IMPROVING STORM SURGE RISK COMMUNICATION

Stakeholder Perspectives

by Betty H. Morrow, Jeffrey K. Lazo, Jamie Rhome, and Jesse Feyen

Survey findings from forecasters, emergency managers, broadcast meteorologists, and the public pave the way toward more effective communication of storm surge forecasts associated with tropical and extratropical cyclones.

Surge is deadly and one of the hardest things to communicate
—NWS warning coordination meteorologist

The current surge information is vague and confusing
—Broadcast meteorologist

People worry about wind and are hit by surge
—Emergency manager

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Storm surge associated with tropical and extratropical cyclones has a long history of causing death and destruction along our coastlines—and the threat has never been greater (Rappaport 2013). According to 2011 U.S. Census data, more than 123 million people, or 39% of the U.S. population, live in coastal shoreline counties (http://stateofthecoast.noaa.gov/population/). The average density in these counties is 446 persons per square mile, compared to 105 persons per square mile in the nation as a whole. Much of the densely populated Atlantic and Gulf coastal areas are less than 10 ft (1 ft = 0.3 m) above mean sea level. And sea level rise is "raising the launch pad for coastal storms and high tides" (Climate Central 2014). It is imperative that the ever-increasing coastal public understands cyclone risk, particularly related to storm surge. As Rappaport (2013, p. 12) notes, ". . . the potential for massive loss of life due to storm surge persists. It provides a call to action for the nation's hurricane research and operations program to develop and implement new storm surge mitigation strategies."

This article summarizes and integrates a series of studies evaluating the storm surge communication perceptions and preferences of two categories of stakeholders: experts (forecasters, broadcast meteorologists, and emergency managers) and members of the public. Before presenting the results, we provide background on storm surge impacts, forecast response, risk perceptions, and prior initiatives. We then summarize the methods used for this applied research (quantitative survey analysis with qualitative examples) before presenting our findings related to the public understanding of storm surge, support for a separate storm surge warning, and preferences for warning text and graphics. We end by highlighting the need for further research on the communication of storm surge risk.

BACKGROUND. Within the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS) and its offices are responsible for cyclone forecasts. For tropical cyclone (TC) events, the National Hurricane Center (NHC) issues several products that include storm surge information, including the TC public advisory, probabilistic hurricane storm surge model forecast guidance (P-surge), and tropical forecast discussion. Weather forecast offices (WFOs) issue detailed hurricane local statements that include surge forecast information and a tropical cyclone impacts graphic (experimental status) that includes the storm surge threat. For extratropical (ET) threats, WFOs have a suite of products they can issue, such as extreme coastal flood and flash flood watches and warnings. Even though these text and graphic products include the storm surge forecast, it is usually combined with other forecast information and therefore may seem relatively less important, ambiguous, or locally relevant.

Storm surge forecasting. Communication of storm surge forecasts is closely tied to how such forecasts are generated and the accuracy of the scientific data they are based on. For tropical cyclone surge forecasts, issues of meteorological uncertainty play a large role in how storm surge risks are communicated. While hurricane track forecasting continues to improve, the average track error for the Atlantic basin is near 70 nautical miles and the average 48-h intensity forecast error is 15 kt (1 kt = 0.5144 m s^{-1}). While these average errors are relatively low, they could still mean the difference between a category 1 hurricane making landfall in Pensacola, Florida, or a category 3 hurricane striking New Orleans, Louisiana. Since storm surge is strongly dependent on location, such differences in landfall location and intensity can have significant impacts on the resulting storm surge. Therefore, NWS generates probabilities of potential storm surge to inform forecasts in the 24–48-h window before landfall that is often critical for decision making. The P-surge product is generated by statistically evaluating hundreds of Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model simulations that are permutations of the official NHC track forecast (see www.nhc.noaa.gov/aboutpsurge3.shtml). These requirements for model guidance require a very fast and efficient storm surge model (see Zhang et al. 2013). At longer lead times, decisions are based on precomputed storm surge atlases that account for all potential cases (see www.nhc.noaa.gov/surge/momOverview.php).

Storm surge forecasts need to communicate the risk of flooding in light of these uncertainties, which produce a range of possible inundation conditions for each geographic location and limit the amount of spatial and temporal specificity possible in a surge forecast.

Storm surge forecast response. The main strategy for protection from storm surge is moving out of harm's way ahead of the storm. Most official evacuation zones are based on potential storm surge vulnerability, and when these areas are threatened, local officials typically make evacuation recommendations or issue evacuation orders. In a democracy, people decide for themselves whether to leave, and information on risks should play a crucial part in their decision process. They typically turn first to their local television station for information and then seek confirmation from other sources such as national television stations, cable weather stations, websites, and social networks (Dash and Gladwin 2007; Zhang et al. 2007; Lazo et al. 2009; Taylor et al. 2009; Morss and Hayden 2010; Sherman-Morris et al. 2014). Of particular interest is the increasing use of websites for weather information, even among more vulnerable groups such as the elderly and the socioeconomically disadvantaged (Kiefer et al. 2008).

