gradually weakened to tropical storm force as the storm neared New Jersey, where a third landfall occurred near Little Egg Inlet, NJ, at 5:30 a.m. on August 28. During this period, torrential rains extended inland up to 100 miles from eastern North Carolina northward to eastern Pennsylvania, bringing record flooding to heavily populated areas in New Jersey.

Shortly thereafter, Irene made landfall near Coney Island, Brooklyn, NY at 9:00 am on August 28, and then moved over New York City about 1 hour later. Irene lost tropical characteristics during the evening of August 28 as it tracked across Vermont; however, torrential rains continued to fall during this time, resulting in devastating flash flooding across mountain valleys in eastern New York, Vermont, and northern New Hampshire

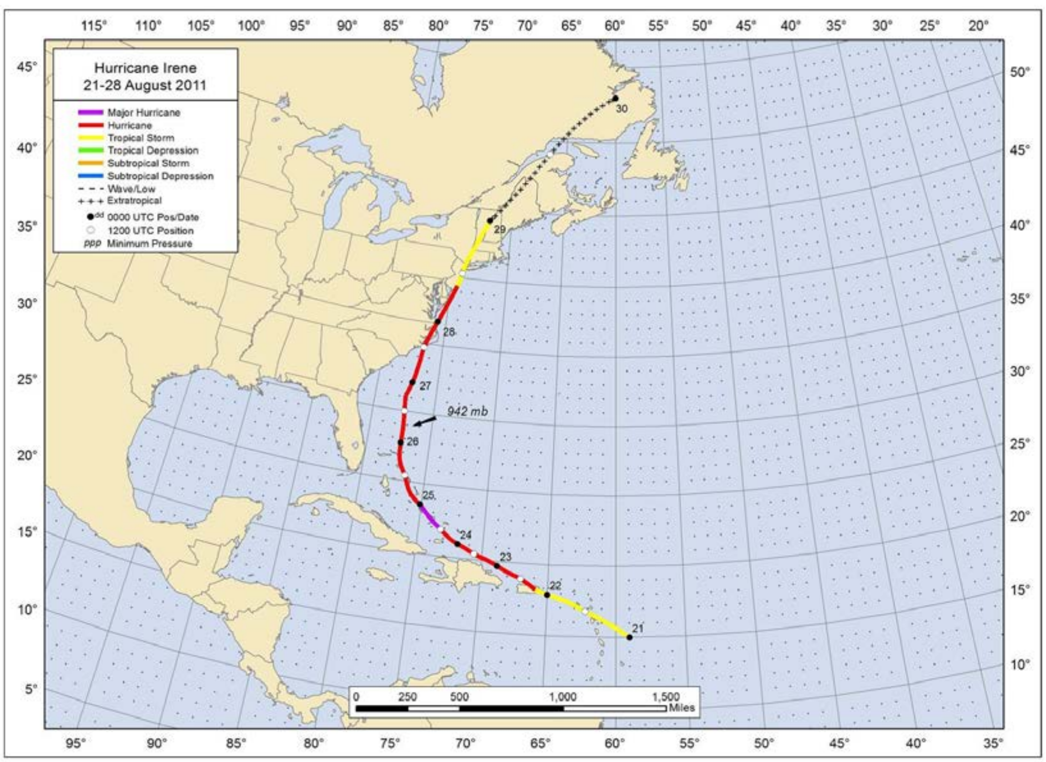

Figure 3: Post-storm analysis of track and intensity of Irene (best track).

[1] All times referenced through the remainder of the document are in Eastern Daylight Time

2.3. Wind

Irene brought winds of at least tropical storm force from the U.S. Virgin Islands to Maine (**Figure 4**). While NWS did not record hurricane force winds during the first landfall in the Caribbean, terminal Doppler radar in San Juan showed winds over hurricane force only 500 feet above the surface of the ocean, just northeast of the city. The wind estimates are not representative in mountainous terrain where small-scale accelerations cannot be resolved. The wind analyses are research products created by the H*WIND team at NOAA's Hurricane Research Division of Atlantic Oceanographic and Meteorological Laboratory. For more information on H*WIND see http://www.aoml.noaa.gov/hrd/data_sub/wind.html.

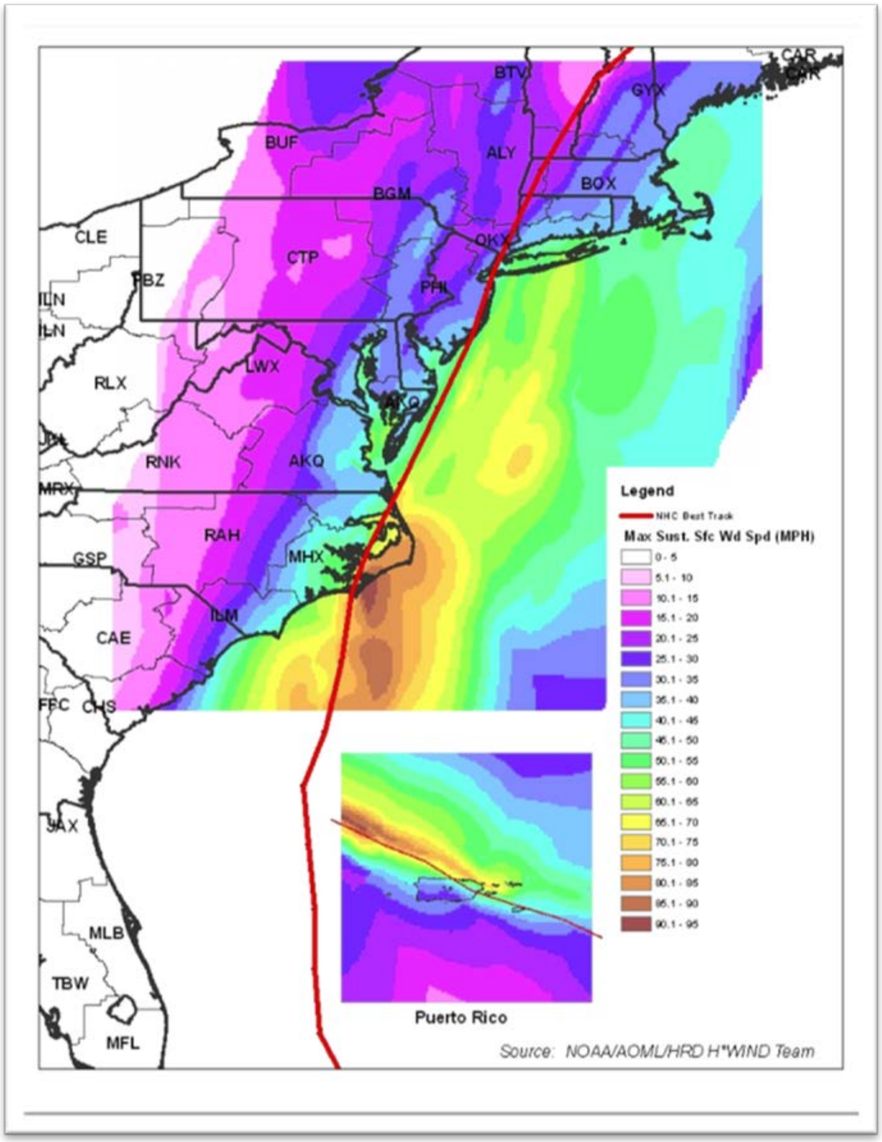

Figure 4: Maximum sustained (1 minute average) surface (10 m AGL) winds (MPH) for an open exposure experienced during Irene over Puerto Rico and U.S. Virgin Islands and the U.S. East Coast.

When Irene made a second landfall near Cape Lookout, NC, it brought sustained hurricane force winds to the Outer Banks. Wind gusts exceeded hurricane force over much of the coastal area near Pamlico and Albemarle Sounds, NC. Tropical storm force wind gusts were common over the remainder of the eastern half of the state.

The large wind field of Irene spread well inland as the storm's center moved northward just offshore of the Delmarva Peninsula. Tropical storm force wind gusts occurred over much of Northern Virginia and in all but the westernmost counties of Maryland. Gusts to near hurricane force occurred over the Chesapeake Bay. Wind gusts of 45–55 mph were common in Washington, D.C.

Irene made its third landfall near Little Egg Inlet, NJ, as a tropical storm. Hurricane-force wind gusts were recorded a short distance away in Cape May, NJ. Tropical storm force wind gusts occurred over all of Delaware, New Jersey, and easternmost Pennsylvania.

The fourth and final landfall of Irene brought widespread tropical storm force winds to the NYC and Boston metropolitan areas. Wind gusts in excess of hurricane force occurred north of Levittown, on Long Island, NY, at Conimicut Lighthouse, RI, on Narragansett Bay, and at Blue Hill Observatory in Milton, MA. A localized area of intense winds (microburst) occurred at Sayville on Long Island, NY, where a 91 mph wind gust was recorded. Maximum wind gusts in NYC ranged from 60 to 70 mph.

Tornadoes occurred in North Carolina, Virginia, Delaware, and New York during Irene. One EF2 and two EF1 tornadoes occurred in North Carolina, two EF0s in Virginia (Sigma and Chincoteague), one EF1 in Lewis, DE, and two EF0s on Long Island, NY (Glen Oaks and Babylon).

2.4. Storm Surge

As Irene passed over Puerto Rico on August 22, the maximum observed storm surge along the coast of Puerto Rico and the U.S. Virgin Islands ranged generally from 0.4 to 1.5 feet. The maximum storm surge was 1.6 feet at the National Ocean Service (NOS) National Water Level Observation Network (NWLON) real-time observing still-water station at Fajardo, PR.

On August 27, as Irene made landfall on the southern North Carolina coast (**Figure 5**), moved over the Outer Banks, and re-emerged over the Atlantic Ocean near Norfolk, VA, storm surge ranged from 2.5 to 7 feet along the North Carolina coast. The highest storm surge measured at the NOS gage was 7.1 feet at the Oregon Inlet Marina, NC, at 0354 UTC August 28, with a peak storm tide (surge plus astronomical tides) of about 7 feet (NAVD88). Peak storm-tide data from U.S. Geological Survey (USGS) temporarily deployed sensors and USGS post-storm high-water-mark data indicated *peak storm tides* ranging from 7 to 12 feet along the lower Neuse River and 6.6 to 9 feet along the lower Tar River. These peak-storm tides likely included storm-induced runoff from the Neuse and Tar River Basins due to the heavy rainfall during Irene.

On August 28 as Irene moved parallel to the mid-Atlantic Coast storm surge generally ranged between 3.3 to 4.5 feet along the eastern Maryland, Delaware, and New Jersey coasts with the highest reported storm surge 4.7 feet at Sandy Hook, NJ. In the Chesapeake Bay, storm surge ranged from 2.5 to 4.9 feet along the southern Bay. The highest values were near the bay mouth and only 1 to 2.5 feet in the northern half. A storm tide of 6.6 feet (NAVD88) was recorded at Money Point, VA. In the Delaware Bay and River, water residuals at NOS stations included storm surge and abnormally high river flow due to storm-induced runoff in the Delaware River Basin. Water residuals ranged from 2.9 to 8.8 feet.

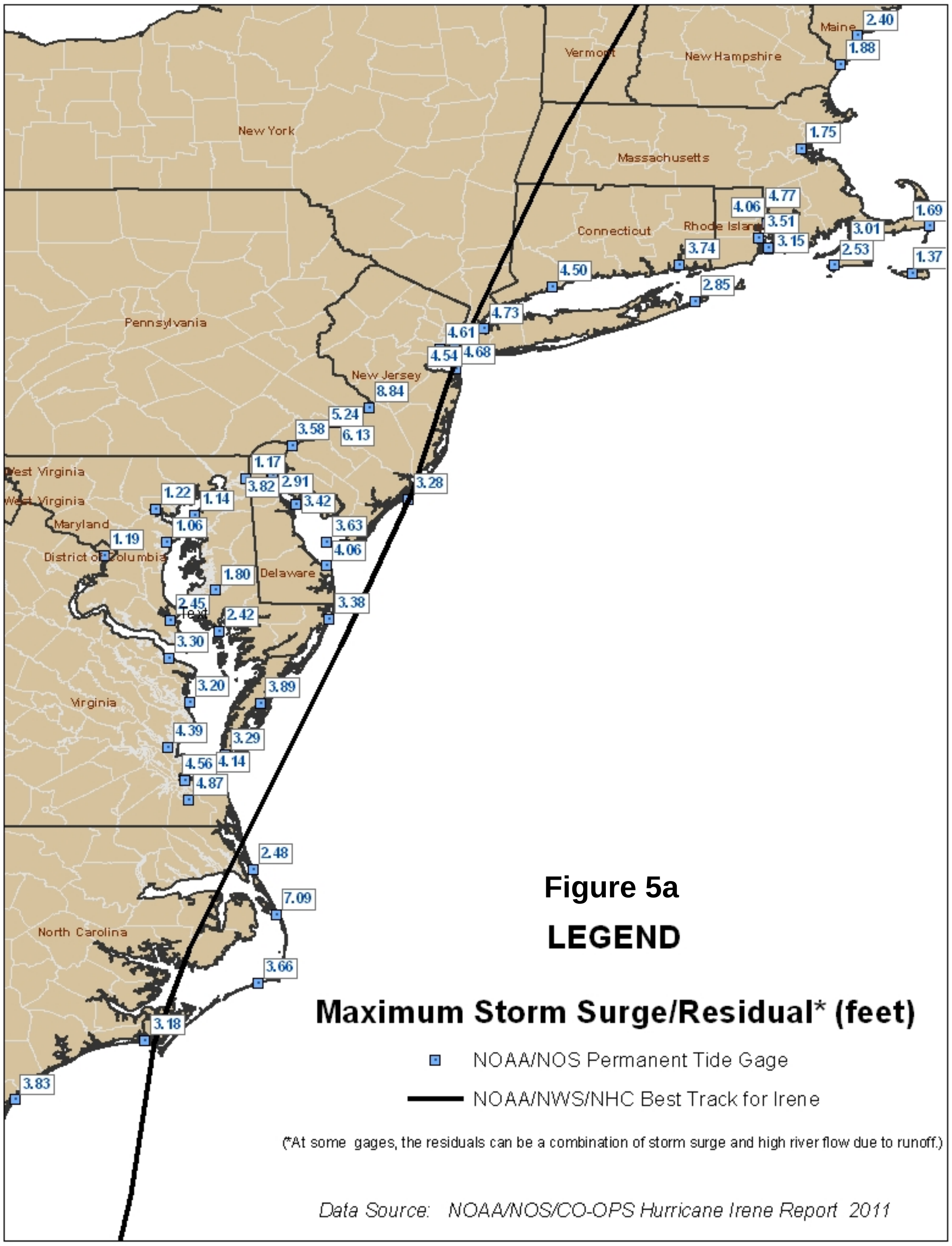

Figure 5a

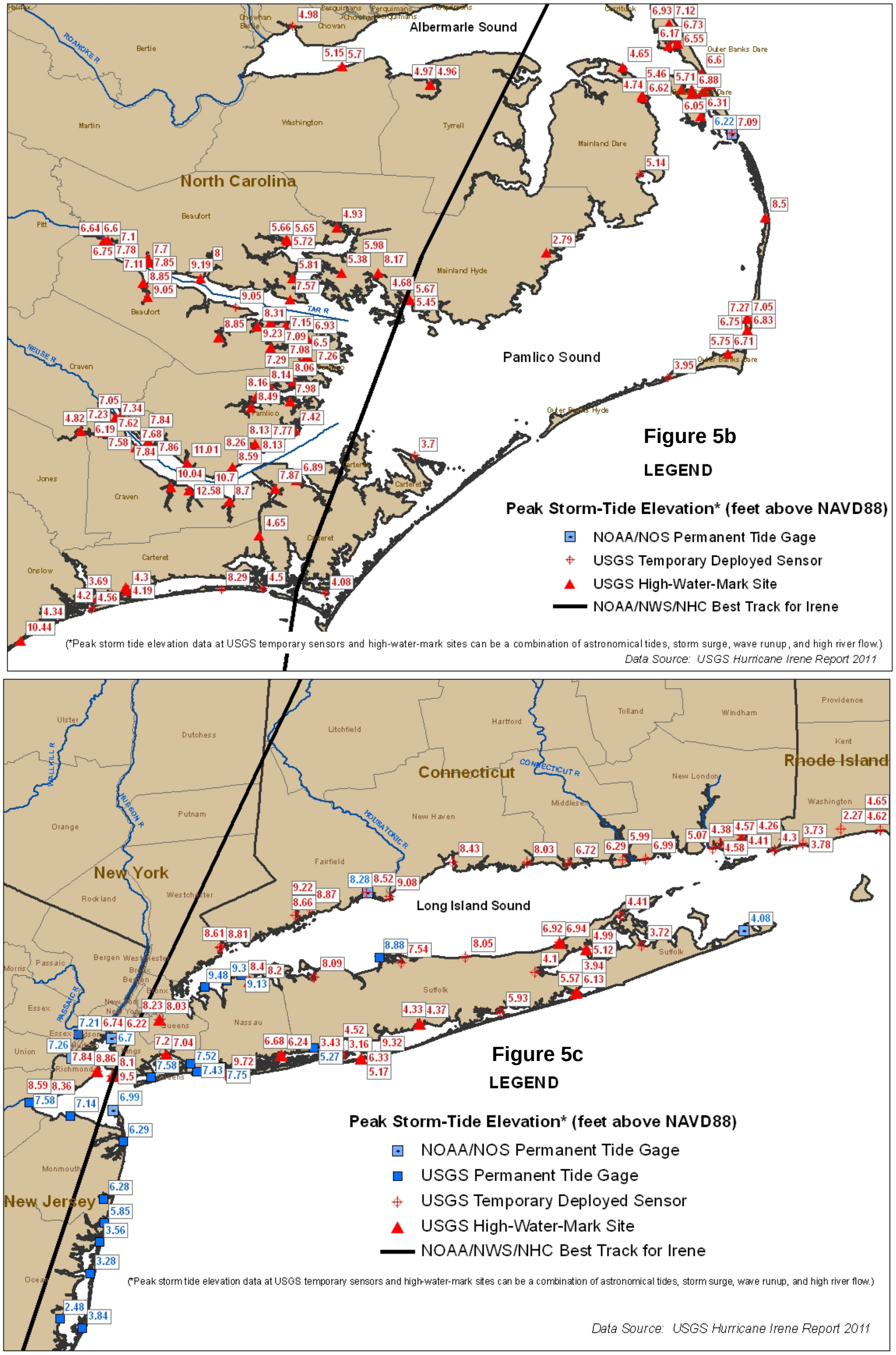

Figure 5: **(a)** Maximum storm surge/residual (feet) recorded at NOAA/NOS Center for Operational Oceanographic Products and Services (CO-OPS) and partners real-time water level observing stations (tide gages) from North Carolina to southern Maine. **(b)** Peak Storm-Tide Elevations (feet above NAVD88) for part of coastal North Carolina and **(c)** portions of the coastal area from New Jersey to Rhode Island

As Irene made its final landfall just to the east of New York City (NYC) on August 28, there was a storm surge of 4.5 feet at The Battery and a storm tide of 6.7 feet (NAVD88). Along the Connecticut and Rhode Island coasts, storm surge values ranged from 2 to 4.8 feet with storm tides of 4.5 to 8.2 feet (NAVD88). Additional storm surge and storm tide data for Irene are available in NOS and USGS reports at the following URLs respectively:

http://tidesandcurrents.noaa.gov/publications/Hurricane_Irene_Water_Level_and_Meteorological_Data_Report.pdf and http://pubs.usgs.gov/of/2012/1022/

2.5. Rainfall

Figure 6 shows cumulative rainfall over the mainland United States during Irene. Localized totals of more than 10 inches were recorded in Connecticut and New York. Note the swath of 5–10 inches from New Jersey into Vermont. This is the area shown in **Figure 2** having high antecedent soil moisture.

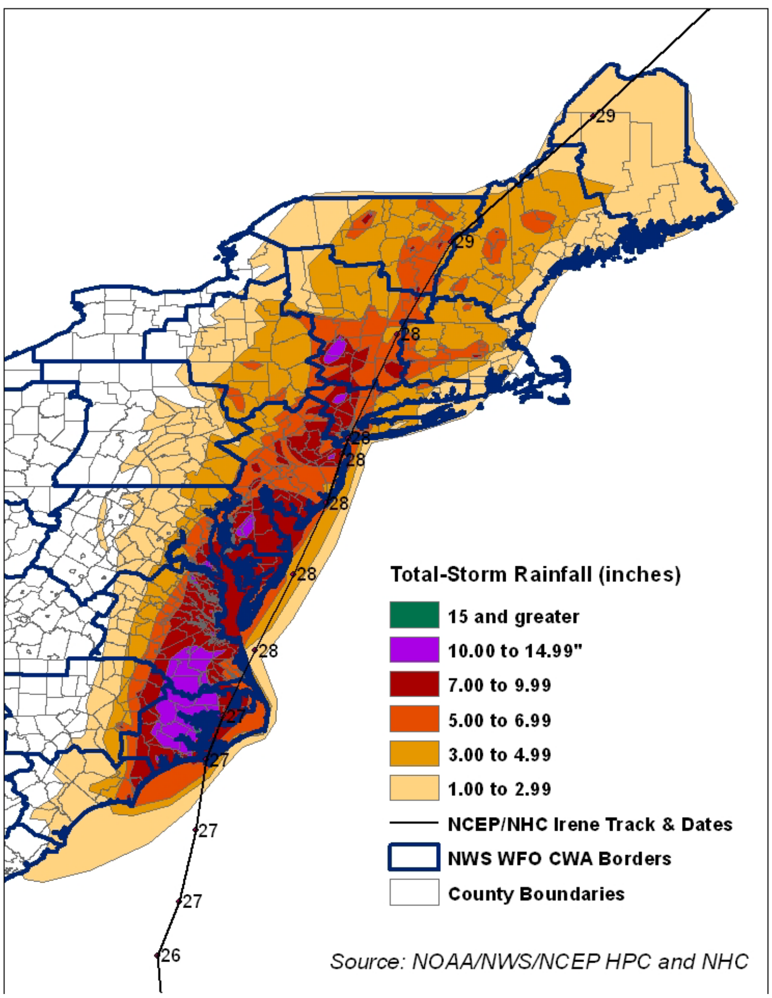

Figure 6: Cumulative observed rainfall during Irene from August 24-30, 2011. Black line shows NHC observed track.

Figure 7 shows 3-day rainfall totals over Puerto Rico. Up to 22 inches of rain fell in the eastern part of the island, the same area that received more than 6 inches of rain from Tropical Storm Emily earlier in August.

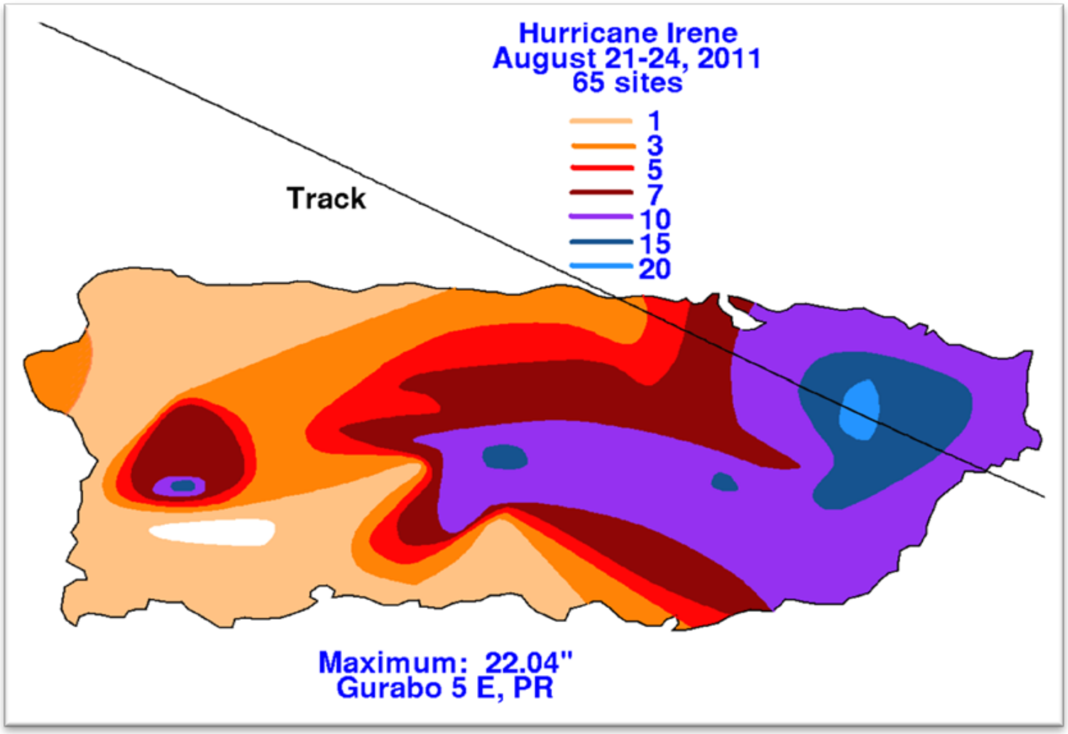

Figure 7: Total rainfall during Irene over Puerto Rico. Black line shows NHC observed track.

3. Impacts

Irene caused 45 deaths from Puerto Rico to Maine. Of that number, 41 were directly related to the storm and 4 were considered indirect deaths. More than half the deaths, 23, were the result of drowning from inland flooding. Wind caused 12 fatalities, primarily via falling trees; and waves and surge, the remaining 6.

3.1. Damage

Irene's most damaging impact was from rainfall**.** Irene's rains caused devastating flash flooding across many mountain valleys in eastern New York, Vermont, and northern New Hampshire, with dozens of record-breaking flood stages on larger rivers. This flood event likely will rank second only to the November 1927 flood in its impacts, with nearly 2,400 roads, 800 homes and businesses, 300 bridges (including historic covered bridges) and a half dozen railroad tracks destroyed or damaged from the flooding in Vermont. Three towns in the Catskill Mountains of New York were uninhabitable after the floods.

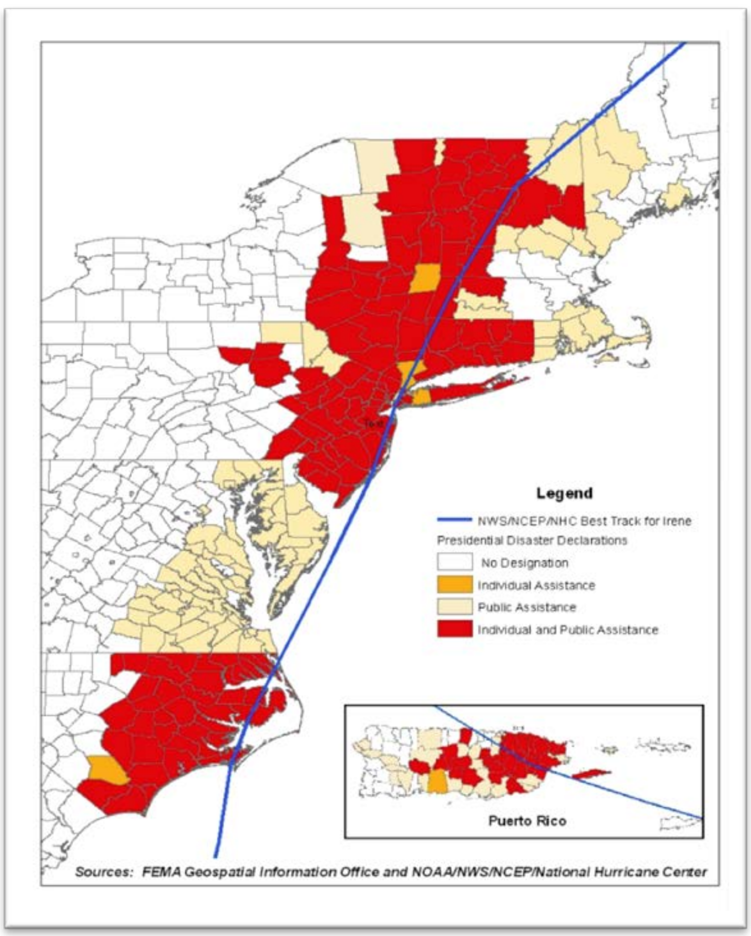

Figure 8: Map depicting the track of Irene along with counties and municipalities included in presidential major disaster declarations.

Damage from flooding caused by rains was also extensive across Puerto Rico and was severe near Gurabo Abajo, PR. In the mainland United States, Irene caused widespread damage to homes and extensive power outages from North Carolina to New England. **Figure 8** depicts major disaster declarations due to the impacts from Irene. In North Carolina, the storm surge from Pamlico Sound to the ocean damaged Highway 12, creating several breaches. The most severe storm-surge damage occurred between Oregon Inlet and Cape Hatteras, NC, but significant storm surge damage also occurred along the southern Chesapeake Bay. In the Hampton Roads, VA area and along coastal sections of the Delmarva Peninsula from Ocean City, MD, southward, flooding from storm surge was comparable to that from Hurricane Isabel of 2003. In New Jersey and eastern Pennsylvania, Irene produced torrential rains resulting in major flooding and many record-breaking crests on rivers. In New Jersey, six dams failed because of the storm. A storm surge of 3–5 feet along the New Jersey shore caused moderate to severe tidal flooding with extensive beach erosion. The Oyster Creek nuclear power plant, on the Atlantic coast south of Toms River, NJ, was shut down as a precautionary measure. Atlantic City closed its casinos for only the third time since gambling was legalized there in 1978 due to the storm.

NYC escaped severe wind-related damage because Irene's strongest winds were over water east of the path's center. Nonetheless, a storm surge of 3–6 feet caused property damage in NYC, as well as damage in Long Island and parts of the Connecticut coastline. Tropical storm force winds, along with heavy rains, resulted in power outages for up to 3 million residents for up to a week, mainly across Connecticut and Long Island.

Irene caused damage to farms and crops from North Carolina to New Hampshire with the U.S. Department of Agriculture designating many counties as primary natural disaster areas. Some of the most severe impacts occurred in upstate New York and Vermont where Irene destroyed farmers' homes and barns, crops flattened or submerged, and killed livestock. New York's Governor estimated agricultural losses in the state at least $45 million. In Vermont, over 450 farms were impacted and over 9,000 acres of farmland were damaged. According to its 2011 assessment of natural catastrophes, Munich Re estimates that Irene and associated inland flooding resulted in $6.5 billion in total losses in the United States. Of this amount, $5 billion were insured losses.

3.2. Transportation

Irene severely impacted transportation in the heavily populated corridor from Washington, D.C., to Boston. Air, train, bus, and subway systems shut down across NYC as Irene approached. In advance of Irene, all three NYC area airports closed to arrivals at noon on Saturday, August 27. The last departure from Newark Liberty International Airport occurred at 1:30 p.m., and the last departure from John F. Kennedy (JFK) International Airport was at 7:30 p.m. Newark and JFK airports opened for arrivals at 6:00 a.m. and for departures at noon on Monday, August 29. LaGuardia airport reopened at 7:00 a.m. on August 29. Transportation was also disrupted at Philadelphia International Airport, which closed at 9:25 a.m. on Sunday, August 28, and reopened at 3:53 p.m. on Sunday, August 28. A flight tracking company, FlightAware, estimated 11,800 flights were cancelled because of Irene, grounding approximately 650,000 travelers.

Irene was the first natural disaster to close the NYC subway system. All service was suspended late Saturday, August 27, and did not fully resume until Monday, August 29.

All Greyhound Bus service was cancelled between Richmond, VA, and Boston, MA, during the entire weekend. AMTRAK began reducing train service across much of the Mid-Atlantic and Northeast on Saturday, August 27, and cancelled all trains in the D.C. to Boston corridor on Sunday. Service was not restored in the heavily traveled Philadelphia to New York corridor until Wednesday, August 31, because of flooding on the tracks. In Vermont, much of the state's highway and town road infrastructure was severely crippled with communities isolated for days. In New Jersey, 350 roads were closed during the height of the storm; a stretch of Interstate 287 was washed out by the Rockaway River. In North Carolina, more than 270 roads and 21 bridges were closed due to flooding, debris, and damage.

In addition to impacts on transportation, some nuclear power plants along the east coast reduced their power output in preparation for Irene to ensure electric grid stability. Nuclear power plants in North Carolina, New Jersey, Pennsylvania, and Connecticut reduced output by 3 percent to 50 percent. During Irene, the Calvert Cliff 1 plant in Maryland shut down automatically when a transformer was struck with airborne debris late Saturday, August 27.

4. Coordination/Collaboration

During high-impact weather events such as Irene, partnerships are essential among the various offices and units of NWS as well as with other federal, state, and local entities. These partnerships are built and sustained through coordination and collaboration among NWS personnel. NWS staff works with partners to ensure they understand NWS products. NWS personnel serving in liaison positions are critical to the establishment and maintenance of strong, flexible, productive, and collaborative relationships; however, during Irene it was clear from our interviews that in a few situations meeting the needs and expectations of a complex and varied group of federal, state, and local decision-support partners was a challenge. NWS's ability to adapt successfully to such challenges is contingent on its capacity to collect better data, to process that data more quickly and reliably, and to communicate current and forecast conditions and their impacts more effectively, especially to users who rely on that data for decision making during high-impact events such as Irene.

The next stage in successful NWS adaptation requires the creation of a more user-driven information platform in which individuals can create customized services primarily through digital media and on mobile devices. This new generation of NWS products and services should be adapted to the needs of a range of key decision-support partners. This assessment determined key areas for improvements in NOAA and NWS decision-support services.

