TECHNICAL REPORT

BRIEF OVERVIEW OF COMMUNICATION PRACTICES AROUND STORM SURGE RISK

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Communicating Storm Surge Risks:
Best Practices and Case Study

Abstract
Storm surge communication is becoming a significant area of study as increased incident-related fatalities have been recorded during recent tropical storms. A review of forecast products from several countries was conducted to compare communication practices currently employed. Past storm surge communications from the U.S., India, Bangladesh, Japan, and Australia were analyzed for text and graphics. In addition, the communication pathway for Hurricane Sandy (2012) was traced from U.S. federal weather agencies to the public as a case study in storm surge.

1. Storm Surge Communication in the U.S.

Federal Weather Agencies
Hurricane and storm surge warnings in the U.S. are the purview of the National Weather Service (NWS), an agency within the National Oceanic and Atmospheric Administration (NOAA). Within the NWS, the National Hurricane Center (NHC) is responsible for tracking and modeling/predicting weather systems (see Figure 1).

The NHC issues advisories every 6 hours comprising texts and graphics whenever a tropical cyclone (known as hurricane in the North Atlantic and Northeast Pacific, and typhoon in the Northwest Pacific) is active, and every 3 hours or as necessitated when watches and warnings are in effect. Text products include public and forecast advisories (each is comprised of watches and warnings), discussion, and wind speed probability. Graphical products are watch-warning graphics, wind speed probability graphics, maximum intensity probability table, wind field graphics and cumulative wind history graphics. The above all pertain to wind, but a potential storm surge flooding map, tropical cyclone storm surge probabilities, and exceedance probability graphics are also issued with each advisory whenever a hurricane watch or warning is in effect. The following is a brief description of hurricane and storm surge products.

Figure 2 describes the hurricane and storm surge communication products developed by these national agencies.

An example of a public advisory (for Hurricane Ike, 2008), as excerpted from the NHC website, and the portion mentioning the storm surge is shown in Figure 3.

Text and graphical (table) products are also generated by the NWS.

NOAA Hurricane Products. The products are:

1. Forecast advisories – watches and warnings
2. Public advisories – watches and warnings
3. Discussions
4. Strike probabilities
5. Graphics – tables, maps, graphs

Hurricane IKE

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ZCZC MIATCPAT4 ALL
TTAA00 KNHC DDHHMM
BULLETIN
HURRICANE IKE ADVISORY NUMBER  47
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL   AL092008
400 PM CDT FRI SEP 12 2008
...IKE'S FURY AIMED AT THE UPPER TEXAS AND SOUTHWEST LOUISIANA
COAST...
COASTAL STORM SURGE FLOODING OF UP TO 20 FEET...WITH A FEW SPOTS TO
NEAR 25 FEET...ABOVE NORMAL TIDES ALONG WITH LARGE AND DANGEROUS
BATTERING WAVES...CAN BE EXPECTED NEAR AND TO THE EAST OF WHERE THE
CENTER OF IKE MAKES LANDFALL. THE SURGE EXTENDS A GREATER THAN
USUAL DISTANCE FROM THE CENTER DUE TO THE LARGE SIZE OF THE
CYCLONE. WATER LEVELS HAVE ALREADY RISEN BY MORE THAN 5 FEET ALONG
MUCH OF THE NORTHWESTERN GULF COAST.  DO NOT VENTURE OUTSIDE IN THE
EYE.
THE STRONGEST WINDS AND HIGHEST
SURGE WILL LIKELY OCCUR NEAR OR JUST AFTER THE EYE MAKES LANDFALL.
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Figure 3. Public Advisory for Hurricane Ike