The role of risk perception in hazard preparation, management, and mitigation practices is well established (e.g., Slovic et al. 2000). At all levels of the decision chain, the essential first step is gathering information and weighing the risk (Whitehead et al. 2000; Morrow et al. 2011, Stein et al. 2013). In the case of storm surge, the probabilities of occurrence may be low but *should* it happen, the outcome can be fatal. Therefore, it is imperative that storm surge forecasts effectively portray the risk in an easily understood manner. The overarching goal in the work reported here is to strengthen storm surge forecast communication, thus promoting appropriate evacuation decisions to save lives.

Perception of wind and surge risk. After Hurricane Andrew in 1992, stronger building codes, hurricane shutters, and other wind mitigation activities received national attention (Sainz 2007). Universities and private companies developed wind tunnels for testing building construction materials. A Storm Struck interactive exhibit was installed at the Epcot Theme Park at Disney World, allowing visitors to "design" a home and test its strength against wind (www.stormstruck.org). Moreover, coastal residents have learned to assess the danger of hurricanes using the Saffir–Simpson hurricane wind scale (SSHWS) (www.nhc.noaa.gov/aboutsshws.php). Evacuation intent (stated likelihood of evacuating in future storms) tends to increase linearly with SSHWS category (Lazo et al. 2010). Following decades of hurricanes with primarily wind impacts, Hurricane Katrina in 2005 dramatically brought the nation's attention to the life-threatening danger from surge-induced flooding (Rappaport 2013). Over 1,000 people died from the forces of the storm, the vast majority from drowning when the levees were breached in New Orleans, and at least 180 died in surge that reached 24–28 ft above normal tide levels as it came ashore in coastal Mississippi (Knabb et al. 2005). A post-Katrina behavioral survey revealed that most of the respondents in Alabama, Mississippi, and Louisiana could not interpret an NWS storm surge forecast correctly (Gladwin and Morrow 2006). In 2008 Hurricane Ike brought surge heights of 5–10 ft in Louisiana and 10–13 ft in Texas (Berg 2009), where residents reported being surprised by the storm surge (Morss and Hayden 2010). Three years later Hurricane Irene affected North Carolina with 7 ft of surge and the New Jersey region with 4–6 ft (Avila and Cangialosi 2011) and resulted in record-breaking inland flooding. Most recently Hurricane/Post-Tropical Storm Sandy pounded the northeastern Atlantic coast in late October 2012 with as much as 9 ft above ground level surge in the New York City metropolitan area (Blake et al. 2012). A survey completed just before Sandy indicated that people expected the primary threat to be from wind (Baker et al. 2012). Most of the 67 direct deaths from Sandy in the United States, however, were caused by drowning, mostly when the storm came ashore (Centers for Disease Control 2012). It is important to note that none of these storms ranked high on the SSHWS. Hurricane Katrina came ashore as a category 3 storm, Ike as a category 2, and Irene as a category 1. Sandy was a post-tropical cyclone with winds of category 2 strength when it made landfall in the Northeast. These surge events associated with lower-category hurricanes brought increased attention to storm surge communication throughout the weather enterprise.[1]

Previous initiatives. Starting in 2004 (following Hurricane Isabel's impacts on the Atlantic coast in 2003) and building on a series of workshops and white papers, an interdisciplinary working group developed a social science research agenda for the hurricane forecast and warning system (Gladwin et al. 2009). As indicated in that effort, research is critically needed across several areas in addition to storm surge (including focus on vulnerable populations, developing nonlinear models of communication and behavioral response, and interdisciplinary work integrating meteorological and social science research) and should be prioritized and balanced across all needs to meet societal objectives. With respect to storm surge research issues, this agenda indicated the need to answer questions such as "should surge, rain, and wind probabilities be included as part of forecast and warning products, and how might they effectively be displayed?" and "would a color-coded threat index be useful to communicate threat levels from various hazards such as wind, storm surge, and inland flooding?" (Gladwin et al. 2007, p. 90). Research conducted in Mississippi after Hurricane Katrina highlighted the need for better ways to communicate surge threat, such as inundation maps, particularly for inland areas (Melton et al. 2010). Understanding that physical science improvements alone will not address the nation's hurricane vulnerability, NOAA created a Storm Surge Leadership Team in January 2005 to explore the storm surge needs of various stakeholders. Its recommendations highlighted the need for less technical communication, more easily understood graphics, and reduced datum confusion (Safford et al. 2006; Thompson et al. 2012).

Following Katrina, a national task force called for a National Hurricane Research Initiative (National Science Board 2007), focusing on improving the forecast but also recognizing the need to improve citizen response. NOAA initiated the Hurricane Forecast Improvement Project (HFIP), a 10-yr funding initiative with the main goal of improving track and intensity forecasts (Gall et al. 2013). A small portion

[1] All of the data collection for the research reported here was completed before Hurricane Sandy and thus we are unable to assess the impact of that event on our findings. Qualitatively, though, we feel that the storm surge impacts of Hurricane Sandy are consistent with our findings and only emphasize the need for better communication and response to storm surge threats.

of HFIP funds is dedicated to social science research, guided by the HFIP Social Sciences Working Group. NOAA's Coastal Services Center funded a review of the relevant social science literature, including how social marketing techniques might be used to improve storm surge communication (Morrow 2007). The National Science Foundation and NOAA collaborated in 2008 to fund several "communicating hurricane information" research projects that have resulted in specific recommendations for improving forecast communication (Demuth et al. 2012; Lazrus et al. 2012; Cox et al. 2013; Meyer et al. 2013; Wu et al. 2014). While documenting the complex, challenging nature of the hurricane warning system, Demuth et al. (2012) strongly recommended greater use of risk communication research in the development and testing of hurricane risk messages.

