

Superstorm Sandy: A Game Changer?

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Abstract Superstorm Sandy was a late season hurricane that transformed into a monster post tropical storm, making a New Jersey landfall on October 29, 2012. Sandy was a transformative event with respect to its impacts on the natural environment, to changes in forecast and emergency management procedures, and, even more so, to the psyche of those living in coastal states. Seen through a New Jersey focused lens, this chapter will delve into physical and social science aspects of Sandy. Lessons learned and important continuing dialogs will be addressed. For example, the National Hurricane Center has revised watch and warning criteria. Zoning changes that would move homes and businesses away from the shoreline are being discussed and in some cases implemented. Improved means of communication between the forecast community and decision makers, and subsequently in getting the message out to the greater population, are being studied and implemented. Sandy has led to a greater appreciation of the power of Mother Nature and the ever-growing vulnerability of individuals and their communities to storms. However questions remain as to whether New Jersey and other coastal states are better prepared for the next major storm. Was Sandy truly a game changer?

Keywords Superstorm • Nor'easter • Tropical cyclone • Hurricane • Storm surge • Westerlies • Warm/cold core storms • Evacuation • Storm category • Storm track

1 Introduction

Those of us living along the United States East Coast are generally well aware of the threat of a major storm at any time of the year. With such events, there are the attendant threats and consequences to life and property within coastal and inland communities. In middle latitude coastal regions, it can be a strong winter-type

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storm, known along the East Coast as a “nor’easter.” Or it might be a system of tropical origin, such as a hurricane or tropical storm. It might even be a hybrid storm sharing characteristics of both, such as a post-tropical cyclone.

The effects and subsequent natural impacts of such storms are strong winds, coastal flooding (including surge and wave action), heavy rain and/or snow, freezing rain, river (fresh water) flooding, re-sculpting of coastal and riverine landscapes, and damage to trees and other vegetation. Societal consequences may include injury and loss of life, damage to buildings and utility and transportation infrastructure, major disruptions to business and commerce, and enormous and potentially long-lasting consequences to the overall well being of individuals and their communities.

How we prepare for and respond to coastal storms helps determine how effectively we recover from such events. Lessons learned hopefully enhance the level of preparedness when the next storm arrives, and the next and the next. Have forecast improvements been made, are more effective watches and warnings being issued, have modes and methods of hazard communication become more effective? Has infrastructure been hardened to enhance safety and help keep people out of harms way before and during events, while also facilitating faster recovery following a direct hit or even a glancing blow? And what about threats of increasing vulnerability due to a changing climate that holds the potential for stronger or more frequent storms and rising sea level? Though on the other hand, might threats of heavy snow and ice storms be reduced in the warmer decades ahead?

This chapter will delve into physical and social science aspects of coastal storms. A multitude of excellent studies, articles and books have and continue to be generated that are associated with each. Thus, here the focus will be on Sandy, particularly from a New Jersey perspective. Sandy was a late season hurricane that transformed into a monster hybrid storm as it approached and ultimately made a New Jersey (NJ) landfall on October 29, 2012 as a post-tropical storm having hurricane and nor’easter characteristics. The storm wrecked havoc along the Mid-Atlantic coast, in particular within New Jersey and the greater New York (NY) Metropolitan region (Sobel 2014).

This story is told through the eye of a life-long New Jersey resident who has been privileged to serve as the state climatologist for the past 25 years. This chapter will describe the whys and wherefores of Sandy and place it within a broad perspective of NJ geography and past storms. It will posit that Sandy was a transformative event with respect to its impacts on the natural environment, to changes in forecast and emergency management procedures, and, even more so, to the psyche of the state. Sandy has altered how those within the state think of coastal storms and, for that matter, extreme events of most any kind. Lessons have been learned. However questions remain as to whether this coastal state is better prepared for the next major storm. So was Sandy truly a game changer?

2 New Jersey at a Glance

With the focus of this chapter on New Jersey, it is appropriate to introduce some Jersey geography that is germane to the discussion. At 7790 square miles, New Jersey is the fifth smallest state. It lies between 39 and 41 °N and straddles the 74 ° W meridian. The highest location is 1803 feet above sea level at High Point in the far northwestern corner of the state. It has 127 miles of Atlantic coast, approximately 60 miles of Delaware Bay shoreline and shoreline along the Hudson River, NY Harbor, Raritan Bay, the lower Delaware River and coastal wetlands, all of them at or near sea level. Several moderate-size river basins, including the Delaware, Passaic and Raritan, drain the hills and valleys of northern and central NJ. They discharge into coastal bays, as do many smaller rivers flowing out of the south Jersey coastal plain. NJ is approximately 40 % forested, including deciduous hardwoods in the north and conifers within the unique Pine Barrens ecosystem that covers a large portion of south Jersey.

New Jersey has four relatively well-defined seasons, with clashes between cold and warmth that trigger occasional severe weather conditions over the course of any year (Robinson 2009). However, most of the threatening weather and climate events affecting New Jersey fail to reach the extremes experienced in other parts of the United States. This results from New Jersey's proximity to the Atlantic, which moderates winter cold and helps keep summer heat in check. The Atlantic Ocean also inhibits severe thunderstorms, and its waters are not warm enough to sustain the strength of hurricanes arriving from the south.

The dominant feature of the atmospheric circulation over New Jersey is the wind flow from west to east. These prevailing "westerlies" vacillate north and south over North America and vary in strength during the course of the year. Winter brings the strongest westerlies in their southernmost position. Storms form where cold and warm air clash, and on occasion a coastal nor'easter or other strong inland low-pressure system may bring a bout of heavy rain and/or snow. Spring and fall are transition seasons when winter type weather may occur, yet summer heat and severe thunderstorms may also make an appearance. A New Jersey summer without several weeks of heat and humidity is rare. Daylong storms are unusual; however, conditions are frequently ripe for thunderstorms, which may bring flooding rains, strong winds, and dangerous lightning. While land-falling tropical systems are rare, New Jersey is no stranger to tidal and river flooding and the strong winds associated with these summer and fall storms as they pass close by.

With a population approaching 8.8 million, New Jersey is the most densely populated state (U.S. Census Bureau 2015). As a result, it is all but "built out", meaning that most every parcel of land is spoken for. This does not mean the land is fully developed with homes, shopping malls, businesses and the like. In fact, there is considerable open space in many areas of the state. However, with an abundance of people living within its borders, there are many who reside, work, travel through or recreate within areas that are vulnerable to extreme natural events. Not being a

region particularly vulnerable to geologic activity, this means that NJ residents are mostly at the occasional mercy of extreme atmospheric and oceanic forces.

New Jersey has 21 counties and 565 incorporated municipalities (New Jersey State Library 2015). The governmental structure is such that “home rule” applies prominently to the manner in which business is conducted in the Garden State. Planning, zoning and emergency services are just some of the aspects of governance that in many respects reside under municipal and county jurisdictions. New Jersey’s economy is diverse, including service, research and development, industrial, and agricultural sectors. The state ranks sixth in tourism, the vast majority of this being at or near the coast. New Jersey has a rich coastal heritage. Day trips or weekly summer stays “Down the Shore” are common and often to the same community or cottage year after year, and generation after generation. Without question, the Jersey shore resides deeply within the psyche and hearts of most state residents.

