Suggestions for alternative tropical cyclone warning graphics in the USA

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Abstract

Purpose – The cone of uncertainty (COU) warning graphic has created confusion for people trying to make evacuation and safety decisions. The purpose of this research was to create several alternative tropical cyclone graphics and present them to the public and college students via face-to-face surveys and polling.

Design/methodology/approach – Surveys depicting hypothetical landfall scenarios were administered in Pensacola and Jacksonville, FL. Respondents ranked five graphics in order of preference, and were encouraged to discuss their rankings. Following this initial field research, the most popular graphic of these five was compared to a graphic resembling the one used by The Australian Bureau of Meteorology. Comments were recorded for respondents favoring or disliking the Australian graphic in two separate analyses. A final graphic emphasizing post-landfall hazards was also created as a suggestion for future research and evaluated directly against the most popular graphics from field research.

Findings – A graphic called the color-probability-cone was the most popular graphic in field research. There were subtle differences in graphic preference resulting from age and gender influences, with only one significant result. Comments from subsequent analyses reveal that the Australian graphic causes mixed reactions. A final analysis with a larger sample of college students revealed that the color-probability-cone was the most popular choice; however, comments reveal that many respondents who had used hurricane graphics before liked the specificity presented by the Australian graphic and the hazards graphic.

Originality/value – This research represents a possible initial step in the process of establishing a tropical cyclone warning graphic that is informative, visually appealing, and effective.

Keywords Tropical cyclone, Warning graphics, Hazards, Preferences, Suggestions, United States of America

Paper type Research paper

Introduction

The official hurricane warning graphic used in the USA is the Cone of Uncertainty (COU). The COU (Figure 1) represents the forecasted track the center of a tropical cyclone will take and the likely error in the forecast track. It is based on the predictive skill of past years, as well as numerous additional details about the storm (National Hurricane Center, 2012). This graphic is used by the National Hurricane Center (NHC) to convey potential risk and to assist people with preparation and evacuation plans. Currently, several versions of the COU are used to communicate hurricane risk to the public. The NHC creates the official COU, and local and cable TV meteorologists modify it slightly for discretionary emphasis. The most common modification is

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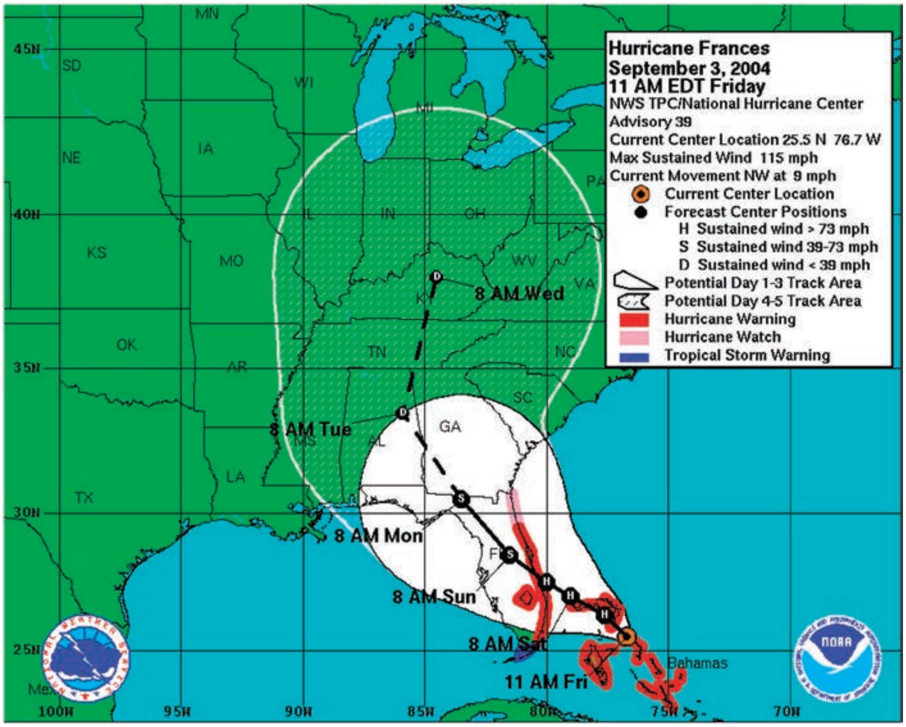


Source: National Hurricane Center

Figure 1.
The COU, the current graphic employed by the National Hurricane Center for disseminating risk information to the public

removing the track line from the center of the cone, which the NHC experimented for the 2012 hurricane season. The track line has been a consistent feature from 2002 to 2012.

The COU has come under criticism for its ability to be misinterpreted. Many people believe the cone depicts the swath of damage from the storm while in reality the intent is to portray the geographic area that could be potentially traversed by the center of the storm. Others believe that it shows the growth in size as the tropical cyclone approaches land. The most common error is a focus on the track line with deterministic interpretation or perception, not understanding that the center of the storm can pass to either side of the line (Broad *et al.*, 2007). Thus, many residents have possibly been transforming the graphic into the cone of certainty. Statistics from the NHC indicate that track forecasts are becoming more accurate over time, and the COU is shrinking in size due to error reduction each year (www.nhc.noaa.gov/aboutcone.shtml, accessed January 9, 2013); nevertheless, the COU was determined to be a source of confusion after Hurricane Charley and other major hurricanes in 2004 (Broad *et al.*, 2007).

Since its implementation, the COU has been a vital tool for the communication of hurricane risk information; however, relatively little is known about how the public interprets, evaluates, or utilizes this important graphic (Broad *et al.*, 2007). Furthermore, there is a dearth of literature devoted to this specific topic; however, errors in landfall location interpretation of evacuees have been quantified (Senkbeil *et al.*, 2010) and also ways to more effectively communicate hurricane risk information have been discussed (Demuth *et al.*, 2012). Recent research has used numerical and statistical techniques to make improvements on quantifying the uncertainty of hurricane track forecasting (Meuel *et al.*, 2012; Cox *et al.*, 2013).

If the graphic is causing confusion for a substantial portion of the population, perhaps there is a better way of communicating potential risk through alternative graphics. In an online NHC survey in 2004, most respondents preferred the current COU over two alternative graphics; however, the alternative graphics provided minimal stylistic and information differences when compared to the COU. Here we are exploring a greater breadth of alternative graphics with the intent on creating dialog on possible ways that risk communication might be enhanced for tropical cyclones.

