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Understanding perceptions of changing hurricane strength along the US Gulf coast

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ABSTRACT: The scientific debate on the impact of climate change on hurricane intensity/strength continues. Regardless of its causes, the consequence of increasing hurricane intensity is undeniably immense among coastal residents. In this study, we investigate how various objective measures of hurricane strength affect people's perception of changing hurricane strength over time. We utilize original survey data to examine the relationship between perceived and actual shift in hurricane strength. In this article, hurricane strength is indicated as maximum wind speed at landfall, storm surge, and economic damage. We find that the characteristics of hurricane strength associated with the most recent landfall are much more closely associated with perceptions of changing hurricane strength than objectively measured trends. This result is consistent with availability bias, suggesting that perceptions are associated with most accessible and retrievable events. We also find that people's belief in climate change play a powerful role in one's perception of changing hurricane strength. Political predispositions are found to affect one's perceptions of changing hurricane strength. Compared to Democrats and Independents, Republicans are far less likely to believe that climate is changing and thus they tend to not believe that hurricanes are becoming stronger. Given that this study focuses on how physical characteristics of past hurricane events influence individual perceptions of hurricane strength shift, future research should focus on how expectations of future climate and weather-related events influence individual attitudes and behaviours.

KEY WORDS climate change; hurricane strength; perceptions of changing hurricane strength; maximum wind speed at hurricane land fall; political communication on natural hazards

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1. Introduction

Climate change and its impacts on hurricane activity in the Atlantic basin is a much debated topic, representing one of the uncertainties in our current and future climate. For example, there has been an increase in the number and intensity of major hurricanes in the Atlantic basin since 1995 (Goldenberg *et al.*, 2001; Pielke *et al.*, 2005; Webster *et al.*, 2005). One possible explanation for this upward trend of Atlantic hurricane activity is the increase of sea surface temperature (SST) driven by greenhouse gas forcing (Emanuel, 2005; Webster *et al.*, 2005; Elsner, 2006; Holland and Webster, 2007). In contrast, another interpretation is multi-decadal climate variability in SST driven primarily by the Atlantic Multi-decadal Oscillation (AMO). The AMO is a measure of the SST in the North Atlantic and thus affects hurricane activity (Senkbeil *et al.*, 2011). However, it is premature to directly link the AMO with climate change (Landsea, 2005; Pielke *et al.*, 2005; Landsea *et al.*, 2006).

Regardless of the debate, the consequences of these events are undeniably large and include damage from both wind and water. Of all natural hazards of the past century, hurricanes have inflicted the most property damage in the United States (Meyer *et al.*, 2014), with Hurricanes Katrina in 2005 and Sandy in 2012 amounting to over $120 billion in damage combined (Pielke *et al.*, 2008; Blake *et al.*, 2011, 2013). Exposure to these risks necessitates coastal residents and planners to take adaptive and mitigation measures such as installing storm shutters, strengthening roof and wall connections, using flood-proof material, and elevating houses with piles. These measures are effective in protecting coastal properties against damages from hurricane impact now and under future climate scenarios (Klima *et al.*, 2011). Public involvement is also essential to cooperative governance in order to build sustainable and resilient communities in the face of higher hurricane risk, climate change, and sea level rise (Burby, 1998, 2003; Burstein, 1998, 2003). For example, public support is a necessary condition for effective implementation of land use planning policies (Peacock *et al.*, 2005), regional flood protection measures (Aerts *et al.*, 2014), and construction and maintenance of sand dunes (Hatzikyriakou *et al.*, 2015).

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For any substantive planning for hurricanes to take place, however, society must perceive the problem, and often there is a disconnect between perception and reality when it comes to weather and climate (Goebbert *et al.*, 2012; Howe and Leiserowitz, 2013; Shao, 2015; Shao and Goidel, 2016). Also, Meyer *et al.* (2014) found that residents tend to over-estimate the risks of hurricane-force winds and under-estimate the threat posed by flooding during hurricane events. In contrast, Peacock *et al.* (2005) found that most Florida single family homeowners do indeed accurately perceive their level of risk. Clearly, research on perceptions of hurricanes is far from complete. As a result, this study addresses four research questions:

1. How does the intensity of past hurricanes affect residents' risk perception towards the changing hurricane strength?
2. Which physical characteristics of hurricane strength (e.g. wind speed, magnitude of storm surge) have the large impacts on perceptions of changing hurricane strength over time?
3. Do the consequences (i.e. economic damage) of a hurricane landfall have a large impact in shaping one's perception of changing hurricane strength?
4. Do people's opinions of climate change affect their perception towards changing hurricane strength?

The paucity of research on how coastal residents perceive past hurricane strength warrants further investigation. Examining perceptions of past hurricane strength would also enhance our understanding of one's decisions/indecision to adapt to the increasing challenges posed by increasing hurricane risk owing to climate change. In this article, we attempt to identify factors that affect coastal residents' perceptions of changing hurricane strength over time along the US Gulf Coast. The US Gulf Coast makes a great test case as its population has risen dramatically over the past century. Keim and Muller (2009) document that the US population in the coastal counties has experienced a rate of growth that is 3.5 times greater than that for the United States as a whole. A more recent Census report records that the population in the coastline counties of the Gulf grew by 8.4 million (150%) from 1960 to 2008, demonstrating the popularity of the Gulf Coast (Wilson and Fischetti, 2010). The population growth is likely to continue (NOAA, 2013). In addition, this coastal zone has enormous investment in oil and gas infrastructure, resort hotels, yacht clubs and marinas, and luxurious homes. Hence, there is an abundance of people, coupled with very expensive infrastructure.

