METEOROLOGICAL APPLICATIONS
Meteorol. Appl. **24**: 120–134 (2017)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/met.1611

Perceptions of hurricane hazards in the mid-Atlantic region

Michelle E. Saunders[a]* and Jason C. Senkbeil[b]
[a] *School of Geosciences, University of South Florida, Tampa, FL, USA*
[b] *Department of Geography, University of Alabama, Tuscaloosa, AL, USA*

ABSTRACT: The mid-Atlantic region of the United States is susceptible to tropical cyclone hazards. Within the past 15 years this region has experienced Hurricane Isabel in 2003, Hurricane Irene in 2011 and several tropical storms. The region was also impacted by post-tropical Sandy in 2012. The perception of hurricane hazards among residents of the mid-Atlantic region has not been directly researched. Furthermore, there is a lack of research on the comprehension of information from hurricane warning graphics that influences hazard perception. This research used a total of eight hypothetical scenarios (four pairs) that varied storm track and storm size to assess risk perception of hurricane hazards and characteristics. Each scenario was represented using a four-panelled map featuring the National Hurricane Center's cone of uncertainty, a new storm surge map and a new damaging wind map created by the authors. A Qualtrics survey was used to collect responses to questions about concern for personal harm and evacuation intent. Residents of the region perceived falling trees, potential for damaging winds and the size of the storm to be the greatest threats. Scenarios depicting larger storms with track lines that moved inland were seen as more hazardous, resulting in greater concern and evacuation intent. Coastal residents showed greater concern about distance from the track for all scenarios and greater evacuation intent for larger storms compared to inland residents.

KEY WORDS tropical cyclones; mid-Atlantic region; hazard perception; hurricane warning graphics

Received 26 February 2016; Revised 26 May 2016; Accepted 20 July 2016

1. Introduction

The mid-Atlantic region of the United States does not have a high frequency of tropical cyclones compared to other regions of the United States, but in the past 15 years has experienced Hurricane Isabel in 2003 and Hurricane Irene in 2011, as well as several tropical storms. Post-tropical storm Sandy in 2012 behaved like a hurricane in terms of its hazards, and the destruction it caused pointed to confusion about hurricane warnings which ultimately led to a lack of preparation in the region (Baker *et al.*, 2012). Historically, the mid-Atlantic's average return period for a tropical storm is between 4 and 6 years and for a hurricane between 52 and 105 years (Keim *et al.*, 2007; Zandbergen, 2009). However, this could change in the future as LaRow *et al.* (2014) suggest a 35% increase in the number of named tropical cyclones for the Atlantic, as well as an increase in the number of storm tracks that will impact the US East Coast for the years 2020–2099. If these modelling scenarios are accurate, it is crucial to understand better the hazard perception for hurricanes in this region so that decision makers are able to help residents prepare and potentially evacuate for an impending storm.

The perception of hurricane hazards among residents of the mid-Atlantic region has not been directly researched. Hurricane risk perception and evacuation decisions represent a combination of physical and social factors with a voluminous body of literature. The emphasis of this research is how physical storm characteristics influence risk perception and evacuation intent. Previous research has analysed evacuation decisions associated with hurricane characteristics such as forecast storm intensity, landfall location and storm surge, among others (Zhang *et al.*, 2007; Senkbeil *et al.*, 2010; Matyas *et al.*, 2011; Petrolia *et al.*, 2011). Furthermore, Huang *et al.* (2012) suggest that storm characteristics are some of the prominent variables involved in evacuation decision making. Hurricane intensity, as measured on the Saffir–Simpson scale, was the leading variable motivating tourists to evacuate in hypothetical scenarios in Florida (Villegas *et al.*, 2013). Despite the motivation provided by an increasing number on the Saffir–Simpson scale, Stewart (2011) found evidence that Gulf Coast residents do not understand potential destructive risk. Additionally, Dueñas-Osorio *et al.* (2012) reported that evacuation behaviour was related to surge and wind risk, although this risk was mismatched with overestimation and underestimation especially near waterways. Although coastal Texas residents may have overestimated or underestimated risk, residents of coastal Louisiana generally had accurate perceptions of meteorological hazards in their zip codes and these perceptions were the major reason for evacuating (Brommer and Senkbeil, 2010). Storm characteristics were also particularly emphasized for evacuees of Hurricane Rita as Zhang *et al.* (2007) found that the most popular evacuation responses (28%) listed specific meteorological variables (storm surge, flooding, winds and tornadoes) as motivation for evacuation. Physical storm characteristics are important metrics for assessing personal risk in regions outside the mid-Atlantic accustomed to frequent hurricane activity. The role of physical storm characteristics on risk decision making is unknown for the mid-Atlantic region.

This research has three areas of emphasis: (1) to identify which hurricane hazards residents of the mid-Atlantic find most concerning; (2) to determine if differences in hurricane size cause greater concern for personal risk, and (3) to determine if different hurricane track orientations influence evacuation intent and concern for personal risk for coastal and inland participants. The

* Correspondence: M. E. Saunders, School of Geosciences, University of South Florida, 4202 E. Fowler Avenue, NES 107, Tampa, FL 33620-5550, USA. E-mail: msaunders1@mail.usf.edu

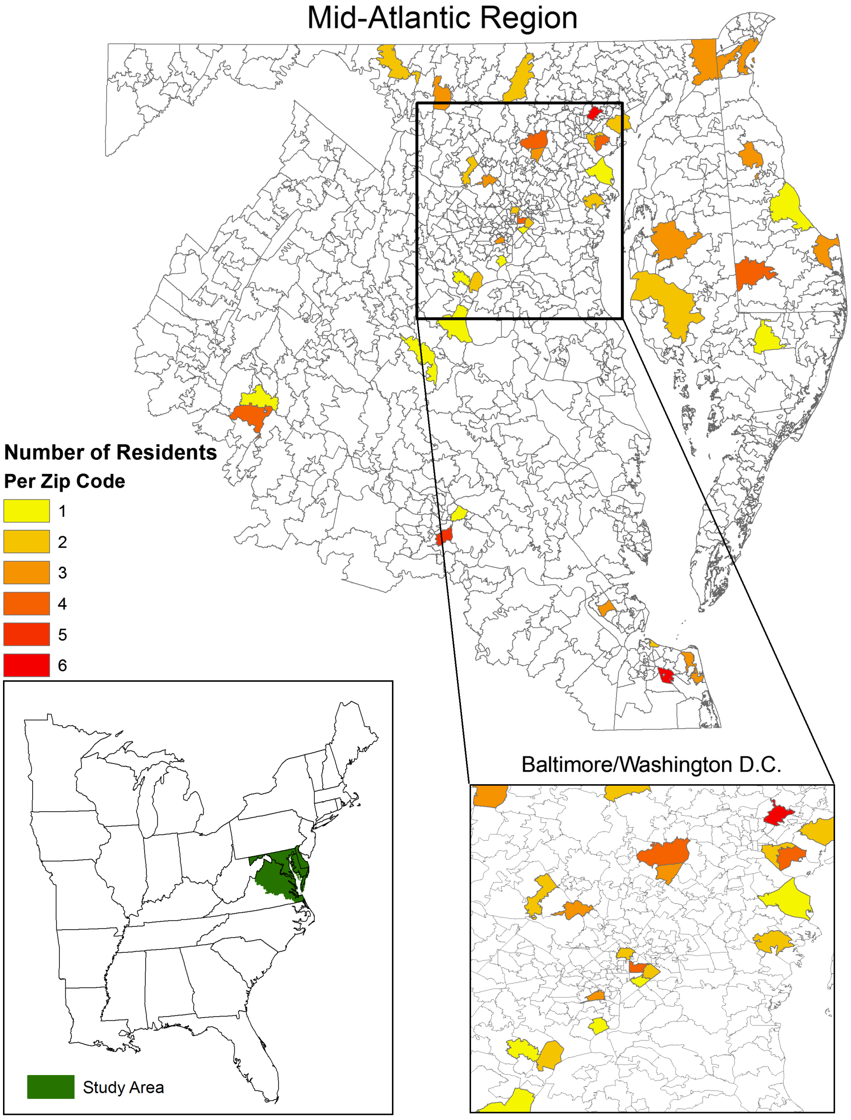

Figure 1. Distribution of zip codes represented by mid-Atlantic participants.

Methods section includes a subsection for each of these objectives, and also subsections for a description of the study area, survey and graphic design, and storm scenario track rationale. The Results section parallels the Methods with a subsection for each of the three objectives mentioned above. A brief Limitations section follows the Results.

2. Methods

2.1. Study area

The study area for this research was within the mid-Atlantic region of the United States, including Delaware, Maryland, Virginia and the District of Columbia (Figure 1). Chesapeake Bay was also of interest as many people reside near its shoreline where storm surge is a factor. Chesapeake Bay is the largest estuary in the United States and has about 50 tributaries (Cho *et al.*, 2012). With an approximate 2010 population of 15 million among these three states, including the District of Columbia, a large number of people are at risk when a hurricane makes landfall in this area (US Census Bureau, 2010).

2.2. Survey development and data collection

A 43 question Qualtrics survey was used to collect a sample of 105 responses from the mid-Atlantic region across three states. Most of the participants were from urban or suburban zip codes, but no metropolitan area was overrepresented (see Figure 1). The authors chose specific zip codes to ensure that Qualtrics could select participants from their database who were also within the study area. Qualtrics required a population of at least 10 000 people in a zip code to increase the chance of a resident being a member of the Qualtrics database. Participants were chosen until demographic targets approximating the regional population were reached and verified by Qualtrics. The locational specificity of our request resulted in a higher cost, thus limiting our sample size to 105 participants. The majority of questions involved eight hurricane scenario graphics and these are explained in the next section. The survey was administered *via* email and took an average of 18 min to complete. There were 14 open-ended and 29 closed-ended questions, and many of the questions could be answered rapidly.