4.1. Internal

4.1.1. NWS and Other NOAA Offices

During Irene, NOAA's Incident Command Center was co-located with the NWS National Operations Center (NOC). Standard NOC protocol provides a flexible pool of 9 NWSHQ employees on 16-hour shifts. These shifts were expanded first to 20 hours on August 24 as Irene approached the East Coast, and then to 24/7 on Saturday, August 27, continuing through Sunday, August 28. The NOC prepared slide presentations for Command Center briefings to senior NOAA management and provided 24-hour support to NOAA and NWS Public Affairs. NOAA Legislative Affairs also used these slide presentations to brief Congress. Reuse of these presentations freed WFO and RFC staff to focus on other partners.

The success of the NOC during Irene illustrated the need to expand NOC support to other high-impact events. As part of the NWS Roadmap 2020 Pilot Projects, four new Full Time Equivalent (FTE) positions were created to staff an Operations Center Pilot Project. This pilot project is testing the efficacy and sustainability of a NOC.

Finding 1: The NOC does not support all high-impact weather events for which WFO and RFC staff produce briefings for specialized audiences. NHC staff commented that the NOC did not reach out to NHC for collaboration or explanation of its products during Irene.

Recommendation 1 (Strategic): Through the Operations Center Pilot Project, NWS should expand and develop the NOC capabilities demonstrated during Irene, particularly the coordinated decision making among NOAA line offices. These activities should be expanded to other high-impact events. NOC needs to communicate and collaborate with NHC during events to ensure proper interpretation of products and a consistent message within and outside of NOAA.

The NHC Storm Surge Unit (SSU) is a small group of highly-trained meteorologists and oceanographers specializing in predicting storm surge heights accompanying land-falling tropical cyclones. The SSU collaborates closely with the NWS Meteorological Development Laboratory (MDL), which develops and maintains the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) modeling system. During the hurricane season, the unit supports NHC's Hurricane Specialist Unit and WFOs to communicate storm surge vulnerability estimates during land-falling tropical cyclones. SSU staff also responds to questions and participates in conference calls with NWS partners such as FEMA and USGS.

During Irene, the SSU reached out to the NOAA community for additional expertise. A storm surge modeler from MDL was deployed to the SSU from Wednesday, August 24, through Monday, August 29. Among many contributions, this person ensured P-Surge model products were available in kml files for users and made guidance from experimental SLOSH+Tide model available to NHC forecasters.

In addition, the SSU reached out to oceanographers and ocean modelers at the NOS Coastal Survey Development Laboratory (CSDL) forecasters at OPC, and experts in the academic community for assistance interpreting storm surge guidance from the experimental NCEP-NOS Extra-Tropical Surge and Tide Operational Forecast System (ESTOFS) and other forecast models. The SSU also contacted personnel at NOS/CO-OPS but some were unavailable during weekends.

Finding 2: The SSU is a small group with a heavy workload during land-falling tropical cyclones. The SSU reached out to MDL, OPC, NOS/CSDL, and academia for additional expertise during Irene. However, not all NOS/CSDL employees are allowed to work on evenings and weekends.

Recommendation 2 (Strategic): NHC and NOS should work together to ensure that NHC has access to training on NOS forecast models, products, and vertical datum conversion tools prior to the hurricane season. In addition, NOS and NWS should formulate a plan that would allow personnel from NOS/CSDL and CO-OPS with storm surge forecast modeling, observational, and/or VDatum expertise to assist SSU personnel on evenings and weekends during land-falling hurricanes.

4.1.2. Field Office and NHC

NHC began mentioning significant potential impacts from Irene to the East Coast in its 11 a.m. advisory on Wednesday, August 24, providing a 3-day lead-time. NHC official track errors for Irene were smaller than the recent 5-year average by 20–40 nautical miles through 96 hours. Forecasts during the U.S. watch/warning stage were good—mean 48-hour error was 52 nautical miles; however, when Irene transitioned to an extra-tropical storm over WFO Caribou's County Warning Area (CWA), NHC ceased its support. Because of this action, WFO Caribou could no longer issue a Hurricane Local Statement (HLS), thus the WFO had to cancel the tropical storm warning and issue an inland high wind warning instead. While significant wind impacts were still associated with the extra-tropical period of Irene, the inland high wind warnings did not convey the same level of risk as a tropical storm warning.

Finding 3: The change in terminology from tropical storm warning to inland high wind warning is inconsistent in terms of expected impacts and can be misinterpreted as a lower-level risk from wind impacts.

Recommendation 3 (Strategic): The NWS product suite for wind risk from hurricanes and tropical storms should consistently convey potential impacts when a storm transitions from tropical to extra-tropical. Policies should be revised to ensure that any transition is transparent to partners.

Impacts to the airspace covered by CWSU's New York (ZNY) and Boston were large, and communication among CWSUs and key NWS forecast offices, such as NHC, was critical for optimal support to the Federal Aviation Administration (FAA). During Irene, all three NYC area airports closed to arrivals at noon Saturday, August 27, and did not resume full operations until Monday, August 29; however, CWSU forecasts prior to these closures were key to FAA planning. CWSU ZNY routinely issues the New York oceanic forecast for Day 1 at 10 a.m. and 10 p.m. The coverage extends out to 40W and between approximately 20N and 45N. The forecast provides information for international planners on sub-SIGMET criteria such as icing, turbulence, and thunderstorm activity throughout CWSU ZNY's oceanic sectors. CWSU ZNY also issues an experimental version of the product for Day 2 (valid 8 a.m. – 2 p.m.) at 1 p.m. on an as-needed basis. This forecast is conveyed to FAA traffic managers and planners verbally and illustrated with hand-drawn graphics for tropical cyclones. FAA traffic managers use the Day 2 oceanic outlook to determine if main traffic routes over the west North Atlantic Ocean should be closed the next day due to tropical cyclone conditions.

Although CWSUs New York and Boston delivered decision support to the FAA during Irene, neither CWSU had the ability to participate in hurricane hotline conference calls with NHC.

Finding 4: CWSUs New York and Boston have no way to participate in hurricane hotline conference calls. CWSU New York used the NHC Web site to get updated forecasts for Irene. The staff at both CWSUs should be able to take part in hurricane hotline conference calls to ensure they have the latest NHC forecasts, including uncertainty.

Recommendation 4 (Operational): To ensure public, marine, and aviation program services are fully coordinated, all offices bearing forecast responsibility over coastal and offshore waters should be included in Hurricane Hotline Conference calls.

4.1.3. WFOs and RFCs

According to NWS Instruction (NWSI) 10-922, Sections 7.2.2 and 9.2.2 on "River Forecast Center Operations," the "*RFCs and WFOs are full partners in collaborating to achieve successful warning and forecast operations for every hydrologic event.*" To accomplish this partnership, the "*RFCs have a variety of interactions with external water-related partners in addition to their support for WFOs.*" The Instruction states the "*RFCs have considerable latitude to configure their forecast operations to meet the requirements of these external NWS* *partners*." In the days prior to Irene, there was a varying degree of inter-WFO and RFC coordination.

RFCs made significant efforts to coordinate with the WFOs in the RFC's respective Hydrologic Service Area regarding the flood threat by Irene. Coordination began several days in advance of Irene, primarily regarding the Quantitative Precipitation Forecast (QPF), and conducted on a one-on-one or office-by-office basis. Contingency QPFs considered and, in the case of the Mid-Atlantic RFC (MARFC), probabilistic hydrologic forecasts were made available from the NWS Experimental Short-term Hydrologic Ensembles (MMEFS). Interviews with Northeast RFC (NERFC) and MARFC staffs indicated that they had very high confidence in the QPF due to the unusual day-to-day consistency in both the QPF issued by HPC and the QPF presented in the numerical model output. This confidence transferred to the hydrologic forecasts of major flooding on many rivers in both the NERFC and MARFC domains with average lead times in excess of 30 hours (NERFC average lead time= 43 hours, MARFC average lead time= 31.5 hours) and in some cases in excess of 48 hours. Some of these forecasts were available to the public on AHPS pages; however, despite the high confidence in the QPF and long lead time forecasts of flooding from the RFCs, WFO-issued river flood warning lead times averaged less than 5 hours (see Section 6.1). WFO Philadelphia/Mount Holly had significantly better lead times, averaging 15.6 hours for its river flood warnings. One reason given for waiting to issue river flood warnings was that they would dilute the impact of flash flood warnings issued closer to the event.

Although hydrologic modeling expertise resides primarily at the RFCs, the responsibility for messaging regarding flood warnings rests at the WFO level. Thus, decisions on warning product format, content, and lead time issuance are made at the WFO level. As the Irene event unfolded, each WFO independently chose which products to use for conveying flood threats, with some offices collaborating with neighboring offices on these products and some offices simply notifying adjacent offices of their product issuance via the Instant Messaging program utilized by NWS operational personnel, NWSChat.

Improvements to internal NWS coordination should include agreement among WFOs and RFCs on product types to issue during high-impact events. Additionally, collaboration should involve RFC hydrologists by utilizing their expertise and large-scale perspective to promote meaningful, simplified messaging with the right sense of urgency.

Finding 5: A more streamlined and simplified product suite for NWS hydrologic headlines would enable greater consistency among WFOs regarding the types of inland flood watches and warnings and would reduce the potential for confusion for the media, public, and other decision makers (see Section 6.1).

Recommendation 5 (Strategic): NWS should simplify and better coordinate messaging internally for inland flood impacts prior to and during widespread high-impact rainfall events.

Finding 6: Although QPF forecasts of extreme rainfall were consistent over a period of several days and RFC river forecasts of major to moderate flooding exceeded 30 hours, WFO river flood warnings averaged a much lower lead time of 5 hours.

Recommendation 6 (Operational): NWS, in conjunction with social scientists, should determine strategies and training to effectively maximize NWS river flood warning lead time in high-confidence, high-impact situations.

4.1.4. WFOs and Emergency Response Specialists

During Irene, the NWS deployed seven Emergency Response Specialists (ERS): four at Offices of Emergency Management (OEM) and three at FEMA regional headquarters. Coordination among these deployed meteorologists and their host WFOs was critical to ensuring NWS delivered one authoritative, consistent message.

Best Practice: To ensure a clear, concise, and consistent internal message was delivered, WFO New York City/Upton appointed an event coordinator who worked with the SSU to communicate storm surge forecasts with NWS ERSs working at the NYC OEM, Nassau County OEM, and Suffolk County OEM. The event coordinator used NWSChat in a special Decision Support Services (DSS) Chat Room.

4.1.5. NWS Regional Headquarters with WFOs and RFCs

Irene affected a vast area of the eastern United States, including offices in the NWS Southern and Eastern Regions. In the NWS Southern Region, WFO San Juan, two (2) CWSUs, and the Southeast RFC (SERFC) were affected. The NWS Eastern Region (ER) experienced the greatest impact, with thirteen (13) WFOs, three (3) CWSUs, and two (2) RFCs affected.

At NWS Eastern Region Headquarters (ERH) in Bohemia, NY, the Regional Operations Center (ROC) began coordinating activities for Irene on Sunday, August 21, 2011. At the request of the NHC, the ROC coordinated supplemental sounding releases, scheduled to begin at 2 p.m., Monday, August 22, by five ER WFOs (WFO Blacksburg, VA; WFO Charleston, SC; WFO Newport/Morehead City, NC; WFO Raleigh, NC; WFO Sterling, VA) and NASA's Wallops Island Flight Facility.

ERH continued its preparations for Irene on Monday, August 22, with a focus on ensuring ERH and its field offices would be ready if Irene threatened the eastern United States. These preparations included meeting with ERH senior staff and personnel; hosting conference calls with regional field office management teams; contacting RFCs and coastal WFOs to assess local staffing levels, equipment, and backup communications; and determining availability of personnel for deployment to local offices to assist with tropical cyclone operations. ERH continued its preparation and coordination process throughout the week via daily in-house senior staff meetings, conference calls with field office management teams, and Irene status update briefings.

In addition, ERH created and executed a plan to deploy meteorologists to federal, state, county, and city emergency operations centers to provide on-site Decision Support Services (DSS). Seven meteorologists were deployed to provide on-site DSS during Irene: FEMA Region I (Philadelphia, PA); FEMA Region 2 (New York, NY); FEMA Region 3 (Maynard, MA); Maryland EOC; Nassau County, NY, EOC; Suffolk County, NY, EOC; and NYC OEM.

The ERH ROC transitioned to 24-hour operations for Irene at 7 a.m., Thursday, August 25. ROC personnel began providing 6-hourly situational reports to NWS HQ regarding current conditions and impacts at ER field office locations. In addition, the ROC arranged coordination calls with field offices and NHC; assisted offices with technical questions and issues with software and hardware; coordinated with governmental partners such as FEMA; and conducted media interviews, including requests from a Spanish-speaking radio station and a Spanish-speaking television station. ER DSS meteorologists began arriving at federal, state, and local EOCs at 2 p.m., August 25. The ERH ROC discontinued 24-hour operations at 6 a.m., Tuesday, August 30.

NWS Southern Region Headquarters (SRH) ROC, in Fort Worth, TX, began preparing for Irene's impact to Puerto Rico on Friday, August 19, by conducting an operational readiness coordination call to WFO San Juan, Puerto Rico (SJU). The call assessed the functional readiness of office systems and plans for staffing the event. The call identified a possible need for augmented staffing at SJU, which the ROC quickly facilitated through use of a pre-established deployment pool. A staff member from WFO Austin/San Antonio, TX, who was proficient in Spanish, was readied for possible deployment early Saturday morning, August 20. Early Saturday, the ROC determined the forecaster was not needed and cancelled the deployment order.

SRH management facilitated the process of establishing a staffing schedule for the ROC should it be required to elevate its operational status over the weekend. The schedule was finalized Friday afternoon.

The SRH ROC elevated its operations status to Level 1 (24-hour on-site operations) at 5 p.m., Saturday, August 20, coincident with the NHC plan to issue a Tropical Storm Warning for Puerto Rico and the U.S. Virgin Islands. The SRH ROC conducted more frequent coordination calls with WFO SJU and prepared the first of 11 Regional Impact Statements. The SRH ROC began reviewing service backup plans and assessed various options. In addition, the SRH ROC facilitated the establishment of a coordination link between a few of the ER offices and WFOs Melbourne and Miami, FL. The Florida WFOs were asked to provide guidance regarding an issue with the Coastal Waters Forecast (CWF) formatter and use of the Tropical Cyclone Message (TCM) wind tool.

4.2. Federal Partners

4.2.1. Federal Emergency Management Agency (FEMA)

The National Hurricane Program (NHP) helps protect communities and residents from hurricane hazards through numerous projects and activities. The NHP also conducts assessments and provides tools and technical assistance to state and local agencies that develop hurricane evacuation plans. The program is a multi-agency partnership involving:

- FEMA
- U.S. Department of Transportation
- U.S. Army Corps of Engineers (USACE)

- NOAA
- NWS

The NHP maintains software and programs, and activates liaison teams to help NHC communicate forecasts and warnings to federal, state, and local government entities.

NHP developed a Hurricane Liaison Team (HLT) concept after the active 1995 hurricane season. The HLT updates the EM community about the growth and movements of tropical storms. HLT team members function as a bridge between scientists, meteorologists, and EMs. Team members provide immediate and critical storm information to government decision makers at all levels to help them prepare their response operations, including evacuations, sheltering, and mobilizing equipment.

One of the main functions of the HLT is to provide a video-teleconference (VTC) briefing from the NHC during a major tropical cyclone. The VTC is coordinated by FEMA's National Response Coordination Center. The call includes state and federal government staff and the White House. A member of the HLT leads the brief. This VTC is highly effective because everyone hears the same information simultaneously, shares issues, limitations, plans, and time lines.

The NHC Director can request HLT activation whenever a tropical storm threatens. The HLT remains active until the hurricane threat has passed. During an inland event, the HLT and HPC coordinate with the appropriate WFOs and RFCs, and, when needed, meteorologists from HPC provide precipitation forecasts and hydrologists from the RFCs provide hydrological briefings as part of the VTC. During Irene, the daily briefings by the NHC Director began on Sunday, August 21. HPC staff was on camera during only one VTC, on Thursday, August 25. Otherwise, HPC provided the precipitation graphics and forecast interpretation to the NHC Director, who used the information in his VTC presentations.

The HLT effectively manages DSS requirements for FEMA at a national level. The HLT lead played a critical role establishing an effective relationship between FEMA and NHC. During Irene, NHC Director Bill Read worked with the HLT lead to prepare appropriate graphics to highlight the potential storm impacts for use in daily weather briefings to FEMA and other national decision makers. FEMA finds these graphics essential.

"Bill Read gets it!" –Russ Washington, Director of the National Watch Center, FEMA

Technical difficulties hindered the efficacy of the HPC briefing on Thursday, August 25. In addition, FEMA representatives stated that HPC briefings tended to be too long and technical, and unless HPC improves its briefing style, FEMA would not add HPC to future VTC briefings.

> *"HPC doesn't understand how to convey the information to non-meteorologists the way NHC does (too technical). NHC gets it!"* –John Juskie, FEMA Senior Policy Advisor

Finding 7: After the HPC briefing on August 25, FEMA removed HPC from the VTCs for the duration of Irene. HPC serves as the backup for the NHC and provides the critical rainfall component of the hurricane forecast, the component associated with the majority of fatalities associated with Irene.

Recommendation 7 (Operational): Leveraging the success of NHC briefings, the NWS should support the creation of a Service Coordination Hydrologist (SCH) position at HPC to deliver more effective briefings to key partners.

Finding 8: The NHC is the most visible national entity for tropical cyclone information. FEMA and national media partners will continue to go to the NHC as the single source for tropical cyclone information; however, NHC participation in FEMA VTCs phases out when the coastal threat ends.

Recommendation 8 (Operational): Even though rainfall forecasts and inland flood threats are outside of the NHC's forecast focus, when briefing FEMA and national media, briefings (by NHC, HPC, or some combination) should give attention to each tropical cyclone-related threat at an appropriate level. This support should continue until the tropical cyclone is no longer affecting the Nation, including the impact of deadly flooding from coastal surge or inland rainfall. This procedure should be standard practice, not the exception.

NWS Southern and Eastern Region ROCs gave valuable support to affected FEMA Regions during Irene. There were, however, a number of coordination issues between NWS offices and FEMA Region Watch and Regional Response Coordination Centers. In particular, FEMA Region II Regional Response Coordination Center personnel were unfamiliar with the organizational structure of the NWS and how to obtain local expertise. Personnel in FEMA Region III needed information about WFO county warning area boundaries within its region.

Finding 9: FEMA Region II Watch Center expressed a desire to become better educated on NHC product issuance times and associated high-demand workload times at NHC in order to minimize their impact (time demands) on NHC operations. FEMA Region II also stated that while conference calls with ERH were useful, conference calls concerning Puerto Rico or other CWAs should also involve WFO personnel to ensure the use of local expertise.

Recommendation 9 (Operational): NWS should work with all components of FEMA to familiarize FEMA staff with the NWS organizational structure and provide FEMA with contact information for local expertise. In particular:

- FEMA Region conference calls should include an NWS representative from impacted WFOs and RFCs to provide local expertise.
- NWS should coordinate with FEMA Regional Watch Centers regarding NWS product schedules and general NWS office operations to maximize coordination efficiency of briefing activities.

4.2.2. USGS and USACE

The MARFC stated that there was great interest and value in sharing hydrologic-related forecast impacts during major flood threats such as a hurricane with other agencies in addition to EMs, such as USGS, USACE, and other water management agencies.

Best Practice: MARFC briefings to the USGS before Irene enabled USGS to deploy personnel and equipment to important locations. As a result, the USGS quickly repaired damaged gages, ensuring the RFC received data at vital locations during the event. The USGS found this coordination and information valuable.

During Irene, storm surge expertise was needed at coastal WFOs and the ERH ROC to help WFO forecasters, partners, and users interpret SSU storm surge forecasts, model forecast guidance, datums used, and relating surge to impacts on coastlines and infrastructures; however, coastal/ocean expertise related to inundation and storm impacts is limited in the NWS at local offices. Additional storm surge expertise exists within the federal government. For example, USACE recently conducted a survey of coastal engineering/science expertise and found approximately 75 full-time employees nationwide with those skills.

Finding 10: During Irene, a USACE employee was providing storm surge expertise to the NYC OEM and working closely with SSU.

Recommendation 10 (Strategic): NWS, through the National Hurricane Program, Office of the Federal Coordinator of Meteorology (OFCM), the Interdepartmental Hurricane Conference and the National Hurricane Operations Plan, should discuss with USGS and USACE the possibility of deploying their personnel with storm surge expertise to assist and/or supplement NWS staff during potential land-falling hurricanes. These non-NOAA personnel should receive advance training about NOAA storm surge forecast models, NWS and NOS coastal observing networks, and NWS forecast operations.

4.3. Private Sector Collaboration

A NWS ERS was present at the NYC OEM command center during Irene and gave frequent briefings. As stated later in this report (see Section 6.4.1), NYC OEM Commissioner Bruno stated: *"The most important point I can communicate is the importance of having an Incident Meteorologist onsite."* The NYC OEM routinely includes a large contingent of private sector representatives in its command center during high-impact events. Commissioner Bruno stated that he made the inclusion of the private sector in OEM operations a prerequisite for accepting the job, and that their presence in the NYC OEM command center, including during NWS briefings, was very beneficial.

"The private sector drives New York City." –Commissioner Joe Bruno

Finding 11: NWS does not consistently provide critical event information to private sector entities in critical, mission-related endeavors such as utilities, transportation, and medical services.

Recommendation 11 (Strategic): NOAA, and in particular NWS, should explore ways to consistently provide improved access to critical event information shared with the EM community, for private sector entities engaged in critical mission-related industries (e.g., utilities, transportation, medical services).

4.4. Foreign Governments

A relationship has grown over the last 10 years between the Canadian Hurricane Centre (CHC), a specialized center in Environment Canada, and NHC that led to the unification of tropical cyclone impact terminology between Canada and the United States. This reflects the geographical and meteorological reality of weather and weather impacts, and highlights the fact that weather does not respect political boundaries.

Recently, through post-storm analysis and data sharing, the CHC and NHC established warning messages and breakpoint information for the Canadian public. During Irene, NHC coordinated its forecast guidance packages with the CHC. On August 24, CHC began providing teleconferences using NHC and other NWS office providing products to the Quebec weather office. Forecasters from the Quebec Storm Prediction Center, Quebec senior weather office leadership, and Canadian Warning Preparedness Meteorologists participated on these calls. During Irene, the NERFC conducted calls with hydrologists at the Quebec office of Meteorological Service of Canada (MSC) and the Saint John River Forecast Centre in New Brunswick Province on potential flooding impacts on the Richelieu River, which flows from Lake Champlain into Quebec.

Best Practice: According to CHC, NERFC briefings on August 26, 2011, allowed the Quebec weather office to prepare for potential impacts from Irene.

Unfortunately, Quebec *did* experience severe flooding along the Richelieu River basin but, thanks to this kind of international cooperation and coordination, was better prepared. This type of coordination strengthens NOAA/NWS's efforts to achieve a WRN.

4.5. Liaison Challenges

4.5.1. The Martin Luther King, Jr. Memorial Dedication Ceremony

As is the case for virtually all complex and large-scale public events, the planned dedication of the Martin Luther King, Jr. (MLK) Memorial in August 2011 involved close coordination with dozens of individuals, as well as several governmental and private entities. Organizers had to consider carefully the political, pragmatic, and natural forces, nearly all of which were outside of the direct control of any one person or group. In this case, no physical injury or loss of life resulted from the decision to postpone the dedication ceremony, although there was some damage to crucial working relationships between NOAA/NWS and members of the highest levels of the federal government.

The Martin Luther King, Jr. Foundation (MLKF) planned for a ceremony at 11 a.m., Sunday, August 28, to unveil a 30-foot statue in honor of the civil rights leader. More than 300,000 people were expected to attend the outdoor event, potentially including the President of the United States. The U.S. National Park Service (NPS) Capital Region, which contains the location of the MLK Memorial, is within the CWA of WFO Baltimore/Washington.

The NPS Capital Region Police Commander, Special Events Unit, stated that his office and WFO Baltimore/Washington have a history of excellent coordination and established trust. The Multi-Agency Coordination Center (MACC), which comprises 30 federal and district agencies, handled coordination for the MLKF event; however, the decision to cancel the MLK Memorial dedication belonged to the MLKF.

Because of the nature of the event, FEMA was involved and the FEMA Administrator, Craig Fugate, suggested the FEMA Office of the National Capital Region coordinate weather support through the NWS FEMA Liaison. The NWS Liaison to FEMA ensured that coordination was going on between the NPS and WFO Baltimore/Washington.

At the NHC 10 a.m., Wednesday, August 24, conference call, which included both HPC and WFO Baltimore/Washington, NHC adjusted its track forecast farther east with an increase in forward speed. The NHC public product was subsequently released at 11 a.m. Because the HPC 4-5 day Probability of Precipitation (POP) guidance is heavily dependent on NHC track forecasts, the conference call prompted HPC to change its Day 5 POP guidance for the Washington, D.C., area for Sunday evening, August 28, from 100 percent to 23 percent (**Figure 9**). In response, and in accordance with NWS directives and ERH procedures, WFO Baltimore/Washington adjusted its POP forecasts at 11:26 a.m. The change in the WFO Baltimore/Washington forecast package removed the rain risk in the Day 5 forecast for the Washington, D.C., area by lowering POP below 26 percent (POP >26 percent is needed to trigger a mention of rain in the forecast). The WFO Baltimore/Washington forecast change was coordinated with the other affected WFOs and RFCs.

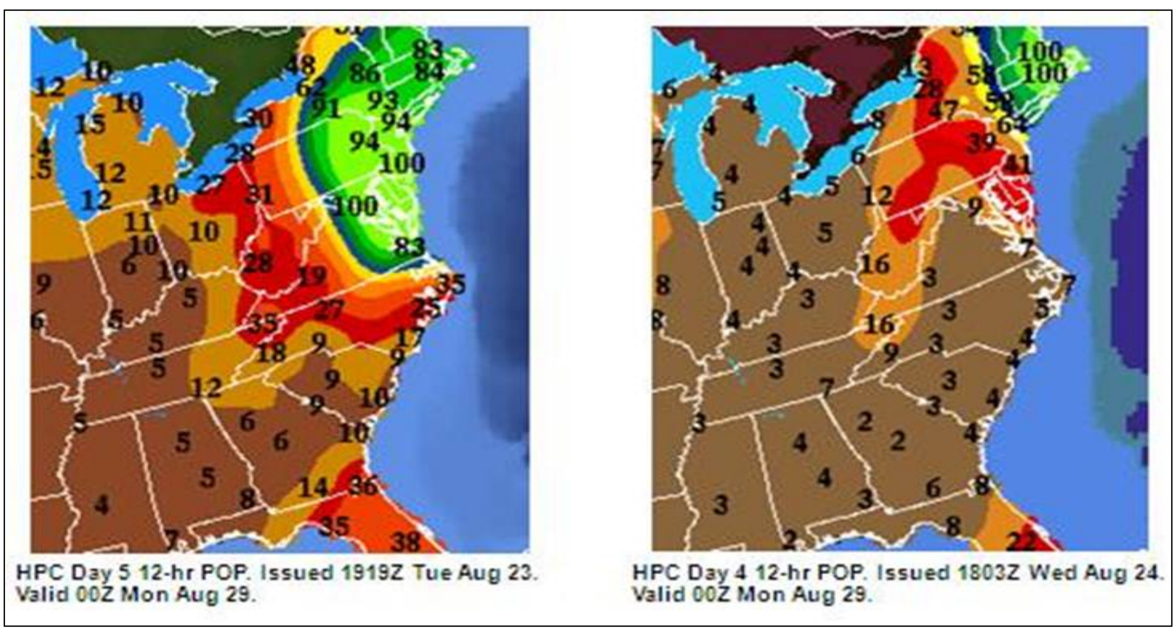

Figure 9: HPC POP forecasts valid for 8 p.m., Monday, August 29. The left image, Day 5 forecast, was issued on Tuesday, August 23, and the right image, Day 4 forecast, was issued on Wednesday, August 24.

Around midday on Wednesday, August 24, the NWS Liaison to FEMA noted the change in the WFO Baltimore/Washington forecast for the Washington D.C. area for Sunday. The NWS Liaison was concerned that the forecast did not fully describe the potential hazards implied by the NHC guidance, which continued to show the Washington D.C. area within Irene's cone of uncertainty (**Figure 10**).

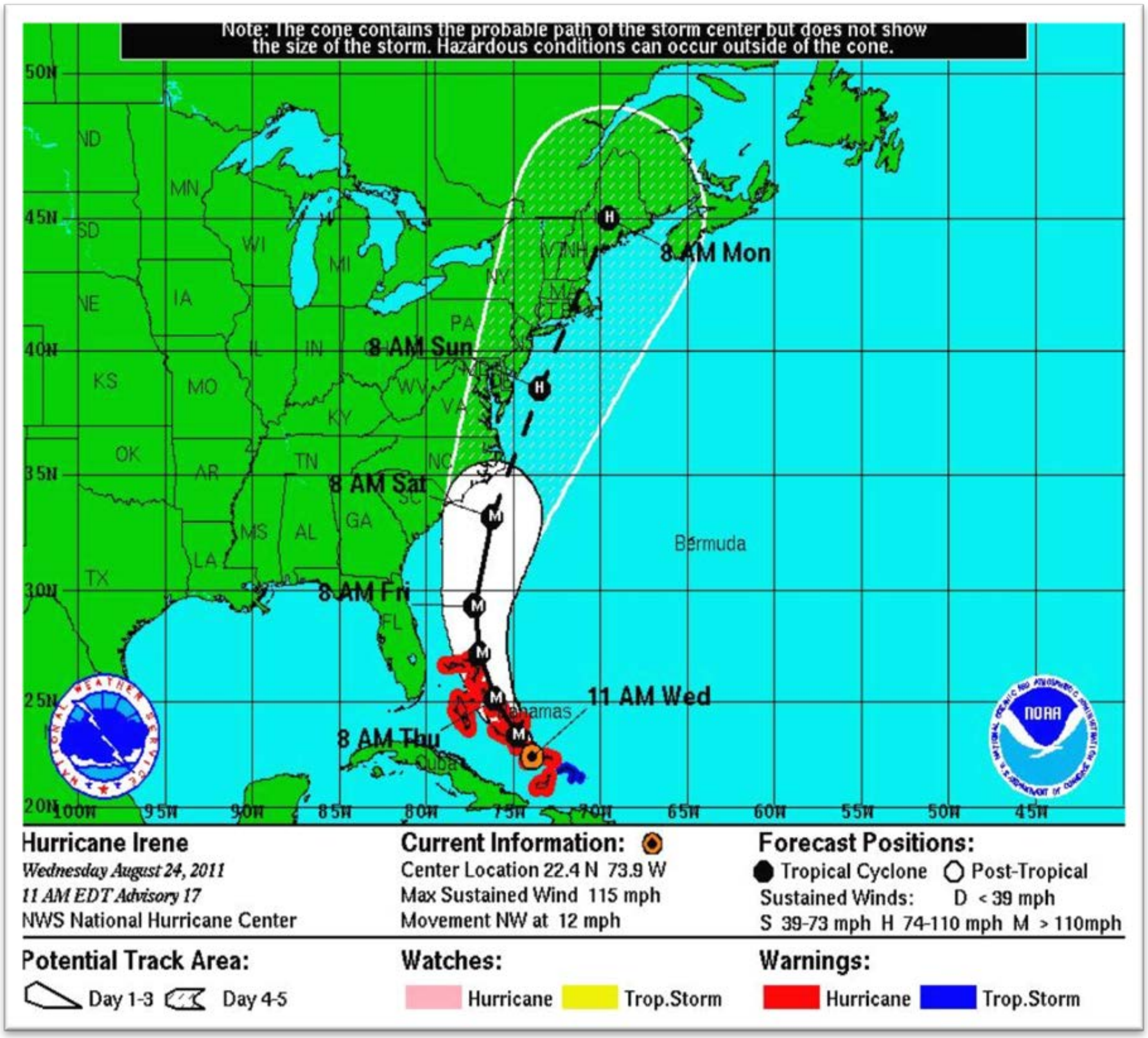

Figure 10: NHC Hurricane Cone of Uncertainty Forecast issued on Wednesday, August 24, 11 a.m.

The NWS Liaison to FEMA contacted the OCWWS Director regarding the discrepancy between the WFO Baltimore/Washington forecast and the fact that Washington, D.C. was still included in the NHC's cone of uncertainty for Irene. The OCWWS Director was informed of the concern expressed by FEMA and other federal agencies regarding the perceived inconsistency between the NHC and WFO Baltimore/Washington forecast guidance, and that WFO Baltimore/Washington did not appear to understand the significance this change posed to decisions surrounding the MLK Memorial dedication ceremony.

Attempts to reconcile a deterministic Day 5 precipitation forecast with a probabilistic forecast of the storm's location caused much of the perceived inconsistency. The embedded meteorologists noted inconsistencies between the NHC probabilistic track forecast, the cone of uncertainty that reflects 67 percent of the historical track forecast error, and the deterministic gridded forecasts from WFO Baltimore/Washington. They reasoned that having Washington, D.C. in the forecast cone, implying that Washington D.C. was within the potential track area, was not consistent with the WFO's forecast of windy and no chance of rain. Attempts to reconcile this discrepancy proved difficult. Much of this communication was stressful to the parties involved and ultimately led to further degradation of already strained relationships. Arguably, both parties did their jobs as defined by directives and established procedures; however, a lack of coordination resulted in senior NWS and NOAA leadership intervening.

Fact: Because of the perceived inconsistency and to more fully describe the potential impacts of Irene, at 7 p.m. on Wednesday, August 24, the WFO Baltimore/Washington MIC was directed by NWSHQ staff to increase the POP from 23 to 29 percent to trigger a mention of rain in the forecast for Sunday, August 28. The MIC was told this request came from the NWS Director.

While the WFO Baltimore/Washington forecast was changed for Washington, D.C., as requested, the process leading to the change caused concern for the WFO Baltimore/Washington MIC. This process illustrated a lack of effective collaboration among NWS field personnel and embedded ERSs in time-sensitive, highly visible situations, which require a thorough assessment of risk based on more than the hydrometeorological situation alone.