With the growing concentrations of coastal population and infrastructure, hurricanes pose even higher risks to the Gulf coastal communities. Hurricane intensity is primarily represented by its maximum sustained wind speed. More complex indices of hurricane strength include hurricane destructive potential (HDP) (Bell *et al.*, 2000) and power dissipation index (PDI) (Emanuel, 2005), which are constructed based on wind speeds and storm duration. Both attempt to determine how much energy is exerted by the hurricanes. These other metrics are becoming more prominent as limitations of the Saffir–Simpson Hurricane Scale are realized. With this in mind, several recent storms with low wind speeds have generated impacts far beyond what would be expected. For instance, Hurricane Sandy (2012) was a post-tropical cyclone at landfall with a wind speed at landfall of 120 km h^{-1}, but caused over $50 billion US dollars due to its extensive area of storm surge inundation (Zhai and Jiang, 2014). Hurricane-induced storm surge can lead to severe structural damages and losses to coastal communities (Aerts *et al.*, 2013, 2014), even with some storms that seem modest on the Saffir–Simpson Hurricane Scale (Xian *et al.*, 2015). Storm surge has, therefore, become another important measure of hurricane strength (Lin and Emanuel, 2015). Although the maximum sustained wind speeds at and before landfall are highly correlated with the peak storm surge heights (Lin *et al.*, 2010; Needham and Keim, 2014a), storm size can also have significant influence (Irish *et al.*, 2008; Needham and Keim, 2014b). For example, Hurricane Ike in 2008 produced a catastrophic surge in coastal Texas as a Category 2 storm (Berg, 2009). In addition, some storms with high maximum wind speed may generate a small amount of surge due to rapid intensification before landfall, such as Hurricane Charley in 2004 (Pasch *et al.*, 2004). Therefore, despite the fact that the maximum sustained wind speed at landfall is the most important parameter to indicate hurricane intensity, storm surge could also provide a complementary measure in some cases. In this study, we include both maximum wind speeds at landfall from the HURDAT data set (Keim and Muller, 2009) and peak heights of storm surge from the SURGEDAT developed by Needham and Keim (2012) to represent hurricane intensities. Additionally, we include economic damages from hurricanes as a measure of hurricane impact. This measure encompasses both physical destructiveness of hurricanes and socio-economic vulnerabilities to hurricane impacts. We directly test which of the three indicators most affect risk perceptions.

By merging survey data with environmental data, we develop several multilevel models to explain variations in perceptions of hurricane strength shift. Some previous studies have identified the link between past experience with extreme weather events and perceptions of these events (Matyas *et al.*, 2011; Spence *et al.*, 2011; Akerlof *et al.*, 2013; Myers *et al.*, 2013). For example, Matyas *et al.* (2011) find a link between past experience with hurricanes and likelihood of tourists to perceive risk by surveying 448 tourists visiting central Florida. However, the past experience is based on survey responses in most of these studies. Self-reports of weather and climate can be subject to heuristics and biases, and are therefore considered unreliable (Egan and Mullin, 2012). One advantage of this study is that we adopt objective measures of past hurricane intensities rather than subjective assessments, and study the effect on risk perception of changing hurricane strength. Results of this study shed some light on the effects of objective measures of past hurricane intensities on individual perceptions, and therefore provide policy-makers with useful insights into how to effectively inform the public of real hurricane risks and engage them in community planning.

In the following sections, we first describe the data, variables, and methods. We then present and discuss the results. We conclude with the general implications of the findings, and point out the direction of future studies in this field.

2. Material and methods

2.1. Individual-level data

The survey data are extracted from the 2012 Gulf Coast Climate Change Survey which includes items related to coastal residents' perceptions of local climate shifts and their willingness to take actions to adapt to climate change impacts (Goidel *et al.*, 2012). Stratified random sampling was used to draw an adequate sample across Gulf Coast states (Florida, Alabama, Mississippi, Louisiana, and Texas) and regionally within Florida, Louisiana, and Texas. The data were collected by landline telephone from January 3 through April 4, 2012. Individual-level variables are built upon these survey data. The survey asked respondents, 'would you say that the hurricanes that do impact your local community are stronger, not as strong, or about as strong as hurricanes in the past?' The dependent variable – *perceptions of hurricane strength shift* – is based on responses to this question and measured on a three-point scale as −1 ('not as strong'), 0 ('the same'), and 1 ("stronger). 'Don't know' is recoded as missing. Socio-demographic attributes include: *age* measured in years from 18 to 94, *gender* ('female' = 1, 'male' = 0), *education* on a scale from 1 (less than ninth grade) to 8 (doctorate or postdoc degree), *income* from 1 (under \$10 000) to 8 (\$100 000 or more), *African American* ('African American' = 1; 'other' = 0), *Hispanic* ('Hispanic' = 1; 'other' = 0), and *party identification* on a three-point scale as 0 (Democrat), 1 (independent), and 2 (Republican).

In addition to these socio-demographic variables, we include *attentiveness to information about climate change* and *belief in climate change*. The on-going scientific debate on relationships between climate change and increasing Atlantic hurricane activity through media reports may somehow shape the public debate. Being more attentive to information about climate change may affect one's perceptions of changing hurricane strength differently, depending on which information source has been accessed. Thus, we include four measures including *how informed about climate change*, indicated by frequencies to go to *newspapers and TV*, *radio*, and *internet* for information about climate change. Furthermore, previous studies have shown that pre-existing attitudes towards climate change play a powerful role in determining one's perception of specific climate risks (Howe and Leiserowitz, 2013; Shao, 2015). For instance, those who believe climate change is occurring are more likely to perceive abnormal weather patterns (Shao, 2015). Thus, we include the binary variable of *belief in climate change* in models explaining perceptions of hurricane strength shift. Because Meyer *et al.* (2014) found that the respondent's proximity to water increased one's awareness of the threat of storm surge, we also include the measure of *distance from the coast* in this study. This measure is based on one's subjective assessment of their distance from the coast.

2.2. Contextual data – objective indicators of hurricane strength

Before discussing objective measures of hurricane strength, we need to define both the temporal frame and spatial context within which these objective measures are constructed. The original wording of the survey question about the change in hurricane strength does not refer to a specific time period. It is therefore somewhat arbitrary for us to select the past 20-year period as the baseline. The interview was conducted in the spring of 2012 (from January 3 through April 4). Hurricane landfalls of the last 20 years extend over the period of 1992–2011 (no hurricane landfalls occurred along the Gulf Coast in 2011). This selection is based on two major considerations: (1) extreme weather events such as hurricanes do not occur often at a single location and thus requires a relatively long period to form a pattern due to either climate change or climate variability; (2) although a longer term than 20-years is more ideal for a conspicuous trend to form, human memory tends to be short. In addition, because this question specifies 'hurricanes that do impact your communities', we only consider respondents who lived in coastal counties with at least one hurricane landfall from 1992 to 2011. Figure 1 demonstrates the tracks hurricanes/high-impact tropical storms that have made landfalls between 1992 and 2011 along the Gulf Coast. Therefore, 1961 of 3856 respondents are selected based on these temporal and spatial criteria.