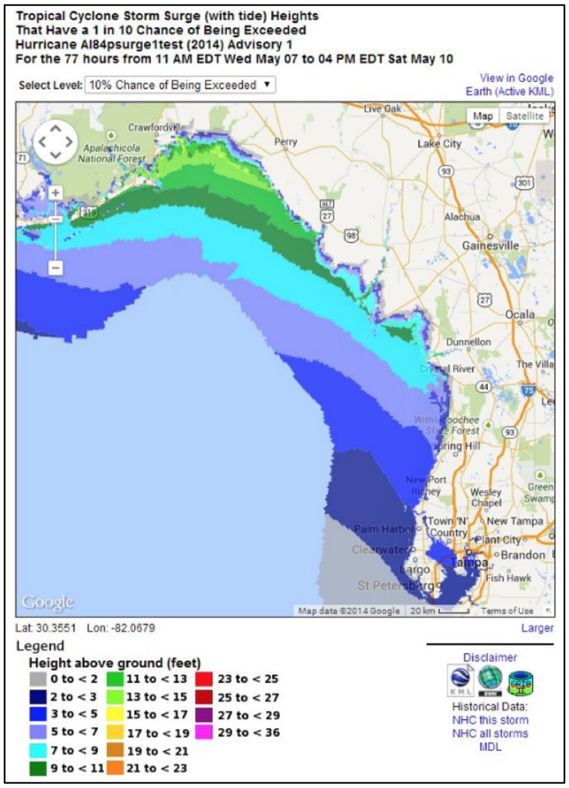


Figure 4a. Tropical Cyclone Storm Surge Probabilities (0 - 20 feet)

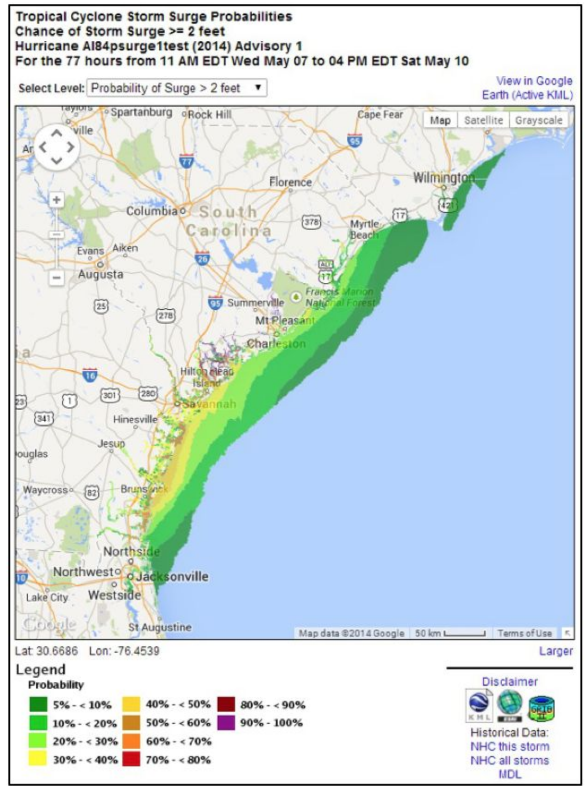


Figure 4b. Tropical Cyclone Storm Surge Probabilities (exceedance)

The following is an example of a storm surge hazard warning map. Hazard levels are indicated with mappings of predicted storm surge heights (see Figure 4a) and probabilities of exceeding 2 feet in depth (see Figure 4b).

NWS is planning to begin using new communication tools (discussed below). Till now, however, hurricane and storm surge products for the public have been focused on winds, with only a passing reference to storm surges, usually in text form, but based on probabilistic models from NOAA's NWS' Meteorological Development Lab, as shown in Figure 5.

NOAA is testing a prototype storm surge map, to be put in use beginning 2017 (see Figure 6). These maps will be issued 48 hours before landfall and updated every six hours.

1a. Differences across states and agencies in the U.S.

As described above, the NHC provides expert (technical) forecasts and watch and warning products through the NWS to the WFOs in the watch and warning areas. WFOs then issue advisories, warnings, statements and short-term forecasts to Emergency Managers and the public, as the HLT facilitates exchange of information between the NHC, NWS and WFO. WFOs also add additional local specific conditions. Sorensen (2000) reported that there is no comprehensive national warning strategy

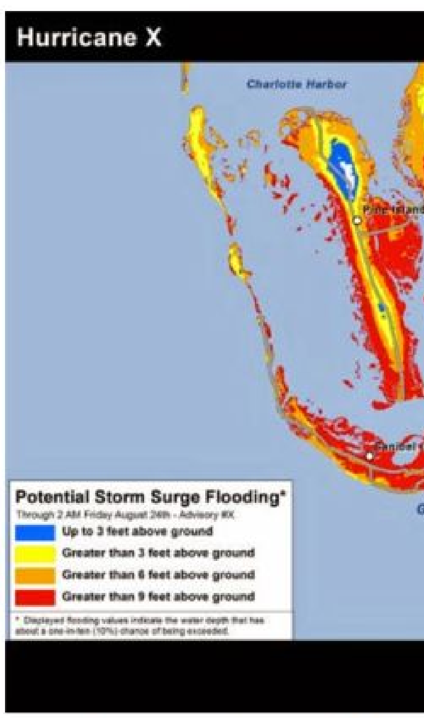


Figure 6. Prototype Storm Surge Maps (cu… nentation)