Qualtrics was able to gather a diverse sample allowing for the data to be representative of the study area's population, albeit with a small sample size. Within this study, 75% of the participants were White, 13% Black/African American, 5% Asian, 5% Latino/Hispanic and 2% other. Gender representation was equal. These percentages are close to the averages for the mid-Atlantic according to the 2010 US Census. The Black/African American and Latino/Hispanic populations were slightly under-represented in this study as the averages for the region were approximately 24 and 9%, respectively. The median household income for this study population was around $70 000, which was slightly higher than but close to the mid-Atlantic household median income. The median age was 48 years, and a total of 61% of the sample owned their homes.

The first part of the survey consisted of personal and demographic questions that allowed Qualtrics to fill quotas for the regional population (Table 1). Next, participants were asked if they had experienced tropical cyclones in the past and if so which ones. They were then asked how often hurricane warning graphics played a role in their decision to evacuate before a storm made landfall. The research portion of the survey asked participants to assess their level of concern for eight hurricane scenarios, using the warning graphics described in the next section. They were also asked about their level of concern for seven test variables, which included hurricane hazards and characteristics, using the hurricane scenario warning graphics. The five hazards were storm surge, damaging winds, inland flooding from rainfall, falling trees and tornadoes. The two characteristics were the size of the storm and the distance to the hurricane track. Participants were asked to rate their level of concern using four categories: not at all concerned, slightly concerned, concerned and very concerned (see Table 1). Responses were then fitted to the three primary objectives of overall hazard concern, size concern and track concern for coastal or inland residents.

Storm surge, damaging winds, distance to the track and storm size were assessed using the four response categories for questions about perception from the hurricane warning graphics included for each scenario. Inland flooding from rainfall, falling trees and tornadoes are three hazards that occur during tropical cyclones but were not depicted within our scenario graphics. Although inferred from the graphics, these non-depicted hazards are substantial as from 1963 to 2012 almost 50% of all deadly tropical cyclones had fatalities caused by flooding from rainfall (Rappaport, 2014). Falling trees caused by tropical cyclones accounted for 14% and tornadoes 7% of the 407 deaths from 1995 to 2007 (Schmidlin, 2009). Kribel *et al.* (2014) concluded that trees with larger crowns are more easily uprooted due to strong winds during a hurricane than smaller trees. The mid-Atlantic is home to a number of tree species that have large crowns.

2.3. Graphic development

For this research, a series of eight hurricane scenarios was created using Environmental Systems Research Institute's ArcGIS 10.2 and was presented in the form of four-panelled hurricane warning graphics. These graphics were designed using the current National Hurricane Center (NHC) graphics, wind radii and the Sea Lake and Overland Surges from Hurricanes (SLOSH) surge data (Jelesnianski *et al.*, 1984, 1992; NHC, 2015).

Providing more hazard information was a goal in graphic creation. Making a wrong decision during a disaster most commonly stems from poor information and not a person's inability to process that information (Lindell and Perry, 2012). Furthermore, Severtson (2013) suggests that maps can influence an individual's risk perception and even their behaviour. The convenience of our four-panel format is that it provided all storm hazard information in one graphic. Hurricane hazard information is typically displayed on separate maps with an emphasis on wind speed. Showing participants other hazards in addition to wind speed, in one graphic, allowed them to have a better understanding of the range of hazards they may experience during the storm (Senkbeil *et al.*, 2011).

The graphics used in this study provided participants with a range of hazard information for multiple hurricane scenarios so that they could assess their own level of risk for their location within the study area. This also allowed participants easily to associate the forecasted track with the potential storm surge and damaging winds. Drake (2012) found that there is a disparity between tropical cyclone information provided by forecasters and how the general public perceives that information. By displaying multiple hazard information within the same graphic, the information could be communicated efficiently to reduce time and keep the attention of participants during a long survey. Each scenario depicts the tropical cyclone several days from making landfall using the cone of uncertainty (COU) (Matyas *et al.*, 2011; Radford *et al.*, 2013). The wind radii and storm surge maps were purposefully depicted in the form of forecast maps to show the effect each hazard would have over the study area. This method is currently not available operationally by forecasters; however, similar depictions of potential local storm hazards are found on various weather websites.

A total of four paired hypothetical hurricane tracks was used, each with a large and a small storm. A large and a small storm was included for each track to determine if the size of the storm would influence perception of each cyclone scenario. Storm size is a variable that has received very little attention in risk perception literature. Qualtrics could not accommodate the functionality of randomly shuffling our scenarios since they were paired; therefore, the order remained the same for each participant: A1, A2 through D1, D2. In order to be realistic, each storm track was modelled after a historical hurricane track. The top left panel included the track of the storm with the associated NHC COU. The COU was used in these graphics because it is the most commonly used graphic to depict the probable path of a hurricane and it is used operationally, despite its shortcomings (Broad *et al.*, 2007; Eosco, 2008; Radford *et al.*, 2013).

The top right panel included the track line and the potential storm surge (Figure 2). The surge for these maps used the standard SLOSH format and was modified to show changes in surge resulting in changes in track orientation and hurricane size in each scenario (Irish *et al.*, 2008). Colours were chosen following recent research on storm surge (US Department of Commerce, NOAA NWS, 2015). Furthermore, Morrow *et al.* (2015) surveyed emergency managers who reported a lack in public awareness for storm surge, and Sherman-Morris *et al.* (2015) examined graphical communication for storm surge, finding which colours best conveyed storm surge threat. All of these concepts were applied to the storm surge maps. The bottom left panel included the track line and the potential for damaging winds using wind radii. The radii used for these maps were modelled after previous hurricanes and were used to establish hurricane size. This panel was used to help participants better visualize the size of the storm, and minimize potential misinterpretations of the COU.

The lower right section of each collection of maps contained the legend for all three panels, inspired by the NHC legend. This was used in order to simulate accurately the information that would be publicly available via multiple maps on multiple websites. People are using several sources in evacuation decision making (Sherman-Morris *et al.*, 2011).

Table 1. An abbreviated sample of the 43 survey questions.

Questions	Categories						
1. Zip code	Open						
2. City	Open						
3. Age	Open						
4. Gender	Male	Female	Decline to answer				
5. Race/ethnicity	White	Black/African American	Native American	Asian	Hispanic/Latino	Other	
6. Level of education	High school, no diploma	Regular high school diploma	Some college	Associate's degree	Bachelor's degree	Master's degree	Doctorate degree
7. Occupation	Open						
8. Household income (US$)	0–14 999	15 000–29 999	30 000–69 999	70 000–119 999	120 000+		
9. For the following hazards please assess your level of concern for personal harm or emotional distress for hurricane A1 at your home location							
Storm surge	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Damaging winds	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Inland flooding from rainfall	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Distance to hurricane track	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Tornadoes	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Falling trees	Not at all concerned	Slightly concerned	Concerned	Very concerned			
Storm size	Not at all concerned	Slightly concerned	Concerned	Very concerned			
10. Would you evacuate your home location for hurricane A1?	Binary						
11. Why?	Open						

Questions 9–11 were used and repeated with Figures 2–9 to assess concern for each hurricane scenario.

Another important feature displayed within hurricane warning graphics is the track line. The track line is used to display the most likely future path that the eye of the hurricane will take. One unique characteristic about each of the map panels was that both the storm surge and wind radii maps contained the hurricane track line in addition to the track line displayed within the COU. By including the track line within each map panel, participants would have a better understanding of their threat level for multiple hurricane hazards while maintaining a reference point for where the storm is expected to make landfall without having to reference the COU continually. One drawback to not having the COU would be that participants may perceive the track line as the true path of the storm; however, this was not measured. This method has not been previously applied. Meyer *et al.* (2013) concluded that survey participants who viewed hurricane graphics which contained the track line of a storm showed higher levels of preparation compared to participants who only viewed graphics that did not contain a track line.

2.4. Hurricane scenario explanations

Each scenario was based on a historical hurricane track. Each one was modified slightly to enhance the effects of the storm for the study area but was meant to be realistic. The intensity of each scenario was kept the same, a category 3 hurricane, so that intensity would not be a deciding factor in how people reacted to each storm. Previous research has shown that there is a correlation between intensity and resident evacuation (Whitehead *et al.*, 2000; Lazo *et al.*, 2010; Matyas *et al.*, 2011). Because intensity weakens as a storm makes landfall, each of the hurricane scenarios (A–D) starts as a major hurricane and is downgraded to a hurricane after landfall (Kaplan and DeMaria, 1995, 2001).

While intensity was held constant, size was not. Size was used because it is understudied and also because the mid-Atlantic spans coastal, estuarine, inland, urban and elevated environments all with different hazard potentials. Four track lines were created, each with a large and a small storm that were directly compared. For scenario A, the track line resembles Hurricane Isabel in 2003 (NHC, 2015) (Figures 2 and 3). The Isabel track line would have the potential to bring a large storm surge up the Chesapeake Bay as well as the tributaries both in Virginia and Maryland. Scenario B is modelled after Hurricane Irene which made landfall in 2011. This storm would not have a large storm surge for Chesapeake Bay west of the track line allowing counterclockwise winds to push water down the bay for both scenario B1 (Figure 4) and scenario B2 (Figure 5). Scenario C (Figures 6 and 7) resembles post-tropical Sandy 2012, which was the largest storm out of the eight scenarios. Instead of making landfall in New Jersey, as Sandy did, the track makes landfall in Virginia, near the mouth of the Chesapeake Bay, as a storm surge threat. Scenario D (Figures 8 and 9) was modelled after tropical storm Barry in 2007 which is a common track line for the study area.

2.5. Hurricane hazard concern

The first objective was simply to understand which hazards were of most concern across the entire region before considering scenario impacts. Participants were asked to rate their level of concern for five hurricane hazards (storm surge, damaging winds, inland flooding, falling trees, tornadoes) and two hurricane characteristics (distance to track, storm size). Four options were possible for rating concern: very concerned, concerned, slightly concerned and not concerned. A bimodal distribution resulted from very low numbers of responses in the not concerned and very concerned groups. Therefore, the four categories were combined into two groups, concerned and less concerned.