To begin our analysis, we map the spatial pattern of perceptions of hurricane strength – the dependent variable – among these selected coastal residents (see Figure 2). As can be seen in Figure 2, perceptions that hurricanes are getting stronger are heightened along the coast line in Mississippi and Louisiana, reflecting the devastation due to Hurricane Katrina. Residents further west in coastal Texas and east in coastal Florida along the Gulf, in contrast, are less likely to say hurricanes have grown stronger. We will attempt to determine which physical indicators of hurricane landfall explain this pattern. We project spatial patterns of trends in maximum wind speed at landfall, storm surge, and economic damage, respectively (see Figure S1–S3, Supporting Information). We then map the spatial patterns of the maximum wind speed at landfall, storm surge, and economic damage from the last hurricane landfall before 2012. As can be seen in Figure 3, this spatial distribution of maximum wind speed at landfall from the last hurricane landfall neatly matches our map of perceptions. The categorization of maximum wind speeds at landfall is mainly based on the Saffir–Simpson scale except that category 0 indicates

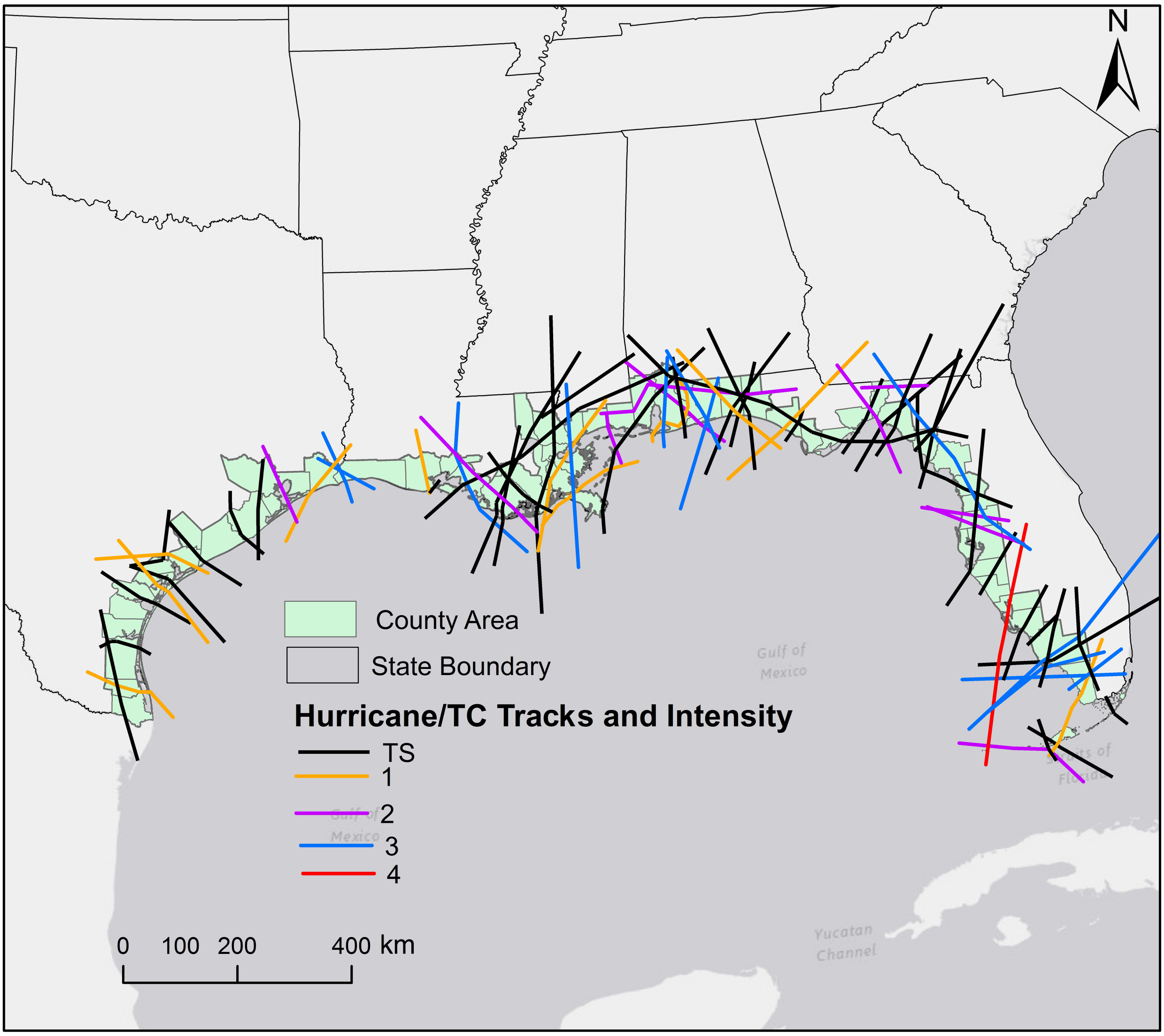

Figure 1. Tracks of hurricanes and high-impact tropic storms that made landfalls along the US Gulf Coast from 1992 to 2011. [Colour figure can be viewed at wileyonlinelibrary.com].

tropical storms which have not reached the level of hurricanes. Nevertheless, while these preliminary analyses are suggestive, more detailed and multivariate analyses are necessary. For the spatial patterns of storm surge and economic damage from the last hurricane landfall, please see Figure S4–S5.

Maximum wind speed of each storm at landfall is extracted from the ICAT Damage Estimator Database. ICAT is an insurance company that provides catastrophic insurance coverage to businesses and homeowners in the United States. The data set from ICAT is consistent with the NHC's HURDAT. Previous studies have used the maximum wind speed at landfall from ICAT data set (Murnane and Elsner, 2012; Chavas *et al.*, 2012; Zhai and Jiang, 2014). The maximum wind speed is taken as the 1-min average at 10 m elevation during the landfall over the affected regions. It is estimated to be the final 6-h magnitude prior to the landfall from the HURDAT Best Track data (Jarvinen *et al.*, 1984; Landsea *et al.*, 2004).