Risk communication. Communicating risk in a convincing manner is a complex process studied by numerous disciplines and fields for more than 30 yr (Covello et al. 1986; Fischhoff 1995; Lundgren and McMakin 2009; Morrow 2009), with the findings successfully applied in many areas such as climate change (Sterman 2008), geohazards (Rosenbaum and Culshaw 2003), and health issues (Maibach and Parrott 1995; McComas 2006). There is scarce evidence, however, that the weather enterprise has utilized risk communication knowledge in a systemic way (Lazo 2012). Significant research efforts have focused on understanding how people make evacuation decisions (e.g., Whitehead et al. 2000; Dash and Gladwin 2007; Petrolia and Bhattacharjee 2010; Gladwin at al. 2011; Stein et al. 2013), including the important effects of past experience (Trumbo et al. 2011; Murray-Tuite et al. 2012). This research shows that before deciding to take a disruptive and often expensive action such as evacuation, people must understand the forecast; believe it applies to them; and, most important, feel that they and/or their loved ones are at risk (Baker et al. 2012; Villegas et al. 2013). However, common practice has been to prepare and release forecast messages without adequately understanding how they are received, understood, and interpreted.

Risk message effectiveness depends on the development of arguments based on knowledge of the targeted communities, particularly those at high risk (Morgan et al. 2002; Lundgren and McMakin 2009). Even though emergency managers and officials bear more direct responsibility for citizen response, forecasters, at a minimum, need to test how their forecast messages are received and interpreted within the context of targeted communities and, in risky situations, the extent to which they evoke cognitive and emotional responses that promote protective action (e.g., Witte 1992).

Role of visualization in risk perception. Visualization is an important communication tool for helping people understand data and its implications, including warnings and other risk information (Eppler and Aeschimann 2009). We live in a visual society where information is increasingly presented as graphics, photos, maps, and illustrations. Forecasts are no exception, particularly in the private sector, where television and websites often feature attractive visuals. As forecast skills improve, it is possible to provide maps illustrating local hazard risk, including the uncertainty inherent in forecasts, earlier and in greater detail (Melton et al. 2010; Pang 2008; Steed et al. 2009). Advances in science and technology have made enhanced visualization of potential storm surge possible through higher-resolution inundation maps and 3D simulations (e.g., Allen et al. 2013). However, if poorly designed, graphics can also confuse recipients and potentially impede risk communication and decision making (Tufte 2001). To this end, we developed and tested several surge-related maps as part of this work.

While the focus of the research reported here is not to test theory, we built on this background and closely related concurrent research efforts to elicit perceptions, understanding, and preferences of multiple stakeholders to inform the development of NWS storm surge communication products.

METHODOLOGIES. We report here on applied research to 1) assess the extent to which coastal residents understand their storm surge risk and 2) explore with key stakeholders (experts and laypersons) their perceptions and preferences regarding new ways of communicating storm surge forecasts associated with TC and ET cyclones. The work was completed in two phases. In the first, largely qualitative phase, we used in-depth interviews, focus groups, group discussions, and one-on-one webinars to explore the issues with local emergency managers (EMs), broadcast meteorologists (BRs), and the public.[2] We also conducted a limited number of interviews with key stakeholders in other settings (e.g., health systems, schools, and tourism agencies). Out of this process several potential hurricane forecast communication products were developed. Throughout this work, the NOAA Storm Surge Roadmap, a cross-NOAA program for improving storm surge products and services that includes pertinent experts, provided guidance and review. These exploratory findings then guided the design of formal surveys to solicit opinions from these stakeholder groups (EMs, BRs, and the public) as well as NWS warning coordination meteorologists (WCMs) in the second, largely quantitative phase.[3] The focus was on storm surge, but several current and exploratory wind and track forecast products were also assessed. Only the storm surge findings from these surveys are reported here.

We conducted seven stakeholder surveys. Table 1 summarizes each, including its target population, implementation dates, study area, sample size, response or cooperation rate, and a reference. The surveys are listed in Table 1 left to right in order of temporal implementation but are described here by target populations. Two online surveys gathered the opinions of EMs, key users of NWS tropical cyclone forecast products. The first survey, conducted in 2011, targeted emergency management directors in all counties bordering on the Atlantic and Gulf coasts. The second EM survey expanded the sample in 2012 to include emergency management directors in areas that can be affected by TC or ET storms or both (Morrow and Lazo 2013a,b). Three surveys over a 3-yr period gathered the public's perspective. One surveyed members of the public living in areas subject to TCs who are part of an existing panel, followed by an expanded telephone survey of coastal residents living in areas subject to TCs, ETs, or both (Lazo and Morrow 2014b, 2013).[4] Finally, we conducted a TC and ET survey of

[2] A closely related project on the Hurricane Forecast Improvement Project elicited extensive information on perceptions and communication of storm surge with members of the public through 4 focus groups in Tampa Bay, Florida, in May 2010 with 40 subjects (13 male and 27 female ranging from 21 to 69 yr of age); 4 focus groups in Miami, Florida, in August 2010 with 36 subjects (18 male and 18 female ranging in age from 20 to 63 yr old); and 11 in-depth cognitive interviews (5 male and 6 female ranging from 18 to 70 years of age) in Miami, Florida, in September 2010. Focus group participants were recruited from coastal areas by a research company and received a small remuneration. Further qualitative data were collected through 40 in-depth interviews and one-on-one webinars, discussions with EMs participating in three Federal Emergency Management Agency (FEMA) Hurricane Evacuation Study workshops, and polling at the 2012 AMS Weatherfest and the 2012 National Hurricane Conference.

