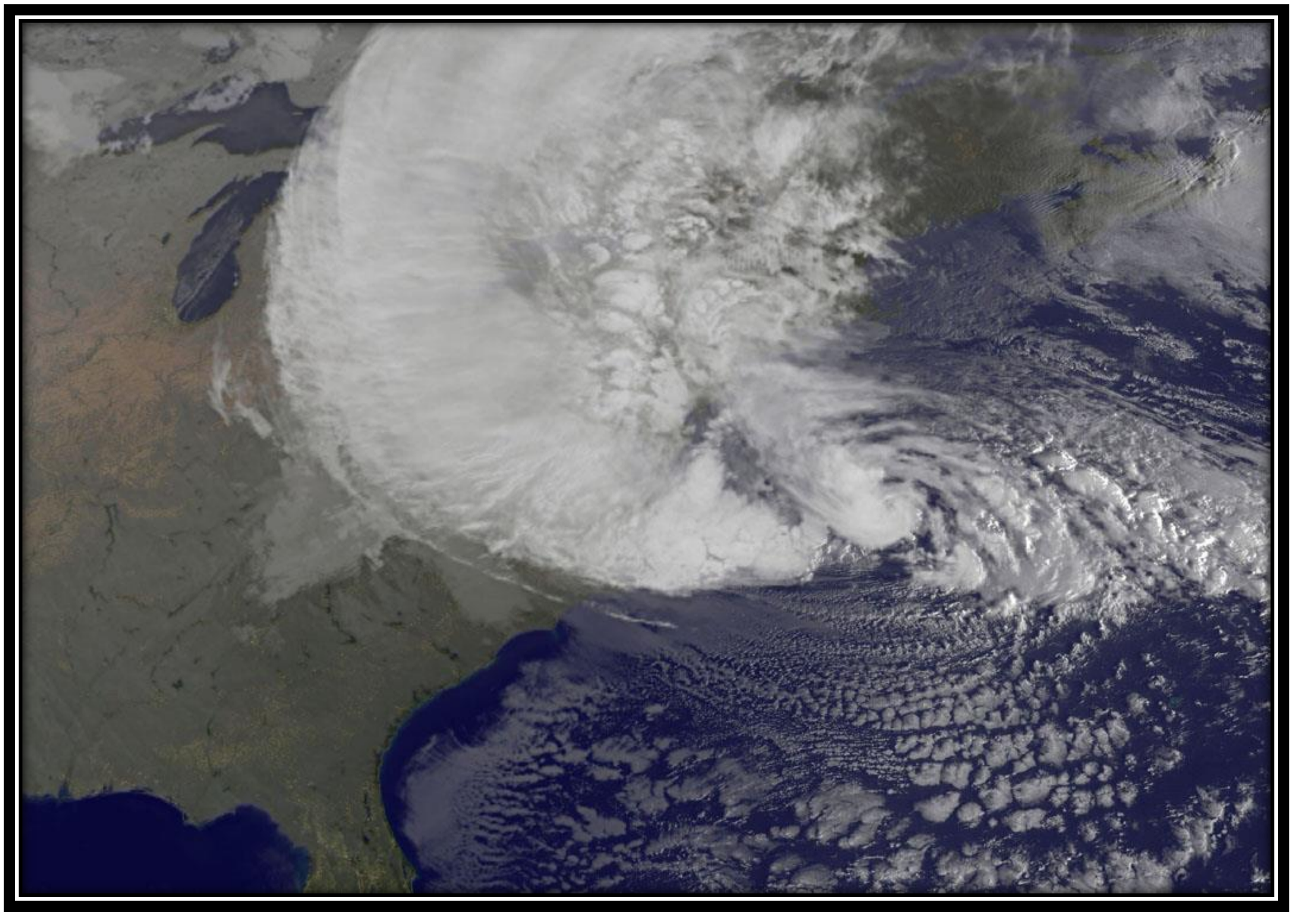
Service Assessment

Hurricane/Post-Tropical Cyclone Sandy, October 22–29, 2012



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

Cover Photograph: NOAA's GOES-13 satellite captured this visible image of Hurricane Sandy battering the U.S. East Coast on Monday, October 29, 2012, at 9:10 a.m. Sandy's center was about 310 miles south-southeast of New York City. Tropical storm force winds were about 1,000 miles in diameter.

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May 2013

National Oceanic and Atmospheric Administration
Kathryn D. Sullivan, Ph.D., Acting Administrator

National Weather Service
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Preface

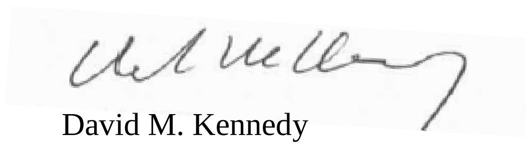
On October 22-29, 2012, Hurricane/Post-Tropical Cyclone Sandy moved from the Caribbean to the U.S. Eastern Seaboard, ultimately making landfall near Brigantine, NJ, around 7:30 p.m. on October 29. The storm resulted in an enormous impact to life and property in both the Caribbean and continental United States. The National Hurricane Center's Tropical Cyclone Report estimated the death count from Hurricane Sandy at 147 direct deaths. Sandy damaged or destroyed at least 650,000 houses and left approximately 8.5 million customers without power during the storm and its aftermath. The effects of Sandy extended as far west as Wisconsin. This late season storm also generated blizzard conditions in western North Carolina and West Virginia, resulting in snowfall totals as high as 3 feet.

Storm surge created some of the most devastating impacts, including flooding in New York City's subway tunnels, water overtopping runways at La Guardia (**Figure 1**) and Kennedy airports, and damage to the New Jersey Transit System estimated at approximately $400 million.

Figure 1: LaGuardia Airport during Sandy. *Source: The Port Authority of New York and New Jersey*

In light of the Sandy's significance, the National Oceanic and Atmospheric Administration (NOAA) formed a Service Assessment Team to document and evaluate the agency's performance and effectiveness. The Team focused on three key points: first, the National Weather Service's forecast, watch, and warning products, including its underlying philosophies and policies and its dissemination/communication tools. Second, the Team reviewed the NWS web presence as a tool for communicating with the public. Finally, the Team looked at NWS's production and issuance of storm-surge related products.

NOAA will use the findings and recommendations in this assessment to increase awareness of critical needs during future extreme weather events and improve products and services to further protect life and property. Given the relationship of this assessment to the agency's broader portfolio, NOAA will also improve integration and collaboration across mission lines to ensure ongoing responsiveness to partner needs in light of Sandy's impacts.



David M. Kennedy
Deputy Under Secretary for Operations
National Oceanic and Atmospheric Administration

May 2013

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Executive Summary

Hurricane/Post-tropical Cyclone Sandy[1] was unique in many ways. Its historically unprecedented track approached New Jersey and New York from the east; storms typically approach from the south. Sandy also made an atypical transition to post-tropical status. The storm evolved when a tropical cyclone merged with an intense low pressure system and dramatically increased in size before landfall.

Sandy made landfall along the southern New Jersey shore on October 29, 2012, causing historic devastation and substantial loss of life. The National Hurricane Center (NHC) Tropical Cyclone Report estimated the death count from Sandy at 147 direct deaths. In the United States, the storm was associated with 72 direct deaths in eight states: 48 in New York, 12 in New Jersey, 5 in Connecticut, 2 each in Virginia and Pennsylvania, and 1 each in New Hampshire, West Virginia, and Maryland. The storm also resulted in at least 75 indirect deaths (i.e., related to unsafe or unhealthy conditions that existed during the evacuation phase, occurrence of the hurricane, or during the post-hurricane/clean-up phase). These numbers make Sandy the deadliest hurricane to hit the U.S. mainland since Hurricane Katrina in 2005, as well as the deadliest hurricane/post-tropical cyclone to hit the U.S. East Coast since Hurricane Agnes in 1972.

Damage estimates from Sandy exceed $50 billion, with 24 states impacted by the storm. Sandy was so large that tropical storm force winds extended over an area about 1,000 miles in diameter. Sandy caused water levels to rise along the entire East Coast of the United States from Florida northward to Maine. The highest storm surges and greatest inundation, which reached record levels, occurred in New Jersey, New York, and Connecticut, especially in and around the New York City metropolitan area. In many of these locations, especially along the coasts of central and northern New Jersey, Staten Island, and southward-facing shores of Long Island, the surge was accompanied by powerful, damaging waves. Storm surge caused flooding exceeding 8 feet above ground level in some locations. Power outages from the combined effects of wind and surge left some coastal communities in New Jersey without power for months. In addition, because of the storm's late October timing, it also generated heavy snows across portions of the central Appalachians, especially in West Virginia and the mountains of western North Carolina. Snowfall totals of up to 36 inches combined with strong winds to produce blizzard conditions. Closer to the coast, more than 12 inches of rainfall resulted in river, stream, and creek flooding over portions of the Mid-Atlantic.

Emergency Managers (EMs), media, and commercial weather service providers thought the National Weather Service (NWS) forecasted Sandy well. The NHC forecast track error at 3 and 5 days for the storm was well below the 5-year average. Hydrometeorological Prediction Center (HPC)[2] day 6 and 7 forecasts were also highly accurate, giving the first indication that Sandy was a threat to the northeastern United States. EMs at the state and local level consistently stated

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[1] Hereafter referred to as "Sandy."
[2] This center has since been renamed the Weather Prediction Center but is consistently referred to in this report as the Hydrometeorological Prediction Center (HPC) because this was its name during the Sandy event.

they were well aware of the serious threat posed by Sandy several days in advance. More than 90 percent of coastal residents surveyed after the storm reported that, as Sandy approached them, they would have rated the storm as being "dangerous." Approximately 84 percent of study participants characterized the forecast to be "Excellent" or "Good." Media and commercial weather companies also indicated that numerical model guidance and NHC forecasts were very good. The early awareness for this significant storm provided lifesaving information to decision makers well in advance and resulted in declarations of several States of Emergency and activation of numerous Emergency Operations Centers (EOC) long before landfall.

Overall, the National Oceanic and Atmospheric Administration (NOAA) performed well in forecasting the impacts of this extremely large storm. NOAA issued high wind watches and warnings well in advance of their associated impact and extended them well inland to include portions of the Ohio valley. NHC issued the initial storm surge inundation forecast of 4 to 8 feet above ground level for the New Jersey, New York, and Connecticut coastlines in its 1500 Coordinated Universal Time (UTC) 27 October public advisory, well over 2 days prior to landfall of the center of the cyclone. While surge forecasts were consistent with the observed conditions as the storm approached landfall, the amount of lead time for surge and the way it was communicated represent two areas the Sandy Assessment Team found to be most in need of improvement.

Storm Transition and Coordination: The unique evolution of Sandy from a Category 3 hurricane in the Caribbean to an intense post-tropical cyclone in the hours before landfall posed several operational challenges to NWS offices. A final decision was made on Friday, October 26, to have local NWS Weather Forecast Offices (WFO) issue non-tropical watches and warnings versus having NHC issue hurricane watches/warnings north of Duck, NC. NWS made this decision after extensive discussion between NHC, NWS Eastern Region Headquarters (ERH), the Ocean Prediction Center (OPC), and the HPC, as well as several WFOs. NWS needed to make this decision well before landfall because EMs and other public officials, including a governor, expressed a strong preference that the warning suite type (i.e., tropical or non-tropical) not change once NWS initiated watches and warnings. NWS policy in place through 2012 required WFOs to issue non-tropical watches and warnings for post-tropical cyclones. The EMs and other officials were concerned with the potential for confusion and disruption during critical periods of preparation, including evacuations. Despite efforts to publicize this decision, the Service Assessment Team found that as Sandy approached the coast, not all EMs were aware of how the information flow would change once the storm became post-tropical. Further, NWS did not consistently reflect this service approach across all its websites (e.g., NHC's highly trafficked website lacked WFO-issued coastal flood and high wind warnings). Given the unprecedented nature of Sandy, fully resolving all of these challenges beforehand may have been impossible. However, this Assessment identifies critical needs to improve service delivery for future storms.

Weather Forecast Watch and Warning Products: The Service Assessment Team found differences between many of the views of NOAA's partners and public opinion research on whether issuing non-tropical watches and warnings for Sandy's landfall influenced perceptions of severity and response. A University of Pennsylvania Wharton School telephone survey of people along the Mid-Atlantic coast (Virginia to New York) conducted during the Sandy event revealed a majority thought they were under a hurricane watch on the day Sandy made landfall (even though they were under non-tropical watches and warnings). A telephone survey of coastal residents conducted 5 months after the storm also found a significant proportion thought a hurricane watch or warning was in effect when Sandy made landfall *(Gladwin, Morrow & Lazo, 2013)*. The level of concern they reported, however, did not differ substantially from respondents who thought a non-hurricane warning was in effect. Both of these academic surveys also found no statistical difference between the proportions of coastal residents who planned to evacuate or in fact did evacuate for Sandy versus Hurricane Irene, even though one made landfall with a hurricane warning in effect and the other did not have one. This statistic is consistent with the views of EMs interviewed by the Team who thought the tone and urgency of information from NOAA/NWS offices and the media regarding Sandy's intensity was strong enough that people responded properly. In some areas, especially along the central and southern New Jersey coast, local officials feared the public would dismiss hurricane warnings because the last hurricane to affect the area (Irene 2011) did not produce expected impacts. Many vulnerable residents ignore evacuation orders, even when they are accompanied by hurricane watches/warnings (*Cutter et al., 2011*). This fact highlights the need for NWS to evaluate its current suite of watch and warning products and terminology to ensure it offers clear and compelling motivation for action during storms like Sandy.

Communication and Information Dissemination: The Assessment Team found several issues with the ability of NWS users and constituents to find critical information easily among various NWS products and websites. This difficulty included finding needed information on a particular website as well as knowing which website to go to for information in general. *"Too many clicks"* was a phrase often repeated with respect to the number of sites necessary to visit to get needed information. In contrast, there are examples of particular products that served customers well. Local and state EMs in New York and New Jersey praised briefing packages sent by WFOs Upton and Mt. Holly. NWSChat also received consistent praise. Nonetheless, the need for significant improvements to NWS communications and dissemination of information is a key theme of this assessment.

Social Media and Web Services: It was clear from interviews with media, EMs, and NOAA/NWS staff that social media played an important role in increasing awareness of Sandy's threats. Social media was an effective means of reaching the public, as measured by local offices that picked up thousands of new followers during the event. WFOs, RFCs, and the National Centers for Environmental Prediction accrued 27,633 new Facebook likes during the event, providing the potential to reach millions of other Facebook users. In some cases, those interviewed stated more people sought storm information through a city or county Facebook page or Twitter feed than from the city or county web pages. EMs stated their Facebook pages gained credibility by being associated with NOAA/NWS office Facebook pages and encouraged NWS to continue enhancements to its social media presence. Social media also played a key role in assessing impacts from the storm as it made landfall. Some local emergency officials noted they learned of the need for water rescues by monitoring social media feeds. Even with this increase in the use of social media, NOAA websites remained one of the most significant sources of information on Sandy, collectively receiving close to 1.3 billion hits during the storm.

Storm Surge: The highest priority need identified by NOAA/NWS customers and constituents is for improved high-resolution storm surge forecasting and communication. In particular, there is a crucial need for storm surge graphical inundation guidance. Seventy-nine percent of coastal residents surveyed in March 2013 said the impact of Sandy's surge in their area was "more than they expected" (*Gladwin, Morrow & Lazo, 2013)*. Further, the variety of vertical and horizontal datums used by NOAA and its partners is confusing not only to EMs and to the media, but also to NWS personnel. Identifying a single and consistent basis for communicating surge relative to land elevation and providing training for NWS staff and EMs is necessary to address this confusion. There is widespread support for a storm surge warning product for coastal and tidally influenced waterways. NOAA has identified this need in previous service assessments. Improving inundation forecasting and communication of storm surge impacts should be a top priority for NOAA. To meet this need, NOAA needs to allocate additional resources to adequately support storm surge forecasting and software development for tropical and extra-tropical storms.

Decision Support Services: Decision support services (DSS) played a critical role during Sandy. NWS deployed Emergency Response Specialists to serve in a number of EOCs. The value ascribed to this support was generally high. There are examples where this support significantly improved decision-making. Specifically, the response specialist who reported to the Connecticut EOC prior to the arrival of Sandy used his expertise in coastal flooding to provide critical information to State officials. This information enabled the government of the State of Connecticut to move approximately 100 million dollars in newly purchased commuter rail cars from a coastal rail yard in the surge inundation zone to a rail yard above the flood zone. This action saved tens of millions of dollars in damage to the newly purchased rail cars.

Hurricane Irene Service Assessment: Many of the findings and recommendations from the Hurricane Irene Service Assessment are applicable to this assessment. Given the compressed time frame and more focused charter for the Sandy Assessment, the Team has not repeated all of the Hurricane Irene findings and recommendations, but has highlighted those that are highly relevant and important in Appendix C. Examples include the urgent need to develop dynamic inundation forecasts and maps, to strengthen the Storm Surge Unit staffing and resources, to improve the clarity and usability of web pages, and to focus more effectively on impacts from hazards associated with future storms.

Service Assessment Report

1. Introduction

1.1. NWS Mission

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) protects life and property by providing weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. NWS data and services form a national database and infrastructure usable by other government agencies, the private sector, the public, and the global community.

1.2. Purpose of Assessment Report

The NWS conducts service assessments of significant weather-related events that result in at least one fatality, numerous injuries requiring hospitalization, extensive property damage, widespread media interest, or an unusual level of scrutiny of NWS operations by the media, EMs, or elected officials. The intent of service assessments is to thoroughly evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting its mission. NWS conducts service assessments to improve its ability to protect life and property, and enhance the nation's economy.

This document presents findings and recommendations resulting from the evaluation of NOAA and NWS performance during Sandy, October 22–29, 2012. The objectives of this assessment are to identify significant findings and to issue recommendations and best practices related to the following key focus areas:

- Philosophies and policies underlying NWS weather forecasts and/or impact watch and warning products, their dissemination, and their clarity specifically addressing the complexities of Sandy
- NOAA's—and in particular NWS's—web presence as a tool for communicating with the public
- The production and issuance of storm surge products from multiple NOAA line offices

1.3. Methodology

NOAA chartered the Sandy Assessment Team on December 10, 2012. The Team consisted of employees from several NOAA line offices; NWS field offices; the Office of Climate, Water, and Weather Services (OCWWS) in NWS Headquarters; representatives of other federal agencies, including the Federal Emergency Management Agency (FEMA) and Centers for Disease Control and Prevention (CDC); and a behavioral/social scientist from the Uniformed Services University of the Health Sciences.

The Sandy Service Assessment Team completed its work primarily by conducting several series of interviews with NWS employees, EMs, federal partners, and the media. The Team used the results of two public surveys conducted by other research institutions to garner input on public response.

NWS, Emergency Managers, and Federal Partners

The Service Assessment Team conducted the majority of its fieldwork January 6-12, 2013, focusing on the New York/New Jersey region, which was the most heavily impacted by Sandy. Following a briefing at ERH in New York, the Team divided into two subteams as follows:

- Subteam 1: focused on New York, including WFO Upton
- Subteam 2: focused on New Jersey, including WFO Mt. Holly

The Service Assessment Team interviewed local and state EMs, including the New York/New Jersey Port Authority, as well as federal partners, including the U.S. Geological Survey (USGS) and FEMA regional office staff.