Peak height of storm surge come from the updated version of SURGEDAT which compiles data from 62 sources and identifies 195 storm surge events with the minimum height of 1.22 m (Needham and Keim, 2012). Among the 69 tropical cyclone events that have affected the Gulf Coast since 1992, 66 events have either storm surge or storm tide data available. In this study, we use the peak storm surge height for 10 events and peak storm tide height for the other 56 events to represent the peak height of the storm surge. Among these 66 events, 10 events have only peak storm surge height data available and 42 have only peak storm tide data available. Although there is a small disparity between the storm surge and storm tide especially in high tide scenarios, the difference is only between 0.5 and 1 ft for small surge events. Those ten events with only surge data are mostly small events with peak surge heights of around 4 ft. The largest peak surge height among these ten events was 8.67 ft in Hurricane Ivan.

Economic damage is defined as the direct monetary loss. The damage estimate consists of wind, storm surge, and

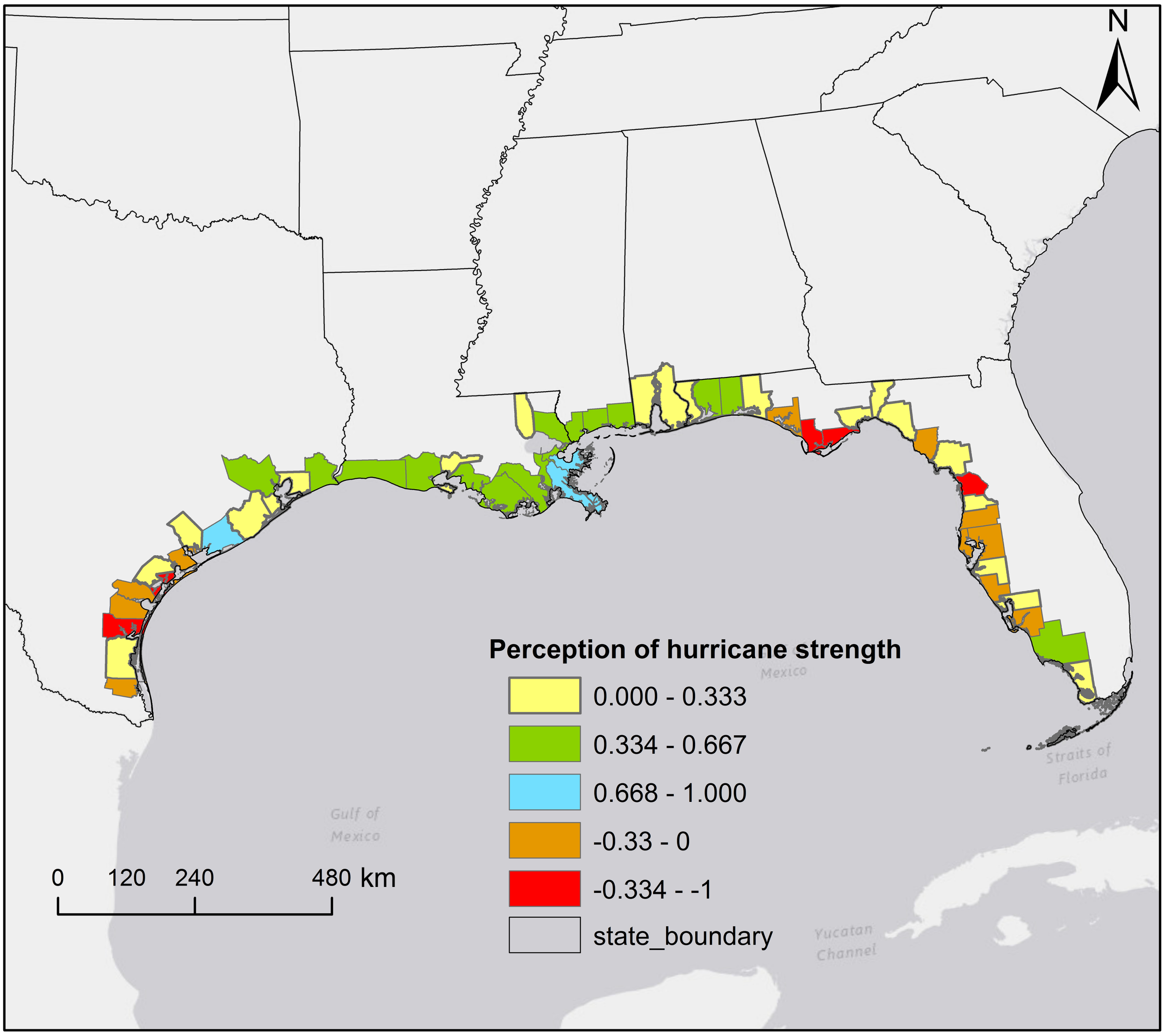

Figure 2. Spatial pattern of perceptions of overtime hurricane strength shift by counties along the US Gulf Coast. [Colour figure can be viewed at wileyonlinelibrary.com].

inland flooding losses. This damage amount is often estimated as 2:1 ratio in National Weather Service (NWS)'s reports to the reported insured damage. ICAT Damage Estimator database documented the economic damage data that are consistent with the NWS's estimation. Our economic damage data come from the ICAT Damage Estimator database. The economic damage data are normalized to 2014 US Dollars adjusted by inflation, wealth, and population growth (Pielke *et al.*, 2008). ICAT also provides the list of counties/parishes affected by each storm (Jarrell *et al.*, 1992).

