PERCEPTIONS OF HURRICANE HAZARDS

IN THE MID-ATLANTIC REGION

by

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ABSTRACT

The Mid-Atlantic region of the United States is susceptible to many tropical cyclone hazards such as storm surge, damaging winds, and flooding from heavy rainfall. Within the past fifteen years this region has experienced hurricanes Isabel in 2003 and Irene in 2011, as well as several tropical storms. This region was also influenced by post-tropical Sandy in 2012. The perception of hurricane hazards among residents of the Mid-Atlantic region of the United States is currently unknown as there is a lack of research on the comprehension of information from warning graphics. This research uses a total of 8 hypothetical scenarios (4 pairs) that vary each hurricane's track and size to assess hurricane hazard risk perception. Each scenario is represented using a four-paneled graphic 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 created and administered via email, asked Mid-Atlantic residents key questions about their concern for personal harm and evacuation plans. Participants of this survey perceive potential for damaging winds, falling trees, and the size of the storm to be the greatest threats. Both scenarios with track lines that moved inland were also seen as most concerning. Evacuation rates were greatest for each large storm and for both scenarios where the track line moved inland.

DEDICATION

This thesis is dedicated to the future, in hopes that one day fewer lives and properties will be lost due to tropical cyclones.

LIST OF ABBREVIATIONS AND SYMBOLS

b	The number of blocks
df	Degrees of freedom: number of values free to vary after certain restrictions have been placed on the data
ft	Feet
k	The number of treatments
mph	Miles per hour
N	The grand total
p	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
r	Pearson product-moment correlation
t	Computed value of t test
$X_{\bullet j}$	The column total for the j^{th} treatment
$X_{i\bullet}$	The row total for the i^{th} block
X^2	Pearson's chi-square test
<	Less than
=	Equal to

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

The perception of hurricane hazards among residents of the Mid-Atlantic region of the United States is unknown. This region in particular does not have a high frequency of tropical cyclones compared to other regions of the USA, but in the past fifteen years has experienced hurricanes Isabel in 2003 and Irene in 2011, as well as several tropical storms. This region was also hit by post-tropical storm Sandy in 2012, which behaved like a hurricane in terms of its hazards. Historically, the Mid-Atlantic's average return period for a tropical storm is between 4-6 years and for a hurricane between 52-105 years (Keim et al., 2007; Zandbergen, 2009). There are many attempts at modeling the future of hurricane hazards. LaRow et al. (2014) modeled 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 USA East Coast for the years 2020-2099. Mudd et al. (2014) modeled how wind hazards would change due to a changing climate. They found that future wind speeds may increase and extreme events could occur more frequently when they used the RCP 8.5 climate scenario. If these modeling scenarios and other future climate projections are correct, it is crucial to better understand the hazard perception for hurricanes in this region so that residents can properly prepare for an impending storm. Ge, Peacock, & Lindell (2011) suggest that residents are more likely to participate in hazard mitigation incentive programs if they feel they are at risk for a particular hurricane hazard. Gathering the perceptions of hurricane hazards for Mid-Atlantic residents could allow for the introduction of such programs.

There are many hazards associated with a hurricane, best separated for discussion as water and wind hazards which affect both lives and property (Senkbeil et al., 2011). An abundance of forecast information is given to the public as a storm approaches the coastline, some of which might be overwhelming and complex for people to comprehend. If residents are unable to accurately assess risk, they could potentially make a wrong decision when deciding to evacuate from their location when it is unnecessary, or stay at their location when they should evacuate. This research has many objectives but the main emphasis is to identify which hazards residents of the Mid-Atlantic find most concerning at their location and to see if they can assess changes in hazard threats from different storm scenarios. This study assesses a resident's ability to detect changes in their personal level of risk between scenarios in order to understand how people perceive tropical cyclone hazards. This type of hazard perception research has not been evaluated in this particular geographic region. If hurricane frequency for this region increases according to projections, it will be necessary to understand more effective ways to communicate risk.

CHAPTER 2

METHODS

a. Research Questions

This study addresses two main research questions about hurricane hazards perception in the mid-Atlantic:

1) Which geophysical hazards are most concerning?
2) Does level of concern for each geophysical hazard change for different hurricane scenarios?

Level of concern for residents is directly related to risk for personal harm. This was established by including the term “personal harm” within the survey questions so that residents would better understand the type of concern being asked. Understanding which hazards were most concerning to residents is important so that emergency managers can better prepare people for a landfalling hurricane. It also may explain which hazards residents consider to be most threatening for each scenario, and will show if they are correctly comprehending the information found in warning graphics. It was important to see if levels of concern changed between different scenarios of storm track and storm size to determine if residents can accurately assess risk from geophysical hazards. These questions were tested statistically using responses from 8 different hurricane scenarios.

b. Study Area

The study area for this research was the mid-Atlantic region of the United States, which includes Delaware, Maryland, and Virginia (see figure 2.1). The Chesapeake Bay was also of interest as many people reside near its shoreline where storm surge is a factor. The Chesapeake Bay is the largest mixed estuary in the USA and has about fifty tributaries (Cho, Wang, Shen, Valle-Levinson, & Teng, 2012). With an approximate population of 15 million between these three states as of 2012, a large number of people are at risk when a hurricane makes landfall in this area (United States Census Bureau, 2012).

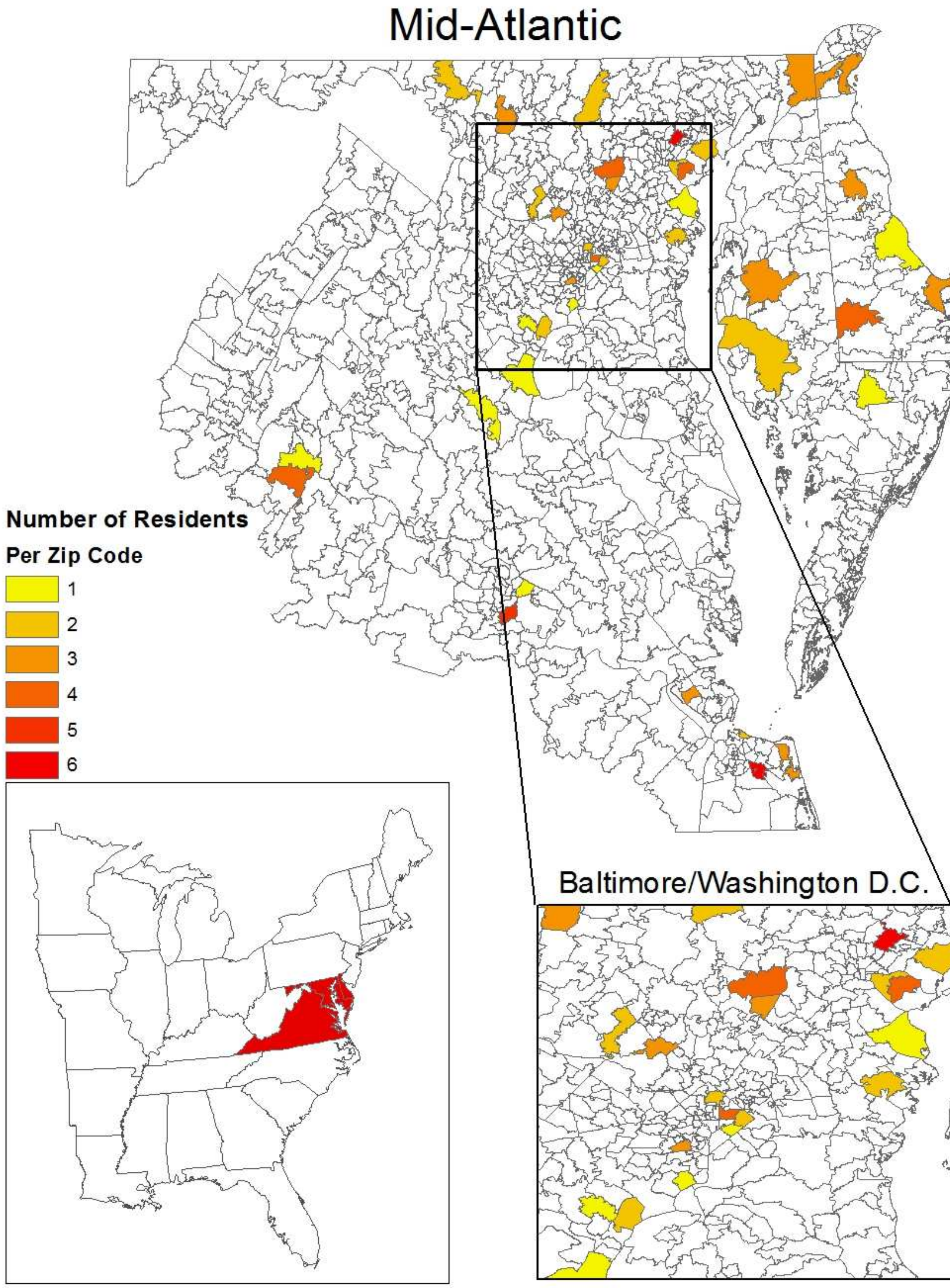

Figure 2.1. Distribution of zip codes represented by Mid-Atlantic participants.

c. *Graphic Development*

The hurricane forecast and warning system is responsible for reducing the number of fatalities caused by hurricanes (Lazo et al., 2010; Willoughby et al., 2007). For this research, a series of eight hurricane scenarios were created in ESRI's ArcGIS 10.2 and were presented in the form of four-paneled 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 (C. Jelesnianski, Chen, Shaffer, & Gilad, 1984; C. P. Jelesnianski, Chen, & Shaffer, 1992; "NHC Data in GIS Formats," 2015). A total of four-paired hypothetical hurricane tracks were used, each with a large and small storm which resulted in the creation of eight maps. A large and small storm was included for each track to determine if the size of the storm would influence perception of each cyclone scenario. Each storm track was modeled after an historical hurricane track to be more realistic. The top left panel included the track of the storm with the associated NHC Cone of Uncertainty. The Cone of Uncertainty, however, has been under scrutiny since its implementation because it does not address the size of the storm and could play a large role in the misunderstanding of information (Broad, Leiserowitz, Weinkle, & Steketee, 2007; Eosco, 2008; Radford, Senkbeil, & Rockman, 2013). The NHC Cone of Uncertainty 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 (Senkbeil et al., 2011).