The nation’s most critical transportation corridor runs through New Jersey and is often found lying close to sea level. This includes the nation’s most heavily traveled highway (NJ Turnpike) and bridge (George Washington). The Northeast Corridor rail line passes through, and two of the nation’s busiest ports are shared with New York and with Pennsylvania and Delaware. Newark Liberty International Airport is one of the nation’s busiest. Major cyber infrastructure also runs through the state.

While the litany of facts and figures discussed above may seem rather distant from a focused discussion on Sandy, they will later help to understand the impacts Sandy imposed on the Garden State.

3 Historic Mid-Atlantic Storms

Sandy followed in a long line of coastal storms that have battered New Jersey and other Mid-Atlantic locations in past decades and centuries. An overview of some of the more notable storms helps to place Sandy in historic context and in some respects explains the whys and wherefores of community and personal action (or inaction) before, during and after the storm. This discussion will touch on tropical storms, hurricanes and nor’easters.

3.1 Tropical Storms and Hurricanes

A tropical storm or hurricane is defined to originate over warm (generally 80 °F or warmer) water in an environment favorable for the percolation of moist, energy-laden air well up into the troposphere (roughly the lowest 45,000 feet of the atmosphere in the tropics and subtropics). In the process, a counter clockwise rotation (in the Northern Hemisphere) to the rising air may be spawned by an atmospheric pressure wave coming off Africa or perhaps from a dying frontal

system that has moved from the middle latitudes into the subtropics. These “warm core” storms are “lone wolves”, as they best develop in an environment distant from colder air and active horizontal winds at various levels of the atmosphere that tend to shear apart the rising column of air. The strongest storms have very low atmospheric pressure near the surface that is associated with rising air, and high pressure at the upper reaches of the troposphere, which helps to evacuate the rising air away from the storm region, thus promoting further upward motion within the storm “flue”. In addition to encounters with shearing environments, these storms weaken when they move over cooler waters or totally lose their moist energy source and encounter surface frictional impedances when they move over land. To be considered a tropical storm, 2-min average wind speeds must be at least 39 mph. Once these sustained winds reach 74 mph the storm is considered a hurricane. Five categories of hurricanes are based only on wind speed, with the lowest, a category 1, followed by category 2 (96–110 mph), category 3 (111–129 mph), category 4 (130–156 mph) and category 5 (157 mph and higher). Given the requirements of warmth at the surface and the relative absence of shearing winds, these storms are most common from mid summer to early fall. While defined by sustained wind speed, tropical systems are also known to deliver exceedingly heavy rainfall and winds that push ocean water toward coasts and may result in a storm surge. A surge can raise coastal waters many feet above normally expected tidal levels. In fact the majority of deaths in tropical systems are from surge and fresh water (rain induced) flooding.

3.2 *Nor’easter*

A nor’easter is an area of low atmospheric pressure that forms or deepens (pressure decreases) along the U.S. East Coast. These storms blossom from the clash of cold air over eastern North America and mild moist air over the western Atlantic. These ocean waters include the Gulf Stream, a perpetually northward flowing current of warm water from the subtropics. These “cold core” storms thrive from the mixture of air of different temperatures and moisture contents, thus attain their greatest strength within the middle latitudes, especially off the Mid-Atlantic coast. The strongest storms benefit from high altitude jet stream winds to the east of the coldest air that help evacuate rising air within these systems. Thus when the jet stream is in a particularly wavy phase with a dipping wave (trough) over eastern North America and a rising wave (ridge) over the western Atlantic, cold air invading from the north and warmer air off shore clash along the eastern limb of the trough and a major storm may develop and track up the East Coast.

Nor’easters receive their name due to the counterclockwise motion of the low-pressure system wind field, which brings winds toward the coast from the northeast. In Colonial days it was thought the storms moved from northeast to southwest with the winds. That is, until an exchange of letters between Ben Franklin in Philadelphia and his brother in Boston discussing the viewing of a

November 2, 1743 lunar eclipse indicated otherwise. Atmospherically wise Ben realized that they had both witnessed a storm that was moving northeastward, as he missed viewing the eclipse due to clouds accompanied by rain and a northeast wind, while his brother saw it and did not experience the storm until a day later.

There is no precise definition of a nor'easter, though in addition to their location and movement they include strong winds, heavy precipitation that may fall as rain or snow, and generate high tides and strong wave action offshore and along the coast. Given the thermal ingredients necessary for their development, these storms are most common from mid fall through mid spring.

3.3 *Historic Storms*

Reports of hurricanes from early Colonial times through today are documented in diaries and reports of Mid-Atlantic Colonial settlers and mariners up through U.S. National Hurricane Center (NHC) reports and those of others regarding recent storms (e.g. Ludlum 1983; Savadove and Buchholz 1993; Schwartz 2007, Blake et al. 2013). Seemingly the strongest of the pre 19th century Mid-Atlantic hurricanes occurred in 1635, 1667, 1724, 1778 and 1783. Narratives often focus on lives lost at sea, but also mention the pummeling of coastlines, river flooding, deep snowfalls and destruction within communities.

The most severe hurricane to strike the Mid-Atlantic in the 19th century occurred on September 3, 1821. It is arguably the only hurricane on record to make landfall in New Jersey, coming ashore in Cape May and tracking through the state along a path similar to that of the current Garden State Parkway. Debate continues as to whether it was a strong category 2 or “weak” category 3 storm upon landfall. Damage was severe to woodlands and communities throughout the state, as well as in Philadelphia and New York City. Accounts have led some to consider it a category 3, although others feel that the type of trees in the region and the particulars of building construction suggest what might be category 3 damage in subtropical regions more prone to hurricanes can be achieved with category 2 winds in the Mid-Atlantic. The Jersey shore was sparsely inhabited at this time, thus information on storm surge flooding and impacts to the coastal landscape are lacking.

When speaking of potential hurricane threats to New Jersey, it has long been the practice of this author to state that the best thing about the 1821 storm was that it happened. Eyebrows rise when hearing such words, however this drives home the point that such storms are a possibility in this day and age, eliminating thoughts that they cannot occur across the state. It is worth adding that it is fortunate that the storm struck prior to coastal development. Suffice it to say that since Sandy struck, there has been little need to remind everyone of the 1821 storm in order to make the point. Other notable 19th century hurricanes to impact the region were in 1804, 1846 and 1889.

While there are numerous pre-20th century reports of strong coastal storms that were likely nor'easters and not of tropical origin, the most notable to impact the Mid-Atlantic and offshore waters was from March 11–13, 1888. Multiple books have been written about this white tempest that brought hurricane force wind gusts to coastal areas, multiple feet of snow that drifted to the second floor of buildings in New York City, brutally cold air within a storm that began as rain, and the loss of life in rural and urban communities as well as numerous deaths at sea. This storm is said to have inspired the development of buried utility lines and the subway system in New York City (Caplovich 1987).

The strongest 20th century hurricane to impact New Jersey occurred on September 13–14, 1944. Moving northward approximately 50 miles off the coast, the storm winds and surge resulted in considerable damage to beaches, boardwalks and many buildings along the coast. The hurricane of September 21, 1938 only sideswiped New Jersey from approximately 100 miles off shore, while bringing horrific death and destruction to eastern Long Island and southeastern New England (Brickner 1988). Still, rainfall on the western side of the storm resulted in New Jersey's 2nd greatest statewide rainfall, an average of 7.76 in., since records commenced in 1895. This storm illustrates a typical characteristic of tropical systems as they move through the middle latitudes; the strongest winds are on the right side (typically east side) of the storm and the heaviest rains are on the left (western side). Later in this chapter when Sandy is discussed, the right/left definition will markedly come into play.

