

## Gulf Coast Residents Underestimate Hurricane Destructive Potential

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### ABSTRACT

Most people do not realize that hurricane destructiveness increases nonlinearly with increases in storm intensity. Three studies were conducted to examine people's perceptions of hurricane destructive potential and their likelihood of evacuation. In the first study, undergraduate students ( $n = 349$ ) provided damage ratings of hurricanes in each Saffir–Simpson category. A majority (84%) of students produced only linearly increasing damage profiles by hurricanes. In the second study, a simple random sample of Gulf Coast residents ( $n = 402$ ) who participated in a telephone survey when a tropical storm was affecting the U.S. east coast revealed that a majority (77%) thought hurricane damages increased linearly with hurricane category and hence underestimated the damage major hurricanes could produce. In the third study, a simple random sample ( $n = 396$ ) of Gulf Coast residents participated in an experiment over the telephone during an active phase of the 2008 hurricane season. One-half of the sample received information about the nonlinearly increasing damage potential of hurricanes; the other half received the Saffir–Simpson hurricane scale category alone. The group in which hurricane damages were framed nonlinearly reported significantly greater self-reported likelihood of evacuation than residents who received the Saffir–Simpson hurricane category information. Studies 1 and 2 suggest that the public needs to learn more about the nonlinear relationship between hurricane intensity and the corresponding damages that may result. Study 3 suggests that framing possible storm damages in the nonlinearly increasing multiples of damages produced relative to a minimal hurricane may increase compliance with evacuation orders.

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### 1. Introduction

#### *a. Evacuations before hurricanes remain below desired levels*

As society has continued to develop the coastal regions of the southeastern United States, hurricane landfalls pose increasing challenges to survival and adaptation (Changnon et al. 2000; Pielke and Sarewitz 2005). A persistent and life-threatening problem, in the face of increased societal vulnerability to hurricane impacts, is that compliance with orders to evacuate ahead of an approaching hurricane remains below desired levels (Blendon et al. 2008).

Prior research has identified several influences that affect people's decisions not to evacuate ahead of an approaching hurricane. These include (i) beliefs that one's dwelling can withstand hurricane winds and storm surge, (ii) needs to protect property against looting and vandalism after the hurricane, (iii) concerns about not

being able to return to one's dwelling after the storm if one does evacuate, (iv) concerns about elderly or infirm family members who may be difficult to evacuate, (v) concerns about pets and other animals that may not have shelter if one evacuates, and (vi) not having a hurricane preparedness or evacuation plan (Blendon et al. 2008; Dash and Gladwin 2007; Dow and Cutter 1998, 2000; Gladwin and Peacock 1997; Horney et al. 2008; Whitehead et al. 2000). Further, some residents in hurricane warning areas may not evacuate because they have experienced hurricane-related weather conditions previously and believe that they can weather yet another storm (Dash and Gladwin 2007; Dow and Cutter 2000). Some people may not possess socioeconomic resources or have access to transportation that is needed for evacuation (Elder et al. 2007; Whitehead et al. 2000). A persistent and overarching finding from this research is that evacuation decisions are affected by the hurricane's intensity and the ensuing perceived risks posed by the storm (Lazo et al. 2010). Many of the influences cited above for not evacuating are balanced against the severity of the hurricane and the destructive potential that it possesses

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as people make their evacuation decisions (Grothmann and Reusswig 2006; Stewart 2009).

#### *b. Hurricane intensity and destructive potential*

Wind engineer Herb Saffir (Saffir 1973) and meteorologist Robert Simpson (Simpson 1974) created what has become known as the Saffir–Simpson hurricane scale (SSHS) to provide an indication of a hurricane's intensity based on its maximum sustained winds. The SSHS has been used widely since its creation to convey a hurricane's destructive potential to the public. Importantly, the Saffir–Simpson categorization is a linear and interval-level scale ranging from 1 (minimal damage) to 5 (catastrophic damage). By definition, for each increase in hurricane category (i.e., from 1 to 2, 2 to 3, and so forth), there is an approximately linear, uniform increase in the wind speed and the accompanying storm surge.

Although hurricanes are categorized and described according to linear increases in wind speed, the physical destructiveness and the potential societal impacts of hurricanes are a nonlinear function of the hurricane category. With respect to physical effects, two indices of destructive potential have been developed that are based on the kinetic energy of the cyclone (Drews 2009). First, Bell et al. (2000), in consultation with William Gray, developed the *hurricane destructive potential* (HDP) index to convey the seasonal magnitude of hurricane activity. HDP is calculated by “summing the squares of the estimated 6-hourly maximum sustained wind speed ( $V_{\max}^2$ ) for all periods in which the system is a hurricane” (Bell et al. 2000, p. S19). The HDP represents the *accumulated cyclone energy* (ACE) for the time in which the cyclone is a hurricane.

Second, Emanuel (1998, 2005) developed a *power dissipation index* (PDI) to convey the amount of kinetic energy dissipated by a hurricane, which relates to its danger and destructiveness. The PDI is related to the third power of its maximum sustained winds ( $V_{\max}^3$ ), the areal extent of the hurricane, and the lifespan of the storm (Emanuel 1998, 2005). An important feature of both indices is that with increases in wind (and the publicized increases in the SSHS category of the storm), hurricane destructive potential increases nonlinearly (i.e., exponentially).