Familiarity with NWS directives and procedures is not enough when dealing with time-sensitive and highly visible decisions that should include consideration of additional factors beyond the hydrometeorological situation. NWS should ensure all ERSs in sensitive decision support positions have the necessary training, skills, and field support to manage such highly sensitive issues.

Finding 12: The working relationship among NOAA/NWS liaisons/embedded meteorologists and the local WFO was strained and deficient under time sensitive, high visibility pressures.

Recommendation 12 (Strategic): NOAA/NWS should develop a protocol for building, sustaining, and evaluating working relationships among embedded meteorologists/NWS liaisons, WFOs, and RFCs. This protocol should include reciprocal, face-to-face visits to build trust and a robust understanding of the work demands and needs of each entity.

4.6. Breakpoints

As in earlier landfalling hurricanes, the use of predetermined geographical references or breakpoints to describe watch/warning products caused internal confusion among WFOs in the Chesapeake Bay region. Breakpoints also created unnecessary confusion and challenges among media and EMs.

Breakpoints have a direct connection to coastal counties, but typically do not correspond with CWAs. For example, WFOs Baltimore/Washington, Wakefield, and Philadelphia/Mount Holly share forecasting responsibility for the Chesapeake Bay, where there are nine NHC breakpoints. When a hurricane or a tropical storm is expected to affect a coastal area, the local offices coordinate with each other and NHC about which breakpoints to use when issuing tropical cyclone headlines.

The consequence of this system is to warn for counties not expected to receive warning-level impacts simply because they are included in predetermined breakpoints. In one case during Irene, St. Mary's County, MD, was included in a hurricane warning when neither WFOs Wakefield and Baltimore/Washington, nor the NHC felt the county would experience hurricane force impacts. Unfortunately, this was unavoidable if neighboring counties were to receive hurricane warnings appropriately, as all counties are tied to the same breakpoint.

Another unintended consequence during Irene arose from a technical oversight resulting in tying Talbot and Caroline counties in Maryland (WFO Philadelphia/Mount Holly's CWA) to the Chesapeake Bay Drum Point and North Beach break points. WFO Wakefield did not realize these two counties were tied to two different breakpoints. When NHC upgraded to a hurricane warning for the Chesapeake Bay Drum Point breakpoint, Talbot and Caroline Counties unintentionally also were upgraded to a hurricane warning.

Finding 13: Several technical problems relating to the use of breakpoints, subsequently corrected, resulted in significantly degraded services; however, these corrections are short-term fixes that do not address the fundamental problem associated with the use of breakpoints. Breakpoints are a tool that has outlived its utility, frequently causing problems for NWS staff during high-impact events.

Recommendation 13 (Strategic): NHC should follow the Storm Prediction Center (SPC) procedure and shift from using breakpoints to using the Graphical Forecast Editor (GFE) to develop their products. NHC should shift to a polygon-based system for tropical cyclone watches/warnings similar to that used by SPC for tornado and severe thunderstorm watches. This change would improve coordination using the GFE, eliminate the confusion and technical problems associated with breakpoints, and allow WFOs to cancel tropical cyclone headlines for affected counties when those conditions are no longer observed.

5. Resource Allocation

While substantial improvements in NOAA/NWS infrastructure and communications have occurred over the last decade, Irene exposed several areas where gaps in available infrastructure and communications capabilities, or a lack of efficient use of existing resources hampered operations. The tools to collect, process, and disseminate weather-related data are an irreducible element in the weather forecasting system.

5.1. Staffing

5.1.1. Prepositioning

Preplanning and strategic positioning of additional staff are essential elements to maintain a healthy, sharp workforce and provide services during large, prolonged events, such as tropical cyclones.

Best Practice: Following previous practices, SRH sent members of a pre-established deployment pool to impacted offices. The deployment pool detailed each member's skill set to best match the capability with the MIC's/HIC's needs.

ERH, SRH, and NHC dispatched additional personnel to many NWS offices and Emergency Operation Centers (EOCs) to support Irene services. Proactive prepositioning of additional staff provided a critical level of support and capability for decision support services internally and externally; however, dispatches were not equally effective. For example, ERH deployed a forecaster who was not familiar with his assigned CWA. To assist the WFO effectively, this employee needed additional training. Conversely, ERH deployed a Service Hydrologist (SH) to WFO Newport News/Morehead City who had worked at the WFO, enabling her to integrate immediately into office operations.

Best Practice: ERH's proactive prepositioning of 22 additional staff provided a critical level of support and capability for enhanced DSS both internally and externally.

While hurricanes are traditionally considered coastal threats, inland flooding has consistently proven to be the most deadly consequence and one that results in costly impacts. In anticipation of a potential inland flood threat with Irene, ERH deployed the SCH from the Ohio RFC to the NERFC; however, ERH did not assign similar deployments to inland WFOs.

Finding 14: While local offices were grateful for the additional personnel, office managers found both efficiencies and challenges in integrating the additional personnel. Office managers want to be involved in future resource allocation decisions regarding deployments to their offices and EOCs within their CWAs.

Recommendation 14 (Strategic): When prepositioning additional staff for high-impact events, NWS regional headquarters should, if possible, assign employees who have previously served at the WFO/RFC in need of assistance, even if they currently serve in another NWS region. Assignments should be coordinated with the recipient MIC or HIC and at a minimum include:

- Who is deployed
- To which offices and EOCs they are deployed
- When they will travel

Finding 15: Coastal offices and EOCs were the only recipients of additional prepositioned staff, even though inland flooding was a primary threat from Irene.

Recommendation 15 (Operational): When prepositioning additional staff to WFOs and EOCs threatened with tropical storm or hurricane impacts, the enhanced staffing should include areas threatened by inland flooding.

Best Practice: The deployment of a WSR-88D Radar Operation Center (ROC) team from Norman, OK, to a location near the forecast impact area allowed critical equipment and technicians to be within a day's drive of vital radar systems. The team deployed with a satellite communications kit in anticipation of potential widespread communication outages in the affected areas. The team was able to respond quickly after the storm passed to help WFO Philadelphia/Mount Holly repair its radar.

5.1.2. Scheduling

WFO plans to manage tropical storm preparations, operations, and post-event support varied dramatically. For example, WFOs Wilmington, New York City/Upton, and Boston/Taunton have pre-established, well-coordinated, Tropical Cyclone Operation Plans (TCOP) detailing shift coverage, briefing schedules and templates, and staff and family safety measures. These WFOs enacted their TCOP early and seamlessly. WFO Boston/Taunton's plan even included a negotiated switch to 12-hour shifts to accommodate necessary rest for the staff.

Conversely, WFOs Burlington and Albany created event staffing plans only days prior to Irene's impact. WFO Burlington's plan assigned additional staffing only during the day of the event to handle increased monitoring, product generation, and DSS as the event unfolded. Despite the lack of cohesive pre-established staffing plans, good DSS occurred; however, for future events a pre-established TCOP is highly recommended. DSS, and associated additional staffing, is necessary not only during the event, but also prior. This planning is especially imperative in areas without countywide EM entities. Additional staff is vital to ensure all threatened communities are adequately briefed and prepared in advance of a major event.

The Southeast RFC (SERFC) enacted an aggressive incident support plan, which included hydrologic vulnerability assessments and other DSS products shared with relevant WFOs, EMs, and SERFC staff. The SERFC also designated an Incident Manager. Implementing the Incident Command System (ICS) allowed the office to better prepare for extreme events. NERFC did not have an Incident Manager and event coordination was not as smooth. Hydrologists were taken off forecasts of rapidly evolving situations to provide briefings, often for less important threats.

Most WFOs noted additional staffing was also needed days after the event to provide continued DSS for damaged areas and compile data for post event reports.

Best Practice: The SERFC designated an Incident Manager; implementing the Incident Command System (ICS) allowed the office to better prepare for extreme events.

Finding 16: There is a lack of consistency among field offices with regard to documented TCOPs. WFOs with comprehensive plans successfully prepared for enhanced services to EM and media partners, and better accounted for staff safety.

Recommendation 16 (Strategic): Staffing templates for high-impact events should be developed by all WFOs and RFCs. For offices in the line of tropical storms, these should be contained in the TCOP. These templates should allow for flexibility and ensure appropriate staffing is available to cover before, during, and after a major event. For high-impact events such as Irene, all enhanced staffing plans should include an event coordinator and coverage for extended hours of electronics and other information technology. (Refer to the Southeast United States Floods, September 18-23, 2009 Service Assessment.)

5.1.3. Hiring

The work demands on WFO staff during an extremely high-impact event such as Irene are extraordinary. Many facilities act as shelters-in-place for staff members who provide critical services 24/7, even in the most extreme conditions. This fact requires a clear understanding among the staff and management of the requirement to be available for duty.

Best Practice: During the interview process for all positions at WFO Wilmington, the MIC clearly states the office is subject to tropical cyclones and explains the expectations and local policies to prospective employees. Candidates are informed it is a requirement to be available to work during a hurricane threat. The MIC discusses individual responsibilities and states leave may be canceled to ensure coverage for a hurricane threat.

Finding 17: Several candidates have declined to be considered for a position at WFO Wilmington after gaining a clear understanding of staffing expectations during a hurricane threat. These candidates were not comfortable leaving their families during a hurricane. Those applicants hired know exactly what is expected well before high-impact events unfold.

Recommendation 17 (Operational): Hiring officials in WFOs that are susceptible to potential long duration, very high-impact events such as tropical cyclones should clearly inform prospective employees of duty requirements, including the likelihood of sheltering-in-place at the WFO.

NHC and HPC provide unique services on a national scale. Their services for EMs, other NWS offices, federal partners, and national media are not only critical, but stretched when a large geographic area is impacted by a tropical storm.

During Irene, only the lead of the NHC SSU could issue the official NHC storm surge forecast guidance and represent SSU on conference calls with WFOs, RFCs, ROCs, embedded NWS meteorologists, and external partners. Only this person could perform these duties since he is the only permanently assigned federal employee in the unit; the other members of the unit are contractors. This one individual provided almost continuous storm surge expertise and decision support during Irene.

> *"[The Storm Surge Unit Team Lead] deserves a medal...."* –David Vallee, Hydrologist in Charge, NERFC

Finding 18: The reliance of NWS on a single person at the SSU for internal and external storm surge decision support led to extreme fatigue and is not sustainable. This is a potential single point of failure.

Recommendation 18 (Strategic): An additional federal employee should be allocated to the SSU. The NWS should establish a 24-hour SSU tropical cyclone support and Technical Support Branch capability with staff members who can provide official guidance and support to field offices, ROCs, and external partners during a threat for a landfalling tropical cyclone.

A highly developed communication skill set is a cornerstone to an effective tropical cyclone program. The service assessment team found widely varying communication skills in field personnel working with the highest levels of government. An example of this issue is described in Section 4.2.1 of this report. FEMA representatives stated that unless HPC improves its briefing style, they would likely not add HPC to future VTC briefings. Unlike NHC, HPC lacks a member on the FEMA Hurricane Liaison Team or a SCH to help prepare briefings for FEMA.

Finding 19: FEMA and other national decision makers found HPC briefings ineffective. Conversely, the NHC Director was widely praised by FEMA and the White House as a trusted voice of the NWS/NHC who understood FEMA's needs and communicated clearly to the highest levels of government.

Recommendation 19 (Strategic): Through programs such as the FEMA Hurricane Liaison Team at NHC, NOAA/NWS should actively recruit new and develop existing NOAA/NWS scientists who can effectively communicate with those at the highest levels of government.

5.2. Training Issues

The service assessment team discovered several significant training issues. During Irene, NWS deployed meteorologists to three FEMA regional headquarters and to a few state, county, and city EOCs. When an incident requires response from multiple local EM and response agencies, effective cross-jurisdictional coordination using common processes and systems is critical. FEMA's Incident Command System (ICS) is a standardized, on-scene, all-hazards incident management approach that:

- Allows for the integration of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure
- Enables a coordinated response among various jurisdictions and functional agencies, both public and private
- Establishes common processes for planning and managing resources

ICS is flexible and can be used for incidents of any type, scope, and complexity. The system allows its users to adopt an integrated organizational structure to match the complexities and demands of single or multiple incidents. ICS is used by all levels of government—federal, state, tribal, and local—as well as by many nongovernmental organizations and the private sector. ICS is also applicable across disciplines. The system not only provides an organizational structure for incident management, but it also guides the process for planning, building, and adapting that structure.

Finding 20: Not all embedded meteorologists were ICS trained.

"*All individuals who walk into my EOC must have completed ICS 100, 200, 300, 400, 700, and 800*." –Tom Collins, Pender County, NC, EM

DSS requires the NWS to train staff to deliver high quality services during high-impact events using ICS principles; however, not all embedded meteorologists were ICS trained.

Recommendation 20 (Strategic): NWS should ensure forecasters and hydrologists selected for deployment in an EOC are required to be sufficiently trained in ICS, including ICS 100, 200, 300, 400, 700, and 800 courses.

Pursuing creation of a WRN and aiming to improve the resilience of people, structures, and our national infrastructure will require, in part, training for NWS meteorologists and hydrologists, and EMs to effectively prepare, respond to, and recover from high-impact weather events such as tropical cyclones. While the human cost of any weather-related event is difficult to define, the economic costs are measurable. The cost estimates for Irene are provided in Section 3.1, Damage.

Hurricanes are the highest impact weather events (43 percent of the $1.76 trillion total damage cost) with the highest return interval. Effective response to this threat requires a comprehensive tropical training program to develop the NWS workforce's competencies and skills so it can most effectively perform and carry out the mission of protection of life and property. Such programs are most needed at WFOs in tropical cyclone impacted regions, but are also needed in the WFOs serving as primary and secondary backups.

There are three Advanced Warning Operations Courses offered by the OCWWS Warning Decision Training Branch:

- Severe Convective Weather
- Winter Weather (not offered in FY 12 and not scheduled in FY 13)
- Core Decision Making

Currently, the WFO tropical training group consists of six individuals, five of whom are assigned to field offices. The training focuses primarily on the development and operational impacts of the HLS. The HLS training is perceived by Mid-Atlantic and Northeast offices to be excessively long and lacking pertinence to northern impacts and events. Offices also request earlier HLS training sessions to ensure classes are completed before the tropical season, which can be difficult because of office leave and spring severe weather.

The COMET® training group offers an online tropical meteorology course helpful in understanding certain scientific issues, but forecasters noted it lacked connection to WFO operations. The NHC provides yearly hurricane training for emergency partners, but only two NWS slots are available for each course. Several NWS regions proposed a "Tropical Advanced Warning Operations Course" for NWS forecasters in 2006, 2007, 2008, and 2009; however, there was a lack of broad support from NWS senior-level management and as a result, NWS did not fund any of the Tropical Advance Warning Operations Course proposals.

At the time of this assessment, the NWS did not offer a single-source, organized, storm surge series training. COMET® offers storm surge modules, the NWS Meteorological Development Laboratory (MDL) provides SLOSH model tutorials, and the NHC periodically offers tropical storm surge Webinars for forecasters, but there is no organized, mandatory storm surge training program for coastal offices.

At the 2011 NOAA Hurricane Conference, the NWS Marine and Coastal Weather Services Branch (OS21) was assigned as action to include a comprehensive Tropical Training Program in the National Strategic Training and Education Program (NSTEP) process for FY 13. OS21 submitted the Performance Needs Statement for the NSTEP process. Via the current NSTEP voting process (voting by NWS Regions and NCEP), the Performance Needs Statement received an average priority of 3 on a 1-9 voting scale with 9 being highest priority. Thus, the effort was not funded for FY 13.

Finding 21: Some NWS offices lack operational experience working tropical cyclone events, particularly inland offices and coastal offices that have longer return periods for tropical cyclone occurrences. Periodic and pertinent training is essential to maintain needed tropical cyclone operational skills.

Recommendation 21 (Strategic): The NWS should make it a priority to fund a comprehensive Professional Development Series (PDS) on tropical cyclones, including training on effective delivery of DSS and comprehensive material on both coastal and inland impacts. The funds would support the development and delivery of an operations-based tropical course targeted to the 1,200 NWS meteorologists and hydrologists who have tropical warning and decision support responsibilities. The PDS would involve and include:

- Multiple subject matter experts to develop the comprehensive training, not just the six individuals currently working on the program on their own time
- Onsite meeting to allow these experts to develop the training
- Full-scale simulations providing all WFO forecasters who have tropical warning and decision support responsibilities the capability to develop tropical cyclone decision support skills with their local EMs and media
- NWS Regional Directors ensuring this tropical training is integrated into their staffs' tropical seasonal readiness training at all relevant WFOs and RFCs

NWS directs a substantial portion of its training efforts towards severe weather events such as tornadoes and severe thunderstorms. Flooding, however, continues to be the cause of a majority of weather related deaths and impacts. Training to handle extreme hydrologic events, even when those events are rare, needs to be more consistent and given a higher priority to meet the goals of a WRN.

Finding 22: The level of hydrologic training and experience varies within and among WFOs. WFO hydrologic training programs range from detailed and thorough to one Weather Event Simulator case or an annual quiz.

Recommendation 22 (Strategic): NWS should establish and implement a baseline standard for annual hydrologic training at all WFOs. NWS Regional Directors will ensure this hydrologic training is integrated into their WFOs' and RFCs' seasonal readiness training.

Familiarization with the NOAA/NWS tropical cyclone program is vitally important to external partners. NHC, in conjunction with FEMA, conducts three, weeklong, L-324 *Hurricane Preparedness for Decision-Makers* courses each winter. Each course has approximately 25 students and covers forecasts, uncertainties, and product interpretation. Per the FEMA Hurricane Program Manager, funding is provided to FEMA with the explicit purpose of training state and local EMs. As a courtesy from FEMA, two NWS slots are available for each of the three, weeklong courses. Unfortunately, because of limited travel funding for WFOs, some of the NWS slots were not filled for the winter 2012 courses.

Finding 23: EMs were highly complimentary of FEMA's week-long Hurricane Preparedness Course at NHC, calling the training sessions "*excellent*" and the scenarios "*realistic.*" Several EMs stated they had attended the course at NHC 5–10 years ago, and would benefit from refresher training. In addition, as a courtesy to the NWS, FEMA provides two NWS employee slots for each of the three, weeklong L-325 Hurricane Preparedness for Decision-Makers courses each winter.

Recommendation 23 (Strategic): NOAA/NWS, together with FEMA, should expand its support for the FEMA weeklong Hurricane Preparedness Course at NHC. This should include funding for NWS staff to participate.

5.3. Service Backup

During Irene, WFO Burlington's fiber optic communications were severed because of severe flooding in Vermont and New York during the peak of the event. This flooding nearly required WFO Burlington (BTV) to ask another WFO to take over BTV forecast operations. As depicted in **Figure 11**, the primary backup office for WFO Burlington is WFO Albany (ALY) and the secondary backup is WFO Caribou (CAR). These backup WFOs also were impacted by Irene.

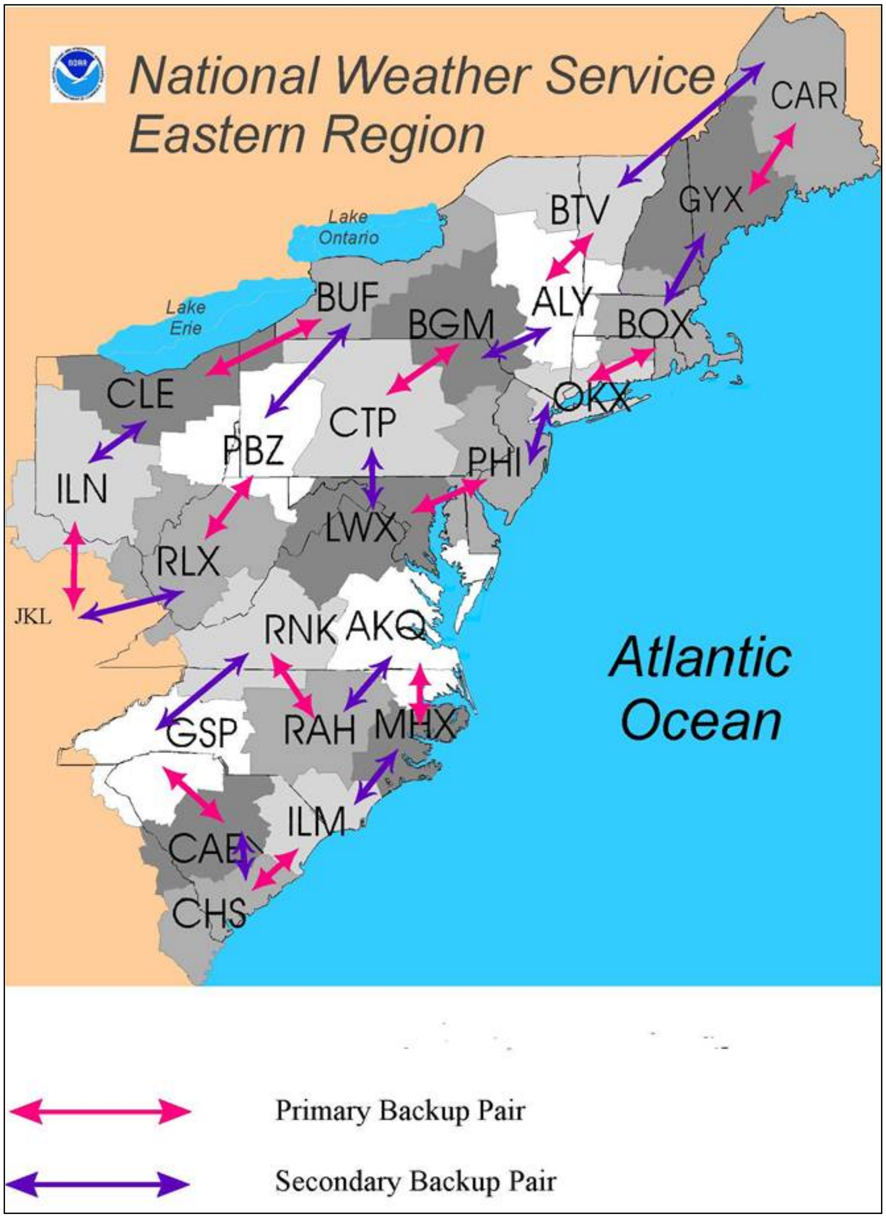

Figure 11: Primary and secondary backup sites for ER WFOs

This incident, along with comments the service assessment team received from MICs at coastal and inland WFOs, raises questions about the current WFO backup structure. This topic has been highlighted in previous assessment reports, such as the Hurricane Katrina, August 23-31, 2005, Service Assessment.

Finding 24: Having adjacent offices as the only means of office backup leaves the NWS vulnerable to service interruption during critical times if a large-scale event affects numerous neighboring offices.

Recommendation 24 (Strategic): Service backup should be re-evaluated. The operative parameters for effectiveness of a backup plan should include flexibility, efficiency, and knowledge of products, services, and impacts.

As mentioned elsewhere in this report, storm surge was a major concern of NWS partners and users when Irene approached and made its way up the East Coast; a significant demand was placed on the SSU. In the assessment teams' interviews of NHC personnel, it was discovered that while HPC and the Central Pacific Hurricane Center serve as backup for NHC's hurricane track/intensity forecasts, there is no official backup center to assume the SSU's responsibilities. Since Irene, NHC has discussed potential back-up plans with personnel from MDL and OPC.

Finding 25: There is no official backup site to assume the NHC SSU's responsibilities.

Recommendation 25 (Strategic): The NHC SSU should have a backup site and continuity of operations plan supported by NWS management.

5.4. Equipment and Technical Support

The NWS Advanced Weather Interactive Processing System (AWIPS) Network Control Facility (NCF) does not provide 24/7 technical support for WFO generation of tropical cyclone deterministic wind fields. One person in the OCWWS Training Division's Forecast Decision Training Branch (FDTB) handles this support. The service assessment team was informed that the HLS software does not have 24/7 technical support because it is not considered baselined in AWIPS. This statement was later discovered to be incorrect; the software is baselined in AWIPS for 2011 and the NCF should be providing 24/7 technical support.

The HLS is currently the flagship product produced by WFOs to issue hurricane/tropical storm warnings and watches and to describe the evolution of the event, threat, and impacts. Both the HLS software and the tool to generate deterministic wind fields suffered technical problems during Irene. In one case, there was a complete failure that required a workaround from the FDTB employee. This employee's position is classified as non-essential and on-call duty is not part of the position description.

Finding 26: NCF does not sufficiently support WFO software critical for the generation of products and services specific to tropical storms and hurricanes. NCF calls usually assign support to one FDTB employee whose position is not designated to provide on-call support.

> "*We need a better service-level agreement with Raytheon.... This has been going on for 7 years… We need more clear and realistic/timely constraints in contracts for restoration of service...*" – OCWWS/FDTB employee.

Recommendation 26 (Operational): All WFO software critical to the hurricane program should be included in the AWIPS baseline. Technical support for products essential for HLS production, including the Radii/Clipper (RCL) should reside at NCF. NCF/Raytheon should acquire sufficient proficiency to support these baselined applications.

Finding 27: Many forecasters identified bugs in the HLS software code during Irene, even though mandatory testing of the software is required at each WFO before each hurricane season. With assistance of an FDTB employee who was called after hours, the majority of the bugs were fixed by forecasters who happened to have written the code and were working shift.

"We need to stress the importance of field testing…particularly the HLS. There were a number of cases where no testing had been done, even though positive responses had been received on annual testing. These support calls drive me nuts…They are totally unnecessary." –OCWWS FDTB employee

Recommendation 27 (Operational): Software critical to the hurricane program should be extensively tested before each tropical cyclone season at WFOs prone to tropical cyclones.

The MARFC experienced a hard drive failure of one of its four operational AWIPS workstations Thursday, August 25. It struggled with NCF instructions to rebuild the new workstation because the partitioning setup steps were incorrect. It took a couple of weeks for the MARFC and NCF to restore the machine properly. To meet operational requirements for Irene, the MARFC's Electronic Systems Analyst (ESA) had to swap out the failed workstation with an alternate personal computer. During this process, it was discovered the partitioning procedures were tested only on WFO workstations, not RFC workstations.

Finding 28: WFO and RFC workstations are different, and therefore require different partitioning procedures. While the NCF tests these procedures on WFO workstations, NCF did not test RFC workstations. This inconsistency resulted in a significant delay bringing a MARFC workstation back to operational status.

Recommendation 28 (Operational): NCF should test procedures on both WFO and RFC workstation configurations.

Limitations in computer infrastructure created challenges for the SSU. Shared resources could mitigate this issue.

Finding 29: The NHC's lack of robust computing infrastructure causes limitations and creates additional work for SSU specialists.

Recommendation 29 (Strategic): The SSU should explore the feasibility of using the NOAA Central Computer System operated by NCO to run Storm Surge Forecast models. This change also would make the Continuity of Operations Plan more effective when another NWS facility needs to back up NHC.

5.4.1. Workstation Availability

During Irene, the typical coastal WFO workstation configuration consisted of five operational AWIPS workstations and one non-operational AWIPS workstation. The non-operational AWIPS workstations cannot generate text products; they only have graphic capabilities. WFOs typically used their workstation configuration as follows:

- Operational workstation dedicated to maintaining hurricane-related grids, including running the TCM wind tool, and generating the HLS and tropical impact graphic grids
- Operational workstation dedicated to short-term forecasting of all other weather elements in the first 2–3 days, including the Area Forecast Discussion

- Operational workstation dedicated to monitoring areal flooding concerns, flash flood warnings, and issuing special weather statements
- Operational workstation dedicated to data collection and aviation operations
- Operational workstation dedicated to radar operations
- Non-baselined workstation used by the Event Coordinator to monitor watches, warnings, and forecasts and for DSS support

Tropical cyclone warning operations required greatly increased staffing to handle multiple roles. Many of these roles required access to a fully functional AWIPS workstation, which stretched workstation availability.

In one example, there was a tornado threat while Irene was approaching eastern North Carolina. WFO Newport/Morehead City reconfigured two workstations to sectorize the severe weather threat and transferred some product generation to its non-operational AWIPS workstation. Other offices noted they were fortunate to escape the need to use a workstation for severe weather radar operations as potential severe weather in their CWA did not materialize. WFO San Juan noted a lack of available workstations to query ongoing hydrologic databases during Irene.

Workstation availability would have been hampered further if an office already affected by Irene had been asked to provide backup support to an adjacent office. This scenario nearly occurred at WFOs Albany and Caribou because of a communications failure at WFO Burlington.

Finding 30: Several WFOs impacted by Irene did not have enough workstations to facilitate the increased staffing necessary for all critical tropical cyclone-related functions. The complexity of Irene's impacts nearly exceeded the capabilities of the office workstation array.

Recommendation 30 (Strategic): To handle the increased workload from a landfalling tropical cyclone, the NWS should do one or more of the following:

- Increase the number of fully operational workstations in coastal offices to at least six
- Incorporate workload shedding in the COOP through service backup for high-impact events. This change will allow WFOs to focus on the high-impact elements versus the routine products and free up workstations, allowing forecasters to focus on impact-based DSS.
- Allow offices to repurpose existing laptops and non-workstation PCs prior to large events to provide additional access to the Internet and free-up workspace near AWIPS workstations
- Use PC-based software applications, such as FXNet and SimuAWIPS, as a supplement when AWIPS workstations are not available

5.4.2. VSAT and OpsNet

While personnel and staff performed consistently well throughout Irene, technical problems with the communications systems and infrastructure clearly posed a number of significant problems. During Irene, four offices (WFOs New York/Upton, Burlington, Wilmington, and Newport/Morehead City) experienced a loss of their primary data communications (OPSnet), which includes the AWIPS and WFO operational Wide Area Network (WAN). Only two of the four sites that experienced an OPSnet outage were equipped with a Very Small Aperture Terminal (VSAT) back-up satellite communications system. Faced with these technical challenges, NWS staff made creative adaptations to keep communication and data lines functioning. This scenario is not a best practice.

Currently, communications use OPSNet, with VSAT as the backup system. OPSNet is a terrestrial system typically overloaded *without* the increased demand associated with a major weather event. It is well documented that the bandwidth capacity of OPSnet is inadequate for WFOs to effectively perform enhanced DSS. Data from multiple NWS WFOs have shown bandwidth usage frequently reaching at least 90 percent.

VSAT is not a sufficient backup system, and VSAT is only installed permanently at approximately half of the WFOs. Significantly, the bandwidth capacity of the VSAT backup solution is inadequate to support WFO operations, especially in the scenario of multiple offices simultaneously using VSAT backup. In this case, the bandwidth capacity shrinks to a quarter of its normal size.

Consequently, due to the severe bandwidth limitations of VSAT, various protocols are restricted. These restrictions have significant operational impacts. Multiple offices also reported severe slowdown of operational PCs attributed to the bandwidth limitations of VSAT. Downloading high-resolution data sets to multiple locations further compounds this problem.

Fact: Typically, WFOs have a bandwidth capacity of only 3 megabits per second (Mbps). This bandwidth is shared between AWIPS and WFO operations.

Finding 31: Operational WAN links are often saturated, even during non-weather events. During high-impact events, offices are unable to perform enhanced DSS.

Recommendation 31 (Operational): The NWS should increase the total amount of bandwidth into each office from 3 Mbps to at least 5 Mbps.

Finding 32: VSAT, the primary backup system for OPSNet is only installed permanently at approximately half of the WFOs.

Recommendation 32 (Operational): Until the NWS can implement a more resilient backup system, VSAT should be permanently installed in all WFOs.

Finding 33: VSAT bandwidth is not adequate, particularly when multiple offices are using the system simultaneously. VSAT also experiences degradation of signal (attenuation) in heavy rain and snow.

Recommendation 33 (Strategic): The NWS should implement a backup solution that meets operational needs. The solution should be a diverse communication path from the primary terrestrial path, have sufficient bandwidth to support operations, be resilient to environmental factors such as rain and snow, and be scalable and support multiple offices simultaneously without operational degradation.

Fact: Only one individual at NCF, working remotely in California, is able to make the transition to VSAT and return it to normal service.

Finding 34: WFO staff members are unprepared to manage the limitations of the VSAT backup system because they often do not know they have been switched to it, they receive no training on it, and site administrators do not have enough information to mitigate the inherent bandwidth limitations of VSAT.

> "*We received no training whatsoever on VSAT*." –ESAs at WFOs Morehead City and Wilmington

Recommendation 34a (Operational): Instead of simply issuing an AWIPS administrative message, NCF should call a site when it is switched to VSAT.

Recommendation 34b (Operational): All WFO electronics staff should be trained on the basic operations of VSAT.

Recommendation 34c (Operational): Mission critical communication requirements should be defined, prioritized, and implemented during VSAT operations.

Recommendation 34d (Operational): Due to VSAT's limited bandwidth that causes severe slowdown of operational PCs, NWS should explore independent Internet connection solutions such as 4G mobile WiFi.

Finding 35: Several offices were unable to update the point-and-click Web pages while on VSAT because of RSYNC protocol blocking. Inefficient transmission of netCDF files to multiple locations further compounds this problem.

Recommendation 35 (Operational): NWS should investigate having its Information Dissemination Service pull netCDF files from the National Digital Forecast Database (NDFD) for the generation of the point-and-click Web forecasts. This change also would eliminate the possibility of NDFD misalignment with the point–and-click Web forecast, as well as reduce extraneous bandwidth utilization of VSAT and OPSNet.

Fact: NWSHQ policy is to deploy the VSAT when the outage is expected to exceed 72 hours.

Finding 36: Current NWS VSAT deployment policy is based on the availability of backup offices to take over operations of the failed WFO. In geographically large-scale events, such as Irene, backup offices are not capable of managing this additional workload.

Recommendation 36 (Operational): Like prepositioning personnel, NWSHQ should develop a plan to strategically preposition VSAT/backup communication equipment to rapidly mitigate degraded operations.