In the second phase of interviews, conducted January 14-18, 2013, Team members interviewed National Centers for Environmental Prediction (NCEP) staff at OPC and HPC, and NWS Headquarters office staff. The Team also conducted phone interviews with WFOs Wakefield and Sterling, VA, and Taunton, MA, and River Forecast Centers (RFC) Middle-Atlantic/State College, PA, and Northeast/Taunton, MA.

A final phase of interviews occurred between late January and early March. These interviews included an in-person session with the FEMA Administrator and site visits to the NHC and New York City Office of Emergency Management (NYCOEM). The Service Assessment Team conducted additional telephone interviews with the West Virginia Division of Homeland Security and Emergency Management, the NCEP Director[3], and NHC Director.

Media

Dr. Deborah Girasek, a Service Assessment Team member and social/behavioral scientist from the Uniformed Services University of the Health Sciences, along with NWS meteorologist John Sokich, one of the Team's subject matter experts, conducted telephone interviews with representatives of 13 media outlets on January 7–25, 2013. These interviews included nine local television stations, eight of which were network affiliated, serving audiences in New Jersey, New York, and Connecticut. They also spoke to representatives of one print wire service, two cable television networks, and one commercial weather services provider. In several instances, producers or other news team members joined on-air meteorologists for the interviews.

Public

Because of time and administrative constraints (e.g., Paperwork Reduction Act), collecting data directly from the public was difficult. Fortunately, the Service Assessment Team benefitted from the findings of two highly relevant investigations: one conducted at the time of the storm and one conducted during the timeframe of the assessment. The investigations were as follows:

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[3] At the time of the interview, the NCEP Director was Dr. Louis Uccellini. He has since become the Assistant Administrator of NOAA's National Weather Service.

- The Risk Management and Decision Processes Center (The Wharton School, University of Pennsylvania) published a preliminary report based on telephone surveys conducted with a random group of 538 adult homeowners from coastal communities in Virginia, Maryland, Delaware, and New Jersey (including suburban New York City). These interviews lasted approximately 25 minutes and were conducted between October 26 and October 29, the days leading up to Sandy's landfall (*Baker et al., 2012).*

- The National Science Foundation funded a study focusing on communications related to Hurricane Sandy. Investigators from Florida International University, the National Center for Atmospheric Research, and SocResearch oversaw telephone interviews of 607 adults who lived in coastal surge risk areas in New Jersey and New York City. Data were collected in March 2013. Interviews were conducted in both Spanish and English, and lasted approximately 25 minutes (*Gladwin, Morrow & Lazo, 2013).*

Several other research reports not specific to Sandy also are cited in this report. These studies are listed in Appendix D.

2. Summary of Hydrometeorological Event[4]

2.1. Event Overview

Sandy (2012) formed in the Caribbean Sea and subsequently made three landfalls: Bulls Bay, Jamaica (October 24), Santiago de Cuba, Cuba (October 25), and Brigantine, NJ (October 29). **Figure 2** shows the track of the storm. Sandy caused a catastrophic storm surge in the Northeast United States that claimed most of the U.S. lives lost in this event (41), caused extensive damage due to wind, and resulted in blizzard conditions over the Appalachian mountain region.

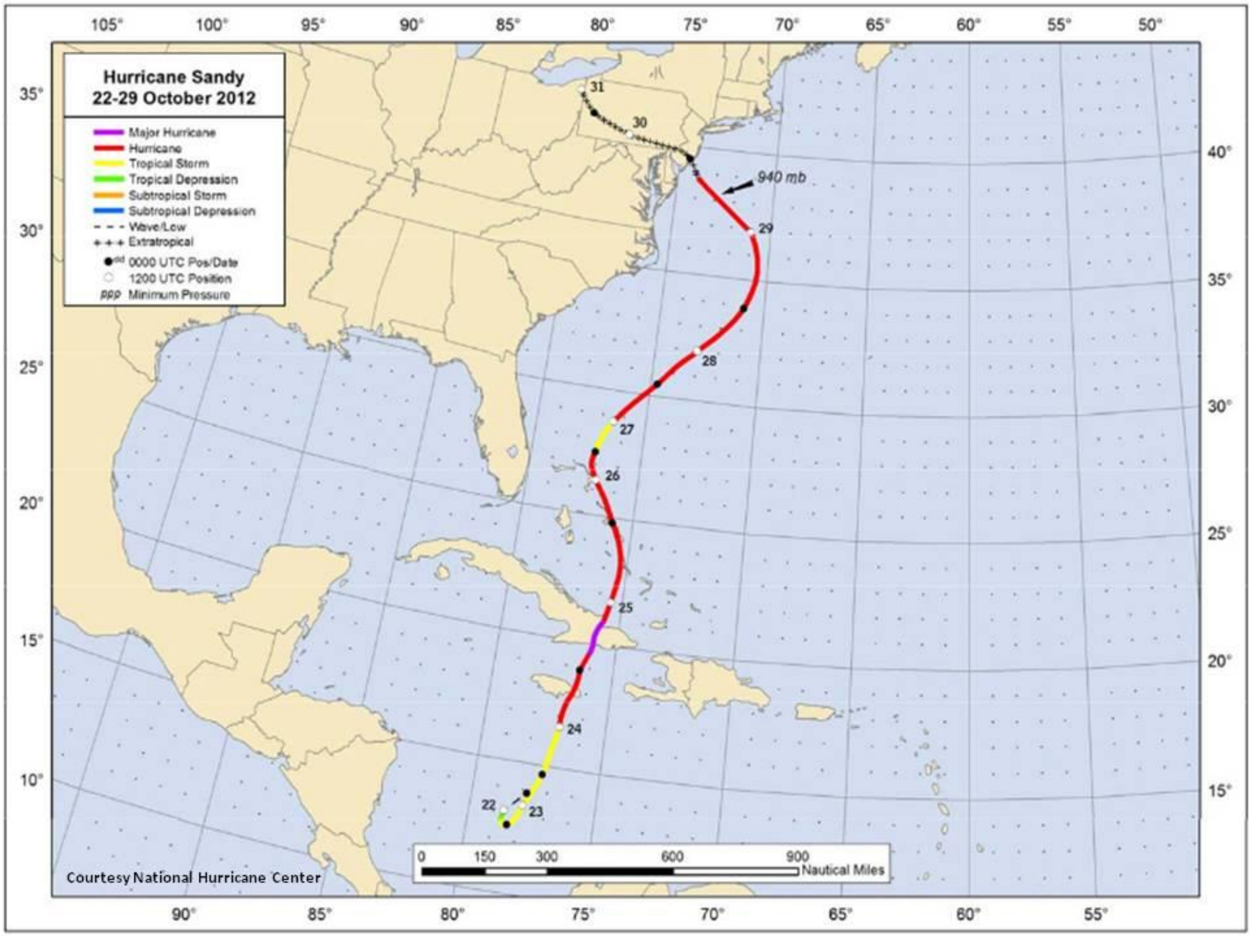

Figure 2: Best track positions for Sandy, October 22-29, 2012. *Source: NHC TCR*

[4] This section provides a generalized description of the event. More detailed information can be found in the NHC Tropical Cyclone Report (TCR) at http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf.

2.2. Tropical Cyclone Genesis, Track, Intensity and Post-Tropical Transition

Figures 3–4 shows NHC's surface wind speed and minimum central pressure trends**,** respectively. On October 11, an easterly wave emerged off the western African coast and, by October 18, steadily moved westward into the eastern Caribbean Sea. Late in the day on October 21, NHC identified a circulation approximately 200 nm south of Jamaica. NHC identified this circulation as Tropical Depression 18 around midday on October 22 when it was located at around 275 nm south of Jamaica. The circulation center then drifted to the southwest. Only 6 hours after being diagnosed as a depression, NHC upgraded it to Tropical Storm Sandy because the maximum sustained winds reached the tropical storm threshold of 39 mph.

By late on October 24, NHC's forecasts showed Sandy's track bending back toward the U.S. East Coast early the following week. NHC began communicating that Sandy had the potential to combine with a powerful frontal system approaching from the central United States and transition into a hybrid storm, i.e., having characteristics of an intense Nor'easter and a tropical cyclone.

Just a few hours later, Hurricane Sandy made landfall as a Category 1 hurricane (Saffir-Simpson Hurricane Scale: winds 74–95 mph) near Bull's Bay, Jamaica, with a peak sustained wind of 85 mph. The storm then rapidly intensified before making a second landfall as a Category 3 hurricane with a peak sustained wind of 115 mph near Santiago de Cuba, Cuba, early on October 25 **(Figure 3)**.

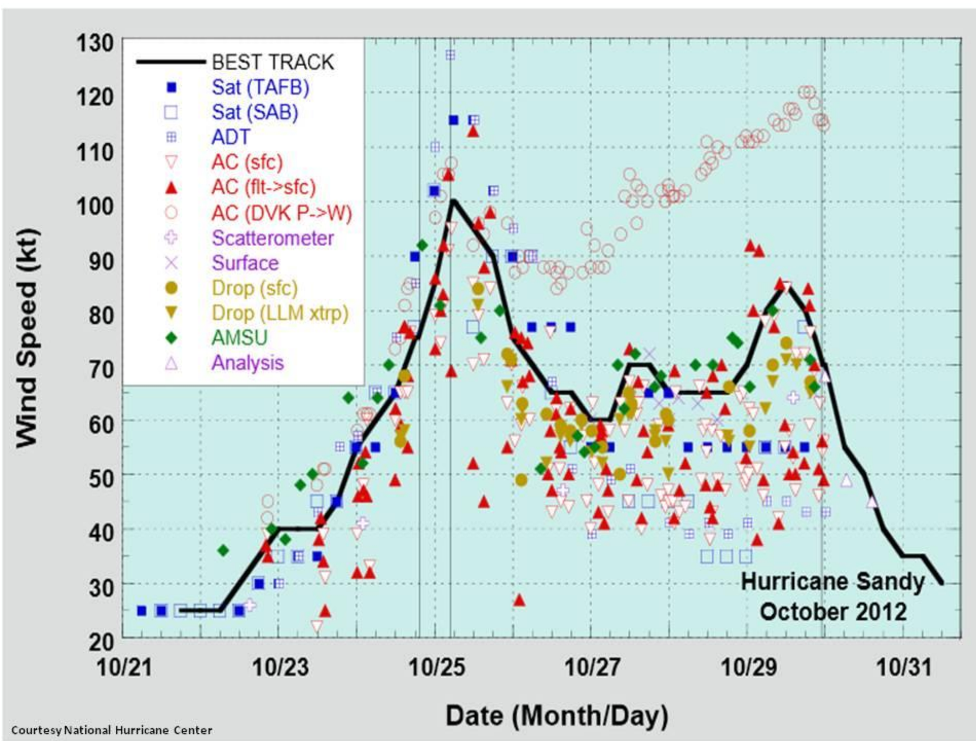

Figure 3: Selected wind observations and best track maximum sustained surface wind speed for Sandy, October 22–29, 2012. The graph's dashed vertical lines correspond to 0000 UTC and the solid vertical lines show time of landfall. *Source: NHC TCR*

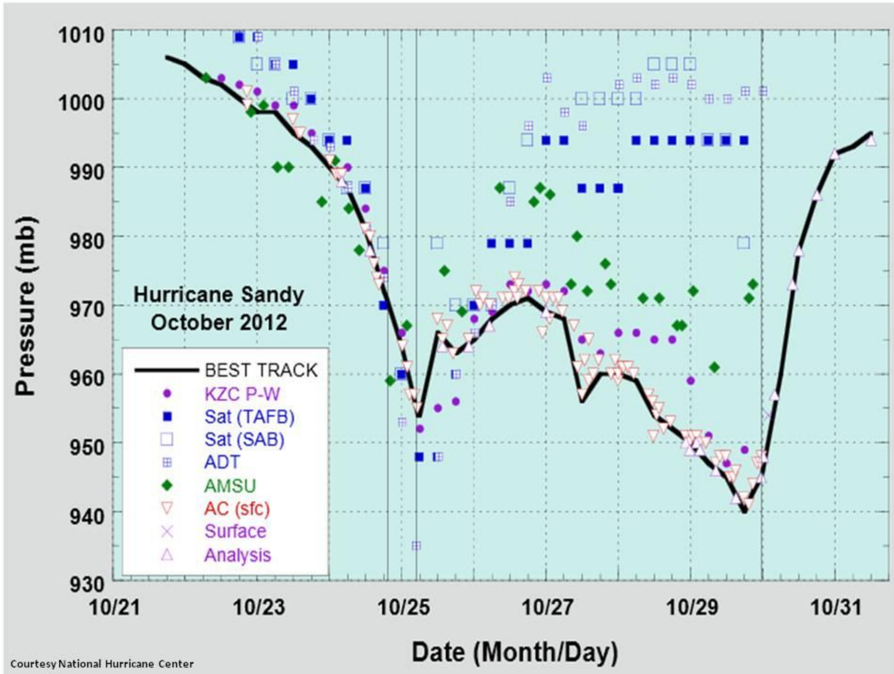

Figure 4: Selected pressure observations and best track minimum central pressure curve for Sandy, October 22–29, 2012. The graph's dashed vertical lines correspond to 0000 UTC and the solid vertical lines show time of landfall. *Source: NHC TCR*

Sandy began to weaken quickly by late October 25, when it encountered strong wind shear across the southern Bahamas. The storm also began moving to the northwest as a combination of a western Atlantic ridge and an approaching middle- and upper level trough steered the storm northwestward through the Bahamas. After moving north of the Bahamas, the storm greatly increased in horizontal extent (i.e., a doubling of the average radii of tropical storm force winds since the Santiago de Cuba landfall, **Figure 5**). The storm was also beginning to entrain drier and cooler continental air into its circulation, which was starting to erode its tropical characteristics. Sandy briefly fell below hurricane intensity late on October 26.

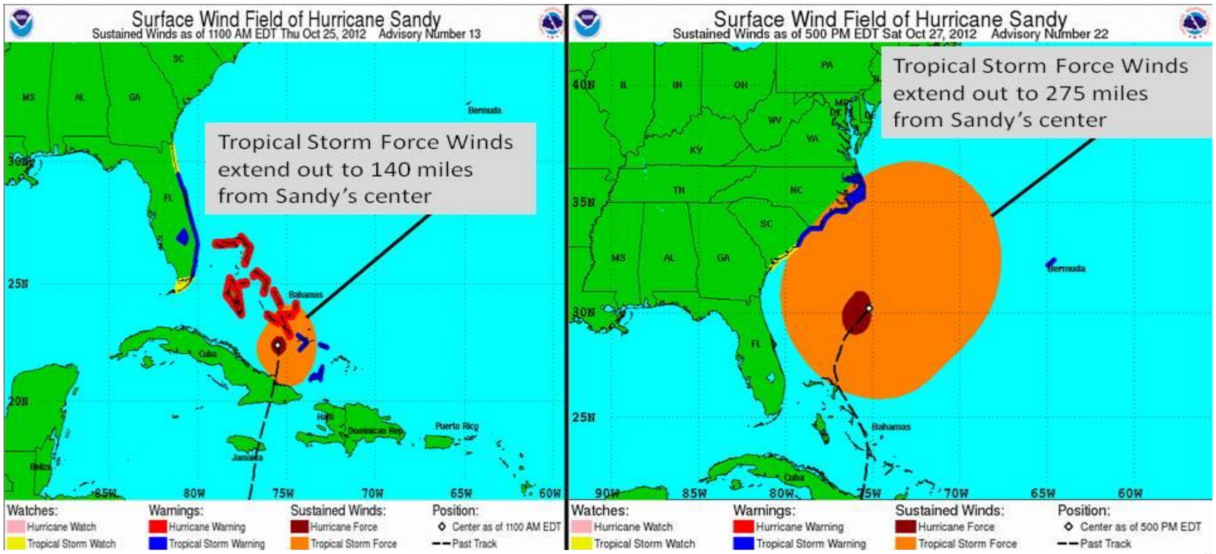

Figure 5: A comparison of the radius of tropical storm force winds between NHC Advisory #13 and #22 (operational data vs. post-storm analysis). *Source: NHC*

Sandy resumed a northeast motion after departing the Bahamas, achieving hurricane status again about 12 hours later (near sunrise October 27). Strong observational evidence existed at the time that Sandy's extra-tropical transition remained in progress given the following:

- Great expansion of the horizontal wind field resulting in the radius of maximum winds extending over 100 nm outward from the storm's center
- Development of the cyclone's strongest winds within its western semicircle
- Development of a warm front
- Dissipation of the cyclone's inner-core deep convection

Sandy continued moving to the northeast and passed a few hundred miles to the southeast of North Carolina on October 28. The storm then temporarily took a more tropical appearance as an eye-like feature again developed.

During the early morning hours of October 29, Sandy began to make a hard turn to the northwest because of the large-scale wind flow pattern within which it was embedded. The combination of an anomalous blocking pattern over the North Atlantic and yet another approaching middle- and upper-level trough from the southeast United States was forecast to maintain the direction of motion, making landfall in the highly populated Northeast a virtual certainty. **Figure 6** shows the large-scale mid- and upper-level wind pattern that steered Sandy into the New Jersey coastline.