The first step in this process is to determine what aspects of tropical cyclone warning graphics are liked by the public. The COU depicts the current location, intensity, forward speed, and likely landfall time in addition to the uncertainty in where the storm may make landfall (see Figure 1). It does not provide a numerical probabilistic forecast of the intensity at landfall, or the probability of landfall location. The probability of landfall location is, however, provided in text products on the NHC web site. Such probability forecasts have been shown to be well received and understood by the public (Baker, 1995). Furthermore, participants in hypothetical weather decision making and choice method scenarios effectively used uncertainty to attenuate forecast error and improve the accuracy of decision making (Roulston *et al.*, 2006; Joslyn and LeClerc, 2012). Additionally, while the public may understand, infer, and accept uncertainty in weather forecasts (Morss *et al.*, 2008); evidence suggests that many also expect over-forecasting for extreme events such as tropical cyclones (Joslyn and Savelli, 2010). Including probability in graphics would help reduce the perception of over-forecasting by communicating a numerical range of uncertainty. These results suggest that probability should be a featured component of new warning graphics; however, for tropical cyclones the public may require a certain degree of scientific knowledge to fully understand forecasted storm attributes (Eosco, 2008; Drake, 2012).

Therefore, it appears as if the creation of a new tropical cyclone warning graphic should incorporate probability and uncertainty, but yet still be simplistic and informative in its message. The creation of a graphic such as this may be very difficult, requiring several iterations. This is confirmed by Eosco (2008). Eosco met with government and private forecasters to discuss the objectives of the COU, and established a concept called visual validity. Visual validity refers to the process of correctly transferring scientific intent through visuals to evoke public understanding of risk. Eosco concluded that a complicated relationship exists between graphic design, scientific intent, and public interpretation. Visual validity research with tropical cyclone warning graphics is currently ongoing; however, the authors are not aware of any preliminary tropical cyclone warning graphic research that has been conducted with a large public sample.

Using a large sample size with face-to-face and large group survey methods this research has three major objectives and questions:

(1) Determine how often people are using hurricane warning graphics
   - Does graphic usage vary by location according to recurrence intervals?

(2) Develop several alternative warning graphics and explore public preference for each; and
   - Does preference vary by age, gender, and frequency of usage?

(3) Discuss what aspects of alternative graphics are most useful to people.
   - What elements of a tropical cyclone warning graphic are desired and effective?

A methods section describes survey design, graphic creation, and data collection as well as quantitative and qualitative analysis procedures. The results section is similarly organized into several sub-sections following the objectives above. Descriptive and statistical analyses from field survey data were used to summarize the results of objectives 1 and 2. In objective 3, the qualitative results of a small additional field study are discussed, which led to a more comprehensive final qualitative analysis using student polling with a large sample size. A conclusion follows with suggestions for incorporation of results into operational practice.

Methods

Survey design and graphic creation for field analysis

A seven-page survey was developed for collection of preference data for the initial field research. The survey consisted of several demographic questions, and a question about the use of hurricane graphics and past experiences. The next five pages were devoted to alternative Figure 2(a)-(e) with one graphic displayed per page (Figure 2). Four additional graphics were evaluated by college students as possibilities prior to field research, but were eliminated due to unfavorable opinions.

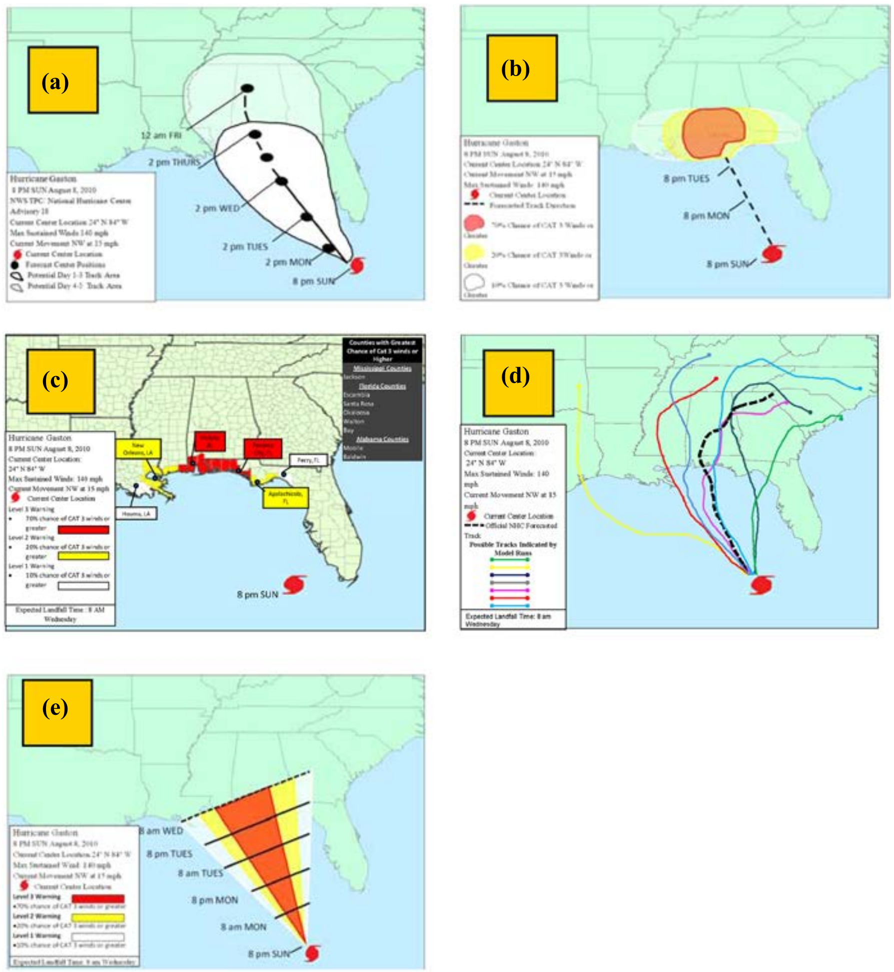
The survey was designed to capture responses to a few background questions with most of the time devoted to ranking and commenting on the graphics. Most respondents finished in about three to four minutes which led to very high-estimated participation rates of two-thirds of people asked. These graphics were created using ArcGis 9.3 and Microsoft Powerpoint, and consisted of different ways of representing the same information. Respondents were instructed to carefully view each graphic and then rank the graphics from 1 to 5 in order of preference. Figure 2(a) is a re-creation of the current COU used by the NHC. Figure 2(b)-(e) are based on COU variations from several internet sites. Figure 2(b) has three circular warning probability areas. Figure 2(c) uses three warning probability levels denoted by counties, and does not include a projected path or track line. It was included because many people cannot find their location on a map (Arlikatti *et al.*, 2006). Figure 2(d) is a spaghetti graphic that shows the projected paths from different weather forecasting models.