#### *c. Hurricane destructiveness and socioeconomic impacts*

Early work by Gray and Landsea (1992) estimated that hurricane destructive potential increased exponentially such that a category 4 or 5 storm produced 100 to 300 times the physical and economic damage as a category 1 hurricane. More recently, Pielke et al. (2008) estimated the economic costs of hurricanes that made landfall on the Atlantic or Gulf Coasts of the United States from 1900 to 2005 by normalizing the dollar

estimates for damage according to changing societal conditions. Pielke et al. used two different methods, one of which was derived from earlier work (Pielke and Landsea 1998) and involved adjustments for inflation, per capita wealth, and population. The second method was that of Collins and Lowe (2011) and involved normalization of dollar damage estimates according to wealth, inflation, and coastal county housing units. The two methods of examining the economic impacts of hurricanes yielded similar results in that the economic costs of hurricane damage increased exponentially as a function of hurricane category. Pielke et al. (2008) also expressed median normalized dollar damages as multiples of damages stemming from a category 1 hurricane. For instance, using the Pielke and Landsea normalization method, a category 2 hurricane produced 6 times the damage of a category 1 storm; the remaining multiples of damage are presented in Table 1. These damage estimates evidenced an exponential, sigmoid-shaped increase with hurricane category.

In summary, the main points from the literature reviewed here are that 1) hurricane preparedness and evacuation behavior remains below the desired levels; 2) the SSHS has been in use for many years to characterize hurricane intensity and to provide information to the public; 3) hurricane power dissipation increases exponentially with the increases in the SSHS; and 4) economic damages from hurricanes also increase nonlinearly with increases in SSHS. Several research questions naturally emerge from this literature review.

#### *d. Research questions*

Given that the public's hurricane preparedness and evacuation levels remain below the desired levels, despite the use of the SSHS for over 30 yr, one may question the level of perceived destruction that the public associates with each category of the SSHS. Do residents of vulnerable coastal regions understand just how destructive major hurricanes (i.e., those of category 3 and higher) really are? Thus, the first two research questions of this project are as follows:

- What are people's perceptions of hurricane destructiveness for each category of the SSHS?
- Specifically, to what extent do people realize that the economic damages increase exponentially with increases in the SSHS?

With respect to these questions, study 1 in this article examined perceptions of hurricane destructiveness in a sample of university undergraduate students. Study 2 represented a replication of the first study with a simple

TABLE 1. Multiples of hurricane destructive potential (compared to a category 1 hurricane).

Method of evaluating hurricane destructive potential	Saffir-Simpson hurricane scale category			
	2	3	4	5
Pielke and Landsea normalization method* (Pielke et al. 2008)	6	18	97	134
University students**				
Linear profile ( $N = 290$ , 84%)	2.0	3.0	4.0	5.0
Nonlinear profile ( $N = 55$ , 16%)	2.8	7.3	18.0	47.2
Gulf Coast residents <sup>2</sup>				
Linear profile ( $N = 240$ , 77%)	2.8	4.8	6.7	8.7
Nonlinear profile ( $N = 73$ , 23%)	3.9	5.9	8.8	20.3

\* The entries in this table represent multiples of the damage produced by a category 1 (using the SSHS) hurricane. For instance, using the Pielke and Landsea normalization method of median dollar damages, a category 2 hurricane produced 6 times the damage of a category 1 storm, a category 3 storm produced 18 times the damage, and so forth (Pielke et al. 2008).

\*\* The multiples of hurricane destructive potential for university students and U.S. Gulf Coast residents were derived from the equations that were fit to the standardized data for each group (i.e., linear and nonlinear groups). The results obtained using the standardized data were back-transformed (from  $z$  scores) to the format the participants used in originally producing their ratings. Median values were used in the back-transformation from  $z$  scores because they provide a robust, resistant, and meaningful indication of central tendencies in scores and are less affected by extreme values and outliers than are mean values (Wilks 2006).

random sample of people residing in counties bordering the United States Gulf Coast during the hurricane season.

Following from the literature review and from the results of studies 1 and 2, the third research question concerned the effects of framing hurricane information on the likelihood of evacuation. If people were provided with information that conveyed the exponentially increasing nature of hurricane destructive potential with increases in the storms SSHS category, would this change their self-reported behavior? Therefore, the third research question is the following:

- Does framing hurricane destructive potential in exponentially increasing terms as a function of the SSHS category result in a greater self-reported likelihood of evacuation compared to the provision of the SSHS category information alone?

Study 3 in this article addressed this research question using a random sample of Gulf Coast residents during the hurricane season who participated in an experiment to evaluate the effects of framing hurricane destructive potential.

## 2. Study 1: Undergraduate students' perceptions of hurricane destructive potential

### a. Method

#### 1) PARTICIPANTS

The first investigation involved a pilot study using a sample of  $N = 349$  University of Georgia undergraduate students who self-reported at least minimal familiarity with the nature and use of the SSHS. The sample consisted of 94 men and 255 women, most of whom (97.7%) lived in Georgia before enrolling at the university. The

remaining 2.3% of the participants were from California, Florida, Indiana, Kentucky, Louisiana, Tennessee, and Utah. Given their undergraduate status, the sample was generally young with respect to age (mean = 19.1 yr,  $SD = 1.6$ ). Of the  $N = 349$  participants, 82.5% were Caucasian American, 5.4% were African American, 5.4% were Asian American, 2.6% were Hispanic American, and 4.1% Other. A small proportion of participants (17.7%) self-reported that they had evacuated their homes previously because of the threat posed by a hurricane. The procedures followed in completing this study were reviewed and approved by the University of Georgia Institutional Review Board (IRB).