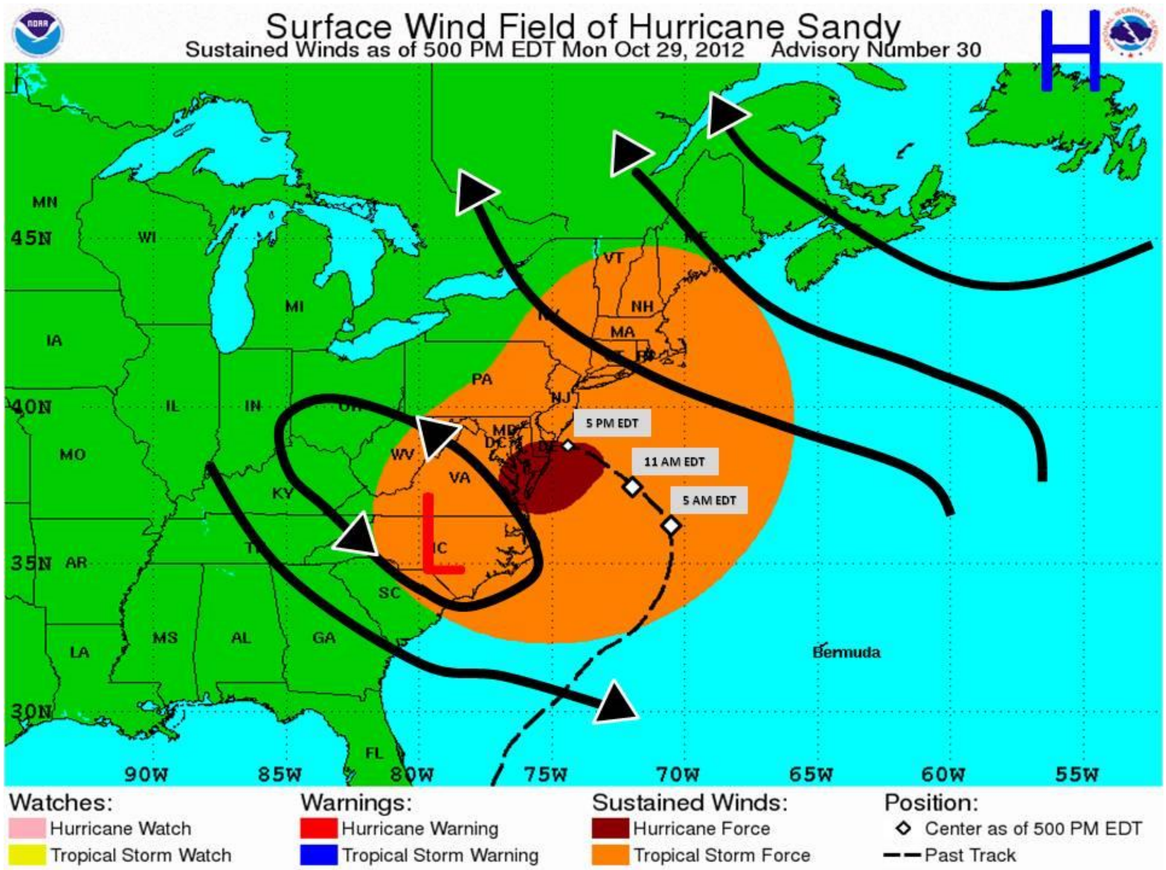

Figure 6: A depiction of NHC Advisory #30 (5 p.m., October 29, 2012) before landfall of Sandy and a depiction of the large scale mid- and upper-level wind pattern that steered Sandy into the New Jersey coast (operational data vs. post-storm analysis). *Source: NHC*

Sandy's peak winds increased to near 100 mph while passing over the warm waters of the Gulf Stream approximately 220 nm south of Atlantic City, NJ. The trend would not be maintained as the storm passed west of the Gulf Stream's western wall and into a much colder continental air mass. These factors contributed to surface pressure rises and a slight decrease in maximum sustained wind speed the last few hours before landfall. Based on available surface, reconnaissance, and satellite data, NHC determined Sandy had become post-tropical during the afternoon of October 29 while the center was about 45 nm southeast of Atlantic City, NJ. The center of Sandy then made landfall near Brigantine, NJ, around 7:30 p.m., with an estimated wind speed near 80 mph and a minimum central pressure of 945 mb. This number makes Sandy one of the lowest recorded pressures for a landfalling hurricane/post-tropical cyclone north of Cape Hatteras, NC.

At landfall, Sandy broke all-time low pressure records for Philadelphia, Harrisburg, and Baltimore. The tropical storm force winds extended across approximately 1,000 miles, making Sandy one of the largest Atlantic tropical storms ever recorded. Shortly after landfall, NOAA satellite imagery showed Sandy covering 1.8 million square miles. Days in advance, two operational global spectral models (i.e., the NCEP Global Forecast System and the European Center for Medium Range Weather Forecasting) depicted landfall of an intense low pressure center between the Mid-Atlantic and southern New England states. The European model illustrated this scenario earlier and was more consistent than the Global Forecast System model; however, both depicted a strong coastal storm with multiple potential hazards.

After landfall, Sandy turned west-northwest and slowed while moving over southern New Jersey. The center became poorly defined over northeastern Ohio by sunrise on October 31. The remnants of Sandy eventually merged with a mid-latitude low pressure system over eastern Canada after passing over Ontario, Canada. Wind gusts over 60 mph were recorded as far away as the upper Midwest.

2.3. Storm Surge

Storm surge is defined as "An abnormal rise in sea level accompanying a hurricane or other intense storm, and whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone."[5] Sandy forced high coastal water levels from Georgia to Maine (**Figure 7**).

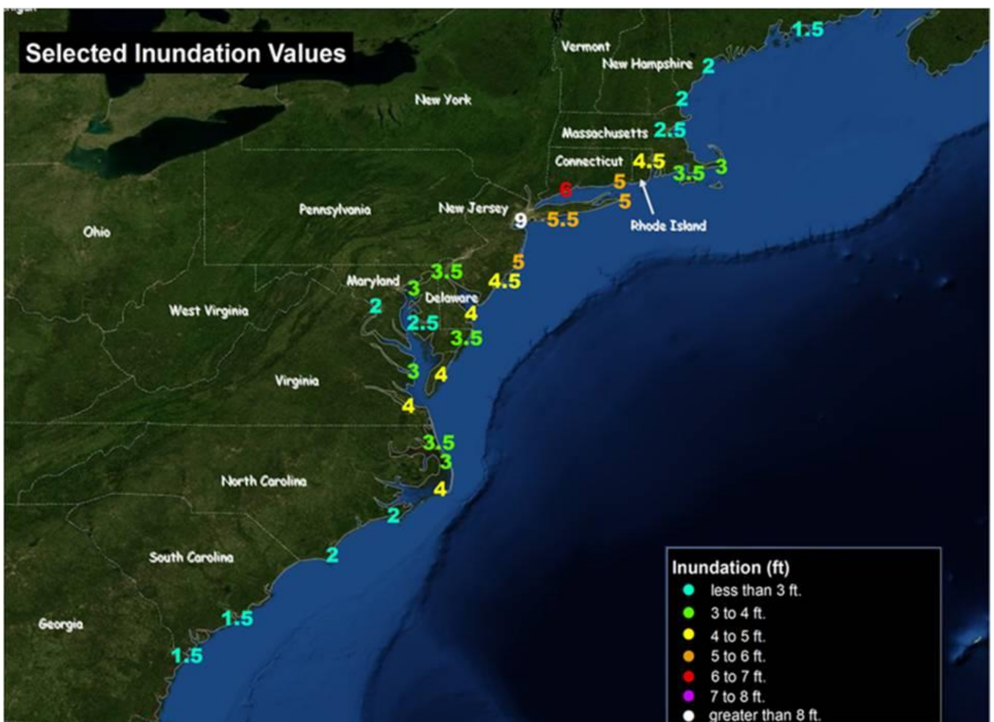

Figure 7: Estimated inundation (feet, Above Ground Level [AGL]) calculated from USGS high-water marks and NOS tide gages. Values are rounded to nearest half foot. *Source: NHC TCR*

The pressure gradient between Sandy's extremely low pressure and high pressure to its north created enhanced wind speeds from the northeast and contributed to record setting surge. The persistent northeasterly winds over the water (i.e., fetch), caused the water to pile up and become trapped along the coast, bays, harbors, etc., during multiple high tide cycles. These astronomical high tide cycles coinciding with Sandy's landfall on October 28–29 were some of the highest of

[5] NHC Glossary of NHC Terms

the year. The maximum storm surge thus occurred north and well away from the storm's center at landfall.

Damaging wave action atop the storm surge increased flooding and battered the south and east facing shores of Long Island and northern New Jersey, respectively. East winds along the axis of Long Island Sound caused high surge in western Long Island Sound. Portions of New York, New Jersey, and western Connecticut experienced catastrophic, record-setting water levels (**Figure 8**).

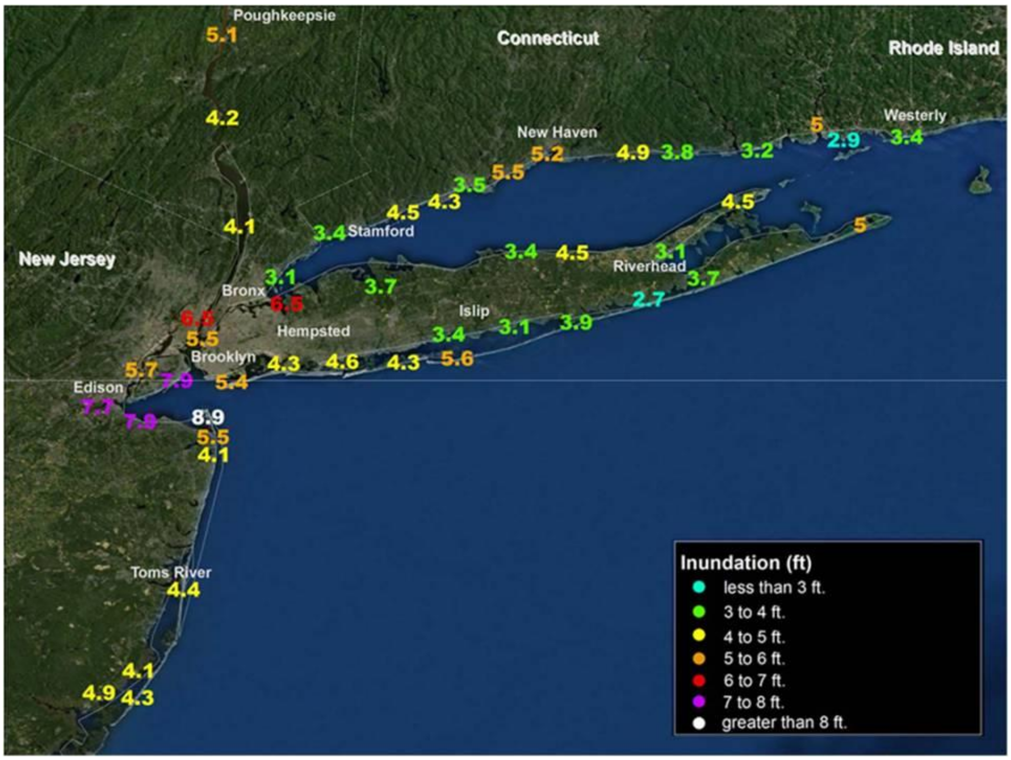

Figure 8: Estimated inundation (feet, AGL) calculated from USGS high-water marks and NOS tide gages in Connecticut, New York, and northern New Jersey. *Source: NHC TCR*

The worst flooding occurred over Staten Island and to the south along the New Jersey shore (Middlesex, Monmouth, and Ocean Counties). In coastal Monmouth and Ocean Counties, post-storm surveys confirmed entire communities were flooded, with houses washed off foundations, and cars and boats carried well inland by the surge. The storm surge caused significant flooding in parts of the Hudson River Valley, with record flooding at Poughkeepsie and minor flooding as far north as Albany.

The NOS tide gages at the Battery in Manhattan and at Bergen Point West Reach on Staten Island recorded water level values of 9.0 feet and 9.53 feet above Mean Higher High Water (MHHW), respectively. If a rise of the water level beyond the MHHW line is considered a proxy for inundation of normally dry land, flooding reached as high as 9 feet at low-lying spots along the shoreline.

The NOS tide gage at Sandy Hook in New Jersey reported 8.01 feet above MHHW before it failed. The NOS tide gages in Bridgeport and New Haven, CT, reported water levels of 5.82 feet and 5.54 feet above MHHW, respectively, suggesting that inundation values could have been as high as 6 feet AGL in parts of Fairfield and New Haven Counties.

2.4. Wind

Analysis of data associated with Sandy's three landfalls near Bulls Bay, Jamaica; Santiago de Cuba; Cuba, and Brigantine, NJ, reveal sustained hurricane force winds (≥74 mph) likely occurred over far eastern Jamaica (although not measured) with widespread tropical storm force winds elsewhere in Jamaica. During the second landfall near Santiago de Cuba, NHC estimated Sandy produced sustained surface winds of 115 mph (Category 3) based on a peak flight-level wind observation of 145 mph. A peak 1-minute wind of 93 mph was measured in Cabo Lucretia, Cuba (northeastern Cuban coast), where wind gusts over 115 mph were measured. **Figure 9** shows select sustained wind observations along the Mid-Atlantic and New England coasts.

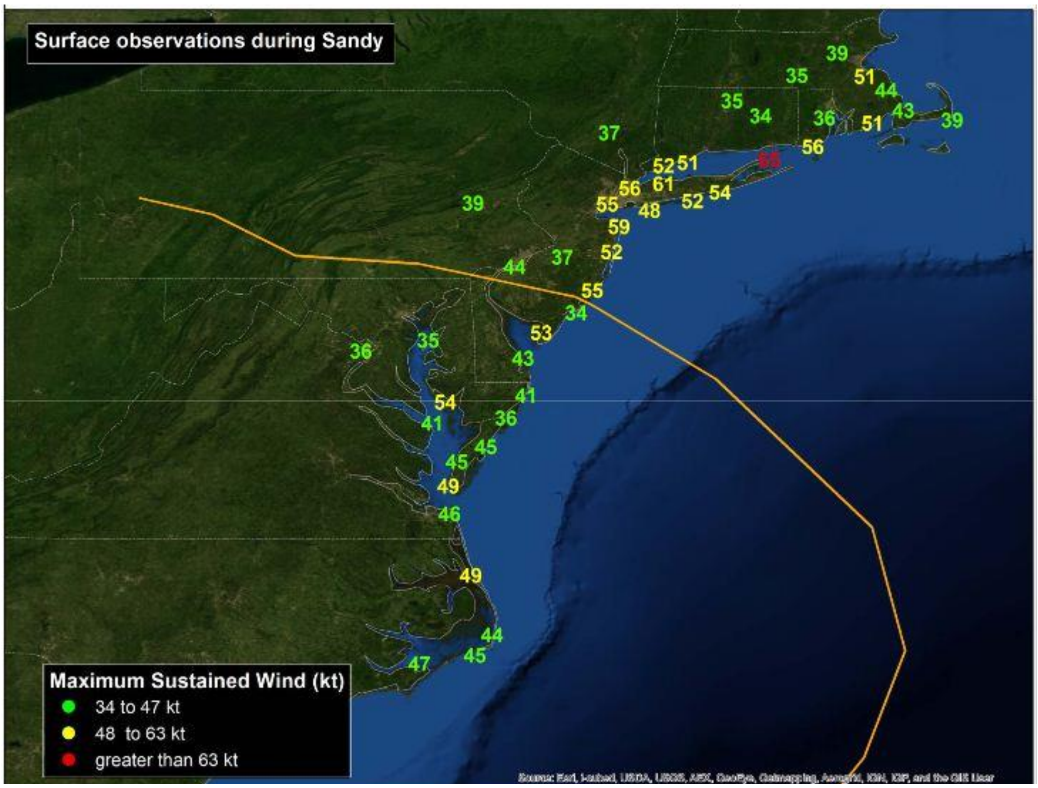

Figure 9: Selected observations of sustained winds 34 knots (38 mph) or greater along the Mid-Atlantic and New England coasts associated with Sandy. Storm track shown in orange. All observations are at 24 meters (79 feet) or less. *Source: NHC TCR*

NHC measured sustained hurricane force winds at only one U.S. location, Great Gull Island, NY (northeast Long Island Sound). NHC measured a 1-minute mean wind of 75 mph was measured at a height of 59 feet around 4:35 p.m.; however, it should be noted this 1-minute mean wind of 75 mph does not correspond to hurricane conditions because it was measured in the free air at 59 feet elevation. At standard height (10 meters or ~33 feet), the wind speed there would have been sub-hurricane strength. One of the wind speed measurements exceeding 55 knots shown along the New Jersey shore was taken at 2.25 meters, converting to a wind greater than 75 mph at 10 meters. Therefore, this latter observation supports the analysis that Sandy measured hurricane force winds at landfall. The storm created a widespread and long duration high wind impact spanning a large part of the eastern United States extending into the upper Midwest. The data show that several locations in greater northern New Jersey and southern Long Island region reported peak wind gusts of 86–90 mph (at 33-foot standard anemometer height). Falling trees killed 20 U.S. residents, further highlighting the magnitude of the wind's impact. Approximately 8.5 million homes lost power at the peak of the event, mostly due to wind blowing trees down over power lines. The combined impact of cold weather and widespread power outages resulted in several deaths due to hypothermia.

2.5. Other Hazards

Sandy also produced blizzard conditions over the adjacent southern and central Appalachian mountain region within 3 hours after landfall. Snowfall accumulated up to 1 foot over a large part of West Virginia and the higher elevations of western North Carolina. **Figure 10** shows a multi-day event-total snowfall for October 28–31. Between 2–3 feet of snow fell over the higher terrain of western Maryland, southwestern Virginia, extreme northwestern North Carolina, and eastern Tennessee. This wet, heavy snow caused a number of structures to collapse. Wind and heavy snow combined to cause significant tree and large limb fall throughout southern and central Appalachia.

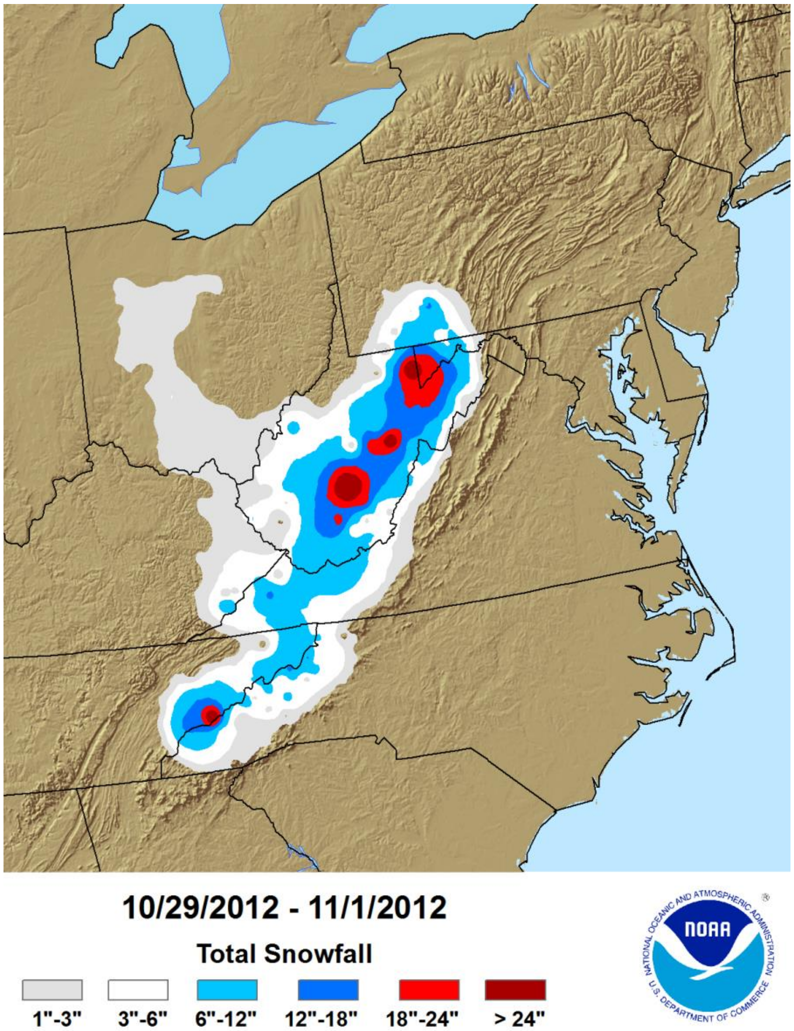

Figure 10: Multi-day event snowfall (inches) associated with Sandy from October 28-31, 2012. *Source: National Climatic Data Center*

Sandy produced torrential rainfall across parts of Jamaica, eastern Cuba, and Hispaniola. The maximum rainfall occurred over Mill Bank, Jamaica (28.09 inches), with a few additional reports of over 10 inches on the upslope side of eastern Jamaica. Widespread 4 to 8 inch rainfall amounts were measured over eastern Cuba, with a maximum of 11.12 inches in Gran Piedra. In the United States, **Figure 11** shows Sandy's multi-day event total rainfall for the Mid-Atlantic from October 27–31. The highest rainfall accumulations occurred southwest of Sandy's track over extreme southern New Jersey and the Delmarva Peninsula. Of the several hundred rainfall reports received, only eight reports were greater than or equal to 11.0 inches, with a maximum of 12.83 inches occurring in Belleview, MD. Rainfall amounts of 6 to 9 inches occurred over northeastern North Carolina, though most locations experienced less than 4 inches of rainfall. The rainfall caused major flooding in portions of the Potomac River basin, but only minor damage. Drought conditions mitigated the effects of the heavy rainfall over the Mid-Atlantic.