5.5. Facilities

NOAA's most valuable resource is its people. Irene exposed the need for safe and sanitary accommodations in which staff can shelter-in-place for an extended time. During tropical cyclones, NCEP (NHC, OPC, HPC) and WFO staff members are exposed to significant risks by traveling to and from work, the very risks we advise the public to avoid. For example, a WFO Wakefield staff member on his way to work was trapped on the highway for approximately 3 hours because a tree fell across the highway blocking traffic; there was no alternate route for him to get to the office.

The majority of these facilities do not have appropriate facilities to support reasonable sanitation and rest for staff who should remain at the office because of extreme weather conditions. At a minimum, this affects operations when employees are unable to reach the WFO because of a local infrastructure failure. During Irene, numerous employees at several WFOs spent the night or caught short naps on couches and floors of offices and conference rooms.

Fact: FEMA recommends all citizens develop a 72-hour plan for emergencies. The plan should include a kit with 3 gallons of fresh water per person, canned goods, prescription medications, etc., during extreme events (Reference www.ready.gov/build-a-kit).

Fact: According to the 1994 NOAA/NWS WFO design criteria manual, the majority of NWS buildings were constructed to withstand a low-end Category 3 hurricane/120 mph sustained wind speed.

Finding 37: NHC, OPC, HPC, and WFOs are expected to remain operational during even the most extreme weather events, yet most are not equipped to do so. (See Hurricane Katrina August 23-31, 2005 Service Assessment.) During Irene, staff sheltered in place at both WFO New York City/Upton and WFO San Juan. There and elsewhere along the path of Irene, WFO staff operated in facilities neither designed for, nor adequately equipped to, shelter in place for 72 hours.

Recommendation 37a (Operational): NWS should establish a plan ensuring a safe and restful sleeping environment for employees who remain at the office because of unsafe travel conditions in areas at risk for very high-impact events. Where practical, this plan should consider providing a temporary shower in each facility. NWS offices should keep a stock of at least 72 hours of non-perishable food and water onsite.

Recommendation 37b (Strategic): Future NWS construction should be designed as storm-resilient offices that provide sleeping, shower, and eating facilities for staff.

6. Decision Support Services

The NWS provided a host of products and services to help its partners and users prepare for, respond to, and recover from the likely impacts of Irene as it moved from the Caribbean along the U.S. East Coast.

6.1. Products

6.1.1. Inland Flood Warnings

Although a tropical storm at the time, Irene wrought much of its worst damage inland in the Mid-Atlantic and New England communities as much as several hundred miles away from the Atlantic coastline. The large volume of rain falling on soil already saturated, then quickly running off into waterways already at high levels, triggered intense and destructive flooding.

Communicating the threat of inland flooding associated with tropical cyclones to the media and everyday users remains a challenge. NWS offices issued seven different hydrologic product types to convey the flooding threat from this storm, which cluttered hazard maps and created confusion. Some media partners opted to stop receiving flood warning updates because they were too numerous and confusing.

"We can't even keep them straight. We turned the automatic notification off all together."
–Matt Noyes, Meteorologist, New England Cable News

These media partners also refused to use a graphic display of flood and flash flood watches and warnings due to the complexity of the hazards map.

"It is hard to explain the different colors on a watch/warning map to viewers..."
–Sharon Meyer, WCAX, CBS Burlington, VT

Three prior Service Assessments highlighted the confusion over the numerous hydrologic products:

- **2011:** Spring 2011 Middle & Lower Mississippi River Valley Floods: Section 3.1.7
- **2010:** Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010: Section 3.3
- **2009:** Southeast United States Floods: Section 3.5.2

Feedback from NWS product users reflected a lack of understanding for Irene's extreme hydrologic potential:

"We didn't get a forecast from the National Weather Service that made us sit up and pay attention." –Ross Sneyd, News Editor, Vermont Public Radio.

"We had no warning saying it would be so bad. I knew it was going to rain a lot, but I thought it was going to be the kind of rain that would test the patch I just put on my

roof. I had no idea it would be the kind of rain that would wash my neighbor's house away." –Rochester, VT, Selectman

"I never saw any forecast that suggested rivers might crest at record levels; however the warnings of record flooding were certainly there. Although it was listed as Flash Flood Watches, I'm not sure the public makes that distinction as a flood warning. In retrospect, I would put more emphasis on that." –Mark Breen, Eye in the Sky forecaster for Vermont Public Radio.

The volume, complexity, and length of various hydrologic warning products issued by WFOs was overwhelming to partners and confusing to users. EMs and media partners struggled to find the most critical information; impacts were often buried in the messages. The service assessment team supports Recommendation 12 in the *Spring 2011 Middle and Lower Mississippi River Valley Floods* Service Assessment identifying the need to simplify the suite of hydrologic products.

As Irene approached the mainland United States, forecasts of associated extreme rainfall amounts by HPC were consistent and accurate. Using HPC's forecasts, the RFCs produced high quality river forecasts for moderate and major flooding with lead times for many locations exceeding 40 hours (NERFC average lead time = 43 hours, MARFC average lead time = 31.5 hours). Flood and flash flood watches and warnings issued by the WFOs met or exceeded the national performance lead-time goals. WFOs issued various hydrologic watches (flood or flash flood) on Friday, August 26, that provided around 2 days lead time for the event. For initial flash flood warnings, the average lead time was 38 minutes and probability of detection was 0.72. WFO Albany's performance of 3 hours average lead time for its flash flood warnings was particularly noteworthy. In addition to the exceptional forecasts, coordination with external and internal partners began 5 to 6 days prior to any impacts.

"Had it not been for the proactive posture of the NWS Albany staff and the accurate and timely information provided, the cost in human loss would have been devastating."
–Mark Ferrari, Director, New York State Office of Emergency Management, Region II

A number of NWS and partner agency staff mentioned coordination of hydrologic events during Irene was much improved compared to past storms. This change was largely attributed to the SCH positions added to RFCs several years ago.

Based on interviews, the more sophisticated users of hydrologic forecast information all seemed to recognize the severity of expected impacts and the confidence in that forecast. For others, however, interviews indicated the transition from watch to warning was a trigger for increased confidence in the urgency of the situation. The lead time for hydrologic warnings issued by the WFOs was short, as shown in **Table 1**.

Table 1: Average lead times for initial river flood and flash flood warnings issued by WFOs during Irene.

WFO	Average Initial River Flood Warning Lead Time	Average Initial Flash Flood Warning Lead Time
Albany	3.2 Hours	3.0 Hours
Boston/Taunton	7.5 Hours	0.58 Hours*
Gray	5.0 Hours	0.91 Hours
Burlington	1.3 Hours	1.65 Hours
Binghamton	4.7 Hours	1.53 Hours
Philadelphia/ Mount Holly	12.1 Hours	2.5 Hours

* WFO Boston/Taunton used flash flood warnings to issue flash flood emergencies for areas already covered by existing areal flood warnings.

Despite generally high confidence in the QPF, WFOs were reluctant to issue flood warnings for mainstem river locations until the rain started. Although there was strong wording in some flood and flash flood watches, these products do not convey urgency to the extent warnings do. Additionally, warnings trigger activation of the Emergency Alert System (EAS) and, therefore, have better penetration in the media. In some cases, issuing flood warnings before the onset of rainfall is justified due to unusually high forecast confidence levels, especially given the expected impacts, potentially resulting in an earlier public response.

Finding 38: The public and media did not fully recognize the devastating flood threat that land-falling tropical cyclones pose for inland areas of New England.

Recommendation 38a (Operational): When there is high confidence of a historic flood event, the NWS should use all available tools and imperative language to convey the urgency and to ensure the message is timely, clear, and understood by the media and decision makers. Forecasters should be encouraged to modify guidelines and cultural practices and issue flood warnings, thus increasing lead time, rather than waiting until they receive reports of extreme rainfall or flooding. NWS should provide training on how to balance the relationship between forecast confidence levels and potential high impacts to extend lead times.

Recommendation 38b (Strategic): NWS should partner with the media and social scientists to educate the public on the inland flooding threat associated with landfalling tropical cyclones, especially in areas such as New England where such events are rare.

6.1.2. Hurricane Local Statement

The HLS is the flagship WFO tropical product, yet the majority of users interviewed found the HLS inconsistent, verbose, and ineffective. HLS production is resource intensive.

The HLS issued by WFOs Philadelphia/Mount Holly and New York City/Upton ranged from 10 to 13 pages. NWS staff, media, and EMs commented negatively on the excessive length of the HLS.

> *"(HLS products) were too long if you were trying to deal with multiple offices, too much to read.... It was difficult to find the HLS on NWS office Web sites."*
> –Brian Norcross, The Weather Channel.

Fact: On average, it took about 1 hour for each of the 12 Irene-impacted WFOs to issue an HLS after the release of the NHC tropical cyclone watch/warning text product (TVC).

Fact: The HLS required a dedicated forecast shift and workstation, which resulted in a variation in HLS content, organization, and length from WFOs.

Previous NWS service assessments also found the HLS problematic. In the Hurricane Charley, August 9-15, 2004, Service Assessment, the team observed, "*Not all HLS users across Florida shared [the same] sentiment. Some found the HLS to be of little use because they contained too much information given in other products, covered too wide of an area, were too long, and often repeated the same information contained in previously issued HLS*."

The HLS has become a problem because it evolved from a single, user-specific product into a product that should satisfy the needs of numerous users.

Finding 39: The HLS is inefficient and ineffective. NWS should consider both a short-term (operational) and long-term (strategic) solution.

Recommendation 39a (Operational): The NWS should modify the HLS using input from social scientists. Changes to the HLS should include:

- Structuring it in a bulleted format like the NWS winter storm/non-precipitation/red flag warning products
- Reducing the product's length
- Including event-driven, impact-based updates, as opposed to static update times
- Reducing generation time by at least 30 percent

Recommendation 39b (Strategic): The NWS should develop requirements for a Web-based HLS using input from social scientists. These requirements should include:

- Putting location of impacts first
- Including graphics, images, and video depicting all expected impacts

- Adding a site-configurable template to allow forecasters to populate the HLS with pertinent information similar to selecting CTAs
- Offering the ability to automatically populate with NDFD grids

Irene proved that inland WFOs have an infrequent but real need to communicate tropical cyclone impacts to their users. A WFO can only issue hurricane and tropical storm watches/warnings through the HLS; some inland offices do not have that capability. These offices were unable to issue the appropriate advisories and warnings. The net result was that within Vermont, adjacent counties were not under the same advisory or warning, creating public confusion.

> *"Southern Vermont and the southern Adirondacks are under a Tropical Storm Watch for the weekend, an unusual designation signaling the enormous scope of Irene as it heads northward."* **–**The Burlington Free Press, August 26.

WPTZ Burlington/Plattsburgh NBC Chief Meteorologist Tom Messner said the different types of warnings were "*hard for viewers to understand*."

Best Practice: Although WFO Burlington was unable to issue an HLS product, they improvised and constructed a special weather statement, which mimicked in many ways the format and information found in an HLS. This product was first issued 2 days prior to Irene's impact and continued through the event. Feedback from the media was positive.

Finding 40: The inability of some WFOs to issue salient and appropriate advisories and warnings needs to be resolved.

Recommendation 40 (Operational): All WFOs facing the potential for significant impacts from a tropical cyclone should have capability to issue an HLS.

6.1.3. Tropical Cyclone Watches and Warnings

In striving toward the reality of a WRN and its focus on the impacts of severe weather, the NWS needs to adjust its use of tropical cyclone watch and warning products and the associated forecasts of sensible weather elements to communicate the impacts clearly with the greatest advance notice possible.

The team discovered a perceived inconsistency between the criteria NHC used to issue hurricane warnings, and the actual deterministic wind field forecasts within some areas covered by the hurricane warning. NWSI 10-604, Tropical Cyclone Weather Services Program, defines the threshold for such hurricane warnings as anticipated winds of 64 knots (74 mph) or greater within the specified area. In addition, NHC rightly incorporates uncertainty in tropical cyclone track and intensity forecasts when determining the areal extent of a hurricane warning. The result, due to this uncertainty, is that nearly always an area covered by a hurricane warning will not have a deterministic forecast of hurricane force winds. An example of this occurred during Irene when a hurricane warning was issued for WFO Boston/Taunton's CWA when the maximum wind value in the corresponding deterministic forecast wind grids (NDFD grids) was only 54 knots (62 mph). This forced the WFO staff to spend time explaining the perceived inconsistency to its media partners.

NHC products were sometimes perceived as sending an inconsistent message regarding an impending threat. For example, representatives of local and national media in New York and New England expressed concern about a false sense of security derived by some people in areas not specifically mentioned as under threat in the public advisory text products, while at the same time, the NHC track graphic clearly showed them within the 5-day cone of uncertainty. For example, the 5-day uncertainty cone graphic issued at 2 a.m., Wednesday, August 24, showed an "H" symbol directly over Manhattan surrounded by a large hashed area extending nearly to the Canadian border. The first mention of a threat in the public text advisory to anywhere north of the Mid-Atlantic states was at 5 p.m., Wednesday, August 24.

Media representatives have commented the timing of watches and warnings are inflexible, even when there is high confidence of risk, "*…a major threat to a highly populated, vulnerable coastal area should change how NHC operates*."

Finding 41: At times, current practice in the way tropical cyclone warnings and associated deterministic wind forecasts are issued creates confusion and concern on the part of media partners and other customers.

Recommendation 41 (Operational): NWS, working with Social Scientists, media partners, and EMs, must improve understanding of NHC hurricane warnings and how they relate to deterministic forecasts. Results should include clear and consistent definitions of terms and phrases related to tropical cyclones. In addition, appropriate impact messaging should be directed to all geographic areas within the 5-day cone of uncertainty, and traditional watch and warning lead times should be flexible when confidence allows and impacts are expected to be significant.

Flexibility in issuing watches and warnings is also needed when confidence is high that a tropical cyclone will develop. WFO San Juan staff expressed a need to have a tropical storm watch issued before naming a system when confidence is relatively high that the system will impact Puerto Rico or the U.S. Virgin Islands.

Finding 42: At times, too little time remains after naming a system to issue a watch, and instead NWS issues a warning. As a result, the EM community and the public are left with less time to prepare and react.

Recommendation 42 (Strategic): When confidence exists that a tropical wave will develop into a tropical storm or hurricane and potentially affect land within 2 days, NHC and the affected WFOs should issue a watch, even when the system has not been named.

Some users also believe the NHC intensity analyses were too high during the slow weakening phase. Approximately 10-20 percent of the official high forecast bias during the slow weakening phase can be attributed to the initial (analysis) intensity error.

Operational intensity assessments (analyses) had a high bias. This bias was partly a result of traditional operational inertia (continuity constraint) and a concern that strong winds aloft, as sampled by aircraft observations, might descend to the surface if the core redeveloped.

Finding 43: Analyses of Irene's intensity often had a high bias during the weakening phase of the storm.

Recommendation 43 (Operational): NHC should identify strategies to help mitigate occurrences of a high bias in intensity analyses.

Timing, as well as the use of definitions, created another difficulty. A Tropical Cyclone Update (TCU) was issued at 9 a.m., Sunday, August 28, 2011, to indicate Irene was reclassified from a hurricane to a tropical storm; however, NHC did not issue a special advisory package or subsequent TCU to update existing watches and warnings to match this new classification. The next full advisory package was issued at 11a.m., Sunday, August 28, 2011. NHC kept the hurricane watches and warnings up due to a "provision in the definition of a hurricane warning that allows the warning to remain in place on account of high water, even after winds fall below hurricane force." This definition of watch/warning is not commonly known outside of NHC, however, and confusion among WFOs and the media resulted.

Finding 44: Current policies at NHC allowed a several hour gap during which Irene had been downgraded, but a hurricane warning was still in effect. This caused confusion for WFOs and the media in the impacted area.

Recommendation 44 (Operational): NHC should issue a TCU to change the watch/warning status of a tropical cyclone. This action will avoid delays in clearly communicating changes in tropical cyclone status between advisory packages.

Communicating a well-crafted message to the public requires a nuanced understanding of how people interpret specific words in the context of a forecast. NHC, WFOs, and the media used the phrases "*weakened into a Tropical Storm*" and "*downgraded*" when describing changes in the meteorological conditions during the progress of Irene, with unintended and unanticipated consequences.

> *"I think that what I needed to hear was that the downgrade to a tropical storm does not mean that this is no longer a threat."* –Central Vermont resident

> *"I mean they said 'There's this huge, huge hurricane, oh my God... and then it was like 'Oh it's downgrading, Oh it's downgrading, and now it's just a tropical storm,' right, and that's what we heard! And so it was like 'Oh, it's not really that big of a deal now..."* –Central Vermont resident

Finding 45: The use of some terms, although scientifically accurate, creates potentially dangerous misperceptions on the part of the public.

Recommendation 45 (Strategic): Use of terms such as "*downgraded*" and "*weakened*" should be carefully contextualized in statements intended for the public. NHC should work with social scientists to determine the most effective language to use in cases where a tropical cyclone is weakening but significant threats still exist.

6.1.4. Storm Surge

The NWS provided its partners and users with a set of storm surge decision support products during Irene, similar to those provided during other tropical cyclones that threaten the coast. These products include the Maximum of the Maximum Envelope of High Water (MOM), Maximum Envelope of High Water (MEOW), Probabilistic Storm Surge (P-Surge), the storm surge sections of the NHC's advisory, and the WFOs' HLS. In addition, NWS began providing an Internet SLOSH Display Program in 2009 for trained EMs, FEMA personnel, and NWS forecasters to display the latest NHC real-time runs. NWS partners often use these products together depending on the number of hours before predicted landfall of a tropical cyclone. Three storm surge products frequently used when a tropical cyclone is forecast to make landfall within 48 hours are the P-Surge, the storm surge section of the NHC advisory, and the storm surge section of the HLS.

P-Surge is a graphical product depicting the overall probabilities that a specified storm surge height will occur at individual locations on the map during the indicated forecast period. The probabilities are calculated by statistically evaluating a large set of SLOSH model runs based on the latest NHC official forecast and taking into account historical errors in NHC track and intensity forecasts. The SSU generates the storm surge section in the NHC advisory, which provides real-time storm surge forecasts at a regional scale in text format. The storm surge section of the WFOs' HLS refines storm surge forecasts to a local scale. These forecasts are occasionally coordinated with the SSU.

Overall, NWS storm surge forecasts were on target for Irene, and NHC SSU provided outstanding and nearly continuous support to affected WFOs, ERH ROC, and external partners. However, the team found that understanding and communicating NWS storm surge/storm tide forecast information was one of the most difficult challenges faced by the NWS, EMs, and the media during Irene. The team received comments that the storm surge forecasts were sometimes perceived as being insufficient, confusing, and conflicting.

> "*EM's don't understand or remember how to use/interpret SLOSH… Outside of a few coastal flood savvy EMs and local officials... there is considerable confusion on their part on what the datums mean in terms of real world impacts*." –MIC at coastal WFO

> "*The storm surge forecast was excellent but we are missing the ability to communicate it more visually,*" and "*NHC should provide storm surge values in the public advisory starting with when a hurricane watch is issued, not just when a hurricane warning is issued.*"
> –The Weather Channel staff

The most widespread comment about forecasts heard from EMs, government officials, WFO forecasters, and media was that the text forecasts are insufficient and that NWS needs simplified, graphical, impact-based coastal inundation forecast maps. For example, the New York City Office of Emergency Management (NYCOEM) Commissioner stated:

> "*Mayor Bloomberg asked me every time, 'If I walk out of my door, how far will the water be up on my legs' ...He doesn't want to know 12 feet, 8 feet, etc.... The more you can give me about the impact of surge by area—that would be helpful. Graphical inundation forecasts would be helpful.*"

In addition, NYCOEM, numerous Emergency Management Associations (EMA) and FEMA Region III HQ personnel expressed a critical need for coastal inundation forecast maps extending out to 72–96 hours to help them in evacuation planning, especially for elderly and special needs populations.

The team found that there was at least one occurrence of users and partners being confused with NWS probabilistic storm surge forecasts. The media in North Carolina relayed to the team a confusion caused by a probabilistic storm surge forecast distributed by WFO Morehead City. A North Carolina reporter stated there was a perceived "*drastic change*" in the graphical probabilistic forecast from Advisory 24 to Advisory 26 (**Figures 12** and **13**). The probabilistic surge *graphic* issued at 5 p.m. Friday, August 26, and shown in **Figure 13** (Advisory 26) differed significantly from the official NHC surge forecasts contained in the *text* advisory.

NHC *text* advisories contained a surge forecast of 6 to 11 feet until Advisory 28, which was not issued until 5 a.m., Saturday, August 27 (2.5 hours before landfall in North Carolina), indicated the storm surge forecast for Albermarle and Pamlico Sounds was reduced to 5–9 feet. In addition, these graphical forecasts did not include astronomical tide anomalies, which should be factored in manually to obtain storm tide. Development is underway by NWS to automate the incorporation of tides for 2013.

> "*Surge: we said '5–7 [feet]' but it was higher. Worst ever in Pamlico Sound. It was a bad Category 1 storm. People are fixated on the category. This one shocked some folks. Viewers were upset with the Storm Surge Forecast and confusion.*"
> –North Carolina Broadcast Meteorologist

Another North Carolina media member stated,

> "*Viewers were upset with the Storm Surge Forecast and confusion.*"

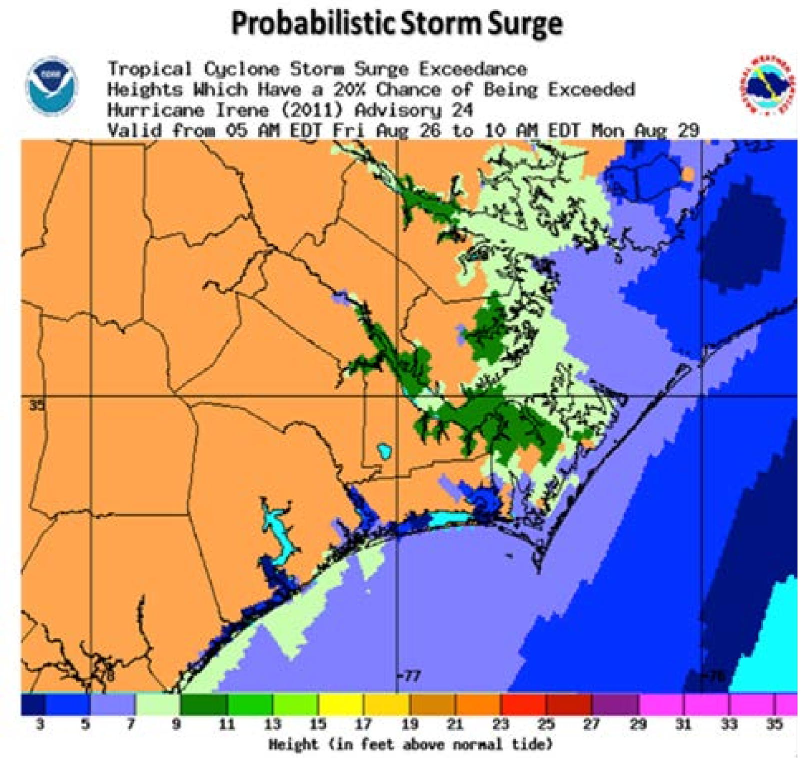

Figure 12: The height of the surge displayed for a 20 percent exceedance.

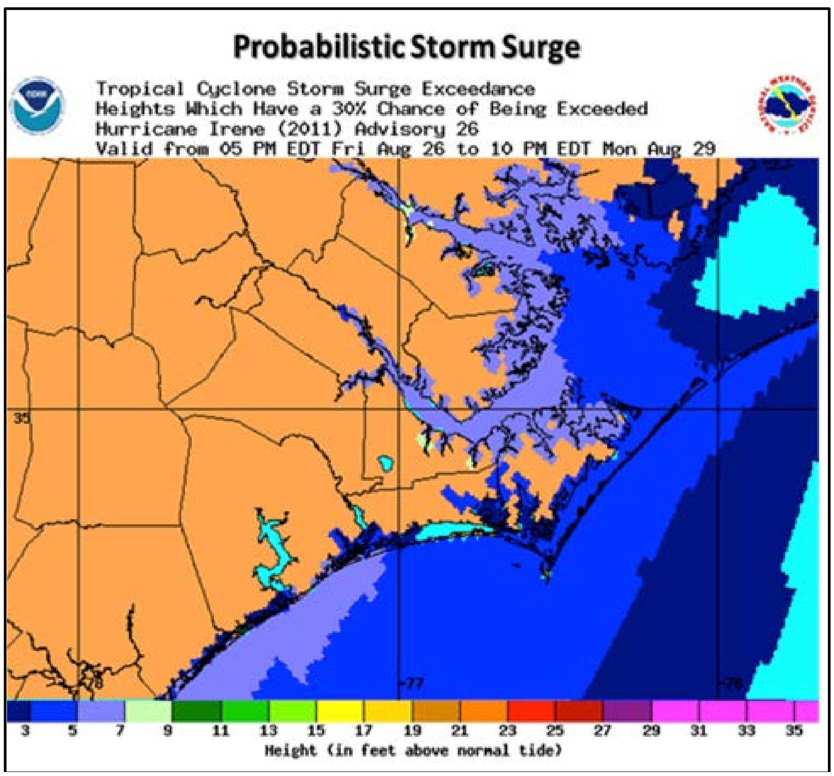

Figure 13: The height of the surge displayed for a 30 percent exceedance.

The team received comments from users and partners emphasizing the need for better communication of storm surge/storm tide information and focus on impacts. A graphical approach to storm tide in the form of interactive coastal inundation above ground level (AGL) forecast maps with an expression of horizontal and vertical uncertainty would meet the needs of partners and users. Graphical inundation mapping based on AGL would clear up confusion over vertical datums (e.g., Mean Lower Low Water, Mean Sea Level) and confusion between storm surge and storm tide terminology.

Currently, the NWS does not have the capability to provide such inundation maps; however, NOAA is developing this capability and has reached out to the community to discuss, identify, and catalogue best practices in coastal inundation mapping. One of the major goals of the NOAA Storm Surge Roadmap is to develop the next-generation storm surge modeling and mapping capability in NOAA. Eventually NOAA plans to provide a large-scale, street-level forecast coastal inundation mapping capability. Using the identified best practices along with results from an HFIP-funded social science project, NHC is developing and prototyping inundation graphics for possible experimental implementation during the 2013 Hurricane Season. For the 2012 Hurricane Season, MDL is making its Probabilistic Hurricane Inundation Surge Height (PHISH) model guidance available in a Google Map interface.

In addition, graphical coastal inundation forecast maps would serve as a singular, authoritative, and collaborative forecast between WFOs and SSU. SSU and local offices could incorporate even experimental NOAA and academic products into this collaborative forecast. This approach would minimize conflicting information among different NWS products when WFOs use experimental model guidance to provide a local storm surge forecast.

Finding 46: Irene revealed confusion over storm tide/surge terminology, vertical datums (e.g., MLLWS, AGL, NAVD 1988, HAT), and effects (actual physical impact on land) among WFOs and a wide range of users of NWS tropical cyclone products. NWS partners and media strongly expressed their need for coastal inundation forecast maps.

Recommendation 46 (Operational): The NOAA Storm Surge Roadmap, which includes improving communication, outreach, and education regarding definitions and use of storm tide, storm surge, and datums and to create coastal inundation forecast maps and corresponding impacts, needs to be a top NWS and NOAA priority.

Another issue the team discovered was that coastal WFOs and NHC did not have a convenient tool to convert between different vertical datums. Many WFOs needed to express their storm tide forecasts in different datums to meet the needs of their users and partners.

In the months following Irene, NOS and NWS worked together to help coastal WFOs and SSU easily convert between different datums. NOS shared its Vdatum Transformation Tool database with NWS. Additionally, NOS modified select VDatum transformation fields to provide coverage of overland inundation areas. NWS used this data to modify the WFO's TCCoastalFlood Threat tool in AWIPS so forecasters can choose the datum for storm surge model output (above MSL, MLLW, and NAVD 88), depending on their users' needs. Use of this tool was covered in NWS's tropical cyclone products training in 2012. In addition, NWS has been working with the AWIPSII contractor to port this tool to AWIPSII.

The team also found that there was a lack of local expertise to help partners and users interpret storm surge model guidance and forecasts. In addition, to convey the impacts of storm surge to users, local offices require a better understanding of how storm surge relates to beach and dune erosion, barrier island breaching, and structure and infrastructure damage.

It is essential NWS provide around-the-clock support to field offices and external partners during events that may produce dangerous marine and coastal storm surge and wave impacts. This support is a difficult task given the insufficient federal employee staffing in the SSU.

Finding 47: The available information regarding damage potential is limited and affected WFOs need knowledge of surge and wave impact based on their local geomorphology to better inform customers of impact potential. The NWS, USGS, and USACE have significant interest in better understanding this issue and in conducting additional research in this area.

Recommendation 47 (Strategic): NWS, through the National Hurricane Program, needs to closely coordinate research on tropical cyclone-related geomorphological impacts with the USGS and USACE, both of which have existing knowledge from which the NWS would benefit.

An ERH staff member was working shifts in the ROC while coordinating storm surge conference calls with NHC or WFOs and providing best estimates of surge around NYC to an embedded meteorologist in the NYC EOC, who, in turn, briefed the NYCOEM.

Finding 48: NWS has an insufficient number of storm surge and wave experts at the local and regional office level. The primary function of these experts is providing expertise in storm surge and wave forecast formulation and interpretation to the WFOs while working with the SSU.

Recommendation 48 (Operational): NWS should train and provide additional storm surge and wave experts at the NWS Regional and WFO levels to answer storm surge and wave-related questions from EMs and coordinate with SSU.

Best Practice: WFO Morehead City completed detailed surge surveys immediately after Irene. Three teams went out consecutively for 5 days to map high water marks and document impacts from the storm surge. Response from the community was resoundingly positive. Service hydrologists from WFOs Raleigh, Wilmington, and Cleveland participated in the storm surge surveys.

“ *Our challenge to you is to take a look at the surge forecast and match it up with the observations of what really occurred, and tell us how well you did…*”
–Michael Lee, Special Assistant to Mayor Bloomberg

Finding 49: While post-storm surge surveys are conducted by several groups, there is a need to coordinate these efforts and quickly collect observations of actual storm surge heights after tropical cyclones.

Recommendation 49 (Operational): NWS should coordinate with NOS and USGS to gather and consolidate post-storm surge and storm tide gage observations and high water marks in a common database.

Finding 50: GIS-compatible maps of observed coastal inundation will assist in the refinement of prediction inundation maps and future service assessments. Many external partners expressed interest in post-storm coastal inundation maps. These maps also would be useful to evaluate planned NWS coastal inundation forecast maps.

Recommendation 50 (Strategic): NWS should consider undertaking joint research efforts with NOS/CO-OPS, USGS, and USACE to produce GIS-compatible maps of *observed* coastal inundation for significant tropical cyclones using observational data and storm surge model hindcasts.

6.1.5. Wind and Severe Weather

The magnitude of Irene's impact brought to light many challenges in collaborating and in communicating relevant warning information among WFOs, national centers, the media, EMs, and ultimately, the public.

Best Practice: WFO Wilmington developed and shared Call to Action statements (CTA) for falling trees, branches, and wind damage that are effective public messages appropriate to land-falling tropical systems. Messages are descriptive and include appropriate actions for the public. The following are a few examples of CTAs that could be used in products during a land-falling tropical system:

- **Stay inside**

```
Going outside for any reason during the storm can lead to serious injury
or death.  Strong winds can turn debris into deadly projectiles.  Trees
and large limbs will likely continue to fall.
```

- **How to shelter in place**

```
Strong winds can knock down trees and tree limbs...creating flying debris.
To avoid serious injury or death...stay inside away from exterior walls.
If possible...stay in an interior room on the lowest floor.
```

- **Driving Hazards**

```
Do not venture onto the roads during the storm.  Downed limbs and trees on
the road will create significant road hazards.  A tree or tree limb can
fall onto your vehicle...resulting in serious injury or death.
```

Finding 51: CTAs for trees, branches, and other debris falling due to strong winds should inform the public of appropriate actions to take, not just describe possible damage.

Recommendation 51 (Strategic): The NWS should compose AWIPS-baselined CTAs for trees, branches, and other debris falling due to strong winds. These CTAs must contain appropriate actions to take.

Wind hazards specific to large cities, such as increased wind speeds with increased height above the ground, were not quantitatively addressed in a way users could translate into action.

"*We need actionable guidance to help with evacuation decisions due to increased wind hazards in high rises…*" –Michael Lee, Special Assistant to New York City Mayor Michael Bloomberg

Finding 52: Specific, actionable guidance related to increased risk due to winds in high-rise buildings does not exist in the current NWS suite of tropical cyclone warning products.

Recommendation 52 (Operational): NWS should formulate specific guidance to communicate increased wind risk in high-rise buildings during tropical cyclones.

A higher than average tornado warning false alarm rate in some areas caused consternation among some media partners. WFO Philadelphia/Mount Holly issued 16 tornado warnings , two of which verified; however, the post-event damage survey was challenging due to widespread tropical storm-induced wind damage and may have contributed to the high false alarm rate. Other WFOs have had a similar experience, including WFO Raleigh during Tropical Storm Lee (2011), which issued more than a dozen tornado warnings but confirmed only three tornadoes (*Blaes, WFO Raleigh, Collaboration for Improved Meteorology in the Mid-Atlantic and Southeast, Sept. 2011).*

Local media were dissatisfied with the high rate of tornado false alarms in the greater Philadelphia area. A TV meteorologist in Philadelphia expressed strong displeasure with the large number of tornado warnings issued during Irene and the high false alarm rate, which, in his opinion, distracted from the coverage of the main hurricane threats, which were wind and flooding. In addition, the meteorologist stated, "*the numerous tornado warnings affects* [sic] *news management in a totally wrong way*."