#### 2) PROCEDURES

The participants provided relative ratings of monetary damages resulting from hurricanes of different intensities (i.e., all respondents provided ratings for hurricanes of categories 2 through 5) using the open-ended scale on a brief survey. There were three reasons for using an open-ended response format for soliciting damage ratings: 1) to not constrain people in possibly producing nonlinearly increasing estimates with an upper endpoint, 2) to avoid cuing participants how they should respond (Stevens 1975), and 3) to reflect the reality that it is difficult to estimate (with an endpoint) just how much damage a given hurricane can cause. A category 1 hurricane was used as a standard of comparison: "If the monetary cost of the damages produced by a Category 1 hurricane were represented by the number 1, what number would you think best represents the cost of damages produced by a Category 2 hurricane?" Ratings for the other categories of hurricanes were similarly elicited.

### 3) ANALYSIS

Prior to the analysis of the profiles of hurricane damage, the author standardized the participants' responses using the  $z$  transformation (Wilks 2006):

$$z = \frac{(\text{Rating} - \text{Mean}_{\text{Ratings}})}{\text{SD}}$$

This transformation expressed the perceptions of hurricane destructiveness in standard deviation (SD) units, with each profile having a mean of zero and a standard deviation of one. The  $z$  transformation was performed using the mean value of each participant's ratings to put the damage profiles on a common metric that allowed comparison from one participant to another (Wilks 2006).

The author then used the Statistical Analysis System software, version 9 (SAS Institute 2004, 101–145) cluster procedure (i.e., *proc cluster*) to conduct a hierarchical cluster analysis to group the profiles of standardized responses according to their similarities. Ward's (1963) method of clustering was chosen because it minimizes the sum of squares between observations with a cluster with respect to the variables used to produce the cluster. The cubic clustering criterion and the pseudo- $F$  statistics both suggested that the observations formed two distinct clusters. An examination of the mean values for each of the standardized hurricane damage rating variables indicated that one cluster corresponded to a linear profile of ratings and that the second cluster of observations exhibited a nonlinear profile.

For both groups (i.e., linear and nonlinear profile groups) the author then used the SigmaPlot software (Systat Software 2006) to examine the comparative goodness of fit of linear and nonlinear regression models that were fitted to the data. The SigmaPlot curve fitting software uses the Marquardt–Levenberg algorithm to calculate the coefficients of the independent variables that yield the best fit between the equation and the data (Marquardt 1963).

Once the fit of the equations (linear and nonlinear) was evaluated, the equations were then used to create multiples of perceived damage for each SSHS category of hurricane, compared to a category 1 hurricane. The results obtained from the equations by using the standardized data were back-transformed (from  $z$  scores) to the format the participants used in originally producing their ratings. Median values were used in the back-transformation from  $z$  scores because they provide a robust, resistant, and meaningful indication of central tendencies in scores and are less affected by extreme values and outliers than are mean values (Wilks 2006).

### b. Results

All of the participants produced monotonically increasing profiles of perceived hurricane damages (see Table 1). There were 290 participants (84%) who produced profiles that increased linearly (i.e., increases in perceived destructiveness were approximately even with increases in SSHS). A linear equation yielded the best fit to the data of the models that were evaluated (i.e., those with quadratic and cubic components):  $F(1, 1158) = 163\,514.8$ ,  $p < 0.0001$ ,  $R_{\text{adj.}}^2 = 0.99$ .

The remaining 55 participants (16%) produced response profiles that exhibited progressively steeper increases in perceived hurricane damages with each unit increase in SSHS. For this group, an equation that included both linear, quadratic, and cubic terms exhibited the best fit to the data of the models that were evaluated (i.e., linear and quadratic):  $F(3, 213) = 2241.9$ ,  $p < 0.0001$ ,  $R_{\text{adj.}}^2 = 0.97$ . This cubic equation improved the variance accounted for by the equation to a statistically significant extent over that of a linear equation:  $F(2, 213) = 907.5$ ,  $p < 0.0001$ . The median values for the rated damages for each group (linear and nonlinear) derived from the equations appear in Table 1. For a category 5 hurricane on the SSHS, for example, people in this group evaluated the destructive potential to be 47.2 times that which would be produced by a category 1 storm (see Table 1).

### 3. Study 2: Perceptions of hurricane destructive potential in a random sample of Gulf Coast residents

The second study was undertaken to examine the extent to which the results of the first study might be replicated in a random sample of people residing along the Gulf Coast of the United States. Residents' perceptions of hurricane destructive potential may well differ from those of university undergraduate students who did not live or own property near the coast or have as extensive life experiences with hurricanes.