[3] Closely related concurrent work on two National Science Foundation (NSF)-funded primary research projects on communicating hurricane information ("Warning Decisions in Extreme Weather Events: An Integrated Multi-Method Approach" and "Examining the Hurricane Warning System: Content, Channels, and Comprehension") also helped inform the survey development efforts.

[4] We note that the survey indicated in Table 1 as "TC public online panel survey" conducted in November 2010 does not have a completed report and is listed as Lazo and Morrow (2014b), pending report completion. The survey was implemented in 155 coastal counties from Texas to North Carolina by Knowledge Networks using their proprietary KnowledgePanel, which is designed to be representative of the U.S. population based on probability sampling covering both online and offline populations in the United States.

Table 1. Survey Information

Target population	1. TC public online panel survey	2. TC EM online survey	3. ET–TC public telephone survey	4. ET–TC EM online survey	5. BR online survey	6. NWS WCM online survey	7. ET–TC public online survey
Date	Nov 2010	May–Aug 2011	Sep–Oct 2011	Jun–Jul 2012	Jun–Jul 2012	Jun–Jul 2012	Oct–Nov 2012
Study area	Atlantic and Gulf coasts	Atlantic and Gulf coasts	Atlantic, Gulf, and Pacific coasts; Alaska; Hawaii; USVI	Atlantic, Gulf, and Pacific coasts; Alaska; Hawaii; USVI	Atlantic, Gulf, and Pacific coasts; Alaska; Hawaii; USVI	Eastern, Southern, and Western, Pacific, and Alaska NWS regions	Atlantic and Gulf coasts
Sample size	1,218	53	900	110	51	54	459
Response or cooperation rate	48%	45%	59%	52%	42%	77%	84%
Reference	Lazo and Morrow (2014b)	Morrow and Lazo (2013a)	Lazo and Morrow (2013)	Morrow and Lazo (2013a)	Morrow and Lazo (2013b)	Morrow and Nadeau (2013b)	Morrow and Nadeau (2012a)

people residing within 50 miles of a coastline that included a subsample of those living within 10 miles of the coast. For the latter, a commercial company identified sample e-mail addresses of people who volunteered to be contacted for surveys (Morrow and Nadeau 2013a). Two surveys were completed by meteorologists: one with broadcast meteorologists from local television stations located in coastal areas (Morrow and Lazo 2013c) and one with NWS WCMs located in WFOs serving TC and ET coastal areas (Morrow and Nadeau 2013b). The ET–TC public survey in 2011 was conducted by telephone, and the other six were online surveys because the respondents were usually asked to assess graphics. In total, responses were obtained from 155 coastal EMs, 51 broadcast meteorologists, 54 NWS WCMs, and 2,577 members of the public. (Some EMs participated in both rounds of the EM surveys.) Depending on the survey, respondents lived in or worked in counties bordering the Atlantic, Gulf, or Pacific Oceans or in Puerto Rico, the U.S. Virgin Islands (USVI), Alaska, or Hawaii.

RESULTS. In this section, we provide overall results from the seven surveys on (i) the public understanding of storm surge vulnerability and (ii) expert and lay public preferences for a separate storm surge warning. These were the initial foci of the funded research. Work was extended then to (iii) initial evaluations of storm surge warning text and (iv) storm surge graphics. We then provide (v) general comments about storm surge forecasts in part to indicate potential concerns raised by stakeholders that were not resolved in the current efforts. The project reports as listed in Table 1 and additional manuscripts (Morrow and Lazo 2014; Lazo and Morrow 2014a) provide more information on quantitative analysis. While we have undertaken extensive research as reported here, we also strongly feel that many of these issues should be subject to ongoing or future research as products are developed and implemented.

While the topics and questions, as well as modalities, differed somewhat in each survey, the results, at a minimum, address the extent to which the respondents feel the public understands its storm surge vulnerability and how storm surge forecast communication might be improved for both TC and ET storm surge events. For the latter, most respondents were asked if a separate storm surge warning should be issued and were asked their perceptions and preferences regarding a range of possible text and graphic products that might be used to communicate it.[5] To explore potential storm surge communication products, most were also asked to indicate their preference among three possible inundation maps for conveying location-specific, storm-specific surge forecasts. Many questions were open-ended, allowing stakeholders to make comments. This important information cannot be presented in its entirety, but illustrative quotations are presented along with the quantitative data. (See the references in Table 1 for complete reports on the survey efforts.)