The top right panel included the track line and the potential storm surge. The surge for these maps used the standard SLOSH format and was modified only to show changes in surge resulting in changes in track orientation in each scenario. Colors were chosen following new research on storm surge which has led to a new watch and warning system for storm surge that will be operational during the 2015 hurricane season (US Department of Commerce, NOAA, 2015). Morrow & Lazo (2014) surveyed emergency managers who reported a lack in public awareness for storm surge and requested more visual aids to communicate storm surge. Sherman-Morris, Antonelli, & Williams (2015) examined graphical communication for storm surge, finding which colors represented storm surge best. Irish et al. (2008) discussed how a large storm will have a greater total surge area with a smaller peak surge value, and a smaller storm will effect a smaller area but will have a greater peak surge value. This concept was applied to our storm surge maps. The Intergovernmental Panel on Climate Change's fifth assessment report, (2014) projects sea level rise to likely increase between 0.26 and 0.55 m (RCP 2.6) and rise between 0.45 and 0.82 m (RCP 8.5) at a medium level of confidence for the remainder of the 21st century. With an increase in sea level, storm surge levels would also increase which would have a direct impact on the Chesapeake Bay and the Mid-Atlantic coastline (USCCSP, 2009; Williams, 2013).

The major components of a tropical cyclone are its winds located in the outer rain bands and inner core (McDONALD, 1935; Willoughby & Black, 1996; Emanuel et al., 2006; Lee & Bell, 2007; Powell & Reinhold, 2007). The bottom left panel included the track line and the potential for damaging winds using wind radii. The radii used for these maps are also modeled after previous hurricanes and were used to establish hurricane size. This panel was used to help participants better visualize the size of the storm. The wind radii map was also included to help minimize the misinterpretations of the Cone of Uncertainty.

The lower right section of each collection of maps contained the legend for all three maps, inspired by the NHC legend. This was used in order to accurately simulate 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).

The convenience of our 4-panel format is providing this information in one graphic. Surge graphics and wind radii varied depending on the orientation of hurricane track and size. Hurricane hazard information is typically displayed on separate maps with an emphasis on wind speed. Showing the public other hazards in addition to wind speed, in one graphic, allowed them to have a better understanding of what they would experience during the storm (Senkbeil et al., 2011). This also allowed the public to easily associate the forecasted track to the potential storm surge and damaging winds. Additionally, it made our Qualtrics survey more time-efficient by consolidating the number of graphics to display all geophysical hazards for each 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 the eye of the hurricane will take. One unique characteristic about each of our 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, residents would have a better understanding of their threat level for multiple geophysical hazards while maintaining a reference point for where the storm is expected to make landfall without having to continually reference the COU. This method had not been previously applied. Meyer et al. (2013) concluded that survey participants that viewed hurricane graphics which contained the track line of a storm showed higher levels of preparation as compared to participants who only viewed uncertainty cone graphics that did not contain a track line. However, other research has shown that there is a personal landfall bias when residents are assessing hurricane hazard graphics with a track line. This shows that people are more likely to think that the storm will impact their location (Senkbeil et al., 2010). Even if a resident's location falls within the cone, there may be a false sense of safety if the track line is not directly forecasted to be over their location (Broad et al., 2007). By including the wind radii graphics, residents would be able to view the hurricane size, alerting that they could still be effected by winds even if they are not near the track line.

d. Survey Development and Data Collection

A Qualtrics survey was created to ask participants about their personal levels of concern for seven geophysical hazards for each scenario. Qualtrics is a survey software company which the University of Alabama is a subscriber and has a site license. Qualtrics has a registered database of over six million users who take online surveys for small monetary or gift card compensation.

Specific zip codes were selected from the Qualtrics database to ensure that survey participants lived within the study area. Each zip code required a population of at least 10,000 people in order to be selected to increase the chance of a participant being a member of the Qualtrics database. Zip codes were also selected so that they would not be spatially clustered; so that each part of the study area would be represented. Using these selected zip codes, participants were chosen from the Qualtrics database until demographic targets were reached. A total of 8 screener questions were created and used to help collect a representative sample of the population. A sample of 105 Mid-Atlantic residents was collected. Our survey had a total of 43 open and closed-ended questions. It was administered via email and took an average of 18 minutes to complete.

In the first part of the survey participants were asked a total of 8 screener questions. These screener questions consisted of the survey consent/information form, their zip code, city, age, gender, race/ethnicity, level of education, occupation, and household income (see Table 2.1). These questions allowed Qualtrics to fill demographic quotas in order to collect a sample that was representative of the population. Participants were asked if they had experienced a tropical cyclone in the past and if so which ones. Past experiences are important because they can be perceived in different ways by different people (Dillon et al., 2013). This could help to explain why residents perceive the same hazard differently for the same tropical cyclone. They were then asked how often hurricane warning graphics played a role in their decision to evacuate before a storm made landfall. The main portion of the survey asked participants to assess their level of concern for each hurricane scenario and for seven different geophysical hazards using the hurricane scenario warning graphics (see Table 2.2). The hazards were storm surge, damaging winds, distance to the hurricane track, inland flooding from rainfall, falling trees, tornadoes, and the size of the storm. Participants were asked to rank their level of concern using four categories: not at all concerned, slightly concerned, concerned, and very concerned.

Storm surge, damaging winds, distance to the track, and storm size were assessed using the hurricane warning graphics included for each scenario. Inland Flooding from rainfall, falling trees, and tornadoes are three hazards that can also occur during a tropical cyclone, but were not depicted within our scenario graphics. Although inferred from the graphics, these hazards are still important as from 1963-2012 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 1995-2007 (Schmidlin, 2009). Kribel et al. (2014) concluded that large trees that have larger crowns are easier to be uprooted due to strong winds during a hurricane than smaller trees. The Mid-Atlantic is home to a great number of tree species that have large crowns that contribute to large basal areas. (Comiskey, 2012) states that the Mid-Atlantic is a forested ecoregion and is therefore a major habitat for local wildlife. Our study area is home to several different ecoregions including the Central

Appalachian Broadleaf Forest, the Eastern Broadleaf Forest, the Outer Coastal Plain Mixed Forest and the Southeastern Mixed Forest.

e. Hurricane Scenario Explanations

Each scenario is based on an historic hurricane track. Each one was modified slightly to enhance the effects of the storm for the study area, but are meant to be realistic using the Saffir-Simpson Scale (SSHS). The intensity of each scenario was kept the same, category 3 hurricane, so that it would not be a deciding factor in how people reacted to each storm. Since intensity weakens as a storm makes landfall each of the hurricane scenarios (A-D) start as a major hurricane and are downgraded to a regular hurricane once it makes landfall.

While intensity was held constant, size was not since size is understudied and also because the Mid-Atlantic spans coastal, estuarine, inland, urban, and elevated environments all with different hazard potential. Four track lines were created, each with a large and small storm. For scenario A, the track line resembles hurricane Isabel that made landfall in North Carolina in 2003 ("NHC Data in GIS Formats," 2015) This track makes initial landfall in North Carolina and tracks north through Virginia, Maryland and then Pennsylvania. This 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 A1 (figure 2.2) covers a large section of the East Coast. It has an extensive area of storm surge and the wind radii cover the entire study area. Scenario A2 (figure 2.3) covers a much smaller area of coastline. The storm surge is greater but is concentrated within the bay. This storm was positioned in order to funnel water up the bay due to the counterclockwise nature of a tropical low pressure system. The wind radii do not cover the entire study area. Scenario B is modeled after hurricane Irene which made landfall in 2011. This track makes landfall around the South Carolina, North Carolina border and moves northeast, cutting across the mouth of the Chesapeake Bay and brushing the eastern shores of Virginia, Maryland, and Delaware. This storm would not have a large storm surge for Chesapeake Bay on the west of the track line allowing counterclockwise winds to push water down the bay for both scenario B1 (figure 2.4) and B2 (figure 2.5). Scenario C’s track line resembles post-tropical Sandy, which made landfall in 2012 and is the largest storm out of the eight scenarios. The main modification made to this track line is the landfall location. Instead of making landfall in New Jersey the track makes landfall in Virginia, just under the mouth of the Chesapeake Bay. This track would have the potential to force a large surge up the bay. This storm also would cover a large area, effecting every participant in this study. Scenario C2 (figure 2.7) is smaller than C1 (figure 2.6) but still covers the entire study area. Scenario D, which was modeled after tropical storm Barry, 2007, cuts across the Outer Banks in North Carolina and then scrapes the eastern shores of Virginia, Maryland, and Delaware. Scenario D1 (figure 2.8) would have low surge and the winds would only impact the Eastern Shore and some areas on the mainland of Virginia and Maryland. Scenario D2 (figure 2.9) would only impact the Eastern Shore and coastal Virginia.

Table 2.1. The eight screener survey questions used to collected demographic data.

Question	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	0-14,999	15,000-29,999	30,000-69,999	70,000-199,999	120,000 +		

Table 2.2. Survey question example for Mid-Atlantic residents.

Question	Categories			
1. 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
Distance to Hurricane Track	Not at all Concerned	Slightly Concerned	Concerned	Very Concerned
Inland Flooding from Rainfall	Not at all Concerned	Slightly Concerned	Concerned	Very Concerned
Falling Trees	Not at all Concerned	Slightly Concerned	Concerned	Very Concerned
Tornadoes	Not at all Concerned	Slightly Concerned	Concerned	Very Concerned
Storm Size	Not at all Concerned	Slightly Concerned	Concerned	Very Concerned
2. Would you evacuate your home location for hurricane A1?	Binary			
3. Why?				