A Cochran's Q test was used to detect significant differences in the number of participants who were concerned or less concerned for each hazard. Cochran's Q is commonly used in medical research with dichotomous categories. The null hypothesis was

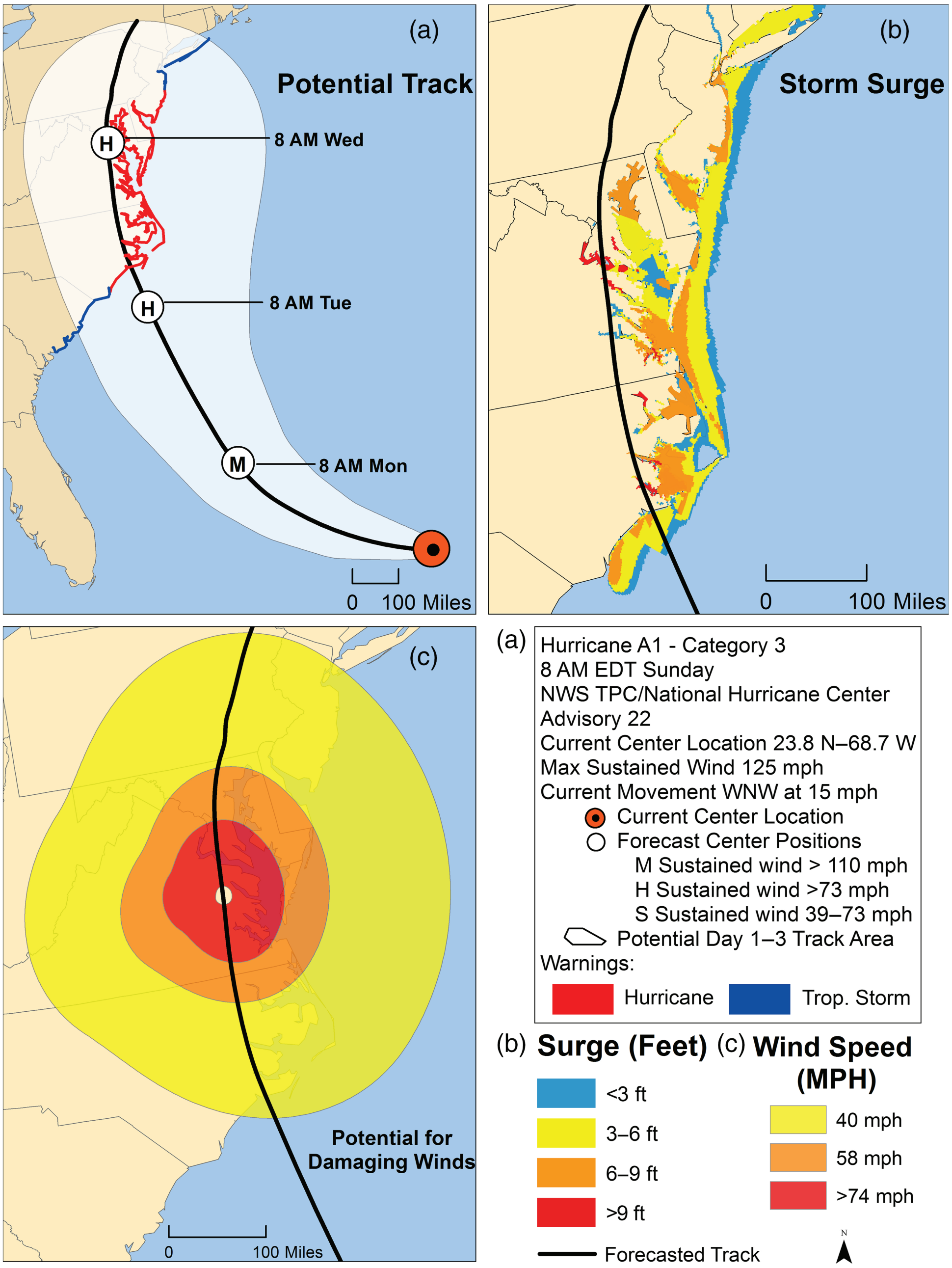

Figure 2. Scenario A1 warning graphic depicting large storm with inland track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

that the level of concern was the same for each hazard across the region. Logically, each participant's location should have influenced the responses to the level of concern for each hazard, and location aspects are addressed in the third objective between coastal and inland residents.

2.6. Hurricane hazard concern based on hurricane size scenarios

As previously described, a total of four paired hypothetical hurricane tracks was used, each with a large and a small storm. Since there were eight hurricane scenarios (A1–D2) with seven test variables, participants were asked to rank their level of concern for each variable in each hurricane scenario using the two collapsed categories of concerned and less concerned. Several McNemar's tests were performed to test for statistically significant differences between levels of concern for paired hurricane scenarios. Mason and Senkbeil (2015) used McNemar's tests to determine the statistical significance of a change in safety decisions based on tornado threat scenarios. Similarly in this research, scenario A1 was directly compared to scenario A2 for changes from concerned to less concerned and less concerned to concerned for each hazard as one example. Additional McNemar's tests were performed to compare each large hurricane scenario (e.g. scenario A1 *versus* scenario B1).

2.7. Hurricane track concern and evacuation intent

Attempts were made to predict level of concern (concerned or less concerned) and evacuation intent (yes or no) using logistic

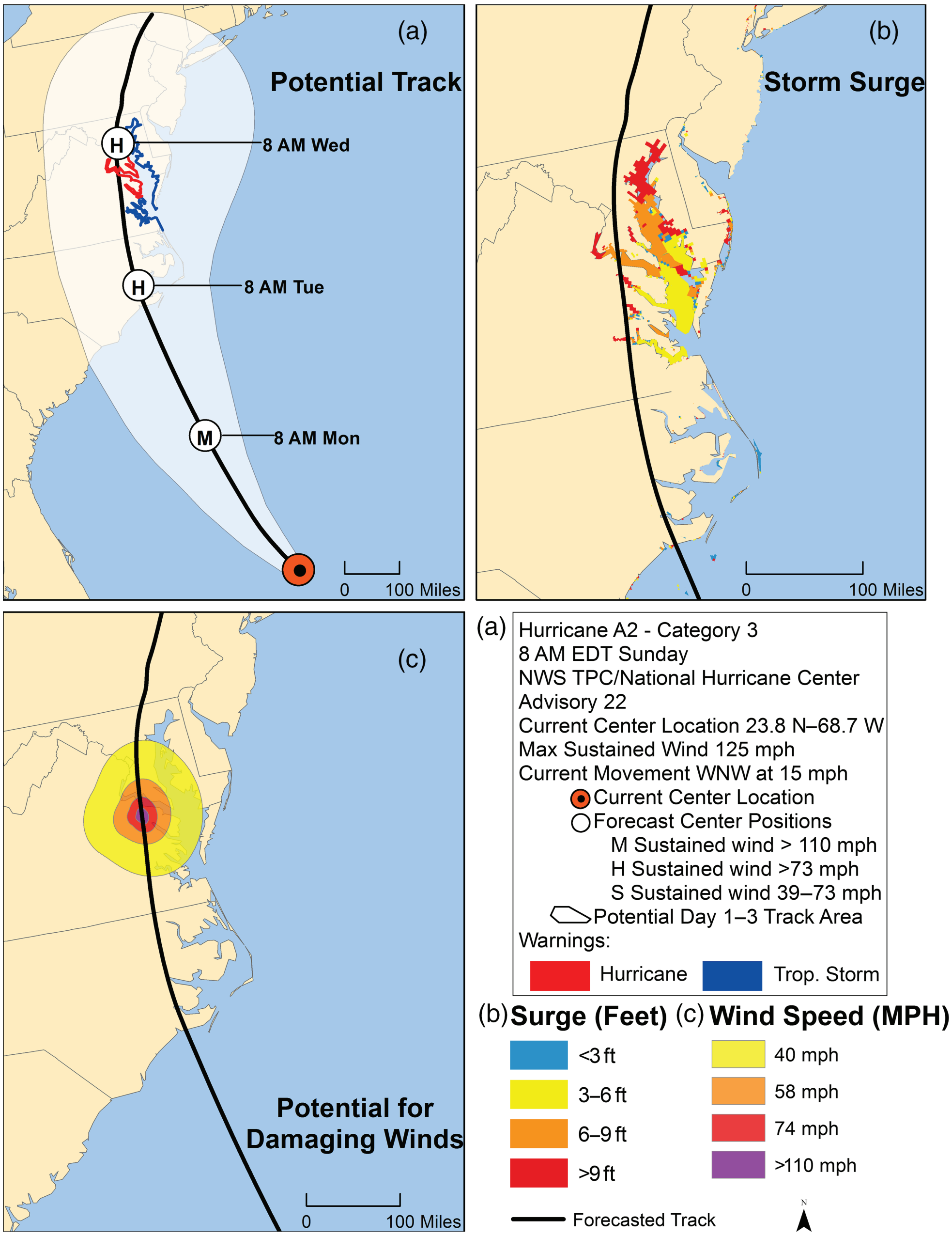

Figure 3. Scenario A2 warning graphic depicting small storm with inland track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

regression with predictor variables of distance from the storm track and demographics. None of the results for these attempts was statistically significant or consistent; therefore, additional procedures were simplified. A few different categories were considered to classify the locations of participants for analysis. From a hazards perspective, the most important factor is whether or not a participant is located in a storm surge or inland flooding zone since most tropical cyclone fatalities are from water hazards (Rappaport, 2000; Czajkowski *et al.*, 2011), and exposure to wind, falling trees and tornadoes is primarily a function of distance from the storm track. The variety of storm tracks depicted in our scenarios ensured that all participants were impacted at least once. Due to the vulnerabilities associated with water hazards, participant locations were categorized either as coastal or inland. A coastal zip code had to contain a coastline on the Atlantic Ocean, Delaware Bay or Chesapeake Bay. This resulted in 34 participants with coastal locations and 71 inland. Zip codes near Newark, Delaware, technically had a Delaware Bay or Chesapeake Bay coastline but this is where the river transitions into the estuary and it was far enough inland to be in that category since the coastal effects were greatly diminished there. Similarly, Stafford, Virginia, was too far up the Potomac River to be considered coastal, and the majority of the population of that zip code is not on the river.