2.3. Two types of variables related to hurricane strength

Based on the three basic measures of hurricane strength, two types of variables are constructed. The survey item was designed to capture one's impression of the change in hurricane strength over time. As such, we first create three variables to represent trends of maximum wind speed, storm surge, and economic damage over the period from 1992 to 2011. Broadly, an upward trend of potential intensity and destructiveness of tropical cyclones was observed in Atlantic storms from 1975 to 2005 (Emanuel, 2005), yet there is no evident trends in normalized economic damage of landfall-based tropical cyclones in the United States over the period of 1900–2005 (Pielke, 2005; Bouwer *et al.*, 2007; Pielke *et al.*, 2008). As we constrain our contextual data to include landfall hurricane events from 1992 to 2011 along the US Gulf of Mexico coast, the majority of the counties/parishes were affected by fewer than four tropical cyclones (and some counties/parishes were not affected at all). The determination of the counties being affected by a storm was primarily based on whether the county experienced hurricane-force winds and/or a storm surge of at least 4 ft high or above. The limited number of observed storm events in each county over the 20-year period limits our ability to derive statistical temporal trends at each location. Nevertheless, by examining time-series graphs of maximum wind speed, storm surge, and economic damages associated with each hurricane

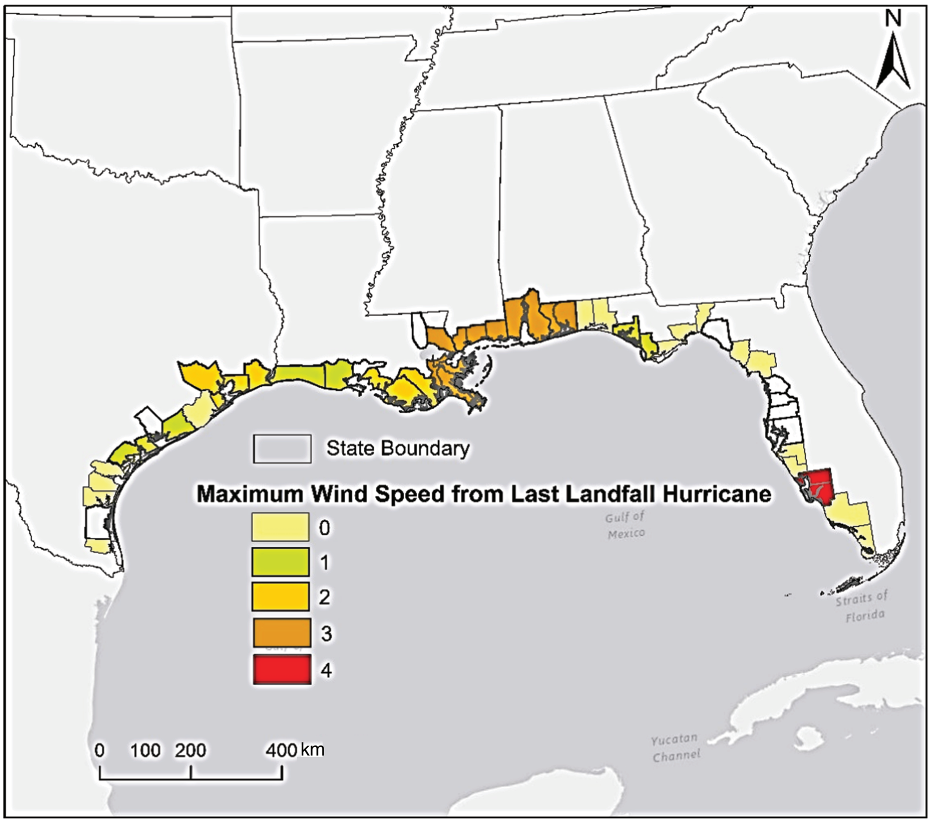

Figure 3. Spatial pattern of maximum wind speed from the last landfall by counties along the US Gulf Coast. Maximum wind speed is represented by Saffir-Simpson Hurricane Wind Scale. [Colour figure can be viewed at wileyonlinelibrary.com].

landfall over time, we assign '1' to counties that appear to have any semblance of an upward trend and '−1' to counties with downward trends over this designated time period. It would be ideal to derive statistical measures to represent trends. Because of the limited data over the study period, we decide to draw trends based on presence or absence of an/a upward/downward trend. For counties that have experienced either no trends (e.g. two events with similar maximum wind speed within 5 miles per hour) or only one landfall event over this period, we assign '0'. The survey data in this study exclude counties that have no hurricane landfalls from 1992 to 2011. For counties with only one hurricane landfall during this 20 year period, it is impossible to form a trend. However, these counties should be considered differently from those that have experienced no landfalls. One way to account for the effects of the one landfall is to include the measures associated with the last landfall. It is with understanding that the only hurricane landfall experienced in some counties is also the last occurrence.

The second type of variables related to hurricane strength encompasses three measures (maximum wind speed at landfall, storm surge, and economic damages) associated with the last hurricane landfall in a county/parish. This variable is included based on the consideration that human judgement is subject to availability bias (Tversky and Kahneman, 1973, 1974). Tversky and Kahneman (1974, p. 1127) define availability bias as a 'situation in which people assess the frequency of a class, probability of an event by the ease with which instances or occurrences can be brought to mind'. Several mechanisms including retrievability of instances, the effectiveness of search set, imaginability, and illusory correlation get involved in the process of judgement (Tversky and Kahneman, 1974). For instance, 'one may estimate probability by assessing availability, or associative distance' (Tversky and Kahneman, 1973, p. 208). This 'associative distance' can be psychological, geographic, or temporal. The various aspects of the last hurricane landfall manifested in maximum wind speed, storm surge, and economic damage incurred may be the most retrievable instance in one's mind due to its short associative distance. Therefore, we include this group of variables to directly test this theory in perception of hurricane strength.

2.4. Methods

The 2012 Gulf Coast Climate Change survey data provide county fips codes, based on which we are able to merge the individual-level data with contextual data to carry out regression analysis. By merging individual-level and contextual data, certain statistical complications arise if left unaddressed. The most prominent one is that error terms of individual observations nested within the same county are no longer independent of one another, which violates one of the fundamental assumptions in regression analysis. Therefore, to account for the multilevel data structure of this study and avoid the violation of the fundamental assumption, we apply a mixed-effects ordered logit regression model (Hamilton, 2013).