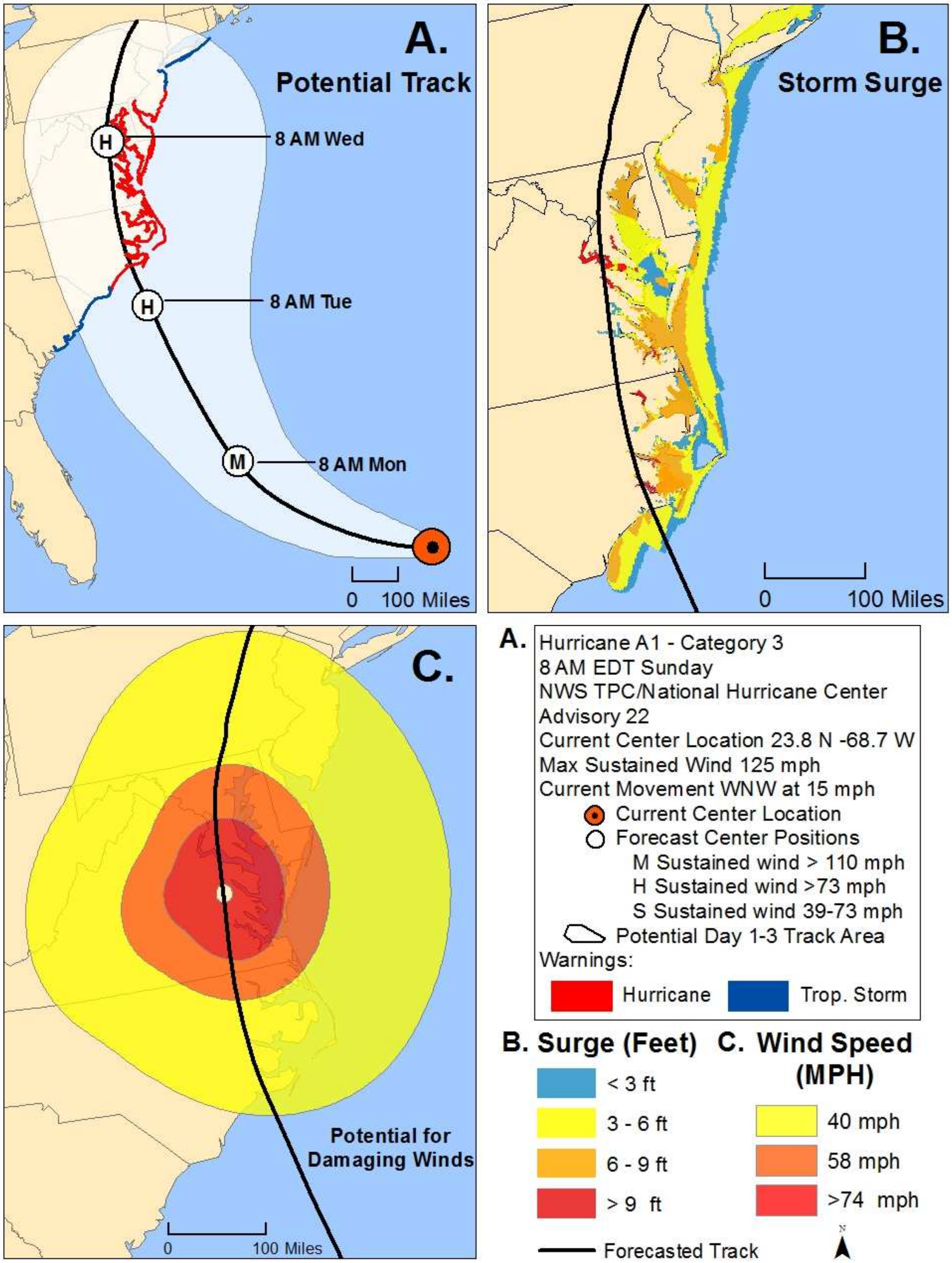

Figure 2.2. Scenario A1.

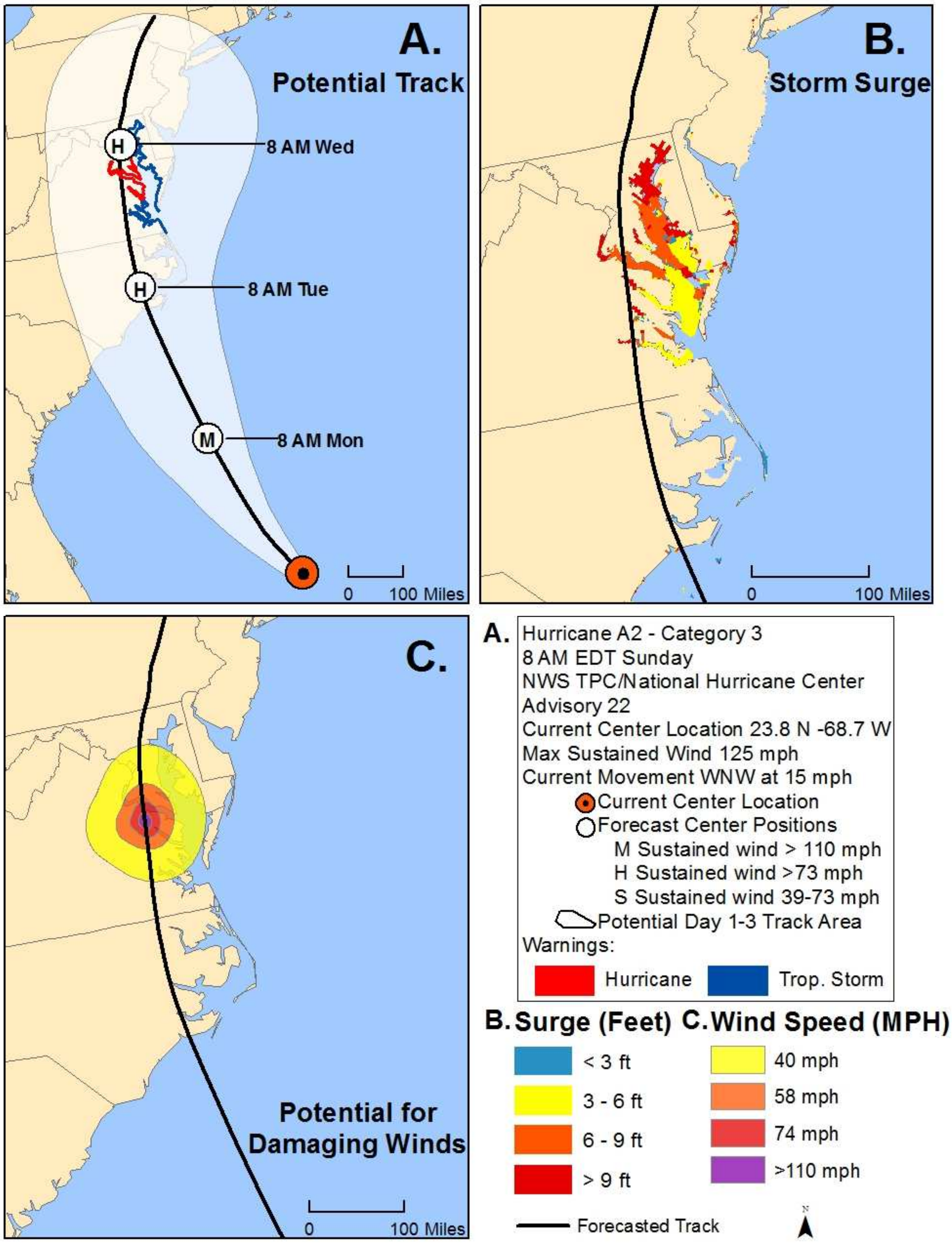

Figure 2.3. Scenario A2.

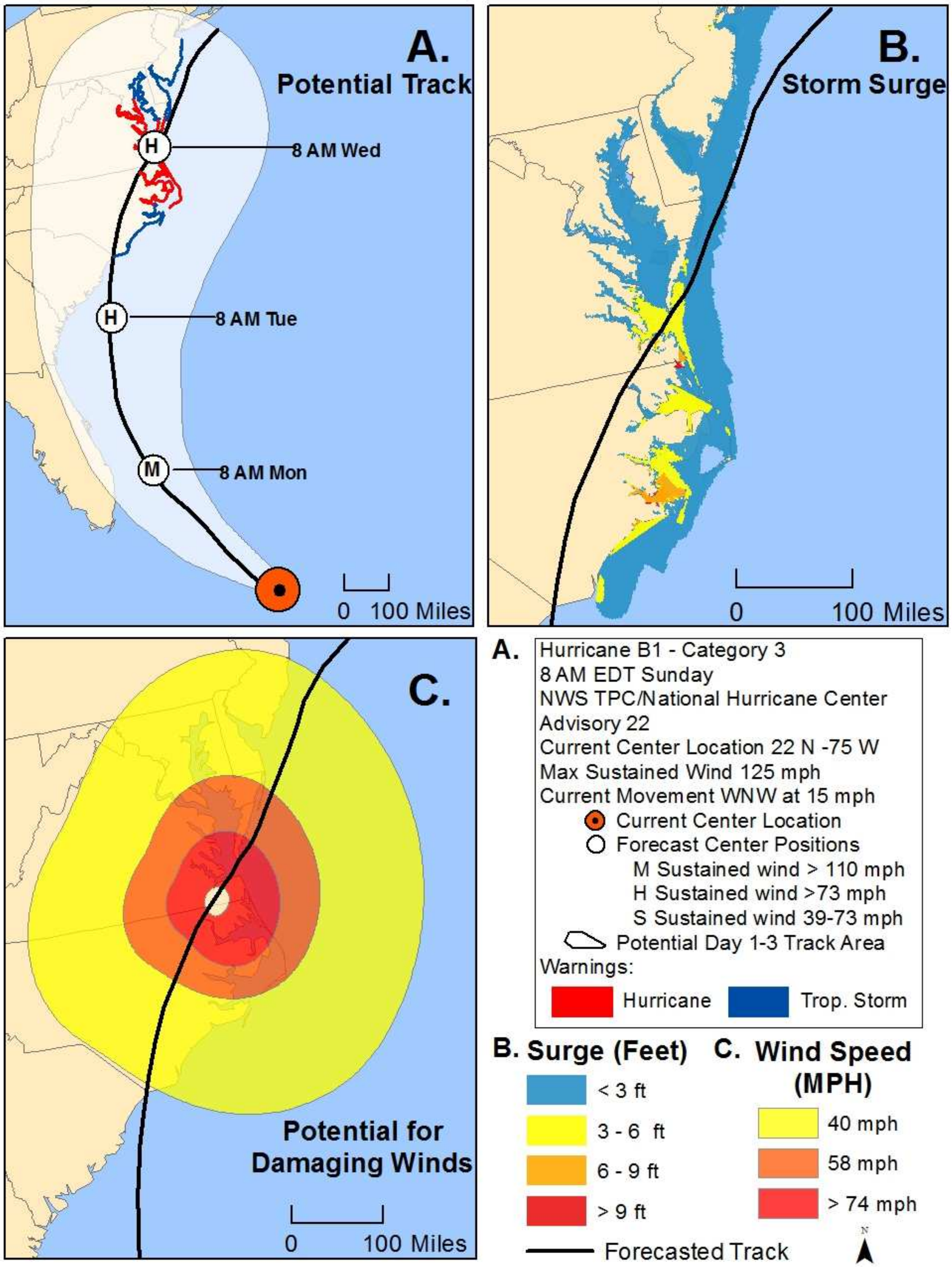

Figure 2.4. Scenario B1.