In the previous analysis, the four categories of concern were collapsed into two categories. The emphasis in the previous analysis was on the change in concern between paired scenarios, whereas here it is the level of concern between coastal and inland residents. The four categories were retained with very concerned, concerned, slightly concerned and not concerned ranked 4 to 1. Mann–Whitney U tests were used to explore statistically significant differences in the ordinal level of concern for distance

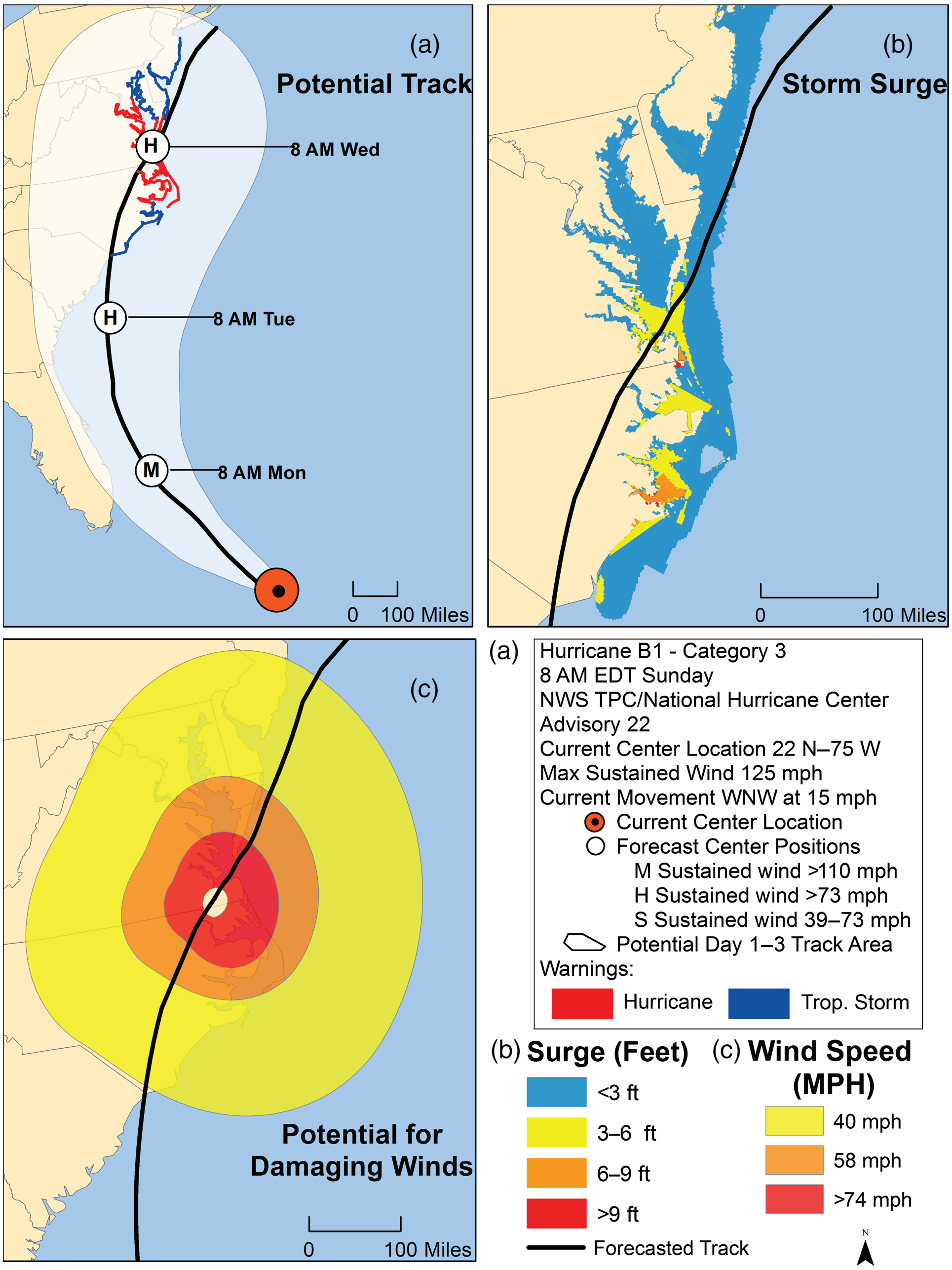

Figure 4. Scenario B1 warning graphic depicting large storm with recurving track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

to the track within each scenario, and for each scenario pair for the unequal group membership between coastal and inland residents. Relationships between level of concern, percentages of evacuation intent and mean distance to the storm track for coastal and inland participants are discussed for each scenario.

3. Results and discussion

3.1. Hurricane experience

When asked about past hurricane experience, 83% of the participants said that they had experienced a hurricane. The most commonly listed storms were Sandy 2012, Irene 2011 and Isabel 2003. Participants were also asked how often hurricane warning graphics played a role in their decision making process for evacuation. A total of 15 participants said they always refer to hurricane warning graphics, 26 said often, 42 participants said they occasionally refer to them and 22 participants never view warning graphics. The number of participants who responded that they never or only occasionally use hurricane warning graphics made up 61% of the participants. This is a stark contrast to the more frequently impacted Pensacola, Florida (Radford *et al.*, 2013).

3.2. Hurricane hazard concern

The first objective of this research was to discover which hazards were the most concerning for mid-Atlantic residents. The Cochran Q test was used to detect significant differences in the number of participants who were concerned or less concerned

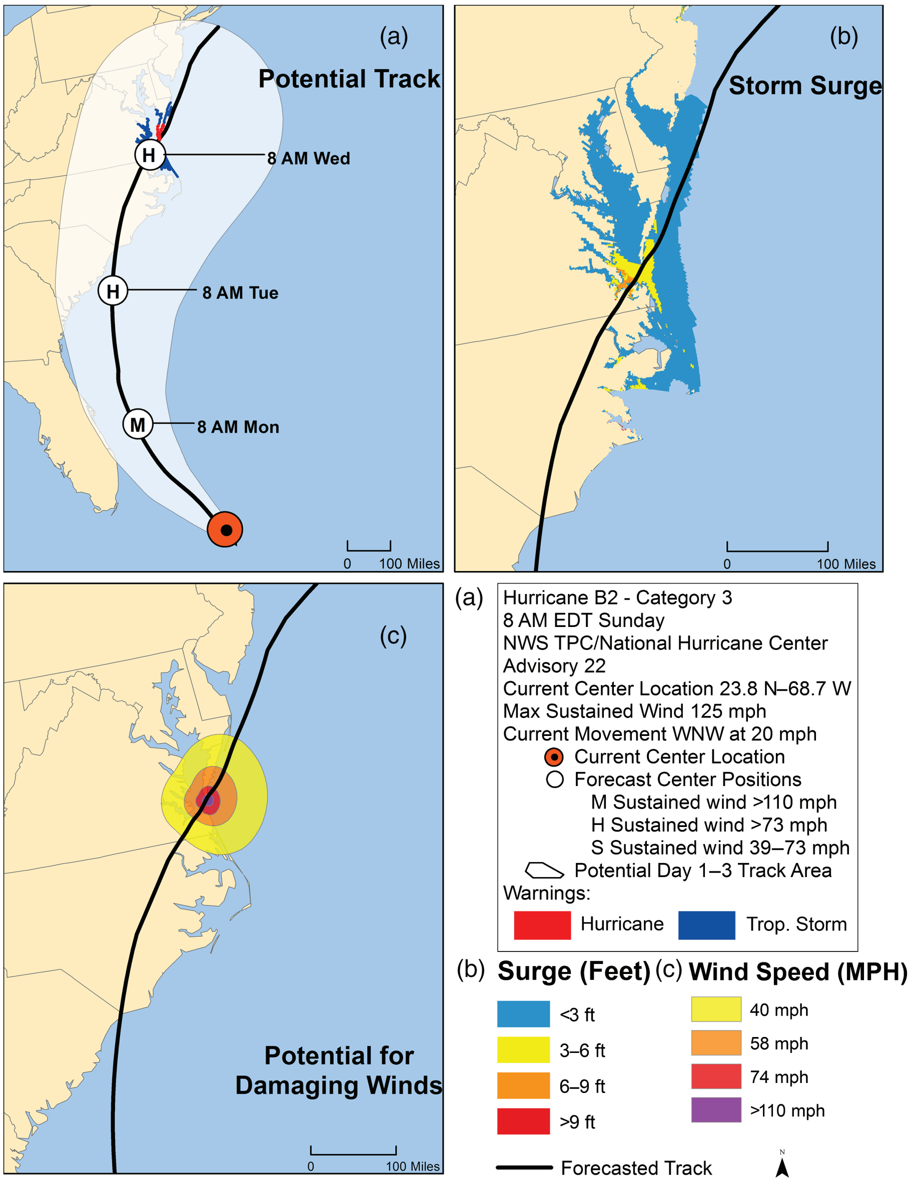

Figure 5. Scenario B2 warning graphic depicting small storm with recurving track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

for each hazard. For each hazard the *p* value was statistically significant at the 0.01 level. This meant that the null hypothesis that the level of concern was the same for each hazard could be rejected. Although all *p* values were significant, Cochran's *Q* value was highest for damaging wind and falling trees and lowest for storm surge, tornadoes and inland flooding. The lower number of coastal participants (34) explains the storm surge finding, but the higher number of inland participants does not explain the lack of concern for inland flooding. Perhaps the inland participants were not in flood prone areas, but street-level information is not available to answer this question. The majority of participants in our sample view wind and falling trees as a stronger threat than other hurricane hazards.

3.3. Hurricane hazard concern based on hurricane size scenarios

Each scenario's large storm was compared to its companion small storm (e.g. A1 to A2, B1 to B2) for differences using McNemar's tests. A Holm–Bonferroni sequential correction (Holm, 1979) was applied to the alpha level of 0.05 to reduce the potential for type I errors. This resulted in 28 tests, four scenario comparisons and seven test variables. In Table 2 and the following tables, results in bold indicate statistical significance after the Holm–Bonferroni correction.