Only one tornado, an EF-0 (Enhanced Fujita Scale, winds between 73–112 mph), was confirmed in association with Sandy. The tornado occurred in Somerset, Bermuda, on October 28. There were seas as high as 47 feet just off the Atlantic coast.

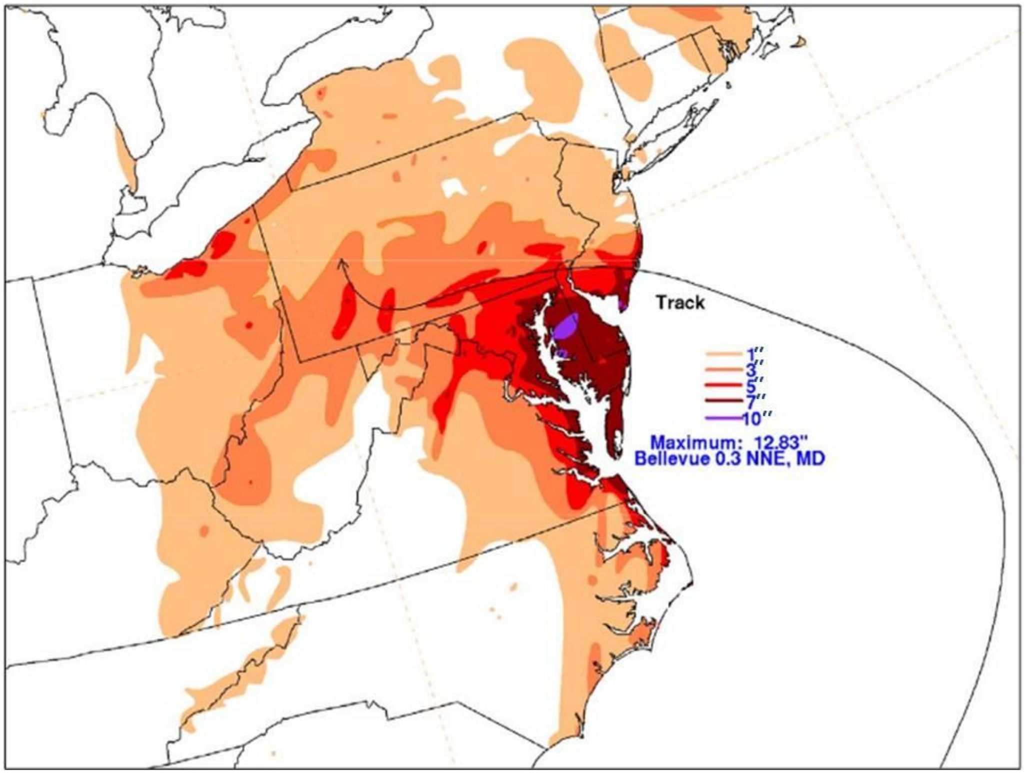

Figure 11: Multi-day event total rainfall (inches) associated with Sandy from October 27–31, 2012. *Source: HPC*

3. Facts, Findings, Recommendations, and Best Practices

3.1. Weather Forecast, Watch and Warning Products and Their Dissemination/Communication

NOAA works with a variety of partners, including EMs, the media, commercial weather services providers, other federal agencies, and the public. EMs, the front line during hazardous events, interact with the NWS with greater frequency and intensity during an event like Sandy. The public sometimes receives information directly from the NWS, but most often gets its weather information from a television station/cable network or commercial weather service provider.

The NWS provides weather and water information in a variety of formats: text products (e.g., Area Forecast Discussion and Hurricane Local Statement [HLS]), graphical products (e.g., PowerPoint briefings, track forecast maps), and dynamic products (e.g., interactive websites). NWS has designed certain web pages for EMs that provide specific information about hazards that may affect their area; however, there is no communications strategy for serving the full range of NOAA's constituents and partners. The information NOAA provides is publicly available; however, the Service Assessment Team found it was often not easy for users to figure out where to obtain the information they needed, leading to confusion.

3.1.1. Internal Pre-Coordination

The evolution of Sandy from a Category 3 hurricane in the Caribbean to an intense post-tropical cyclone in the hours before landfall posed operational challenges to NWS offices. NWS realized early that it would need to coordinate services to ensure a high level of continuity and consistency. Around midday on Thursday, October 25, the Acting ER Director requested a management coordination meeting to develop an operational strategy for Sandy's expected post-tropical transition. ERH wanted to ensure watches and warnings for Sandy were consistent as the storm approached landfall. The "Hurricane Sandy NWS Coordination Plan," developed by NHC, OPC, HPC, and ERH, dated October 25 stated, *"The NHC product suite is configured for tropical systems, and continuation of traditional NHC products after extra-tropical transition could yield skewed and potentially misleading products."* The directors of the HPC, OPC, and NHC (who were all assembled for a Center Directors Meeting) participated in the meeting. NWS also conducted several coordination calls. The coordination call on Friday, October 26, included WFOs Morehead City, NC, and Wakefield and Sterling, VA, because they would be the first WFOs affected by the storm. There was concurrence by management to handle Sandy consistently once the storm transitioned from tropical to post-tropical.

Based on the latest forecast, on Friday, October 26, NWS decided to issue non-tropical watches and warnings north of Duck, NC. This decision was discussed extensively with NHC, OPC, HPC, and ERH leading up to the event; in addition, NWS management agreed that it would be best handled in this fashion. NWS needed to make this decision well before landfall to eliminate any potential confusion that could ensue if the transition occurred suddenly or near the coast. NWS was concerned that if it issued hurricane watches and warnings and then dropped them before the storm struck land (and after the storm transitioned to post-tropical), there would be significant confusion on the part of decision makers and the public.

On Friday, October 26, during the routine 6-hourly hurricane hotline call initiated at 4 p.m., it was revealed that WFO Mt. Holly had issued a Gale Watch (a non-tropical product) for the New Jersey coastal waters. This decision set expectations for the use of non-tropical products and services. NHC indicated this action accelerated the timeframe by 6 to 12 hours in which NHC had to make a decision. Given the forecast and the need to be consistent throughout the post-tropical phase, NWS sustained the WFO Mt. Holly precedent by issuing non-tropical products from that point forward. ERH offered to cancel the Gale Watch, but NHC did not feel this was necessary.

Despite efforts by the NWS to publicize this decision, including a press release issued on Saturday, October 27, the Service Assessment Team found not all EMs were aware of the protocol for handling Sandy as the storm approached the coast. In addition, graphical and text-based information regarding Sandy did not reflect this service transition (i.e., between the NHC Advisories and the WFO product suite) in a seamless manner. NHC did not display WFO-issued watches and warnings (addressing coastal flooding and high wind impacts) across the Mid-Atlantic and New England coasts on the NHC graphic for Sandy and mentioned those WFO products only briefly, in summary form, for the public advisory text. The decision to shift to non-tropical products also affected dissemination of watches and warnings because New York and New Jersey do not use systems such as the Emergency Alert System and Wireless Emergency Alerts for high wind and coastal flood warnings (CFW).

Finding 1: Despite publicizing the fact that responsibility for issuing watches and warnings north of Duck, NC would shift to WFOs, NWS web pages and graphical displays did not clearly communicate this change. Specifically, NWS websites sent mixed messages by not highlighting coastal flood and high wind watches and warnings north of North Carolina on the widely viewed NHC graphic accompanying Sandy advisories and by relying on the NWS Watch/Warning/Advisory graphic that cannot clearly display multiple watches, warnings, and advisories in effect simultaneously for a county.

Recommendation 1: For future storms like Sandy, NHC should be the principal point of contact responsible for the event, including delivery of a consistent suite of products and a unified communications protocol within NOAA, to key NOAA federal partners, and the media. NOAA/NWS websites should consistently reflect all watch/warning/advisories on websites, regardless of organizational structure or office/center responsibility. Web page design should ensure the most important message is quickly evident.

3.1.2. NOAA/NWS Product Focus

The media and EMs interviewed had different reactions to the decision to issue non-tropical watches and warnings for Sandy's U.S. landfall. There was no clear consensus within these groups on whether the decision was right or wrong, but there is evidence suggesting the non-tropical warnings led to confusion for some EMs and complicated the task of reporting on the storm for the media. Survey results suggest this judgment call may not have led to the public perception problems that many professionals feared (see Section 3.1.3 below), although there is evidence of confusion. Internal discussions within the NWS as early as Wednesday, October 24, focused on the unique challenges posed by a hurricane forecasted to become post-tropical but remaining an intense, dangerous storm as it made landfall.

There were differences in overall satisfaction with NOAA/NWS services for Sandy between partners with local decision-making responsibilities (e.g., county EMs) and those with responsibility for communicating and managing across larger boundaries (e.g., FEMA). One media interviewee commented: *"All nine county managers were in touch with [WFO] Mt. Holly. They...had the best information possible to make their decisions...Very few mistakes if any were made [here]...Everyone knew how serious it was and I think the NWS deserves the credit there."*

Local and state EMs and decision makers in New York and New Jersey told the Service Assessment Team they were overwhelmingly pleased with the information received in the days leading up to and during landfall, and, in general, did not think the type of warnings affected response. A significant factor in the high level of satisfaction was the availability of tailored briefing packages and webinars developed by staff at WFOs Upton and Mount Holly and at MARFC, among others. These partners also appreciated the close and longstanding working relationships that helped develop a high level of trust for NWS services. Despite NWS efforts, the NYCOEM and Nassau County OEM indicated the transition from tropical products caused confusion. Many media representatives and commercial weather services sector partners felt issuing non-tropical watches and warnings was a mistake leading to information not conveyed as effectively as it should have been. One media representative put it this way: *"[Forecasters at the NHC] got caught up in the technicalities [of explaining the transition of tropical to subtropical] and lost sight of the big picture, which is getting the word out and warning people properly. That made my job harder. I had to explain what a post-tropical storm was time after time when I could have been telling them how to prepare.*"

Best Practice: Development and delivery of concise DSS briefings and briefing packages, including one-pagers and presentations that synthesized complex information, delivered in commonly available formats (e.g., PowerPoint or Portable Document Format (PDF)), reduced or eliminated the need for local EMs to search for the same information among multiple NWS forecast products and web pages. The briefings contained graphic and text-based information, focused on impacts, and contained confidence and worst-case scenario information that aided decision making.

The myriad of watches, warnings, and advisories issued for Sandy posed particular challenges for media trying to focus on storm impacts over a large area. The lack of a hurricane warning was perceived as a complicating factor by the media. Many media representatives felt explaining the change took valuable time away from focusing on impacts and preparedness actions. One media representative stated, *"There needs to be a clear bottom line"* for the variety of information available from NOAA to help *"tell the story"* effectively. Officials at the Port Authority of New York and New Jersey, while generally pleased with NWS services during Sandy, stated that NWS terminology was confusing to the general public. In particular, terms such as "coastal flooding" or "major flooding," in the absence of detailed and specific impacts, were not well understood. These officials recommended using simplified language that includes impact-based threats.

There was also broad agreement among the media that NWS needs to place more emphasis on impacts and many also recommended that, for a large storm like Sandy, communications need to be centralized. One broadcast media member stated, *"Next time, spend more time talking about what it is going to do, rather than what it is going to be when it makes landfall. That will* *serve the public better."* Similar comments addressed the need to speak in plain and simple language devoid of jargon, which would allow people to better distinguish the levels of threat from various hazards. One media representative stated, *"There were two or three competing voices. They were all saying the same thing, but with slight variances. Someone should have recognized early that this storm was special. Everything needed to come from one place to be coherent. Someone with the highest possible title at [NWS Headquarters] should have been the centralized source of information."* Another media interview elicited this comment: *"Right now, reports are coming out from many different offices [NHC, HPC, local offices]. Is there a 'Command Center' way to do it during the storm so you have one source pushing everything out? That sure would make our work a lot easier."*

Fact: Based on computer model guidance, the NHC forecast Hurricane Sandy to transition from a hurricane to an extra-tropical storm as it approached the Mid-Atlantic coast. While Sandy approached the coast of New Jersey, fundamental changes occurred in the structure of the cyclone, resulting in its transition to post-tropical status near 2100 UTC October 29 (*NHC Tropical Cyclone Report, 02/13/13*).

Finding 2: The existing array of NWS products for coastal storms (i.e., tropical storms, post-tropical storms and nor'easters) is confusing. This array led to misinterpretation of the predicted impacts during Sandy.

Recommendation 2: The NWS should generate and provide products focused on impacts. Such products need to specify where and when impacts will occur and should clearly communicate hazards posed, including wind, flooding from both rainfall and storm surge, and tornadoes.

Finding 3: Local and state EMs interviewed by the Service Assessment Team were generally satisfied with the way WFOs handled Sandy as an extra-tropical storm; however, many media outlets and commercial weather services providers did not support the decision to stop hurricane watches and warnings and found communication lacking.

Recommendation 3: In partnership with the media and commercial weather services providers, NWS should develop a strategy detailing information flow and new tools for communicating threats during future storms like Sandy. This strategy should include clear responsibilities for external coordination with key partners such as media, EMs and FEMA, and the public. This strategy should establish the primary communications point of contact for these types of storms and the types of products (e.g., watches, warnings, advisories) to be issued. [*The communications strategy should be developed as a companion to the proposal outlined in Recommendation #6.*]

3.1.3. Public Response

Many local EMs stated that the various names and local WFO-issued watches and warnings had no negative impact on public response, whereas many broadcast media and private weather forecast companies believed the lack of hurricane warnings adversely influenced public perceptions of storm intensity and potential threats.

A telephone survey of Mid-Atlantic coastal residents in the lead-up to Sandy's landfall (*Baker et al., 2012*) reveals that most respondents erroneously thought they were under a hurricane watch when Sandy made landfall. In contrast, on the day before Irene's landfall, a higher proportion of survey respondents thought they were under a hurricane watch (which they were). Although the samples involved were not identical, the study found that survey respondents felt "10 percent" safer (on a 100 point scale) when Sandy was approaching than when Irene was approaching the year before (*from personal communication with Robert Meyer, March 5, 2013*). The survey data also suggest a larger proportion of respondents had intended to evacuate for Irene than for Sandy, but that difference was not statistically significant. The study found that perceptions of the threat posed by Sandy mirrored patterns observed for other hurricane events. Both of the surveys the Service Assessment Team reviewed found more concern expressed by coastal respondents about the threat posed by wind than by surge.

In the *Gladwin, Morrow & Lazo, 2013* post-storm survey, 47 percent of respondents were not sure what type of storm Sandy was when it made landfall. This statistic may reflect the fact that those data were collected approximately 5 months after the storm. Of those who did name a type of storm, the largest proportion (44 percent) said it was a hurricane when it made landfall. The proportion of respondents who indicated they evacuated for Sandy (33 percent) was comparable to the proportion who reported they had evacuated for Irene (30 percent), despite the fact that hurricane watches/warnings had been issued for Irene but not for Sandy (difference not statistically significant). When asked how concerned they were when Sandy was heading for the coast, 58 percent of post-storm survey participants who believed a hurricane watch/warning was in effect said they were "very concerned." An almost equal number, 56 percent, who thought another type of NWS warning was in effect (e.g., for coastal flooding or hurricane force winds) also were "very concerned," as were 39 percent for those who thought no NWS products had been issued for their area. More than 90 percent of all respondents said that as Sandy approached, they felt the storm was going to be somewhat or very dangerous.

Some EMs in New Jersey mentioned that since the most recent hurricane experience in their area (Irene in 2011) resulted in impacts that were less than expected, referring to Sandy as a hurricane might cause some to recount that experience and lead to a diminished response (a.k.a. "Hurricane Fatigue"). At least some media reps and local EMs felt referring to previous storms and using terms such as "record levels" was helpful when attempting to elicit an appropriate public response. One broadcaster explained the need for such references because, "*you are always fighting the last storm*" in terms of the expectations established. Scientific data collected during Sandy supports that sentiment. When Baker and colleagues (*2012*) interviewed Mid-Atlantic coastal residents in the days preceding Sandy's landfall, they found public perceptions of risk were consistently lowest among those who had experienced a hurricane before (in most cases, Irene), without experiencing any personal or property damage. In terms of response to evacuation announcements though, both storms appeared to arouse a comparable response.

The public survey data do not support the view that labeling Sandy as a “post-tropical cyclone” significantly diminished threat perceptions in the eyes of the public; however, there is also evidence of confusion in the minds of the public with regard to what type of storm Sandy was. In addition, many of NOAA’s key partners felt that its decision on how to classify this storm made their jobs more difficult.

The public often responds to health threats in ways that appears counterintuitive, or even irrational, to technical experts. Risk communications experts, social psychologists, and public health behavioral scientists are trained to study such phenomena and design programs that are reflect by empirical evidence. In 2003, and again in 2009, the NOAA Science Advisory Board’s (SAB) *ad hoc* Social Science Working Group submitted a report stating the capacity of NOAA to meet its mandates and mission is diminished by the underrepresentation and underuse of social science (*SAB Social Science Working Group*). Further, the NOAA Social Science Needs Assessment, conducted as a direct result of the report mentioned above, continues to underscore the need for NWS to increase its social science capacity. There is also information relevant to improving public response from the SAB’s task force that reviewed NOAA's research and development portfolio. The board’s final report, “*In the Nation’s Best Interest: Making the Most of NOAA’s Science Enterprise*” (March 27, 2013), includes the following emerging research initiative to achieve NOAA’s Weather-Ready Nation strategic goal: “*development of better ways of assessing and communicating risk so that both the public and decision-makers have the information they need to react appropriately when faced with oncoming extreme events.”*

Fact: The NWS currently employs one person with doctoral-level training in a social science[6].

Finding 4: Studies reviewed for this Assessment illustrate that the public's response to risk communications is influenced by a complex set of factors. NWS does not have a sufficient number of behavioral/social sciences or communications professionals involved in the design and delivery of weather forecast products and services.

Recommendation 4: NWS needs to broaden and expand its social science and communications capacity by hiring at least one more social scientist/behavioral expert within NWS or by increasing contracts with outside experts. This expanded capacity should be used to develop products, services, and communications tools (e.g., Internet, social media) to drive the appropriate public response to severe weather events.

3.1.4. Articulation of Impacts

NWS used a variety of tools to communicate impacts as Sandy approached landfall. NWS offices used briefing packages, webinars, conference calls, e-mails, and NWSChat to convey information to EMs, the media, and the public. Many of the communications tools used during Sandy contained concise summaries, often on one page or through a few talking points, to improve situational awareness and help ensure rapid, effective decision making. This communication style was repeatedly praised by EMs who were often the intermediary between elected officials and weather forecasters.

[6] For the purposes of this report, the term “social science” includes psychologists, sociologists, risk communicators, and others who have expertise in studying human behavior in relation to risk communication and self-protection.