Finding 53: Multiple tornado warning false alarms during tropical storms damaged NWS credibility and failed to focus public attention on the actual wind-related risks.

Recommendation 53 (Operational): The NWS should work with the scientific community to develop case studies and criteria to assist NWS forecasters in issuing tornado warnings associated with landfalling tropical cyclones.

Wind speed forecasts were generally too high during Irene in the Philadelphia and New York City areas. This illustrates the need to understand how to translate open ocean measurements of tropical cyclone wind speeds aloft and at the ocean surface to wind speeds over land as the tropical cyclone moves inland.

Reported peak sustained winds within the WFO New York City/Upton CWA ranged from 40 to 45 mph across coastal Connecticut, 32 to 36 mph in the NYC area, and 45 to 50 mph across Long Island. Reported peak wind gusts within the WFO New York City/Upton CWA ranged from 52 to 65 mph across coastal Connecticut, 45 to 58 mph in the NYC area, and 56 to 90 mph (associated with a microburst near Sayville, NY) across Long Island; however, the forecast winds were much higher just several hours prior to landfall.

> "*SUSTAINED TROPICAL STORM FORCE WINDS ARE EXPECTED TO DEVELOP OVERNIGHT...WITH HURRICANE FORCE WINDS POSSIBLE BY EARLY SUNDAY MORNING. MAXIMUM WINDS ARE FORECAST TO BE IN THE 50 TO 70 MPH RANGE WITH GUSTS UP TO 80 MPH.*"

Finding 54: The limited number of observations of hurricane force wind gusts within areas under a hurricane warning led to the perception by the media and the public that deterministic wind field forecasts were too high, particularly for hurricane-force winds.

Recommendation 54 (Strategic): In addition to the need for better estimates of surface wind speeds/intensity in tropical cyclones prior to landfall (see Recommendation 43), WFOs in close collaboration with NHC and their neighboring and backup offices, should apply meteorologically appropriate inland surface wind speed reductions as opposed to a blanketed wind reduction. NWS should support research such as the NOAA Collaborative Science, Technology, and Applied Research (CSTAR) project, "Improving Understanding and Prediction of Hazardous Weather in the Southeastern United States: Landfalling Tropical Cyclones and Convective Storms." This change will likely require the development of a more robust and scientifically sound smart tool that applies spatially varying wind reductions that more appropriately account for boundary layer meteorology and topography.

6.1.6. Local Storm Reports

Consistent with the aims of WRN, Local Storm Reports (LSR) provide essential information to the media and the public.

Best Practice: WFO Newport/Morehead City issued nearly 100 LSRs when Irene was affecting its CWA. This information was immediately and effectively disseminated through local media.

6.1.7. Aviation Impacts

Irene caused major disruptions to the airspace across the East Coast. Nearly 12,000 flights were cancelled, affecting approximately 650,000 passengers. Representatives from several major airlines were interviewed with regard to NWS products and services during Irene. Comments were favorable and included:

> "*The infrastructure investment NWS makes is invaluable to us.*" Delta Airlines staff
> *"The track forecast was great."* –Southwest Airlines staff

As Irene approached the United States, the NWS provided decision support through CWSU New York to New York and Philadelphia Terminal Radar Approach Control, NY Air Route Traffic Control Center, and New York area airport towers.

CWSU ZNY routinely issues the New York oceanic forecast for Day 1 at 10 a.m. and 10 p.m. The coverage extends out to 40W and between approximately 20N and 45N. The forecast provides information for international planners on sub-SIGMET criteria such as icing, turbulence, and thunderstorm activity throughout CWSU ZNY's oceanic sectors.

CWSU ZNY also issues an experimental version of the product for Day 2 (valid 8 a.m. – 2 p.m.) at 1 p.m. on an as-needed basis. This forecast is conveyed to FAA traffic managers and planners verbally and illustrated with hand-drawn graphics for tropical cyclones. FAA traffic managers use the Day 2 oceanic forecast outlook to determine if main traffic routes over the West North Atlantic Ocean need to be closed the next day because of tropical cyclone conditions.

Finding 55: During Irene, the FAA New York Air Route Traffic Control Center Boundary traffic managers found the experimental Day 2 product very helpful.

Recommendation 55 (Strategic): NWS OCWWS, in collaboration with NWS regional headquarters and the FAA, should develop requirements for an official Day 2 oceanic forecast outlook, or equivalent product, geared to tropical conditions affecting CWSUs with overwater forecast responsibilities along the Atlantic and Gulf of Mexico Coasts.

6.2. Designing Products to Meet End User Needs

NWS staff, especially at forecast offices, dedicate enormous energy and time to customizing materials and translating current NWS products into usable information for stakeholders. This customization includes such activities as creating text-based messages, visual representations, and storm tracks. To do this effectively, it is important that NWS staff understand the sensitivities and knowledge level of users when conveying storm-associated threats such as inland flooding, wind, and surge, and when recommending actions.

Despite this effort to customize products, the NWS liaison to FEMA Headquarters was frustrated by a lack of appropriate material from the NWS product suite to use when briefing FEMA decision makers on the potential impacts from Irene. She said FEMA finds the NWS products hard to understand and interpret. Even the President of the United States used a private weather company's Web page (Stormpulse.com) to monitor the track of Irene. Stormpulse® does not produce its own forecasts. Its Web site states, "*Stormpulse monitors weather threats to your operation by combining the location of your facilities with the latest forecasts and observations from the National Weather Service.*" Stormpulse simply packages NWS information in a more interactive, user-friendly format.

Finding 56: The standard NWS product suite, while meaningful to some NWS personnel in preparing briefing products during Irene, is tailored to subject matter experts. In some cases, it did not sufficiently explain risk or potential impacts to key national and local decision makers.

Recommendation 56 (Strategic): NWS needs to improve information services and product delivery to convey relevant impacts, risks, and the urgency of required actions associated with landfalling tropical cyclones for use by decision makers without meteorological expertise. This includes the creation of a more user-driven information platform in which users can create customized services primarily through digital media and on mobile devices. This new generation of NWS products and services must be adapted to the needs of a range of key decision-support partners.

Fact: AWIPS text formatters use a combination of official NHC watches and warnings, official WFO deterministic wind fields, and 64- and 34-knot probability grids to assign forecast phraseology to the forecasts; i.e., Hurricane Conditions, Hurricane Conditions Expected, Hurricane Conditions Possible.

Finding 57: Incorporation of probabilistic wind impacts into a deterministic wind forecast remains a challenge. Existing probabilistic triggers for phraseology in text and graphical forecasts were not universally understood within the NWS and among external partners.

Recommendation 57 (Strategic): NWS needs a comprehensive, social science-based approach to incorporate universally understood, probabilistic information into tropical cyclone forecasts.

6.2.1. Coastal and Inland Inundation Mapping:

"*Where is the water going to go, and how bad will it be?*" These were the key questions for communities threatened by both coastal and river/stream floods during Irene. A clear and easily understood response to these questions requires GIS-compatible inundation forecast maps for inland and coastal flooding to convey flood threat to the media, EMs, and the public. These issues are not new; they have been highlighted as service gaps in previous assessments (see the Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010). Specifically, the key issues are an inability to display on inundation maps:

- Geographic extent and severity of the forecasted inundation
- Forecast uncertainty
- Potential impacts from flooding

Graphical tools, outreach, education, and forecaster training are all needed so NWS may best serve its partners and the public by clearly communicating hydrological threats.

The NWS, in close collaboration with NOS, USGS, FEMA, USACE, and others, needs to develop a large-scale, street-level coastal and inland flood inundation forecast mapping capability. The need for *GIS-based* inundation forecast maps is clear as stated in the IWRSS Roadmap and the NOAA Storm Surge Roadmap. During Irene, local, state, and regional EMs, responders, and media requested interactive tools that depict coastal and inland flood inundation maps. EMs stated a need for maps showing high-risk areas based on rainfall forecasts to increase public awareness and improve evacuation planning. Surge information for relevant runway complexes lacked resolution inside of 24 hours and did not exist beyond 24 hours. Runway complex impacts at LaGuardia, JFK, and Logan Airports included not only wind and rain but also storm surge.

Both Service Hydrologists (SH) and their users expressed a strong need to get Advanced Hydrologic Prediction System (AHPS) inundation mapping for river forecast points. The Susquehanna River Basin Commission expressed appreciation for the AHPS flood inundation mapping in place for the West Branch of the Susquehanna River at Jersey Shore.

"Just want to say THANK YOU for your promotion of the [inundation] maps; it is thoroughly appreciated! Also, your briefings have been timely and helpful! Keep up the great work and good luck to you and your team as we get through this storm."
–Ben Pratt, Susquehanna River Basin Commission.

Numerous partners in the Northeast specifically noted GIS-based flood inundation maps showing forecast river-flood levels would have been extremely beneficial prior to and during Irene. These partners requested GIS-compatible formatted files (e.g., shapefiles, KML) for maps and access via HURRicane EVACuation (HURREVAC) Tracking and Analysis software. New Jersey EMA staff requested the maps be available via Open Geospatial Consortium **(**OGC) Web Map Services.

"*What does 8 inches of rain mean?*" This question, heard from many sources with respect to Irene, exemplifies a need to provide much clearer impact-based visualization of the risks from flood and inundation.

The multi-agency Integrated Water Resources Science and Services (IWRSS) Consortium and a new National Water Center (NWC) could be valuable resources in working toward this goal. IWRSS and the NWC are foundational to meeting NOAA's Next Generation Strategic Plan and the WRN Roadmap for improved freshwater management. IWRSS is an innovative partnership between NOAA, USGS, and USACE, to meet the growing demand for enhanced water resources information. IWRSS will deliver an accessible new suite of national, high-resolution water resources information and forecasts through joint modeling activities and seamless system interoperability and data synchronization of improved water information between federal agencies. The NWC under construction in Tuscaloosa, AL, is scheduled for completion in June 2013. It will be the first U.S. center for water forecast operations, research, and collaboration across federal agencies. Collaborative NWC activities will enable the NWS, in partnership with other federal agencies, to provide EMs and the public with detailed maps that explicitly show forecasted locations and effects of flooding for faster and more effective evacuations.

Finding 58: The NWS is not meeting user needs for inland and coastal flood inundation forecast maps.

Recommendation 58 (Strategic): NOAA, leveraging resources such as the NOAA Storm Surge Roadmap, IWRSS, and NWC needs to provide inland and coastal flood inundation forecast maps to depict the geographic extent and severity of the predicted inundation along with forecast uncertainty. The coastal flood forecast inundation map needs to represent the inundation or water depth expected over the land due to the combination of storm surge, tides, waves, and freshwater inflow. The inland flood inundation forecast map needs to utilize RFC river-model forecast guidance driven by QPF. The flood inundation maps should be made available via an interactive map viewer to allow users to overlay the locations of critical infrastructure to determine the potential impacts of flooding as well as latest information (e.g., weather radar reflectivity, river stages, storm-total rainfall estimates, and active watches/warnings). In addition, the flood inundation forecast maps should be made available to users in GIS-compatible formats.

6.2.2. Other GIS-Compatible Products

A single source, graphical depiction of all hazard impacts, including wind gusts, inundation, tornadoes, and inland rainfall, does not currently exist. To address this need, from July 1, 2012, to November 30, 2012, NWS is seeking user feedback on experimental tropical cyclone impacts graphics. The suite of graphics addresses four hazards: wind, tornadoes, coastal flooding, and inland flooding. These experimental products will be generated by participating coastal WFOs when NHC issues a tropical cyclone watch or warning for a WFO's CWA. The potential impacts graphics are intended to answer a key question: "What should I prepare for?" The graphics, along with a description and static examples, are available at: http://www.weather.gov/tcig/ **.**

Finding 59: In noncoastal areas, the public did not fully understand the scope of Irene and consequently did not perceive the threats as real and immediate.

Recommendation 59 (Strategic): Building on the experimental tropical cyclone impacts graphics, NWS should dedicate specific resources and work with social scientists to develop a GIS-compatible, all-hazards graphical suite depicting tropical cyclones' impacts.

The NWS is making strides to increase its GIS-compatible products. For example, HPC makes products available in GIS-compatible formats, including QPF through day 5, excessive rainfall forecasts, and the 5-day significant river flood outlook. In addition, the NHC provides many of its products in GIS-compatible formats, including the graphical tropical weather outlook, forecast track, cone of uncertainty, watches/warnings, surface wind field/radii, wind speed probabilities, probabilistic storm surge, and preliminary best track information.

During Irene, NHC generated all GIS products automatically and reported no errors or outages. Many EMs and Department of Homeland Security staff members used NHC's GIS-compatible files during Irene.

> *"Thanks for the great information on your Web site. I am currently working for the Forest Service in Atlanta developing a Common Operating Picture [COP] for the region. It will mostly be used for wildfires nationwide, but in this region, we also need hurricane information. I have put together a compilation of your latest forecast track, cone, and warning for Irene in addition to the best preliminary track kmz and net-linked them into our COP."* **–** U.S. Forest Service, Atlanta, GA.

From August 20 to August 30, NHC recorded over 248,000 daily downloads of the zip file containing various NHC shapefiles. At the peak, these shapefile downloads accounted for over 20 percent of the total hits on the NHC Web site.

NCEP also recognizes the need to further incorporate GIS into its products. NCO initiated the GIS@NCEP Technology Leadership Plan Project (Project Management Office [PMO] 129) *"to determine the best practices, users, and direction for GIS technologies within NCEP."*

The NCEP Strategic Plan for 2010-2013 includes a goal to "*enhance the use of geographical information system (GIS) technology*," and "*assess and select formats and dissemination methods for NCEP data and products adaptable to changing requirements*."

Finding 60: There is a growing demand for additional NWS products available in GIS-compatible formats via interactive map viewers and Web map services.

Recommendation 60 (Strategic): NWS needs to make additional products available in GIS-compatible formats (e.g., shapefiles, KML files) and via Web map services to support the EM and water resources communities.

6.2.3. Web Tools for Emergency Managers

Some WFOs, such as WFO Wakefield, have a Web page specifically designed as a briefing tool for EMs and other partners. This page serves as a one-stop shop. The Virginia Office of Emergency Management found the local WFO's EM page to be a valuable resource during Irene and other high-impact events.

Finding 61: The Massachusetts EMA, FEMA Region I, and Boston EMA specifically requested a password-protected site containing probabilistic information. Many EMs wanted more information on which to base worst-case scenario decision making.

Recommendation 61 (Strategic): Local WFOs should develop a password-protected EM Web page that includes briefings, probabilistic information/ensembles, and user-defined sensitive information.

6.3. NWSChat

NWSChat is an Instant Messaging text service that allows multiple users to send and read messages in a chat room. NWSChat was introduced at WFO Birmingham in 2001 and was an instant success when used during the 2002 Veteran's Day tornado outbreak.

> ABC colleague Mark Prater said, "*We started using the text messaging system which vaulted us to a whole new level of coverage and getting the word out because we were linked to the National Weather Service office.*"

Despite this promising beginning, NWSChat is not consistently used across the NWS. In locations where it is used, it continues to be highly successful. During Irene, broadcast meteorologists who had access to the NWSChat praised the communication tool.

> "*I really understand the value of this communication*" and "*I can't believe I got by without it.*" –Tom Messner, Chief Meteorologist, WPTZ Burlington/Plattsburgh

In other media markets, however, the experience of broadcast meteorologists was not as good.

"Since Albany isn't on chat [NWSChat] we don't have as much contact with them. With Burlington, it is easier to just type in a question and get a response."
–Sharron Meyer, WCAX Burlington/Plattsburgh

Previous NWS service assessments noted the value of NWSChat and recommended organization-wide use. WFOs using NWSChat were able to quickly and directly contact meteorologists embedded with EMs offices or FEMA.

Finding 62: Inconsistent use of nationally approved technologies, such as NWSChat, results in an inconsistent level of service.

Recommendation 62 (Operational): All offices, including National Centers, should use NWSChat to communicate with key external and internal entities, especially with embedded NWS Meteorologists, ERSs, broadcast meteorologists, and Incident Meteorologists.

6.4. Specialized EM Services

Improved and extended weather DSS are a cornerstone of the WRN initiative. Numerous interviews with external partners revealed overwhelming support for these services. The resounding success of DSS during Irene raises serious questions about the ability of the NWS to meet increasing demands for these valuable services. The keys to successful DSS include:

- Ensuring the NWS has a clear understanding of key partner needs
- Leveraging emerging technologies to effectively communicate risk to a diverse group of partners
- Training current NWS staff in effective communication
- Recruiting NWS professionals who have the skill set to effectively communicate during high-impact events

The following sections address the primary DSS issues the service assessment team discovered.

6.4.1. Onsite Support at EOCs

NOAA/NWS must continue to pursue ERS Pilot Projects to expand DSS capabilities for external and internal deployment. There is enthusiastic support for this form of DSS.

"It is a phenomenal practice having a NWS meteorologist embedded at our Regional HQ. We were very satisfied with having him in our HQ…I think this is second time in 4 or 5 years that has happened. The last time was Hurricane Earl."
–FEMA Region III, Philadelphia

"The most important point I can communicate is the importance of having an Incident Meteorologist onsite." –NYCOEM Commissioner Joe Bruno

During Irene, ERH deployed 15 meteorologists, 7 to EOCs and FEMA Regions I, II, and III. One hydrologist was deployed to NERFC. Six Electronics/Facilities Technicians were prepositioned to react quickly to electronics/facilities issues. These deployments provided crucial support for NYC's first mandatory evacuation of approximately 350,000 residents from flood-prone areas. Nassau and Suffolk Counties on Long Island evacuated 470,000 residents. For the first time in history, NYC shut down the entire mass transit system several hours before the onset of tropical storm force winds.

Winds well ahead of the core of Irene forced the closure of evacuation routes, including bridges. Many roads and bridges were closed several hours before the onset of tropical storm force winds, severely affecting escape routes. These decisions required detailed DSS staff 24/7. The staff of the NYCOEM observed:

> "*Can you send 10 or 12 more people to the WFO? The challenge for this WFO is tremendous.*" –NYCOEM

The runaway success of the DSS program indicates demand will rise. This form of DSS is a key opportunity to further the goals of a WRN.

NYCOEM stated, "*We have a terrific relationship with the NWS… that is what New York City relies on....We have tremendous communication with the NWS WFO New York City/Upton. The relationship is what is important, and you couldn't have a better relationship than the one between NYCOEM and the National Weather Service. We challenge you to find a better relationship anywhere in the country.*"

Finding 63: DSS delivered by onsite meteorologists was widely praised by EOC staff. Many EOCs had one deployed meteorologist on loan during Irene, leading to extreme fatigue while delivering nearly continuous DSS.

Recommendation 63 (Strategic): NWS should evaluate the need to deploy 2 ERSs for 24/7 duty in extremely high workload deployments, and the possibility of using this deployment as a training opportunity for new ERSs as DSS demands increase.

The runaway success of this program indicates demand will rise and that this form of DSS is a key opportunity to further the goals of a WRN.

6.4.2. Briefing Packages, Webinars, Conference Calls, Video Teleconferences

While much positive feedback was received on the utility of deployed ERSs during Irene, there is recognition of limited resources and the need to use other methods as well to distribute critical information to key decision makers at the local municipality, state, and county levels. NWS Philadelphia/Mount Holly's most popular product for EMs during Irene was the weather briefing packages prepared in PowerPoint and distributed as a PDF. Briefing packages use straightforward graphics and text to highlight key information for decision makers using non-technical language. Briefing packages were posted on WFO Philadelphia/Mt. Holly's Web page for EMs as well as distributed via email. These packages received extremely broad distribution and redistribution, reaching thousands of EMs and other key decision makers. Post-Irene feedback from EMs stated strong support for briefing packages during Irene and similar high-impact weather events.

"The presentations were direct, succinct, and enabled others to make decisions with an awareness of what was happening and expected developments. You really helped us stay on top of what we needed to do and make the best decisions we could. Thank you!"
–Lisa Makosewski, Philadelphia Federal Executive Board

Best Practice: WFO Philadelphia/Mt. Holly produced high quality and timely briefing packages that were widely distributed to the EM community.

Handling the exceptional increase in live EM briefings and coordination calls during a major event takes careful planning. As an example, WFOs Boston/Taunton and New York City/Upton employed previously established media and EM briefing/coordination call schedules. WFO Philadelphia/Mount Holly serves four states: Pennsylvania, New Jersey, Delaware, and Maryland. WFO Philadelphia/Mount Holly is the State Liaison Office for New Jersey and Delaware and, as such, scheduled the calls for those states. This type of proactive planning prevented a plethora of calls and allowed partners to plan around scheduled meetings/calls.

Best Practice: Over the past several years, WFO Wilmington developed a series of briefing templates for use by EMs during tropical cyclone events based on the time from hurricane impact. The use of these templates ensured message consistency. These templates are on a local office intranet page.

6.4.3. Individual Calls

The Governor of Vermont declared a proactive State of Emergency Saturday afternoon, August 27. This declaration occurred after the WFO Burlington's SH worked through Vermont Emergency Management to have them ask the Governor's office for stronger language. A similar call was made by the WFO New York City/Upton Meteorologist in Charge (MIC) to Nassau County OEM. One hour later, the Nassau County Executive held a press conference and implemented the county's coastal storm plan. These advance contacts often were more effective in communicating vital messages than email. When used sparingly, this personal touch heightened the sense of urgency in the minds of key stakeholders.

"*Their call triggered us to do things that we wouldn't have done otherwise.*" –Essex and Clinton County, NY EMs.

Best Practice: To the extent possible, in advance of high-impact events WFOs with primary liaison responsibility should encourage their state and county level EMs to engage high-ranking elected officials in their discussion of potential impacts.

6.5. Methods/Means/Channels: Public

6.5.1. Web Pages

The AHPS Web site provides access to a wide variety of hydrologic/hydrometeorologic forecasts and products from WFOs, RFCs, NWSHQ, and NCEP.

NWSI 10-932, *National Hydrologic Web Products Specification*, does not provide standards or guidance on the display of water level observations or forecasts at tide forecast locations.

The team found that the water level forecast displayed on AHPS hydrographs (time series plots) at coastal locations varies by WFOs. This may have misled users during Irene about the forecasted total water level/storm tide (astronomical tides plus [+] storm surge) level at the coast. One WFO displayed the NOS astronomical tide predictions as the forecast and thus did not include contribution of storm surge to the total water level. This may have been confusing to users during Irene because by not incorporating the NWS storm surge forecast it provided an underestimation of the expected storm tide. It also contradicted with the storm tide forecast found in the WFO's HLS for that geographic area. A different WFO displayed the forecast at its coastal AHPS locations as the total water level determined by adding the storm surge predictions from the NWS Extra-Tropical Storm Surge (ETSS) Model to the NOS astronomical tide predictions. Although this was better than not including the effects of storm surge, the ETSS model is not designed for tropical cyclones. Therefore, the forecasts on these AHPS hydrographs may have underestimated the storm tide and potentially misled users during Irene. The forecast may have also contradicted with the storm tide forecast found in the WFO's HLS.

In addition, the label on the vertical axis on the AHPS hydrographs for coastal locations is given as 'Tide Height (ft)' and the datum is given as "n/a." The user does not know whether the depicted observed and forecast water levels are referenced to Mean Sea Level (MSL), Mean Lower Low Water (MLLW), or NAVD88, which can cause some users to misinterpret the data.

Finding 64: During Irene, the AHPS pages for affected WFOs were not displaying the same type of water level forecast for tide forecast locations. None of these pages displayed the official storm surge forecast contained in the HLS or NHC advisories. In addition, the AHPS hydrographs did not identify the water level datum or indicate the forecast might not be valid for tropical cyclones.

Recommendation 64 (Operational): The NWS needs to develop national standards for the graphical display of water level forecasts at tide locations on the AHPS Web page.

The NOAA/NWS Guide to Hydrologic Information on the Web describes the AHPS hydrograph for river/stream locations.

Finding 65: There was no information for AHPS users to interpret the observations and forecasts on AHPS hydrographs at tide locations during Irene.

Recommendation 65 (Operational): The NWS needs to modify the NWS Guide to Hydrologic Information on the Web to include information on how to read and interpret AHPS observations and forecasts for AHPS tide forecast locations.

Best Practice: WFOs Baltimore/Washington and Wakefield have Web pages for briefing EMs about various hazardous weather events (e.g., hurricanes, winter storms). These partner-driven pages allow EMs and the media to find important information quickly.

Throughout the Irene assessment, partners articulated the need to better understand the impacts from Irene and hurricanes in general. Partners felt they did not always appreciate the severity of the impacts from the expected conditions. As an example, NHC's Web site does not contain threats or impact information from inland rainfall. The flooding that occurred in the Northeast provided some of the greatest impacts from Irene.

Finding 66: Key partners expressed interest in having a single Web site that explains all hurricane impacts, including information on inland flooding threats.

Recommendation 66 (Operational): NWS should develop a comprehensive Web site that includes coverage of all threats and impacts of tropical cyclones.

Internet radar data became unavailable on the WFO San Juan Web page during Irene when the FAA-owned WSR-88D failed. WFO San Juan has access to a Terminal Doppler Weather Radar (TDWR) but did not have a link to the TDWR on its Web page during Irene. WFO San Juan has since devised a way to display the TDWR data on its Web page.

Finding 67: Access to additional or backup radar information, such as TDWR information, is crucial during high-impact events.

Recommendation 67 (Operational): NWS should ensure the accessibility to TDWR data centrally and at local WFO Web sites, where applicable, in case of WSR-88D outages**.**

6.5.2. Social Media: Facebook and Twitter

Although used for many reasons, social media have quickly evolved into a set of useful tools for disseminating timely information. Irene became a named storm on August 20, 2011. Between August 20 and August 31, the terms "Irene," "Hurricane," "Irene," and "Hurricanes," generated over 10 million tweets. The peak occurred on the morning of August 27, 2011, when Twitter logged over 3 million tweets referencing Irene. That number climbs significantly if additional hash tags (#irene, #irenenyc, for example) are added.

Equally compelling was the use of social media by traditional media and EMs during Irene. The assessment team found television meteorologists were automatically disseminating NWS products (warnings) from their station's Facebook page. Jim Duncan, Meteorologist with NBC News 12 in Richmond, VA, mentioned that Facebook became an important conduit for communicating Irene information.

> *"When the power went out, many TV viewers lost their TV signal. They had to rely on their smart phones to get information. Many people were without power for several days, but they still had their smart phones and used their Facebook and Twitter accounts to get important information."*

Three additional specific uses of social media that stand out across the impacted areas were:

- The Wall Street Journal worked with Foursquare, a location-based check-in application, to develop an online interface to find evacuation centers:
    - http://mashable.com/2011/08/27/hurricane-irene-foursquare/
    - https://foursquare.com/wsj/list/nyc-hurricane-evacuation-centers
- NYC developed a way for citizens to report various kinds of damage, allowing the city to target its response:
    - http://mashable.com/2011/08/29/nyc-crowdsources-tropical-storm-irene-damage-map/
    - https://nycsevereweather.crowdmap.com/main
- Finally, senior government officials used Twitter to exchange, and not simply put out information with the public:
    - http://ohmygov.com/blogs/general_news/archive/2011/08/31/Hurricane-Irene-What-Governors-and-Mayors-Were-Tweeting.aspx

Using social media as a valuable dissemination tool during significant weather events is not a new concept. Finding and Recommendation 14 in the Historic Tornadoes of April 2011 Service Assessment highlighted the need for NWS to more fully use social media to communicate and inform the public of severe weather risks.

Of the 11 WFOs interviewed, 5 offices were using Facebook during Irene and a sixth started a page just after Irene. HPC and NHC also have Facebook pages. Facebook was not a significant workload issue during Irene mainly due to the increased staffing on hand.

The daily summary of new subscribers to the NWS Facebook page during Irene is provided by **Figure 14**. The five local forecast offices running Facebook during Irene had the following response:

- Number of page “Likes” increased by 46 percent
- Total number of “Likes” increased by 2,592
- Number of “Post Views” tallied well over 265,000
- Number of “Page Views” was more than 7,000

Figure 14: NWS Facebook posts about Irene

For the HPC Facebook page:

- Number of page "Likes" increased by 25 percent
- Total number of "Likes" increased by 291
- Number of "Post Views" tallied over 55,000
- Number of "Page Views" tallied over 1,200 views.

Social media, especially Facebook, currently, are a valuable asset to NOAA/NWS; however, individual WFO Facebook pages were difficult to find. There was no link from the NWS national Facebook page to local office Facebook pages.

The NHC Facebook page enhances public awareness of threats, such as Irene, and creates a public face for the NWS, NOAA, and the NHC. It is crucial to the future support and functioning of NOAA/NWS that these entities have a vibrant social media presence. In addition, it is clear that dramatic weather events drive people to the Web and Facebook pages in search of information.

Best Practice: NHC provided frequent and relevant updates on its Facebook page. In some communities where power went out, cell coverage was still available, sometimes by hiking to a higher elevation. Residents and EMs were assessing/reporting damages and disseminating/receiving safety information through Twitter and Facebook.

Finding 68: The NWS does not currently serve as an authoritative source of weather information in the social media environment. Doing so would not only ensure relevant, important, and lifesaving information is distributed through social media, but also would help limit misinformation.

Recommendation 68 (Operational): The NWS should incorporate Facebook, Twitter, and other relevant social media as principal dissemination tools as quickly and consistently as possible, making certain that salient links are included.

6.5.3. Community Outreach Activities

Gaps in understanding about tropical cyclones and the NWS products associated with these cyclones emerged from discussions with NWS staff and EMs and their staff. Enhanced DSS will need to encompass and expand upon outreach efforts underway at each forecast office.

In addition, WRN will require extensive and well-developed relationships capable of evolving into full-fledged partnerships. These crucial partnerships have been fostered by the ongoing, fruitful outreach efforts of WFOs. There were a wide variety of effective outreach efforts among the 13 WFOs visited and contacted.

Among the many successful outreach practices, a number stand out as Best Practices. What these practices have in common is that they result in stronger relationships. Most significantly, these relationships are characterized by trust and respect and therefore form the context for sharing knowledge. This context is the platform upon which rests easy, efficient, and reliable mutual understanding that leads to improved responsiveness.

Best Practice: Several NWS offices participated in training programs with their local and state EM offices. This training included participation in tabletop, functional, and full-scale exercises, as well as completing FEMA-based online ICS modules.

Programs related to WRN are especially valuable not only for creating better-prepared organizations and communities, but for enhanced responsiveness during high-impact events.

Best Practice: Many counties and communities throughout the affected area participate in the StormReady and TsunamiReady programs. Partner response and relationships with their supporting WFOs were enhanced because of these programs.

There were individual stories of targeted outreach and communication of the urgency of the flooding threat as Irene approached. Assistant Chief Peter Lynch, of the Brattleboro Fire Department in Vermont, attributed lives saved to WFO Albany conference calls:

> *"The Saturday [August 27, 2011] conference call led us to expect flooding and evacuations. We made the decision to evacuate two elderly apartment complexes – Melrose Terrace and Hayes Court. The action to evacuate saved lives. Many apartments were completely flooded. With the elderly safe, we could focus our operations where needed during the height of Irene. There would not have been time on Sunday to do it."*

Unfortunately, even while robustly pursuing outreach, some WFOs are hampered in the dissemination of critical weather event information. Many communities in Vermont interviewed did not receive direct notification through state EMs or WFOs Burlington and Albany that this could be a record, historic, or very serious flood event. This list includes regional media in Vermont outside of the Champlain Valley.

> *"We had no warning saying it would be real bad. I knew it was going to rain a lot, but I thought it was going to be the kind of rain that would test the patch I just put on my roof. I had no idea it would be the kind of rain that would wash my neighbor's house away."*
> –Rochester, VT, Selectman

> *"Rutland is the largest community outside of Chittenden County, but did not get a phone call from NWS.... The one thing I've always thought that's missing is a face for the National Weather Service locally. In a storm like this, it could have been very effective to have someone out there from the Weather Service proactively reaching out to the media, explaining what the problems were and explaining why. There's not really a proactive outreach to the media. They send warnings."*
> –Steve Costello, Director of Public Affairs for Central Vermont Public Service

The Montpelier City Manager noted several smaller neighboring communities asked where the city received its weather information.

> *"I said, 'We called the National Weather Service', and they [the neighboring community] said 'You can do that?'"* – City Manager, Montpelier, VT

Particularly in New England, local level outreach varies by WFO but generally decreases further from the WFO office. Some WFOs noted that the requirement to cut the use of office vehicles by 40 percent had reduced its outreach to more distant communities.

Finding 69: New England WFOs each have several hundred local EMs. WFOs rely heavily on the state EMs to disseminate information to local communities. This setup makes direct, local outreach and DSS difficult.

Recommendation 69 (Operational): WFOs should work with State EM officials to keep a current listing of local EMs.

Outreach also serves as a venue for educating the public about weather phenomena and their impacts. Images of dramatic weather in popular culture are often misleading and sometimes incorrect. Whatever the specific reasons may be, misunderstandings or areas of ignorance became apparent in the aftermath of Irene. These gaps in understanding and awareness need to be corrected for all NWS audiences.

For example, tornadoes are an important aspect of landfalling tropical systems that can occur outside of the right front quadrant of a tropical cyclone, as occurred during Irene. Some partners had the misconception that tornadoes only occur in the right front quadrant of landfalling tropical systems.

The assessment team found that inland flooding did not receive the same level of concern from the public as wind or storm surge. There may be several explanations for this lack of concern but the key finding from the assessment is that the NWS can and must do a better job articulating this threat before the rain begins to fall.

> "*While most eyes warily watched the shoreline during Hurricane Irene's grinding ride up the East Coast, it was inland — sometimes hundreds of miles inland — where the most serious damage actually occurred. And the major culprit was not wind, but water."* –The New York Times, August 29, 2011

Efforts to better educate the public and specific constituencies will need to be complemented by targeted training for EMs and media representatives.