#### a. Method

##### 1) PARTICIPANTS

Hurricane damage perceptions were examined in a simple random sample of 402 residents (267 women and 135 men) who lived in one of 49 counties bordering the Gulf of Mexico, spanning from the southernmost point in Texas moving east to the southern tip of the Florida peninsula. The mean age of participants was 52.7 yr, the median was 52.0 yr, and the standard deviation was 16.9 yr. The participants' ages ranged from 18 to 90 yr. The participants had lived near the coast

for a mean of 30.8 yr, (median = 27.0 yr, SD = 20.9 yr, range = 90 yr). Men and women in the sample did not differ with respect to their age. Women (mean = 32.7 yr) had resided in the region for a significantly longer period of time than men (mean = 27.0 yr),  $t(390) = 2.54$ ,  $p = 0.011$ . No information about the participants' race or ethnicity was gathered in this second study. All but three participants included in the study reported at least minimal familiarity with the Saffir–Simpson scale; 43.3% of the participants self-reported *complete understanding* of hurricane categories. There were 223 respondents (55.6%) who indicated that they had evacuated their homes previously because of the threat of a hurricane. There were 266 respondents (69.4%) who indicated that they have sustained some kind of property damage from a hurricane in the past.

## 2) PROCEDURE

This study was conducted on 28–31 August 2006 during the time that tropical storm Ernesto made landfall on the North Carolina coast. The study was purposely conducted when a storm was threatening the United States coastline so that the destructive potential and risks posed by a tropical cyclone were more perceptually salient in the minds of the participants (Stokols 1979). Further, the data collection also happened to coincide with the one-year anniversary of the landfall of Hurricane Katrina in New Orleans, an event that resulted in heightened media attention of that event and of hurricane threats in general. The data were gathered through random digit dialing procedures via the University of Georgia Survey Research Center. The sampling error for this procedure was  $\pm 4.8\%$ . The survey questions and open response format were the same as those used in the study with undergraduates reported in study 1.

## 3) ANALYSIS

The analysis of the data in this study was conducted similarly to the analyses performed in study 1. The participants' hurricane damage rating profiles first were standardized within the respondent by using the  $z$  transformation (Wilks 2006). The standardized scores then were cluster analyzed using Ward's (1963) method. The cubic clustering criterion and the pseudo-F statistics suggested that two primary clusters of profiles existed. Similar to study 1, one group exhibited a profile of linearly increasing hurricane damage ratings and a second group exhibited a nonlinear increase in damages. The data for each group were then analyzed with the SigmaPlot software to examine the comparative goodness of fit of linear and nonlinear regression models that were fitted to the data. Because some participants did not

provide two or more damage estimates, which resulted in missing data, the analysis was completed on the 320 participants who produced complete damage profiles. As in study 1, the linear and nonlinear equations then were used to create multiples of perceived hurricane destructiveness in comparison to a category 1 hurricane.

## b. Results

In this study 240 (77%) of the participants produced linearly increasing ratings of monetary damages as storm intensity increased from a category 1 to a category 5 hurricane (see Table 1). A linear regression model exhibited the best fit to the data:  $F(1, 958) = 37\,919.1$ ,  $p < 0.0001$ ,  $R_{\text{adj.}}^2 = 0.98$ , among the models evaluated (i.e., those including quadratic and cubic terms). Although the damage ratings were linear, they increased at a greater rate compared to the results of study 1, with a SSHS category 5 storm rated to result in 8.7 times the damage as a category 1 storm.

There were 73 participants (23%) who produced nonlinearly increasing profiles. As in study 1, several models were fit to the data for the group that produced nonlinearly increasing damage profiles. The model that included linear, quadratic, and cubic terms exhibited the best fit to the data compared to other models that were evaluated:  $F(3, 288) = 3701.3$ ,  $p < 0.0001$ ,  $R_{\text{adj.}}^2 = 0.97$ . This cubic model improved the variance accounted for by the equation to a statistically significant extent over that of a linear model alone:  $F(2, 531) = 1759.6$ ,  $p < 0.0001$ . The median values for the rated damages for each group (linear and nonlinear) derived from the equations appear in Table 1. For a SSHS category 5 hurricane, for example, the participants indicated on average that 20.3 times the damage would result compared to a category 1 storm (see Table 1).

Compared to the undergraduate sample in study 1, the coastal residents produced a lower proportion of linear and a higher proportion of nonlinear profiles and this was a statistically significant result ( $p = 0.018$ , Fisher's exact test). Profiles of damage ratings (linear versus nonlinear) were unrelated to the participants' previous hurricane evacuations or to their sustaining hurricane-related property damage in the past.

## c. Discussion of studies 1 and 2

In samples of both undergraduates (84%) and coastal-dwelling residents (77%), a majority of study participants produced ratings of hurricane destructive potential that increased linearly with increases in the category of the hurricane in the SSHS. This meant that most of the people in each sample did not evidence an understanding that hurricane destructive potential increased nonlinearly with increases in hurricane strength on the

SSHS. For the undergraduate sample producing the linear profile, the damage ratings were equivalent in numerical quantity to the SSHS category (i.e., the slope of the regression line was approximately one). Using the Pielke and Landsea normalization method as a standard of comparison that represented historical hurricane damage multiples (see Table 1), the magnitude of the underestimation for the undergraduate sample ranged from a factor of 3 for category 2 hurricanes to a factor of 27 for category 5 hurricanes. In contrast, the Gulf Coast residents produced a linear profile that possessed twice the slope of the undergraduate sample (i.e., damage rating multiples increased by approximately two for each unit increase in the SSHS). With this steeper slope the magnitude of underestimations, compared to the Pielke and Landsea normalization multiples, ranged from 2.14 for a category 2 hurricane to 15.4 for a category 5 hurricane.