Figure 2(a) is a re-creation of the current COU. Figure 2(b) shows color-probability areas of landfall location. Figure 2(c) also shows colored probabilities of landfall location but without a cone structure or track line. It also uses city names to assist people in finding their location. Figure 2(d) shows the possible storm tracks as depicted by computer model forecasts. Figure 2(e) is the color-probability-cone (CPC).

This type of model output graphic is common on multiple web sites. Figure 2(e) uses a CPC with three warning levels and no track line. All five graphics were developed for land-falling scenarios targeting Pensacola, FL and Jacksonville, FL. Studies using tropical cyclone graphics with hypothetical scenarios have recently been used by Petrolia and Bhattacharjee (2010) and Matyas *et al.*, (2011); albeit for different purposes. The graphics shown in Figure 2 are based on hypothetical Pensacola, FL landfalls.

Data collection

Pensacola, FL and Jacksonville, FL were chosen as target cities primarily due to disparities in tropical cyclone activity. The two cities have similar demographics, and Pensacola (455,000 MSA population) is about one-third the size of Jacksonville (1.35 million MSA population) (United States Census Bureau 2012). Pensacola has a recurrence interval of 21 years for category three hurricanes or greater on the Saffir Simpson scale, while Jacksonville has a recurrence interval of 105 years for that



Notes: Figure 2 was used in field surveys. (a) is a recreation of the current COU; (b) shows color-probability areas of landfall location; (c) also shows colored probabilities of landfall location but without a cone structure or track line. It also uses city names to assist people in finding their location; (d) shows the possible storm tracks as depicted by computer model forecasts; (e) is the color-probability-cone

Figure 2.
Alternative graphics used in field survey research

intensity (Keim and Muller, 2007). Pensacola was most recently directly impacted by Hurricane Dennis in 2005. Jacksonville's last direct landfall was Hurricane Dora in 1964. When answering objective 1, it was important to determine if the use of hurricane graphics was different between a location that is frequently impacted and a location that is infrequently impacted. Due to the relative inactivity in Jacksonville, it was hypothesized that residents would pay less attention to warning graphics when compared to Pensacola residents. Furthermore, the two cities were ideal locations for ascertaining warning graphic preference with large coastal populations likely accustomed to seeing hurricane warning graphics. Written responses, further elaborating on preference, were encouraged; however, written response rates were poor.

Our research team targeted public areas with high foot traffic to administer face-to-face, convenience sample surveys. The first surveying location was a 5 km run in downtown Pensacola. Our team of eight researchers separated and surveyed spectators as well as race participants after they finished. The surveys were administered simply by approaching bystanders and runners and describing the purpose of the research. Later that day, the team went to the Pensacola Seafood Festival. Team members walked around the festival collecting data from the crowd in the same manner as the race. This location was chosen for its large flow of potential participants and the people in attendance were much more demographically diverse.

Our team then traveled to Jacksonville, FL on September 26, 2010. The venue chosen in Jacksonville, FL was outside of the Jacksonville Jaguars American football stadium before a game that evening. Like the Seafood Festival, the football pre-game environment was chosen as a site that would have a high concentration of people in a relaxed environment. Our team collected data in the aforementioned manner. The demographics of this population were slightly more diverse than the Pensacola Seafood Festival. Although about the same number of surveys were gathered, it would be assumed that all the participants are fans of American football. How that corresponds to their attention to hurricane warning graphics is uncertain, but not believed to be a major limiting factor. A total of 166 completed surveys were collected from Pensacola and 149 from Jacksonville.

Quantitative analysis of field survey data

Quantitative analysis was used to answer questions from objectives 1 and 2 for the field survey data. First, descriptive analysis was conducted on the data. Descriptive analysis provided information on overall graphic preference as well as the age and gender distribution of the participants. Next, statistical tests were used to ascertain the relationships between graphic preference and location, age, and gender, as well as the relationship between graphic preference and the categorical use of hurricane warning graphics. We did not ask questions about race, ethnicity, or socioeconomics as these questions were not essential to answering the questions in our objectives.

Graphic preference at both locations was summarized using count data. Data from both locations were combined to assess overall graphic preference of the participating residents. These data were displayed in percentages. Eight age groups were created encompassing all participants. Groups in six-year increments are as follows: 19-24, 25-30, 31-36, 37-42, 43-48, 49-54, 55-60, >60. Gender distribution was established using similar methods. Count data were used to understand the distribution of how often hurricane warning graphics play a role in making evacuation decisions. Participants were given four options: never, occasionally, most of the time, and always.

Two separate Kruskal-Wallis tests were performed to test for significant differences in graphic preference between the two locations and also for two categories of gender. Thus, the grouping variable is the binary location or gender, and the test variable became the five different hurricane warning graphics. A critical test value and p-value were produced for significant differences in location and gender preference for all five graphics. The Kruskal-Wallis tests determined significant differences in gender or location preference between at least two of the five graphics. Therefore, the graphics appearing to have the largest magnitude difference were directly compared to each other using Mann-Whitney tests.

A contingency table with a χ^2-statistic was employed to assess the cross-tabulation of graphic preference vs age and graphic preference vs frequency of graphics usage. This test was chosen for these variables because both variables contain multiple subcategories. For age, all eight age subcategories were tested against each graphic. Expected vs observed counts within groups and within graphics were analyzed to determine the strength of the relationship. For use of graphics, all four use subcategories were tested against each graphic. Methods of analysis follow the aforementioned methods for the analysis of age.

Qualitative analysis of student polling and additional field data

The landfall of cyclone Yasi in Australia January 2011 turned our attention toward hurricane warning graphics developed by the Australian Bureau of Meteorology (ABM). The ABM graphic contains an abundance of information portrayed in a visually appealing yet concise graphic. A secondary qualitative study was devised to compare a revised Australian graphic (AG) adapted for the USA and the CPC graphic from field research. A sample of 115 geography 101 students at the University of Alabama was polled with a brief one-page questionnaire. The questionnaire asked the students to circle which graphic they preferred, and to provide written responses discussing why they chose that particular graphic.

Following the student polling, a version of the revised AG with a Pensacola landfall was used in the field during a subsequent hurricane evacuation study (Rockman, 2012). The revised AG was compared directly to a re-creation of the current COU for various hypothetical hurricane scenarios that would impact Pensacola. Out of 100 participants, 32 respondents were willing to comment on the revised AG. Their comments are summarized with a short discussion in the results section.