For scenario A, only distance to track was significant at the 0.05 level after correction (Table 2). Participants were more concerned for hazards and characteristics associated with larger storm scenario A1 than A2. A1 was probably seen as more threatening owing to the majority of those surveyed residing within inland zip codes. Storm surge, damaging winds, distance to track, inland flooding, falling trees and storm size for scenario B were all statistically significant (see Table 2). The majority of mid-Atlantic participants were more concerned for hurricane B1 than B2, showing again that the larger storm was more threatening. This storm scenario stayed offshore for the majority of the study area, with the exception of coastal Virginia. Therefore, most participants were less concerned

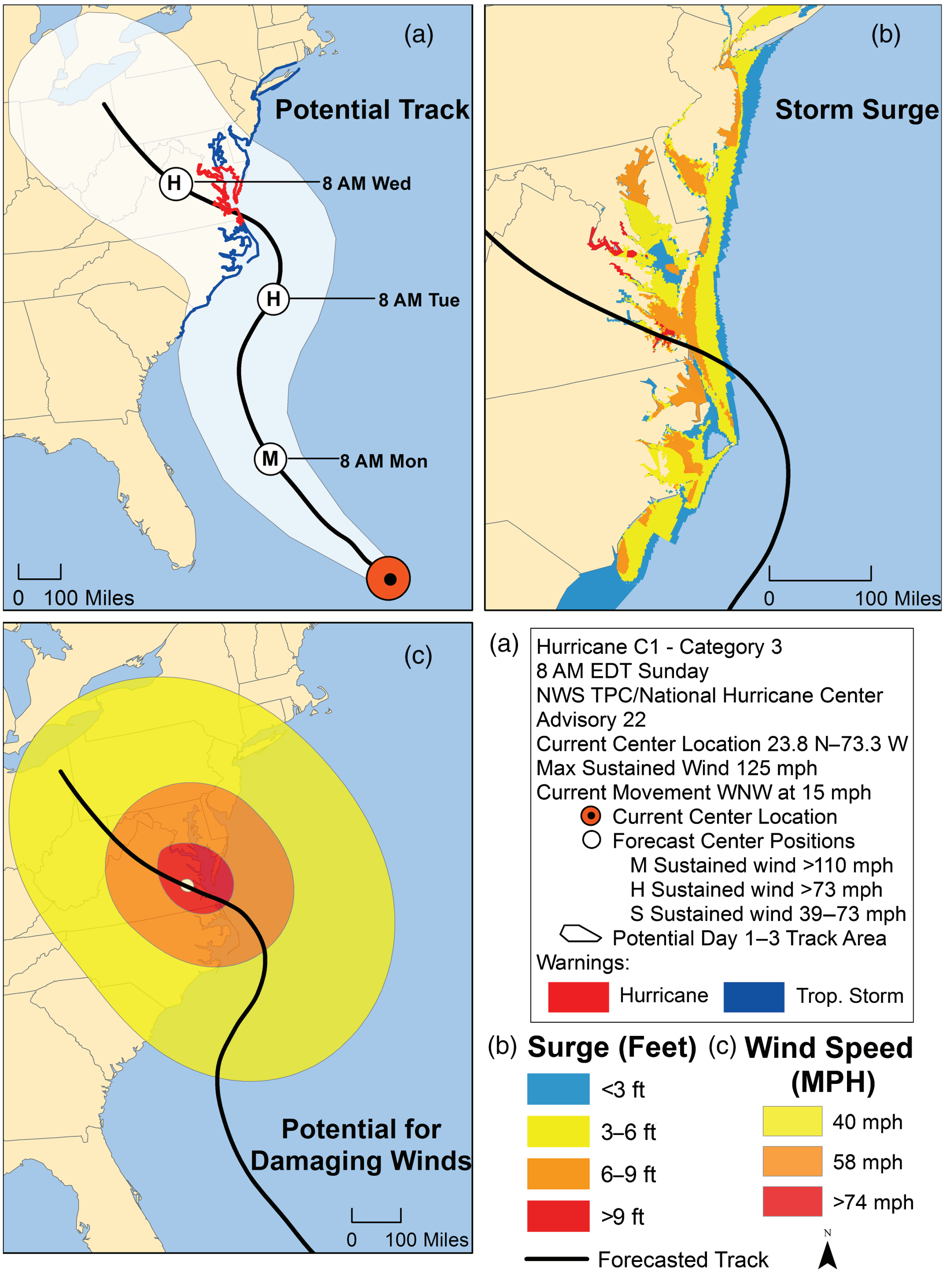

Figure 6. Scenario C1 warning graphic depicting large storm with inland track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

for hurricane B compared to other scenarios both large and small.

Scenario C was the largest storm scenario, designed after post-tropical storm Sandy. The majority of participants were more concerned with hurricane C1 than C2 for each variable, but a large number of participants stayed concerned for both scenarios resulting in no statistical significance. This was most probably due to the orientation of the storm track and the size of the wind radii. Since even the small scenario covers the entire study area, participants would be impacted by both the large and small storm. The results for scenario D were similar to scenario C. For each variable the majority of participants were more concerned with hurricane D1 than D2, with falling trees and storm size being statistically significant. The track of this storm only affects the coastline of the study area and the wind radii do not cover as large an area as other scenarios.

3.4. Large storm comparisons

Since the large storms were more concerning in the previous section, each large storm was compared to the other large storms using 42 McNemar's tests and a Holm–Bonferroni correction as discussed in the previous section. Scenarios A1 and C1 elicited the most concern; thus numerous variables were statistically significant on comparing A1 and C1 to both B1 and D1 (Table 3). This is especially true for scenario D where five of the seven variables were statistically significant with scenario A and all seven with scenario C. However, on comparing scenario A1 to C1 and B1 to D1, there were no significant results (see Table 3) meaning that participants felt similarly about the hazards and characteristics for both pairs of storms. Large hurricanes with direct landfall track orientations (C1) or storms that parallel the coast with an inland track (A1) appear to stimulate the most concern

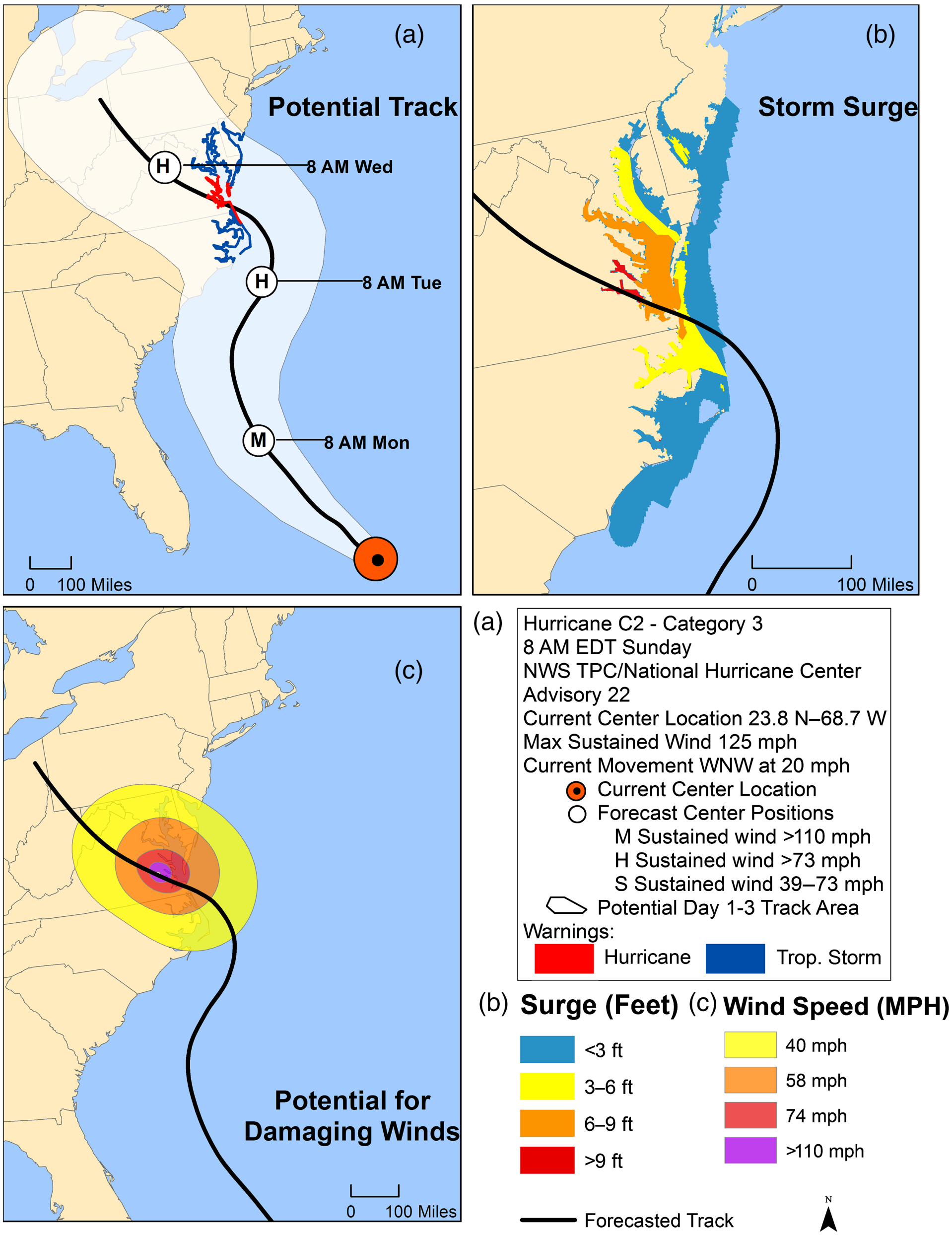

Figure 7. Scenario C2 warning graphic depicting small storm with inland track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

for potential hazards. These results also suggest that a small but powerful hurricane could surprise mid-Atlantic residents who underestimated the associated hazards and characteristics in these scenarios.