> "*We were focused on New York and Boston and thought by the time it got here it would be a tropical storm. None of us expected to be clobbered.*" –Ross Sneyd, News Editor, Vermont Public Radio

Finding 70: There is still a widespread belief that hurricanes are coastal, not inland hazards.

Recommendation 70 (Strategic): NOAA/NWS should commission a team of forecasters, social scientists, and media to develop outreach and training efforts focused on raising public awareness of potentially significant impacts of inland flooding. This particular outreach effort might include:

- Highlighting flood-prone areas on the NHC 3- and 5-day track forecasts.
- Placing "Inland Flooding" under "Hurricane Awareness" on the left frame of the NHC Web page right after "Storm Surge"
- Integrating inland flooding threat associated with landfalling tropical cyclones in Kindergarten through12th grade (K-12) education
- Adding all tropical cyclone impacts into the StormReady program requirements
- Developing and implementing training modules on inland flooding impacts from tropical cyclones for EMs and media. Such training should consist of nationally standardized Web-based training modules augmented by regional and local workshops.

Public interest and attention are often at their highest right after a major weather event. Although this may not be the most convenient time for outreach, if NWS has prepared programs, WFOs could take advantage of this heightened interest with media outreach.

Training alone will not fully address the need for a high level of comprehensive interagency coordination. There have been successful coordination efforts. For example, a year prior to Irene, a local EM in New Hampshire contacted the SH at WFO Portland, ME, regarding past inaccuracies with Pemigewasset River. This allowed WFO Portland to work with the NERFC to fix errors prior to an event and provide forecasts of river crests and flood stages more accurately.

A WRN will require sensitivity to local needs and circumstances. This sensitivity should result in a high degree of adaptability on the part of various NOAA offices (to include local NWS offices) as they seek to enhance long-term outreach efforts. One local need relates to non-English speaking populations.

According to the 2010 U.S. Census, 58.5 percent of the 2.4 million residents of Dade County, FL, speak Spanish; half of those say they don't speak English well. English-only speakers make up only 27.2 percent of the county's residents (source MSNBC).

NWS in general, and NHC in particular, does not have a sufficient pool of subject matter experts (SME) fluent in Spanish who are exclusively available to conduct media interviews and provide DSS when needed. NHC did make an effort to provide information to the Spanish-speaking audience.

Best Practice: A Spanish-language audio podcast was created and posted on the NHC Web site with each new advisory.

Currently**,** media demands at NHC are managed through local and national English and Spanish language media pools, all South Florida local TV stations, and National Network Bureaus. Before NWS issued the first hurricane watch for Irene, the NHC Public Affairs Officer had several discussions with senior management at Univision Network, the primary Spanish-language media pool station for 2011, regarding opening the Spanish-language pool.

After Univision Network consulted with other Spanish-language stations in the media pool to gauge interest, it opted not to open the media pool. A primary factor in its decision was the significant expense incurred by the stations. It is the assessment team's opinion that this decision was influenced by the lack of a direct threat to South Florida.

During Irene, NHC provided Spanish-language interviews on a request basis, using the producer and photographer in the English language pool. NHC held several interviews using onsite Spanish-speaking NHC meteorologists, when available, and on a volunteer basis. This pool provided 12 live, on-camera Spanish language TV interviews and at least 20 Spanish-language radio interviews. The local *Telemundo* affiliate sent a reporter and photographer to NHC, providing onsite reports and live interviews.

Spanish translation of weather information is a financially driven luxury rather than a requisite part of weather information dissemination and is often dependent on third-party participation. Similarly, there is no Spanish translation for NHC Facebook posts.

Finding 71: Outreach efforts are hampered because NWS professionals are not able to communicate easily with Spanish speaking groups. The NWS mission "for the protection of life and property" cannot be fully realized if significant numbers of the population in one or more regions cannot use the warnings and forecasts because of a language barrier.

Recommendation 71 (Strategic): NWS should develop a comprehensive program to address the informational needs of the growing Spanish language community during high-impact events.

This program should include a cadre of mobile, decision support meteorologists/hydrologists who are not only Spanish speakers, but are trained to deal with local and national media and local decision makers. This trained group should be available for deployment in decision support roles as needed, providing interviews and translation for social media sites such as Facebook.

7. Data Collection, Dissemination, and Forecast Models

During tropical cyclones, NWS forecasters rely on collection and dissemination of near real-time observations from a variety of in-situ and remote-sensing platforms, forecast and numerical model guidance from NCEP centers (NHC, HPC, and SPC), and river model forecast guidance from RFCs. In addition, WFOs run their own local river forecast models for some fast responding rivers.

Overall, NOAA performed very well during Irene in the collection, processing, and dissemination of observations, forecast guidance, and numerical model output; however, the service assessment team identified several issues, which are discussed in this section.

7.1. Data Collection and Dissemination

Despite substantial improvements to NOAA and NWS infrastructure and communications over the last decade, Irene exposed several areas where gaps in the observational infrastructure and inefficient use of existing resources hampered operations.

7.1.1. River and Water Level (tide) Gages

USGS river gages provided real-time stage observations critical to RFC and WFO forecast and warning operations during Irene. Because of Irene's rainfall, more than 80 USGS stream gages measured record peaks. Unfortunately, several USGS gages in New Jersey and New York were damaged or flooded (**Figure 15**) and failed because the gages could not handle an event of this magnitude. In Eastern New York, 3 gages were destroyed, 58 had some type of damage, 17 were flooded, and 1 exceeded operational limits.

In the Gulf of Mexico region, the USGS is hardening about 120 continuous-record streamgages within 100 miles of the Gulf Coast to withstand hurricane-generated floodwaters. In addition, USGS is hardening 8 to 10 open-water tidal/water quality gages in Mississippi and Louisiana. The streamgage hardening modifies the structures to withstand a 200-year flood.

Finding 72: Several USGS gages failed because they were not built to handle an event of this magnitude. The data outages caused uncertainty and anxiety, especially related to the Gilboa Dam, part of NYC's Catskill Water Supply System in Schoharie County. Gage failures meant decision makers did not know upstream flow into the reservoir, nor the flow heading down the Schoharie Valley from Gilboa Dam.

Recommendation 72 (Strategic): NWS, in coordination with external partners, should prioritize gages in need of hardening to ensure the gages can handle record floods.

Figure 15: Flooding at the USGS gage on the Saddle River at Lodi, NJ, after the peak measurement on August 28, 2011. (Source: John Trainor, USGS)

Coastal WFO forecasters, the SSU, and NOAA partners and users also relied on observations from real-time water level (tide) gages operated by NOS/CO-OPS. During Irene, on average, over 99 percent of 6-minute water level observations from NOS/CO-OPS National Water Level Observation Network and Physical Oceanographic Real-Time System stations were disseminated in near-real time (data not older than 18 minutes). There were some problems disseminating water level observations from CO-OPS stations, such as the one at Wachapreague, VA, when the water level sensor overtopped for 18 hours on August 27-28. This site had no backup sensor due to ongoing rebuilding of a pier. In the future, the CO-OPS plans to switch to backup sensors when a tropical cyclone threatens the coast.

In addition, WFO forecasters relied on tide gages operated by the USGS or its partners, especially along the New Jersey and Long Island coast, to supplement the NOS network. For example, in the WFO New York City/Upton CWA, the USGS operated 11 real-time tide gages during Irene: 4 in Long Island Sound and 7 on the south shore of Long Island. Since Irene, three of the four real-time tide gages in Long Island Sound have lost funding.

A combination of federal, state, and local funds pays for USGS river and tide gages. This funding is severely threatened because of budget shortfalls in local, state, and federal governments. Presently, over 300 gages are threatened, including many that were critical for NWS operations during Irene. USGS appropriations lag 1–2 years behind the states. The USGS has proposed the National Streamflow Information Program (NSIP) to operate as a federally-funded, backbone network supporting approximately 4,750 stream gages and tidal gages necessary to fulfill specific national purposes. NSIP is presently only 22 percent funded.

> *"If cuts materialize it will be unfortunate. We will lose the ability to forecast river stages due to loss of data"* –Brian McCallum, USGS.

Several WFOs identified the need for additional real-time river and tide gages for coastal estuaries. WFO Newport/Morehead City noted the need for additional gages, specifically in the sounds adjacent to mainland areas, to improve the warning process for coastal and inland flooding. WFO Boston/Taunton has expressed a similar need for additional tide gages, especially for Buzzards Bay, MA. WFO Baltimore/Washington identified the need for gages on the Potomac River from Washington, D.C., to the mouth of the Potomac River (**Figure 16**).

Fact: WFO Newport/Morehead City has 24 USGS river gages and 4 NOS water level (tide) gages within its CWA. WFO Baltimore/Washington noted a data void for about 60 miles between Washington, D.C., and the mouth of the Potomac River because of a lack of NOS tide gages.

Finding 73: Real-time river and coastal water level observations were critical for RFCs and WFOs to monitor and forecast flood potential and severity during Irene. These observations are also critical for the operation and verification of present and planned NWS river forecast and NOS oceanographic forecast modeling systems.

Recommendation 73a (Strategic): The RFCs should engage groups spanning from federal to local levels to:

- Ensure flood forecast points are appropriately prioritized, resourced, and supported
- Identify problems that can be addressed prior to high-impact events
- Ensure external partners responsible for funding are informed of the NWS or NOS reliance on gages during high-impact coastal storms.

Recommendation 73b (Strategic): The NWS should develop prioritized lists of recommended sites for future river and tide gage installations. The lists should be provided to the USGS via the Joint NOAA/USGS Committee on Hydrology and NOS, respectively.

In advance of Irene, USGS hurricane response teams deployed a total of 203 storm tide sensors, 70 barometric pressure sensors, 3 wave height sensors, and 8 Rapid Deployment Gage (RDG) real-time reporting sensors from South Carolina to Maine (**Figure 17**). The storm tide sensors were used to record the event and provide water-level data on the extent of the storm tide inundation and the depth of water over the land surface. Barometric pressure sensor data were used to adjust the recorded water-level data. This deployment was the largest USGS operation of its kind, three times larger than any similar operation.

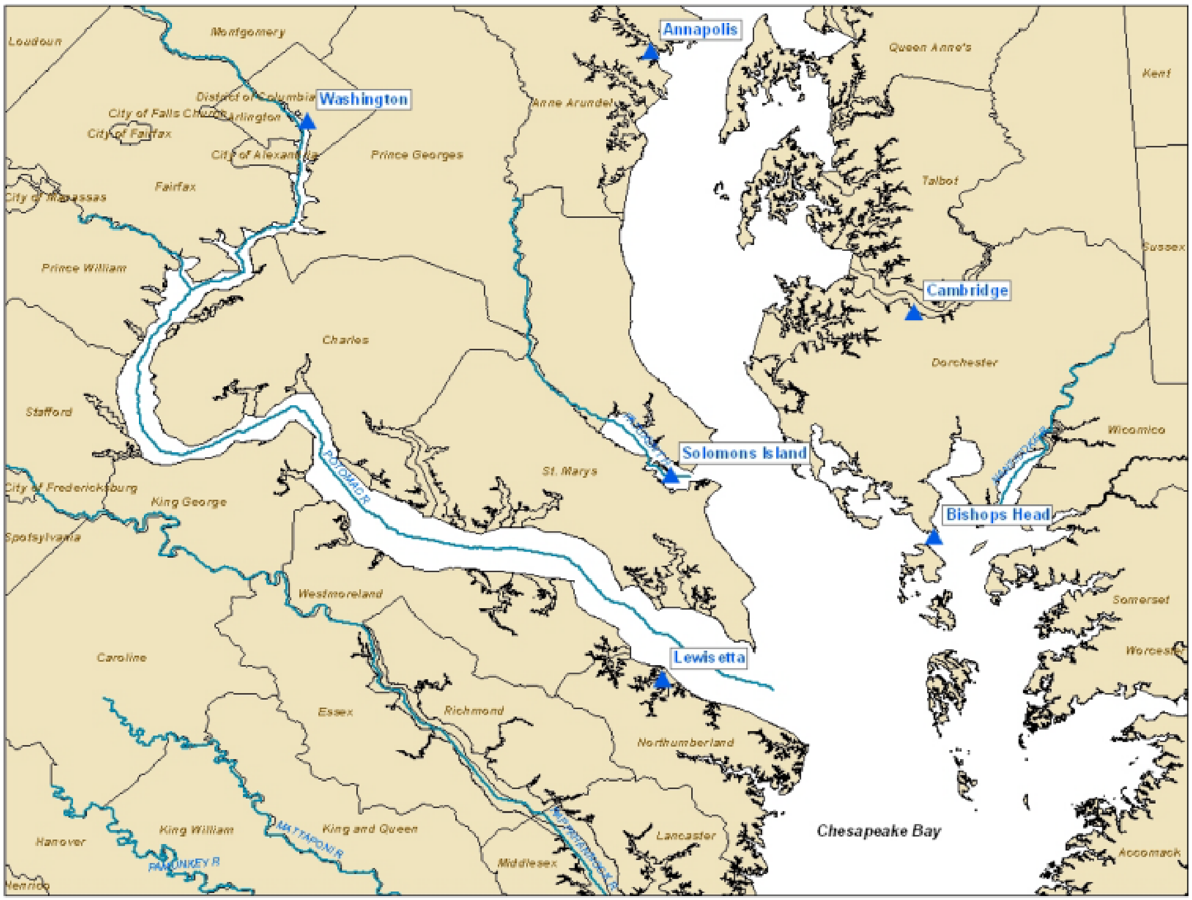

Figure 16: Map depicting locations of NOS/CO-OPS water level and meteorological stations along the Potomac River and part of the Chesapeake Bay.

Best Practice: The USGS coordinated daily with NHC and NOS/CSDL on track and intensity forecasts to determine the best locations for deployment of the USGS sensors. The conference calls between USGS and NOAA *"influenced our decision very heavily on where to deploy. We must evacuate 12 hours prior to landfall, and redeployments are not possible if the track shifts. Discussions were held daily for a week prior to the storm, and a deployment decision was made 2 days prior to landfall. They did a great job giving information…."*

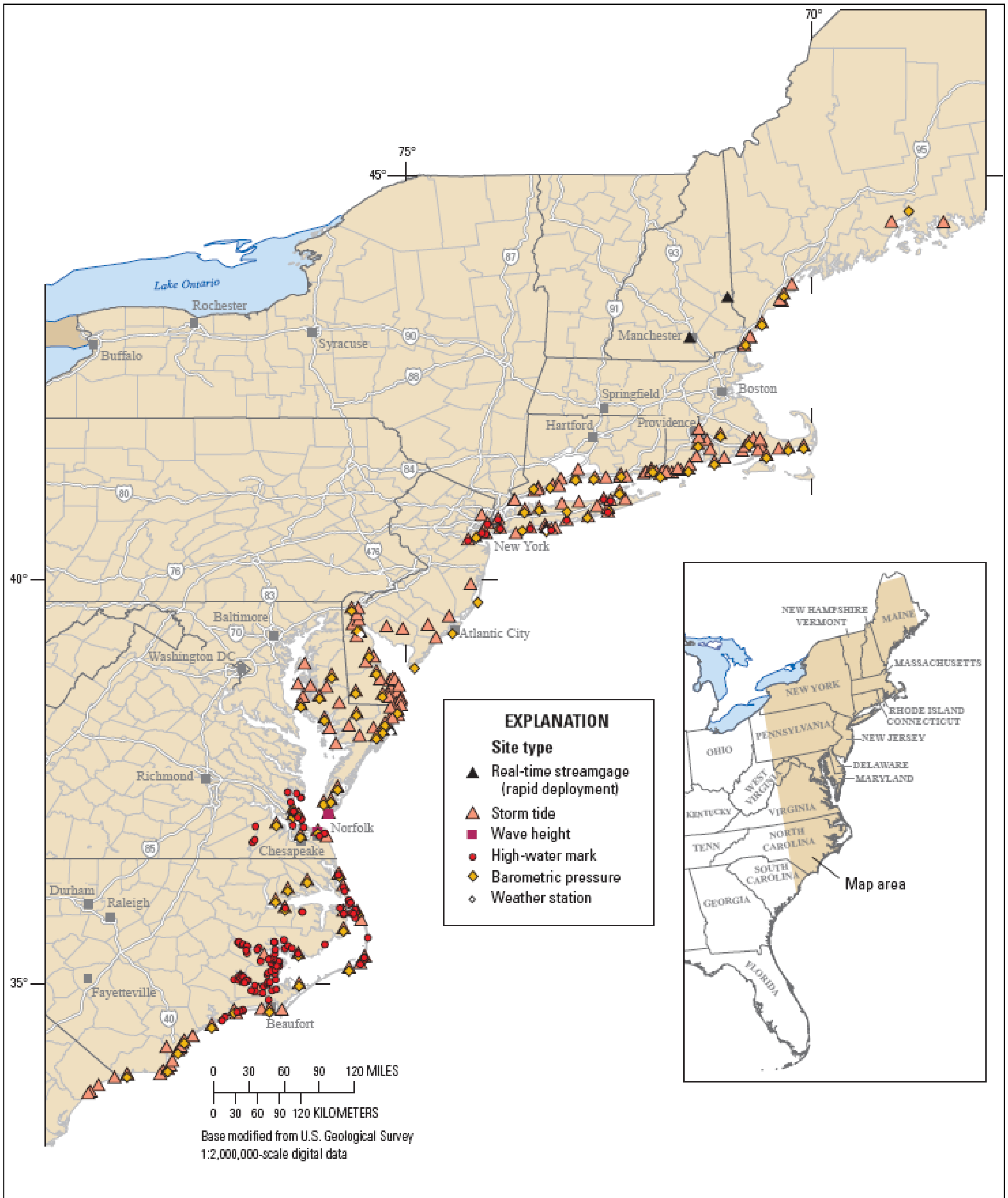

Figure 1. Locations of sensors and high-water mark data-collection sites to monitor the effects of Hurricane Irene, August 2011.

Figure 17: Locations of USGS sensors and high-water mark data collection sites to monitor the effects of Irene (Source: USGS).

Finding 74: The USGS project to deploy storm-tide sensors, stream gauges, and wave height sensors at key locations along the East Coast in advance of tropical cyclones is critical to NWS and NOS development and verification of future Storm Surge Forecast models and coastal inundation maps.

Recommendation 74 (Strategic): NWS and NOS need to engage with USGS, USACE, and FEMA to ensure USGS has sufficient resources to continue its sensor deployments in advance of land-falling tropical cyclones.

The RDG transmits its data in real-time via the Geostationary Orbiting Environmental Satellite (GOES); however, the majority of data from the Data Review Group did not make it into the NWS operational data streams.

Fact: Only one RDG was added to the Hydrometeorological Automated Data System (HADS) ahead of Irene and thus made it into the NWS operational data streams provided to WFOs, RFCs, and NCEP.

NWS HADS personnel usually learn of an RDG via USGS or a WFO/RFC. If the USGS notifies them, then HADS will work with WFOs to establish a temporary NWS Location Identifier (NWSLI) that does not conflict with existing station IDs. If a WFO/RFC notifies it, HADS usually supplies a National Environmental Satellite, Data, and Information Service ID (NWSLI), location name and possibly latitude and longitude coordinates.

The real-time observations from RDGs are used by coastal WFOs, RFCs, OPC, and NHC to monitor conditions in areas without permanent river or tide gages during major storms.

Finding 75: HADS does not have a process for notifying all of NWS, NOS, and other NOAA agencies when data from RDGs are added to HADS.

Recommendation 75a (Operational): The Joint NOAA/USGS Committee on Hydrology should develop a Standard Operating Procedure to specify how the USGS should notify the NWS, NOS, and NOAA users when RDGs are deployed.

Recommendation 75b (Operational): HADS should notify impacted ROCs, WFOs, RFCs, and NCEP/NCO, NOS/CO-OPS, and USGS once the RDG observations are available in NWS data streams.

7.1.2. Weather Buoys

Fixed weather buoys and coastal marine weather stations operated by the NWS National Data Buoy Center (NDBC) and its regional ocean-observing partners provided valuable near-real-time observations of surface winds and wave conditions during Irene. NCEP's data assimilation and forecast numerical modeling systems, NWS and private sector forecasters, EMs, and the public used this information.

Several fixed buoys owned and operated by NDBC were not operating during Irene and two had been down for many months, as shown by **Figure 18**.

Fact: Three NDBC buoys south of Long Island (44017, 44066, and 44025) were not operational before, during, and after Irene:

- Buoy 44017 (23 nm southwest of Montauk, NY) stopped transmitting on August 20, 2011. This buoy was recovered November 10, 2011, and will be restored to service when it can be worked into the maintenance schedule. As of May 5, 2012, the buoy was not reporting.
- Buoy 44066 (Texas Tower #4) stopped transmitting January 23, 2011. The buoy was serviced and began transmitting again on November 10, 2011. It went adrift on January 9, 2012, and will be restored to service when it can be worked into the maintenance schedule. As of May 5, 2012, the buoy was not reporting.
- Buoy 44025 (33 nm south of Islip, NY) stopped transmitting July 31, 2011. The buoy was serviced and began transmitting again on November 9, 2011.

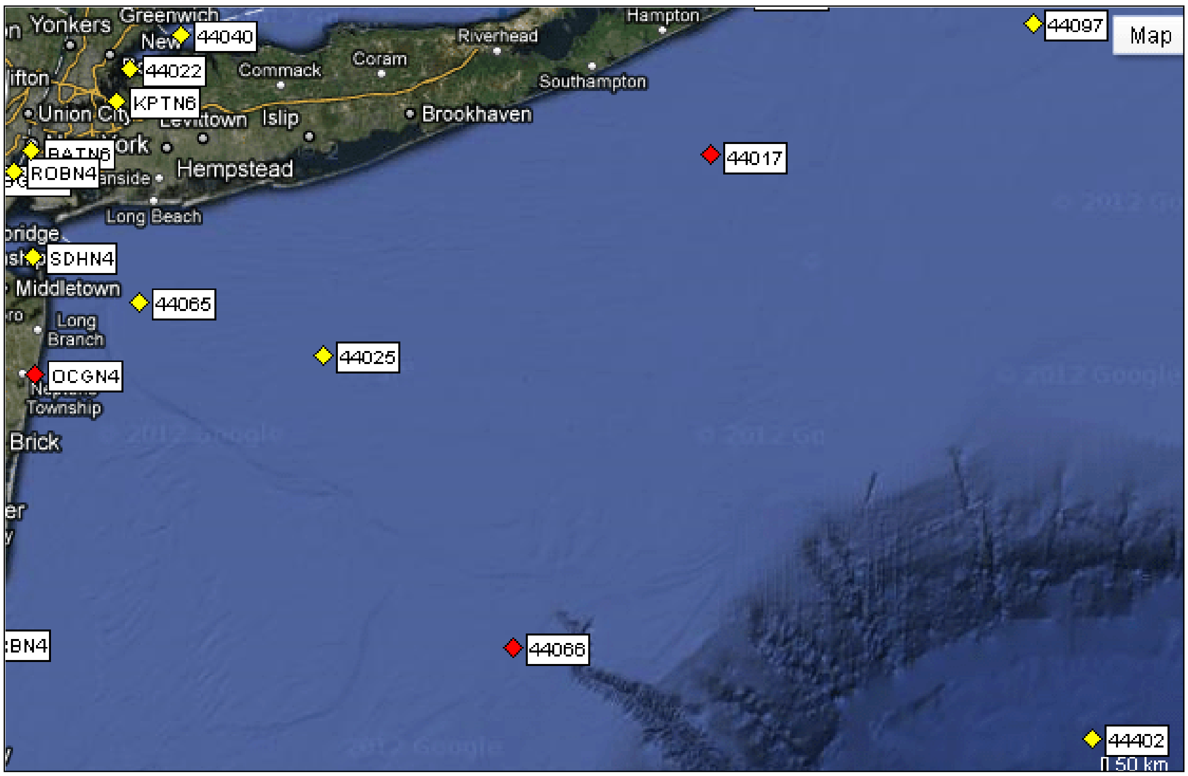

Figure 18: Locations of fixed buoys 44025, 44066, and 44017, which were not operating during Irene. Red indicates the buoy has not reported recently. Yellow indicates the buoy has reported recently.

WFO staff and NWS partners and users expressed frustration with not having observations from these buoys during Irene.

"*Can we get our buoys fixed?*" –Personnel at the NYCOEM

"*...not having them [the buoy observations] hurt and hindered some of our operations...creates a blind spot where you used to having observations.*"
–U.S. Coast Guard (USCG) District Command Boston Center Search and Rescue Specialist

"The loss of these buoys has impacts on our operations every day, not just during Irene.... We rely on this data to produce accurate forecasts and warnings. In addition,

these observations are often automated on products that are transmitted on NOAA Weather Radio, Web sites, etc. Mariners rely on that information for their livelihood –Mark Willis, NWS ERH Marine Manager

The NWS invests a significant amount of money to purchase, operate, and maintain its buoy network. A NDBC 3-m discus turnkey weather buoy costs approximately $220,000–$250,000. Approximately $60,000 to $70,000 is budgeted yearly for operations and maintenance of a buoy. Except for the hurricane expansion buoys and Deep-Ocean Assessment and Reporting of Tsunamis buoys, NWS does not budget funding for ship support to service NDBC buoys. NDBC relies on the USCG to provide ship support under an agreement between USCG and NWS.

NOAA ships are not typically used to deploy or service weather buoys, but the NOAA Ship *Thomas Jefferson* was used in mid-August 2011 to deploy the tenth observing buoy in the NOAA Chesapeake Bay Office's Chesapeake Bay Interpretive Buoy System. This was done in coordination with the NOAA Chesapeake Bay Office, the NOAA/Office of Marine and Aviation Operations, and the NOS/Office of Coast Survey.

Finding 76: USCG places NDBC needs for buoy maintenance below other USCG mission priorities. This prioritization delays corrective and preventive maintenance of buoys for months and results in observational gaps. NWS does not have available funds to pay for ship time for buoy maintenance.

Recommendation 76 (Operational): NOAA should provide funding to be used in the most economical and efficient way for ship support to maintain weather buoys.

In addition, there were issues with buoys operated or funded by NWS partners, which impacted the ability of the coastal WFOs to monitor conditions during Irene. One issue involved the removal and disestablishment of Buoy 41035 (LEJ2), Onslow Bay Inner, NC, on August 22, 2011, 5 days prior to Irene’s passage within 30 miles of the buoy. According to the NDBC Web site, this fixed buoy was funded by the U.S. Marine Corps but was owned and operated by NDBC. The coastal WFOs had only about a week notice of the planned disestablishment.

The WFOs were concerned about the loss of data from this buoy. The MIC at WFO Newport/Morehead City, NC, wrote a letter to the head of U.S. Marine Corps Operations at Camp Lejeune, NC, dated August 19, 2012, informing him about the importance of the data from the buoy for marine, rip current, high surf, and other coastal forecasts and warnings

“*Losing this buoy is expected to have a major impact on our ability to provide accurate and timely forecasts and warnings in the area.*” –Richard S. Bandy, MIC, NWS WFO Newport/Morehead City, NC

With the disestablishment of the buoy, forecasters and mariners had to rely on observations from Buoy 41036, 23 nm to the southeast of Buoy 41035.

Finding 77: WFOs Wilmington and Newport/Morehead City had only about 2 weeks advance notice of the planned removal of the Buoy 41035 during the peak of the hurricane season.

Recommendation 77 (Operational): NDBC and NWS need to facilitate greater advance notice (i.e., greater than 2 weeks) from partners whenever possible regarding the permanent removal or temporary service interruption of a partner's buoy or coastal station and inform WFOs, NHC, OPC, and other users as soon as possible. In addition, the NDBC should avoid scheduling the removal or planned temporary service outage of NDBC-owned platforms along the East Coast and Gulf of Mexico during the peak of the hurricane season (i.e., mid-August thru mid-September) whenever possible.

A second issue occurred with Buoy 44039, Central Long Island Sound, owned and maintained by the University of Connecticut (UCONN) Department of Marine Sciences as part of the MYSound observing network. This buoy is funded by NOAA Coastal Ocean Technology System. Data are transmitted from the buoy via Code Division Multiple Access modems. The near-real-time observations are made available over NWS data streams and displayed on NDBC and UCONN Web pages. During Irene, observations from the buoy were not available to forecasters via NWS data streams.

Fact: Buoy 44039 had missing data from 1 p.m., Friday, August 26, until 3:45 p.m., Saturday, August 27, from 4 a.m. until 11 a.m., Sunday, August 28, and 1:15 a.m. until 3:45 p.m., Monday, August 29.

The outage occurred at the time NWS measured the highest surface winds along the south central Connecticut coast (4:03 a.m. – 9:30 a.m. on Sunday) along with destructive storm surge.

> *"Lack of ocean [NDBC] buoy data and loss of Long Island Sound buoy data for about 8 hours during the height of storm severely limited ability to predict wave action on top of surge."* –MIC, WFO New York City/Upton

The outage problem did not appear to be isolated to Buoy 44039 because during the early afternoon of Saturday, August 27, WFO New York City/Upton discovered data from all MySound buoys were not being received in AWIPS. WFO New York City/Upton emailed UCONN about the problem.

In a press release after Irene, the NOAA IOOS Program Office stated, "*The U.S. Integrated Ocean Observing System (IOOS) provided data and information to support preparation and response efforts, and to inform forecasts and predictions, ahead of Irene last week…. The Delaware River Basin Commission, Connecticut Governor's office, U.S. Coast Guard, New York Times, National Hurricane Center, and NOAA all used IOOS data about the storm for various purposes.*" (http://www.ioos.gov/news_splash.html). Given the importance of real-time observations from IOOS platforms to NWS and a variety of users as demonstrated during Irene, it is critical for data providers to have robust power and telecommunication capability to ensure the transmission of real-time observations to NWS and other users during major coastal storms.

Finding 78: Surface marine weather observations, including wind and significant wave heights, for central Long Island Sound were not available to WFO New York City/Upton when the southern Connecticut coast measured its highest surface winds of the event (0830–1330 UTC). Data from NWS and NOAA Integrated Ocean Observing Systems (IOOS) offices are sent to NDBC and from there to AWIPS.

Recommendation 78 (Operational): The NOAA IOOS Program Office, in cooperation with NDBC, should work with regional ocean observing system data providers to determine how NOAA can assist partners technically and financially to improve their telecommunication and backup-power capability to ensure near real-time observations from their platforms are transmitted to NWS and NOAA users during coastal storms.

7.1.3. Upper-Air Soundings, Rawinsondes Special Releases

By August 21, 2011, it became apparent that Irene likely would affect much of the Eastern Seaboard. NHC requested 18 WFOs release special rawinsondes at 2 p.m. (1800 UTC), August 22. Supplemental rawinsonde requests are common in support of improved hurricane intensity and track forecasts. At 10:05 p.m., August 23, 2011, an emergency NWSHQ directive was issued for all WFOs from Montana, Wyoming, Colorado, and New Mexico eastward to launch 6-hourly rawinsondes beginning at 2 a.m. (0600 UTC), August 25, 2011, until further notice. NCEP's Senior Duty Meteorologist notified field offices. This action was intended to help the models provide better forecasts of the track of Irene. The supplemental rawinsonde launches were suspended after 2 p.m. (1800 UTC), August 27, 2011.

Fact: From 2 p.m. (1800 UTC), August 22, 2011, to 2 p.m. (1800 UTC), August 27, 2011, 415 additional rawinsonde flights were launched to support Irene forecast guidance. Estimated total labor and non-labor costs for these additional observations was $134,000.

EMC ran experiments using the Global Forecast System (GFS) and Hurricane Weather Research and Forecasting (HWRF) operational models to test forecast guidance improvement from the extra rawinsondes. EMC determined the extra rawinsondes improved the forecast track in the GFS model by a few percent out to 120 hours, but degraded the forecast track slightly in the HWRF model. The guidance results were mixed in the HWRF for intensity forecasts, degrading the forecasts a few percent at 24–36 hours, but improving it slightly beyond 48–120 hours. Given intensity guidance for Irene was generally poor, according to NHC, this impact was not significant.

Finding 79: Comparisons of forecast guidance hindcast runs by two NCEP numerical weather prediction models using data from additional rawinsondes indicated little impact on accuracy of the hurricane track or intensity forecasts.

Recommendation 79 (Strategic): The NWS should commission a multi-event, cost/benefit analysis of augmenting North American rawinsonde observations for the purpose of improving numerical weather prediction model forecasts during landfalling tropical cyclones. This analysis should include domain extent, lead time, and synoptic observation time to determine if extra rawinsonde releases are a worthwhile investment.

7.1.4. Remote Sensing: Satellite and Weather Radar

The WFO Philadelphia/Mount Holly Weather Surveillance Radar 88 Doppler (WSR-88D) (KDIX) became inoperable due to a transmitter over-voltage alarm on the morning of August 27, 2011, before Irene affected the CWA. **Figure 19** provides the locations of WSR-88D and TDWR sites in Mid-Atlantic region. Technicians worked on KDIX's problems until ordered to evacuate at approximately midnight on August 27, 2011. KDIX remained down throughout the event. Troubleshooting resumed on August 28, 2011. Airspace shutdown prevented the delivery of replacement parts until the morning of August 30, 2011.

With KDIX down, the meteorologists at WFO Philadelphia/Mount Holly relied on data from WSR 88Ds at WFO New York City/Upton and Dover, DE. In addition, WFO Philadelphia/Mount Holly used data from nearby TDWR sites at Newark International Airport, Philadelphia International Airport, and Andrews Air Force Base. The forecasters indicated that the TDWR data were vital in monitoring conditions during Irene, including heavy rain and possible tornadoes.