While not as destructive a tropical system as the '44 storm or several others in the past, the storm on September 16, 1903 is worthy of mention as it is possibly the only hurricane since the 1821 storm to make landfall in New Jersey. It also took a path somewhat akin to the unusual one of Sandy, as it came toward NJ from the southeast and made landfall near Atlantic City (Hall and Sobel 2013). There is some debate as to whether winds were of sustained hurricane force at landfall, however it was certainly a strong storm that exited the state into Pennsylvania near Trenton. There was considerable damage throughout the region but no reports of a major storm surge or fresh water river flooding (Ludlum 1983).

The most memorable New Jersey nor'easter of the 20th century hit the Mid-Atlantic from March 5–7, 1962. The strongest impacts were on the coast, with major destruction occurring when the storm stalled offshore for several days. This led to a prolonged period of onshore winds that piled water up on the beaches, in the back bays and, onto coastal lands during six tidal cycles. Breaches of Long Beach Island subsequently needed human assistance to mend in order to keep the barrier island intact. Earlier 20th century nor'easters impacted coastal and inland communities, including ones in 1935 and 1953, however they did not pummel the coast to the extent of the 1962 event (Savadove and Buchholz 1993).

Many people still recall the 1962 nor'easter and even hurricanes (or the remnants thereof) that impacted the Mid-Atlantic in 1954 (Hazel), 1955 (Connie and Diane) and Donna in 1960 (tropical systems were first given female names in 1953). This includes the still reigning record Delaware River flooding from the back-to-back 1955 storms. Some may even recall the wind gusts of 108 mph at Newark Airport

and the considerable damage across NJ and along the Delaware Bay coast during a November 27, 1950 storm. Although not a nor'easter, this storm also deposited massive snows in the eastern Ohio Valley and West Virginia. Rather it was a powerful rogue storm that traversed the eastern U.S. from North Carolina to Washington, DC and then northwest into Ohio and eventually eastern Canada, demonstrating that not every low-pressure system severely impacting NJ must travel up the coast (Bristor 1951).

3.4 Recent Storms

Certainly, far more citizens are familiar with storms of the past several decades. While most of these events were not as powerful as those mentioned previously, they provide important context when individuals consider the potential impacts of a forthcoming storm. Thus, along with earlier storms, they play an important role for purposes of storm preparation, response and recovery.

Notable hurricanes and tropical storms of recent decades include David (September 1979; the first year where male names alternated with female names), Gloria (September 1985), and Floyd (September 1999). Each impacted daily life in New Jersey due to flooding rains, tree-toppling winds and erosive coastal poundings. Then there was Irene (August 28, 2011), a noteworthy storm, especially as it occurred only a year before Sandy. Thus it played a role with regard to the public response to Sandy warnings. Irene was a hurricane until shortly before landfall in Egg Harbor, NJ. While coastal winds and surge were less than forecast, there was damage to boardwalks and considerable beach erosion. The real story of the storm was inland, where drenching rains falling on soils already soaked from heavy rains earlier in the month, resulted in major flooding throughout north and central Jersey river basins, including the Raritan and Passaic. The Raritan experienced flooding almost to the century-shattering levels of Floyd. Irene was the third largest state-wide rain event on record, averaging 7.20 in.

Among notable nor'easters in recent decades, storms that pounded NJ with snow, wind and coastal flooding are ones that occurred in February 1978, February 1983, March 1993 (an inland storm track kept this from being a true nor'easter), January 1996, December 2000, February 2003, January 2005, February 2006, December 2010 and October 2011. Other nor'easters are best remembered for their strong winds and coastal flooding. The most notable of this lot was the December 1992 storm that took down trees around the state and resulted in some of the worst coastal flooding since the 1962 storm. Spring storms in April 2007 and March 2010 brought flooding rains and, especially with the 2010 storm, damaging winds.

Another coastal storm of interest garnered considerable attention during the event and even more so afterwards. This was the "Perfect Storm" that struck the northeastern U.S. and the Canadian Maritimes from October 28 to November 2, 1991. It began as a nor'easter off Atlantic Canada and soon encountered a high-pressure ridge over eastern Canada that blocked the common northeastward

path of such a storm, actually forcing it south. The storm next grew in strength as it absorbed a dying Hurricane Grace. Eventually it looped back to the northeast and briefly developed into an unnamed hurricane as it headed out into the North Atlantic. This hybrid storm created memorable damage along the New England and Mid-Atlantic coasts. Coastal New Jersey beach erosion, boardwalk damage and back bay flooding was considerable, and prompted some evacuations (NCDC 2008). While no two storms are ever completely alike, Sandy exhibited some of the same hybrid characteristics and took an unusual path, as did the 1991 storm.

An understanding and appreciation of past storms cannot fully serve to prepare New Jersey for what Mother Nature may have in store today or tomorrow, especially with more people living in vulnerable areas. This is even more apparent when considering that storm characteristics will differ as climate changes and sea level rises. Read on to see how Sandy evolved into one of the most extraordinary, deadly and destructive storms to impact the Mid-Atlantic in several generations, a storm that seemed to be influenced by climate changes already underway.

4 Sandy's Fury

4.1 *Genesis and Early Days*

By late October, climatology suggests that threats of hurricanes or tropical storms are rather slim in areas where they may blossom, let alone in more distant locations where they may travel. Climatology also tells us that if a storm forms late in the season this is likely to occur in the Caribbean Sea. Thus it was no great surprise on October 22, 2012 when Sandy formed south of Jamaica. Within less than two days the storm reached hurricane status. It was about this time that the European Center for Medium Range Forecasting (ECMWF) numerical forecast model first suggested that the storm would move northward off the East Coast and eventually turn to the west and make landfall somewhere in the Mid-Atlantic region. Quite the unusual forecast, as such a track would be odd any time of the tropical season, let alone at this late juncture when westerly winds (blowing from west to east) begin to increase in intensity across the Northern Hemisphere middle latitudes. Then again, the 1991 Perfect Storm had been temporarily blocked from moving into the North Atlantic by a high pressure ridge—and ECMWF was predicting this to be the general situation with Sandy a week or so ahead. So, given the well-respected quality of the model and the behavior of the 1991 storm, a westward turn could not be dismissed (Mattingly et al. 2015). Over the next few days Sandy moved northward, punishing eastern Cuba on the 25th as a category 3 storm and still strong enough once north of Cuba to maintain category 1 or 2 status for the majority of its northward trek (Blake et al. 2013).

Meanwhile, cold air was plunging out of Canada into the central US as the polar jet stream dipped well south of its most common seasonal position. This was

evident in the anomalous snow cover in the Canadian prairies down to the US border. With this trough moving east, it was apparent that a significant early season nor'easter could develop along the East Coast several days ahead.

This raised the very real possibility that what remained of Sandy would join forces with a developing nor'easter and deliver quite a blow to the East Coast as the end of October approached. By October 26th the U.S. National Weather Service (NWS) models had come on board with a forecast track much like that of the ECMWF model and thus the National Hurricane Center issued tropical storm watches and warnings up the coast to Cape Hatteras. The models suggested that Sandy would lose tropical characteristics to the north of Hatteras, well before turning toward the coast. Therefore, the NHC never issued watches or warnings north of there. Rather, issue of storm watches and warnings of many kinds (wind, surf, rain, flooding) were left to local NWS forecast offices and the NWS hydrological forecast center situated in the Mid-Atlantic.