Several text products and briefings stood out for explicitly stating the storm's potential impacts. The 11:45 a.m., October 25 briefing from WFO Mount Holly stated, *"record coastal flooding is possible"* if the center makes landfall along the New Jersey or Delaware coasts. The 5:16 a.m., October 25 Hazardous Weather Outlook issued by WFO Upton stated, *"…increasing confidence that the Tri-State area will feel the impacts of a major coastal storm late this weekend into early next week. This includes the potential for heavy rainfall, high winds, coastal flooding and beach erosion"* **(Figure 12)**. The Coastal Flood and High Wind Warnings issued for the New York and New Jersey coasts on Sunday morning, October 28, contained very strong language regarding impacts from *"major coastal flooding…possibly to record levels…"* and that high winds of up to 70 mph Monday would result in *"power outages [that] could last at least several days."*

Figure 12: Mantoloking, N.J., November 5, 2012. Drainpipe shows the pre-storm height of sand dunes. *Source: Liz Roll, FEMA*

NWS used social media outlets to help convey storm impacts well before landfall. WFO Upton began tweeting on Sandy's potential impacts as early as the morning of October 25 and mentioned the potential for 20-foot waves south of Long Island later that day. Similarly, WFO Mount Holly used Twitter and Facebook to announce the availability of new briefing packages with Sandy-related impacts. Despite the use of social media, coastal residents primarily relied upon mass media to seek weather information during Sandy.

One particular briefing from WFO Mount Holly stood out for its frank and persuasive language and effectiveness in focusing immediate attention on the gravity of the situation. On Sunday, October 28, the Meteorologist in Charge (MIC) at WFO Mount Holly posted a personal plea (**Figure 13**) for coastal residents to evacuate if requested to do so by local officials. This MIC used a combination of history and a forceful plea to consider how remaining in their homes as rising waters trapped them would affect others. Many EMs interviewed pointed to this plea as the point when they realized the true magnitude of the threat. A media representative commented going *"outside of the box"* in this manner may have saved lives.

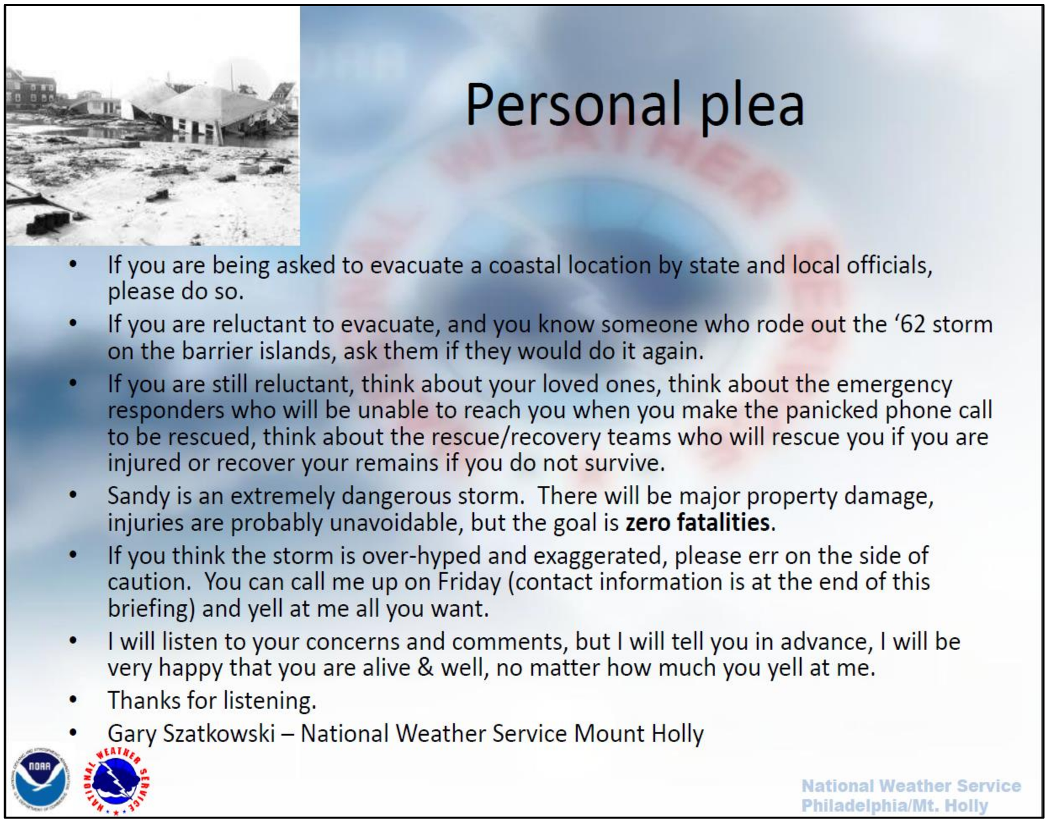

Figure 13: Personal plea issued by WFO Mt. Holly MIC. *Source: Mt. Holly WFO*

The early forecast discussions by HPC also were noteworthy, as represented in the following excerpts from medium range discussions:

- Nine days prior to landfall: "…A LARGE, SPRAWLING HYBRID LOW IS DRAWN TOWARD THE MID ATLANTIC COAST BY THE END OF DAY 7. MUCH REMAINS TO BE SORTED OUT, BUT THE POTENTIAL IMPACT IS IMPRESSIVE."
- Seven days prior to landfall: "…BESIDES THE WIND, THE OTHER SENSIBLE WEATHER THREAT IS HEAVY RAINS, WITH HEAVY SNOWS POSSIBLE ON THE SOUTHWEST SIDE OF THE HYBRID CIRCULATION…"

Some 48 percent of coastal residents who took part in a telephone survey approximately 5 months after the storm characterized the quality of the weather forecast as "excellent" in terms of "letting them know what might happen," 36 percent said it was "good," and 16 percent judged it to be "fair" or "poor." *(Source: Gladwin, Morrow & Lazo, 2013.)*

Despite some success in conveying likely impacts, a variety of interview subjects expressed surprise at the magnitude of the storm surge associated with Sandy, including the speed with which the waters inundated areas along and near the coast. Whether this reaction was due to inadequate wording about the anticipated impacts or to the message not being included in all NWS products relating to Sandy is unknown. In either case, NWS needs to improve communication, particularly with respect to storm surge.

Fact: The coastal flood and high wind warnings issued as early as Sunday morning for the New York and New Jersey coasts contained very strong language regarding impacts from *"major coastal flooding…possibly to record levels…"* and that high winds of up to 70 mph Monday would result in *"power outages [that] could last at least several days."*

Finding 5: NCEP, RFCs, and WFOs in the affected region employed a variety of tools to communicate impacts, some of which were more effective than others. EMs repeatedly found simple materials (e.g., briefing slides and 1-page summaries) to be most valuable for maintaining situational awareness.

Recommendation 5: The NWS should develop more effective and consistent products to communicate severe weather impacts, specifically:

- Concise summaries of weather and its impacts using non-technical text and graphical material provided in a short and easy-to-read format
- Confidence or uncertainty and worst-case scenario information

These products should be pretested using evidence-based social science. NWS should also provide effective training on the use of these products to ensure WFO personnel know how to best communicate with decision makers and the public during extreme weather events.

3.1.5. Watch, Warning, and Advisory Policies

Previous NWS directives specified that NHC would issue tropical cyclone public advisories for all tropical cyclones except for certain tropical depressions over land, for which HPC would issue a similar product[7]. Further, policy dictated NHC would issue the final public advisory when a cyclone dissipates, becomes a remnant low, becomes extra-tropical, etc. This policy presented the aforementioned dilemma—the forecast called for Sandy to change from a tropical to non-tropical system potentially a day before it was to make landfall.

The Service Assessment Team heard a number of comments about the suite of watch, warning, and advisory products used for Sandy. Users thought the CFW was a cumbersome way to communicate fast breaking surge-related forecast information. EMs and other partners commented that issuing a CFW in lieu of an HLS reduced the level of visibility. EMs stated that people typically hear a CFW and think it only affects the coast. Media representatives said NWS issues high wind and CFWs frequently in the Northeast and therefore these products are unlikely to trigger alarm or action. Beginning on Saturday, October 27, coastal WFOs coordinated with ERH to ensure a consistent use of warnings: CFW, high wind warning, flood watch, and hurricane wind warning.

The best weather and water forecast can only save lives if it is communicated effectively to at-risk residents and the public officials who are charged with protecting them. This service assessment, including the studies referenced above, indicate the public finds NOAA's current suite of watch, warning, and advisory products to be confusing.

Finding 6: Despite efforts to publicize the decision to transition NWS products and services from hurricane watches and warnings to non-tropical watches and warnings, this decision led to confusion and was viewed unfavorably by many. This resulted partly from a lack of flexibility in the previous policy for handling a complex storm like Sandy.

Recommendation 6: The NWS should adopt the proposed new process developed at the 2012 NOAA Hurricane Conference by the NHC (**Figures 14 and 15**), specifically the following recommendations:

1. Modify the protocol for issuing coastal hurricane and tropical storm watches and warnings to allow NHC to continue issuing them or keeping them in effect after a tropical cyclone becomes post-tropical.

2. Allow NHC to continue issuing advisory products after a tropical cyclone becomes post-tropical in those cases in which the system continues to pose a significant threat to life and property and in which the transfer of responsibility to another office would result in an unacceptable discontinuity in service or change in communications patterns already established for the event.

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[7] NWS issued a service change notice on April 4, 2013, motivated by experience with Hurricane Sandy and Recommendation 6 of this (then draft) Report. The first of these changes gives the NWS the option to continue issuing formal advisories on post-tropical cyclones, in those cases when the system continues to pose a significant threat to life and property, and when a transfer of responsibility to another office would result in an unacceptable discontinuity in service. The second change gives the NWS the option to keep hurricane and tropical storm watches and warnings in place for those systems.

3. Modify the directives as appropriate, including NWS Instruction 10-601, Tropical Cyclone Products.

Implementing this proposal will simplify the information dissemination process. Challenges will remain, however, for future storms like Sandy. Simply retaining the hurricane watches and warnings will not fully solve the problem. NWS should take four additional steps:

1. Advisories and discussions should emphasize that the strongest winds and highest surge may be well removed from the storm's center.

2. Advisories and discussions should focus on substantial hazards, regardless of post-tropical status. Studies have documented the challenges of encouraging evacuation for Category 1 and 2 storms (*Cutter et al., 2011*). Recommendations #2 and #4 should help advance the NWS ability to address this challenge.

3. Personalize the storm surge threat for coastal residents by further refining forecasting techniques for post-tropical storms (see surge Recommendation #14).

4. Address potential issues with the use of the HLS for a future storm similar to Sandy. The Service Assessment Team has further addressed this issue by endorsing the Irene Service Assessment finding and recommendation in Section 3.4.

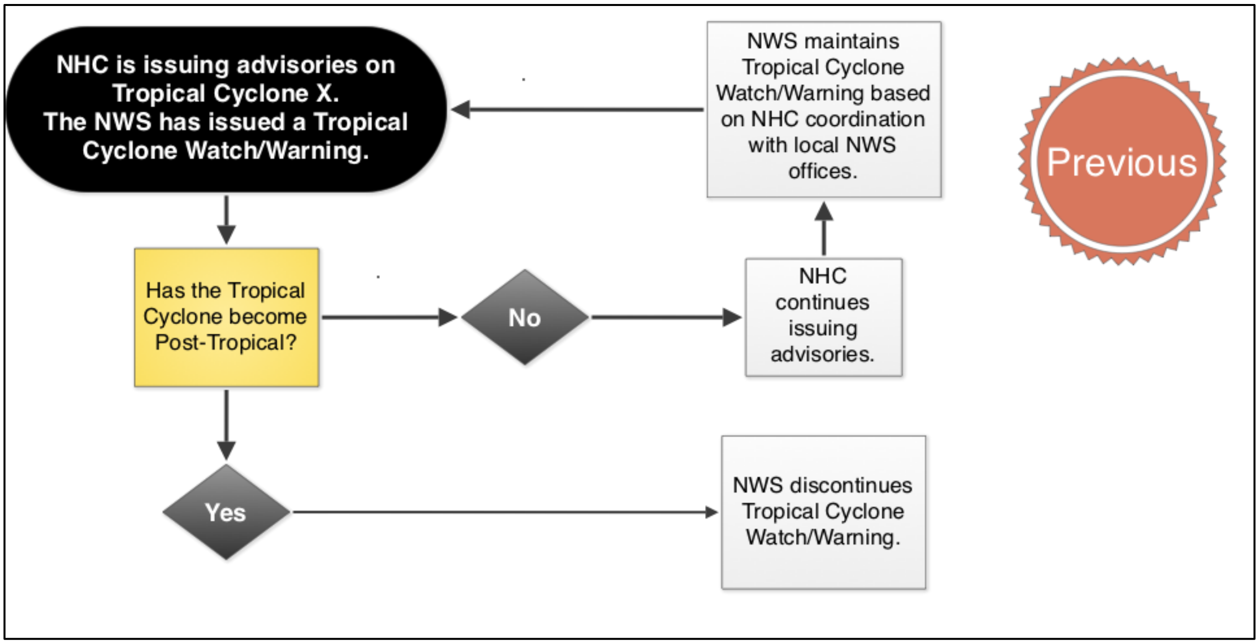

Figure 14: Previous advisory, watch, and warning process for hurricanes that become post-tropical storms. *Source: NHC*

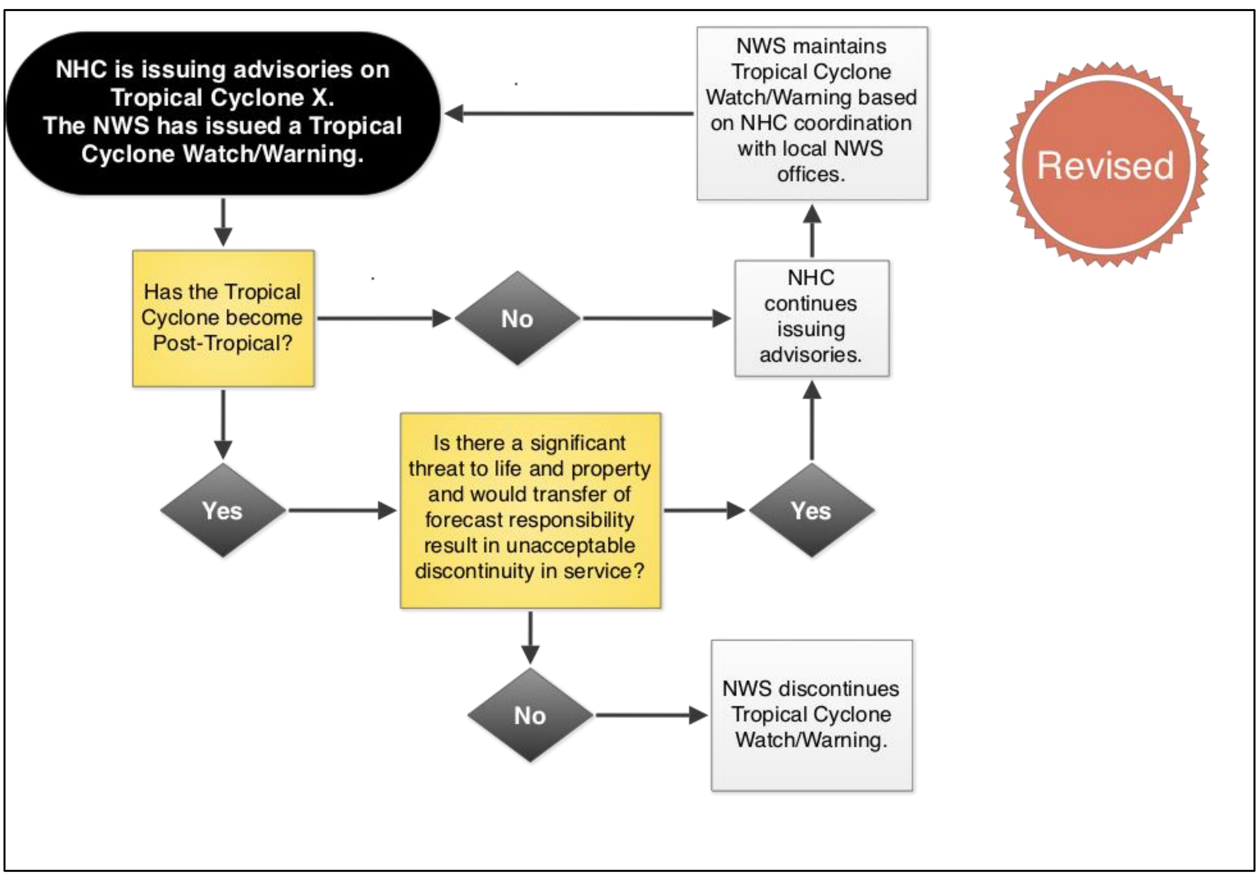

Figure 15: Revised advisory, watch, and warning process for hurricanes that become post-tropical storms. *Source: NHC*

3.2. NWS Web Presence as Tool for communicating with Public

Eliciting public response in a fast-paced media age requires a multi-faceted strategy, using a variety of tools and messages to reach diverse audiences. These tools include traditional one-way products linked to radio, television, personal computers, and mobile devices, as well as social media outlets, which create channels for rapid, two-way communication between NWS information providers and the public. This breadth of outreach presents challenges for NWS, because it has developed many of its web and outreach products to reflect the part of the agency that generated the information (organizational design) versus the needs of the intended recipient. Weather events that affect multiple NWS WFOs and regions call for strong cross-agency consistency.

NOAA/NWS can more effectively use the Internet by linking web pages to more dynamic and popular tools. The hallmarks of this new Internet Age are social media and mobile devices such as mobile phones, tablets, and handheld media readers. Social media outlets encourage and even demand interaction between content providers and recipients. They also rely heavily on relationships that leverage common interests and trust. These outlets can quickly amplify a convincing message from a credible source, going viral and reaching far beyond its initial audience. Mobile technology makes it easier to send real-time, geographically relevant information, enabling highly mobile users to obtain information where they are, when they need it. In many cases, such communication channels continue to function when landline phones fail.

During Sandy, NWS websites received 1,295,474,429 hits; the NHC accounted for 89 percent of this traffic. On October 29, 2012, as the storm made landfall, NHC received 91 percent of the NOAA/NWS website traffic. A similar pattern held for Facebook, although the WFOs received a higher percentage. WFO Upton compiled an interesting statistic for "Daily Friends of Fans." This calculated the total number of people who are friends with the fans of the WFO web page, meaning if all fans share a post, this number of people would potentially see it. Since the number rises with the number of fans, looking at the October 29 number represents the day with the most interaction and new likes. On that date, potentially 2,231,113 social media users could have seen the WFO's posts.

OPC and WFOs Mt. Holly, Upton, and Wakefield, among others, created specific web pages for EMs that consolidated information and provided tools to track and monitor conditions throughout the event. Even so, as illustrated in **Figures 16 and 17**, the public gets most of its weather information from television.

3.2.1. Clarity and Usability of NOAA Websites

It was evident from the many interviews with EMs, media, and commercial weather service providers that NWS web pages are critical resources during high-impact events such as Sandy. Virtually all of the people interviewed by the Service Assessment Team cited one or more NWS websites among their suite of weather monitoring tools. With such a high level of importance, however, comes scrutiny on the reliability and design of those pages. The Team heard repeatedly there is room for improvement.