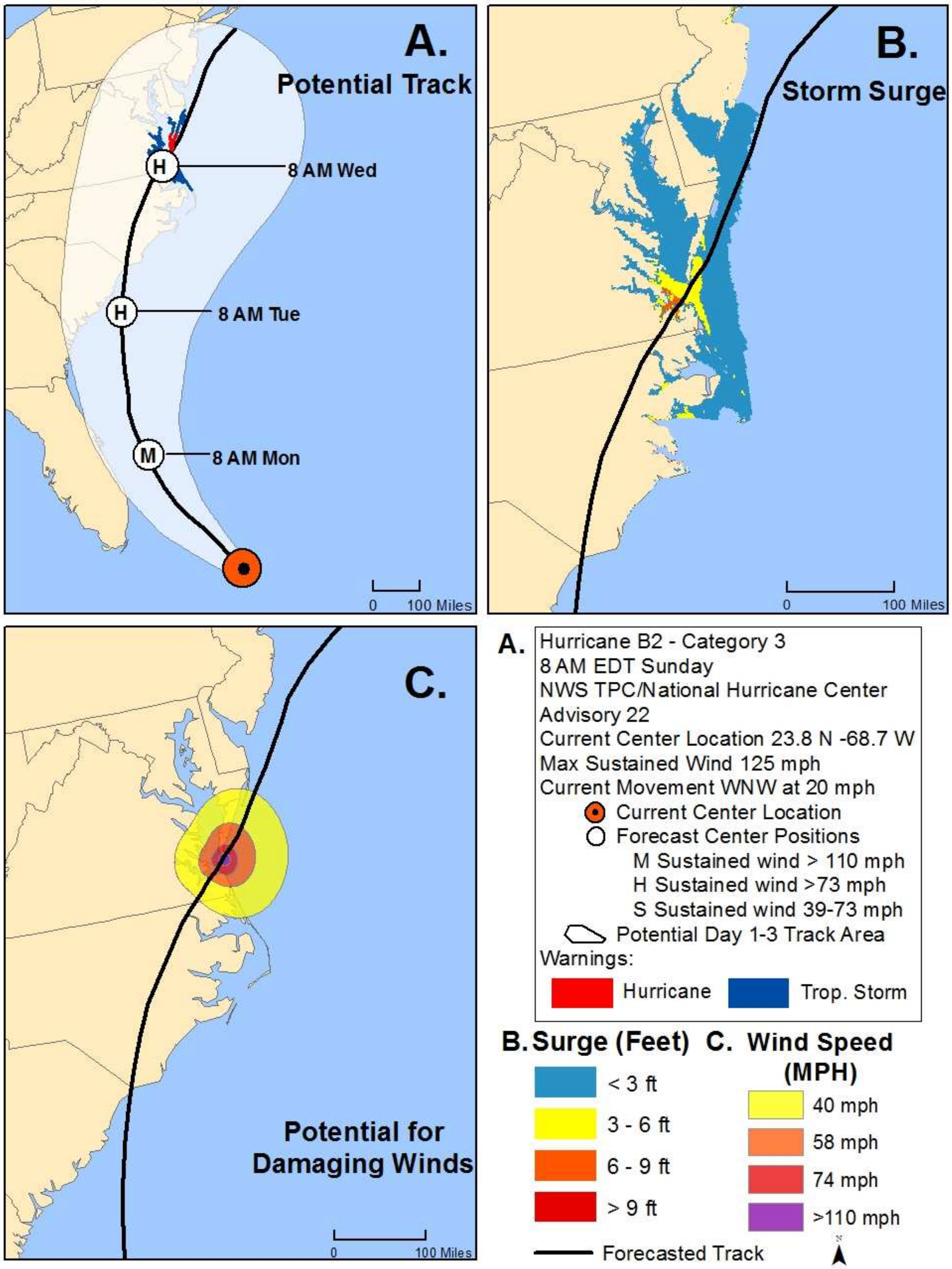

Figure 2.5. Scenario B2.

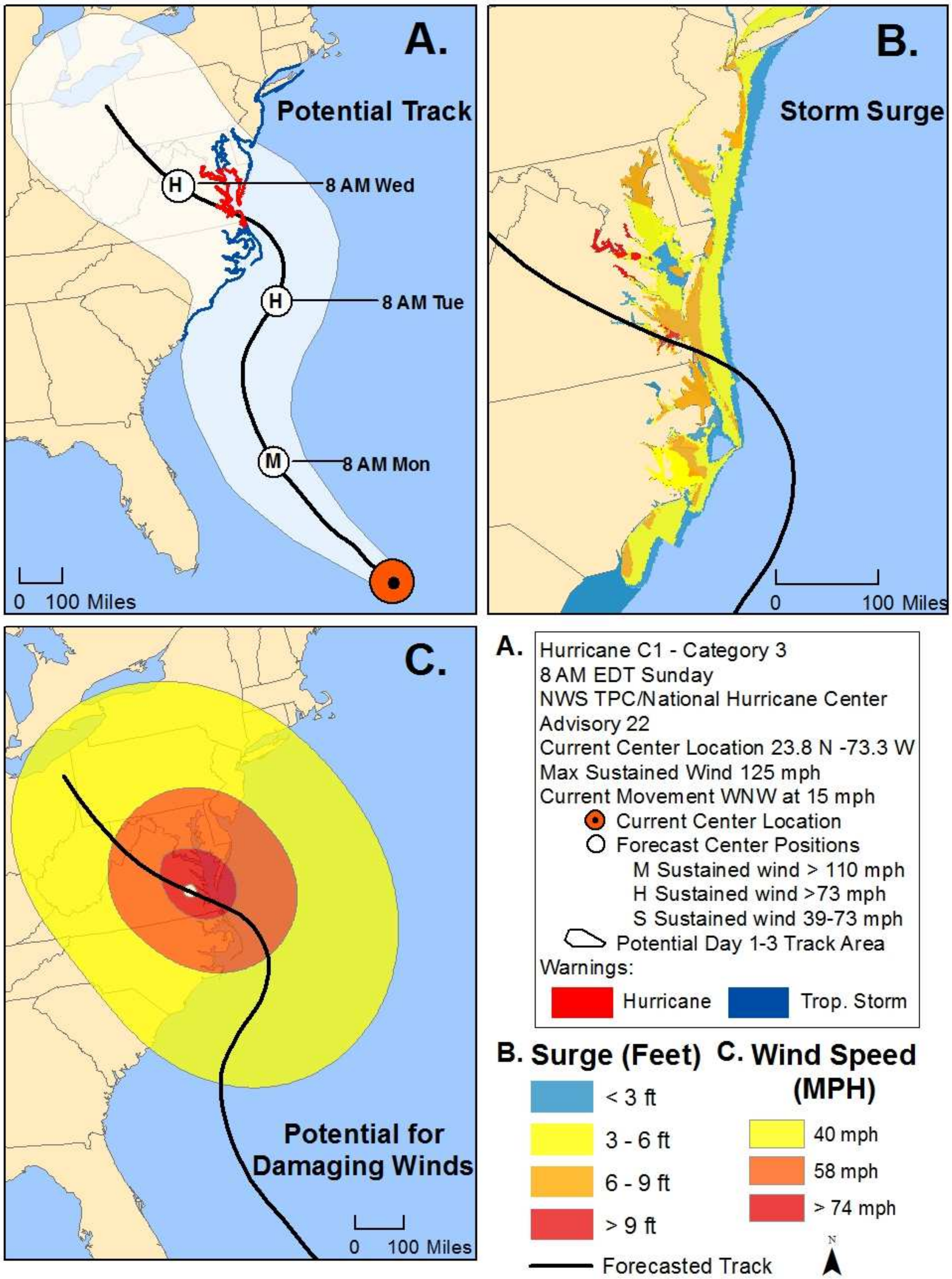

Figure 2.6. Scenario C1.