3.5. Coastal and inland track perception and evacuation decisions

Each scenario was evaluated using a value between 4 and 1 for coastal and inland participant concern for distance to the track. For each scenario the level of concern was greater for coastal participants, but this was not statistically significant for any individual scenario after Holm–Bonferroni correction (Tables 4 and 5). For each pair of scenarios (e.g. A1 *versus* A2), the distance to the track associated with the larger storm was of greater concern than for the smaller storm even though there was no difference in the track distance (see Tables 4 and 5). There was only one statistically significant result comparing B1 to B2 for inland participants after Holm–Bonferroni correction. Similar to the size comparisons, scenarios A1 and C1 generated the greatest concern and this resulted in the highest evacuation percentages at 47 and 50% for coastal participants (see Tables 4 and 5). Evacuation percentages were higher for coastal participants for all large storms, while the smaller storms had similar or lower evacuation percentages for coastal compared to inland participants.

4. Limitations

There are a few limitations in this research that deserve mention. The sample size of 105 participants in a region of over 15 million is small, but our budget restricted gathering more responses. Despite the relatively small sample size, Qualtrics ensured that the sample represented the mid-Atlantic population as closely

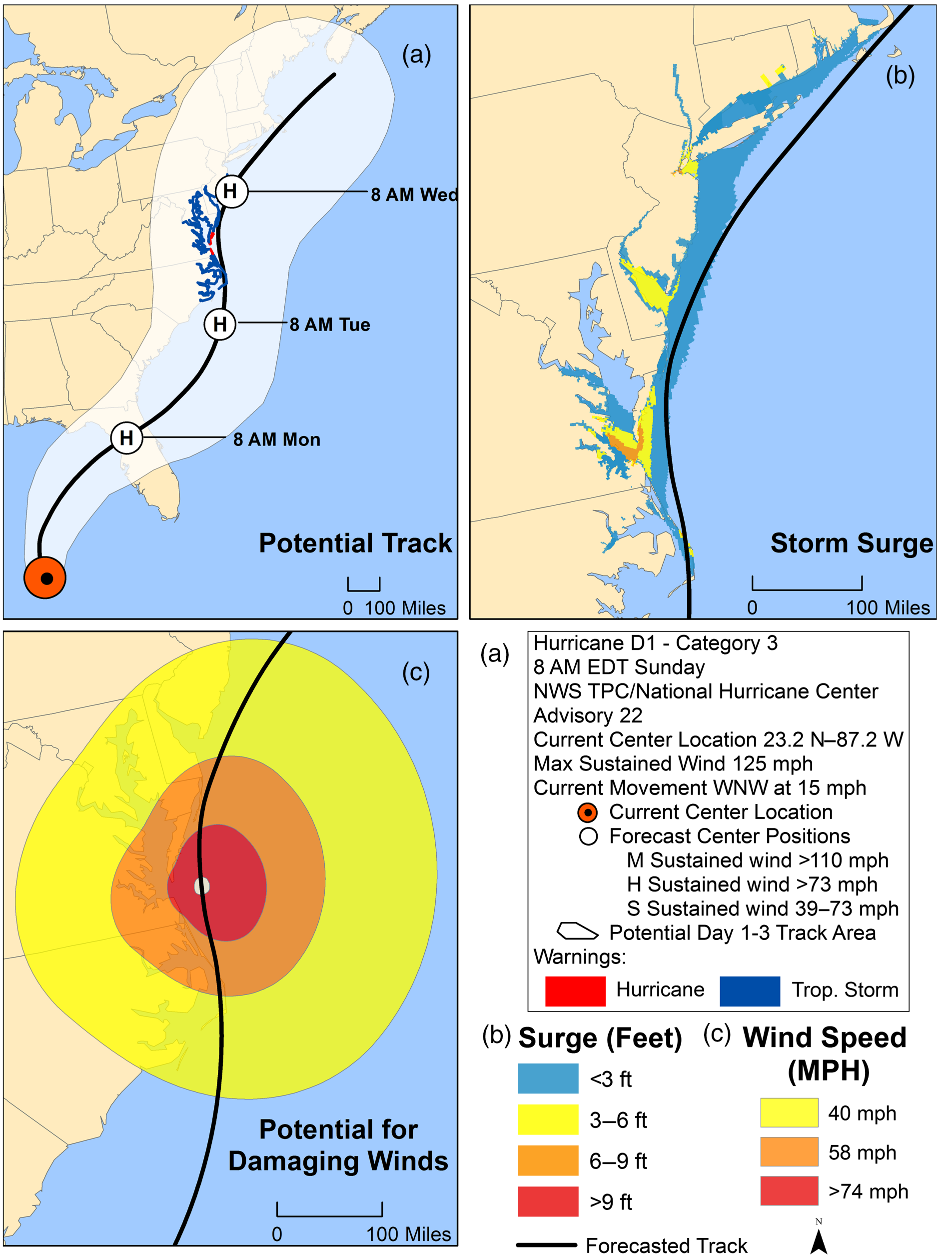

Figure 8. Scenario D1 warning graphic depicting large storm with recurving track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

as possible according to the Qualtrics database of registered members. With an average age of 48 and 61% home ownership, our sample was slightly skewed toward older and higher income members registered in the Qualtrics database.

The adapted version of the COU graphic was one of the panels, but it did not exactly match the official NHC COU, nor were the derived graphics directly compared to current graphics to analyse risk perception. The hurricane graphics and hurricane scenarios were modelled after previous events to be realistic. This could have introduced unintended bias if memories from a negative experience were associated with one of the hurricane tracks. A question about previous hurricane experience was included, but there is no way to determine how a specific experience may have influenced responses to our scenarios. The small storm scenarios display characteristics of concentric storms more commonly seen in the tropics, but these types of storms could be possible in the mid-Atlantic. The paired arrangement of large and small storms with the same tracks A, B, C and D prevented random shuffling of the scenarios to prevent possible order effects. It is hoped that our chosen order of track orientation alternating between a more direct landfall (A and C) with more parallel tracks (B and D) mitigated some of these concerns. There were very subtle differences in scenario pairs that were most likely insignificant for participants making inferences and decisions with an 18 min average completion time for 43 questions. For example, the landfall timing was slightly different for scenarios A1 and A2, and in scenario D there was a latitude and longitude error in the legend. Neither of these errors was noticed by a random sample of 10 graduate students when told to examine and compare each paired scenario for 1 min.

A final limitation was the choice of wording used to evaluate concern and its potential nebulous meaning. Concern about the

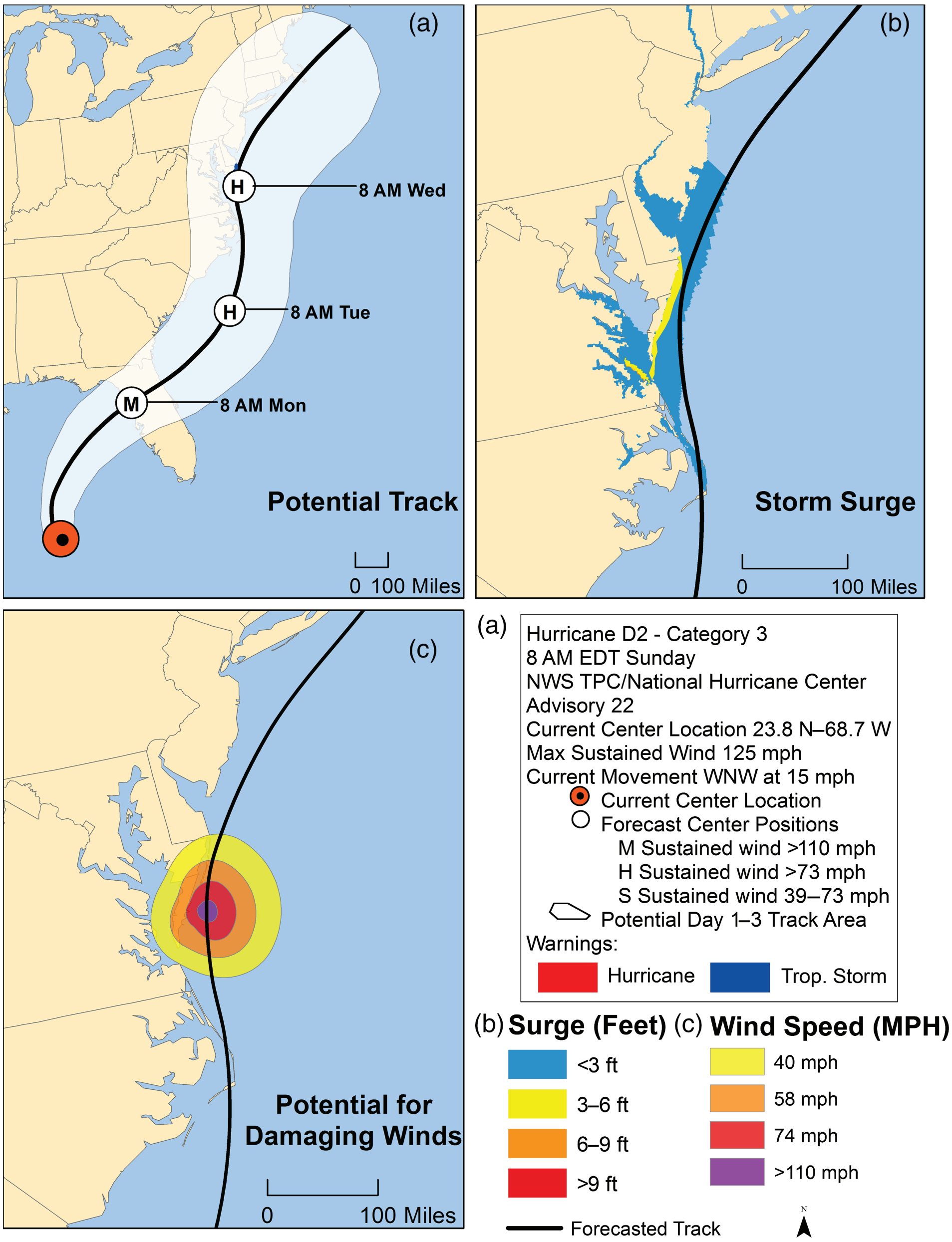

Figure 9. Scenario D2 warning graphic depicting small storm with recurving track. (a) Potential hurricane track with advisory information, (b) Storm surge (feet) and (c) Potential for damaging winds (MPH).

potential for personal harm and concern about emotional distress were considered to be so similar that a participant could not experience one without experiencing the other. In reality, it is possible to experience emotional distress without being concerned about personal or physical harm. These two constructs should have been separated. Since they were not separated, it is not possible to determine the relationship between the two constructs or which played a larger role in the results. The lack of responses in the original categories of not at all concerned and very concerned suggests that neither construct was perceived as being particularly threatening.