In the process of surveying respondents, many commented about including other tropical cyclone hazards besides wind in a graphic. This led us to create one last alternative graphic with the goal of featuring coastal and inland hazards. Due to logistics, this post-landfall hazards graphic (HG) was not evaluated in the field, but was directly compared to the CPC and AG with a sample of 231 college students. Students were asked to be very critical in ranking their favorite graphic of the three, and required to comment about what aspects were particularly appealing advantages. Comments were organized and displayed thematically by similar responses.

Results and discussion

Use of hurricane graphics

Field participants were asked how often hurricane warning graphics play a role in evacuation decision making. There were four categorical options: never, occasionally, most of the time, and always (Figure 3). In Pensacola, respondents indicated that they always used graphics 36 percent of the time and this decreased for each category of lesser use. However, in Jacksonville the most common response was most of the time, at 36 percent, and always dropped to 19 percent. These results are expected when recurrence intervals and recent hurricane activity are considered at each location. Since the never category had the lowest response ranking at both locations, it can generally be assumed that most residents are using or viewing hurricane warning graphics at least once prior to landfall regardless of location. This is especially true for those seeking storm-specific information via web sites (Lee *et al.* (2009); Sherman-Morris *et al.*, 2011).

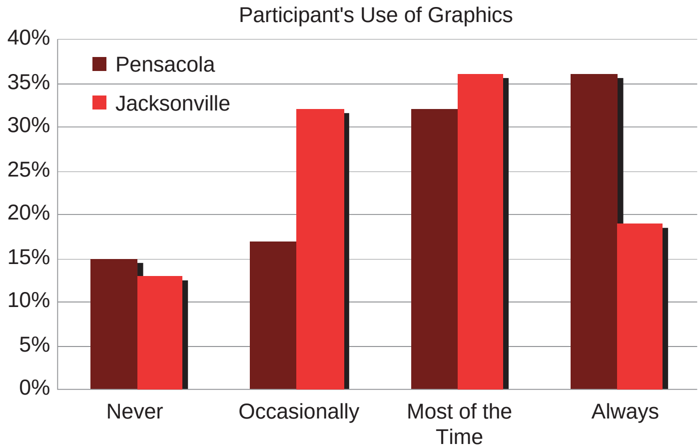


Figure 3.
Categorical use of graphics in Pensacola and Jacksonville

Preferences for alternative graphics
Four alternative warning graphics in addition to a re-creation of the COU were used for surveying in the field. In both Pensacola and Jacksonville the CPC was the most popular (45 and 36 percent, respectively). The combined Pensacola and Jacksonville rankings in descending order of preference of graphics in Figure 2 were (a) – 23 percent, (c) – 17 percent, (b) – 11 percent, and then (d) – 8 percent. A cone-like structure is well received since the CPC and Figure 2(a) (the current COU) were the most popular. Figure 2(d) was the least preferred at both locations. Therefore, the only practical differences in graphic preference between Pensacola and Jacksonville pertain to Figures 2(a), (c) and (e). Figure 2(e) the CPC, appears to be well liked, but is it liked equally by both genders, by all age groups, and by categories of how often people use hurricane graphics?

A Kruskal-Wallis test was used to determine if there was a statistically significant difference between graphic preference and gender. Nearly significant results were found for Figure 2(c) ($p = 0.06$) and 2d ($p = 0.09$). Men tend to prefer Figure 2(d) more often than women and women tend to prefer Figure 2(c) more often than men. Further investigation was pursued using Mann-Whitney tests. The preferences of men and women were directly compared for Figure 2(c) and 2(d). Results were found to be insignificant.

A χ^2-contingency table was used to determine if there was a statistical difference between graphic preference and age. There were eight subcategories for age. Results show that there is no statistical difference for age and Figure 2(a)-(c), or (e) in Figure 2. There is a significant difference for age and Figure 2(d) ($p = 0.02$). Older and middle-aged men contributed most to the statistical significance of this result. The 19-24 age group strongly disliked Figure 2(d) with only a few exceptions. Speculation on an explanation for this result could be due to an increase in knowledge and possessions with age, and greater decision-making responsibility for heads-of-households. Ensemble and model forecast graphics such as Figure 2(d) and those suggested by Cox *et al.* (2013) are popular only with a small subset of our large sample.

A second χ^2-contingency table was used to determine the relationship between graphic preference and the usage of hurricane warning graphics. The results show that there is no statistically significant difference between these two variables. Further analysis of the results indicates that respondents that liked Figure 2(d) tend to always use hurricane warning graphics. Since Figure 2(d) is not that common on cable or local television outlets, it is likely favored by people that are perusing web sites trying to collect information to make their own personal decisions. A qualitative approach was used to summarize and discuss further analyses since there were very few significant quantitative results.

Useful aspects of alternative graphics

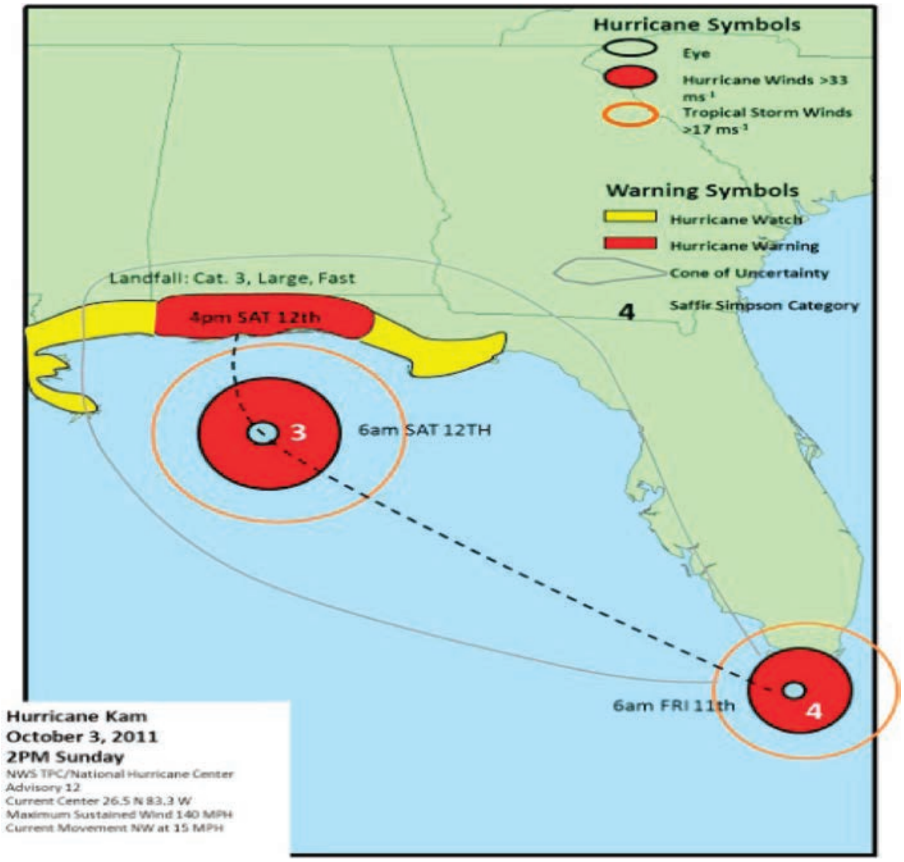
1. Student polling and additional field comments using the AG and COU. As previously mentioned in Methods, the landfall of cyclone Yasi in Australia January 2011 turned our attention toward hurricane warning graphics developed by the ABM. Therefore as part of a related but separate study, we compared a revised AG directly against the CPC. A sample of 115 geography 101 students chose the AG 64 percent to 36 percent for the CPC. The most common response was that the AG provided more detailed information, or that it better prepares people in the path for the conditions that can be expected. Conversely, those that preferred the CPC like its simplicity and also the time increments present in current COU graphics. A high-resolution graphic with a landfall in Texas was used for the AG in this student polling comparison. This could have introduced bias and skewed results in favor of the AG; although that was not mentioned in evaluation comments.