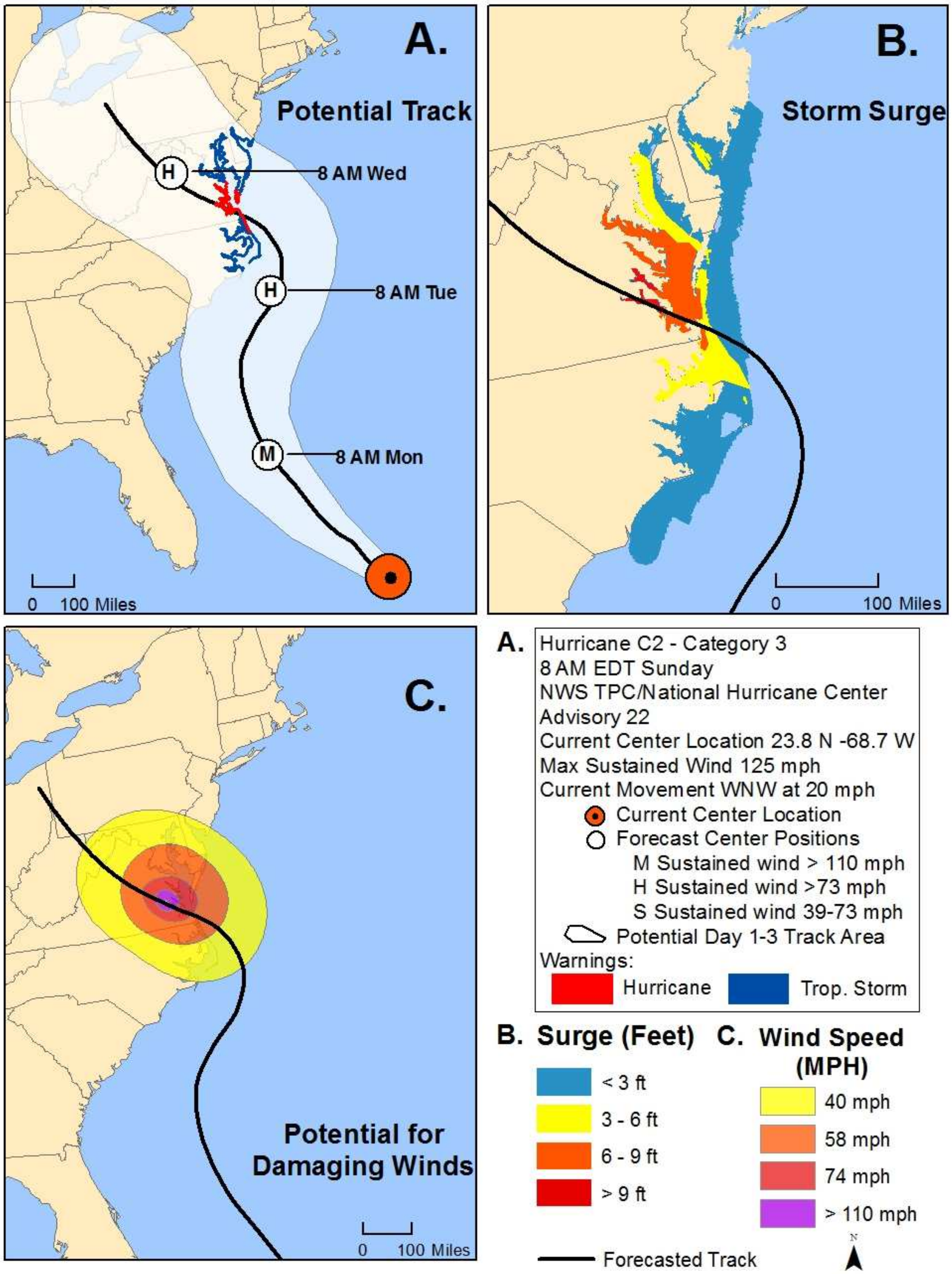

Figure 2.7. Scenario C2.

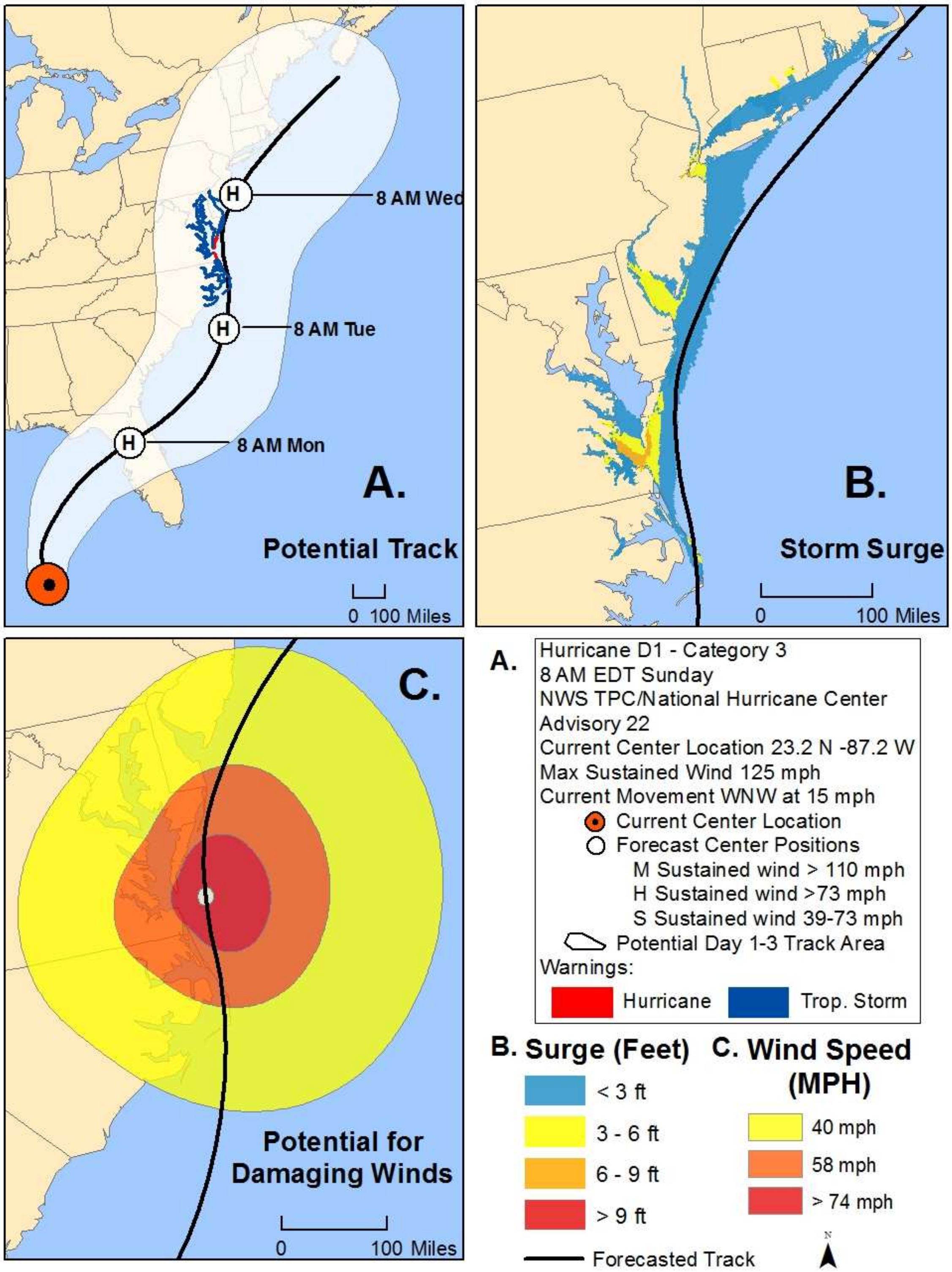

Figure 2.8. Scenario D1.

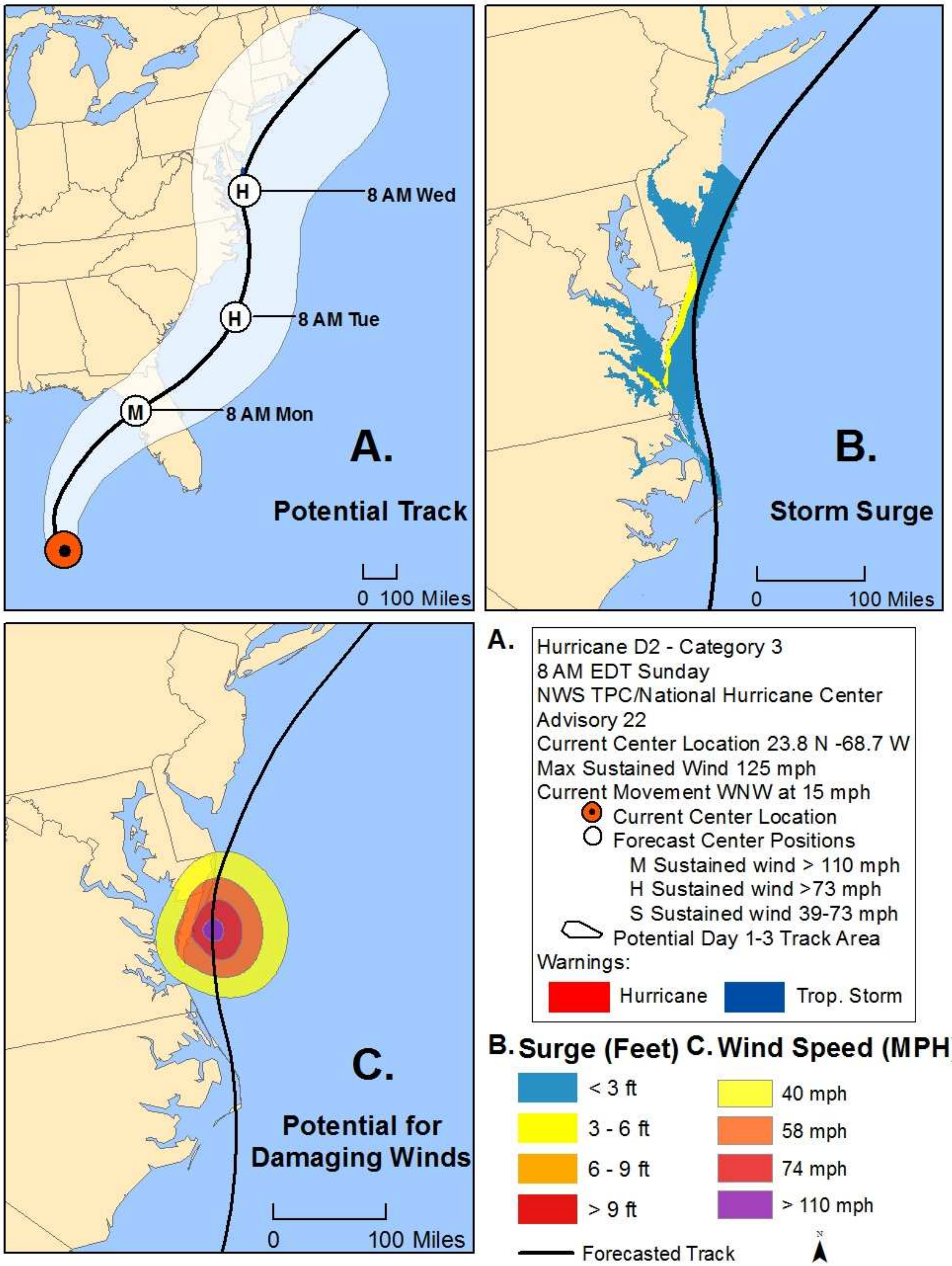

Figure 2.9. Scenario D2.

f. Statistical Analysis

Participants were asked to rank their level of concern for each hazard in each hurricane scenario using four options (see Table 2.2). These categories were then combined into two groups, concerned and not concerned, due to the low numbers of responses in the not at all concerned and very concerned groups.