Users consistently singled out two aspects of NWS web page design as impeding them from finding critical information. First, NOAA spread out information over multiple web pages, largely as a function of its organizational structure. WFOs and RFCs posted local information on Sandy, but NHC, HPC, OPC, and the NWS Meteorological Development Laboratory also posted useful storm content. OPC and WFOs Mt. Holly, Upton, and Wakefield (among others) created a specific web page that consolidated information and provided useful tools for EMs to track and monitor conditions throughout the event. Although many WFOs have developed effective EM websites and e-mail lists and use briefing pages to combine and summarize information from multiple NOAA/NWS websites, some EMs told us it was difficult for them to find briefing pages quickly.

The second issue related to NOAA/NWS web pages is the need to go several clicks beyond the main web page. The FEMA Region II staff stated they often use non-NOAA websites because those pages are less technical and more effectively improve situational awareness. NYCOEM uses the Stevens Institute of Technology Storm Surge Interface because it is cleaner and requires fewer mouse clicks to navigate.

The media relied heavily on multiple NOAA/NWS websites during Sandy, but the public was much more likely to get its weather information from the media ((**Figures 16 and 17** *and personal communication from Robert Meyer, March 5, 2013*). This observation mirrors a pattern observed in other storms (*Dow & Cutter, 2000; Smith, Wilson & Kain, 2010*). The media wants clearly worded messages that do not require reworking, especially during intense events like Sandy, when broadcasters have limited time to process complex weather data. Many media representatives interviewed stated that when they are on the air 24/7, all they have time to do is “rip and read” the NWS products coming over their computers.

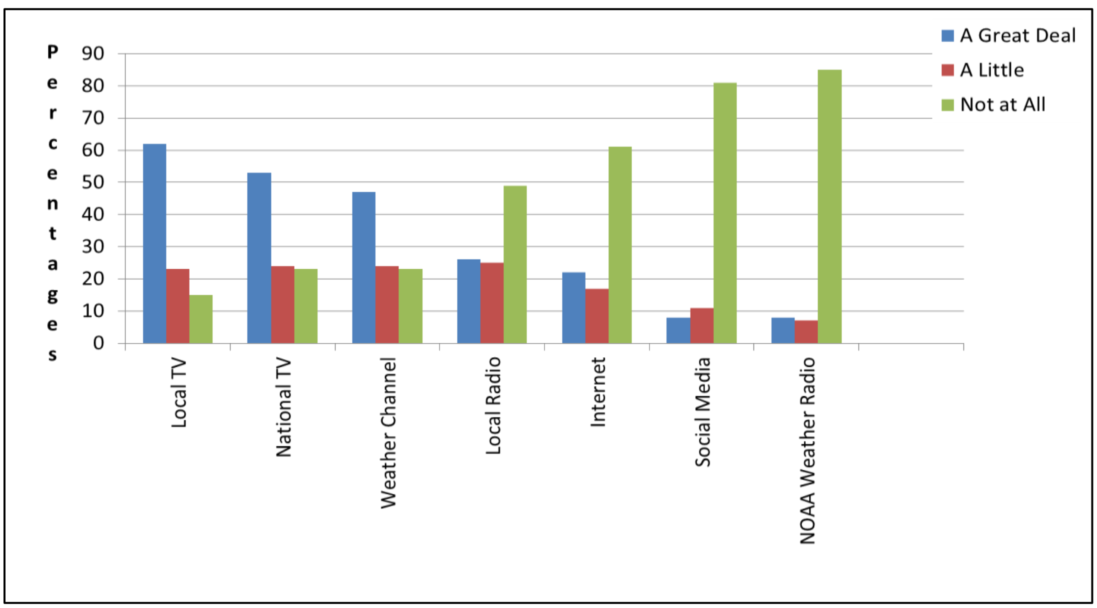

Figure 16: Coastal residents’ sources of weather information as Sandy approached. *Source Gladwin, Morrow & Lazo, 2013*

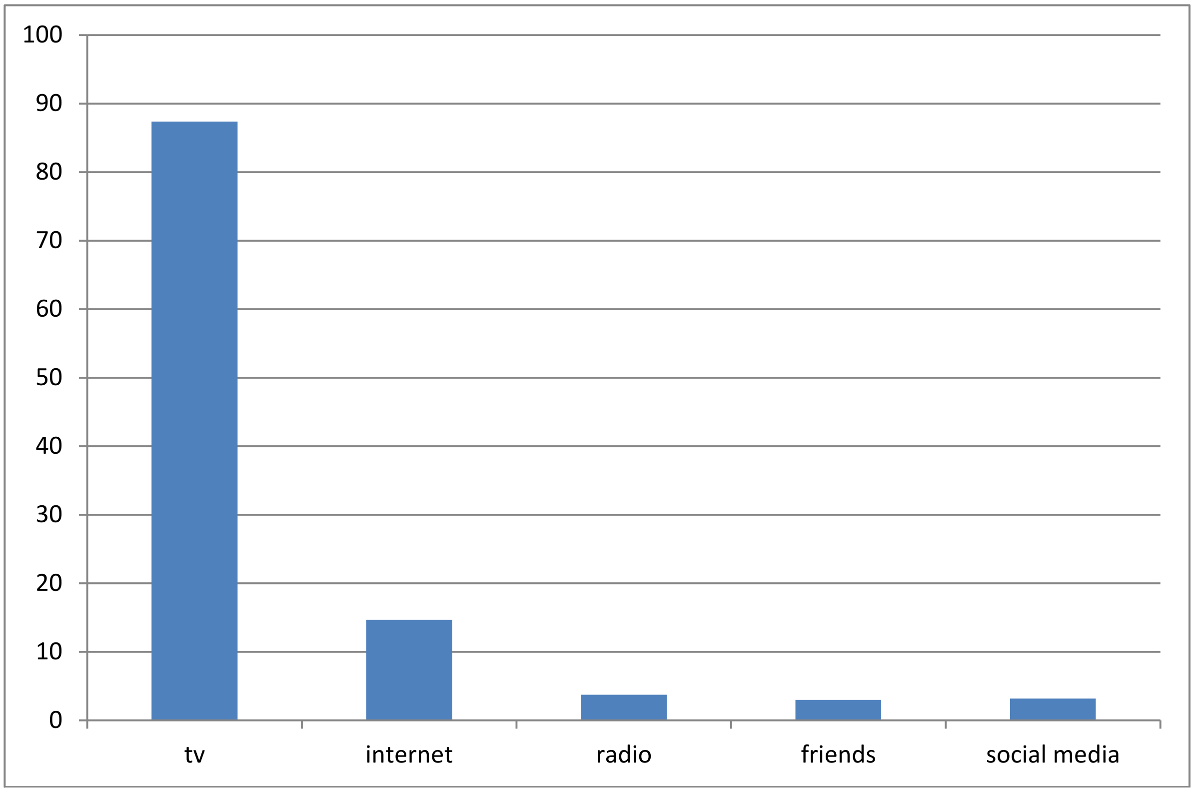

Figure 17: Survey respondents' source of most recent information for Sandy.
Source: Baker et al, 2012

Of post-storm survey respondents who reported getting weather information from the NHC or WFO websites, 75 percent and 58 percent respectively, found those sources to be useful. Those assessments, however, are based upon small numbers—8 and 19 users, respectively (*Gladwin, Morrow & Lazo, 2013*).

Finding 7: Just prior to Sandy's landfall, some WFO web pages in the impacted area did not effectively highlight the seriousness of the impending storm. WFOs did not consistently use large fonts, attention-getting banners, and headlines to catch the public eye.

Recommendation 7: For geographically large storms with multiple hazards, NOAA/NWS should provide a single website, such as "Storm.gov" that offers critical observations and forecast and watch/warning information, including easy to follow links to other web pages with more detailed information, such as confidence and worst-case scenarios.

Finding 8: Many media reps and WFO employees who fielded questions from users stated they felt NWS websites were complicated and that they found it difficult to find vital information. The most important message needs to be more obvious.

Recommendation 8: The NWS needs to make its websites more user-friendly. NWS should expedite this effort and base changes on how the user looks for information, not on the NWS organizational structure, e.g., WFO, RFC, and NWS Region. NWS should use social science when revising its websites.

Fact: The media are the channel through which most of the public gets weather information.

Finding 9: The media is the primary intermediary for publicizing NOAA/NWS products and services.

Recommendation 9: The NWS should provide the media with information that includes a concise overview of storm impacts, ready for public consumption as written.

All NWS Eastern Region offices experienced an Internet outage on Tuesday, October 30, 2012. Although NWS restored a basic version of these web pages within a day, it took over a week for NWS to restore the fully functioning sites. Several interviewees noted this outage and stated it prevented them from acquiring needed information quickly. Outages affecting reliable access to NOAA/NWS websites are not unusual during critical weather situations. Multiple NWS staff expressed frustration with this problem.

Finding 10: The ERH website outages at the peak of the storm resulted in the loss of web-based services from Eastern Region WFOs and RFCs.

Recommendation 10: NWS needs to develop redundancies in web services prior to the 2013 hurricane season to ensure backup in case of equipment failure.

3.2.2. Improving NOAA's Web Presence and Use of Social Media

NOAA/NWS needs to move to a more integrated and seamless delivery of weather information over the Internet. In addition, NOAA/NWS needs to develop more and better tools for use by the public via mobile and handheld devices. It was noted that the public's only Internet access during a power outage might be through a mobile device. Many partners interviewed in New York and New Jersey mentioned the need for NOAA/NWS information to be accessible via mobile phones or tablets, particularly through apps that display text and graphical information. Although NWS has developed mobile-enabled information for some of its websites, NWS has not redesigned many of its sites for mobile access. Unlike NWS web pages, which rely on users to seek out information and may not present the screaming message of the day or moment, social media reaches out to users automatically.

NWS does not format some of its products, such as special weather statements, to be automatically picked up by the computer software used by media partners. This deficiency means busy broadcasters may share less than current information with their viewing audiences. Rectifying this problem will likely require coordination with the vendors that NWS partners use. As one media-based meteorologist stated, "*Frankly, the biggest thing you could do to help us is to produce products that can get pushed out to Weather Central, WSI, Barron and AccuWeather.*"

Since Hurricane Irene in 2011, the NWS has gained experience using social media, particularly Twitter. This outreach became even more relevant during Hurricane Sandy. As then-NCEP Director Dr. Louis Uccellini remarked, "*It was a game changer*" with respect to how people learned of and responded to weather information. In one community of approximately 6,500 people, the EM was initially skeptical of the value of social media outlets; however, during Sandy, he characterized them as "*spectacular successes,*" when his office's Facebook page went from 250 to over 5,000 likes.

NWSChat was praised both externally, as a means for collaboration with media/EMs, and internally, as a separate tool for coordination between WFOs, National Centers, and Regional Headquarters.

Finding 11: NOAA/NWS needs to make more information accessible via mobile phones and tablets. Although NWS has developed mobile versions for some of its websites, all sites need to offer mobile access.

Recommendation 11: The NWS should ensure its web pages are easily accessible by smart phone and tablet technologies and develop new mobile applications and tools that allow effective display of text and graphical information.

Finding 12: Social media outlets are becoming a more significant source of information for severe weather-related impacts. These tools allow better communication between the NWS, partners, and the public—providing real-time feedback on message comprehension. These formats require a concise delivery of information and can easily leverage the advantages of simple, easy-to-use graphics, e.g., web robots that pass along WFO graphicasts.

Recommendation 12: The NWS should improve its use of social media, including message refinement and posting mechanisms to elicit public response before, during, and after high-impact weather events. NWS should use these tools for reporting and sharing ground truth of impacts.

3.3. Producing and Issuing Storm Surge Products

Storm surge from Sandy was the most damaging aspect of the storm and the most difficult to predict. NHC's Storm Surge Unit (SSU) includes one NWS government employee and several contractors who track the storm and create and examine surge guidance to prepare forecasts. WFOs predict local storm surge conditions and their impacts by relying on NHC storm surge forecasts and storm surge model predictions, as well as knowledge and expertise on local vulnerabilities. NWS provides additional detail on local coastal inundation impacts through a suite of products describing storm surge hazards. Storm surge height and location are closely correlated with the track and landfall time of a storm, but uncertainty in the storm forecast makes it difficult to generate precise surge predictions until close to landfall. Therefore, NWS bases its surge products on a broad range of scenarios that are narrowed the closer the storm gets to landfall. For example, a shift in track just 12 hours before landfall can result in changes in storm surge of 10 feet or more for a specific location. These tools are valid only for tropical cyclones in the tropical phase. Similar capabilities do not exist for non-tropical cyclones or rapidly transitioning tropical cyclones.

When storms are more than 48 hours from landfall, NHC advises EMs to use pre-computed assessments of storm surge hazards for their region. These assessments are generated by running thousands of hypothetical potential storms and compositing the results into a worst case scenario. The Maximum Envelope of Water (MEOW) provides the worst case for a particular tropical cyclone storm category, forward speed, trajectory, and tide level. The Maximum of the Maximum Envelope of Waters (MOM) provides the worst case scenario for each storm category. Once a storm is within 48 hours of landfall, NWS generates a probabilistic storm surge prediction based on the actual forecast track. This prediction, called PSurge, uses the NWS Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to run variations of the forecast track. The track, in turn, accounts for uncertainties in landfall location, forward speed, intensity and size. PSurge is the primary source of guidance for NHC's forecast advisories and HLSs from WFOs, both of which include descriptions of the storm surge hazard.

NWS used primarily WFO text products and CFWs to alert users about storm surge during Sandy. The offices affected by Sandy used PSurge guidance, but OPC gave these offices operational extra-tropical storm surge models via web and grids on Wednesday, October 24, providing further information on the storm surge hazard. These WFOs were supported by expertise from SSU and OPC staff. NHC public advisories were an important source of information of storm surge impacts,

3.3.1. Improving NOAA's Storm Surge Warnings and Products

Fact: NHC issued its first public advisory for Sandy with explicit surge forecast on Saturday, October 27, at 11 a.m.

NHC provided storm surge guidance as inundation or total water above ground level. Initially, NHC forecasted 4–8 feet inundation and then increased the range Saturday evening to 5–10 feet. On Sunday morning, NHC increased the inundation range to 6–11 feet, and specifically added New York Harbor to the area of highest inundation; NHC also added the headline of "Life-Threatening Storm Surge." WFO Mt. Holly linked its CFW to the Advanced Hydrologic Prediction System (AHPS) web page because AHPS pages for coastal stations showed only tidal departures and did not include surge. WFO Upton used tide tables and added storm surge values on top of tidal predictions to indicate predicted times for water levels and total surge (**Figure 18**). These examples illustrate that, while NHC and WFOs responded to requests for information and storm surge forecasts, there was no consistent method for conveying the information.

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                    NATIONAL OCEAN SERVICE GAGES

..........................MAXIMUM.......ASTRONOMICAL....STORM
LOCATION................WATER LEVEL......TIDE LEVEL.....SURGE.....TIME
BERGEN POINT............14.60 FT MLLW...5.15 FT MLLW....9.45 FT...924 PM
BATTERY.................13.88 FT MLLW...4.65 FT MLLW....9.23 FT...924 PM
KINGS POINT.............14.38 FT MLLW...5.60 FT MLLW....8.78 FT...1000 PM
BRIDGEPORT..............13.26 FT MLLW...5.31 FT MLLW....7.95 FT...1006 PM
NEW HAVEN...............12.30 FT MLLW...3.97 FT MLLW....8.33 FT...930 PM
NEW LONDON...............8.04 FT MLLW...2.08 FT MLLW....5.96 FT...812 PM
MONTAUK..................7.12 FT MLLW...1.88 FT MLLW....5.24 FT...812 PM
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Figure 18: National Ocean Service tide table with storm surge values included. *Source: WFO Upton*

NOAA/NWS forecasters in local and regional offices, EMs, FEMA, and the media unanimously said inundation mapping graphics are *"desperately needed now"* to convey local impacts to viewers and policy makers. One media representative said "*lives would be saved*" if that product could be developed earlier than its projected 2014 delivery date. Many of those interviewed (e.g., FEMA, Nassau County OEM) expressed the need for a separate surge product decoupled from wind information. In recent surveys commissioned by NOAA, approximately 72 percent of coastal residents expressed support for a separate storm surge warning product, as did 79 percent of EMs and 95 percent of broadcast media reps (*Lazo & Morrow, 2013a, 2013b*). EMs also indicated they need storm surge forecasts sooner than 36 hours out, because evacuation plans require much longer lead times than 36 hours (e.g., for medical facilities). EMs indicated their priority was to get information quickly even if NWS has a lower level of certainty rather than waiting for more accurate projections. The Service Assessment Team notes significant uncertainty in predictions at these forecast horizons would limit the precision and detail normally found in storm surge forecasts.

Finding 13: EMs need storm surge forecasts with longer lead times before landfall to help support decision making. EMs request that these predictions reflect forecast uncertainty.

Recommendation 13: NWS should provide information about potential storm surge hazards in its forecasts at least 48 hours before onset of tropical storm or gale force winds.

While users praised many of the NOAA offices currently providing storm surge guidance and support, NOAA staff was not able to respond to some key partners' requests for specific storm surge forecast information because of the large number of locations included. SSU does not have sufficient staff to meet demand during high impact events. NWSs should expand this unit.

In response to requirements expressed by EMs and media, NOAA has been developing an inundation map that can illustrate NHC storm surge forecasts. Developing this inundation graphic requires enhancements to NWS storm surge modeling, procedures to map storm surge guidance with Geographic Information System (GIS) software, and user testing and evaluation of these prototypes with NWS partners.

In response to these requirements, NOAA also is adding tide information to the PSurge model so it can capture coastal inundation hazards. NOAA is testing GIS procedures to map PSurge output onto local high resolution topography. Finally, NOAA has conducted social science studies with EMs, broadcast media, and the public to gain feedback on the design and layout of prototypes for the inundation graphic (**Figure 19**).