5. Conclusion

The mid-Atlantic region of the United States is expected to be more frequently impacted by tropical cyclones in the future (LaRow *et al.*, 2014). Tropical cyclones have historically affected the region with varying intensities, sizes and tracks causing considerably greater damage for certain storms compared to others. In particular, variability in storm size and track may have also introduced confusion about why some storms cause more damage than others since hurricane damage potential is only rated by categorical wind speed on the Saffir–Simpson scale.

In this research, hurricane hazard perception was explored using eight scenarios in four pairs. Each pair of scenarios used the same track, four total tracks, based on historical events. For each pair, the size of the hurricane was presented as a large storm and a small storm with the intensity held constant. Participants were asked to identify which hurricane hazards and characteristics they found most concerning. They were also asked if differences in hurricane size cause greater concern for personal risk for each hurricane hazard, and if different hurricane track orientations influence concern for personal risk and evacuation intent between coastal and inland participants.

Table 2. The *p* values and the number of participants (parentheses) who changed from concerned to not concerned for each paired scenario for each hazard using McNemar's test.

Hazards	*p*	Concerned → not concerned	*p*	Concerned → not concerned
Scenario A1 *vs* A2 test statistics			Scenario B1 *vs* B2 test statistics	
Storm surge	1.00	A1 → A2 (9) / A2 → A1 (9)	**<0.01**	B1 → B2 (17) / B2 → B1 (2)
Damaging winds	0.03	A1 → A2 (20) / A2 → A1 (8)	**<0.01**	B1 → B2 (35) / B2 → B1 (2)
Distance to hurricane track	**<0.01**	A1 → A2 (25) / A2 → A1 (7)	**<0.01**	B1 → B2 (25) / B2 → B1 (7)
Inland flooding from rainfall	0.25	A1 → A2 (17) / A2 → A1 (10)	**<0.01**	B1 → B2 (25) / B2 → B1 (2)
Falling trees	0.01	A1 → A2 (21) / A2 → A1 (7)	**<0.01**	B1 → B2 (28) / B2 → B1 (3)
Tornadoes	0.02	A1 → A2 (17) / A2 → A1 (5)	<0.01	B1 → B2 (18) / B2 → B1 (4)
Storm size	0.01	A1 → A2 (23) / A2 → A1 (7)	**<0.01**	B1 → B2 (27) / B2 → B1 (3)
Scenario C1 *vs* C2 test statistics			Scenario D1 *vs* D2 test statistics	
Storm surge	0.08	C1 → C2 (15) / C2 → C1 (6)	0.31	D1 → D2 (15) / D2 → D1 (9)
Damaging winds	<0.01	C1 → C2 (17) / C2 → C1 (4)	0.02	D1 → D2 (20) / D2 → D1 (7)
Distance to hurricane track	0.01	C1 → C2 (16) / C2 → C1 (4)	<0.01	D1 → D2 (24) / D2 → D1 (7)
Inland flooding from rainfall	0.01	C1 → C2 (18) / C2 → C1 (5)	0.02	D1 → D2 (20) / D2 → D1 (7)
Falling trees	0.04	C1 → C2 (17) / C2 → C1 (6)	**<0.01**	D1 → D2 (23) / D2 → D1 (6)
Tornadoes	<0.01	C1 → C2 (17) / C2 → C1 (3)	0.03	D1 → D2 (19) / D2 → D1 (7)
Storm size	<0.01	C1 → C2 (19) / C2 → C1 (4)	**<0.01**	D1 → D2 (21) / D2 → D1 (5)

Values in bold indicate significance at 0.05 after Holm–Bonferroni correction.

Table 3. As Table 2 but only comparing large storms.

Hazards	*p*	Concerned → not concerned	*p*	Concerned → not concerned
	Scenario A1 *vs* B1 test statistics		Scenario A1 *vs* C1 test statistics	
Storm surge	0.70	A1 → B1 (15) / B1 → A1 (12)	0.05	A1 → C1 (10) / C1 → A1 (22)
Damaging winds	0.01	A1 → B1 (18) / B1 → A1 (5)	0.28	A1 → C1 (12) / C1 → A1 (19)
Distance to hurricane track	**<0.01**	A1 → B1 (28) / B1 → A1 (6)	0.87	A1 → C1 (19) / C1 → A1 (17)
Inland flooding from rainfall	0.21	A1 → B1 (15) / B1 → A1 (8)	0.25	A1 → C1 (10) / C1 → A1 (17)
Falling trees	0.01	A1 → B1 (18) / B1 → A1 (5)	0.84	A1 → C1 (13) / C1 → A1 (11)
Tornadoes	<0.01	A1 → B1 (22) / B1 → A1 (7)	0.59	A1 → C1 (13) / C1 → A1 (17)
Storm size	**<0.01**	A1 → B1 (25) / B1 → A1 (7)	1.00	A1 → C1 (13) / C1 → A1 (14)
	Scenario A1 *vs* D1 test statistics		Scenario B1 *vs* C1 test statistics	
Storm surge	0.10	A1 → D1 (20) / D1 → A1 (10)	<0.01	B1 → C1 (5) / C1 → B1 (20)
Damaging winds	**<0.01**	A1 → D1 (33) / D1 → A1 (7)	**<0.01**	B1 → C1 (4) / C1 → B1 (24)
Distance to hurricane track	**<0.01**	A1 → D1 (34) / D1 → A1 (7)	**<0.01**	B1 → C1 (4) / C1 → B1 (24)
Inland flooding from rainfall	<0.01	A1 → D1 (31) / D1 → A1 (11)	<0.01	B1 → C1 (5) / C1 → B1 (19)
Falling trees	**<0.01**	A1 → D1 (36) / D1 → A1 (8)	0.05	B1 → C1 (8) / C1 → B1 (19)
Tornadoes	**<0.01**	A1 → D1 (32) / D1 → A1 (9)	**<0.01**	B1 → C1 (2) / C1 → B1 (21)
Storm size	**<0.01**	A1 → D1 (36) / D1 → A1 (8)	**<0.01**	B1 → C1 (4) / C1 → B1 (23)
	Scenario B1 *vs* D1 test statistics		Scenario C1 *vs* D1 test statistics	
Storm surge	0.21	B1 → D1 (15) / D1 → B1 (8)	**<0.01**	C1 → D1 (29) / D1 → C1 (7)
Damaging winds	0.05	B1 → D1 (26) / D1 → B1 (13)	**<0.01**	C1 → D1 (38) / D1 → C1 (5)
Distance to hurricane track	0.47	B1 → D1 (18) / D1 → B1 (13)	**<0.01**	C1 → D1 (33) / D1 → C1 (8)
Inland flooding from rainfall	0.02	B1 → D1 (20) / D1 → B1 (7)	**<0.01**	C1 → D1 (34) / D1 → C1 (7)
Falling trees	0.02	B1 → D1 (25) / D1 → B1 (10)	**<0.01**	C1 → D1 (36) / D1 → C1 (10)
Tornadoes	0.17	B1 → D1 (17) / D1 → B1 (9)	**<0.01**	C1 → D1 (32) / D1 → C1 (5)
Storm size	0.09	B1 → D1 (19) / D1 → B1 (9)	**<0.01**	C1 → D1 (34) / D1 → C1 (5)

Values in bold indicate significance at 0.05 after Holm–Bonferroni correction.

The hazards and characteristics that were of most concern overall were damaging winds, followed by falling trees and the size of the storm. Most participants found wind hazards more threatening than water hazards. This region is heavily wooded, therefore validating participants' concern for the threat of falling trees. Neither storm surge nor inland flooding from rainfall was as significant as each of the wind hazards. Because of the smaller number of coastal participants, storm surge was of less concern for this study sample.

Hurricane size and distance to the track were common significant areas of concern for several scenarios. Participants were generally more concerned about the hazards and characteristics associated with larger storms, especially if the larger storms had a track line that moved inland, such as scenarios C1 and A1. For each pair of scenarios, the distance to the track associated with the larger storm was of greater concern than for the smaller storm even though there was no difference in the track distance.

The track or orientation of the storm also influenced decisions about concern and evacuation intent for each hurricane scenario. This was particularly the case for comparisons between coastal and inland participants. Evacuation percentages were higher for coastal participants for all large storms. Similar to the size comparisons, scenarios A1 and C1 generated the greatest concern and this resulted in the highest evacuation percentages at 47 and 50% for coastal participants. According to this research the majority of mid-Atlantic participants would not evacuate for any of our hurricane scenarios. Furthermore, 61% of participants never or only occasionally use hurricane graphics, and evacuation

Table 4. Mann–Whitney *U* results for concern about distance to the track (score 1–4), for mean distance to the track (km), and evacuation percentage for each group for each scenario.