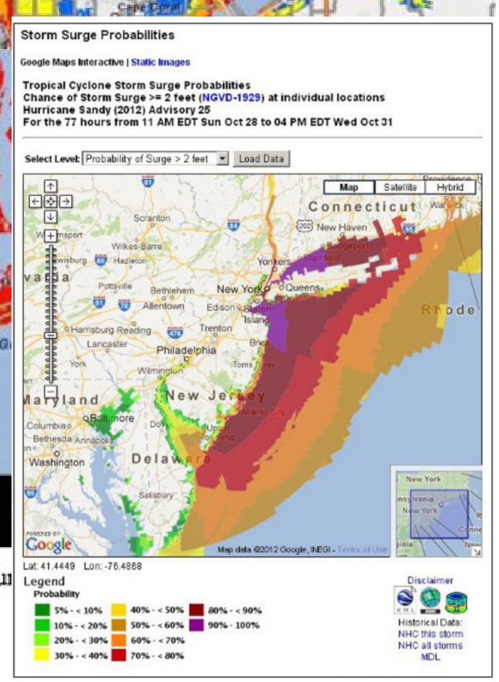


Figure 5. Conventional Storm Surge Probability Map (U.S.A.).
Source: Bostrom, D. (2012).

that covers all hurricane and storm surge hazards in the United States; public warnings are decentralized across different governments and the private sector. The difference in the way states handle hurricanes and storm surges lies in the strength (especially local knowledge) of WFOs, because these WFOs receive the same information from the national agencies and are expected to tailor it to their county warning area, which is a combination of zones or counties.

Storm surge graphics for Connecticut, North Carolina, and Texas are depicted in Figures 7 to 9, respectively.

Private organizations have also been involved in creating storm surge graphics (Figures 10 and 11).

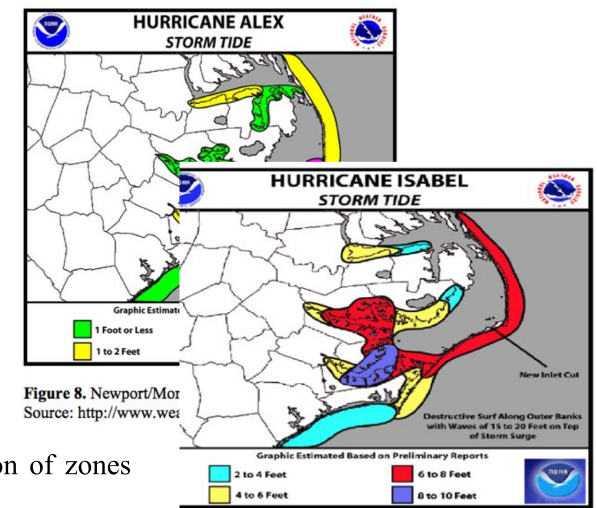


Figure 8. Newport/Mor
Source: http://www.wea

ıre 7. Newport, CT WFO Storm Tide Graphic.
rce: www.nws.noaa.gov/os/assessments/pdfs/**isabel.pdf**

2.

International Storm Surge Warning Tools

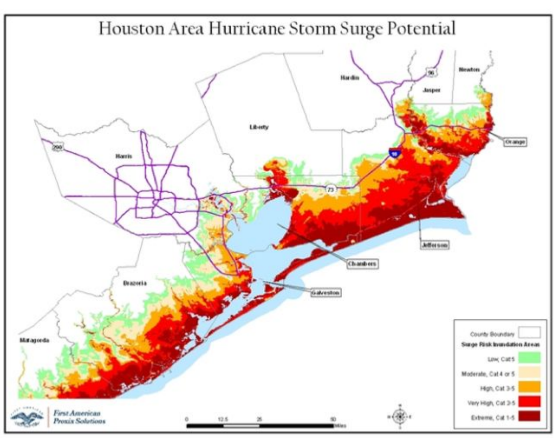


Figure 10. Map Created by First American Proxix Solutions
Source: www.wired.com

2a. India

The following is an example of a cyclone and storm surge warning, issued by the national Storm Surge Early Warning Centre (see Figure 12) in India.