A separate but related study on hurricane evacuation (Rockman, 2012) also used a version of the AG to show a hypothetical scenario for Pensacola as well as scenarios using the current COU graphic (Figure 4). A total of 32 respondents were willing to spend extra time to discuss the AG in greater detail. Comments from these respondents indicate that the revised AG is not a popular option causing confusion for many. Seven respondents specifically mentioned that they prefer the current COU graphic because it is what they are used to seeing. Supporters of the AG liked more information, commented on greater certainty, or commented that it was more helpful to visualize the path. Others said the red impact area at landfall was scary or more threatening (Table I). Out of a sample of 100, it was found that 19-29-year olds liked the AG more than older age groups, and that women disliked it slightly more than men.

2. Large sample student polling with three graphics. Results from field research suggest that the CPC graphic (Figure 5) was superior to the current COU. Additional research suggested that college students preferred the AG to the CPC; however, a smaller sample of respondents in subsequent field research revealed that many people had negative impressions of the AG when compared to the current COU. This circular logic indicates that there may not be a clear preference for a tropical cyclone graphic. The CPC was not evaluated directly against the AG in the field which left many questions unanswered.

Furthermore, many respondents suggested a graphic that included post-landfall hazards during our field surveys. Thus, one final analysis was conducted using three graphics with a large sample of 231 geography 101 students.

Current hurricane warning graphics do not warn about all potential hazards that are associated with land-falling hurricanes. People sometimes use these graphics to make evacuation decisions based on hazards at their locations (Brommer and Senkbeil, 2010). It is odd that hurricane warning graphics do not portray other hazards besides wind speed. Risk communicators have recently begun to discuss the need for incorporating post-landfall hazards into an existing warning graphic. Contrarily, existing graphics have already created confusion, and adding more shapes and colors



Note: This version was also compared to the CPC and HG in later student polling

Figure 4. Australian graphic with a Pensacola, FL landfall used in a separate but related hurricane evcuation study

to an already ambiguous graphic could complicate matters. Despite the potential complications, an effort was made to create an all encompassing HG attempting to incorporate post-landfall hazards (Figure 6). This graphic was evaluated against the CPC and AG.

Student polling results indicate that the CPC was the most popular choice by over a 2:1 margin, at 53.7 percent, followed by the AG 24.7 percent, and the HG 21.6 percent. This preference ratio was similar to the CPC vs the current COU in our initial field research. The CPC was the most popular for both males and females at 48 and 61 percent, respectively. The AG was more popular with males 30 percent to 18 percent for females. The HG was approximately equal in preference. The sample of 231 students was 55 percent male and only 36 percent of the respondents had used hurricane warning graphics in the past. The CPC was also the most popular graphic when considering only respondents who had previously used hurricane warning graphics. Comments describing the advantages of each graphic are summarized and listed in Tables II-IV.

The CPC comments were summarized into three dominant categories (Table II). A total of 52 respondents commented about the graphic being easy to read and uncomplicated with an additional ten respondents writing similar comments. Seven

	Gender and age
No	
I like the normal graphic because I am used to it	Female (20), male (38), female (37) and 3 others
It does not have as much information as the COU	Female (44)
Hates it! would cause unnecessary evacuation and displace too many people	Female (52)
Cannot make an evacuation decision using this one	Female (37), female (40), female (37)
Harder to read than the COU	Male (49)
That graphic is scary; the red is scary	Female (32)
I prefer a cone with a warning area	Female (48)
Harder to understand the severity or depth of impact	Male (24)
Nothing specific, this graphic is better	3 responses
Yes	
I always stay unless it is really bad, so I like the intensity forecast	Female (44)
I like it because it lets everyone know how much of the storm they will see	Female (20)
I can read and understand this graphic quickly and easily	Female (23)
Likes it because it has more detailed information, easier to make a decision	Male (19)
Likes this graphic's intensity directions, would have helped with previous experiences	Male (43)
The red seems more threatneing, but I will never leave	Female (24)
Gives more certainty about evacuation plans	Female (27)
Definitely more helpful in viewing the path of the storm	Female (19)
Nothing specific, this graphic is better	6 responses

Notes: Comments are summarized into No and Yes columns indicating reasons for liking or disliking the AG

Table I.
Summary of comments from a hypothetical hurricane evacuation study conducted in Pensacola, FL comparing the AG to the current COU