Public understanding of storm surge vulnerability. Most EMs and broadcast meteorologists participating in this research are concerned about the public's lack of understanding of its storm surge vulnerability (Morrow and Lazo 2013a,b,c). In their opinion, many coastal residents lack sufficient knowledge about their vulnerability and do not comprehend the nature of storm surge. Typical EM comments include, "Citizens do not adequately understand the speed in which storm surge can strike" and "[They] don't comprehend their vulnerability to the amount of water that is possible or the power of the water" (Morrow and Lazo 2013a, p. 8). BRs estimate that only 30%–40% of those vulnerable to storm surge adequately understand their vulnerability (Morrow and Lazo 2013c). This appears to have been confirmed when three-fifths of the public said they had never heard or read an estimate of the surge vulnerability in their area. Furthermore, of residents living within 10 miles of a coastline, only 27% thought water from the ocean caused the most deaths associated with hurricanes and coastal storms (Morrow and Nadeau 2013a). Respondents' exact locations were not known, so it was not possible to compare answers with actual vulnerability.[6] Most members of the public were more concerned about damage from winds than storm surge or other flooding. This suggests the need for approaches to better inform the public of their location-specific vulnerability as well as whether or not they are in an evacuation zone.

Separate storm surge warning. Figure 1 shows the responses from six of the seven surveys to questions

[5] The question of whether or not to develop a separate storm surge warning product was the primary focus of the effort funded by NOAA.

[6] Results from other surveys show that about 20% of coastal respondents did not know if they lived in an evacuation zone and that more than 30% of subjects identified as not being an official evacuation zone said that they were (Lazo et al. 2014, manuscript submitted to *Risk Anal.*).

about whether or not the NWS should issue storm surge watches and warnings (this question was not asked in the WCM survey). As shown in Fig. 1, the majority of EMs, broadcasters, and members of the public from areas at risk for TCs as well as ET storms supported NWS issuing a separate warning for storm surge. On the public surveys, 65%–90% supported a storm surge warning. Similarly, expert support varied from 68% to 94% for a separate warning. While well over 50% from all groups, the lowest levels of support (still about two-thirds) were from the first public survey (completed by an existing panel) and the survey of emergency managers from tropical cyclone areas only. The highest levels were from the broadcast meteorologists and the public survey of voluntary Internet users.

When asked if they thought a separate storm surge warning would cause them to take the threat more seriously, 58% of the public responded definitely, with another 32% saying it probably would. Most experts agreed, providing some reasons: "We need to start letting the public know that the Weather Service is decoupling surge from wind speed. The surge threat needs to stand alone and be recognized as the killer it could be" (EM) (Morrow and Lazo 2013b, p. 10); "I believe the general public reacts better to an official storm surge warning than having the potential of the storm surge conveyed independently by a TV station" (BR) (Morrow and Lazo 2013c, p. 11). However, some emergency managers voiced concerns about how this would affect evacuations such as, "I see a minefield here unless done right. People might wait for a surge warning and then it might be too late" (EM) (Morrow and Lazo 2013a, p. 11). Several broadcast meteorologists questioned the state of storm surge forecasting: "I'm not sure the accuracy or the products are good enough at this time" (BR) (Morrow and Lazo 2013b, p. 9). This suggests the need for NOAA to work with EMs and BRs to communicate fully the capabilities and uncertainties in storm surge forecasting so they can make better decisions themselves and better inform others (i.e., the public).

Storm surge warning text. If the NWS issues a storm surge warning, decisions need to be made about how it is communicated in storm forecasts (including what the product is called as the label itself will convey critical information) and how the level of threat is communicated. Asked to assess several wording alternatives, the vast majority of respondents—ranging from 77% of WCMs to 94% of broadcast meteorologists—strongly preferred the terminology "storm surge warning" over wording such as "coastal flood warning" or "extreme coastal flood warning" (Morrow and Nadeau 2013b; Lazo and Morrow 2013; Morrow and Lazo 2013a). One EM observed that people in his area are somewhat desensitized to coastal flood warnings, likely because they are issued for many routine coastal hazards, while a storm surge warning would be reserved for extremely dangerous, life-threatening flooding. A few suggested that other watches and warnings be eliminated: "One of my pet peeves with the Weather Service is that there are too many types of flood watches and warnings, such as Flash Flood, Urban Flood, Areal Flood, and so on. Either an area floods or it doesn't" (BR) (Morrow and Lazo 2013c, p. 11). This suggests a broader need to evaluate the relative importance of all products, as well as legacy products, to ensure that there is not "product overload."

Concerning the datum to use for expressing potential levels of storm surge, most respondents in all stakeholder groups supported it being reported as "above ground level" as opposed to "above sea level." Although the question was not asked the same way in all the surveys, there were suggestions, particularly from the broadcast meteorologists, that it be expressed as "height" rather than "depth" because it refers to water level above ground (Morrow and Lazo 2013c).