Interesting to note is that the surge map only shows surge heights in the water and not on land (the accompanying forecast summary is show in Figure 13).

FORECAST INFORMATION

EVENT SUMMARY

CYCLONE NAME	HudHud
EXPECTED PLACE OF LAND FALL	NORTH ANDHRA PRADESH COAST NEAR VISAKHAPATNAM
EXPECTED TIME OF LAND FALL	Between 12 -13 hrs IST
EXPECTED WIND SPEED	100 kmph
MAX EXPECTED STORM TIDE (SURGE + TIDE)	0.6 m Near Kapulupada, Vishakhapatnam
MAX EXPECTED INUNDATION EXTENT	Nil

STORM TIDE INFORMATION

Details of storm tides expected at different coastal locations are listed below.

* The below listed water level and inundation extent includes tide but does not includes precipitation, river discharge and wind waves.

IMD CYCLONE FORECAST

FAX MESSAGE

FROM: INDIA METEOROLOGICAL DEPARTMENT (Fax No. 24699216/24623220)

Time of issue: 1700 hours IST Dated: 12.10.2014 Bulletin No.: BOB03/2014/41

Sub: Very Severe Cyclonic Storm, 'HUDHUD' over Andhra Pradesh``

The Very Severe Cyclonic Storm '**HUDHUD**' over west central Bay of Bengal moved west-northwestwards, crossed Andhra Pradesh coast over Visakhapatnam between 1200 and 1300 hrs IST and lay centered at 1430 hours IST of 12th October 2014 near latitude 17.8°N and longitude 83.0°E, about 30 km west-northwest of Visakhapatnam.

Date/Time(IST)	**Position (Lat. ^{0}N/ long. ^{0}E)**	**Maximum sustained surface wind speed (kmph)**	**Category of cyclonic disturbance**
12-10-2014/1430	17.8/83.0	130-140 gusting to 150	Very Severe Cyclonic Storm
12-10-2014/1730	18.2/82.7	90-100 gusting to 110	Severe Cyclonic Storm
12-10-2014/2330	19.0/82.0	70-80 gusting to 90	Cyclonic Storm
13-10-2014/0530	19.8/81.2	50-60 gusting to 70	Deep Depression
13-10-2014/1130	20.7/80.5	30-40 gusting to 50	Depression

Figure 13. Accompanying text for HudHud warning

2b. Bangladesh

In Bangladesh, surge warning maps classify hazard on a three-level scale (see Figure 14).

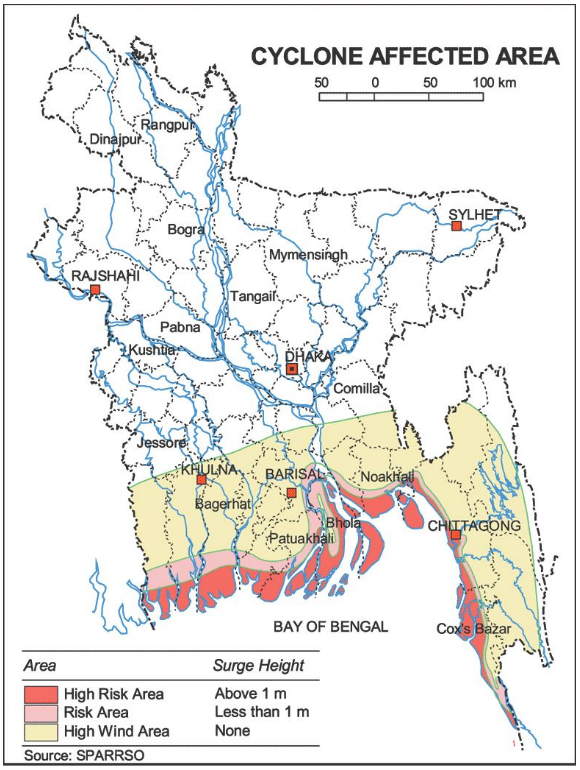


Figure 14. Storm Surge Map for Bangladesh
Source: 'The 1991 Bangladesh Cyclone and its impact on flooding' by Mike Molnar, Geog 361, Spring 2005. http://people.uwec.edu/jolhm/eh2/molnar/map.htm

2c. Japan

Japan Meteorological Agency (JMA) issues warnings or advisories for storm surge, depending on the predicted tidal level, when the phenomena may cause damage. Issuance of the warnings and advisories are done for individual municipalities. The actual warnings and advisories can only be viewed via JMA's webpage http://www.jma.go.jp/en/warn/index.html when the warnings or advisories are active. Observed tidal levels can also be viewed but it is only available in Japanese*, as shown below (see Figure 15).