4.2 New Jersey Prepares

By Friday the 26th, with forecasts of a powerful post-tropical cyclone on its way, there were already customers in line at home improvement stores waiting for shipments of electric generators, as all in stock had quickly sold out. The storm was still three days away, yet savvy citizens were already preparing for what promised to be a storm of consequence. How much of this preparation was born of storm experiences in recent years remains unknown, but they surely played a role. It had been only 14 months since Irene caused major flooding and rather widespread power outages, and October 29, 2011 brought record early nor'easter snows that brought down trees, many still laden with leaves, onto homes and power lines. This resulted in weeklong power outages in portions of northern NJ. Add to this a powerful south Jersey derecho in late June 2012 that took down trees and disrupted power, a number of major floods beginning with Floyd in 1999 and some serious snow storms in recent years, and it was clear that residents had been through this "drill" often enough recently and were going to be ready for Sandy.

Or was everyone going to be prepared? After all, why were there lines for generators? Shouldn't they have been purchased long ago in anticipation of forthcoming storms? More importantly, had this region seen a storm of this magnitude in anyone's memory? One thing is certain, well before arriving, the storm caught the attention of emergency management officials, political leaders, the media, and the general population. Within the Office of the NJ State Climatologist (ONJSC), we began to confer with emergency managers and the media. We also made the decision to rapidly develop and bring online a storm web "dashboard" that would include observations from our statewide 52-station NJ Weather and Climate Network (NJWxNet). This was designed to give decision makers such as forecasters in local NWS offices, emergency managers, political figures, and utility officials, along with the media and public, a quick look at evolving conditions.

Important weather observations would be updated every 5 min for all stations. Storm extremes over the past hour, with minute-by-minute extremes for the storm, would be displayed for top-ranked stations. Such observations include sustained wind speed and direction, instantaneous wind gusts and direction, rainfall, temperature, humidity and barometric pressure. Data from these stations are relayed via cellular service to a server at the Rutgers University computer center. Most of the weather stations, including their cell modems, are powered by solar energy. What made the dashboard development all the more challenging was that this would be the first time anything more than hourly updates would be provided from the NJWxNet. We had only begun polling stations more frequently weeks before, and were in the midst of developing a new database and website before “going public” with 5 min observations. However we realized the importance of having this frequent information. We hoped that the rush to release this new dashboard would succeed.

At the time, one questioned whether shore residents were paying attention to forecasts and would get out of harms way. Or were memories of evacuating (or not) for Irene going to influence their decision-making? Irene failed to deliver the punch along the coast that had been feared, with some who left the coast driving into trouble navigating through inland areas impacted by river flooding. In fact one pundit for the Star Ledger newspaper, NJ’s most widely circulated daily paper, penned a column following Irene that included the following:

After Chris Christie’s performance in the run-up to Hurricane Irene, we should change our nickname. We’re no longer the Garden State. We’re the Nanny State. For a few days there, it was impossible to turn on the TV without hearing Christie and New York Nanny Mike Bloomberg tell citizens what they should do for their own good.

In the aftermath of how Irene turned out, here’s what I suggest you should do for your own good: The opposite of what Christie tells you. In his handling of this hurricane, the governor seems to have achieved a historic first: He became the first public official to evacuate people in the wrong direction. (Mulshine 2011)

In the opinion of this author, Mulshine should not have published this piece, as his words potentially jeopardized ongoing public safety. One can only trust that his column influenced no one.

4.3 New Jersey in the Cross Hairs

Along came the weekend, with forecasters expressing increasing confidence in a landfall somewhere along the Jersey shore. They also were convinced that a major surge would accompany the storm, along with flooding rains throughout the region. A variety of watches and warnings were being issued by local NWS forecast offices, but the decision of the Hurricane Center continued to be not to issue any warnings of a tropical nature in the Mid-Atlantic. Preparations continued, and upon the urging of local and state officials, individuals began to evacuate coastal communities. But would more people be on the move if NHC warnings were in place?

The absence of such led New York City Mayor Michael Bloomberg to state on Saturday evening that the surge, while significant would not be typical of a tropical system

Although we're expecting a large surge of water, it is not expected to be a tropical storm or hurricane-type surge. With this storm, we'll likely see a slow pileup of water rather than a sudden surge, which is what you would expect with a hurricane, and which we saw with Irene 14 months ago. (Bloomberg 2012)

This is not to deride or diminish the persistent efforts of public officials such as Mayor Bloomberg and NJ Governor Chris Christie to get the word out that this was indeed going to be a dangerous storm. They performed a tremendous service, with their pronouncements prior to Irene, and even more so before Sandy, striking chords that no doubt saved lives. However clearly, as became evident when the storm hit, their efforts and those of many others were not enough to move everyone out of harms way.

Come Sunday, evacuations of a mandatory nature led to the departure of many, but too many coastal residents remained in their homes. The weather was cloudy, breezy and a bit rainy, with the ocean beginning to get angry as Sandy was growing in size and continued to maintain hurricane strength as it was now moving north off the southeast U.S. coast, not yet turning toward the mainland.

Come mid day the ONJSC Sandy dashboard was launched. The NJ Office of Emergency Management, the local NWS offices and some in the media were directly notified. Word of the dashboard spread quickly, thanks in part to social media. By the time many began losing power later on Monday over 30,000 unique visitors accumulated 130,000 hits on the site. The question now became whether the NJWxNet would remain functioning throughout the storm. Would stations hold up, communication be maintained, the Rutgers computer center stay powered and the dashboard continue to function?

Gary Szatkowski, the Meteorologist in Charge at the NWS Mt. Holly/Philadelphia Forecast Office maintained an active presence on the web and via social media leading up to Sandy. His office is responsible for issuing forecasts, watches and warnings for much of NJ, eastern Pennsylvania, northeast Maryland and all of Delaware, including coastal NJ. As part of the noon NWS storm briefing released by his office on Sunday the 28th he included this "Personal plea":

- If you are being asked to evacuate a coastal location by state and local officials, please do so.
- If you are reluctant to evacuate, and you know someone who rode out the '62 storm on the barrier islands, ask them if they would do it again.
- If you are still reluctant, think about your loved ones, think about the emergency responders who will be unable to reach you when you make the panicked phone call to be rescued, think about the rescue/recovery teams who will rescue you if you are injured or recover your remains if you do not survive.
- Sandy is an extremely dangerous storm. There will be major property damage, injuries are probably unavoidable, but the goal is **zero fatalities**.

- If you think the storm is over-hyped and exaggerated, please err on the side of caution. You can call me up on Friday (contact information is at the end of this briefing) and yell at me all you want.
- I will listen to your concerns and comments, but I will tell you in advance, I will be very happy that you are alive & well, no matter how much you yell at me.
- Thanks for listening.

Szatkowski (2012: Slide 12 from 10/28 briefing packet)

This is one of the most impassioned statements imaginable from an individual in such a governmental position of responsibility. As a result of Szatkowski's bold words, his overall communication with the public, official decision makers and the media, and his leadership of the forecast office throughout Sandy, the Star Ledger later recognized him as one of the dozen heroes of Sandy. He was the only government individual to be so recognized.