Since there were eight hurricane scenarios (A1 to D2) with seven associated hazards (storm surge, damaging winds, distance to hurricane track, inland flooding, falling trees, tornadoes, and storm size), a Cochran's Q test was used to detect significant differences in the number of respondents who were concerned or not concerned for each hazard without considering scenarios. The null hypothesis was that that the level of concern was the same for each hazard across the region. Following the Cochran's Q test, 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 change in safety decisions based on tornado threat scenarios. Similarly in this research, scenario A1 was directly compared to scenario A2 for changes in level of concern for each hazard as one example. Data were binary representing a participant's response as either being concerned or not concerned for each hazard for each hurricane scenario. Equations for both Cochran's Q and McNemar's test are included below to understand the fundamental differences in each procedure.

$$\text{Equation 2.1. } Cochran's\ Q \qquad T = k(k-1)\frac{\sum_{j=1}^{k}(X_{.j} - \frac{N}{k})^2}{\sum_{i=1}^{b} X_{i.}(k - X_{i.})}$$

$$\text{Equation 2.2. } McNemar's \qquad X^2 = \frac{(c-b)^2}{c+b}$$

g. Individual Participant Analysis

In addition to finding which hazards residents of the Mid-Atlantic found most concerning and whether the level of concern for each hazard would change with varying hurricane scenarios it was also of interest to try and model whether a resident would be concerned for a hazard based on their actual distance to the hurricane track line and the wind speeds that would be experienced during the storm. If their level of concern could be modeled based on these storm criteria then emergency mangers could better understand the thresholds residents have for certain hazards.

For each of the eight hurricane scenarios a series of logistic regression tests were performed in order to predict whether a resident would be concerned or not concerned for three geophysical hazards. These three hazards were damaging winds, the distance to the hurricane track, and the size of the storm and were tested as the dependent or outcome variables. The two covariate or potential predictor variables used were the measured distance a participant was from the hurricane track line and the potential wind speed a participant would be experiencing during that hurricane scenario. These two variables were collected using ESRI's ArcGIS 10.2. Using the measure tool, the distance from each participant's location (zip code) to the closest approach to the hurricane track line was measured in kilometers. Overlaying the zip code map (see figure 2.1) and each hurricane scenario's wind radii shapefile feature class, each participant's potential wind speed was collected in miles per hour.

In the survey, after each large and small hurricane scenario had been viewed and participants had ranked their level of concern for each hazard, participants were asked which of the two scenarios they felt more threatened by. The last analysis performed on these data compared these two questions to assess the consistency of an individual participant's responses between their level of concern for each hazard and which storm they chose as feeling more threatened by.

In order to compare the data, the difference was taken for each participant's response for their level of concern for each hazard between the large and small storm (table 2.3). This allowed any change in the level of concern for each hazard to be easily detected and compared. It also was valuable to assess the magnitude of change, as a larger difference indicated a greater level of change in concern. Analysis was done by reviewing the calculated differences (large hurricane minus small hurricane) and comparing them as a whole to each participant's response for which storm they found most threatening. After taking the differences between the level of concern between the large and small storm for each scenario, a 0 represented no difference or that the participant's level of concern was the same for both the large and small storm. A 1, 2, or 3 indicated that the participant was more concerned for the large storm and a -1, -2, or -3 indicated that the participant was more concerned for the small storm. When comparing these differences to which storm they chose as more threatening, a participant could fall into three categories; 1. Matched, meaning their concern rankings for each storms hazards matched their choice of most threatening storm, 2. Not Matched, meaning their concern rankings did not match their final choice of most threatening storm, or 3. Neutral (no difference) meaning that they had the same level of concern for each storm. The neutral category was created since the option of selecting neither storm for which storm they felt most threatened by was not given to participants. Participants were placed into the neutral category if they did not indicate their level of concern between the two scenarios for at least three of the geophysical hazards. Also, if a participant indicated they were more concerned for the large storm for two hazards and more concerned for the small storm for two different hazards and the rest of the hazards were 0 or no change, this would also fall into the neutral category as one scenario could not be chosen as being more of a concern than the other.

Table 2.3. Example of how the difference in a participant's response for their level of concern for each hazard was calculated. Participant 1 (2) was more concerned about the small (large) storm.

Participant ID	Scenario	Storm Surge	Damaging. Winds	Distance to Track	Flooding Rainfall	Falling Trees	Tornadoes	Storm Size
1	A1	3	3	2	2	2	2	2
1	A2	3	3	3	3	3	3	2
1		0	0	-1	-1	-1	-1	0
2	A1	2	3	2	3	2	3	3
2	A2	1	1	2	1	1	1	1
2		1	2	0	2	1	2	2

CHAPTER 3

RESULTS AND DISCUSSION

A. Demographics

Qualtrics was able to gather a diverse sample allowing for the data to be representative of the study area's population. Within this study, 75% of participants were White, 13% Black/African American, 5% Asian, 5% Latino/Hispanic, and 2% other. These percentages are close to the averages among the Mid-Atlantic according to the United States Census Bureau, as of 2010. The Latino/Hispanic and Black/African American populations were slightly under represented in this study as the average for the region were approximately 9% and 24%, respectively. The median household income for this study population was around 70,000 dollars, which was slightly higher but close to the Mid-Atlantic household median income. The median age of the participants was 48 years. The distribution of age among participants and other demographic data is displayed in table 3.1. A total of 61 percent of the study sample own their homes. Demographic data was also compared to both a participant's level of concern for each hazard for all the scenarios as well as evacuation rates. There was no statistical significance between any demographic data with either variable.

Table 3.1. Demographic data for survey participants.

Characteristic	Number of Participants
Age	
18-24	10
25-34	18
35-44	19
45-54	21
55-64	21
65+	16
Gender	
Male	52
Female	53
Race/Ethnicity	
White	79
Black or African American	14
Native American	0
Asian	5
Hispanic/Latino	5
Other	2
Level of education	
High School- No Diploma	2
Regular high school diploma	17
Some college	23
Associate's Degree	10
Bachelor's Degree	24
Master's degree	22
Doctorate degree	5
Household income	
0-14,999	6
15,000-29,999	16
30,000-69,999	27
70,000-199,999	28
120,000 +	17
Prefer not to answer	8

B. Hurricane Hazard Perception

a. Hurricane Experience

When asked about past hurricane experience, 83% of the participants surveyed said that they had experienced a hurricane. The most commonly listed storms were Sandy, Irene, and Isabel. 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 when compared to more frequently impacted Pensacola, FL (Radford et al., 2013).

b. Scenario Comparisons

Statistical analysis was first performed using Cochran's Q to detect significant differences in the number of respondents who were concerned or not concerned for each hazard without considering each of the eight scenarios. For each hazard the p-value was statistically significant, < 0.01 (see table 3.2). This meant that the null hypothesis that the level of concern was the same for each hazard could be rejected. Next, each scenario's large storm was compared to its small storm (ex. A1- to A2, B1 to B2) for differences using a McNemar's test.

For scenario A, Damaging winds, the distance to the track line, inland flooding from rainfall, falling trees, tornadoes, and storm size were all significant with p-values less than .05. Participants were more concerned for hazards associated with hurricane A1 than A2, except for surge which was not significant with a p-value of 1.00 (see table 3.3). This resulted from an equal number of participants changing from concerned to not concerned and not concerned to concerned, (9 each). The larger of the two storms (A1) was seen as more threatening. This was most likely due to the majority of those surveyed residing inland and therefore not being affected by storm surge. The hazards participants were most concerned for were falling trees and damaging winds (see figure 3.1). A total of 40 participants said they would evacuate for scenario A1, but only 27 participants would evacuate for A2 (see table 3.2).

The hazards for scenario B were all statistically significant (see table 3.3). The majority of Mid-Atlantic participants were more concerned for hurricane B1 than B2, showing that the larger storm was more threatening. This storm scenario stayed mostly offshore for the majority of the study area, with the exception of lower, coastal Virginia. Therefore, most participants were less concerned for hurricane B, both large and small overall. The hazards participants were most concerned for were falling trees and damaging winds (figure 3.1). Only 30 participants would evacuate for scenario B1 and 20 for B2 (figure 3.2).

Scenario C was the largest scenario, modeled after post-tropical storm Sandy. Damaging winds, the distance to the track, inland flooding from rainfall, falling trees, tornadoes, and storm size were all significant ($p < .05$) (table 3.3). Surge was nearly significant with a p-value of .08. The majority of participants were more concerned with hurricane C1 than C2 for each hazard, but a large number of participants, more than half for certain hazards, stayed concerned for both scenario C1 and C2. This was most likely 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 only exception again was surge which had 40 participants staying concerned for both C1 and C2 and 44 participants remaining not concerned for both C1 and C2. The majority of participants do not live on a coastline or by the bay. A total of 47 participants said that they would evacuate for scenario C1. For scenario C2, 34 participants said they would evacuate (figure 3.2). This was the largest evacuation response rate out of all of the scenarios. The hazards participants were most concerned for were damaging winds, falling trees, and the size of the storm (figure 3.1).

The hazards for scenario D, were all statistically significant except for storm surge (see Table 3.3). For each hazard the majority of participants were more concerned with hurricane D1 than D2 but overall remained less concerned with scenario D for both storms. The track of this storm only scrapes the coastline of the study area and the wind radii do not effect as large an area as other scenarios. The hazards participants were most concerned for were damaging winds, falling trees, and the size of the storm (figure 3.1). Only 24 participants would evacuate for scenario D1 and 13 for D2 (figure 3.2).

The size of the storm played the largest role for a participant's level of concern to change, when compared to other hazards. On average 21 percent of people changed from concerned to not concerned when comparing a large storm to a small storm for the distance to each hurricane track, even though their distance to the track line was the same. This suggests confusion on interpreting hurricane graphics using wind radii. Storm surge was not a major concern most likely due to participants living farther inland.

Table 3.2. Cochran's Q test results by hazard.

Test Statistics		
Hazards	**Cochran's Q**	**p**
Storm Surge	52	< 0.01
Damaging Winds	129	< 0.01
Distance to Hurricane Track	99	< 0.01
Inland Flooding from Rainfall	85	< 0.01
Falling Trees	106	< 0.01
Tornadoes	82	< 0.01
Storm Size	114	< 0.01

Table. 3.3. Paired Scenarios using McNemar's statistical test. This table lists each hazards p-value as well as the number of participants who changed their level of concern in association with the direction of the change. (Ex. When testing scenario A1 vs A2, the Distance to the Hurricane Track had a p-value of <0.01. There were 25 participants who were concerned for A1 but not for A2 and there were 7 participants who were concerned for A2 that were not concerned for A1.)