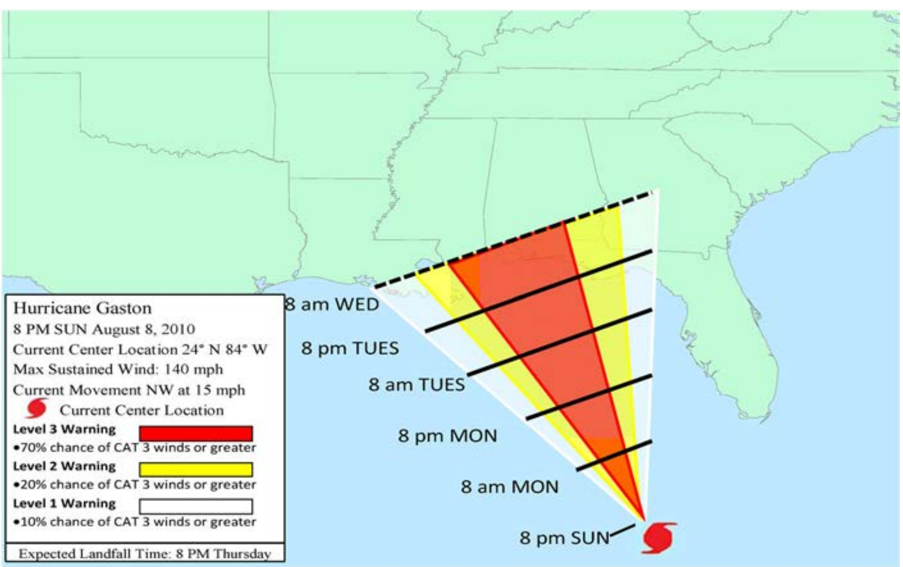


Figure 5.
Larger version of the color-probability-cone 2(e) in (Figure 2) which was the most popular graphic in field research

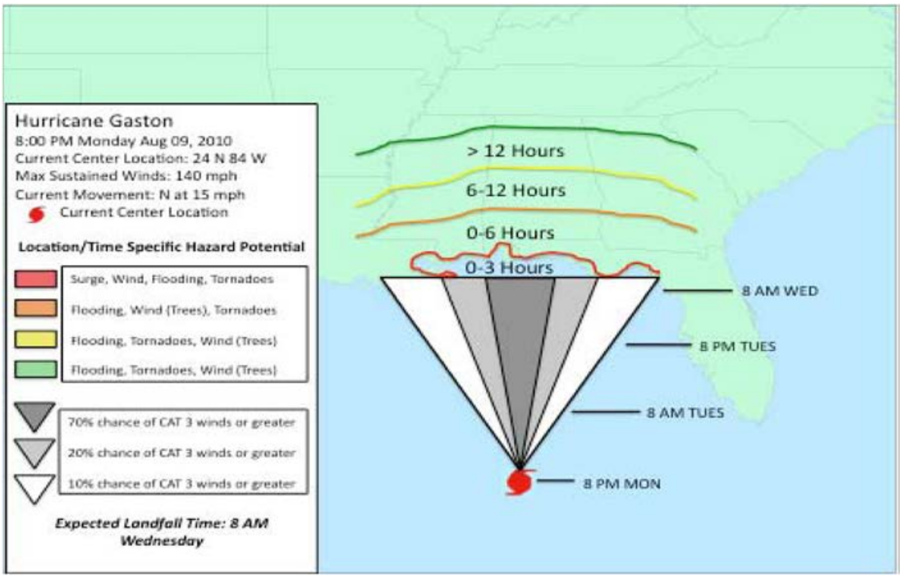


Figure 6. Suggested hazards graphic (HG) that incorporates a cone probability structure with color hazard warnings for post-landfall impacts

Easy to read, less complicated	No	Yes	Male	Female
Easy to understand, less complicated	37	15	22	30
Easy to understand but should have a category rating like AG	1		1	
Most self explanatory, like triangular layout		1		1
More accurate and easier to see how storm is developing		1		1
I am more familiar with this one, see it on news	2	5	5	2
Total	40	22	28	34
Time is mentioned				
Has location, time, easy	1			1
Shows where main concentration of storm will be and at what time	1			1
Showed times	1		1	
Good time estimates and color warning levels	1		1	
Time, power, and location	1		1	
Day by day analysis	1		1	
Levels of warning and time		1		1
Times help with evacuation		1		1
Time management and path direction		1	1	
Shows strength, location, and times	1	1		2
Easy and has times		1	1	
Shows time and how strong	1			1
Time and likely landfall location		1	1	
Most helpful for evacuation, times		1	1	
Times and affected area	1		1	
Severity and times better	1		1	
Times are better		1	1	
Better times and better landfall location	1		1	
Shows projected path, time, strength, range in 1 quick picture		1	1	

(*continued*)

Table II. Comments on advantages of the CPC organized thematically

Easy to read, less complicated	No	Yes	Male	Female
Times, exact percentages, warning levels	1		1	
Times and land fall location	1		1	
Times updated every 12 hours	1	1		2
Dates and times are better	2			2
Times and a red zone		1		1
Times show increase in severity, shows possible areas too		1		1
Time and path are better		1		1
Clear concept of time and landfall		2		2
Very descriptive, times are better	4			4
Times are good, days, level of warning, and where it is going	1	3		4
Total	21	18	15	24
Color, path, land fall				
Tells where it is and where it is going, like colors	1			1
Clear, shows where hurricane is heading	3		1	2
Clear storm path	1	1	1	1
Shows magnitude and how big it will be at landfall	1		1	
Clearly shows affected areas		1		1
Red shows worst area		1		1
Clear and concise, shows worst area		1	1	
Direction and target area		1	1	
Color, land fall probabilities of geographical area	1		1	
Shows possible impact areas and most likely landfall location		1	1	
Shows severity better		1		1
Colors, land fall area, times are better	1		1	
Color code for most dangerous parts, path easy to understand	1	1	2	
Does not require a key and land fall location is clear	1		1	
Colors told me everything with out needing a key	1		1	
Showed the growth and increase in size at landfall		1	1	
Total	11	9	13	7
Other advantages				
Provides more in formation	2		2	
Better visual and graphic	1		1	

Notes: No/Yes refers to previously using hurricane warning graphics; numbers represent counts within each category

Table II.

respondents remarked about their familiarity of this graphic thinking it was the current COU. A total of 39 respondents described the time advantages of the CPC compared to the other graphics. In total, 20 respondents made comments about the colors, path, or landfall location. While these comments accent the advantages of the CPC being simple and communicative, the information in these comments does not elicit the same detail and level of understanding as the AG or HG.

The AG comments were summarized into four categories (Table III). In all, 19 respondents mentioned storm-specific attributes such as size, category, wind, or the eye as an advantage with this graphic. Furthermore, these 19 respondents were almost evenly split between those who had or had not previously used graphics; the most balanced ratio of any category for any graphic. Similar to the CPC, 12 respondents commented about this graphic being the easiest to understand and 14 remarked on the path or landfall location. In total, 12 respondents cited more detailed information.

The HG comments were summarized into three categories (Table IV). In all, 17 respondents mentioned post-landfall impacts or potential hazards as an advantage.