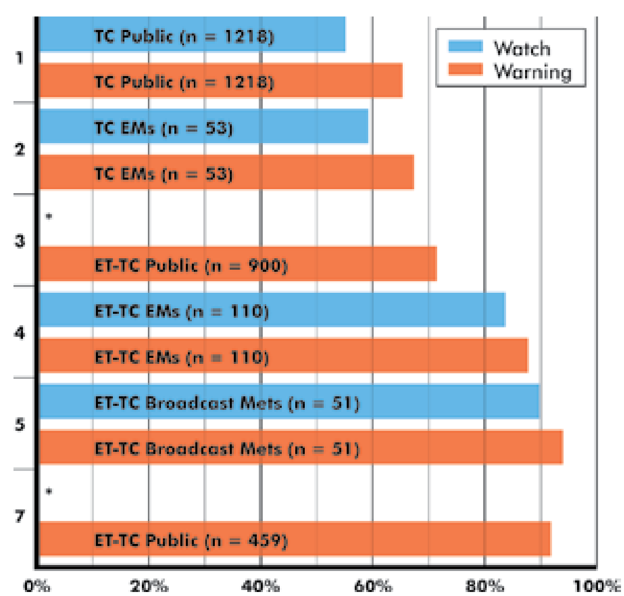

Fig. 1. Percentage of respondents indicating positive support for storm surge watch and warning among various stakeholders; not all surveys included each question. The asterisk indicates that the ET–TC EM survey and ET–TC public online survey did not ask about support for a storm surge watch product. The numbers on the vertical axis identify the surveys as listed in the top row of Table 1.

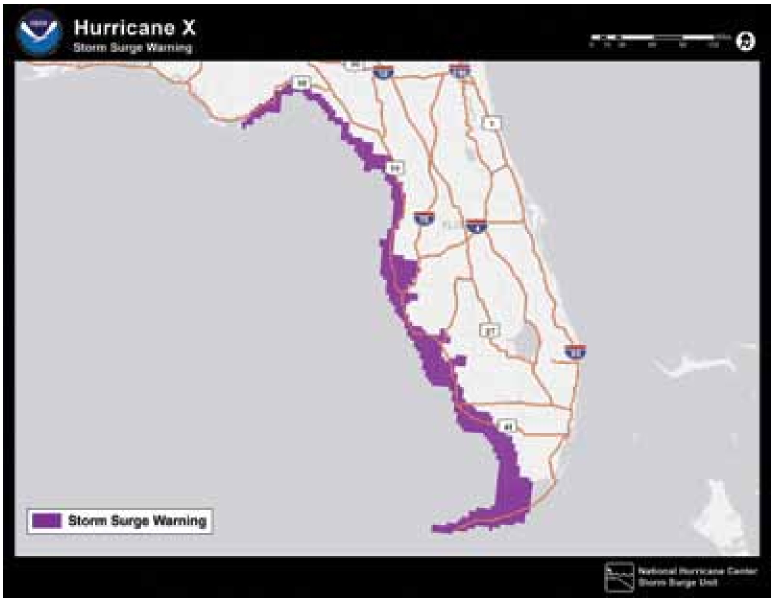

Fig. 2. Prototype of map showing general area under a storm surge warning.

Table 2. Assessment of potential storm surge inundation map based on percentage of survey responses of "excellent," "very good," or "good" (based on a five-point scale).		
	Ease of understanding	**Usefulness**
EMs	86%	84%
Broadcast meteorologists	96%	94%
NWS WCMs	90%	83%
Public	96%	*

* Question was not asked on the public survey.

Storm surge graphics. Four surveys asked respondents to assess several graphics that might be used to convey surge threat. A map developed to illustrate the geographical area under a storm surge warning (Fig. 2) received strong approval from all stakeholder groups (Morrow and Lazo 2013b,c; Morrow and Nadeau 2013a,b). Between 63% (WCMs) and 96% (broadcast meteorologists) felt it was easy to understand. When public respondents were asked to interpret the inundation maps based on specified locations, their assessments of potential surge levels tended to be correct.

The challenge then becomes how to convey in more local detail the varying levels of water that might occur throughout the surge warning area. In the exploratory stage of this work, during one-on-one interviews, focus groups, and webinars, inundation maps showing where potential surge might occur were tested, modified, and retested.[7] Through this iterative process, we qualitatively assessed a range of alternatives and made decisions about background, colors, legend placement, legend text, and landmark use. This process resulted in three prototypes that were then tested empirically in the surveys (see Fig. 3). Each respondent assessed all three maps. On the first map (3A), one solid color (blue) depicted the entire area that might receive any storm surge. For the second (3B), the same color was used but the intensity varied with potential levels of water, lighter to darker indicating increasing water height. For the third (3C), different colors were used to depict four categories of water level.

All stakeholder groups—EMs, BRs, NWS WCMs, and the public—indicated strong preference for the third graphic. When asked to rate it on two criteria, ease of understanding and usefulness, the results from all stakeholder groups were very positive (see Table 2). Comments included, "This multicolored map better explains to people who do not know their elevation" (EM) (Morrow and Lazo 2013a, p. 16) and "clean, useful, easy to understand and TV/Internet ready" (WCM) (Morrow and Nadeau 2013b, p. 20).

Some suggestions for the use of the graphics include, "[We need] tools or products (pictures, animation) that model depth along the coast line and which contain recognizable landmarks" (EM) (Morrow and Lazo 2013a, p. 16) and "consider providing educational materials describing the different levels of potential impact/damage based on structure type . . ." (EM) (Morrow and Lazo 2013a, p. 16).