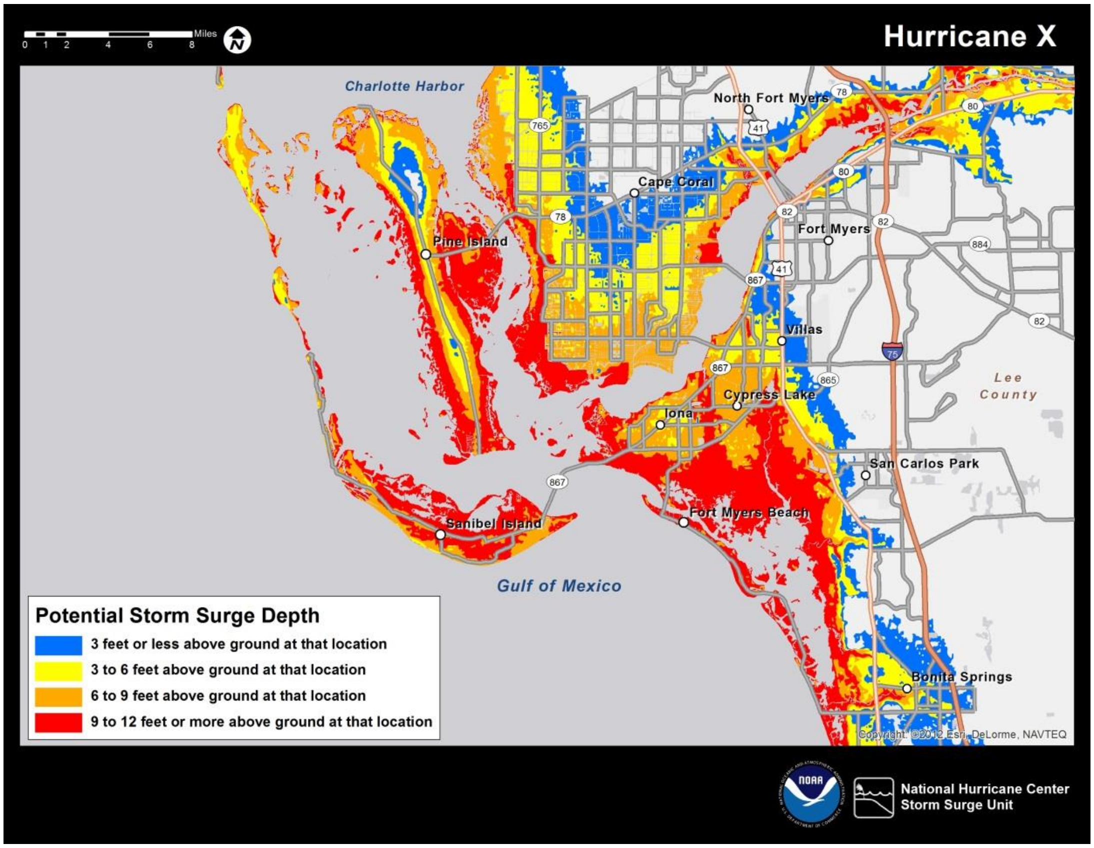

Figure 19: Prototype storm surge graphic for the Gulf Coast of Florida. *Source: NHC*

The Service Assessment Team noted these social science studies, testing, and revision of a new storm surge inundation product before its release are providing critical information on how the product is interpreted, enabling NWS to ensure its new graphic will effectively describe surge hazards through the text, colors, and layout used.

Finding 14: An overwhelming majority of internal NWS entities and external state and local decision makers cited the need for high-resolution graphical inundation mapping. They felt it would improve their ability to interpret NWS storm surge forecasts and their subsequent decision-making capabilities.

Recommendation 14: Consistent with previous assessments and ongoing development efforts, the NWS should implement explicit storm surge graphics and high-resolution mapping tools that clearly illustrate the impacts of surge. NWS should generate the data in GIS format. *This recommendation is the highest priority of the Sandy Service Assessment Team and should be in place for the 2014 hurricane season.*

Fact: The NWS has only one full-time federal employee at the NHC SSU.

Finding 15: The NWS has a severe shortage of staff dedicated to forecasting storm surge that significantly limits service improvements. There is only one storm surge forecaster at NHC and two model developers for tropical and extra-tropical guidance.

Recommendation 15: The NWS should increase storm surge staffing to a minimum of three model developers with one focused on extra-tropical surge effects. The NWS should have three storm surge forecasters at NHC to support 24x7 operations during events and develop expertise to support storm surge forecasting for extra-tropical cyclones.

Numerous NWS forecasters and EMs commented on how difficult it was to prepare for Sandy's coastal inundation hazards. Forecasters at WFOs and RFCs commented that NWS lacks forecast guidance to predict flooding in the vast majority of coastal rivers because NWS storm surge models do not extend far enough inland to represent the extent of tidal rivers; NWS hydrologic river models end well upstream past areas of tidal influence. This deficiency makes it challenging for NWS to forecast storm surge progression up rivers and the transition of high river conditions to the coast.

Additionally, many EMs expressed surprise at the large and damaging waves Sandy caused. Of coastal residents surveyed after Sandy, 77 percent described the impact of waves as more than they expected (*Gladwin, Morrow & Lazo, 2013)*. Even small to moderate storm surges can cause life-threatening and damaging conditions because of severe coastal waves on top of surge. NWS forecasters do not currently have model guidance predicting wave run-up conditions at the coast. These data would help NWS staff to forecast these hazards reliably.

Finding 16: NWS lacks sufficient forecast guidance on inundation associated with wave run-up and coastal rivers making it difficult to forecast impacts from coastal storms.

Recommendation 16: NWS should develop guidance for inundation in coastal rivers and for wave run-up on U.S. coasts for all wind-forced surge and inundation events.

3.3.2. Understanding of Storm Surge Information

"*There were forecasts, but there were no details about what the predicted surges would cause…There was no wording in the warning like, 'Most of lower Manhattan will be under water at a certain point' or 'Staten Island will flood up to Beach Street.*'" media rep

Without a graphic showing inundation extent, forecasters and EMs had difficulty determining inundation guidance at specific locations and responding to EM needs. One of the biggest surprises in this event was the impact of the surge and how fast it moved in. The public and NOAA/NWS partners did not clearly understand what storm surge was or how dangerous it could be. Most of the media representatives the Service Assessment Team interviewed believe NWS is not giving them any means to communicate predicted surge impacts to the public. The current data transmitted by the NWS is confusing, certainly to the public, and to some broadcast meteorologists and EMs. Even NWS forecasters found the computation required to produce storm surge forecasts to be cumbersome and time-consuming.

In addition to the lack of graphical inundation guidance, there was confusion regarding the use of multiple vertical datums referenced for storm surge and how to use that information effectively. The Delaware Emergency Management Agency was unable to provide detailed inundation forecast graphics to the state's senior leadership to help with evacuation decisions. In their view, this deficit needs to be corrected immediately. NYCOEM was confused about the storm surge forecast, what and where the impacts would be, and how high the water would rise. They specifically recollected a call from NHC on Saturday night with an updated surge forecast that was “an eye opener,” noting it was an odd situation to be called directly by NHC, but was effective. This apparent communication breakdown may have delayed critical decision making about evacuations and led to potentially confusing messaging to the public. As shown in **Figure 20**, high-resolution depictions of potential storm surge inundation could be used by local EMs to conduct hazard assessments in GIS on top of critical infrastructure and flood evacuation zones.

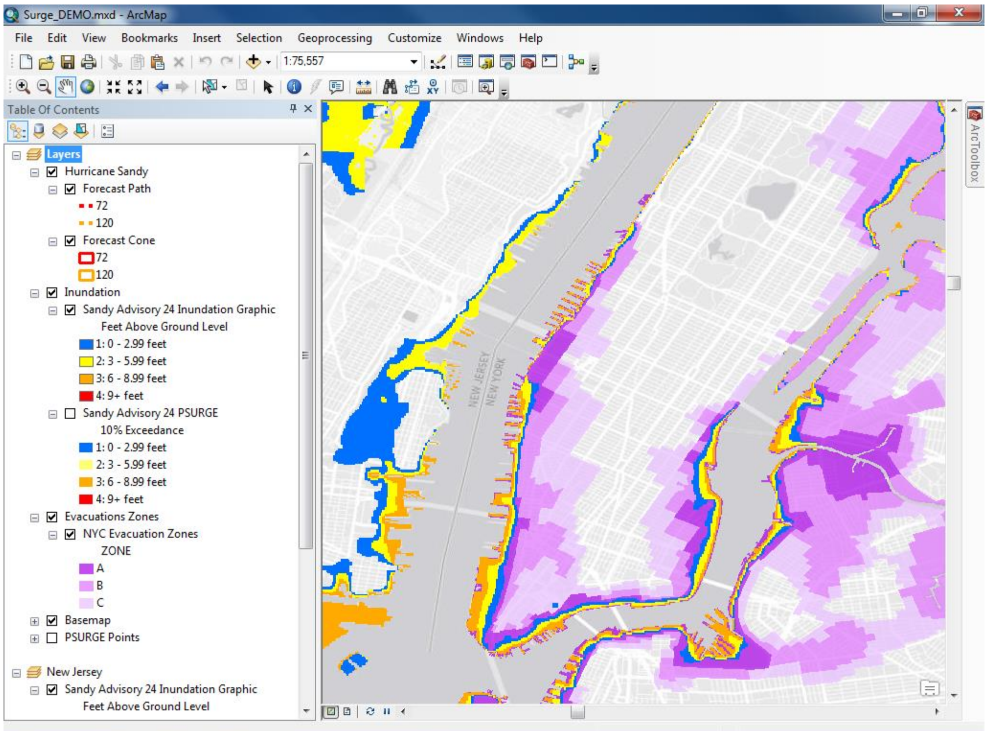

Figure 20: Storm surge information demonstrated in a GIS format, integrated with information on evacuation zones for New York City. *Source: NHC*

WFO staff, customers, and partners also identified the need for more training. While NHC has conducted a series of classes for NWS staff on storm surge forecasting, currently there is no formal training requirement for NWS staff on the science of coastal inundation, including datums, and guidance information. In addition, NHC and NOS have recently implemented a datum conversion tool to support WFOs’ need to convert storm surge guidance; it does not appear to be widely used, possibly because there is a training gap. EMs interviewed after Sandy also requested more training on how to interpret surge forecasts. If local customers desire different reference datums, this should augment, but not replace, the NWS standard.

Finding 17: NWS storm surge terminology, such as reference datums and description of impacts, is confusing. Coastal flood forecasting is difficult and time consuming largely because forecasters need to process storm surge data in a variety of different formats and reference datums.

Recommendation 17: NWS should present storm surge forecasts in a single, consistent datum and adopt a unified format and language for products describing impacts from storm surge, regardless of (tropical or extra-tropical) origin.

Finding 18: NWS personnel vary in their knowledge of coastal inundation science and forecasting. NWS does not provide standardized training for this hazard. In addition, NWS partners vary in their understanding of and familiarity with coastal inundation hazards, terminology, and pertinent NWS products.

Recommendation 18: The NWS Training Division should develop and deliver initial standardized professional training for NWS forecasters before the start of the 2014 hurricane season, as follows:

- All forecasters with tropical-related support responsibilities at coastal WFOs, WFOs providing backup support to those coastal WFOs, and NCEP centers should complete this training by the end of the 2014 hurricane season, and it should become part of routine professional development.
- NWS management at the local and Financial Management Center levels should ensure the forecasters in their area of responsibility have enough time to complete this initial training.
- The Training Division should make basic training on coastal inundation available to NWS customers, including EMs, media, and key federal partners (e.g., FEMA, USGS, and U.S. Army Corps of Engineers) prior to the start of the 2015 hurricane season.
- NWS should add training for non-tropical surge events as tools become available.

3.3.3. Ease of Use of Storm Surge Information

NHC typically runs the SLOSH model to support storm surge forecasting for landfalling hurricanes; however, before NHC begins to make storm surge forecasts, EMs and local forecasters use data in SLOSH's display program to assess the storm surge threat. Some partners were confused about how to use this tool, in part due to the unusual track of Sandy. Some partners thought SLOSH could not be used for westward moving storms or possibly used an outdated version. This belief led to confusion and made it difficult for some partners to understand the threat. In addition, there was a lack of guidance for storm surge up coastal portions of tidally-affected rivers. These deficiencies made it difficult for WFOs to forecast and warn about potential flooding. Producing a coastal flooding forecast is also difficult and time consuming because the forecaster needs to process storm surge guidance and observations on several vertical and horizontal datums.

Best Practice: Many of those interviewed praised AHPS for its delivery of information in new and easier to understand formats, including graphics and illustration of river flooding impacts at specific locations.

Finding 19: Interviews with EMs and broadcast media revealed strong support for a separate storm surge warning for coastal and tidally-influenced rivers. A recent NOAA-funded survey shows 90–95 percent of partners support this proposed new product. Further, the interviews suggested that while EMs understand the importance of CFWs, there was a perception the public does not react as strongly to them.

Recommendation 19: NWS should support the planned implementation of a storm surge warning for tropical, post-tropical and extra-tropical systems, including linkage to explicit storm surge graphics and high resolution mapping tools described in Recommendation 14. Support should ensure NWS can implement this new product before the 2014 hurricane season. Partners and the public should rigorously test this new product to verify it is correctly interpreted. *[Continued refinement of the use of this new warning will require advancements in coupling of coastal surge models with hydraulic models for river flooding in order to warn about surge impacts up rivers.]*

3.4. Other Improvements

3.4.1. Hurricane Local Statements

WFOs did not issue HLSs north of the Virginia/North Carolina border because tropical cyclone watches or warnings were not in effect. While the NHC generates track and intensity forecasts for tropical cyclones, the local WFOs provide added local forecast value to tropical cyclone-related impacts, e.g., surge, high winds, excessive rainfall, river flooding and even tornadoes. The WFOs generate gridded forecasts for these elements, which in turn, drive the NWS point and click web-based forecast for specific points. WFOs officially issue the effective Valid Time Event Code for tropical cyclone-related watch and warning text products. Although the HLS is a highly visible local product that provides a way to detail local tropical cyclone-related impacts, there have been problems with this tool. Feedback indicates many users find it lengthy, cumbersome, and confusing. Since Recommendation #6 entails using the HLS for a future tropical event of this scope, NWS needs to address the issues with this tool. In particular, media users requested more easily digestible impact-related information in a rip and read format.

Fact: HLSs routinely exceed 10 pages. Such length is necessary to produce correct geographical averaging for individual forecast elements such as wind speeds over a county so the NWS text product verbiage appears correctly (see *Hurricane Irene 2011 Service Assessment,* Finding **39** and Recommendations **39a and b**).

Although WFO forecasters generally felt they had adequate training for composing an HLS for Sandy (and it was verified that NWS provided training), some forecasters stated they would have felt uncomfortable composing an HLS if tropical watches and warnings had continued north to the point of landfall. This hesitation potentially compromises the ability of the local NWS office to provide timely and accurate impact-related information.

The Sandy Service Assessment Team reaffirms Finding 39 and Recommendations 39a and 39b of the Hurricane Irene Service Assessment recommendation to modify the HLS to a bulleted format and to reduce the product's length and production time. The Sandy Service Assessment Team also supports improving the HLS's responsiveness to a broad range of demands from users, including WFOs, EMs, media and commercial weather services providers, and the public.

3.4.2. Decision Support Services

As documented in the Hurricane Irene Service Assessment Sections 4.3 and 5.1, the pre-positioning of NOAA/NWS staff is essential to ensure the best possible services during widespread and long duration events. The NWS Weather-Ready Nation Strategic Plan (Goal 1) also refers to the importance of providing DSS to protect lives and livelihoods). During Sandy, NWS detailed DSS personnel to several EOCs. There was near-universal praise for this support.

During interviews with NWS officials and EMs, it was clear the demand for onsite or remote (delivered from NOAA/NWS offices) DSS almost certainly will increase, and that demand will quickly surpass capacity. The WFO Mount Holly MIC did not deploy WFO staff for onsite DSS support because he was concerned such deployments would degrade WFO services during the most critical stages of the storm.

Currently, there are formal NWS Pilot Projects in six locations across the country to explore remote and onsite Impact-Based DSS (*2012 Weather-Ready Nation Roadmap*). Many local and regional NWS offices have developed plans to provide onsite DSS using existing staffing levels. It is clear that NWS will need to develop a more comprehensive plan to meet future onsite and remote DSS demands while maintaining sufficient staffing for forecast and warning operations. Leveraging technology that allows for virtual on-site DSS will be a key aspect of this plan, as will ensuring that staff assigned to DSS roles thoroughly understand customer needs and expectations.

In several instances, NWS deployed meteorologists to EOCs to provide onsite decision support. Local officials praised this onsite support. Those officials expressed particular appreciation for the ability to ask direct clarifying or follow-up questions with NWS staff during conference calls and while providing onsite support.

An important basis for successful DSS is the trust partners have in NWS credibility and availability. The NWS has developed this trust at the local and state levels with EMs by working closely with these partners on tabletop exercises that simulate a real-time disaster. NWS has conducted NWS/FEMA courses like the Hazardous Weather and Flooding class taught by NWS instructors from local WFOs. These classes allow EMs to interact with their local NWS offices, ask questions, and test “what if” scenarios. WFOs enhance this relationship by participating in EM workshops and regional meetings.

With the severely restricted travel budget imposed on WFOs, activities requiring overnight travel are not possible. In the short term, this restriction will have a limited impact on DSS activities; however, if such restrictions persist, relationships will erode. These relationships are built on trust, integrity, and dependability that arise from face-to-face interactions and personal connections.

Finding 20: Travel restrictions are beginning to cause serious impacts on the ability to sustain effective DSS, including involvement in the programs and events that have been critical to the success of DSS.

Recommendation 20: The Fiscal Year 14 budget should include sufficient travel resources to ensure that each WFO may participate in activities with key partners, including overnight travel, to maintain the current level of DSS.

3.4.3. NWS Staff Resources

During the time when Sandy affected the NWS Eastern Region, ERH had eight vacancies. The vacancies limited the ability of the Acting ERH Director to help offices provide DSS and to staff the Regional Operations Center. Other critical vacancies across the region included the MIC slot at WFO Buffalo. This position was problematic because the Acting MIC is also the current Warning Coordination Meteorologist. This person was asked to provide DSS for FEMA Region 1 because of her past experience providing DSS during Hurricane Irene. Meeting this request further depleted WFO Buffalo's resources during the storm. The Electronics System Analyst position at WFO Wakefield was also vacant during Sandy.

Another critical position that was vacant was the Information Technology Officer (ITO) at WFO Upton, an office severely impacted by the storm. Historically, the ITO at WFO Upton plays an integral role in a number of unique, high-visibility DSS initiatives. These include DSS projects tailored to meeting the diverse needs of NYCOEM, such as visualization and forecasting tools depicting tropical storm wind speeds at skyscraper heights, and a graphical, color-coded weather hazards briefing sheet. The ITO vacancy meant the WFO could not provide these products.

The NHC has had a severe staffing shortage in its Technology and Science Branch (TSB) for the past 6 years. Fully staffed, TSB would include 12 federal employees who, among other duties, would maintain NHC's operational computer systems, communications support, and software development. NHC is feeling this staff shortage more over time as partner requirements increase. The associated work and stresses have resulted in near 100 percent turnover in the seven TSB programming positions in the last 3 years, resulting in less experienced staff with ever-increasing workload.

Compounding these staff shortages is the fact that filling vacancies takes more than 6 months on average because of delays by NOAA Workforce Management. These delays place an already excessive workload on a diminished staff that may be new to the NHC and have less experience with its IT systems. During Sandy, two TSB positions were vacant. On April 1, 2013, TSB will be down four positions with system support/programming duties. Two of the remaining three employees have only 1 year of experience and the third has just 3 years of experience. This fact places NHC, NOAA/NWS, and the customers and partners they serve in a precarious position heading into the 2013 season. This situation is requiring NHC to take unusual steps to obtain temporary staffing assistance from other offices within NCEP, NWS, and NOAA. These delays in filling vacancies degrade the capacity of an operational agency.

Finding 21: NHC and the NWS Eastern Region (ERH and WFOs) had critical staff shortages. Because these are operational units, these shortages make them vulnerable to failure during significant weather events when FEMA, EMs, media, and other important partners and the public depend on NWS offices the most.

Recommendation 21a: NWS should identify and fill critical positions at operational facilities. If these positions cannot be filled, NWS should ensure awareness at higher levels in NOAA that these vacancies may result in reduced levels of service, including constraints and potential failure on the delivery of products and services during the next significant weather event.

Recommendation 21b: NWS Headquarters should work closely with NOAA Workforce Management to reduce the amount of time it takes to fill operational positions.