4.4 Storm Day: Monday Morning

Out at sea, Sandy remained a hurricane on Monday morning. This was unexpected, as forecasters believed that by Sunday the storm would morph into a post-tropical cyclone. Why the hurricane remained so strong for so long remains open to study (Galarneau et al. 2013). Sandy was beginning to be influenced by the developing nor'easter and that may have injected some energy into the warm core tropical system, despite this development ultimately contributing to Sandy's demise. Perhaps the biggest influence were the above average sea surface temperatures (SST) along the East Coast. New Jersey was in the midst of its 22nd consecutive month with above average temperatures (1981–2010 mean), an unprecedented run on the plus side since statewide observations began in 1895. This anomalous warmth was also experienced elsewhere in the Mid-Atlantic and off shore waters. In fact, a post-storm study running a forecast model with, first, the observed above average SSTs and second, with long-term average SSTs, found that in both runs the storm took basically the same track; but, when the average SSTs were used, the model produced a weaker storm upon landfall (Magnusson 2014).

Along the NJ coast, Monday morning arrived with rain falling rather heavily in south Jersey and winds beginning to gust in the 30s to low 50s mph range along the coast. Some remaining residents noticed that the morning high tide was exceedingly high. In fact, coastal waters were about the highest that Irene had delivered, which at the Sandy Hook tide gauge situated at the very northern end of the NJ coast, was the fourth highest on record and less than a half foot below the record high of 10.1 feet during Hurricane Donna. Some ocean water washed over Route 35 between Seaside Heights and Point Pleasant. This morning tide proved to be a blessing, serving as a wakeup call to some residents who were initially convinced that they could and would ride out the storm at home. Now they recognized that the "main event," the landfall of Sandy, was still 12 hours away, right in line with the next high tide. They evacuated, no doubt saving the lives of some of these

individuals and potentially lives of emergency responders who might have been called to rescue them. Thus, in this regard the earlier pronouncement of Mayor Bloomberg of a gradual build up of storm waters was correct. However, that evening a sudden surge arrived, something he suggested would not occur.

4.5 Storm Day: Afternoon

By early Monday afternoon, conditions began to deteriorate further, particularly along the beachfront. Winds were now gusting from 40 to the low 60s mph and rain was falling throughout the state, continuing much heavier in the south. It was now apparent that landfall would be in the vicinity of Atlantic City. With this, it became evident that northern NJ would be spared exceedingly heavy rainfall and river flooding, as this area would be on the *right* side of the storm track. While this was fortunate, it seemingly failed to register with citizens and the media. Even well after the storm, some to the north spoke of heavy rain and river flooding during Sandy, perhaps confusing conditions with Irene a year earlier or with the surge that came up streams and rivers. South Jersey would bear the brunt of the heavy rain, but with sandy soils and smaller streams and rivers in this region, the flood threat would not be major. Sandy was beginning to morph into a hybrid storm but still retained its hurricane status. Part of the change was an expansion of the storm's dimensions. This spread out the core energy but meant that winds were now howling over a huge expanse of the Atlantic, pushing more and more water toward a wide coastal area. The NWS was forecasting a record surge arriving close to high tide, making it all the more certain that this storm was going to be unlike any storm to strike the region since meteorological records have been kept, let alone in any living person's memory. Yet still, the message was not getting to or registering with some citizens and decision makers, an unfortunate circumstance that would soon lead to needless terror, death and damage.

By late afternoon, easterly winds were gusting to hurricane force along the Jersey beaches. Inland, winds were strengthening. Rain was falling in central and northern Jersey. However, through late afternoon conditions were not unlike a modest nor'easter blowing through. Mass transit was shut down across the region and most every business and retail establishment closed. When the sun set at 6 pm all knew that the main event was imminent. Any preparations for the storm should have been completed long ago. Everyone should now be safe in locations as far from danger as possible. It was destined to be a long, dark night.

4.6 Storm Day: Evening Landfall

During the early evening, inland winds picked up quickly as Sandy was downgraded (finally) from a hurricane to a post-tropical cyclone. The storm was never a

nor'easter, though one can contend that in the absence of Sandy such a storm would have developed and been a strong one. In fact, with the same atmospheric pattern persisting into November, a nor'easter arrived on November 7–8 that dumped up to 13" of snow in Freehold, NJ, 15 miles inland from the northern coast where several inches of snow also fell, covering damaged beaches and storm debris.

Upon a 7:30 pm landfall in Brigantine, the community immediately north of Atlantic City, the still-expanding storm had a warm core with cold-core, middle latitude characteristics wrapped around it. Along the coast, high tide was approaching and the gauge at Sandy Hook was recording a water level 3.2 feet above the previous record when it was destroyed by the pounding of the waves atop the still rising water. The surge was inundating beach communities and pouring into Raritan Bay and up local streams and rivers. Ten miles inland in New Brunswick, the Raritan River was out of its banks and flowing onto adjacent Route 18, not from freshwater moving downstream as had been the case in Irene, but rather from water surging up the river. Damaging, life threatening surge waters were flowing into a Woodbridge neighborhood west of the NJ Turnpike where it was hard to imagine a surge would ever reach. Harbor waters were inundating Hoboken, while in the Hackensack Meadowlands the largest sewage plant in NJ, a major NJ Transit rail yard filled with cars and engines, and local communities were being swamped.

Inland winds picked up in intensity after nightfall with trees beginning to topple and power beginning to fail across much of the state. Along the coast, surge and wave action was devouring beaches and dunes, opening several breaches in the barrier peninsula in the Mantoloking vicinity, gobbling up homes, tearing up boardwalks, and pouring sand into communities. Initially, waters in Barnegat Bay, which parallels the central coast behind the barrier peninsula and Long Beach Island, did not rise too quickly, as the bay was somewhat sheltered from the easterly winds that were pounding coastal beaches. However, at about 8:30 pm, with the core of the storm onshore and beginning to move across south Jersey, the wind direction abruptly shifted to the south and with it waters were pushed northward up the Bay. Individuals, who just minutes earlier wondered if conditions would get as bad as predicted, were frantically calling emergency officials asking to be evacuated as water poured over bulkheads, into yards and eventually through homes.

Those who chose to ride out the storm in coastal communities were wondering if they would survive the night. Tragically some did not, drowning in their homes. This was particularly true on Staten Island, NY, where 18 drowned. In NJ, four drowned, two were in their homes. A student of the author chose to ride out the storm on Long Beach Island and fortunately survived to show photos of several feet of water invading his one-story home during the height of the storm. He came close to climbing into the attic or onto the roof, not knowing how high the water might rise or if the house would remain intact.

Meanwhile, many inland residents were in the dark, hearing trees crashing down amidst the roar of the wind and feeling their homes shake as some trees hit the ground or house. Many retreated to internal rooms or basements, wise decisions, as trees came through roofs into rooms where some would normally have been sitting or sleeping. Many later reported experiencing more fear than ever before while in

their homes. Tragically during the storm, falling trees killed five individuals; two of whom perished inside homes. Mid evening hours found inland and coastal areas buffeted by wind gusts in the 50 to the mid 70s mph range.

My home lost power at 7:30 pm (not to return for four days), leaving me to conduct a live 11 pm interview on a special edition of NJTV news via Skype on a laptop computer. Communication was via remote cellular means, and I was illuminated by two small flashlights, making me look a bit like a jack-o'-lantern; perhaps adding some humor to what otherwise was a tremendously serious situation. Throughout the evening I had been able to monitor winds and other weather variables via the dashboard and coastal water levels via USGS and NOAA websites. Knowing my home state quite well, I was able to speculate (later proven rather accurate) that NJ and surrounding areas had indeed taken a tremendous pounding and we were not quite yet out of the woods. I expressed grave concern regarding what would be discovered come daybreak, particularly along the coast, but also inland (NJTV 2012). The storm's backlash continued in some areas, including along the Delaware Bay coast where the change in wind direction was pushing water up onto the low-lying shore.