The Gulf Coast residents produced a higher proportion (23%) of nonlinearly increasing damage estimates compared to the undergraduate sample (16%). This result was tempered somewhat by the result (see Table 1) that the nonlinear profile of the undergraduates increased at a higher rate than the profile produced by the Gulf Coast residents. In this regard, the undergraduate sample indicated that a category 5 hurricane produced approximately 47 times the damages as a category 1 storm whereas the Gulf Coast residents indicated that a category 5 hurricane was about 20 times destructive as a minimal hurricane.

Several reasons may account for the differences observed between the groups in studies 1 and 2. It is possible that the closer proximity of the Gulf Coast residents to the coastline, their greater length of residence at this location, and their more frequently reported evacuation for hurricanes may all have resulted in a greater degree of experience with tropical weather and with hurricanes. This experience may translate, within the current project, to both a greater proportion of the residents producing nonlinear profiles and in producing linear profiles with steeper slopes in comparison to the undergraduate group. There was no indication within the data to suggest what might be responsible for the steeper nonlinear profile of the undergraduate group. One may conjecture that such undergraduates, living away from the coastline, may have based their estimates on media reports of hurricane impacts, many of which may show only the most damaged or affected areas.

Regardless of the differences between the groups in studies 1 and 2, the samples within each study still underestimated the multiples of destructiveness that Pielke et al. (2008) reported for each category of storm.

Furthermore, it was somewhat disconcerting that a higher proportion of respondents, especially those living in hurricane-vulnerable areas, did not evidence a more accurate understanding of the way that hurricane destructiveness increased with hurricane intensity. This observation provided the motivation for study 3.

#### 4. Study 3: Effects of framing hurricane intensity on the likelihood of evacuation

Although people may not comprehend how hurricane destructiveness can increase dramatically with increases in hurricane category, does the provision of this information affect the self-reported likelihood of evacuation compared to the provision of the SSHS category of a storm? To investigate this question, two ways of framing hurricane information were compared: the first was the SSHS hurricane category, and the second framed the hurricane in terms of the nonlinear increases in damage reported by Pielke et al. (2008) (see Kahneman and Tversky 2000; Nisbet 2009). People were randomly assigned to receive the hurricane destructive information contained in one of the two frames and then indicate their self-reported likelihood of evacuation in response to the frame.

#### Method

##### 1) PARTICIPANTS

The participants were 396 randomly selected people (269 women and 127 men) who lived in a county that adjoined the Gulf of Mexico or the Atlantic Ocean. The participants were selected through random digit dialing procedures that were conducted by the University of Georgia Survey Research Center. There were 321 (81%) Caucasian American participants, 39 (10%) African Americans, 15 (4%) Hispanic Americans, 7 (2%) Asian American, and 3% multiethnic or other. The mean age of the participants was 56.4 yr and the median was 58.0 yr (SD = 16.1 yr). The participants' ages ranged from 18 to 91 yr. The participants reported that they had lived along the coastal region for a mean of 30.4 yr (median = 26 yr, SD = 21.3 yr, range = 88 yr). Men and women in the sample did not differ with respect to their age or the amount of time that they lived along the coast. Ethnicity was equally represented among gender and people of different races did not differ with respect to their age or the time that they had lived in the coastal region. In the present sample the participants were significantly older (56.4 yr) compared to the sample of Gulf Coast residents reported in the second study (50.8 yr):  $F(1, 704) = 15.68, p < 0.0001$ , partial eta-squared = 0.02. Similar to the demographics

of study 2, there were 194 (49.0%) of the respondents who indicated that they had evacuated their homes previously because of the threat of a hurricane. There were 288 respondents (72.7%) who indicated that they had sustained property damage from a hurricane in the past.

## 2) PROCEDURES

The data for this study was collected over 4–9 September 2008. These dates were chosen for the survey deployment because it was a very active time for hurricanes in the Caribbean Sea and the Gulf of Mexico and thus made the threats posed by hurricanes more salient to the participants (Stokols 1979). That is, on 1 September 2008 Hurricane Gustav made landfall in southwestern Louisiana as a strong category 2 hurricane and caused an estimated total of 4.3 billion dollars in damages (Beven and Kimberlain 2009). At this time Tropical Storm Hanna and Hurricane Ike were moving into positions that would threaten the Gulf and Atlantic coasts of the United States. Then, Tropical Storm Hanna made landfall along the South and North Carolina coastlines on 6 September and was responsible for an estimated 160 million dollars of damages in the United States.

The data were gathered through random digit dialing procedures via the University of Georgia Survey Research Center. The sampling error for this procedure was  $\pm 4.9\%$ . The participants were randomly assigned to one of two conditions that framed the intensity of the hurricane and then were asked about their likelihood of evacuating their homes. In one condition ( $N = 196$ ) the intensity was based only on the SSHS category of the storm. The phrasing of questions in this condition took the form of: *If a Category 3 hurricane was forecasted to directly strike your community, how likely would you be to evacuate your home if the government officials in your community recommended it?* The second condition ( $N = 200$ ) framed hurricane intensity in an exponentially increasing format following the results reported by Pielke et al. (2008). Here, queries about evacuation likelihood took the form of: *If a hurricane were forecasted to directly strike your community and the hurricane was now capable of producing 18 times as much damage in your community compared to when it first became a hurricane, how likely would you be to evacuate your home if the government officials in your community recommended it?* The questions for a category 1 hurricane were the same for both conditions: *If a Category 1 hurricane were forecasted to directly strike your community, how likely would you be to evacuate your home if the government officials in your community recommended it?* For both conditions the respondents used a 7-point rating scale (1 = extremely unlikely,

2 = moderately unlikely, 3 = somewhat unlikely, 4 = not sure, 5 = somewhat likely, 6 = moderately likely, and 7 = extremely likely) to indicate the likelihood of evacuating their homes.