Scenario A1 vs. A2 Test Statistics			Scenario B1 vs. B2 Test Statistics		
Hazards	**p**	**Concern → Not Concerned**	**Hazards**	**p**	**Concern → Not Concerned**
Storm Surge	1.00	A1→A2 (9) / A2→A1 (9)	Storm Surge	**< 0.01**	B1→B2 (17) / B2→B1 (2)
Damaging Winds	**0.03**	A1→A2 (20) / A2→A1 (8)	Damaging Winds	**< 0.01**	B1→B2 (35) / B2→B1 (2)
Distance to Hurricane Track	**< 0.01**	A1→A2 (25) / A2→A1 (7)	Distance to Hurricane Track	**< 0.01**	B1→B2 (25) / B2→B1 (7)
Inland Flooding from Rainfall	0.25	A1→A2 (17) / A2→A1 (10)	Inland Flooding from Rainfall	**< 0.01**	B1→B2 (25) / B2→B1 (2)
Falling Trees	**0.01**	A1→A2 (21) / A2→A1 (7)	Falling Trees	**< 0.01**	B1→B2 (28) / B2→B1 (3)
Tornadoes	**0.02**	A1→A2 (17) / A2→A1 (5)	Tornadoes	**< 0.01**	B1→B2 (18) / B2→B1 (4)
Storm Size	**0.01**	A1→A2 (23) / A2→A1 (7)	Storm Size	**< 0.01**	B1→B2 (27) / B2→B1 (3)

Scenario C1 vs. C2 Test Statistics			Scenario D1 vs. D2 Test Statistics		
Hazards	**p**	**Concern → Not Concerned**	**Hazards**	**p**	**Concern → Not Concerned**
Storm Surge	0.08	C1→C2 (15) / C2→C1 (6)	Storm Surge	0.31	D1→D2 (15) / D2→D1 (9)
Damaging Winds	**< 0.01**	C1→C2 (17) / C2→C1 (4)	Damaging Winds	**0.02**	D1→D2 (20) / D2→D1 (7)
Distance to Hurricane Track	**0.01**	C1→C2 (16) / C2→C1 (4)	Distance to Hurricane Track	**< 0.01**	D1→D2 (24) / D2→D1 (7)
Inland Flooding from Rainfall	**0.01**	C1→C2 (18) / C2→C1 (5)	Inland Flooding from Rainfall	**0.02**	D1→D2 (20) / D2→D1 (7)
Falling Trees	**0.04**	C1→C2 (17) / C2→C1 (6)	Falling Trees	**< 0.01**	D1→D2 (23) / D2→D1 (6)
Tornadoes	**< 0.01**	C1→C2 (17) / C2→C1 (3)	Tornadoes	**0.03**	D1→D2 (19) / D2→D1 (7)
Storm Size	**< 0.01**	C1→C2 (19) / C2→C1 (4)	Storm Size	**< 0.01**	D1→D2 (21) / D2→D1 (5)

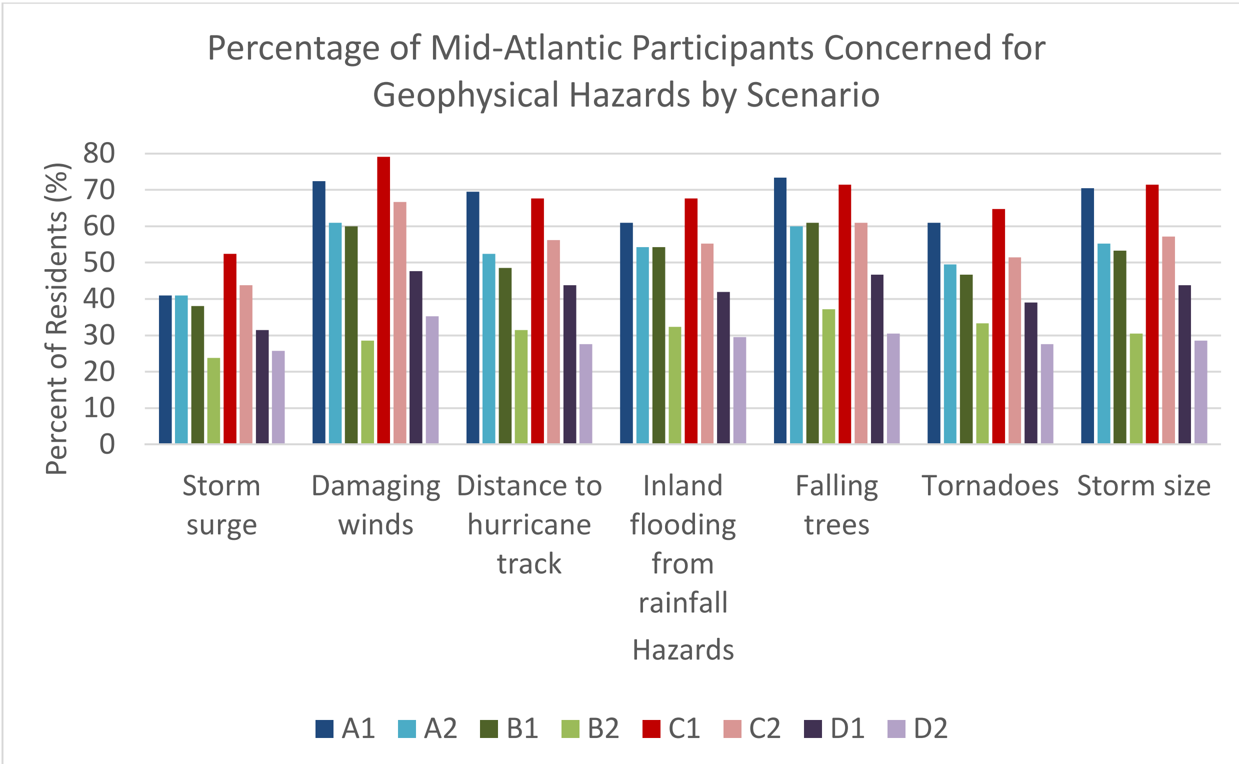

Figure 3.1. The percentage of Mid-Atlantic participants who were concerned for geophysical hazards for each scenario.

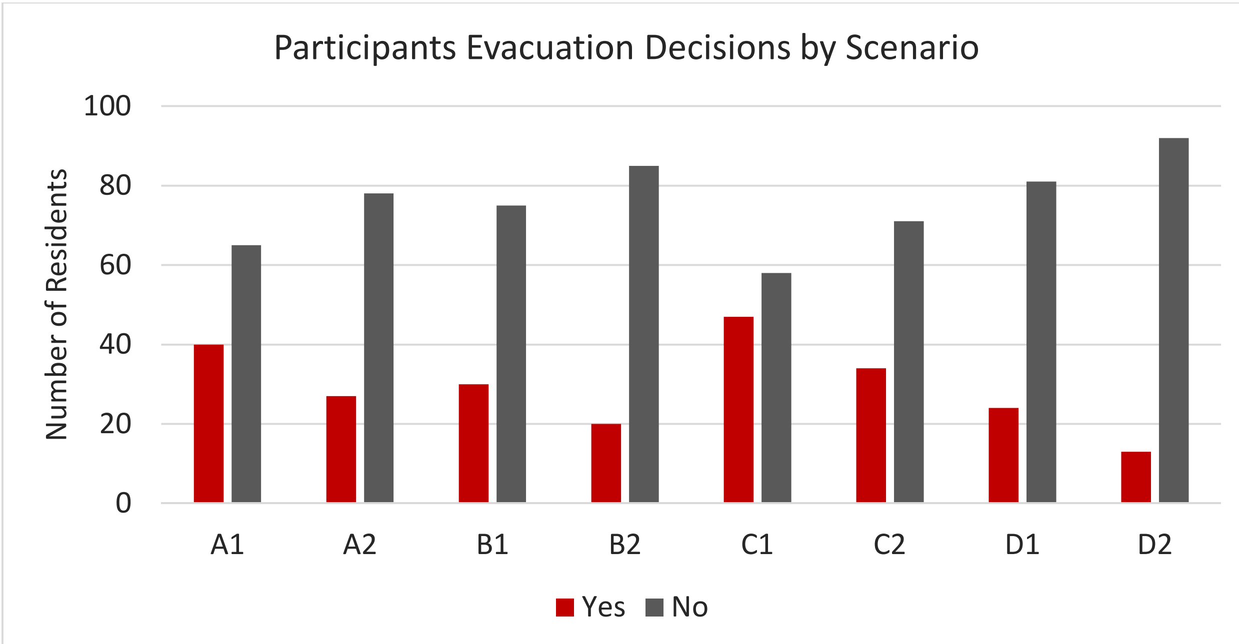

Figure 3.2. Number of participants that would evacuate for each hurricane scenario.

c. All Scenario Comparison

In addition to comparing each large storm to each small storm, scenarios were statistically analyzed to identify differences and similarities between scenarios (A-D). This analysis only included the large storms from each scenario since those were more concerning and compares each of the seven hazards in pairs using a McNemar's test. The first comparison was between hurricane A1 and hurricane B1. Damaging winds, the distance to the hurricane track, falling trees, tornadoes, and storm size were all significant with p-values smaller than .05 (see table 3.4). The majority of participants were concerned for each of these hazards for both storms but there was a greater number of participants who were concerned for scenario A1. This means that hurricane A was seen as more of a threat than hurricane B. This is likely caused from the difference in storm track as scenario A moves inland while scenario B moves offshore. Storm surge and inland flooding from rainfall were both not statistically significant for this comparison. Overall, participants were not concerned with storm surge for either storm. Inland flooding from rainfall had some participants concerned, however the changes between these groups was small which lead to an insignificant result.

The next comparison was between hurricane A1 and C1, both of which held the most concern among study area participants. The only hazard that was statistically significant was storm surge. This was due to more participants changing from being not concerned for hurricane A1 to being concerned for C1. The surge for both of these storms were more severe than for scenarios

Table 3.4. Test Statistics for all large storm scenarios using McNemar's test. This table lists each hazards p-value as well as the number of participants who changed their level of concern in association with the direction of the change. (Ex. When testing scenario A1 vs B1, the Distance to the Hurricane Track had a p-value of <0.01. There were 28 participants who were concerned for A1 but not for B1 and there were 6 participants who were concerned for B1 that were not concerned for A1.)