Across all models, the dependent variable is the same – perceptions of changing hurricane strength. We include a different objective variable in each model in Tables 1 and 2, i.e. normalized economic damage, peak storm surge, and maximum wind speed at landfall. Specifically, in Table 1, all the three objective measures are trends while all the three measures are from last hurricane landfall in Table 2. In order to test whether the significant effects of the objective measures from the last hurricane landfall still remain in the presence of the trends of these physical characteristics, respectively, we include both in Table 3. In order to test which objective measure associated with the last hurricane landfall among three stands out as a more significant factor, we include all three in one model presented in Table 4. Maximum wind speed at landfall has consistently shown significant effects on perceptions of changing hurricane strength. Therefore, we include variables relating to information sources and belief in climate change, and maximum wind speed in the model of Table 5.

3. Results

We start with models that include demographic attributes, distance from the coast, and county-level trends of objective measures of maximum wind at landfall, storm surge, and normalized economic damage (see Table 1). First, the likelihood-ratio tests confirm that the models with random intercepts fit better ($p < .001$) than similar models with fixed effects only, which indicates that significant variations exist among coastal counties. On the other hand, none of the trends are significant in these models. A possible explanation is that trends of extreme weather events require a certain amount of mental processing and are thus not accessible. The trend may be less mentally accessible than, e.g. the total number of extreme events, which was found to be significant in affecting perceptions of extreme weather (Shao, 2015). Gender and party identification stand out as significant factors among all the individual-level characteristics. Consistent with previous studies on perceptions of extreme weather (Shao, 2015; Shao and Goidel, 2016), females and Democrats are more likely than males and Republicans to perceive an upward trend of hurricane strength in their local counties. In the existing literature, women are consistently found to be positively correlated with perceptions of climate change (Hamilton and Keim, 2009; Borick and Rabe, 2010; McCright and Dunlap, 2011b) and possess more concern for this issue (Hamilton, 2010; McCright, 2010; Shao *et al.*, 2014). Similar to the effects of gender, the impacts of partisanship on both perceptions of climate change (Dunlap and McCright, 2008; Hamilton, 2010; McCright and Dunlap, 2011a; Shao *et al.*, 2014) and weather patterns (Shao, 2015; Shao and Goidel, 2016) have been well-documented. These papers collectively conclude that Republicans are less likely to perceive the existence of climate change, are less likely to attribute its cause to humans, are less likely to believe that climate change will cause negative impacts, and correspondingly are less likely to believe there are trends in the occurrence of extreme weather events.

In Table 2, we consider objective measures of hurricane strength from the latest landfall. Given that human memory tends to become less reliable with time, we include the year gap between 2011 and the year in which the last hurricane landfall occurred in the respondents' local counties as a control variable. The major difference between this group of models in Table 2 and those included in Table 1 is that all the objective measures – the attributes associated with the latest landfall – stand out as highly significant factors. Specifically, residents who live in counties that have experienced a stronger hurricane manifested in maximum wind speed, storm surge, and economic damages, respectively, tend to perceive an increasing trend of hurricane strength compared to those who live elsewhere. The empirical results conform to availability bias that the information related to the latest occurrence is the most mentally retrievable. The year gap turns out to be significant in models 1 and 3 of Table 2. As expected, the longer the temporal gap between the last landfall and the interview year (2012), the less likely one would be to perceive that hurricanes are becoming stronger with time. The vividness of any event would lose its colour in people's memory as time goes by.

Surprisingly, the variable of year gap loses its significance in model 2 of Table 2. This can be interpreted as follows: regardless of the number of years that had passed by since the last hurricane landfall, the memory about the wind speed remains the strongest among all the attributes of a hurricane landfall. We only consider the last 20 years which is the recent past after all. The attributes of any extreme events in the recent past should leave deep imprints in one's mind, which is supported by some empirical evidence (i.e. Stefanovic, 2003; Shao, 2015; Shao and Goidel, 2016), and possibly owing to either their own experience of damage or local media reporting the intensity.

To test whether the significant effects of measures associated with the last landfall still holds when controlling for the trends of the three objective measures, we include both trend and the physical measure of last event in the models of Table 3. The results reinforce that attributes of the last hurricane landfall play a more powerful role in shaping public perceptions of hurricane strength shift in comparison with the objective trend measures.

Furthermore, we examine which among the three measures of the last hurricane landfall is the strongest determinant in affecting perceptions of hurricane strength. The correlation coefficients between the maximum wind speed associated with the last hurricane landfall on the one hand, economic damage and storm surge from the last landfall on the other hand, are 0.614 and 0.308, respectively. The correlation between storm surge and economic damage is 0.536. The correlations are thus not strong enough to cause concern. Results of Table 4 reconfirm the substantial explanatory power of maximum wind speed at landfall. Maximum wind speed appears to leave the

Table 1. Mixed-effects ordered logit estimates for the model of perceptions about hurricane strength, as a function of socio-demographic characteristics, and trends of objective measures including maximum wind speed, storm surge, and economic damage. [Correction added on 28 July 2016, after first online publication: The data associated with "Maximum wind speed at landfall" and "Storm surge" were incorrectly placed at the wrong Model and have been fixed in this current version.]

Variable	Model (1)		Model (2)		Model (3)	
	b	*Z*	*b*	*Z*	*b*	*Z*
Demographic attributes						
Age [−]	0.002	0.47	0.003	0.81	0.002	0.47
Gender [+]	0.249	2.19*	0.209	1.90*	0.248	2.18*
Income [+/−]	0.015	0.52	0.016	0.56	0.015	0.51
Education [+/−]	0.023	0.55	0.019	0.47	0.024	0.57
Race: African American [+]	0.012	0.06	0.035	0.19	0.017	0.09
Race: Hispanic [+]	0.295	1.08	0.297	1.08	0.294	1.07
Party identification [−]	−0.189	−2.44**	−0.186	−2.45**	−0.189	−2.43
Distance from the coast [−] (Subjective)	−0.073	−1.91*	−0.056	−1.50	−0.072	−1.88*
County-level fixed effects: trends of objective measures						
Normalized economic damage [+]	0.308	0.95				
Maximum wind speed at landfall [+]			0.086	0.33		
Storm surge [+]					−0.010	−0.03

County-level random intercept	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)
Standard deviation	0.881	0.284	0.000	0.838	0.270	0.000	0.882	0.285	0.000
N			1285			1357			1285

***prob < 0.001 (one-tail test). **prob < 0.01 (one-tail test). *prob < 0.05 (one-tail test).

Table 2. Mixed-effects ordered logit estimates for the model of perceptions about hurricane strength, as a function of socio-demographic characteristics, subjective assessment of distance to the coast, and objective measures of the year gap between the last hurricane landfall, normalized economic damage, maximum wind speed, and storm surge as results of the landfall. [Correction added on 28 July 2016, after first online publication: The data associated with "Maximum wind speed at landfall" and "Storm surge" were incorrectly placed at the wrong Model and have been fixed in this current version.]