On the cautionary side, some emergency managers feel that "people will be confused as to where they live and what it could mean at their location" (Morrow and Lazo 2013b, p. 17). Also, "too much detail. People may be tempted to ride it out if they see a map that shows water of 1 or 2 ft as opposed to a general single color map that shows their property being inundated" (Morrow and Lazo 2013b, p. 17). One BR expressed

[7] A related research project yielded additional insights about color and text placement decisions (Sherman-Morris et al. 2012).

the forecasting conundrum: "From my experience providing enough information helps viewers make decisions to protect life and/or property. There is always a struggle between providing too much information and providing too little, but if you don't provide enough, complacency seems to be higher" (Morrow and Lazo 2013c, p. 20).

General comments about storm surge forecasts. An important component of the research process was to allow stakeholders to raise issues affecting the communication of surge risk that were not necessarily contained within the closed-ended questions. Several issues were identified in open-ended comments in the various survey efforts. A common concern was the timing of storm surge forecasts. EM concerns included the following: "Releasing storm surge forecasts 2 days before landfall is practically useless. Evacuations would have been initiated by that time. There are private services that are already providing that information" (Morrow and Lazo 2013a, p. 17); "The NWS doesn't seem to recognize the reality of modern day 24 hours a day media coverage of these events" (Morrow and Lazo 2013a, p. 17); and "The NWS needs to issue storm surge predictions way earlier. I think they are afraid they'll be wrong, but by the time they issue the official forecast, it is largely irrelevant" (Morrow and Lazo 2013a, p. 17). A common BR concern was the time of day of their release, preferring to receive them at least 15–20 min before the hour since their broadcasts usually begin on the hour. These statements point to the need for ongoing discussions between NWS, broadcasters, and EMs as to the timing of information as well as the associated reliability.

Education and outreach activities are essential to successful forecast communication. "A lot of education

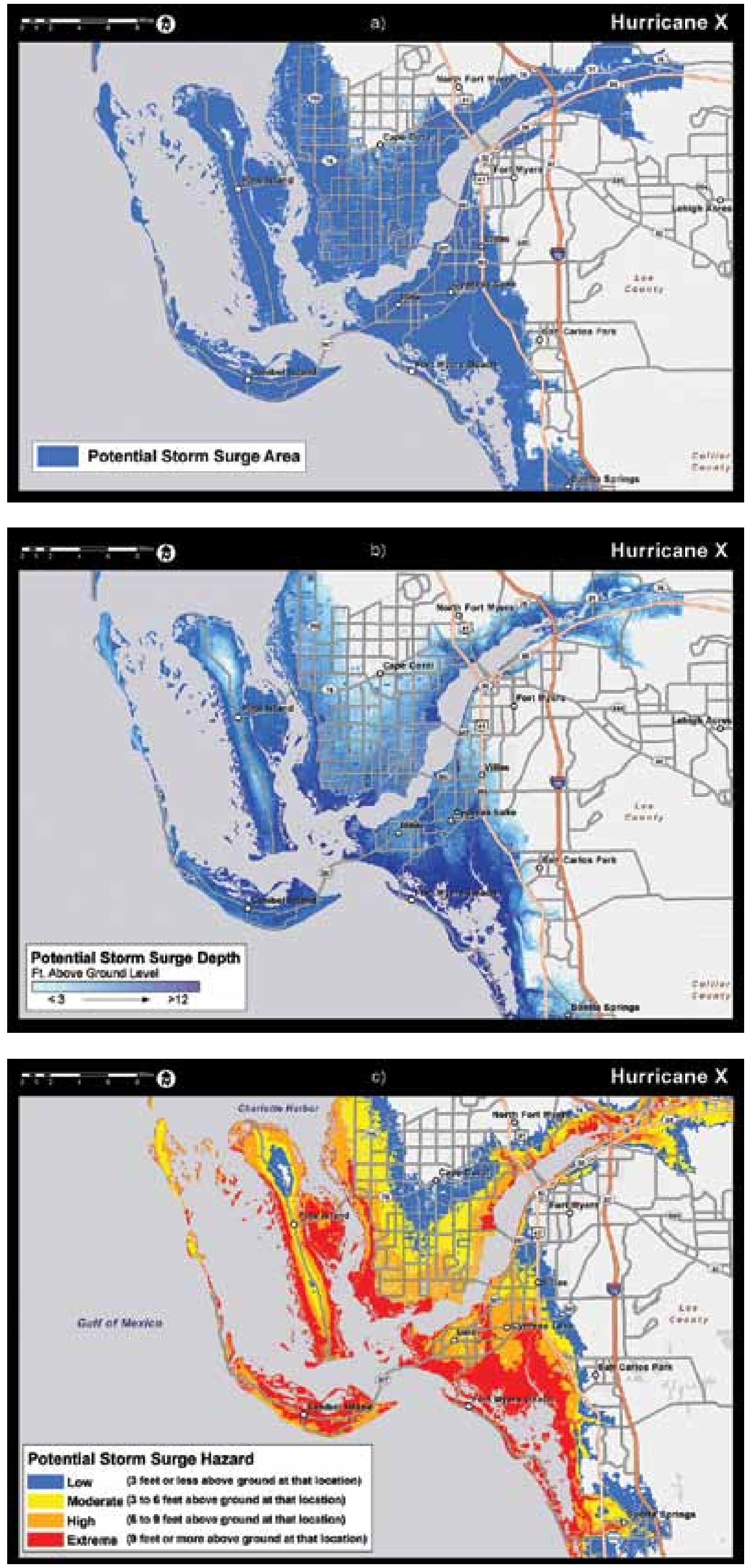

Fig. 3. Prototype maps showing potential storm surge hazard: (a) the entire area at risk for storm surge, (b) a range of potential storm surge depth, and (c) the potential storm surge area divided into four different depth categories.