## 3) ANALYSIS

The author calculated a 2 (history of prior hurricane evacuation)  $\times$  2 (information frame)  $\times$  5 (hurricane intensity) mixed model analysis of variance to assess the relative effects of the two ways of framing hurricane information across the five categories of the SSHS according to whether or not people had reported evacuating for a hurricane in the past. In this analysis, the information frame was the between-subjects factor and the hurricane intensity levels were the within-subjects factor (i.e., were evaluated by all participants in that condition). The respondents' prior hurricane evacuation experience also was a between-groups factor. Here, 194 people reported a prior hurricane evacuation and 202 indicate they had not evacuated. The frequencies of evacuation history did not differ according to the information frame conditions:  $X^2(N = 396, df = 1) = 0.36$ , not significant. The statistical analyses to examine differences in mean values of evacuation likelihood as a function of the independent variables were conducted with the general linear models procedure (i.e., proc glm) of the SAS software, version 9 (SAS Institute 2004, 1731–1096).

## 5. Results and discussion

A statistically significant interaction between prior evacuation and hurricane intensity was observed in that those with a prior history of evacuating expressed significantly greater likelihood of evacuation for less intense hurricanes than those who had not evacuated previously:  $F(4, 1544) = 2.87, p = 0.02, \eta^2 = 0.007$ . Prior evacuation status did not statistically interact with the way of framing hurricane information (SSHS versus nonlinear format).

Controlling for the effects of prior hurricane evacuation, a statistically significant interaction was observed between the way of framing hurricane information and the intensity of the hurricane:  $F(4, 1544) = 17.33, p < 0.0001, \eta^2 = 0.045$ . The nonlinear message group reported a significantly greater likelihood of evacuating for category 2 and 3 hurricanes compared to the group receiving the SSHS intensity information alone. A plot of the means for each group for the five hurricane intensities is provided in Fig. 1. The groups did not differ in their reported likelihood of evacuating for a category 4 or 5 hurricane. No differences were expected for a category 1 hurricane as this functioned as a reference

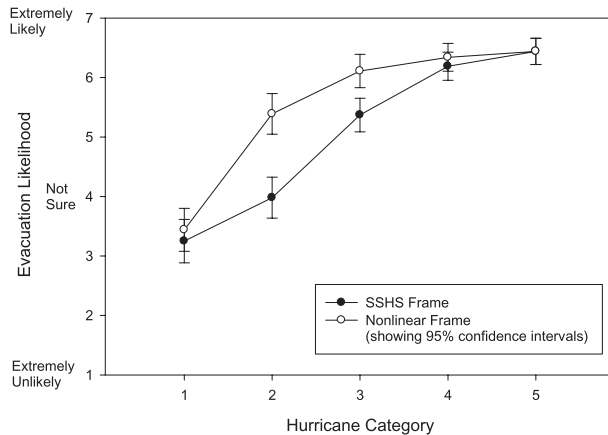


FIG. 1. Likelihood of hurricane evacuation as a function of the way in which hurricane destructive potential is framed (SSHS frame vs nonlinear frame).

category. Finally, it was observed that the experience of sustaining prior property damage from a hurricane, respondent age, years lived along the Gulf Coast, gender, and race were not statistically related to people's self-reported likelihood of evacuation in this study.

Although most of the survey respondents did not realize that hurricane destructive potential increased nonlinearly with storm category, this third study suggested that providing people with exponentially increasing damage estimates resulted in greater likelihoods of evacuation compared to those who received the unelaborated SSHS hurricane category information. Regarding this latter group, the results of the present study were consistent with those of Lazo et al. (2010), who reported a linear relationship between the SSHS intensity of a storm and residents' self-reported likelihood of evacuating their homes in Miami, Florida.

It was noteworthy that the significant differences between the ways of framing hurricane destructive potential occurred for hurricanes in categories 2 and 3 of the SSHS. Hurricanes of these intensities may not appear as dangerous or as destructive as they can be. Yet, increasing the public's responsiveness to storms of this magnitude may be very important in view of the finding that that 30 of the 50 most damaging hurricanes included in the analysis by Pielke et al. (2008) were category 2 or 3 storms. Although the nonlinear method of framing destructiveness resulted in a slightly higher reported likelihood of evacuation for category 4 and 5 hurricanes, these differences were not statistically significant. Apparently, as hurricanes become approach these levels, people are more likely to evacuate regardless of the way the hurricane information is framed. Thus, this result is not surprising.

## 6. General discussion

### a. Limitations

The three studies reported here possess several limitations, the most notable of which is the self-report nature of the data. How people actually behave when they are faced with an evacuation decision may differ from what they say they would do when contacted to participate in a survey. There is some evidence, however, to suggest that people's self reports about their intended behaviors regarding hurricanes are indeed consistent with their subsequent behaviors (Kang et al. 2007). Another possible limitation is that the experimental conditions in the third study were somewhat artificial in that one might argue that people seldom receive the SSHS information in isolation without other data pertaining to an impending hurricane threat and how it could impact their area. Although this is true, the SSHS category is often made more salient than other accompanying information on maps, headlines, sound bites, and text messages disseminated through the media. Therefore, it is not unlikely that weather consumers give higher priority to the hurricane category compared to other data such that it becomes one of the single most important pieces of information they use. A final limitation concerns the work yet to be accomplished in understanding people's perceptions of hurricane destructiveness. Although the present studies documented that a majority of people tend to underestimate hurricane destructive capabilities, the reasons for this remain unclear. Some of the possible reasons are discussed below.