Variable	Model (1)		Model (2)		Model (3)	
	b	*Z*	*b*	*Z*	*b*	*Z*
Demographic attributes						
Age [−]	0.003	0.74	0.003	0.75	0.003	0.78
Gender [+]	0.206	1.87*	0.209	1.90*	0.210	1.91*
Income [+/−]	0.015	0.52	0.017	0.59	0.014	0.48
Education [+/−]	0.019	0.47	0.018	0.43	0.021	0.52
Race: African American [+]	0.022	0.12	0.019	0.10	0.028	0.15
Race: Hispanic [+]	0.216	0.78	0.274	1.00	0.231	0.84
Party identification [−]	−0.182	−2.41**	−0.192	−2.54**	−0.178	−2.35**
Distance from the coast [−] (Subjective)	−0.056	−1.53	−0.053	−1.44	−0.059	−1.61
County-level fixed effects: objective measures from the last hurricane landfall						
Year gap [−] (last hurricane landfall to 2011)	−0.105	−3.03***	−0.058	−1.52	−0.118	−3.25***
Normalized economic damage [+]	0.000	3.45***				
Maximum wind speed at landfall [+]			0.018	3.45***		
Storm surge [+]					0.034	1.84*

County-level random intercept	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)
Standard deviation	0.458	0.170	0.000	0.396	0.154	0.000	0.547	0.190	0.000
N		1357			1357			1357	

***prob < 0.001 (one-tail test). **prob < 0.01 (one-tail test). *prob < 0.05 (one-tail test).

deepest impression in coastal residents' memories, which includes impressive surf along the beachfront, as well as swaying and felled trees, and flying debris. Furthermore, the aftermath of each storm in the form of visualizing wind damage to the built environment and geomorphic impacts on beaches serve to ingrain these memories.

We are also interested in how one's prior belief and attentiveness to information about climate change may affect perceptions of one possible manifestation of climate change – changing Atlantic hurricane strength with time. Previous studies revealed that humans are subject to confirmation bias by seeking information and adopting views to be consistent with their pre-existing thoughts, beliefs, and ideologies (Nickerson, 1998). In the model of Table 5, we add two categories of variables including attentiveness to information about, and belief in, climate

Table 3. Mixed-effects ordered logit estimates for the models of perceptions about hurricane strength, as a function of socio-demographic characteristics, subjective assessment of distance to the coast, and objective measures of the year gap between the last hurricane landfall, normalized economic damage, maximum wind speed, and storm surge as results of the landfall.

Variable	Model (1)		Model (2)		Model (3)	
	b	*Z*	*b*	*Z*	*b*	*Z*
Demographic attributes						
Age [−]	0.002	0.40	0.003	0.76	0.002	0.45
Gender [+]	0.243	2.14*	0.205	1.86*	0.250	2.20*
Income [+/−]	0.014	0.46	0.017	0.60	0.012	0.41
Education [+/−]	0.024	0.57	0.019	0.46	0.026	0.62
Race: African American [+]	0.007	0.04	0.025	0.14	0.010	0.05
Race: Hispanic [+]	0.213	0.77	0.261	0.95	0.236	0.86
Party identification [−]	−0.185	−2.40**	−0.193	−2.56**	−0.181	−2.33**
Distance from the coast [−] (Subjective)	−0.070	−1.84*	−0.053	−1.45	−0.075	−1.97*
County-level fixed effects: objective measures from the last hurricane landfall						
Year gap [−] (last hurricane landfall to 2011)	−0.109	−3.11***	−0.041	−1.06	−0.126	−3.33***
Normalized economic damage [+]	0.000	2.97**				
Trend of normalized economic damage (NED) [+]	−0.205	−0.75				
Maximum wind speed at landfall [+]			0.022	3.80***		
Trend of maximum wind speed (MWS) [+]			−0.306	−1.41		
Storm surge [+]					0.034	1.83*
Trend of storm surge (SS) [+]					−0.222	−0.82

County-level random intercept	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)	Estimate	SE	*p*(LR)
Standard deviation	0.455	0.175	0.000	0.355	0.144	0.000	0.569	0.197	0.000
N	1285		1357			1285			

***prob < 0.001 (one-tail test). **prob < 0.01 (one-tail test). *prob < 0.05 (one-tail test).

change to explain the variation in perceptions of hurricane strength. No variables of self-reported attentiveness and use of specific sources of information are statistically significant, indicating that hurricane experiences are not being mediated by local news or weather/climate coverage. The result of belief in climate change is consistent with previous studies (Shao, 2015; Shao and Goidel, 2016) and the theory of confirmation bias that individuals who believe in current climate change are much more likely to see increasing hurricane strength than those who do not. Moreover, when controlling for the effects of belief in climate change, party identification has become insignificant in the model, which indicates climate change has become a political polarizing force. It also reflects the role of party as indirectly influencing attitudes about weather by influencing beliefs about climate change. Political orientation plays a role, but it is influenced by beliefs about climate change. Meanwhile, the powerful influence of maximum wind speed associated with the last landfalling hurricane does not disappear in the presence of belief in climate change. This result is somewhat surprising given that similar studies all point to the dominant explanatory power of pre-existing beliefs (Brody *et al.*, 2008; Shao, 2015; Shao and Goidel, 2016). Meanwhile, it demonstrates the powerful role that maximum wind speed at landfall plays in shaping one's perceptions of past hurricane strength.