will be needed—not just on how to use these maps but in learning how emergency managers and other local officials will use these maps" (BR) Morrow and Lazo (2013b, p. 26). There was 85% of the public that indicated that they did not know of any educational materials or programs designed to teach about surge and/or severe coastal flooding (Lazo and Morrow 2013). Several stakeholders offered suggestions for education and outreach related to storm surge. An EM suggested, "Get interactive educational tools in the hands of children in elementary school so they can educate their families" (Morrow and Lazo 2013b, p. 16). A WCM noted, "We should aim to personalize any information we provide" (Morrow and Nadeau 2013b, p. 95). And a member of the public suggested, "How about an app or desktop link that anyone can add to any homepage?" (Morrow and Nadeau 2013a, p. A-47). There were calls for products that could be used immediately to communicate in social media, such as Twitter and Facebook. This suggests that given their different backgrounds and experiences, the broader range of stakeholders likely have innovative ideas for improving storm surge communication.

Summary and discussion. According to findings from the seven surveys, both experts and the public support the NWS issuing storm surge warnings, whether associated with TC or ET cyclones. In fact there was more variation within each stakeholder group than between them. Some of this variation may be explained by different survey formats, modalities, and sampling methods. Experts and laypersons typically possess different mental models of hazard risk (Slovic et al. 2000), but there is some evidence that increased experience with a hazard brings their risk perceptions closer (Li 2009). The bottom line is most of these key stakeholders support a storm surge warning and a storm surge warning area map such as the one shown in the surveys. When presented with three alternatives for depicting levels of surge in local areas, most participants chose an inundation map that defined four levels of surge threat using different colors. An important caveat was whether current science and technology were sufficient to deliver the product with implied accuracy and in a timely manner to be useful for evacuation decision making.

Since this work began, NOAA has instituted several initiatives to improve storm surge forecast communication. A Storm Surge and Coastal Inundation informational website (www.stormsurge.noaa.gov) was launched. NHC officially removed storm surge predictions from the now-called Saffir–Simpson hurricane wind scale and added storm surge educational materials, including videos, illustrations, and terminology to its website (www.nhc.noaa.gov/surge/). Across NWS, WFOs are testing the use of tropical cyclone potential impacts graphics to separately delineate the potential local impacts of wind, coastal flooding, inland flooding, and tornadoes associated with each TC cyclone (http://w1.weather.gov/tcig/). Emergency management and meteorology workshops and training sessions sponsored by the Federal Emergency Management Agency have increased the emphasis on storm surge forecast communication.

Findings from the research reported here have already been used to support relevant NWS decisions. Concern that the label "low" in the legend of the inundation maps might cause some to underestimate their risk resulted in the NHC dropping the labels entirely and just providing the potential amount of water for each level. Another change is that storm surge levels are now being reported in the NHC Tropical Cyclone Public Advisory as "height above ground level." Most important, the storm surge inundation graphic was used on an experimental basis in 2014, and the storm surge watch and warning product has been approved by NOAA for use on an experimental basis in 2015. Rarely do research results from stakeholders inform policy in such a timely manner. Further, this social science work sets an important example, particularly in an era of diminishing resources, by combining funds across several NOAA offices to address critical questions. It also serves as an example of combined qualitative and quantitative research methods, using new technology such as one-on-one webinars to explore issues and develop options that can then be tested empirically.

Moving forward. As product development proceeds, we feel that concerns regarding the timing of products, as well as education and outreach needs, have to be addressed to ensure the effectiveness of storm surge risk communication. We also recognize that there are significant real world constraints with respect to the bureaucratic, operational, and technical framework within which NWS develops and implements forecast information products. The work reported here represents a significant, and perhaps unique, effort on the part of NOAA to empirically elicit stakeholder input as part of product development. Specifically, this work reached out to the relevant stakeholders (EMs, BRs, and the public) rather than relying only on input from self-selecting respondents. Noting that the current research focused on communication related to storm surge, we do feel that evaluation of products should be undertaken as part of a continual assessment of the entire suite of NWS products.

The recommendations of Gladwin et al. (2007) regarding social science research needs for the hurricane forecast and warning system are still applicable, including the need to better understand and target high-risk populations such as the elderly and the search for more effective ways to communicate forecast uncertainty. All of these issues require further work to understand and develop best practices in communicating storm surge risks. Given the complexity of societal response to hurricane risks and the ever-changing nature of vulnerabilities, a dynamic ongoing program from primary research to very applied product assessment is necessary to mitigate the terrible toll tropical and extratropical cyclones can exact on coastal communities.

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