5 Sandy's Aftermath

Shortly after midnight the worst of the storm had passed in most areas. Water was slowly receding, waves were not pounding as hard, and the wind and rain were beginning to abate. A post-storm survey determined that the water level had risen to 14.4 feet at Sandy Hook, or 4.3 feet above the previous record high water level. This equates to a storm surge (height of the water above what it normally would be at a given time of the tidal cycle) of close to 9.5 feet. The maximum surge arrived close to high tide and during a phase of the lunar cycle when tides are typically high. This provided a near worst-case scenario for the northern coast and adjacent tidal waters. As Sandy made landfall, the surface barometric pressure fell to a state record minimum of 27.92 in. of mercury. This shattered the previous single location record minimum of 28.36 in. during a 1932 nor'easter. In fact, the entire southern two thirds of the state saw the pressure fall below the previous record minimum. This was the lowest pressure on record observed onshore along the East Coast north of Cape Hatteras. The peak wind gust in NJ was 91 mph at the NJWxNet station in Seaside Heights. Elsewhere in the state, winds gusted over 70 mph along the coast north of Atlantic City, and 60–75 mph over inland central and northern counties, coastal Delaware Bay and southern Cape May County. Wind gusts of 40–60 mph were recorded over the inland southern third of the State, to the *left* (south) of the storm that tracked into southeastern Pennsylvania by daybreak on Tuesday the 30th. Rainfall was copious to the left of the storm track, amounting to as much as 12.71 in. at Stone Harbor in Cape May County, which equates to about a 200-year return period. Rainfall was generally 5–8 in. south of the storm track. North of the

track, totals fell to 2 in. along the Trenton-New Brunswick corridor and from 1 to 2 in. in the northern third of the state.

On Tuesday morning the cloud shield from the storm extended from South Carolina to southern Greenland and from the western Atlantic west to Wisconsin. Several feet of snow had fallen in the mountains of West Virginia. High wind and wave warnings were issued for the shores of Lake Michigan. Severe thunderstorms occurred in Massachusetts, and Montreal experienced a daily record high temperature of 70 °F. Sandy has gone down in the books as one of the largest and most powerful storms in eastern North America history. Across the Mid-Atlantic, shell-shocked residents began emerging from homes and shelters. Perhaps a million trees were down, with utility companies estimating that over 100,000 trees and limbs had to be removed in the process of restoring power to the 80 % of the customers in New Jersey who lost it anywhere from hours to two weeks. Water remained in the streets of Hoboken and other communities. Coastal roads were ripped up, choked with sand or even had homes washed onto them. Fires that had raged during the night in Normandy Beach, NJ and Breezy Point, Queens, NY smoldered.

For those of us in the State Climatologist's Office, it was gratifying to see that the NJWxNet functioned exceedingly well throughout the storm. Of the 52 stations in operation as the storm struck, the fewest reporting during any 5-min interval was 39, and that was at noon on the 30th, well after the storm had left the state. By that evening 45 were active, with the missing seven stations located where AC power was relied upon for modem communication and no generators were available. Clearly, efforts in recent years to install solar power at most stations paid huge dividends. Due to solid station construction and a certain amount of good fortune only a single instrument at one station was damaged during the storm. Every one of the five stations on the immediate coast continued operating and communicating throughout the storm. The Jersey City station in Liberty State Park was flooded with 17 in. of New York Harbor water, which fortunately never reached instrument level. A sonic snow depth sensor at the station recorded this water level. Credit for such a performance goes to NJWxNet field technicians, the cellular service carrier, and the staff at Rutgers main computer center for keeping a generator fueled and functioning until line power was restored.

The intrepid volunteer observers of the national Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), locally managed by the ONJSC, submitted reports as best they could during and following Sandy. Some of these citizen scientists, lacking power or Internet service, called friends and family and asked them to submit their observations online. Others submitted reports once they could get computers back on line, including the Stone Harbor observer who recorded the previously mentioned record rainfall for Cape May County. Two hundred and thirty-three CoCoRaHS citizen scientists contributed rainfall reports, some of them appending anecdotal remarks of storm damage and personal storm experiences.

Damage estimates for Sandy approached at least \$50 billion in the eastern U.S. (Blake et al. 2013). The estimated death toll in the US was 72 from direct and 87 from indirect storm impacts. In New Jersey an estimated 39 deaths were

attributed to direct and indirect impacts, making this the deadliest natural disaster in NJ history. NJ fatalities included those from falling trees, drowning, loss of power to vital medical equipment, fire, asphyxiation from improper generator use, hypothermia, falls, automobile accidents, and post-storm cleanup (Star Ledger staff 2012).

Stories were told of heroic acts during the storm and of generous outpourings of support in its aftermath. Unfortunately, on the darker side, there were stories of scattered looting, unconscionably low damage assessments by insurance companies, slow or confusing responses regarding government aid, unscrupulous building contractors, controversies over debris removal and alleged price gouging at some, but certainly not most, hotels and stores. Now, several years after the storm, thousands have still been unable to return to their homes or resume a normal every day life. The mental health among many of those directly impacted also continues to suffer.

Meanwhile for the majority of residents who did not suffer significant damage or health issues, once power returned, roads were cleared, trees were removed and homes repaired, life returned to a general sense of normalcy. Almost to a person, most considered himself or herself fortunate. They were only left to talk about how many days they were without power or how long they had to wait on line for gas if it could be found at a station with power. Gas rationing was instituted late in the storm week (by odd/even license plate numbers), but by that time enough stations had power back, and gas deliveries had resumed so that in most areas shortages no longer existed. Infantry of power company workers from many parts of the nation, along with local, state and federal agencies responded to assist in recovery efforts. Private concerns, be they businesses or volunteer organizations, joined in.

One cannot understate the emotional impact Sandy had on state residents. For most, this storm is now the bellwether for what future storms may bring and against which they will be measured. Sandy unified the state and made residents more aware than ever before of their emotional attachment to the Shore. Even if one was not directly affected, it was painful knowing how many fellow citizens were severely impacted and how the shore and beaches they had visited so many times before had taken such a beating. Questions and concerns remain as to whether the Shore will ever again be quite the same, as cottages where families had spent summer weeks may not be rebuilt, possibly replaced by expensive homes built to stricter zoning standards. This chapter will not delve further into the turbulent post-Sandy weeks, months and years. Suffice it to say that when it comes to coastal NJ heritage or culture, Sandy will, indeed, likely prove to be a game changer.

6 Lessons Learned

Sandy was a transformative event in the history of the Garden State, throughout the Mid-Atlantic, and for federal entities such as the National Weather Service. With such a tumultuous event in a region so densely populated and so vulnerable to the

power of coastal waters and winds there are clear lessons learned when reflecting back on the days surrounding Sandy. Lessons have already resulted in better practices for the future, and those, we hope, will make the population more aware and better prepared for future storms. While the lessons discussed below emerged from Sandy, many are applicable to any coastal region or areas beyond.