4. Conclusion

As the scientific debate on the connection between climate change and increasing Atlantic hurricane activity marches on, we wondered how coastal residents perceive changes in hurricane strength over time. Do their beliefs in climate change affect how they judge the shift of hurricane strength? Given the disturbingly increasing destruction of hurricanes to coastal communities, it is particularly important to understand how coastal residents perceive hurricane risks. In this study, we focus on residents along the Gulf Coast, who have lived in counties/parishes with at least one hurricane landfall over the period from 1992 to 2011. What we have learned from this study are as follows:

First, the characteristics of hurricane strength associated with the last landfall, namely maximum wind speed at landfall, storm surge, and economic damages, have much more explanatory power in explaining perceptions of changes in hurricane strength than the actual physical trends of these three strength indicators. This result is consistent with availability bias, indicating that characteristics associated with recent events are more accessible and retrievable compared to trends which require a higher level of mental processing. However, we should acknowledge that we measure the trends over a relatively short period of time – 20 years. It is difficult to form any statistically meaningful trends for any extreme events as hurricanes during such a short period of time.

Second, maximum wind speed from the last landfall is the most powerful predictor of an individual's perception of changes in hurricane strength and holds strong effects even when controlling for individual beliefs in climate change. This finding has practical implications for local planners and policy-makers. When encouraging coastal

Table 4. Mixed-effects ordered logit estimates for the model of perceptions about hurricane strength, as a function of socio-demographic characteristics, and objective measures of maximum wind speed, storm surge, and economic damage from the last hurricane landfall.

Variable	Model b	Model Z
Demographic attributes		
Age [−]	0.003	0.72
Gender [+]	0.206	1.88*
Income [+/−]	0.017	0.60
Education [+/−]	0.017	0.42
Race: African American [+]	0.016	0.09
Race: Hispanic [+]	0.254	0.92
Party identification [−]	−0.192	−2.53**
Distance from the coast [−] (Subjective)	−0.051	−1.40
County-level fixed effects: objective measures from the last hurricane landfall		
Year gap [−] (last hurricane landfall to 2011)	−0.064	−1.69*
Normalized economic damage	0.000	1.13
Maximum wind speed at landfall	0.013	2.09*
Storm surge	−0.004	−0.19

County-level random intercept	Estimate	SE	p(LR)
Standard deviation	0.370	0.149	0.000
N		1357	

***prob < 0.001 (one-tail test). **prob < 0.01 (one-tail test). *prob < 0.05 (one-tail test).

Table 5. Mixed-effects ordered logit estimates for the model of perceptions about hurricane strength, as a function of socio-demographic characteristics, subjective assessment of distance to the coast, and objective measures of maximum wind speed, from the last hurricane landfall.

Variable	Model b	Model Z
Demographic attributes		
Age [−]	0.002	0.52
Gender [+]	0.117	0.98
Income [+/−]	0.033	1.06
Education [+/−]	0.023	0.52
Race: African American [+]	−0.097	−0.50
Race: Hispanic [+]	0.167	0.58
Party identification [−]	−0.132	−1.60
Attentiveness to information about climate change		
Informedness [+/−]	0.007	0.08
Newspaper + TV [+/−]	0.109	1.76
Radio [+/−]	0.081	1.39
Internet [+/−]	0.022	0.36
Belief in climate change	0.642	4.41***
Distance from the coast [−] (Subjective)	−0.039	−1.01
County-level fixed effects: objective measures from the last hurricane landfall		
Year gap [−] (last hurricane landfall to 2011)	−0.051	−1.40
Maximum wind speed at landfall	0.019	3.71***

County-level random intercept	Estimate	SE	p(LR)
Standard deviation	0.314	0.135	0.000
N	1243		

***prob < 0.001 (one-tail test). **prob < 0.01 (one-tail test). *prob < 0.05 (one-tail test).

residents to adapt to potential threats from hurricanes, an emphasis on the damaging power of wind may be the first step to carry out a communication strategy, particularly in areas that have recently experienced a hurricane. Because the adaptation strategies to wind and storm surge are different (for instance, elevation is commonly employed to adapt to storm surge while strengthening roofs and putting shelters are usually applied to wind), the strong correlation between wind strength and storm surge should be clearly conveyed to coastal residents through various education programs.

Third, results of this study once again speak of the powerful role played by the political predisposition in determining perceptions of local weather. Relative to Democrats, Republicans are less likely to believe that hurricanes are becoming stronger. Climate change has become a signature political issue that polarizes the American public. Due to its political implication, Republicans generally refuse to accept the existence of climate change out of fears of massive governmental intervention (Dunlap and McCright, 2008). This resistance to climate change is even reflected in their views towards extreme weather events which are arguably linked to climate change (Shao, 2015; Shao and Goidel, 2016). Relatedly, the pre-existing belief in climate change is found to have substantial effects on perceptions of changes in hurricane strength over time. Individuals who believe climate change is occurring are more likely than others to view the increasing strength of hurricanes. Moreover, when controlling for the effects of belief in climate change, party identification has become insignificant in the model, which indicates climate change has become a political polarizing force. It also reflects that party identification may indirectly influence people's attitudes towards weather due to their willingness/reluctances to believe in climate change. These two results together reinforce the presence of confirmation bias in perceptions of local weather patterns.

The research agenda on perceptions of hurricane strength is far from complete. Here, we focus on how physical characteristics of historical hurricane events influence individual's perception of overtime shift of hurricane strength. History, or one's memory of the past, may affect one's perception of future risks and serve as an important factor in individual adaptation decisions. Similarly, the expectation of future events is likely to play an equally important role guiding individual attitudes and behaviours. One might also expect gaps between experts' hurricane risk prediction and coastal residents' risk perceptions, and that these gaps may explain some differences in individual- and community-level resilience. More studies are clearly needed to fill the vacancy in this literature and to shed further light on differences in individual perceptions, expert assessments, and objective measures.

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Supporting information

The following supporting information is available as part of the online article:

Figure S1. Spatial pattern of the trend of maximum wind speed at landfall.

Figure S2. Spatial pattern of the trend of storm surge from landfalls.

Figure S3. Spatial pattern of the trend of economic damage from landfalls.

Figure S4. Spatial pattern of storm surge from the last landfall.

Figure S5. Spatial pattern of economic damage from the last landfall.

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