The maps shows some unique design features. The coastal areas are divided in regions that are designated by the dots. Clicking on each dot leads to a zoomed-in map of the latest tide information for the corresponding region, as shown below the map.

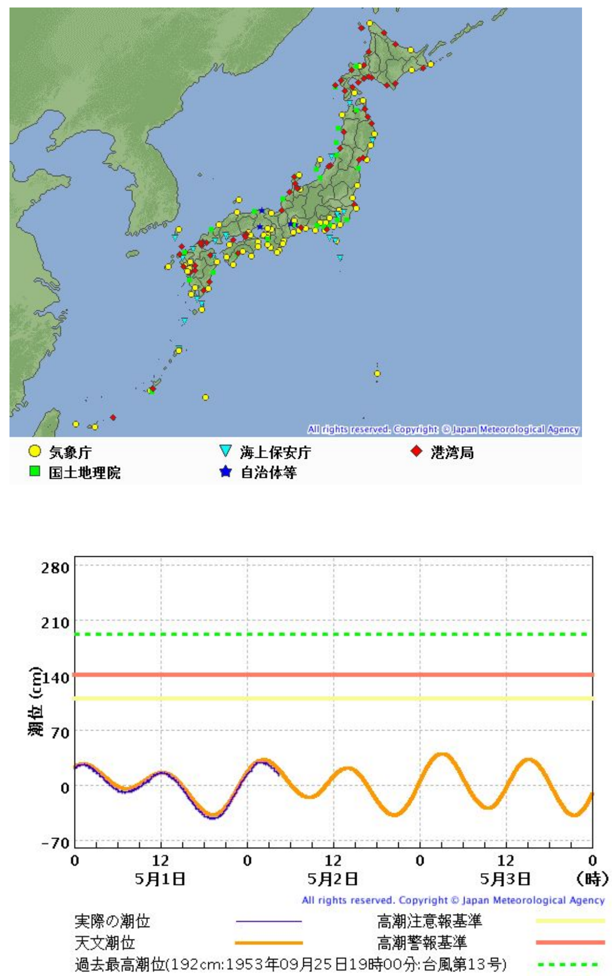


Figure 15. Surge Hazard Map and tide information for Japan
Source: http://www.jma.go.jp/jp/choi/#explain.

Email communication with A. Okagaki from the Office of International Affairs, Japan Meteorological Agency.

However, in 2013, Japan implemented a new Tsunami warning system that provides advisories in the form of a 2-page leaflet (http://www.data.jma.go.jp/svd/eqev/data/en/tsunami/tsunamiwarning-leaflet.pdf). This can be adapted for storm surge communication with modifications like less details/information and a captivating narrative that is capable of eliciting the desired response. Also, color codes should be changed in line with studies discussed in the next section and as depicted for India above, where red should signify the highest danger, as opposed to purple, etc.

The Japanese agency's 14-page brochure (http://www.jma.go.jp/jma/en/Activities/brochure201603.pdf) serves as a good example of an educational material that can be adapted for hurricane and storm surge communication to be distributed in schools, public and private offices, hospitals, etc.