### b. Possible reasons for the underestimation of hurricane destructive potential

Although majority of respondents in the studies of undergraduates and of Gulf Coast residents self-reported at least *some* understanding of the SSHS, a majority of people in both studies did not realize that hurricane destructive potential increased more than linearly with increases in hurricane category. Further, the minority of respondents in both studies 1 and 2 that produced a nonlinearly increasing profile of damage estimates still underestimated the damage profiles that Pielke et al. (2008) reported for hurricanes of different intensities. There are several possible reasons for this underestimation that have to do with 1) the psychophysics of hurricane perception, 2) anchoring effects, and 3) difficulties in understanding nonlinear relationships. Each of these possible reasons is discussed below.

#### 1) PSYCHOPHYSICS OF HURRICANE PERCEPTION

There are three possible reasons that might explain people's underestimations of hurricane destructive



potential, the first of which has to do with psychophysics. The field of psychophysics studies how the physical stimuli to which people are exposed relates to their internal sensations and perceptions of the stimuli (Stevens 1975). Psychophysics seeks to quantify how experienced physical actualities translate psychologically into sensations and perceptions. Psychophysical research has determined that, for most categories and varieties of stimuli, people do not experience actual or true representations of the stimuli to which they are exposed; some estimates of stimulus magnitude are systematically underestimated while others are overestimated. Because people tend to systematically underestimate the magnitudes of stimuli such as loudness, vibration, and velocity (Walker 2007), it is possible that this contributes to the overall underestimation of a hurricane's destructive potential. One implication of Walker's results is that people may conclude on the basis of their senses and perceptions that prehurricane or hurricane conditions are not as intense (or dangerous) as they are in actuality and thus decide not to evacuate. Alternatively, some people may wait until storm conditions build before they decide to evacuate at which point the evacuation itself may be dangerous.

## 2) ANCHORING EFFECTS

A second possible reason for the underestimation of hurricane destructive potential involves a phenomenon from cognitive psychology known as anchoring effects (Chapman and Johnson 1999; Tversky and Kahneman 1974). Anchors can function as informative guides for knowing what to expect about something that the anchor represents. To the extent that people do not sufficiently adjust their expectations from the value provided by the anchor or to the extent that the anchor promotes estimates or expectations that are consistent with the anchor values, then *anchoring effects* are said to occur (Tversky and Kahneman 1974). This means that the informative guide comes to constrain people's expectations and perceptions.

In the present context, the SSHS categories function as informative guides for people to use in knowing to what to expect regarding the severity and potential destructive capabilities of a hurricane (Simpson 1974). If the SSHS categories are functioning as anchors, then people's perceptions of hurricane destructiveness will be constrained by the ways they use the features of the scale. In fact, this was what was observed in both studies 1 and 2. The anchoring effects appeared in two ways in these studies, the first of which was in the linear form of the majority of damage profiles people produced in both studies. Although those participants in study 2 who produced a linear profile evidenced a greater slope than

participants in study 1, the profiles nonetheless were linear in the same way that the SSHS is a linear scale. The second way anchoring effects appeared was through the numerical values of damage ratings of those participants who produced linear profiles of hurricane damages. As a group, the participants in study 1 produced ratings that were numerically identical to the SSHS category numbers. Thus, in the context of these studies, people's perceptions of hurricane destructiveness appear to be anchored by the ways in which they are using the SSHS.

## 3) DIFFICULTIES IN UNDERSTANDING NONLINEAR RELATIONSHIPS

Another possible reason that people more frequently produced linearly increasing ratings of damage estimates is that nonlinear relationships are inherently more complex and thus difficult to understand. In this regard, research from the mathematics education field suggests that people experience difficulties in understanding exponential relationships and are prone to perceive covariation (i.e., changes in one variable as a function of another variable) in linear rather than exponential or other nonlinear terms (Confrey and Smith 1994, 1995; Stavy and Tirosh 2000). The origins of this tendency are not clear; however, it is possible that it has psychophysical roots. Following from the discussion of psychophysics above, the human sensory and perceptual system logarithmically transduces the intensities of stimuli such as light and sound, which naturally vary exponentially in the environment. The effect of this transformation is that stimuli are perceived in linear terms. This feature of human perception along with the difficulty in understanding nonlinear relationships may have contributed to an underestimation of hurricane destructiveness.

### *c. Implications for improving hurricane evacuation behavior*

Although studies 1 and 2 documented the natural tendency of people to underestimate hurricane destructive potential, perhaps for the aforementioned reasons, the results of study 3 are informative for efforts to increase the likelihood of hurricane evacuation. Chapman and Johnson (1999) recommended that one way to reduce anchoring biases involves prompting people to identify target features that are different from the anchor. This was exactly what was done in the nonlinear group in study 3 where, rather than responding to the SSHS numerical categories, people received additional information in the form of multiples (i.e., 6, 18, 97, or 134 times the damage) relative to a category 1 hurricane. In this experimental condition, the profiles of evacuation likelihood as a function

of hurricane category were much improved over provision of the SSHS information alone. Presumably, people's estimations were not constrained by the numerical values of the SSHS. Similarly, providing information to people to avoid letting the anchors (i.e., SSHS categories) constrain their perceptions of hurricane destructive potential and to adequately adjust their expectations may be a helpful strategy to pursue as well (Epley and Gilovich 2006).