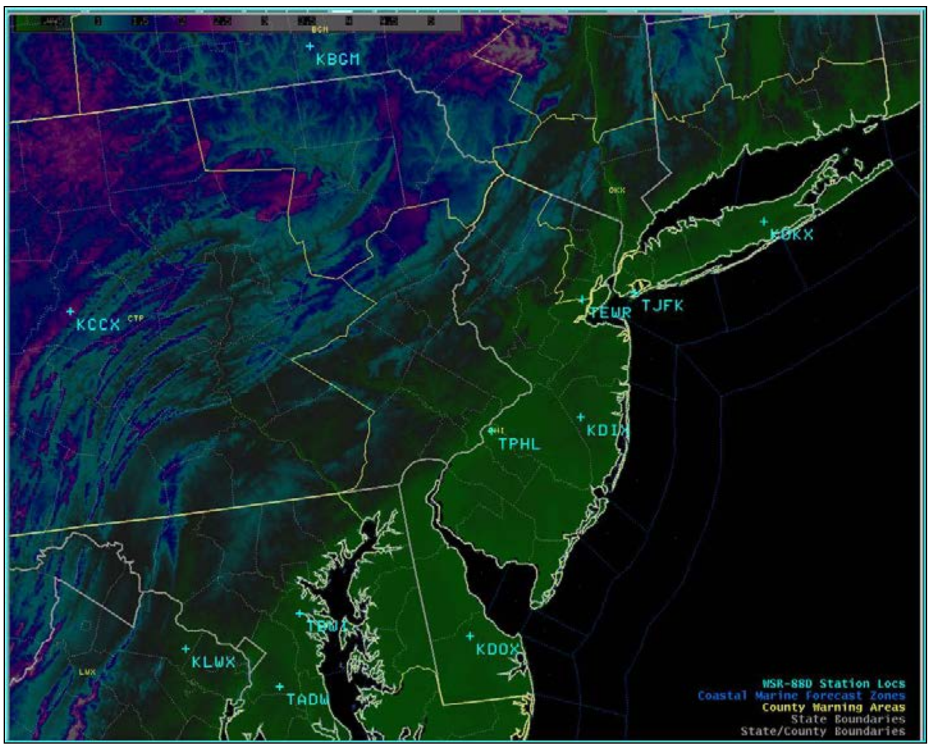

Figure 19: Locations of WSR-88D and TDWR sites in Mid-Atlantic region: location IDs starting with T are TDWR sites, K are WSR-88D sites (Source: WFO Philadelphia/Mount Holly).

The KDIX radar outage highlighted the importance of TDWR sites providing critical data if a WSR-88D site experiences problems; however, primary and secondary backup WFOs do not have access to the same TDWR products.

Fact: WFO Philadelphia/Mount Holly, the primary backup for WFO Baltimore/Washington, only receives data from two of four TDWRs in the Washington area (Washington National, Andrews AFB, Baltimore/Washington, Dulles airport).

Finding 80: A degradation of service by backup offices may occur because of failed WSR-88D radars and a lack of access to radar data from nearby TDWR sites.

Recommendation 80 (Operational): The NWS should ensure that primary and secondary backup WFOs in tropical cyclone-prone areas have access to all nearby TDWR data.

The WFO San Juan, PR, WSR-88D is in a remote area in the eastern interior of the island. The radar is owned and maintained by the FAA. The radar has experienced recurring problems. During Irene, the radar failed before the tropical storm impacted the island on August 22, 2011. The radar began sending only intermittent data beginning at 8:50 p.m. on Sunday, August 21, 2011. The radar stopped transmitting data at 10:37 p.m., after which WFO San Juan used the TDWR at Salinas Point, PR, on the north coast.

Finding 81: WFO San Juan's WSR 88D failed during Irene and has previously experienced recurring problems.

Recommendation 81 (Operational): NWS and FAA should examine the maintenance of the FAA-owned WSR-88D at San Juan to ensure maximum efficiency and performance.

Ascertaining surface wind speeds in land-falling tropical cyclones is difficult due, in part, to the lack of observations. While reconnaissance missions measure surface winds over water via the Stepped Frequency Microwave Radar, these data only capture a small portion of the wind field in a tropical cyclone. NHC forecasters are reluctant to lower wind speed estimates during decay periods of tropical cyclones, in part, because of the limited sampling that presently exists. While observing systems such as satellite-derived Oceans Surface Vector Winds (OSVW) from the European Satellite Advanced Scatterometer (ASCAT) help mitigate this problem, there were large gaps in OSVW passes during Irene and limited coverage in general because the U.S.-operated Quick Scatterometer (QuikSCAT) satellite was shut down (**Figure 20**). There was a sharp reduction in percentage of TCDs mentioning scatterometer data in 2010 after the loss of QuikSCAT—a decrease of almost half compared to the previous 3-year average. The lack of mention was mostly due to a decrease in coverage with ASCAT, leading to fewer passes over tropical cyclones and a lack of sampling of the entire tropical cyclone circulation.

As stated in the 2006 NOAA Operational Ocean Surface Vector Winds Requirements Workshop, "Establishing an operational satellite OSVW data stream and closing the OSVW capability gaps will result in more accurate warnings, watches, and short-term forecasts; improved analyses, model initializations, and atmospheric forcing of ocean models; and a better understanding of coastal and oceanic phenomena. This change will yield significant improvements in NOAA's operational weather forecasting, warning, and analyses capabilities."

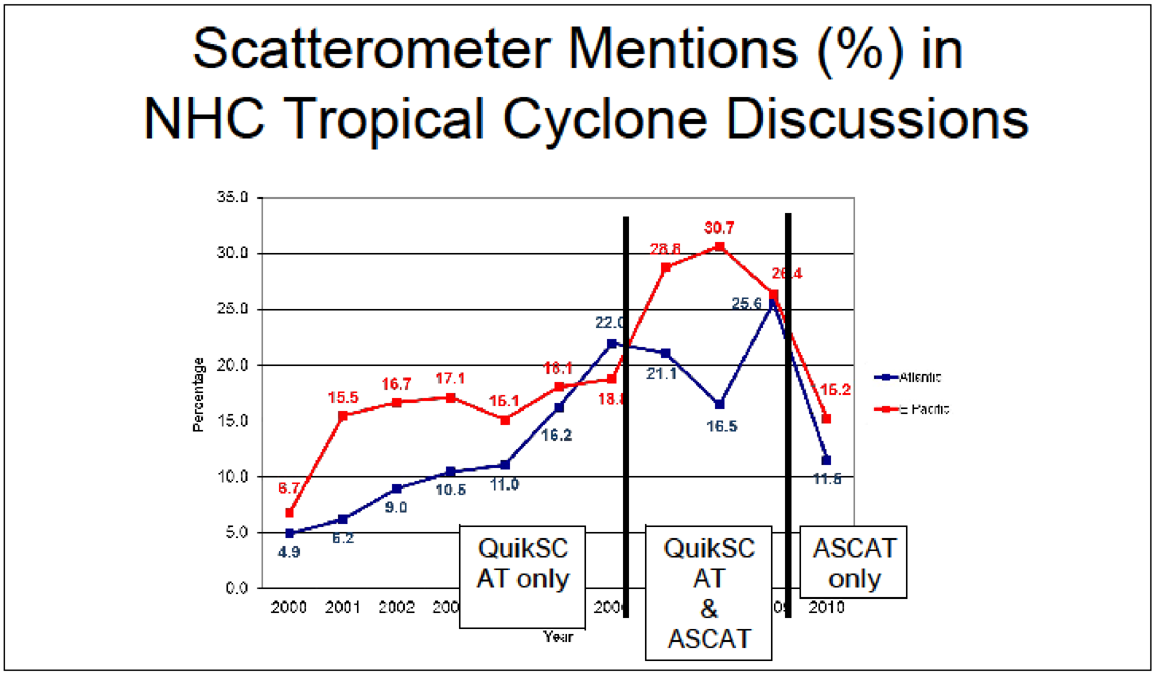

Figure 20: Plot of percentage of NHC Tropical Cyclone Discussions (TCDs) that mention scatterometer data. From Impact of the Loss of QuikSCAT on NHC Operations: Current Mitigation Efforts and Future Plans, Richard Danielson and Michael J. Brennan, NHC, NASA OCWST and International OVWST Meetings, 2011.

Finding 82: As Irene started to lose strength approaching New Jersey, the sparseness of surface observations caused problems for forecasters, not only at NHC, where there was a reluctance to reduce wind speed forecasts due in part to a lack of corroborating data, but also for some WFO forecasters. These forecasters, in retrospect, viewed near shore and inland wind speed forecasts as being too high, as evidenced by a lack of observed hurricane force winds. There was also a perception among the media and public that wind forecasts were too high given the lack of observed hurricane force winds.

Recommendation 82 (Strategic): NOAA should support research and development for OSVW observational platforms to improve surface observation density with the objective of improving forecast confidence during tropical cyclones.

7.2. Assimilation and Forecast Modeling Systems

7.2.1. Storm Surge Forecast Models

Irene tracked along the Eastern Seaboard in such a way that storm surge was a concern from North Carolina to New England. Post-storm interviews revealed that EMs faced with the threat of a significant storm surge had to make evacuation decisions of varying complexity and geographic scale. In the extreme case of NYC, EMs needed a very high level of certainty to justify the evacuation of hundreds of thousands of people and at least 3 days of lead time to evacuate effectively. Currently, the maximum lead time of probabilistic storm surge forecast guidance (P-Surge product) from NWS SLOSH model ensemble runs is approximately 48 hours prior to landfall (i.e., whenever a hurricane watch or warning is in effect). The maximum lead time of deterministic storm surge forecast guidance from NWS SLOSH model operational runs is approximately 36 hours prior to arrival of tropical storm winds (i.e., whenever a hurricane warning is issued).

Effective communication of storm surge was also a major issue; all EMs interviewed preferred detailed inundation depth information in a GIS-compatible format using underlying high-resolution, seamless bathymetry and topographic data sets. This is currently not available, and will require the development of forecast models to predict *total water level* including storm surge, tides, waves, and freshwater inflow. NWS, NOS, and their academic partners are working towards this goal. The NOAA Storm Surge Roadmap is a 10-year, agency-wide, and community-based approach to collaborating on a coastal modeling test bed sponsored by IOOS. The project features ongoing evaluation of surge and wave models and research on ensemble storm surge predictions to calculate uncertainty for inundation predictions. Also, NHC and MDL are working on a new version of SLOSH that includes tides and NHC is working on another version that couples SLOSH to a wave model.

Fact: Advances in storm surge forecast modeling systems are required to provide high-resolution coastal inundation forecast maps with an expression of uncertainty. NOAA is making progress in improving its storm surge modeling capability including coupling with wave and river forecast models.

Finding 83: Present storm surge forecasts do not provide the EM community with sufficient lead time or spatial resolution of inundation areas. This lack of forecast data has opened the door for multiple sources communicating surge and flooding information, which has increased the risk for miscommunication and misinformation among users.

Recommendation 83 (Strategic): NOAA should strongly support efforts of NWS, NOS, and its partners to develop and implement operationally improved storm surge forecast modeling systems in order to provide probabilistic coastal inundation forecasts of total water level out to 72 hours for its users.

Personnel at NHC SSU and OPC examined water level forecast guidance from a new experimental model, ESTOFS, as well as the operational model, ETSS, during Irene. Both the ESTOFS and ETSS are deterministic forecast models. ESTOFS is the result of the joint project between CSDL and EMC as part of the NOAA Storm Surge Roadmap. Although the ESTOFS and the ETSS models are not designed for tropical cyclones, it was thought that the water level guidance from these forecast systems might be useful because Irene was expected to have a large, nonsymmetrical wind field when it reached the northeastern United States, characteristic of an extra-tropical coastal low or nor'easter.

> *"A blend of NHC surge guidance and extra-tropical surge guidance worked well for this transitioning event…so would be something to remember in the future."* –MIC, WFO New York City/Upton

ESTOFS is scheduled for operational implementation on the NOAA Central Computer System in Fiscal Year 2012, Quarter 3. NOS is working to run ESTOFS as an ensemble to produce probabilistic forecast guidance similar to P-Surge.

Finding 84: The experimental ESTOFS and ETSS models provided valuable forecast guidance to NHC and OPC during Irene as it tracked through the northeastern United States.

Recommendation 84 (Strategic): NHC and OPC should work closely with MDL and CSDL to ensure the ETSS and ESTOFS models are continuously improved to provide detailed surge and tide forecast guidance to coastal WFOs, NHC, OPC, and partners. These efforts should be coordinated with the NWS Office of Hydrologic Development to include emerging river, estuarine, and coastal forecast modeling capabilities of the NWS and NOS.

7.2.2. Riverine and Estuary Forecast Models

Performance of the RFCs involved in Irene (i.e., MARFC, NERFC, SERFC) was exceptional. Using forecast guidance from river forecast models, the RFCs provided their WFOs and partners with high-quality main stem river forecasts for moderate and major flooding with lead times exceeding 48 hours. In addition, these RFCs produced experimental short-term (<10 days) hydrologic ensembles using the Meteorological Model-Based Ensemble Forecast System, which uses various meteorological ensemble systems as input to the NWS River Forecast System Ensemble Streamflow Prediction system.

Best Practice: MARFC's experimental short-term hydrologic ensemble forecasts available on its Web page were a useful planning tool for the RFC and its WFOs regarding potential for high river stages in advance of Irene.

Best Practice: SERFC used ensemble model output to develop its Hydrologic Vulnerability Assessment, which was shared with SERFC staff, WFOs, and relevant partners.

Irene also provided a vivid demonstration of a known limitation of present NWS river forecast guidance. RFCs generally do not attempt to forecast at locations where river flows interact with the tides and storm surge. During Irene, the RFCs were unable to provide accurate quantitative forecast guidance for tidally-influenced reaches of the major river systems, such as the Delaware and Potomac Rivers. For example, in the Delaware River and Bay, the NOS water level gage at water level (non-tidal) residuals included both storm surge and abnormally high river flow due to storm-induced runoff in the Delaware River Basin; levels ranged from 2.9 to 8.8 feet, with the highest level recorded at Newbold, PA.

NOAA is working to improve river-estuary transition zone forecasts where present forecast methodology breaks down. Examples of current NOAA activities include the CI-FLOW project in North Carolina and the Tidal Potomac River project. These models have the potential to depict the effects of land-falling tropical cyclones on water surface elevation and associated inundation within estuary systems quantitatively. Meanwhile, the RFCs have recently upgraded their computer architecture to the Community Hydrologic Prediction System (CHPS), which enables them to more easily couple with other models or infuse other models directly. As a result, the RFCs now have the capability to use hydraulic models for river reaches such as the

Hydrologic Engineering Centers River Analysis System (HEC-RAS) model and advanced hydrodynamic models for tidal estuaries.

Best Practice: NERFC worked with SSU to incorporate SLOSH gridded forecast guidance into HEC-RAS starting on Wednesday, August 24. By Friday night, August 26, NERFC staff was able to incorporate a storm surge time series at the river mouth to use as a boundary condition in HEC-RAS.

Finding 85: New collaborative opportunities in estuary modeling are emerging between the NOS and the NWS due to advances in the NWS river forecasting computer architecture, such as CHPS, which could allow the NOS ocean-estuary modeling activities to be integrated into the NWS river forecasting system. The end goal of this joint effort will be a seamless transition in forecast capability from inland river systems to the sea.

Recommendation 85 (Strategic): NOAA should coordinate efforts between NOS, which is working on modeling the intersection of estuaries with the ocean in several locations, and NWS to connect river systems intersecting with estuaries.

7.2.3. Hurricane Forecast Models

NOAA's Hurricane Forecast Improvement Program (HFIP) is coordinating hurricane research needed to significantly improve guidance for hurricane track, intensity, and storm surge forecasts. The goals of the HFIP are to:

- Improve the accuracy and reliability of hurricane forecasts
- Extend lead time for hurricane forecasts with increased certainty
- Increase confidence in hurricane forecasts by enhanced observational strategies and improved data assimilation and numerical model forecast systems

Prior to the hurricane season, HFIP personnel coordinated with NHC to provide real-time research model guidance developed under HFIP to the Hurricane Specialist Unit. Through this process, NHC forecasters usually receive forecast guidance from eight research models they can include in their consensus forecast guidance. Each of the models selected demonstrated skill when compared to the operational consensus for three seasons worth of cases run retrospectively.

During Irene, NHC Hurricane Specialists did not routinely examine HFIP Stream 1.5 model guidance in real-time because model output did not start until the first week of August. There also were some problems getting the output into a standard Automated Tropical Cyclone Forecast system output format for NHC; however, post-storm model evaluation by NHC personnel indicated positive results.

> *"We have two models from HFIP that in Irene [and the whole season] are beating our operational guidance."* –James Franklin, Chief, NHC Hurricane Specialists Unit.

For the 2012 hurricane season, HFIP personnel will test the data flow to NHC for Stream 1.5 output a month earlier to identify and resolve problems.

Finding 86: HFIP consensus model guidance performed much better than the operational guidance for both track and intensity, and two HFIP models, COTI and SPC3, performed well for the 2011 hurricane season.

Recommendation 86 (Strategic): NWSHQ and NHC should continue their full support of HFIP to provide dramatically improved, real-time research model guidance products.

Appendix A: Acronyms

AGL	Above Ground Level
AHPS	Advanced Hydrologic Prediction System
ASCAT	Advanced Scatterometer
AWIPS	Advanced Weather Interactive Processing System
CHPS	Community Hydrologic Prediction System
CHC	Environment Canada Canadian Hurricane Centre
CI-FLOW	Coastal and Inland Flooding Observation and Warning Project
CO-OPS	NOS/Center for Operational Oceanographic Products and Services
CSDL	NOS/Coastal Survey Development Laboratory
CTA	Call to Action statement
CWA	WFO County Warning Area
CWSU	NWS/Center Weather Service Unit
DSS	Decision Support Services
EAS	Emergency Alert System
EM	Emergency Manager or Management
EMA	Emergency Management Association
EOC	FEMA/Emergency Operations Center
ERH	NWS/Eastern Region Headquarters
EMC	NCEP/Environmental Modeling Center
ERS	Emergency Response Specialist
ESTOFS	Extratropical Surge and Tide Operational Forecast System
ETSS	Extra-Tropical Storm Surge
FAA	Federal Aviation Administration
FDTB	Forecast Decision Training Branch
FEMA	Federal Emergency Management Agency
GFE	Graphical Forecast Editor
GFS	Global Forecast System
GIS	Geographic Information System
GOES	Geostationary Orbiting Environmental Satellite
HADS	Hydrometeorological Automated Data System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
HFIP	Hurricane Forecast Improvement Program
HIC	Hydrologist in Charge
HLS	Hurricane Local Statement
HLT	FEMA/Hurricane Liaison Team
HPC	Hydrometeorological Prediction Center
HWRF	Hurricane Weather Research Forecast Model
ICS	Incident Command Center
JFK	John F. Kennedy
K-12	Kindergarten through 12th grade
MACC	U.S. Secret Service Washington Field Office Multi-Agency Coordination Center
MARFC	Mid-Atlantic River Forecast Center
MDL	Meteorological Development Laboratory
MIC	Meteorologist in Charge

MLK	Martin Luther King, Jr.
MLKF	Martin Luther King, Jr. Foundation
MLLW	Mean Lower Low Water
MSC	Meteorological Service of Canada
NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NCO	NCEP Central Operations
NDBC	National Data Buoy Center
NDFD	National Digital Forecast Database
NERFC	Northeast River Forecast Center
NEXRAD	Next Generation Weather radar
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NOC	National Operations Center
NOS	NOAA/National Ocean Service
NWLON	National Water Level Observation Network
NPS	National Park Service
NSIP	National Streamflow Information Program
NSTEP	National Strategic Training and Education Program
NWS	NOAA/National Weather Service
NWSChat	Instant Messaging program utilized by NWS operational personnel
NWSHQ	NWS Headquarters
NWSI	NWS Instruction
NWSLI	NWS Location Identifier
NYC	New York City
NYCOEM	NYC Office of Emergency Management
OCWWS	Office of Climate, Water, and Weather Services
OEM	Office of Emergency Management
OEP	FAA Operational Evolution Partnership
OPC	NCEP/Ocean Prediction Center
OpsNet	Operational Systems Network
OSVW	Ocean Surface Vector Winds
PMO	Project Management Office
POP	Probability of Precipitation
P-Surge	Probabilistic Storm Surge
QPF	Quantitative Precipitation Forecast
QuikSCAT	Quick Scatterometer
RDG	Rapid Deployment Gages
RFC	River Forecast Center
ROC	Regional Operations Center
SCH	Service Coordination Hydrologist
SERFC	Southeast River Forecast Center
SH	Service Hydrologist
SJU	WFO San Juan, Puerto Rico
SLOSH	Sea, Lake, and Overland Surges from Hurricanes

SPC	NCEP/Storm Prediction Center
SSU	Storm Surge Unit
TCM	Tropical Cyclone Message
TCU	Tropical Cyclone Update
TCOP	Tropical Cyclone Operation Plan
TDWR	Terminal Doppler Weather Radar
TOC	Telecommunications Operations Center
UCONN	The University of Connecticut
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
VSAT	Very Small Aperture Satellite Communications Terminal
VTC	Video Teleconference
WCM	Warning Coordination Meteorologist
WRN	Weather-Ready Nation
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar 88 Doppler

Appendix B: Findings, Recommendations, and Best Practices

Definitions

Best Practice – An activity or procedure that has produced outstanding results during a particular situation that could be used to improve effectiveness and/or efficiently throughout the organization in similar situations. No action is required.

Fact – A statement that describes something important learned from the assessment for which no action is necessary. Facts are not numbered, but often lead to recommendations.

Finding – A statement that describes something important learned from the assessment for which an action may be necessary. Findings are numbered in ascending order and are associated with a specific recommendation or action.

Recommendation – A specific course of action, which should improve NWS operations and services, based on an associated finding. Not all recommendations may be achievable but they are important to document. If the affected office(s) and OCWWS determine a recommendation will likely improve NWS operations and services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Findings and Recommendations

Finding 1: The NOC does not support all high-impact weather events for which WFO and RFC staff produce briefings for specialized audiences. NHC staff commented that the NOC did not reach out to NHC for collaboration or explanation of its products during Irene.

Recommendation 1 (Strategic): Through the Operations Center Pilot Project, NWS should expand and develop the NOC capabilities demonstrated during Irene, particularly the coordinated decision making among NOAA line offices. These activities should be expanded to other high-impact events. NOC needs to communicate and collaborate with NHC during events to ensure proper interpretation of products and a consistent message within and outside of NOAA.

Finding 2: The SSU is small group of dedicated professionals with a heavy workload during land-falling tropical cyclones. The SSU reached out to MDL, OPC, NOS/CSDL, and academia for additional expertise during Irene. However, not all NOS/CSDL employees are allowed to work on evenings and weekends.

Recommendation 2 (Strategic): NHC and NOS should work together to ensure that NHC has access to training on NOS forecast models, products, and vertical datum conversion tools prior to the hurricane season. In addition, NOS and NWS should formulate a plan that would allow personnel from NOS/CSDL and CO-OPS with storm surge forecast modeling, observational, and VDatum expertise to assist SSU personnel on evenings and weekends during land-falling hurricanes.

Finding 3: The change in terminology from tropical storm warning to inland high wind warning is inconsistent in terms of expected impacts and can be misinterpreted as a lower-level risk from wind impacts.

Recommendation 3 (Strategic): The NWS product suite for wind risk from hurricanes and tropical storms should consistently convey potential impacts when a storm transitions from tropical to extra-tropical. Policies should be revised to ensure that any transition is transparent to partners.

Finding 4: CWSUs New York and Boston have no way to participate in hurricane hotline conference calls. CWSU New York used the NHC Web site to get updated forecasts for Irene. The MICs at both CWSUs should be able to take part in hurricane hotline conference calls to ensure they have the latest NHC forecasts, including uncertainty.

Recommendation 4 (Operational): To ensure public, marine, and aviation program services are fully coordinated, all offices bearing forecast responsibility over coastal and offshore waters should be included in Hurricane Hotline Conference calls.

Finding 5: A more streamlined and simplified product suite for NWS hydrologic headlines would enable greater consistency among WFOs regarding the types of inland flood watches and warnings and would reduce the potential for confusion for the media, public, and other decision makers (see Section 6.1).

Recommendation 5 (Strategic): NWS should simplify and better coordinate messaging internally for inland flood impacts prior to and during widespread high-impact rainfall events.

Finding 6: Although QPF forecasts of extreme rainfall were consistent over a period of several days, and RFC river forecasts of major to moderate flooding exceeded 30 hours, WFO river flood warnings averaged a much lower lead time of 5 hours.

Recommendation 6 (Operational): NWS, in conjunction with social scientists, should determine strategies and training to effectively maximize NWS river flood warning lead time in high-confidence, high-impact situations.

Finding 7: After the HPC briefing on August 25, FEMA removed HPC from the VTCs for the duration of Irene. HPC serves as the backup for the NHC and provides the critical rainfall component of the hurricane forecast, the component associated with the majority of fatalities associated with Irene

Recommendation 7 (Operational): Leveraging the success of NHC briefings, the NWS should support the creation of a Service Coordination Hydrologist (SCH) position at HPC to deliver more effective briefings to key partners.

Finding 8: The NHC is the most visible national entity for tropical cyclone information. FEMA and national media partners will continue to go to the NHC as the single source for tropical storm information; however, NHC participation in FEMA VTCs phases out when the coastal threat ends.

Recommendation 8 (Operational): Even though rainfall forecasts and inland flood threats are outside of the NHC's forecast focus, when briefing FEMA and national media, briefings (by NHC, HPC, or some combination) should give attention to each tropical cyclone-related threat at an appropriate level. This support should continue until the tropical cyclone is no longer affecting the Nation, including the impact of deadly flooding from coastal surge or inland rainfall. This procedure should be standard practice, not the exception.

Finding 9: FEMA Region II Watch Center expressed a desire to become better educated on NHC product issuance times and associated high-demand workload times at NHC in order to minimize their impact (time demands) on NHC operations. FEMA Region II also stated that while conference calls with ERH were useful, conference calls concerning Puerto Rico or other CWAs should also involve WFO personnel to ensure the use of local expertise.

Recommendation 9 (Operational): NWS should work with all components of FEMA to familiarize FEMA staff with the NWS organizational structure and provide FEMA with contact information for local expertise. In particular:

- FEMA Region conference calls should include an NWS representative from impacted WFOs and RFCs to provide local expertise.
- NWS should coordinate with FEMA Regional Watch Centers regarding NWS product schedules and general NWS office operations to maximize coordination efficiency of briefing activities.

Finding 10: During Irene, a USACE employee was providing storm surge expertise to the NYC OEM and working closely SSU.

Recommendation 10 (Strategic): NWS, through the National Hurricane Program, Office of the Federal Coordinator of Meteorology (OFCM), the Interdepartmental Hurricane Conference, and the National Hurricane Operations Plan, should discuss with USGS and USACE the possibility of deploying their personnel with storm surge expertise to assist and/or supplement NWS staff during potential landfalling hurricanes. These non-NOAA personnel should receive advance training about NOAA storm surge forecast models, NWS and NOS coastal observing networks, and NWS forecast operations.

Finding 11: NWS does not consistently provide critical event information to private sector entities in critical, mission-related endeavors such as utilities, transportation, and medical services.

Recommendation 11 (Strategic): NOAA, and in particular NWS, should explore ways to consistently provide improved access to critical event information shared with the EM community, for private sector entities engaged in critical mission-related industries (e.g., utilities, transportation, medical services).

Finding 12: The working relationship among NOAA/NWS liaisons/embedded meteorologists and the local WFO was strained and deficient under time sensitive, high visibility pressures.

Recommendation 12 (Strategic): NOAA/NWS should develop a protocol for building, sustaining, and evaluating working relationships among embedded meteorologists/NWS liaisons, WFOs, and RFCs. This protocol should include reciprocal, face-to-face visits to build trust and a robust understanding of the work demands and needs of each entity.

Finding 13: Several technical problems relating to the use of breakpoints, subsequently corrected, resulted in significantly degraded services; however, these corrections are short-term fixes that do not address the fundamental problem associated with the use of breakpoints. Breakpoints are a tool that has outlived its utility, frequently causing problems for NWS staff during high-impact events.

Recommendation 13 (Strategic): NHC should follow the Storm Prediction Center (SPC) procedure and shift from using breakpoints to using the Graphical Forecast Editor (GFE) to develop their products. NHC should shift to a polygon-based system for tropical cyclone watches/warnings similar to that used by SPC for tornado and severe thunderstorm watches. This change would improve coordination using the GFE, eliminate the confusion and technical problems associated with breakpoints, and allow WFOs to cancel tropical cyclone headlines for affected counties when those conditions are no longer observed.

Finding 14: While local offices were grateful for the additional personnel, office managers found both efficiencies and challenges in integrating the additional personnel. Office managers want to be involved in future resource allocation decisions regarding deployments to their offices and EOCs within their CWAs.

Recommendation 14 (Strategic): When prepositioning additional staff for high-impact events, NWS regional headquarters should, if possible, assign employees who have previously served at the WFO/RFC in need of assistance, even if they currently serve in another NWS region. Assignments should be coordinated with the recipient MIC or HIC and at a minimum include:

- Who is deployed
- To which offices and EOCs they are deployed
- When they will travel

Finding 15: Coastal offices and EOCs were the only recipients of additional prepositioned staff, even though inland flooding was a primary threat from Irene.

Recommendation 15 (Operational): When prepositioning additional staff to WFOs and EOCs threatened with tropical storm or hurricane impacts, the enhanced staffing should include areas threatened by inland flooding.

Finding 16: There is a lack of consistency among field offices with regard to documented TCOPs. WFOs with comprehensive plans successfully prepared for enhanced services to EM and media partners, and better accounted for staff safety.

Recommendation 16 (Strategic): Staffing templates for high-impact events should be developed by all WFOs and RFCs. For offices in the line of tropical storms, these should be contained in the TCOP. These templates should allow for flexibility and ensure appropriate staffing is available to cover before, during, and after a major event. For high-impact events such as Irene, all enhanced staffing plans should include an event coordinator and coverage for extended hours of electronics and other information technology. (Refer to the Southeast United States Floods, September 18-23, 2009 Service Assessment.)

Finding 17: Several candidates have declined to be considered for a position at WFO Wilmington after gaining a clear understanding of staffing expectations during a hurricane threat. These candidates were not comfortable leaving their families during a hurricane. Those applicants hired know exactly what is expected well before high-impact events unfold.

Recommendation 17 (Operational): Hiring officials in WFOs that are susceptible to potential long duration, very high-impact events such as tropical cyclones should clearly inform prospective employees of duty requirements, including the likelihood of sheltering-in-place at the WFO.

Finding 18: The reliance of NWS on a single person at the SSU for internal and external storm surge decision support led to extreme fatigue and is not sustainable. This is a potential single point of failure.

Recommendation 18 (Strategic): An additional federal employee should be allocated to the SSU. The NWS should establish a 24-hour SSU tropical cyclone support and Technical Support Branch capability with staff members who can provide official guidance and support to field offices, ROCs, and external partners during a threat for a landfalling tropical cyclone.

Finding 19: FEMA and other national decision makers found HPC briefings ineffective. Conversely, the NHC Director was widely praised by FEMA and the White House as a trusted voice of the NWS/NHC who understood FEMA's needs and communicated clearly to the highest levels of government.

Recommendation 19 (Strategic): Through programs such as the FEMA Hurricane Liaison Team at NHC, NOAA/NWS should actively recruit new and develop existing NOAA/NWS scientists who can effectively communicate with those at the highest levels of government.

Finding 20: Not all embedded meteorologists were ICS trained.

Recommendation 20 (Strategic): NWS should ensure forecasters and hydrologists selected for deployment in an EOC are required to be sufficiently trained in ICS, including ICS 100, 200, 300, 400, 700, and 800 courses.

Finding 21: Some NWS offices lack operational experience working tropical cyclone events, particularly inland offices and coastal offices that have longer return periods for tropical cyclone occurrences. Periodic and pertinent training is essential to maintain needed tropical cyclone operational skills.

Recommendation 21 (Strategic): The NWS should make it a priority to fund a comprehensive Professional Development Series (PDS) on tropical cyclones, including training on effective delivery of DSS and comprehensive material on both coastal and inland impacts. The funds would support the development and delivery of an operations-based tropical course targeted to the 1,200 NWS meteorologists and hydrologists who have tropical warning and decision support responsibilities. The PDS would involve and include:

- Multiple subject matter experts to develop the comprehensive training, not just the six individuals currently working on the program on their own time
- Onsite meeting to allow these experts to develop the training
- Full-scale simulations providing all WFO forecasters who have tropical warning and decision support responsibilities the capability to develop tropical cyclone decision support skills with their local EMs and media
- NWS Regional Directors ensuring this tropical training is integrated into their staffs' tropical seasonal readiness training at all relevant WFOs and RFCs

Finding 22: The level of hydrologic training and experience varies within and among WFOs. WFO hydrologic training programs range from detailed and thorough to one Weather Event Simulator case or an annual quiz.

Recommendation 22 (Strategic): NWS should establish and implement a baseline standard for annual hydrologic training at all WFOs. NWS Regional Directors will ensure this hydrologic training is integrated into their WFOs' and RFCs' seasonal readiness training.

Finding 23: EMs were highly complimentary of FEMA's week-long Hurricane Preparedness Course at NHC, calling the training sessions "*excellent*" and the scenarios "*realistic.*" Several EMs stated they had attended the course at NHC 5–10 years ago, and would benefit from refresher training. In addition, as a courtesy to the NWS, FEMA provides two NWS employee slots for each of the three, weeklong L-325 Hurricane Preparedness for Decision-Makers courses each winter.

Recommendation 23 (Strategic): NOAA/NWS, together with FEMA, should expand its support for the FEMA weeklong Hurricane Preparedness Course at NHC. This should include funding for NWS staff to participate.

Finding 24: Having adjacent offices as the only means of office backup leaves the NWS vulnerable to service interruption during critical times if a large-scale event affects numerous neighboring offices.

Recommendation 24 (Strategic): Service backup should be re-evaluated. The operative parameters for effectiveness of a backup plan should include flexibility, efficiency, and knowledge of products, services, and impacts.