Table III. Comments on advantages of the AG organized thematically

Eye, category, wind, or size mentioned	No	Yes	Male	Female
Shows the eye, has color levels		1	1	
Shows changes in size, path clear	1			1
More clear what category the storm would be at landfall	1		1	
Shows everything – category, time, size, location, winds		1	1	
Shows localized threat, size, and path		1	1	
Has diameter of winds		1	1	
Shows the eye, if you are away from the eye less danger		1		1
Shows the magnitude and size	1		1	
Shows size, path, landfall location	1		1	
Clear projected track and cone of uncertainty, shows size and category also		1	1	
More detail, shows eye, shows intensity change		1	1	
Shows the eye and has more info	1		1	
Shows eye, wind speed, category, watch and warning areas, and cone	1			1
Change in size, landfall location, way it is moving		1		1
Shows the eye and size change	1			1
Shows wind range	1			1
Has the eye, and better path line	1			1
Has a curving path and shows the eye, more specific		1		1
Shows category and path, seems more accurate	1		1	
Total	10	9	11	8
Clear, easy to understand				
Easier to understand, more detail		1	1	
Has less words and is less confusing	1			1
Easy to understand	10		6	4
Total	11	1	7	5
Path, landfall location mentioned				
Movement better represented	1		1	
Shows where it could go better	1		1	
Shows size, path, landfall location	1		1	
Clear projected path, landfall location	2		2	
Clearly shows projected path	1		1	
Clear, easy, and has best path		1		1
Has best projection of path and general time		2		2
Better path, better shows possibilities of what might happen	1		1	
Better landfall location and different elements	3		3	
Shows path curvature	1		1	
Total	11	3	11	3
More information, detail, or other				
Many symbols, more specific, better information	1		1	
More information, warning and watch levels	1		1	
Shows area of greatest danger, other graphics vague	1		1	
Uses cone of uncertainty, more information		1	1	
Not complicated, has watches and warnings	2			2
Had the most information		1		1
Most easily recognizable, looks like a storm	1	1	2	
More detail and accuracy	2		2	
Most modern, most detail, simple key	1		1	
Total	9	3	9	3

Notes: No/Yes refers to previously using hurricane warning graphics; numbers represent counts within each category

Table IV.
Comments on advantages of the HG organized thematically

Hazard or impact mentioned	No	Yes	Male	Female
Shows after landfall impacts, color codes for wind and rain		1		1
Covered hazard stuff on land	1			1
Wind speed and where it would be after landfall	1			1
Shows after landfall impacts and what severe weather will occur		1	1	
Shows level of warning and potential hazards	1			1
Gives new description about hazards every few hours	1			1
Greater notice of hazard potential and time		1	1	
Shows inland hazards, severity, times	1		1	
Time specific hazard potential, helps evacuation		1	1	
Very organized, threat at different locations and for different hazards	1		1	
Landfall, affected areas, severity, watches/warnings, eye path		1	1	
What hazards to expect and where		1	1	
Specific hazards, time of potential hazards	1		1	
Shows risks such as flooding, wind, tornadoes		1	1	
More details, variety of impacts, times after landfall	1		1	
Times are better after landfall, shows impacts at your location	1			1
Impacts are better		1	1	
Total	9	8	11	6
Information or other advantages mentioned				
Goes up to 12 hours after landfall with better predictions		1	1	
Different times and days, better for evacuation	1			1
Shows severity and duration at landfall and also inland, more information		1		1
This is what viewers need to see and understand		1	1	
12 h level system, better preparation	1		1	
Gave the most information and was still clear	5	2	4	3
Shows severity and where it is going to hit	1		1	
Like triangular structure	1			1
Total	9	5	8	6
Time, key, or clarity mentioned				
Severity for times and areas	1			1
Easy to understand, less complicated	2	1	2	1
Timing better on land	1		1	
Timing on land, triangular shape, easy to understand	1		1	
Tells which hour storm will hit certain areas		1		1
Knew when and where it was going to hit	1			1
Easy to read and path was more clear		1	1	
Percentages, locations, times, and how far inland it goes	1			1
Clear info without blocking anything		1	1	
Easy to understand and has timeline after landfall	2		2	
Hourly range, time after landfall helpful	1		1	
2 different symbols, lines and triangles, very clear	1			1
Time and intensity	1			1
Has a key to explain the information	1			1
Specific times, clear	1			1
Very detailed key with clear picture of hurricane intensity	1			1
Total	15	4	9	10

Notes: No/Yes refers to previously using hurricane warning graphics; numbers represent counts within each category

Once again this category had an almost balanced ratio between those who had or had not previously used graphics. In all, 19 commented about the time, key, or clarity advantages after landfall. Although the HG was the least popular, the comments provided stimulate discussion about a graphical warning disconnect once the storm is inland.

It appears that the majority of field and student respondents prefer the simplicity, times, and color scheme of the CPC at a ratio of 2:1 or greater over the current COU and any other alternative graphic. Most respondents want to quickly glance at the graphic for 20 seconds or less and process all the information they think they will need. This primarily involves, when, where, and how strong the storm will be. Certain segments of the population prefer to ask more questions and have more information available for personal risk assessment. Thus, it is suggested that the CPC, or a similar version of it, should be recommended as a possible new graphic to be used experimentally for future tropical cyclones. Such an experimental procedure should include an assessment of visual validity to ensure that a graphic is being properly understood. It is also suggested that the current COU and other alternative graphics should be provided for those who wish to access the information in a different format, or have access to more information. Web sites, such as Weather Underground, already provide information in multiple formats.

Conclusion

Heightened salience of tropical cyclones in the last decade has led many academics, forecasters, and emergency managers to question the effectiveness of hurricane warning graphics. The centerpiece of information used by the NHC and the media to communicate the risks associated with land-falling hurricanes is the COU. Many people rely on this graphic when making evacuation and safety decisions; therefore, it is important to gather as much information as possible about how this graphic influences decision making.

This research shows that people are using hurricane warning graphics, and that past tropical cyclone activity plays a role in hurricane warning graphic usage. Valuable insight was gained into what aspects of hurricane warning graphics coastal residents prefer. Field results show that the CPC graphic was liked at both locations, by both genders, and by multiple age groups. The second most preferred graphic at both locations was the current COU; therefore, it would be safe to say that most coastal residents have a preference for a graphic with a cone-like structure. It also appears that gender and age have a minor influence on graphic preference.