3.4.4. Observational and Verification Information During High-Impact Events

Fact: During previous high-impact weather events, NWS has clearly demonstrated that providing observational and verification information related to evolving hazards and impacts (e.g., tide gage water levels during periods of coastal inundation or wind speeds during high wind events) bolsters the confidence of its users and meets a need identified by the private weather industry, e.g., during periods of recovery.

When a storm event like Sandy is evolving, it is important to provide critical observations and verification data because these data improve user confidence in public watches, warnings and advisories. It is equally critical to provide similar information after an event, when recovery efforts are underway. This effort starts with the local WFOs, who issue Local Storm Report and Public Information Statements to meet this demand. Social media outlets already play a role in assisting with this effort and likely will play an even larger future role.

During the Sandy assessment, two utility companies providing power to more than 8 million people in the Northeast stated they would like to see more consistent information, in particular, snow depths, rainfall amounts, peak wind speeds, and gusts. One of the companies stated *"The NWS is our 'life-line'…We need an easier way to get post-event data."*

Finding 22: The Service Assessment Team confirms Finding 11 in the *Hurricane Irene Service 2011 Service Assessment*, that NWS does not consistently provide critical observations and verification information to its users during and after high impact weather events.

Recommendation 22: The NWS needs to renew its efforts to provide pertinent and sometimes critical observational and verification data to its users on a consistent basis during and after events such as Sandy.

3.4.5. Social Science Needs for Service Assessments

The Service Assessment Team was not able to directly interview members of the public impacted by Sandy, despite the fact that several aspects of the Service Assessment Team charter called for public input. The Paperwork Reduction Act of 1995 (PRA) restricts the ability to conduct this type of survey work without prior approval from the Office of Management and Budget (OMB), which can take months or even years to receive. An additional barrier to directly collecting information from the public is government contractual requirements. There is not enough time to develop a new contract for conducting a survey during the period of the service assessment.

The budget for the assessment did not include dedicated funding to undertake a rigorous public survey. Further, the Team was operating under tight time constraints. The Team was only able to incorporate data from the public as a coincidence of two external research efforts underway, independent of the Sandy Service Assessment. In both instances, those investigators generously shared their data and other resources, allowing this report to go beyond weather professionals' assumptions of what members of the public thought and did when Sandy was bearing down on them. In the 2008, Super Tuesday Tornado Outbreak Service Assessment, the following recommendation was made:

"The NWS should use a common set of societal impacts survey questions for all future service assessments, similar to those used in this assessment. This would allow the NWS to continue to build a database of societal impact information to help support service and product improvements in the future."

While NOAA/NWS has made considerable progress on this recommendation, it has taken 5 years. The draft questions still have not been granted OMB approval. Without that approval, the Service Assessment Team could not use them to query the public. This delay represents a missed opportunity. Approved, pre-tested, standardized survey questions will greatly enhance the quality of future service assessments.

Finding 23: NOAA and the NWS lack a standard set of societal impacts survey questions to use as a routine part of service assessments and lack an established funding mechanism to conduct such surveys.

Recommendation 23a: NOAA/NWS should expedite the development and clearance of survey and focus group questions teams can use as part of service assessments. NWS needs to develop a generic list of questions and obtain OMB approval in anticipation of future service assessments.

Recommendation 23b: NOAA/NWS should secure long-term contracting mechanisms for securing the services of data collection contractors that can execute the public survey component for future service assessments.

NWS should complete these two recommendations in consultation with a social or behavioral scientist with survey expertise.

3.4.6. Collaboration with other Federal Agencies

The Service Assessment Team found multiple examples in which NOAA and NWS are working collaboratively with other federal agencies to improve preparation for and response to storms like Sandy. The USGS worked closely with WFO Upton to predetermine locations and deploy temporary USGS water level sensors. The U.S. Army Corps of Engineers consulted on surge for New York City. FEMA regional offices and Headquarters worked closely with NWS during Sandy; NWS deployed a DSS staff member to the FEMA command center in New York. These partners reiterated that a long-term relationship with NWS staff builds trust. NWS should strengthen these ties.

Additionally, the NWS should integrate content from the Centers for Disease Control and Prevention on hurricane preparedness and post-storm safety tips to reduce injury, illness, and death. The injury prevention information can help the public avoid known risks associated with hurricanes (e.g., drowning, mosquitos, stray animals, chainsaw injuries, unstable buildings, electrical burns and fires, hazardous materials, mold, carbon monoxide poisoning, musculoskeletal injuries, wound infection). NWS can easily integrate these resources into its web products.

Appendix A: Acronyms

AHPS	Advanced Hydrologic Prediction System
AGL	Above Ground Level
CDC	Centers for Disease Control and Prevention
CFW	Coastal Flood Warning
DSS	Decision Support Services
EM	Emergency Manager or Management
EOC	Emergency Operations Center
ERH	NWS Eastern Region Headquarters
FEMA	Federal Emergency Management Agency
HLS	Hurricane Local Statement
HPC	Hydrometeorological Prediction Center
ITO	Information Technology Officer
MEOW	Maximum Envelope of Water
MIC	Meteorologist in Charge
MLLW	Mean Lower Low Water
MHHW	Mean Higher High Water
MOM	Maximum of the Maximum Envelope of Waters
NCEP	National Centers for Environmental Prediction
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWS	National Weather Service
NYCOEM	New York City Office of Emergency Management
OCWWS	Office of Climate, Water, and Weather Services
OEM	Office of Emergency Management
OMB	Office of Management and Budget
OPC	Ocean Prediction Center
RFC	River Forecast Center
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SSU	Storm Surge Unit
TSB	Technology and Science Branch
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
WFO	Weather Forecast Office

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: Despite publicizing the fact that responsibility for issuing watches and warnings north of Duck, NC would shift to WFOs, NWS web pages and graphical displays did not clearly communicate this change. Specifically, NWS websites sent mixed messages by not highlighting coastal flood and high wind watches and warnings north of North Carolina on the widely-viewed NHC graphic accompanying Sandy advisories and by relying on the NWS Watch/Warning/Advisory graphic that cannot clearly display multiple watches, warnings, and advisories in effect simultaneously for a county.

Recommendation 1: For future storms like Sandy, NHC should be the principal point of contact responsible for the event, including delivery of a consistent suite of products and a unified communications protocol within NOAA, to key NOAA federal partners, and the media. NOAA/NWS websites should consistently reflect all watch/warning/advisories on websites, regardless of organizational structure or office/center responsibility. Web page design should ensure the most important message is quickly evident.

Finding 2: The existing array of NWS products for coastal storms (i.e., tropical storms, post-tropical storms and nor'easters) is confusing. This array led to misinterpretation of the predicted impacts during Sandy.

Recommendation 2: The NWS should generate and provide products focused on impacts. Such products need to specify where and when impacts will occur and should clearly communicate hazards posed, including wind, flooding from both rainfall and storm surge, and tornadoes.

Finding 3: Local and state EMs interviewed by the Service Assessment Team were generally satisfied with the way WFOs handled Sandy as an extra-tropical storm; however, many media outlets and commercial weather services providers did not support the decision to stop hurricane watches and warnings and found communication lacking.

Recommendation 3: In partnership with the media and commercial weather services providers, NWS should develop a strategy detailing information flow and new tools for communicating threats during future storms like Sandy. This strategy should include clear responsibilities for external coordination with key partners such as media, EMs and FEMA, and the public. This strategy should establish the primary communications point of contact for these types of storms and the types of products (e.g., watches, warnings, advisories) to be issued. [*This communications strategy should be developed as a companion to the proposal outlined in Recommendation #6.*]

Finding 4: Studies reviewed for this Assessment illustrate that the public's response to risk communications is influenced by a complex set of factors. NWS does not have a sufficient number of behavioral/social sciences or communications professionals involved in the design and delivery of weather forecast products and services.

Recommendation 4: NWS needs to broaden and expand its social science and communications capacity by hiring at least one more social scientist/behavioral expert within NWS or by increasing contracts with outside experts. This expanded capacity should be used to develop products, services, and communications tools (e.g., Internet, social media) to drive the appropriate public response to severe weather events.

Finding 5: NCEP, RFCs, and WFOs in the affected region employed a variety of tools to communicate impacts, some of which were more effective than others. EMs repeatedly found simple materials (e.g., briefing slides and 1-page summaries) to be most valuable for maintaining situational awareness.

Recommendation 5: The NWS should develop more effective and consistent products to communicate severe weather impacts, specifically:

- Concise summaries of weather and its impacts using non-technical text and graphical material provided in a short and easy-to-read format
- Confidence or uncertainty and worst-case scenario information

These products should be pretested using evidence-based social science. NWS should also provide effective training on the use of these products to ensure WFO personnel know how to best communicate with decision makers and the public during extreme weather events.

Finding 6: Despite efforts to publicize the decision to transition NWS products and services from hurricane watches and warnings to non-tropical watches and warnings, this decision led to confusion and was viewed unfavorably by many. This resulted partly from a lack of flexibility in the previous policy for handling a complex storm like Sandy.

Recommendation 6: The NWS should adopt the proposed new process developed at the 2012 NOAA Hurricane Conference by the NHC (**Figures 14 and 15**), specifically the following recommendations:

1. Modify the protocol for issuing coastal hurricane and tropical storm watches and warnings to allow NHC to continue issuing them or keeping them in effect after a tropical cyclone becomes post-tropical.

2. Allow NHC to continue issuing advisory products after a tropical cyclone becomes post-tropical in those cases in which the system continues to pose a significant threat to life and property and in which the transfer of responsibility to another office would result in an unacceptable discontinuity in service or change in communications patterns already established for the event.

3. Modify the directives as appropriate, including NWS Instruction 10-601, Tropical Cyclone Products.

Finding 7: Just prior to Sandy's landfall, some WFO web pages in the impacted area did not effectively highlight the seriousness of the impending storm. WFOs did not consistently use large fonts, attention-getting banners, and headlines to catch the public eye.

Recommendation 7: For geographically large storms with multiple hazards, NOAA/NWS should provide a single website, such as "Storm.gov" that offers critical observations and forecast and watch/warning information, including easy to follow links to other web pages with more detailed information, such as confidence and worst-case scenarios.

Finding 8: Many media reps and WFO employees who fielded questions from users stated they felt NWS websites were complicated and that they found it difficult to find vital information. The most important message needs to be more obvious.

Recommendation 8: The NWS needs to make its websites more user-friendly. NWS should expedite this effort and base changes on how the user looks for information, not on the NWS organizational structure, e.g., WFO, RFC, and NWS Region. NWS should use social science when revising its websites.

Finding 9: The media is the primary intermediary for publicizing NOAA/NWS products and services.

Recommendation 9: The NWS should provide the media with information that includes a concise overview of storm impacts, ready for public consumption as written.

Finding 10: The ERH website outages at the peak of the storm resulted in the loss of web-based services from Eastern Region WFOs and RFCs.

Recommendation 10: NWS needs to develop redundancies in web services prior to the 2013 hurricane season to ensure backup in case of equipment failure.

Finding 11: NOAA/NWS needs to make more information accessible via mobile phones and tablets. Although NWS has developed mobile versions for some of its websites, all sites need to offer mobile access.

Recommendation 11: The NWS should ensure its web pages are easily accessible by smart phone and tablet technologies and develop new mobile applications and tools that allow effective display of text and graphical information.

Finding 12: Social media outlets are becoming a more significant source of information for severe weather-related impacts. These tools allow better communication between the NWS, partners, and the public—providing real-time feedback on message comprehension. These formats require a concise delivery of information and can easily leverage the advantages of simple, easy-to-use graphics, e.g., web robots that pass along WFO graphicasts.

Recommendation 12: The NWS should improve its use of social media, including message refinement and posting mechanisms to elicit public response before, during, and after high-impact weather events. NWS should use these tools for reporting and sharing ground truth of impacts.

Finding 13: EMs need storm surge forecasts with longer lead times before landfall to help support decision making. EMs request that these predictions reflect forecast uncertainty.

Recommendation 13: NWS should provide information about potential storm surge hazards in its forecasts at least 48 hours before onset of tropical storm or gale force winds.

Finding 14: An overwhelming majority of internal NWS entities and external state and local decision makers cited the need for high-resolution graphical inundation mapping. They felt it would improve their ability to interpret NWS storm surge forecasts and their subsequent decision-making capabilities.

Recommendation 14: Consistent with previous assessments and ongoing development efforts, the NWS should implement explicit storm surge graphics and high-resolution mapping tools that clearly illustrate the impacts of surge. NWS should generate the data in GIS format. *This recommendation is the highest priority of the Sandy Service Assessment Team and should be in place for the 2014 hurricane season.*

Finding 15: The NWS has a severe shortage of staff dedicated to forecasting storm surge that significantly limits service improvements. There is only one storm surge forecaster at NHC and two model developers for tropical and extra-tropical guidance.

Recommendation 15: The NWS should increase storm surge staffing to a minimum of three model developers with one focused on extra-tropical surge effects. The NWS should have three storm surge forecasters at NHC to support 24x7 operations during events and develop expertise to support storm surge forecasting for extra-tropical cyclones.

Finding 16: NWS lacks sufficient forecast guidance on inundation associated with wave run-up and coastal rivers making it difficult to forecast impacts from coastal storms.

Recommendation 16: NWS should develop guidance for inundation in coastal rivers and for wave run-up on U.S. coasts for all wind-forced surge and inundation events.

Finding 17: NWS storm surge terminology, such as reference datums and description of impacts, is confusing. Coastal flood forecasting is difficult and time consuming largely because forecasters need to process storm surge data in a variety of different formats and reference datums.

Recommendation 17: NWS should present storm surge forecasts in a single, consistent datum and adopt a unified format and language for products describing impacts from storm surge, regardless of (tropical or extra-tropical) origin.

Finding 18: NWS personnel vary in their knowledge of coastal inundation science and forecasting. NWS does not provide standardized training for this hazard. In addition, NWS partners vary in their understanding of and familiarity with coastal inundation hazards, terminology, and pertinent NWS products.

Recommendation 18: The NWS Training Division should develop and deliver initial standardized professional training for NWS forecasters before the start of the 2014 hurricane season, as follows:

- All forecasters with tropical-related support responsibilities at coastal WFOs, WFOs providing backup support to those coastal WFOs, and NCEP centers should complete this training by the end of the 2014 hurricane season, and it should become part of routine professional development.
- NWS management at the local and Financial Management Center levels should ensure the forecasters in their area of responsibility have enough time to complete this initial training.
- The Training Division should make basic training on coastal inundation available to NWS customers, including EMs, media, and key federal partners (e.g., FEMA, USGS, and U.S. Army Corps of Engineers) prior to the start of the 2015 hurricane season.
- NWS should add training for non-tropical surge events as tools become available.

Finding 19: Interviews with EMs and broadcast media revealed strong support for a separate storm surge warning for coastal and tidally-influenced rivers. A recent NOAA-funded survey shows 90–95 percent of partners support this proposed new product. Further, the interviews suggested that while EMs understand the importance of CFWs, there was a perception the public does not react as strongly to them.

Recommendation 19: NWS should support the planned implementation of a storm surge warning for tropical, post-tropical and extra-tropical systems, including linkage to explicit storm surge graphics and high resolution mapping tools described in Recommendation 14.

Finding 20: Travel restrictions are beginning to cause serious impacts on the ability to sustain effective DSS, including involvement in the programs and events that have been critical to the success of DSS.

Recommendation 20: The Fiscal Year 14 budget should include sufficient travel resources to ensure that each WFO may participate in activities with key partners, including overnight travel, to maintain the current level of DSS.

Finding 21: NHC and the NWS Eastern Region (ERH and WFOs) had critical staff shortages. Because these are operational units, these shortages make them vulnerable to failure during significant weather events when FEMA, EMs, media, and other important partners and the public depend on NWS offices the most.

Recommendation 21a: NWS should identify and fill critical positions at operational facilities. If these positions cannot be filled, NWS should ensure awareness at higher levels in NOAA and the Administration that these vacancies may result in reduced levels of service, including constraints and potential failure on the delivery of products and services during the next significant weather event.

Recommendation 21b: NWS Headquarters should work closely with NOAA Workforce Management to reduce the amount of time it takes to fill operational positions.

Finding 22: The Service Assessment Team confirms Finding 11 in the *Hurricane Irene Service 2011 Service Assessment*, that NWS does not consistently provide critical observations and verification information to its users during and after high impact weather events.

Recommendation 22: The NWS needs to renew its efforts to provide pertinent and sometimes critical observational and verification data to its users on a consistent basis during and after events such as Sandy.

Finding 23: NOAA and the NWS lack a standard set of societal impacts survey questions to use as a routine part of service assessments and lack an established funding mechanism to conduct such surveys.

Recommendation 23a: NOAA/NWS should expedite the development and clearance of survey and focus group questions teams can use as part of service assessments. NWS needs to develop a generic list of questions and obtain OMB approval in anticipation of future service assessments.

Recommendation 23b: NOAA/NWS should secure long-term contracting mechanisms for securing the services of data collection contractors that can execute the public survey component for future service assessments.

Best Practices

Best Practice: Development and delivery of concise DSS briefings and briefing packages, including one-pagers and presentations that synthesized complex information, delivered in commonly available formats (e.g., PowerPoint or Portable Document Format (PDF)), reduced or eliminated the need for local EMs to search for the same information among multiple NWS forecast products and web pages. The briefings contained graphic and text-based information, focused on impacts, and contained confidence and worst-case scenario information that aided decision making.

Best Practice: Many of those interviewed praised AHPS for its delivery of information in new and easier to understand formats, including graphics and illustration of river flooding impacts at specific locations.

Appendix C: Irene 2011 Assessment – Relevant Findings and Recommendations

Description: The two tables below show existing corresponding findings (first table) and recommendations (second table) from the Hurricane Sandy 2012 Service Assessment and Hurricane Irene 2011 Service Assessment Teams and any notable or clarifying points. An F represents a finding and an R represents a recommendation.

Corresponding Findings

Sandy 2012 Finding Number	Description	Irene 2011 Finding Number	Additional Notes
F2	Simplifying NWS Product Suite to better communicate forecast and hazards and impacts.	**F56**	
F7	Consequence of not having a single and consistent source to relay critical storm impacts and hazards.	**F66**	
F13	Longer lead time for storm surge forecasts	**F83**	
F14	A request for high resolution storm surge inundation graphics.	**F46, F60**	Inclusion of F60 presumes such a site would provide desired partner files in GIS-compatible formats.
F15	Under-manning of the NHC Storm Surge Unit – potential single point of failure.	**F18**	
F17	Confusion over vertical datums being used by NWS forecasters and end users.	**F46**	
F22	Providing observed hazard and impact verification data during and immediately after the event.	**F11**	Requests made during Sandy were nearly identical to those in the aftermath of Irene .

Corresponding Recommendations

Sandy 2012 Recommendation Number	Description	Irene 2011 Recommendation Number	Additional Notes
R2	Simplifying NWS Product Suite to better communicate forecast and hazards and impacts	**R56**	
R7	Creating a single website for access of forecast and warning related information during high impact cyclones	**R66**	
R11	Demand for mobile access, interactive map viewers and web-based map services	**R60**	
R14	A recognized demand for high resolution storm surge inundation graphics.	**R46, R60**	
R15	Recognized under-manning of the NHC Storm Surge Unit	**R18**	
R22	Needs to do a better job providing observed hazard and impact verification data during and immediately after the event to bolsters public confidence in NWS products.	**R11**	

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