Scenario A1 vs. B1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	0.70	A1→B1 (15) / B1→A1 (12)
Damaging Winds	**0.01**	A1→B1 (18) / B1→A1 (5)
Distance to Hurricane Track	**< 0.01**	A1→B1 (28) / B1→A1 (6)
Inland Flooding from Rainfall	0.21	A1→B1 (15) / B1→A1 (8)
Falling Trees	**0.01**	A1→B1 (18) / B1→A1 (5)
Tornadoes	**< 0.01**	A1→B1 (22) / B1→A1 (7)
Storm Size	**< 0.01**	A1→B1 (25) / B1→A1 (7)

Scenario A1 vs. C1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	**0.05**	A1→C1 (10) / C1→A1 (22)
Damaging Winds	0.28	A1→C1 (12) / C1→A1 (19)
Distance to Hurricane Track	0.87	A1→C1 (19) / C1→A1 (17)
Inland Flooding from Rainfall	0.25	A1→C1 (10) / C1→A1 (17)
Falling Trees	0.84	A1→C1 (13) / C1→A1 (11)
Tornadoes	0.59	A1→C1 (13) / C1→A1 (17)
Storm Size	1.00	A1→C1 (13) / C1→A1 (14)

Scenario A1 vs. D1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	0.10	A1→D1 (20) / D1→A1 (10)
Damaging Winds	**< 0.01**	A1→D1 (33) / D1→A1 (7)
Distance to Hurricane Track	**< 0.01**	A1→D1 (34) / D1→A1 (7)
Inland Flooding from Rainfall	**< 0.01**	A1→D1 (31) / D1→A1 (11)
Falling Trees	**< 0.01**	A1→D1 (36) / D1→A1 (8)
Tornadoes	**< 0.01**	A1→D1 (32) / D1→A1 (9)
Storm Size	**< 0.01**	A1→D1 (36) / D1→A1 (8)

Scenario B1 vs. C1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	**< 0.01**	B1→C1 (5) / C1→B1 (20)
Damaging Winds	**< 0.01**	B1→C1 (4) / C1→B1 (24)
Distance to Hurricane Track	**< 0.01**	B1→C1 (4) / C1→B1 (24)
Inland Flooding from Rainfall	**< 0.01**	B1→C1 (5) / C1→B1 (19)
Falling Trees	**0.05**	B1→C1 (8) / C1→B1 (19)
Tornadoes	**< 0.01**	B1→C1 (2) / C1→B1 (21)
Storm Size	**< 0.01**	B1→C1 (4) / C1→B1 (23)

Scenario B1 vs. D1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	0.21	B1→D1 (15) / D1→B1 (8)
Damaging Winds	**0.05**	B1→D1 (26) / D1→B1 (13)
Distance to Hurricane Track	0.47	B1→D1 (18) / D1→B1 (13)
Inland Flooding from Rainfall	**0.02**	B1→D1 (20) / D1→B1 (7)
Falling Trees	**0.02**	B1→D1 (25) / D1→B1 (10)
Tornadoes	0.17	B1→D1 (17) / D1→B1 (9)
Storm Size	0.09	B1→D1 (19) / D1→B1 (9)

Scenario C1 vs. D1 Test Statistics

Hazards	p	Concern → Not Concerned
Storm Surge	**< 0.01**	C1→D1 (29) / D1→C1 (7)
Damaging Winds	**< 0.01**	C1→D1 (38) / D1→C1 (5)
Distance to Hurricane Track	**< 0.01**	C1→D1 (33) / D1→C1 (8)
Inland Flooding from Rainfall	**< 0.01**	C1→D1 (34) / D1→C1 (7)
Falling Trees	**< 0.01**	C1→D1 (36) / D1→C1 (10)
Tornadoes	**< 0.01**	C1→D1 (32) / D1→C1 (5)
Storm Size	**< 0.01**	C1→D1 (34) / D1→C1 (5)

B and D. Overall most participants were not concerned with storm surge. Damaging winds, the distance to the hurricane track, inland flooding from rainfall, falling trees, tornadoes, and the size of the storm were all not statistically significant with more participants changing from not concerned for hurricane A1 to concerned for C1. As C1 is a larger storm and would affect a larger area, this pattern would support the results. Also the majority of participants stayed concerned for both hurricane A1 and C1 (see table 3.4).

When comparing hurricane A1 to D1, it was determined that participants were more concerned for hurricane A1 for each hurricane hazard and that all hazards were statistically significant except for storm surge. A large number of participants were concerned for both scenario A and D for all hazards except for storm surge.

The next two large scenarios to compare were hurricane B1 and C1. Each individual hurricane hazard was statistically significant and most participants were not concerned for hurricane B1 but changed to being concerned for C1. There were also more participants who stayed concerned for both storms than there were participants not concerned for both storms. This was true for every hazard except for storm surge, where most participants were not concerned for either storm.

Hurricane scenario's B1 and D1 were close in both size and track. Both tracks scraped the coastline, the only difference being that B1 tracked through Virginia Beach and D1 did not. After comparing these two storms using a McNemar's test, the only statistically significant hazards were damaging winds, inland flooding from rainfall, and falling trees. For each of these hazards, more participants were concerned for scenario B1 than they were for D1. Strom surge, the distance to the hurricanes track, tornadoes, and storm size were all not statistically significant.

The final McNemar's comparison was between hurricane scenario's C1 and D1. For this test, each hurricane hazard was statistically significant with a p-value of .000 (see table 3.4). Overall, participants were mostly concerned for scenario C1 and were not concerned for scenario D1 for each hazard. Since scenario C1 is the larger of the two storms it would affect more participants within the study area making it more of a concern.

d. Individual Participant Analysis

The many iterations of logistic regression runs were not statistically significant and the confidence intervals for the odds ratios spanned 1 for every variable. This meant that the distance to the hurricane's track and the potential for damaging winds were not good predictors of whether a participant would or would not be concerned for each storm. It appears that some participants may express concern when faced with certain scenarios, but that concern is not a result of geophysical hazards portrayed in warning graphics.

When comparing the level of concern indicated by each participant for each hazard to which scenario they felt most threatened by, the results were similar between the four hurricane scenarios (A-D), (see table 3.5). Scenario B had the highest number of participants, 54, whose level of concern for each hazard matched the scenario that most threatened them. For scenarios A, C, and D, the majority of participants were within the neutral category. Scenario A and D had 53 participants and C had 61 participants. This meant that the levels of concern were the same for both the large and small storm. Each scenario had ten or fewer participants whose level of concern for hazards did not match the storm they indicated as being most threatening. The conclusion that most participants fell within the neutral category in part explains why the logistic regression was unsuccessful in predicting concern. Since a large number of participants were similarly concerned for each storm, it becomes more difficult to use predictor variables to model what participant’s thinks about a particular hurricane. Perhaps the risk perception of people will vary according to other variables that may possibly be better suited for sociological analysis.

Table 3.5. This table shows the number of participants who’s level of concern for each geophysical hazard matched, did not match, or their level of concern did not change (neutral) when comparing each hurricane scenario’s large and small storm.

Scenario	Matched	Not Matched	Neutral	Total
A	42	10	53	105
B	54	3	48	105
C	37	7	61	105
D	45	7	53	105

CHAPTER 4

CONCLUSION

It was critical to understand the perception of hurricane hazards for the Mid-Atlantic region of the United States so that weather forecasters and emergency managers can better communicate the risks associated with tropical cyclones. This region experiences tropical cyclones and with the number of storms modeled to increase, it was important to understand which geophysical hazards Mid-Atlantic participants found most concerning and to see if their level of concern would change with varying hurricane scenarios.

Participants of the Mid-Atlantic focused mostly on the size of a tropical cyclone when assessing hazards of concern. The track or path of the storm also influenced decisions about their level of concern for each hurricane scenario. Both scenario tracks that moved inland (A and C) were seen as more of a threat and increased the concern for each hazard associated with those storms. This is most likely due to more participants within the study site being affected as the region would take a direct impact whereas tracks (B and D) that turned out to sea would affect a smaller area, thus affecting less of the population.

Participants were most concerned for scenario C1 which was modeled after post-tropical Sandy. This scenario was both the largest of all eight scenarios and had a track line that moved inland. Scenario C1 was also the storm most participants said they would evacuate, followed by scenario A1, where the track also moved inland. Post-tropical Sandy was the most recent storm to impact the Mid-Atlantic and New England coastlines in 2012. This similar storm track may still be fresh on the minds of some participants and could have played a role in why they were most concerned about scenario C.

The hazards that were of most concern overall were falling trees, followed by damaging winds, 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. Storm surge and inland flooding from rainfall both were not as significant as each of the wind hazards. Due to the small number of coastal participants, storm surge was of little concern for this study population.

Evacuation statistics support the findings for both the size of the storm and the trajectory of the storm path. All evacuation rates were greater for each large scenario (A1-D1) and were also greater for scenario's A1 and C1 where the track line also moved inland. This is due to a larger area of impact, resulting in more participants being affected. This also helps to show the threshold that participants may have between evacuating and staying. According to this research the majority of Mid-Atlantic participants would not evacuate for any of the following hurricane scenarios but had a higher rate if the storm was large and moving inland.

The final analysis indicated that modeling the perception of hurricane hazards based on distance to the hurricane track and potential wind speeds was not successful. Finding that a large number of participants showed either an equal concern for both sized hurricane scenarios or correctly indicated which scenario they were most threatened by when compared to which hazards they felt most concerned for showed that participants were able to correctly indicate their level of concern.

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APPENDIX

INSTITUTIONAL REVIEW BOARD CERTIFICATION

Office for Research

Institutional Review Board for the Protection of Human Subjects

THE UNIVERSITY OF ALABAMA

RESEARCH

May 22, 2014

Michelle Saunders
Department of Geography
College of Arts & Sciences
University of Alabama

Re: IRB # EX-14-CM-072 "Perception of Hurricane Hazards in the Mid-Atlantic"

Dear Ms. Saunders:

The University of Alabama Institutional Review Board has granted approval for your proposed research.

Your protocol has been given exempt approval according to 45 CFR part 46.101(b)(2) as outlined below:

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

Your application will expire on May 21, 2015. If your research will continue beyond this date, complete the relevant portions of Continuing Review and Closure From. If you wish to modify the application, complete the Modification of an Approved Protocol Form. <u>When the study closes, complete the appropriate portions of FORM: Continuing Review and Closure.</u>

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number.

Good luck with your research.

Sincerely

Carpantato T. Myles, MSM, CIM, CIP
Director & Research Compliance Officer
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