2d. Australia

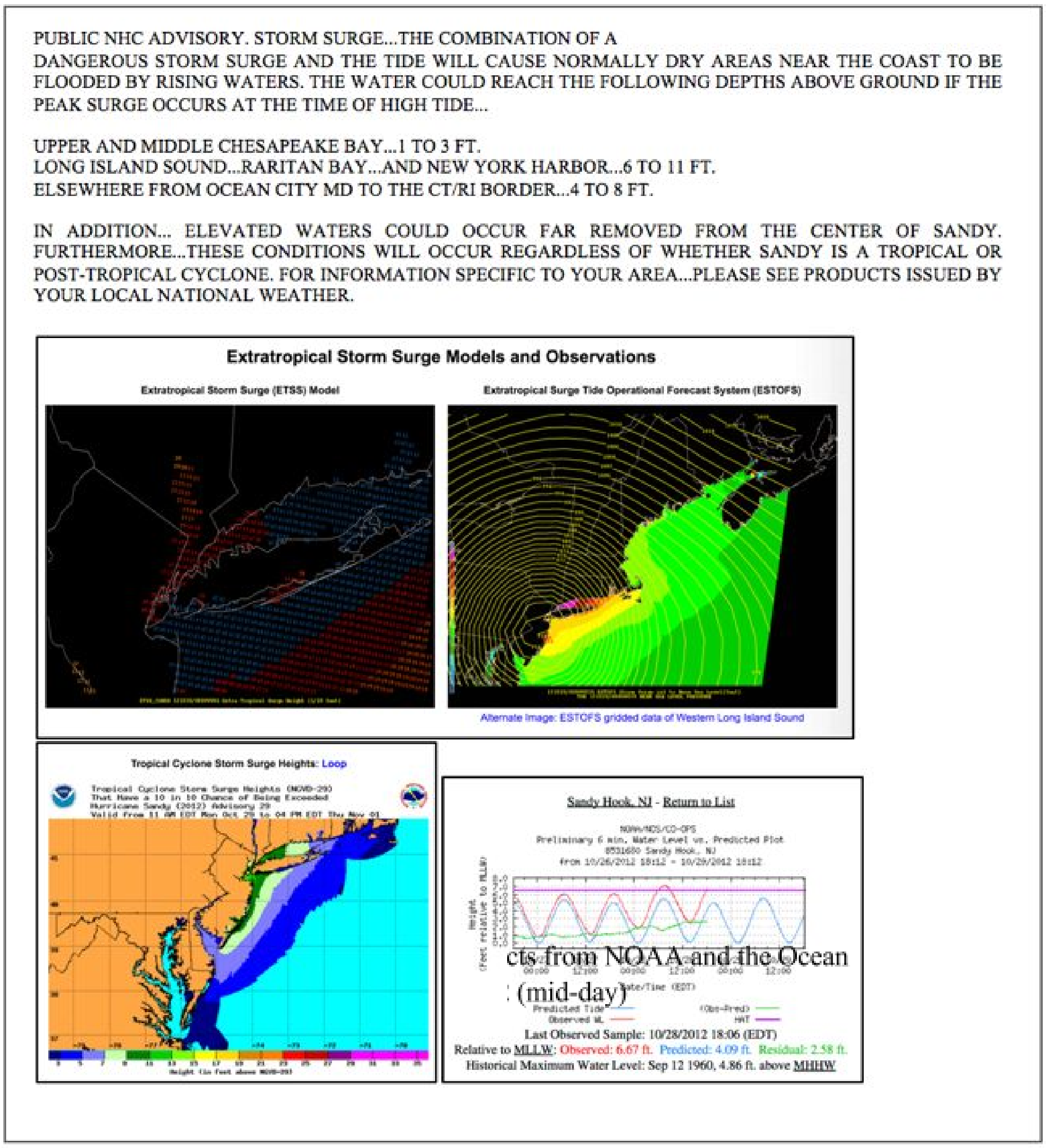
The example from Australia does not employ any hazard maps but it is notable for the kind of description of storm surge risks included in the text of the bulletins (see Figure 16).

3. Case Study: A Brief Look at Hurricane Sandy

NOAA and the Ocean Prediction Center (OPC) issued the normal suite of analysis and forecast products on their website (see Figure 2). As of mid-day October 28, 2012, text and graphics from these federal agencies predicted that "elevated waters could occur far removed from the center of Sandy," regardless of whether Sandy would transition to tropical or post-tropical cyclone.

Surge in the Long Island Sound, Raritan Bay, and New York Harbor were estimated at 6 to 11 feet. As seen in Figure 17, although the website graphics show rich information, including a predicted storm surge map, the text of the press release is much more sparse in terms of information.