Another reason that the multiples of hurricane damage used in study 3 may have increased people's self-reported intentions to evacuate over the SSHS categories may have to do with increases in their levels of perceived risk when hurricane destructive potential was framed in nonlinear terms (Keller et al. 2006). That is, learning that a hurricane is capable of producing 18 times (i.e., multiple for SSHS category 3) more damages than when it first became a hurricane (i.e., minimal category 1) may help to more completely communicate the level of risk and danger than the use of category 3 label alone, for example. In addition, this manner of framing hurricane information may increase people's levels of arousal and attention. Such increased arousal could lead people to experience the risks as feelings and/or motivations (Loewenstein et al. 2001) such that their likelihood of making hurricane preparations or of evacuating is increased (Lazo et al. 2010).

With these findings the author is not advocating the replacement of the SSHS. The longevity of the scale, its popularization among the United States public over many successive hurricane seasons, and its demonstrated value in conveying hurricane information all argue strongly for its continued use. The results of the studies in this article indicated that a majority of coastal residents possess an awareness of the SSHS. The additional needs for knowledge appear to concern what kinds of damage to the built and natural environments will occur with hurricanes as a function of the SSHS category. Given the results of the three studies in this project, the public may well benefit from efforts to help them rely less on the category number of the SSHS and more on what kinds of physical and societal impacts the prototypical hurricanes in each category can produce when they make landfall.

The recent efforts of the National Hurricane Center (NHC 2010) to supplement the SSHS represents just the kind of additional information that is needed to help people understand hurricane destructive potential and move beyond the anchoring and linear bias effects that may have precluded a clearer understanding of hurricanes in the past. In this regard the NHC developed the Saffir-Simpson hurricane wind scale (SSHWS) for experimental use in the 2009 tropical cyclone season; the SSHWS was

slightly revised in 2010. The SSHWS goes beyond the original SSHS to provide examples of both the nature of damages and likely societal impacts that are typically associated with each category of hurricane (<http://www.nhc.noaa.gov/aboutsshs.shtml>). Specifically, the SSHWS describes the effects of hurricanes on people, animals, homes of different types, industrial and commercial buildings, windows, and trees, along with impacts on power and water services. Relatedly, the NHC also has implemented additional products that are designed to convey storm surge information. For example, the NHC storm surge product provides the likelihood of storm surge values from 2 through 25 feet. This product conveys the realization of the dangers posed to humans, animals, and the environment by the onshore surge of seawater. The descriptive information in both the SSHWS and the storm surge products of the NHC and local National Weather Service offices provide the important kinds of descriptive information will help people move beyond the constraints of the numerical category in understanding beforehand the dangers posed by hurricanes. The descriptive information also may help people to more completely understand the risks associated with the typical impacts of storms in each SSHS category such that their preparations more closely correspond to the dangers posed by the hurricane (Keller et al. 2006).

In addition to these efforts by the NHC, consideration should be given to conveying two additional important pieces of information that emerged from this project as part of the seasonal campaigns to educate the public ahead of each hurricane season. First, the public should be educated about how increases in SSHS categories are associated with exponential increases in the physical impacts of the storm. The results of the present studies indicated that more people need to know the *correct form* of the SSHS and damage relationships. One example of such an effort appears on the "Hurricane Damage Potential" web page of the National Weather Service Southern Region Headquarters ([http://www.srh.noaa.gov/jetstream/tropics/tc\\_potential\\_max.htm#quad](http://www.srh.noaa.gov/jetstream/tropics/tc_potential_max.htm#quad)). Second, both verbal explanations and graphics of damage multiples, such as those reported in Pielke et al. (2008), may help people to more fully appreciate the nature and form of the relationship between a hurricane's maximum sustained winds (i.e., SSHS category) and damages that could occur. As the SSHWS is revised over time, the results from study 3 suggest that it may be very worthwhile to incorporate the multiples of Pielke et al. in the SSHWS, perhaps in the tabular format used with some of the existing impact variables. Further, these multiples should be publicized via media outlets when they begin providing their coverage of tropical weather during the hurricane season.

In conclusion, the three studies reported in this article revealed several noteworthy results that bear directly on the public's needs for ongoing hurricane education and preparedness efforts. First, a majority of both inland-dwelling undergraduate students and long-time residents of the U.S. Gulf Coast, despite possessing knowledge of the SSHS, indicated that hurricane destructive potential increased only linearly with storm category. Second, the minority of study participants who evidenced a more correct understanding of the form of the relationship between hurricane intensity and destructiveness still underestimated the damages that major hurricanes could produce. Third, the final study in this article revealed that people were more likely to evacuate their homes when storm damages were presented in a nonlinear format than they were when given the SSHS category of the storm alone. Educating the public further about hurricanes may increase their knowledge of the relationship between the hurricane's intensity and the level of damages that may result. Characterizing possible storm damages in the nonlinearly increasing multiples of damages produced relative to a minimal hurricane may increase compliance with evacuation orders and thus save lives.

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