6.1 Seemingly Slight Differences Can Have Major Consequences

A slight difference with a major consequence is, for example, someone being in the right place at the right time, as when a tree falls on a home or automobile and misses the occupant. Another example relates to the physical characteristics of Sandy. For instance, a 70 mph wind has approximately 2.7 times the power of a 50 mph wind. Whether most citizens realize it or not, this cubic relationship between wind speed and the power produced by the wind made all the difference in where and how many trees fell during Sandy. Inland New Jersey is no stranger to 50 mph gusts in a nor'easter, when sideswiped by a tropical system, or during a summer thunderstorm. However gusts exceeding 60 mph are much less common, particularly throughout the broad dimensions of the landscape over which they blew for several hours during Sandy. Thus there was massive tree fall that took lives, brought down power lines and overall did major damage. Interestingly, clusters of enhanced tree fall over multiple acre tracts occurred in scattered locations in central and north Jersey. Some were associated with topographic features that likely enhanced the wind speed. Other blow-down zones were seemingly random and are the source of ongoing study. Still, what people need to realize is that the bulk of the inland wind damage was not caused by hurricane force winds, but rather by winds that were perhaps only 20 mph more than experienced in more common storms. This is a sobering thought when thinking of the consequences of a future storm where winds might frequently exceed hurricane force.

Then there was the timing of the storm. Had Sandy arrived several hours earlier or later, tides would have been several feet lower where the worst of the storm surge struck. Due to the lunar impact on tides, even a change of a week in storm timing would have meant a lower tide. Actually the expected high tide on the morning of the 29th was almost a foot higher than the evening tide. Thus it could be that a colleague whose shore townhouse came within several inches of having its first floor inundated by the high water likely would not have been as fortunate had the storm arrived 12 hours earlier.

On a larger scale, most everyone is keenly aware that the storm track made an enormous difference. Witness the differences in coastal storm damage between southern and northern coastal Jersey, the inland wind damage and resultant magnitude of power outages between the two areas and the 6-in. plus difference in rainfall between north and south Jersey.

6.2 Storm Conditions Do not Change at a Steady Pace

This lesson ties directly into the first point but deserves its own listing. Erratic behavior of a storm can prove to be so important, as individuals may think they are safe 1 minute but find themselves in grave danger soon after. In Sandy this applied to those experiencing a storm surge that quickly inundated their home. It applies also to those within inland communities who saw wind speeds rapidly increase early in the evening and lulls within the strong gusts later in the evening. This may have given some the false impression that they could safely venture outside, only to be struck, and in some cases killed, by falling trees and branches.

6.3 Storms Stronger Than Sandy Are Within the Realm of Possibility

This may be difficult for some to comprehend so soon after the worst storm they may have ever experienced. However, those in the emergency management and atmospheric science communities are keenly aware of this. A look back at past storms provides some perspective, be it the 1821 hurricane throughout the region, the 1944 hurricane along the coast, Floyd and Irene inland, the 1903 storm and its path, and the 1938 storm. Those on Long Island and in southeastern New England do not have to conceive of a much worse case scenario than that of the '38 storm, but for people in New Jersey a closer look is worthwhile. While heavy rains fell on the state from the '38 storm, imagine if it had taken a track closer to the Jersey coast, perhaps one like the 1944 storm, or storms Donna, Gloria or Irene. This could have brought about the rains and river flooding of Floyd and, despite the strongest winds remaining offshore, sustained winds and gusts exceeding hurricane force on the west side and a storm surge close to Sandy's along the entire coast. One could also imagine this storm making landfall somewhere on the coast, like the 1903 storm or Sandy, just a stronger version of either. The 1821 storm should be brought into scenario building too, if only the kind of surge that hit the Jersey coast (it was about 6 feet at the Battery in lower Manhattan) and how heavy the rains were inland were better known.

6.4 Do not Fully Rely on Storms of the Past to Provide a Look to the Future

New Jersey's climate is warming and sea level is rising. Due to anthropogenic influences, particularly an ongoing increase in greenhouse gases, warming is expected to continue throughout the coming decades. With warming, there will be more moisture in the atmosphere, as the atmosphere holds almost four percent more

moisture for every 1 °F increase in temperature. The combination of increased warmth and moisture will create a more energized atmosphere, one primed for stronger storms, assisted, as was seen in Sandy, by warmer sea surface temperatures. This does not mean storms will necessarily happen more often, as it remains uncertain whether the events that trigger storms will be more or less prevalent. However, the magnitudes of storm precipitation and wind should increase, along with resultant fresh water and storm surge flooding and wind damage.

Another factor had a minor affect during Sandy: sea level continues to rise. Approximately one half of the 15-in. rise in sea level along the Jersey coast since the late 19th century is due to the expansion of warmer ocean waters and melting land-based ice. The other half is the result of ground water withdrawal and the compaction and isostatic suppression of southern NJ lands—a lingering effect of the ice sheet that sat over northern NJ and locations poleward 20,000 years ago (Miller et al. 2013). Sea level is projected to rise about 18 in. by the middle of this century and perhaps more than three feet by centuries end. Thus, in the years ahead, a modest tropical storm system or nor'easter will have the potential to raise storm tides to levels only seen in the most severe storms of the past.

6.5 *Heed Weather Forecasts*

Without question, the Sandy forecasts generated by the ECMWF and the NWS were landmark achievements (Knabb 2013; Uccellini 2013). Forecast models picked up Sandy's genesis in the Caribbean and quickly projected the general track and nature of the storm as it evolved, along with its general progress and landfall as a post-tropical storm. To expert emergency responders, this gave up to a week for preparation. The forecasts were not without flaws. It took time for forecasters to hone in on the landfall location, the storm was stronger than expected as it came onshore, and earlier forecasts of flooding rain in northern and central NJ failed to arise. The devil is always in the details when it comes to even the best forecasts.

Still, not all individuals got out of harms way, some tragically died as a result and others experienced the most frightening evening of their lives. Somehow they did not get the message (more on that shortly) or failed to believe or understand the forecasts they heard.

Despite the general high accuracy of the Sandy forecasts, the forecast community was still subject to a little criticism. This may be due to forecast improvements being accompanied by increased expectations among some individuals. Perfect forecasts are not on the horizon, not in what will always be a chaotic earth-ocean-atmosphere system. However, in many respects what used to be forecast failures are now more likely to be near misses. This goes beyond semantics and is something the forecast community must continue to address scientifically, while working with others to better communicate the whys and wherefores of a forecast.

6.6 Regional Infrastructure Is Too Vulnerable in Severe Storm Conditions

Sandy made it quite clear that a major effort remains to harden or relocate buildings, transportation systems, and utilities that include communication, sewer, natural gas and especially electric. Buildings that are subject to freshwater or coastal flooding need to be eliminated in areas subject to recurrent inundation, or at least raised to reduce potential damage. Otherwise they can be protected by flood control infrastructures such as levees, seawalls, or efforts involving beach, dune and wetland renourishment. The same situation applies to transportation systems. They need to be elevated (e.g. train tracks and roadways) or protected from inundation (e.g. levees around airports or means of preventing water from pouring into rail and road tunnels). Well-conceived plans to relocate movable components of transportation systems must be developed and implemented (or improved) when forecasts warn of severe storm conditions. This includes ships, trains, planes and automobiles.

Communication infrastructure needs to be able to handle an abundance of calls, texts and Internet traffic during critical conditions. Cell towers must remain operable, communication equipment powered, and bandwidth sufficient to handle a heavy load. Water treatment and sewage plants are always near water bodies, making them exceedingly vulnerable to freshwater or tidal flooding. Ideally, they would be relocated to higher ground, but at the least they require sufficient levees surrounding them to remain protected when major storms strike. It is critical that a reliable source of power be maintained at these locations during storms.