Since Sandy wasn't forecast to hit land as a hurricane, the National Hurricane Center did not issue its usual hurricane watches and warnings as the storm approached the coast, instead

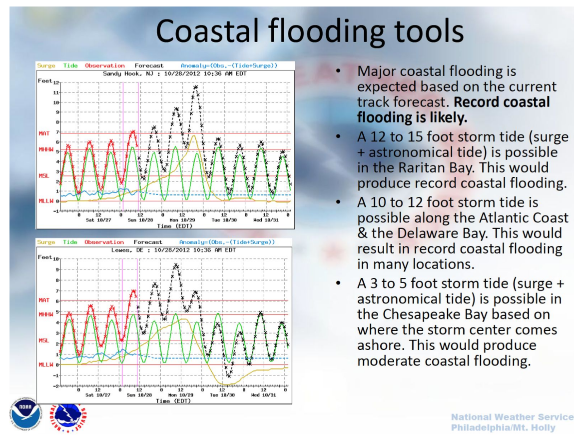


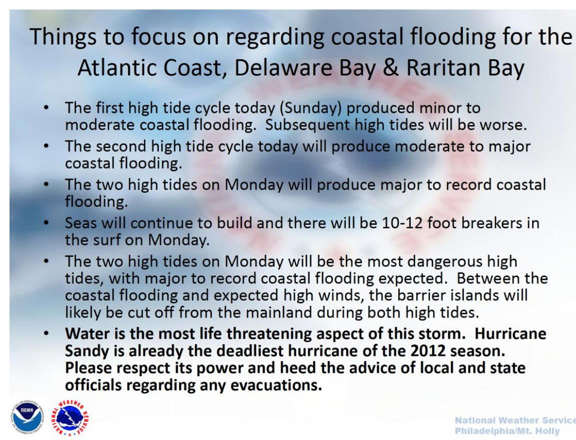
cts from NOAA and the Ocean
: (mid-day)

relying on several local weather service offices to issue "high wind warnings," "coastal flood warnings" and other watches and warnings. Two National Weather Service (NWS) Area Forecast Discussions (AFD) are represented in Figure 18 to compare context and tone between warnings for New York City and Mt. Holly, NJ. Although the AFD for New York City emphasizes "life-threatening surge" and "record levels" of coastal flooding, the language is very dry and technical. It does not give a numerical estimate of how high the surge will reach anywhere in the warning. In contrast, the AFD for Mt. Holly embeds technical information in its warning but uses a more conversational tone. The AFD at midday October 28 mentions a "7 ft" surge in the Sandy Hook vicinity and punctuates this statement with an exclamation point. The warning provides some historical perspective by stating that "7 ft" could surpass the record set by Hurricane Donna in 1960. Furthermore, the warning gives an alternate hurricane scenario by stating that the storm has to "go north of Sandy Hook" or "accelerate inland prior to 6PM or be weaker by 10 to 20 MB" in order to avoid devastation. Here, we see a much more explicit kind of information in the New Jersey, as compared to the New York, advisories, differing in its degree of vivid detail and description of consequences of the event.

In tandem, the communications from Weather Forecast Office (WFO) Mt. Holly to the emergency response managers used an urgent tone in their briefing packages. Figure 19 highlights a bulletin from midday October 28 from meteorologist Gary Szatkowski. He uses graphics from NOAA and OPC in his presentation. He picks up text from both NOAA/OPC and AFD warnings for Mt. Holly. He writes in bold, “Water is the most life threatening aspect of this storm…Please respect its power and heed the advice of local and state officials regarding any evacuations.” He also dedicates an entire slide to a “Personal plea,” where he abandons technical jargon for an empathetic call to action. Note that the post storm NOAA assessment hailed WFO Mt Holly briefing packages as best practice because they contained graphic and text-based information, focused on impacts, and contained confidence and worst-case scenario information that aided decision making. This is an example of a combination of technical and narrative communication although, in this case, this was not broadcast to the public or lower-line agencies and municipalities but only for the briefing with emergency response managers.

In a speech given on October 27, Mayor Bloomberg of New York City said, “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…” (data not shown). On October 28, he changed trajectories about how dangerous the surge would be to the city and issued mandatory evacuations for flood zones (see Figure 20). In contrast, Governor Christie of NJ had already declared a state of emergency for NJ on October 27, and flood-prone areas such as Hoboken were initiating contingency plans across their city (see Figure 20). Note that the Hoboken press release has a map to accompany its emergency updates. It also includes all social media handles at the bottom of the site for access to updates.