Scenario	Group	*n*	*p*	Mean track concern	Mean track distance	Evacuation percentage
A1	Coastal	34	<0.01	3.15	66	47
	Inland	71		2.66	49	34
A2	Coastal	34	0.26	2.71	66	24
	Inland	71		2.51	49	27
B1	Coastal	34	0.02	2.76	88	38
	Inland	71		2.31	182	24
B2	Coastal	34	0.10	2.21	88	21
	Inland	71		1.89	182	18
C1	Coastal	34	0.26	3.03	118	50
	Inland	71		2.77	154	42
C2	Coastal	34	0.19	2.82	118	29
	Inland	71		2.55	154	34
D1	Coastal	34	0.06	2.50	101	29
	Inland	71		2.11	182	20
D2	Coastal	34	0.12	2.06	101	6
	Inland	71		1.83	182	15

Table 5. Paired scenarios for coastal and inland participants for concern about distance to the track.

Scenario	*n*	*p*
A1 *vs* A2 Coastal	34	0.05
A1 *vs* A2 Inland	71	0.24
B1 *vs* B2 Coastal	34	0.02
B1 *vs* B2 Inland	71	**<0.01**
C1 *vs* C2 Coastal	34	0.29
C1 *vs* C2 Inland	71	0.16
D1 *vs* D2 Coastal	34	0.05
D1 *vs* D2 Inland	71	0.07

Values in bold indicate significance at the 0.05 level after Holm–Bonferroni correction.

intent among this group of participants was 36% for scenario C1 and much lower for all other scenarios. Graphics users indicated evacuation intent of 60% for both scenarios A1 and C1. If the majority of mid-Atlantic residents do not use graphics, where do they get their information and how does this influence their decision making? These questions were not asked because it was assumed that the number of participants using hurricane graphics in this region would not be drastically different from previous research in other regions. An emphasis for future research will be to investigate possible regional differences in information seeking and decision making and how this relates to hurricane graphics. The results from this research suggest that the mid-Atlantic may be particularly vulnerable to a future storm without historical analogues or small but intense storms that make a direct hit and are not perceived to be as hazardous as large storms.

References

Baker EJ, Broad K, Czajkowski J, Meyer R, Orlov B. 2012. Risk perceptions and preparedness among Mid-Atlantic coastal residents in advance of hurricane Sandy. Preliminary Report, Working Paper # 2012-18, Wharton, University of Pennsylvannia: Philadelphia, PA; 44. http://opim.wharton.upenn.edu/risk/library/WP2012-18_EJB-etal_RiskPerceptions-Sandy.pdf (accessed 14 January 2015).

Broad K, Leiserowitz A, Weinkle J, Steketee M. 2007. Misinterpretations of the 'cone of uncertainty' in Florida during the 2004 hurricane season. *Bull. Am. Meteorol. Soc.* **88**: 651–667.

Brommer DM, Senkbeil JC. 2010. Pre-landfall evacuee perception of the meteorological hazards associated with Hurricane Gustav. *Nat. Hazards* **55**: 353–369.

Cho KH, Wang HV, Shen J, Valle-Levinson A, Teng YC. 2012. A modeling study on the response of Chesapeake Bay to hurricane events of Floyd and Isabel. *Ocean Model.* **49-50**: 22–46.

Czajkowski J, Simmons K, Sutter D. 2011. An analysis of coastal and inland fatalities in landfalling US hurricanes. *Nat. Hazards* **59**: 1513–1531.

Drake L. 2012. Scientific prerequisites to comprehension of the tropical cyclone forecast: intensity, track, and size. *Weather Forecasting* **27**: 462–472.

Dueñas-Osorio L, Buzcu-Guven B, Stein R, Subramanian D. 2012. Engineering-based hurricane risk estimates and comparison to perceived risks in storm-prone areas. *Nat. Hazards Rev.* **13**: 45–56.

Eosco GM. 2008. A study of visual communication: cyclones, cones, and confusion. Masters Thesis, Cornell University.

Holm S. 1979. A simple sequentially rejective multiple test procedure. *Scand. J. Stat.* **6**: 65–70.

Huang S, Lindell MK, Prater CS, Wu H, Siebeneck LK. 2012. Household evacuation decision making in response to Hurricane Ike. *Nat. Hazards Rev.* **13**: 283–296.

Irish JL, Resio DT, Ratcliff JJ. 2008. The influence of storm size on hurricane surge. *J. Phys. Oceanogr.* **38**: 2003–2013.

Jelesnianski CP, Chen J, Shaffer WA. 1992. *SLOSH: Sea, Lake, and Over- Land Surges from Hurricane*. National Weather Service: Silver Springs, MD. http://slosh.nws.noaa.gov/sloshPub/pubs/SLOSH_TR48.pdf (accessed 22 January 2015).

Jelesnianski C, Chen J, Shaffer W, Gilad A. 1984. SLOSH – a hurricane storm surge forecast model. *OCEANS*. Washington, DC; 314-317, DOI: 10.1109/OCEANS.1984.1152341.

Kaplan J, DeMaria M. 1995. A simple empirical model for predicting the decay of tropical cyclone winds after landfall. *J. Appl. Meteorol.* **34**: 2499–2512.

Kaplan J, DeMaria M. 2001. On the decay of tropical cyclone winds after landfall in the New England area. *J. Appl. Meteorol.* **40**: 280–286.

Keim BD, Muller RA, Stone GW. 2007. Spatiotemporal patterns and return periods of tropical storm and hurricane strikes from Texas to Maine. *J. Clim.* **20**: 3498–3509.

Kribel JRG, Ware S, Kribel JRG, Ware S. 2014. Hurricane-caused tree loss on permanent plots in a temperate hardwood forest. *South. Appalachian Bot. Soc.* **79**: 1–7.

LaRow TE, Stefanova L, Seitz C. 2014. Dynamical simulations of North Atlantic tropical cyclone activity using observed low-frequency SST oscillation imposed on CMIP5 model RCP4.5 SST projections. *J. Clim.* **27**: 8055–8069.

Lazo JK, Waldman DM, Morrow BH, Thacher JA. 2010. Household evacuation decision making and the benefits of improved hurricane forecasting: developing a framework for assessment. *Weather Forecasting* **25**: 207–219.

Lindell MK, Perry RW. 2012. The protective action decision model: theoretical modifications and additional evidence. *Risk Anal.* **32**: 616–632.

Mason J, Senkbeil JC. 2015. A Tornado watch scale to improve public response. *Weather Clim. Soc.* **7**: 146–158.

Matyas C, Srinivasan S, Cahyanto I, Thapa B, Pennington-Gray L, Villegas J. 2011. Risk perception and evacuation decisions of Florida tourists under hurricane threats: a stated preference analysis. *Nat. Hazards* **59**: 871–890.

Meyer R, Broad K, Orlove B, Petrovic N. 2013. Dynamic simulation as an approach to understanding hurricane risk response: insights from the Stormview Lab. *Risk Anal.* **33**: 1532–1552.

Morrow BH, Lazo JK, Rhome J, Feyen J. 2015. Improving storm surge risk communication: stakeholder perspectives. *Bull. Am. Meteorol. Soc.* **96**: 35–48.

NHC. 2015. NHC data in GIS formats. http://www.nhc.noaa.gov/gis/ (accessed 16 April 2015).

Petrolia DR, Bhattacharjee S, Hanson TR. 2011. Heterogeneous evacuation responses to storm forecast attributes. *Nat. Hazards Rev.* **12**: 117–124.

Radford L, Senkbeil JC, Rockman M. 2013. Suggestions for alternative tropical cyclone warning graphics in the USA. *Disaster Prev. Manag.* **22**: 192–209.

Rappaport EN. 2000. Loss of life in the United States associated with recent Atlantic tropical cyclones. *Bull. Am. Meteorol. Soc.* **81**: 2065–2073.

Rappaport EN. 2014. Fatalities in the United States from Atlantic tropical cyclones: new data and interpretation. *Bull. Am. Meteorol. Soc.* **95**: 341–346.

Schmidlin TW. 2009. Human fatalities from wind-related tree failures in the United States, 1995–2007. *Nat. Hazards* **50**: 13–25.

Senkbeil JC, Brommer DM, Comstock IJ. 2011. Tropical cyclone hazards in the USA. *Geogr. Compass* **5**: 544–563.

Senkbeil JC, Brommer DM, Dixon PG, Brown ME, Sherman-Morris K. 2010. The perceived landfall location of evacuees from Hurricane Gustav. *Nat. Hazards* **54**: 141–158.

Severtson DJ. 2013. The influence of environmental hazard maps on risk beliefs, emotion, and health-related behavioral intentions. *Res. Nurs. Health* **36**: 330–348.

Sherman-Morris K, Antonelli KB, Williams CC. 2015. Measuring the effectiveness of the graphical communication of hurricane storm surge threat. *Weather Clim. Soc.* **7**: 69–82.

Sherman-Morris K, Senkbeil J, Carver R. 2011. Who's googling what? What internet searches reveal about hurricane information seeking. *Bull. Am. Meteorol. Soc.* **92**: 975–985.

Stewart AE. 2011. Gulf coast residents underestimate hurricane destructive potential. *Weather Clim. Soc.* **3**: 116–127.

United States Census Bureau. 2010. Census Bureau quickfacts. http://quickfacts.census.gov/qfd/states/# (accessed 22 January 2015).

US Department of Commerce, NOAA NWS. 2015. Potential Storm Surge Flooding Map.

Villegas J, Matyas C, Srinivasan S, Cahyanto I, Thapa B, Pennington-Gray L. 2013. Cognitive and affective responses of Florida tourists after exposure to hurricane warning messages. *Nat. Hazards* **66**: 97–116.

Whitehead JC, Edwards B, Van Willigen M, Maiolo J, Wilson K, Smith KT. 2000. Heading for higher ground: factors affecting real and hypothetical hurricane evacuation behavior. *Global Environ. Change Part B Environ. Hazards* **2**: 133–142.

Zandbergen PA. 2009. Exposure of US counties to Atlantic tropical storms and hurricanes, 1851–2003. *Nat. Hazards* **48**: 83–99.

Zhang F, Morss RE, Sippel JA, Beckman TK, Clements NC, Hampshire NL, et al. 2007. An in-person survey investigating public perceptions of and responses to Hurricane Rita forecasts along the Texas coast. *Weather Forecasting* **22**: 1177–1190.