A common thread throughout the general lesson of hardening our infrastructure is availability of reliable electrical power. With the vast majority of New Jersey losing power for a time during and after Sandy, never before have so many people been made keenly aware of how electrical power is the glue that keeps the state functioning. Without power, gas stations could not pump gas and supermarkets were closed and had to almost fully restock once power returned. Homes had no heat during the chilly late October and early November days following the storm. Inoperable elevators stranded people, particularly the infirmed and elderly.

Contributing to Sandy power outages, dozens of NJ power substations and switching stations experienced considerable damage and downtime, most by storm surge water. Many other power stations were damaged elsewhere in the State during Irene's fresh water flooding. Quite the lesson learned; water and electricity do not mix! These two storms made painfully clear that infrastructure supporting power generation and supply needs hardening or relocation. Electrical utilities need to harden infrastructure throughout company service areas by better tree trimming efforts and establishing some redundancy within power grids. One cannot expect unfailing service during major storms; however, lessons have been learned from recent storms that should lead to more reliable service in the future. So too, has a lesson been learned that key services need backup generator power in case the area grid fails. For example, post Sandy funding was made available for 52 NJ gas

stations to secure generators. Also due to recent storms, owners of a number of businesses and homes have equipped themselves with generators, but they must understand how to use them; gas-powered generators must be properly ventilated or the carbon monoxide they release can be deadly. Seven post-Sandy NJ fatalities are attributed to not understanding this.

6.7 *Messaging Needs Improvement*

Considerable attention in the post-Sandy era has been paid to means of expressing and delivering information associated with potential storm threats. A look back through the literature finds decades of such discourse. Over time, the amount of available information has increased and the means of packaging and distributing it has evolved. An opportunity, warranting additional studies, presents itself to improve a last and most important step in severe storm risk reduction: getting timely information to those who need it.

One change in issuing National Hurricane Center watches and warnings was implemented shortly after Sandy. The NHC will now continue to generate such advisories even if the storm is expected to or has transitioned into a post-tropical storm, provided that it still poses a significant threat to life and property (NOAA 2013). It will never be known if officials and the public might have acted differently and lives potentially saved had this policy been implemented prior to Sandy.

The U.S. National Oceanic and Atmospheric Administration's Sea Grant program has funded a suite of ten studies to better understand the effectiveness of coastal storm communication strategies, focused on coastal areas of the tri-state region (NJ, NY, CT), which was most affected by Sandy (Sea Grant 2015). One issue being addressed in a few of these studies is the public response to voluntary versus mandatory evacuation. Among residents living in a mandatory evacuation area, barely half (49 %) report having left home before the storm, while another 9 % left as the storm was underway (Monmouth 2013). Using hypothetical storm scenarios, another study showed that expected evacuation rates are much lower when the word "voluntary" appears in an evacuation message (Cuite and Shwom 2015). This study also found that more detailed and personalized information is not always better, as block-by-block evacuation notices may not be any more effective than community-level evacuation notices in motivating action. Another study found that indexical information, such as photos showing storm surge, are likely to make people concerned about storm surge risk than iconic or abstract information, such as a map showing the areas at risk for storm surge (Scherer et al. 2015).

The Cuite and Shwom (2015) study also found that using fear appeals in evacuation communications may encourage coastal residents to evacuate. However, existing fear appeal literature in other areas indicates that if a warning goes too far residents may choose to ignore it. Some real world examples of fear appeals were described in their study, but the actual effects of these are still unclear. For instance, does going so far as to insist on writing social security numbers on the arms of

citizens who refuse to evacuate cross the line? Or does the effectiveness of a warning depend on who conveys it and how it is put forth? This also raises questions such as whether Szatkowski's statement from the NWS leading up to Sandy was effective? If so, was it because he was a trusted local source and worded it in a firm and dramatic manner? No doubt these important studies and ensuing discussions will continue as they relate to Sandy and, of course, to other disasters.

Efforts to improve storm messaging are underway in a growing community of individuals who combine expertise in science, social science and communications. For instance, this author is involved in an effort to develop a coastal storm severity index that will generate and convey the forecast strength of an approaching storm with regard to wind, rain or snow, fresh water flooding, and storm surge. The idea is not to develop one synthesized index value. Rather each variable is ranked for its potential severity within a specified region over a selected period. Such information would then be conveyed, perhaps in a color-coded format (an approach similar to The Network of European Meteorological Services Meteoalarm system: <http://www.meteoalarm.eu/>). Whether this index will be conveyed only to emergency managers (for them to use and potentially distribute as they wish) or directly to the public remains open to discussion. So, too, the desired spatial resolution of the alert area remains uncertain. Integral to the development of variable and regional warning thresholds based on NWS forecast information, considerable study is needed of potential impacts of introducing new terminology within the community.

A discussion of messaging must include how to best utilize media outreach. How can environmental scientists, social scientists and community leaders utilize the visibility and outreach of radio, television, print/online news feeds and social media to better inform the public before, during and following storms? Anyone who has paid attention to this discipline over the past decade realizes its ever-evolving dimensions. Paramount to any ongoing study must be fundamental principles that can be woven into whatever communication vehicle one chooses. Among these are knowing the intended audience, utilizing credible sources of information, striving for clarity and consistent timeliness to whatever message is being conveyed, and avoiding "hype."

6.8 Do not Rely Solely on Lessons from Sandy

There certainly is much that has been and will continue to be learned from Sandy. However, no one should become too confident that lessons learned can be applied to all future storms in New Jersey, within the Mid Atlantic region or elsewhere. Of key significance is the fact that the storm struck in the tourism "off season." One must turn to storm threats posed by Irene in late August 2011 and a number of other storms along the Atlantic and Gulf Coast to appreciate the effectiveness of evacuation procedures. Understanding nuances, such as the timing of evacuation orders by day of the week, may prove vital. Was the evacuation of tourists for Irene reasonably successful given the storm was forecast to strike late Saturday? After all,

people were near the end of the Saturday-Saturday home rental week. Would compliance have been lower had beachgoers been asked to leave earlier in the week?

7 Conclusion—A Game Changer?

Was New Jersey “Stronger than the Storm,” as ubiquitous ads throughout much of 2013 claimed? Perhaps in some ways the State was—as in many cases Sandy brought out the best in people and demonstrated the resilience of New Jersey citizens. Furthermore, despite the tragic loss of too many lives, many millions within harm’s way emerged relatively unscathed. Perhaps “Smarter than the Storm” is a more appropriate credo as New Jersey faces the inevitable attack by future storms, with storm tides perched upon rising sea levels and ever more people living in vulnerable areas. Lessons learned from Sandy have already led to what can be considered game changers. The NHC has revised watch and warning criteria. Zoning changes that would move homes and businesses away from the shoreline are being discussed and in some cases implemented. Improved means of communication between the forecast community and decision makers, and subsequently in getting the message out to the greater population, are being studied and implemented.

Sandy, along with other recent coastal storms, has led to a greater appreciation of the power of Mother Nature and the ever-growing vulnerability of individuals and their communities to storms. This a result of increasing population and climate change, including rising sea level. So, too, is increased appreciation of natural coastal defenses such as beaches, dunes and wetlands. However, it is evident that in many instances it is back to business as usual for the state and region while, in some cases, potential game changers are occurring in research and in public discussion. Still, when New Jersey and the surrounding region is tested again, citizens will likely be better prepared and respond more effectively than in the past. Fewer lives will be lost and recovery will be quicker and less painful. Should this occur, we will know for certain that Sandy was a game changer in a very positive sense.

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