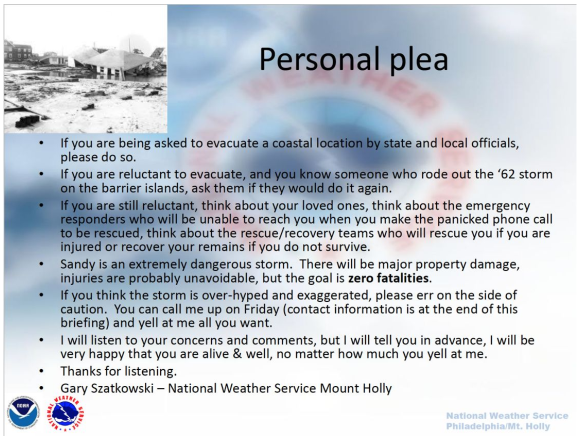


Figure 19. Text and graphics used in briefing package WFO Mt. Holly to Emergency Managers, October 28, 2012 (noon)

Figure 21 shows a still from a local New York area news station on the morning of October 28. The meteorologist mentions "flooding" and "wind" as major threats, but there is no specific mention of surge.

3a. Case study conclusions: ex post evaluation of risk communication during Hurricane Sandy

Despite increased scientific understanding of hurricanes and forecasting, hurricane emergency preparedness has not been commensurate in response. The property damages and economic costs of Hurricane Sandy alone brings light to this fact. Hurricane Sandy was atypical in its storm transition as it moved up the East coast, leading to a series of controversial decisions on how it was communicated to stakeholders and the public itself. No hurricane warnings were issued by the National Hurricane Center for areas north of Duck, North Carolina; rather, the mixed tropical/non-tropical nature of the storm triggered "high wind" and "coastal flood" warnings from local offices instead (NOAA, 2013). The lack of traditional hurricane warnings led to confusion for some emergency managers and complicated the task of reporting for the media. In a survey completed just before Sandy hit, a majority of coastal residents were still very concerned about Sandy's approach despite any uncertainty, and took some preparatory action (Baker, 2012). However, the greatest source of threat was perceived to be high wind (55%-70%), not water (<30%). Storm surge created some of the most devastating impacts, damaging infrastructure and the primary cause of death during Sandy (CDC, 2012). One factor that may contribute a bias toward wind over water risk is that storm intensity is conveyed by NOAA by the Saffir-Simpson scale, which describes the maximum sustained winds a storm possesses, not its maximum storm surge or flood threat.

Transcript from the broadcast meteorologist:

"The rain fall potential where you see the orange in here this is 5-8 inches…that could fall in the next 48 hours so flooding is going to be a huge threat….Hurricane force gusts will be approaching the coast this afternoon…"

Figure 21. Weather forecast from CBS News, October 28, 2012 (morning)

Protective actions by the public are not only influenced by acknowledging the hazard, but by their own perceptions of risk. Meyers et al. (2013) pose that mental models of storm threat affect a person's intent to act. The communication inaccuracies for Sandy may have led to poor mental simulation of actual threats, as evidenced by the misperceived source of threat (wind vs water) and the limited actions taken to protect against wind or flood (eg, evacuation planning, electric generators, window protections). Further research by Morrow et al. (2014) have shown that the decision to evacuate ("act") are affected by differences in culture, vulnerability, experience, information, motivations, and barriers.

In light of the devastating impacts of surge during Sandy and the lack of public awareness of surge, the highest priority need identified by NOAA and National Weather Service customers and constituents was for improved high-resolution surge forecasting and communication, including better graphical inundation guidance (NOAA, 2013). With regard to all of NOAA's risk communication products, customers requested simple summaries of weather and its impacts using non-technical text and graphical material in a short and easy-to-read format. These summaries should also include confidence or uncertainty and worst-case scenarios information. The NOAA service assessment also recognized that since public response is influenced by a complex set of mental processing factors, messaging should be better targeted to the user. Their other primary recommendation was to involve social scientists throughout the process of designing, testing and improving forecast text and graphics products.

References

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Meyer RJ, Baker J, Broad K, Czajkowski J. (Nov 2013). The dynamics of hurricane risk perception: real-time evidence from the 2012 Atlantic hurricane season. Accessed at: http://opim.wharton.upenn.edu/risk/library/WP2013-09_HurrRiskPercep-2012Season.pdf.

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