After initial field research was performed, qualitative analysis was used to compare the CPC to a graphic that resembled the one used by the ABM. A sample of 115 geography 101 students at the University of Alabama compared an AG adapted for the USA to the CPC. The revised AG was preferred, with many favoring more detailed and deterministic information. Bias was possibly introduced with this graphic due to differences in visual resolution and landfall location so a revised version was prepared for field evaluation in a separate but related study. Further field research revealed that many people were confused by the AG. The results from field and student surveys proved to be inconclusive and thus more analysis was required. Many respondents in field research remarked that it would be useful to have a graphic that showed both coastal and inland hazard potential. Therefore, another alternative graphic was created with an emphasis on a variety of tropical cyclone hazards. This HG was then evaluated against the CPC and the AG using student polling with a large sample size.

While there are interpretation problems with the current COU, the design and implementation of a new graphic may not achieve the desired improvement in risk comprehension. In order to develop a universal graphic, several factors must be considered. Based on comments from this research, these factors include elements of the current COU, modifications to provide color threat levels, post-landfall hazards, and changes in storm size and intensity. The inclusion of all these elements on one graphic would likely be too noisy and distract from the basic necessities identified in preferences for the CPC. A possible solution is to use a version of the CPC as the main graphic and also include graphics such as the current COU, AG, and HG as alternatives that can be accessed on web sites if users wish to search for more or different information. Before arriving at that operational implementation, an important aspect of additional research should be to take these results and incorporate assessments of visual validity so the efficacy of each graphic can be truly diagnosed. An assessment of visual validity is probably best conducted with selected smaller focus groups instead of the large convenience sample used in this research.

References

Arlikatti, S., Lindell, M.K., Prater, C.S. and Zhang, Y. (2006), "Risk area accuracy and hurricane evacuation expectations of coastal residents", *Environment and Behavior*, Vol. 38 No. 2, pp. 226-247.

Baker, E.J. (1995), "Public response to hurricane probability forecasts", *Professional Geographer*, Vol. 47 No. 2, pp. 137-147.

Broad, K., Leiserowitz, A., Weinkle, J. and Steketee, M. (2007), "Misinterpretations of the 'Cone of Uncertainty' in Florida during the 2004 hurricane season", *Bulletin of the American Meteorological Society*, Vol. 88 No. 5, pp. 651-665.

Brommer, D.M. and Senkbeil, J.C. (2010), "Pre-landfall evacuee perception of the meteorological hazards associated with Hurricane Gustav", *Natural Hazards*, Vol. 55 No. 2, pp. 353-369.

Cox, J., House, D. and Lindell, M. (2013), "Visualizing uncertainty in predicted hurricane tracks", *International Journal of Uncertainty Quantification*, Vol. 3 No. 2, pp. 143-156.

Demuth, J.L., Morss, R.E., Morrow, B.H. and Lazo, J.K. (2012), "Creation and communication of hurricane risk information", *Bulletin of the American Meteorological Society*, Vol. 93 No. 8, pp. 1133-1145.

Drake, L. (2012), "Scientific prerequisites to comprehension of the tropical cyclone forecast, intensity, track, and size", *Weather and Forecasting*, Vol. 27 No. 2, pp. 462-472.

Eosco, G. (2008), "A study of visual communication: cyclones, cones, and confusion", Master's thesis, Cornell University, New York, NY.

Joslyn, S. and Savelli, S. (2010), "Communicating forecast uncertainty, public perception of weather forecast uncertainty", *Meteorological Applications*, Vol. 17 No. 2, pp. 180-195.

Joslyn, S.L. and LeClerc, J.E. (2012), "Uncertainty forecasts improve weather-related decisions and attenuate the effects of forecast error", *Journal of Experimental Psychology-Applied*, Vol. 18 No. 1, pp. 126-140.

Keim, B.D. and Muller, R.A. (2007), "Spatiotemporal patterns and return periods of tropical storm and hurricane strikes from Texas to Maine", *Journal of Climate*, Vol. 20 No. 14, pp. 3498-3509.

Lee, K.L., Meyer, R.J. and Bradlow, E.T. (2009), "Analyzing risk response dynamics on the web, the case of hurricane Katrina", *Risk Analysis*, Vol. 29 No. 12, pp. 1779-1792.

Matyas, C., Srinivasan, S., Cahyanto, I., Thapa, B., Pennington-Gray, L. and Villegas, J. (2011), "Risk perception and evacuation decisions of Florida tourists under hurricane threats, a stated preference analysis", *Natural Hazards*, Vol. 59 No. 2, pp. 871-890.

Meuel, T., Prado, G., Seychelles, F., Bessafi, M. and Kellay, H. (2012), "Hurricane track forecast cones from fluctuations", *Scientific Reports*, Vol. 2 No. 446.

Morss, R.E., Demuth, J.L. and Lazo, J.K. (2008), "Communicating uncertainty in weather forecasts, a survey of the US public", *Weather and Forecasting*, Vol. 23 No. 5, pp. 974-991.

National Hurricane Center (2012), available at: http://www.nhc.noaa.gov/verification/verify5.shtml (accessed May 20, 2012).

Petrolia, D.R. and Bhattacharjee, S. (2010), "Why don't coastal residents choose to evacuate for hurricanes?", *Coastal Management*, Vol. 38 No. 2, pp. 97-112.

Rockman, M.S. (2012), "The role of hurricane intensity and track on evacuation decisions of Pensacola Florida residents", unpublished Master's thesis, University of Alabama, Tuscaloosa, AL.

Roulston, M.S., Bolton, G.E., Kleit, A.N. and Sears-Collins, A.L. (2006), "A laboratory study of the benefits of including uncertainty information in weather forecasts", *Weather and Forecasting*, Vol. 21 No. 1, pp. 116-122.

Senkbeil, J.C., Brommer, D.M., Dixon, P.G., Brown, M.E. and Sherman-Morris, K. (2010), "The perceived landfall location of evacuees from Hurricane Gustav", *Natural Hazards*, Vol. 54 No. 1, pp. 141-158.

Sherman-Morris, K., Senkbeil, J. and Carver, R. (2011), "WHO'S GOOGLING WHAT? What internet searches reveal about hurricane information seeking", *Bulletin of the American Meteorological Society*, Vol. 92 No. 8, pp. 975-985.

United States Census Bureau (2012), "2010 United States Census", available at: www.census.gov/ (accessed May 15, 2012).

Further reading

Wang, X. and Kapucu, N. (2008), "Public complacency under repeated emergency threats: some empirical evidence", *Journal of Public Administration Research and Theory*, Vol. 18 No. 1, pp. 57-78.

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