Finding 25: There is no official backup site to assume the NHC SSU's responsibilities.

Recommendation 25 (Strategic): The NHC SSU should have a backup site and continuity of operations plan supported by NWS management.

Finding 26: NCF does not sufficiently support WFO software critical for the generation of products and services specific to tropical storms and hurricanes. NCF calls usually assign support to an FDTB employee whose position is not designated to provide on-call support.

Recommendation 26 (Operational): All WFO software critical to the hurricane program should be included in the AWIPS baseline. Technical support for products essential for HLS production, including the Radii/Clipper (RCL), should reside at NCF. NCF/Raytheon should acquire sufficient proficiency to support these baselined applications**.**

Finding 27: Many forecasters identified bugs in the HLS software code during Irene, even though mandatory testing of the software is required at each WFO before each hurricane season. With assistance of an FDTB employee who was called after hours, the majority of the bugs were fixed by forecasters who happened to have written the code and were working shift.

Recommendation 27 (Operational): Software critical to the hurricane program should be extensively tested before each tropical cyclone season at WFOs prone to tropical cyclones.

Finding 28: WFO and RFC workstations are different, and therefore require different partitioning procedures. While the NCF tests these procedures on WFO workstations, NCF did not test RFC workstations. This inconsistency resulted in a significant delay bringing a MARFC workstation back to operational status.

Recommendation 28 (Operational): NCF should test procedures on both WFO and RFC workstation configurations.

Finding 29: The NHC's lack of robust computing infrastructure causes limitations and creates additional work for SSU specialists.

Recommendation 29 (Strategic): The SSU should explore the feasibility of using the NOAA Central Computer System operated by NCO to run Storm Surge Forecast models. This change also would make the Continuity of Operations Plan more effective when another NWS facility needs to back up NHC.

Finding 30: Several WFOs impacted by Irene did not have enough workstations to facilitate the increased staffing necessary for all critical tropical cyclone-related functions. The complexity of Irene's impacts nearly exceeded the capabilities of the office workstation array.

Recommendation 30 (Strategic): To handle the increased workload from a landfalling tropical cyclone, the NWS should do one or more of the following:

- Increase the number of fully operational workstations in coastal offices to at least six
- Incorporate workload shedding in the COOP through service backup for high-impact events. This change will allow WFOs to focus on the high-impact elements versus the

routine products and free up workstations, allowing forecasters to focus on impact-based DSS.

- Allow offices to repurpose existing laptops and non-workstation PCs prior to large events to provide additional access to the Internet and free-up workspace near AWIPS workstations
- Use PC-based software applications, such as FXNet and SimuAWIPS, as a supplement when AWIPS workstations are not available

Finding 31: Operational WAN links are often saturated, even during non-weather events. During high-impact events, offices are unable to perform enhanced DSS.

Recommendation 31 (Operational): The NWS should increase the total amount of bandwidth into each office from 3 Mbps to at least 5 Mbps.

Finding 32: VSAT, the primary backup system for OPSNet, is only installed permanently at approximately half of the WFOs.

Recommendation 32 (Operational): Until the NWS can implement a more resilient backup system, VSAT should be permanently installed in all WFOs.

Finding 33: VSAT bandwidth is not adequate, particularly when multiple offices are using the system simultaneously. VSAT also experiences degradation of signal (attenuation) in heavy rain and snow.

Recommendation 33 (Strategic): The NWS should implement a backup solution that meets operational needs. The solution should be a diverse communication path from the primary terrestrial path, have sufficient bandwidth to support operations, be resilient to environmental factors such as rain and snow, and be scalable and support multiple offices simultaneously without operational degradation.

Finding 34: WFO staff members are unprepared to manage the limitations of the VSAT backup system because they often do not know they have been switched to it, they receive no training on it, and site administrators do not have enough information to mitigate the inherent bandwidth limitations of VSAT.

Recommendation 34a (Operational): Instead of simply issuing an AWIPS administrative message, NCF should call a site when it is switched to VSAT.

Recommendation 34b (Operational): All WFO electronics staff should be trained on the basic operations of VSAT.

Recommendation 34c (Operational): Mission critical communication requirements should be defined, prioritized, and implemented during VSAT operations.

Recommendation 34d (Operational): Due to VSAT's limited bandwidth that causes severe slowdown of operational PCs, NWS should explore independent Internet connection solutions such as 4G mobile WiFi.

Finding 35: Several offices were unable to update the point-and-click Web pages while on VSAT because of RSYNC protocol blocking. Inefficient transmission of netCDF files to multiple locations further compounds this problem.

Recommendation 35 (Operational): NWS should investigate having its Information Dissemination Service pull netCDF files from the National Digital Forecast Database (NDFD) for the generation of the point-and-click Web forecasts. This change also would eliminate the possibility of NDFD misalignment with the point–and-click Web forecast, as well as reduce extraneous bandwidth utilization of VSAT and OPSNet.

Finding 36: Current NWS VSAT deployment policy is based on the availability of backup offices to take over operations of the failed WFO. In geographically large-scale events, such as Irene, backup offices are not capable of managing this additional workload.

Recommendation 36 (Operational): Like prepositioning personnel, NWSHQ should develop a plan to strategically preposition VSAT/backup communication equipment to rapidly mitigate degraded operations.

Finding 37: NHC, OPC, HPC, and WFOs are expected to remain operational during even the most extreme weather events, yet most are not equipped to do so. (See Hurricane Katrina August 23-31, 2005 Service Assessment.) During Irene, staff sheltered in place at both WFO New York City/Upton and WFO San Juan. There and elsewhere along the path of Irene, WFO staff operated in facilities neither designed for, nor adequately equipped to, shelter in place for 72 hours.

Recommendation 37a (Operational): NWS should establish a plan ensuring a safe and restful sleeping environment for employees who remain at the office because of unsafe travel conditions in areas at risk for very high-impact events. Where practical, this plan should consider providing a temporary shower in each facility. NWS offices should keep a stock of at least 72 hours of non-perishable food and water onsite.

Recommendation 37b (Strategic): Future NWS construction should be designed as storm-resilient offices that provide sleeping, shower, and eating facilities for staff.

Finding 38: The public and media did not fully recognize the devastating flood threat that land-falling tropical cyclones pose for inland areas of New England.

Recommendation 38a (Operational): When there is high confidence of a historic flood event, the NWS should use all available tools and imperative language to convey the urgency and to ensure the message is timely, clear, and understood by the media and decision makers. Forecasters should be encouraged to modify guidelines and cultural practices and issue flood warnings, thus increasing lead time, rather than waiting until they receive reports of extreme rainfall or flooding. NWS should provide training on how to balance the relationship between forecast confidence levels and potential high impacts to extend lead times.

Recommendation 38b (Strategic): NWS should partner with the media and social scientists to educate the public on the inland flooding threat associated with land-falling tropical cyclones, especially in areas such as New England where such events are rare.

Finding 39: The HLS is inefficient and ineffective. NWS should consider both a short-term (operational) and long-term (strategic) solution.

Recommendation 39a (Operational): The NWS should modify the HLS using input from social scientists. Changes to the HLS should include:

- Structuring it in a bulleted format like the NWS winter storm/non-precipitation/red flag warning products
- Reducing the product's length
- Including event-driven, impact-based updates, as opposed to static update times
- Reducing generation time by at least 30 percent

Recommendation 39b (Strategic): The NWS should develop requirements for a Web-based HLS using input from social scientists. These requirements should include:

- Putting location of impacts first
- Including graphics, images, and video depicting all expected impacts
- Adding a site-configurable template to allow forecasters to populate the HLS with pertinent information similar to selecting CTAs
- Offering the ability to automatically populate with NDFD grids

Finding 40: The inability of some WFOs to issue salient and appropriate advisories and warnings needs to be resolved.

Recommendation 40 (Operational): All WFOs facing the potential for significant impacts from a tropical cyclone should have capability to issue an HLS.

Finding 41: At times, current practice in the way tropical cyclone warnings and associated deterministic wind forecasts are issued creates confusion and concern on the part of media partners and other customers.

Recommendation 41 (Operational): NWS, working with Social Scientists, media partners, and EMs, must improve understanding of NHC hurricane warnings and how they relate to deterministic forecasts. Results should include clear and consistent definitions of terms and phrases related to tropical cyclones. In addition, appropriate impact messaging should be directed to all geographic areas within the 5-day cone of uncertainty, and traditional watch and warning lead times should be flexible when confidence allows and impacts are expected to be significant.

Finding 42: At times, too little time remains after naming a system to issue a watch, and instead NWS issues a warning. As a result, the EM community and the public are left with less time to prepare and react.

Recommendation 42 (Strategic): When confidence exists that a tropical wave will develop into a tropical storm or hurricane and potentially affect land within 2 days, NHC and the affected WFOs should issue a watch, even when the system has not been named.

Finding 43: Analyses of Irene's intensity often had a high bias during the weakening phase of the storm.

Recommendation 43 (Operational): NHC should identify strategies to help mitigate occurrences of a high bias in intensity analyses.

Finding 44: Current policies at NHC allowed a several hour gap during which Irene had been downgraded, but a hurricane warning was still in effect. This caused confusion for WFOs and the media in the impacted area.

Recommendation 44 (Operational): NHC should issue a TCU to change the watch/warning status of a tropical cyclone. This action will avoid delays in clearly communicating changes in tropical cyclone status between advisory packages.

Finding 45: The use of some terms, although scientifically accurate, creates potentially dangerous misperceptions on the part of the public.

Recommendation 45 (Strategic): Use of terms such as "*downgraded*" and "*weakened*" should be carefully contextualized in statements intended for the public. NHC should work with social scientists to determine the most effective language to use in cases where a tropical cyclone is weakening but significant threats still exist.

Finding 46: Irene revealed confusion over storm tide/surge terminology, vertical datums (e.g., MLLWS, AGL, NAVD 1988, HAT), and effects (actual physical impact on land) among WFOs and a wide range of users of NWS tropical cyclone products. NWS partners and media strongly expressed their need for coastal inundation forecast maps.

Recommendation 46 (Operational): The NOAA Storm Surge Roadmap, which includes improving communication, outreach, and education regarding definitions and use of storm tide, storm surge, and datums and to create coastal inundation forecast maps and corresponding impacts, needs to be a top NWS and NOAA priority.

Finding 47: The available information regarding damage potential is limited and affected WFOs need knowledge of surge and wave impact based on their local geomorphology to better inform customers of impact potential. The NWS, USGS, and USACE have significant interest in better understanding this issue and in conducting additional research in this area.

Recommendation 47 (Strategic): NWS, through the National Hurricane Program, needs to closely coordinate research on tropical cyclone-related geomorphological impacts with the USGS and USACE, both of which have existing knowledge from which the NWS would benefit.

Finding 48: NWS has an insufficient number of storm surge and wave experts at the local and regional office level. The primary function of these experts is providing expertise in storm surge and wave forecast formulation and interpretation to the WFOs and working with the SSU.

Recommendation 48 (Operational): NWS should train and provide additional storm surge and wave experts at the NWS Regional and WFO levels to answer storm surge and wave-related questions from EMs and coordinate with SSU.

Finding 49: Several groups conduct post-storm surge surveys. There is a need to coordinate these efforts and quickly collect observations of actual storm surge heights after tropical cyclones.

Recommendation 49 (Operational): NWS should coordinate with NOS and USGS to gather and consolidate post-storm surge and storm tide gage observations and high water marks in a common database.

Finding 50: GIS-compatible maps of observed coastal inundation will assist in the refinement of prediction inundation maps and future service assessments. Many external partners expressed interest in post-storm coastal inundation maps. These maps would be useful to evaluate planned NWS coastal inundation forecast maps.

Recommendation 50 (Strategic): NWS should consider undertaking joint research efforts with NOS/CO-OPS, USGS, and USACE to produce GIS-compatible maps of observed coastal inundation for significant tropical cyclones using observational data and storm surge model hindcasts.

Finding 51: CTAs for trees, branches, and other debris falling due to strong winds should inform the public of appropriate actions to take, not just describe possible damage.

Recommendation 51 (Strategic): The NWS should compose AWIP-baselined CTAs for trees, branches, and other debris falling due to strong winds. These CTAs should contain appropriate actions to take.

Finding 52: Specific, actionable guidance related to increased risk due to winds in high-rise buildings does not exist in the current NWS suite of tropical cyclone warning products.

Recommendation 52 (Operational): NWS should formulate specific guidance to communicate increased wind risk in high-rise buildings during tropical cyclones.

Finding 53: Multiple tornado warning false alarms during tropical storms damaged NWS credibility and failed to focus public attention on the actual wind-related risks.

Recommendation 53 (Operational): The NWS should work with the scientific community to develop case studies and criteria to assist NWS forecasters in issuing tornado warnings associated with landfalling tropical cyclones.

Finding 54: The limited number of observations of hurricane force wind gusts within areas under a hurricane warning led to the perception by the media and the public that deterministic wind field forecasts were too high, particularly for hurricane-force winds.

Recommendation 54 (Strategic): In addition to the need for better estimates of surface wind speeds/intensity in tropical cyclones prior to landfall (see Recommendation 43), WFOs in close collaboration with NHC and their neighboring and backup offices, should apply meteorologically appropriate inland surface wind speed reductions as opposed to a blanketed wind reduction. NWS should support research such as the NOAA Collaborative Science, Technology, and Applied Research (CSTAR) project, "Improving Understanding and Prediction of Hazardous Weather in the Southeastern United States: Landfalling Tropical Cyclones and Convective Storms." This change will likely require the development of a more robust and scientifically sound smart tool that applies spatially varying wind reductions that more appropriately account for boundary layer meteorology and topography.

Finding 55: During Irene, the FAA New York Air Route Traffic Control Center Boundary traffic managers found the experimental Day 2 product very helpful.

Recommendation 55 (Strategic): NWS OCWWS, in collaboration with NWS regional headquarters and the FAA, should develop requirements for an official Day 2 oceanic forecast outlook, or equivalent product, geared to tropical conditions affecting CWSUs with overwater forecast responsibilities along the Atlantic and Gulf of Mexico Coasts.

Finding 56: The standard NWS product suite, while meaningful to some NWS personnel in preparing briefing products during Irene, is tailored to subject matter experts. In some cases, it did not sufficiently explain risk or potential impacts to key national and local decision makers.

Recommendation 56 (Strategic): NWS needs to improve information services and product delivery to convey relevant impacts, risks, and the urgency of required actions associated with landfalling tropical cyclones for use by decision makers without meteorological expertise. This includes the creation of a more user-driven information platform in which users can create customized services primarily through digital media and on mobile devices. This new generation of NWS products and services must be adapted to the needs of a range of key decision-support partners.

Recommendation 56 (Strategic): NWS must improve information and product delivery conveying relevant impacts, risks, and urgency of required actions associated with landfalling tropical cyclones for use by decision makers without meteorological expertise.

Finding 57: Incorporation of probabilistic wind impacts into a deterministic wind forecast remains a challenge. Existing probabilistic triggers for phraseology in text and graphical forecasts were not universally understood within the NWS and among external partners.

Recommendation 57 (Strategic): NWS needs a comprehensive, social science-based approach to incorporate universally understood, probabilistic information into tropical cyclone forecasts.

Finding 58: The NWS is not meeting user needs for inland and coastal flood inundation forecast maps.

Recommendation 58 (Strategic): NOAA, leveraging resources such as the NOAA Storm Surge Roadmap, IWRSS, and NWC needs to provide inland and coastal flood inundation forecast maps to depict the geographic extent and severity of the predicted inundation along with forecast uncertainty. The coastal flood forecast inundation map needs to represent the inundation or water depth expected over the land due to the combination of storm surge, tides, waves, and freshwater inflow. The inland flood inundation forecast map needs to utilize RFC river-model forecast guidance driven by QPF. The flood inundation maps should be made available via an interactive map viewer to allow users to overlay the locations of critical infrastructure to determine the potential impacts of flooding as well as latest information (e.g., weather radar reflectivity, river stages, storm-total rainfall estimates, and active watches/warnings). In addition, the flood inundation forecast maps should be made available to users in GIS-compatible formats.

Finding 59: In non-coastal areas, the public did not fully understand the scope of Irene and consequently did not perceive the threats as real and immediate.

Recommendation 59 (Strategic): Building on the experimental tropical cyclone impacts graphics, NWS should dedicate specific resources and work with social scientists to develop a GIS-compatible, all-hazards graphical suite depicting tropical cyclones' impacts.

Finding 60: There is a growing demand for additional NWS products available in GIS-compatible formats via interactive map viewers and Web map services.

Recommendation 60 (Strategic): NWS needs to make additional products available in GIS-compatible formats (e.g., shapefiles, KML files) and via Web map services to support the EM and water resources communities.

Finding 61: The Massachusetts EMA, FEMA Region I, and Boston EM specifically requested a password-protected site containing probabilistic information. Many EMs wanted more information on which to base worst-case scenario decision making.

Recommendation 61 (Strategic): Local WFOs should develop a password-protected EM Web page that includes briefings, probabilistic information/ensembles, and user-defined sensitive information.

Finding 62: Inconsistent use of nationally approved technologies, such as NWSChat, results in an inconsistent level of service.

Recommendation 62 (Operational): All offices, including National Centers, should use NWSChat to communicate with key external and internal entities, especially with embedded NWS Meteorologists, ERSs, broadcast meteorologists, and Incident Meteorologists.

Finding 63: DSS delivered by onsite meteorologists was widely praised by EOC staff. Many EOCs had only one deployed meteorologist on loan during Irene, leading to extreme fatigue while delivering nearly continuous DSS.

Recommendation 63 (Strategic): NWS should evaluate the need to deploy 2 ERSs for 24/7 duty in extremely high workload deployments, and the possibility of using this deployment as a training opportunity for new ERSs as DSS demands increase.

Finding 64: During Irene, the AHPS pages for affected WFOs were not displaying the same type of water level forecast for tide forecast locations. None of these pages displayed the official storm surge forecast contained in the HLS or NHC advisories. In addition, the AHPS hydrographs did not identify the water level datum or indicate the forecast might not be valid for tropical cyclones.

Recommendation 64 (Operational): The NWS needs to develop national standards for the graphical display of water level forecasts at tide locations on the AHPS Web page.

Finding 65: There was no information for AHPS users to interpret the observations and forecasts on AHPS hydrographs at tide locations during Irene.

Recommendation 65 (Operational): The NWS needs to modify the NWS Guide to Hydrologic Information on the Web to include information on how to read and interpret AHPS observations and forecasts for AHPS tide forecast locations.

Finding 66: Key partners expressed interest in having a single Web site that explains all hurricane impacts, including information on inland flooding threats.

Recommendation 66 (Operational): NWS should develop a comprehensive Web site that includes coverage of all threats and impacts of tropical cyclones.

Finding 67: Access to additional or backup radar information, such as TDWR information, is crucial during high-impact events.

Recommendation 67 (Operational): NWS should ensure the accessibility to TDWR data centrally and at local WFO Web sites, where applicable, in case of WSR-88D outages.

Finding 68: The NWS does not currently serve as an authoritative source of weather information in the social media environment. Doing so would not only ensure relevant, important, and lifesaving information is distributed through social media, but also would help limit misinformation.

Recommendation 68 (Operational): The NWS should incorporate Facebook, Twitter, and other relevant social media as principal dissemination tools as quickly and consistently as possible, making certain that salient links are included.

Finding 69: New England WFOs each have several hundred local EMs. WFOs rely heavily on the state EMs to disseminate information to local communities. This setup makes direct, local outreach and DSS difficult.

Recommendation 69 (Operational): WFOs should work with State EM officials to keep a current listing of local EMs.

Finding 70: There is still a widespread belief that hurricanes are coastal, not inland hazards.

Recommendation 70 (Strategic): NOAA/NWS should commission a team of forecasters, social scientists, and media to develop outreach and training efforts focused on raising public awareness of potentially significant impacts of inland flooding. This particular outreach effort might include:

- Highlighting flood-prone areas on the three- and five-day track forecasts from the NHC
- Placing "Inland Flooding" under "Hurricane Awareness" on the left frame of the NHC Web page right after "Storm Surge, integrating inland flooding threat associated with landfalling tropical cyclones in Kindergarten through12th grade (K-12) education
- Adding all tropical cyclone impacts into the StormReady program requirements
- Developing and implementing training modules on inland flooding impacts from tropical cyclones for EMs and media. Such training should consist of nationally standardized Web-based training modules, which are augmented by regional and local workshops.

Finding 71: Outreach efforts are hampered because NWS professionals are not able to communicate easily with Spanish speaking groups. The NWS mission "for the protection of life and property" cannot be fully realized if significant numbers of the population in one or more regions cannot use the warnings and forecasts because of a language barrier.

Recommendation 71 (Strategic): NWS should develop a comprehensive program to address the informational needs of the growing Spanish language community during high-impact events. This program should include a cadre of mobile, decision support meteorologists/hydrologists who are not only Spanish speakers, but are trained to deal with local and national media and local decision makers. This trained group should be available for deployment in decision support roles as needed, providing interviews and translation for social media sites such as Facebook.

Finding 72: Several USGS gages failed because they were not built to handle an event of this magnitude. The data outages caused uncertainty and anxiety, especially related to the Gilboa Dam, part of NYC's Catskill Water Supply System in Schoharie County. Gage failures meant decision makers did not know upstream flow into the reservoir, nor the flow heading down the Schoharie Valley from Gilboa Dam.

Recommendation 72 (Strategic): NWS, in coordination with external partners, should prioritize gages in need of hardening to ensure the gages can handle record floods.

Finding 73: Real-time river and coastal water level observations were critical for RFCs and WFOs to monitor and forecast flood potential and severity during Irene. These observations are also critical for the operation and verification of present and planned NWS river forecast and NOS oceanographic forecast modeling systems.

Recommendation 73a (Strategic): The RFCs should engage groups spanning from federal to local level to:

- Ensure flood forecast points are appropriately prioritized, resourced, and supported
- Identify problems that can be addressed prior to high-impact events
- Ensure external partners responsible for funding are informed of the NWS or NOS reliance on gages during high-impact coastal storms.

Recommendation 73b (Strategic): The NWS should develop prioritized lists of recommended sites for future river and tide gage installations. The lists should be provided to the USGS via the Joint NOAA/USGS Committee on Hydrology and NOS, respectively.

Finding 74: The USGS project to deploy storm-tide sensors, stream gauges, and wave height sensors at key locations along the East Coast in advance of tropical cyclones is critical to NWS and NOS development and verification of future Storm Surge Forecast models and coastal inundation maps.

Recommendation 74 (Strategic): NWS and NOS need to engage with USGS, USACE, and FEMA to ensure USGS has sufficient resources to continue its sensor deployments in advance of land-falling tropical cyclones.

Finding 75: HADS does not have a process for notifying all of NWS, NOS, and other NOAA agencies when data from RDGs are added to HADS.

Recommendation 75a (Operational): The Joint NOAA/USGS Committee on Hydrology should develop a Standard Operating Procedure to specify how the USGS should notify the NWS, NOS, and NOAA users when RDGs are deployed.

Recommendation 75b (Operational): HADS should notify impacted ROCs, WFOs, RFCs, and NCEP/NCO, NOS/CO-OPS, and USGS once the RDG observations are available in NWS data streams.

Finding 76: USCG places NDBC needs for buoy maintenance below other USCG mission priorities. This prioritization delays corrective and preventive maintenance of buoys for months and results in observational gaps. NWS does not have available funds to pay for ship time for buoy maintenance.

Recommendation 76 (Operational): NOAA should provide funding to be used in the most economical and efficient way for ship support to maintain weather buoys.

Finding 77: WFOs Wilmington and Newport/Morehead City had only about 2 weeks advance notice of the planned removal of Buoy 41035 during the peak of the hurricane season.

Recommendation 77 (Operational): NDBC and NWS need to facilitate greater advance notice (i.e., greater than 2 weeks) from partners whenever possible regarding the permanent removal or temporary service interruption of a partner's buoy or coastal station and inform WFOs, NHC, OPC, and other users as soon as possible. In addition, the NDBC should avoid scheduling the removal or planned temporary service outage of NDBC-owned platforms along the East Coast and Gulf of Mexico during the peak of the hurricane season (i.e., mid-August thru mid-September) whenever possible.

Finding 78: Surface marine weather observations, including wind and significant wave heights, for central Long Island Sound were not available to WFO New York City/Upton when the southern Connecticut coast measured its highest surface winds of the event (0830–1330 UTC). Data from NWS and NOAA Integrated Ocean Observing Systems (IOOS) offices are sent to NDBC and from there to AWIPS

Recommendation 78 (Operational): The NOAA IOOS Program Office, in cooperation with NDBC, should work with regional ocean observing system data providers to determine how NOAA can assist partners technically and financially to improve their telecommunication and backup-power capability to ensure near real-time observations from their platforms are transmitted to NWS and NOAA users during coastal storms.

Finding 79: Comparisons of forecast guidance hindcast runs by two NCEP numerical weather prediction models using data from additional rawinsondes indicated little impact on accuracy of the hurricane track or intensity forecasts.

Recommendation 79 (Strategic): The NWS should commission a multi-event, cost/benefit analysis of augmenting North American rawinsonde observations for the purpose of improving numerical weather prediction model forecasts during landfalling tropical cyclones. This analysis should include domain extent, lead time, and synoptic observation time to determine if extra rawinsonde releases are a worthwhile investment.

Finding 80: A degradation of service by backup offices may occur because of failed WSR-88D radars and a lack of access to radar data from nearby TDWR sites.

Recommendation 80 (Operational): The NWS should ensure that primary and secondary backup WFOs in tropical cyclone-prone areas have access to all nearby TDWR data.

Finding 81: WFO San Juan's WSR 88D failed during Irene and has previously experienced recurring problems.

Recommendation 81 (Operational): NWS and FAA should examine the maintenance of the FAA-owned WSR-88D at San Juan to ensure maximum efficiency and performance.

Finding 82: As Irene started to lose strength approaching New Jersey, the sparseness of surface observations caused problems for forecasters, not only at NHC, where there was a reluctance to reduce wind speed forecasts due in part to a lack of corroborating data, but also for some WFO forecasters. These forecasters, in retrospect, viewed near shore and inland wind speed forecasts as being too high, as evidenced by a lack of observed hurricane force winds. There was also a perception among the media and public that wind forecasts were too high given the lack of observed hurricane force winds.

Recommendation 82 (Strategic): NOAA should support research and development for OSVW observational platforms to improve surface observation density with the objective of improving forecast confidence during tropical cyclones.

Finding 83: Present storm surge forecasts do not provide the EM community with sufficient lead time or spatial resolution of inundation areas. This lack of forecast data has opened the door for multiple voices communicating surge and flooding information and increased the risk for miscommunication and misinformation among users.

Recommendation 83 (Strategic): NOAA should strongly support efforts of NWS, NOS, and its partners to develop and implement operationally improved storm surge forecast modeling systems in order to provide probabilistic coastal inundation forecasts of total water level out to 72 hours for its users.

Finding 84: The experimental ESTOFS and ETSS models provided valuable forecast guidance to NHC and OPC during Irene as it tracked through the northeastern United States.

Recommendation 84 (Strategic): NHC and OPC should work closely with MDL and CSDL to ensure the ETSS and ESTOFS models are continuously improved to provide detailed surge and tide forecast guidance to coastal WFOs, NHC, OPC, and partners. These efforts should be coordinated with the NWS Office of Hydrologic Development to include emerging river, estuarine, and coastal forecast modeling capabilities of the NWS and NOS.

Finding 85: New collaborative opportunities in estuary modeling are emerging between the NOS and the NWS due to advances in the NWS river forecasting computer architecture, such as CHPS, which could allow the NOS ocean-estuary modeling activities to be integrated into the NWS river forecasting system. The end goal of this joint effort will be a seamless transition in forecast capability from inland river systems to the sea.

Recommendation 85 (Strategic): NOAA should coordinate efforts between NOS, which is working on modeling the intersection of estuaries with the ocean in several locations, and NWS to connect river systems intersecting with estuaries.

Finding 86: HFIP consensus model guidance performed much better than the operational guidance for both track and intensity, and two HFIP models, COTI and SPC3, performed well for the 2011 hurricane season.

Recommendation 86 (Strategic): NWSHQ and NHC should continue their full support of HFIP to provide dramatically improved, real-time research model guidance products.

Best Practices

Best Practice: To ensure a clear, concise, and consistent internal message was delivered, WFO New York City/Upton appointed an event coordinator who worked with the SSU to communicate storm surge forecasts with NWS ERSs working at the NYC OEM, Nassau County OEM, and Suffolk County OEM. The event coordinator used NWSChat in a special Decision Support Services (DSS) Chat Room.

Best Practice: MARFC briefings to the USGS before Irene enabled USGS to deploy personnel and equipment to important locations. As a result, the USGS quickly repaired damaged gages, ensuring the RFC received data at vital locations during the event. The USGS found this coordination and information valuable.

Best Practice: According to CHC, NERFC briefings on August 26, 2011, allowed the Quebec weather office to prepare for potential impacts from Irene.

Best Practice: Following previous practices, SRH sent members of a pre-established deployment pool to impacted offices. The deployment pool detailed each member's skill set to best match the capability with the MIC's/HIC's needs.

Best Practice: ERH's proactive prepositioning of 22 additional staff provided a critical level of support and capability for enhanced DSS both internally and externally.

Best Practice: The deployment of a WSR-88D Radar Operation Center (ROC) team from Norman, OK, to a location near the forecast impact area allowed critical equipment and technicians to be within a day's drive of vital radar systems. The team deployed with a satellite communications kit in anticipation of potential widespread communication outages in the affected areas. The team was able to respond quickly after the storm passed to help WFO Philadelphia/Mount Holly repair its radar.

Best Practice: The SERFC designated an Incident Manager; implementing the Incident Command System (ICS) allowed the office to better prepare for extreme events.

Best Practice: During the interview process for all positions at WFO Wilmington, the MIC clearly states the office is subject to tropical cyclones and explains the expectations and local policies to prospective employees. Candidates are informed it is a requirement to be available to work during a hurricane threat. The MIC discusses individual responsibilities and states leave may be canceled to ensure coverage for a hurricane threat.

Best Practice: Although WFO Burlington was unable to issue an HLS product, they improvised and constructed a special weather statement, which mimicked in many ways the format and information found in an HLS. This product was first issued 2 days prior to Irene's impact and continued through the event. Feedback from the media was positive.

Best Practice: WFO Morehead City completed detailed surge surveys immediately after Irene. Three teams went out consecutively for 5 days to map high water marks and document impacts from the storm surge. Response from the community was resoundingly positive. Service hydrologists from WFOs Raleigh, Wilmington, and Cleveland participated in the storm surge surveys.

Best Practice: WFO Wilmington developed and shared Call to Action statements (CTA) for falling trees, branches, and wind damage that are effective public messages appropriate to land-falling tropical systems. Messages are descriptive and include appropriate actions for the public. The following are a few examples of CTAs that could be used in products during a land-falling tropical system:

- **Stay inside**

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Going outside for any reason during the storm can lead to serious
injury or death.  Strong winds can turn debris into deadly projectiles.
Trees and large limbs will likely continue to fall.
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- **How to shelter in place**

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Strong winds can knock down trees and limbs...creating flying debris.
To avoid serious injury or death...stay inside away from exterior
walls.  If possible...stay in an interior room on the lowest floor.
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- **Driving Hazards**

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Do not venture onto the roads during the storm.  Downed limbs and trees
on the road will create significant road hazards.  A tree or limb can
fall onto your vehicle...resulting in serious injury or death.
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Best Practice: WFO Newport/Morehead City issued nearly 100 LSRs when Irene was affecting its CWA. This information was immediately and effectively disseminated through local media.

Best Practice: WFO Philadelphia/Mt. Holly produced high quality and timely briefing packages that were widely distributed to the EM community.

Best Practice: Over the past several years, WFO Wilmington developed a series of briefing templates for use by EMs during tropical cyclone events based on the time from hurricane impact. The use of these templates ensured message consistency. These templates are on a local office intranet page.

Best Practice: To the extent possible, in advance of high-impact events WFOs with primary liaison responsibility should encourage their state and county level EMs to engage high-ranking elected officials in their discussion of potential impacts.

Best Practice: WFOs Baltimore/Washington and Wakefield have Web pages for briefing EMs about various hazardous weather events (e.g., hurricanes, winter storms). These partner-driven pages allow EMs and the media to find important information quickly.

Best Practice: NHC provided frequent and relevant updates on its Facebook page.

Best Practice: Several NWS offices participated in training programs with their local and state EM offices. This training included participation in tabletop, functional, and full-scale exercises, as well as completing FEMA-based online ICS modules.

Best Practice: Many counties and communities throughout the affected area participate in the StormReady and TsunamiReady programs. Partner response and relationships with their supporting WFOs were enhanced because of these programs.

Best Practice: A Spanish-language audio podcast was created and posted on the NHC Web site with each new advisory.

Best Practice: The USGS coordinated daily with NHC and NOS/CSDL on track and intensity forecasts to determine the best locations for deployment of the USGS sensors. The conference calls between USGS and NOAA, *"influenced our decision very heavily on where to deploy. We must evacuate 12 hours prior to landfall, and redeployments are not possible if the track shifts. Discussions were daily for a week prior to the storm, and a deployment decision was made 2 days prior to landfall. They did a great job giving information…"*

Best Practice: MARFC's experimental short-term hydrologic ensemble forecasts available on its Web page were a useful planning tool for the RFC and its WFOs regarding potential for high river stages in advance of Irene.

Best Practice: SERFC used ensemble model output to develop its Hydrologic Vulnerability Assessment, which was shared with SERFC staff, WFOs, and relevant partners

Best Practice: NERFC worked with SSU to incorporate SLOSH gridded forecast guidance into HEC-RAS starting on Wednesday, August 24. By Friday night, August 26, NERFC staff was able to incorporate a storm surge time series at the river mouth to use as a boundary condition in HEC-RAS.