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# Decision Science Perspectives on Hurricane Vulnerability: Evidence from the 2010–2012 Atlantic Hurricane Seasons

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**Abstract:** Although the field has seen great advances in hurricane prediction and response, the economic toll from hurricanes on U.S. communities continues to rise. We present data from Hurricanes Earl (2010), Irene (2011), Isaac (2012), and Sandy (2012) to show that individual and household decisions contribute to this vulnerability. From phone surveys of residents in communities threatened by impending hurricanes, we identify five decision biases or obstacles that interfere with residents' ability to protect themselves and minimize property damage: (1) temporal and spatial myopia, (2) poor mental models of storm risk, (3) gaps between objective and subjective probability estimates, (4) prior storm experience, and (5) social factors. We then discuss ways to encourage better decision making and reduce the economic and emotional impacts of hurricanes, using tools such as decision defaults (requiring residents to opt out of precautions rather than opt in) and tailoring internet-based forecast information so that it is local, specific, and emphasizes impacts rather than probability.

**Keywords:** tropical cyclone impact on humans; natural hazards; decision making; choice architecture; hurricanes

## 1. Introduction

Over the past few decades, scientific advances in hurricane prediction, coupled with policy changes related to construction codes and evacuation procedures, have reduced mortality and morbidity associated with tropical cyclones in the U.S. In contrast, economic vulnerability to storm impacts continues to rise [1]. The decisions made by individuals and households are key to this growing vulnerability. Individuals and households do not always draw on improved forecasts and new policies to reduce their risk of experiencing harm.

We focus on individual and household choices made over long and short time scales. These decisions are influenced by socioeconomic constraints, policy incentives, and cognitive biases related to risk perception. Here we closely examine several cognitive biases that come into play on both time scales when people make preparation decisions, drawing on evidence from four real-time studies over a three-year period of decisions made during Earl (2010), Irene (2011), Isaac (2012), and Sandy (2012) [2,3]. We then offer a framework for improved decision making in the face of these biases to reduce vulnerability to hurricane damage and loss.

Phone surveys of coastal residents conducted as Hurricanes Earl, Irene, Isaac, and Sandy approached the U.S. east coast (Gulf Coast, in the case of Isaac) during the 2010–2012 Atlantic hurricane seasons reveal that people were concerned and took the warnings seriously. This attentiveness to forecasts and warnings, however, does not necessarily translate into effective preparation. Our results indicate that people have difficulty preparing for low-probability/high-impact events, even when accurately forecasted. These findings have implications for other natural hazards such as earthquakes, wildfires, landslides, and tsunamis.

We identify robust factors that influence vulnerability, including: (1) temporal and spatial myopia; (2) mental models; (3) gaps between objective and subjective probability estimates; (4) prior storm experience; and (5) social factors. We explain how these factors impact judgments about the storm and preparation decisions. Finally, drawing on decision science literature, most notably, 'choice architecture' [4], we offer a framework for reducing vulnerability in the U.S. that includes changes to the forecast warning system and insurance default options.

## 2. Materials and Methods

For each hurricane, telephone surveys were conducted among random samples of residents in coastal areas threatened by a given storm. Each survey interview lasted approximately 25 minutes, during which time respondents were asked to respond to between 60 and 82 questions, depending on screening patterns. The survey questions fell into seven domains:

1. Objective storm and warning knowledge (e.g., knowledge of storm strength, time until impact, current warnings)
2. Threat perceptions (e.g., judged probability of hurricane-force winds and damage due to wind, surge flooding, or rain flooding)
3. Information sources (e.g., media usage and exposure to forecast graphics)
4. Short-term preparation actions and evacuation intentions (e.g., storm-related purchases of food, water, batteries; filling the car with gasoline)
5. Longer-term preparation (e.g., supplies on hand before the storm, ownership of flood insurance)
6. Expectations of government aid
7. Socio-demographics and previous storm experience

The surveys were conducted during three time blocks, between 8:00 AM and 11:00 AM; 11:00 AM and 5:00 PM; and 5:00 PM and 10:00 PM, so as to coincide with the storm and warning information conveyed in the 5:00 AM, 11:00 AM, and 5:00 PM National Hurricane Center advisories. The telephone surveys were administered by the firm of Kerr and Downs, who drew random samples of published telephone numbers for residents in coastal zip codes—any land area directly adjacent to the ocean or major open body of water (e.g, the Chesapeake Bay, MD, USA). On average, the firm was able to complete 60 surveys within each of nine time blocks, over approximately three days. All surveys were administered 2–3 days before the forecasted closest approach of each storm. The absolute response rate (the rate of phone calls that led to completed surveys) varied between 7.1 and 10 percent across surveys. The samples primarily consisted of adult homeowners living in coastal counties. The Earl sample was drawn from North Carolina and Massachusetts. Irene respondents were from North Carolina and New York. Isaac respondents were from Alabama, Florida, Louisiana, and Mississippi. Sandy respondents were from Delaware, Maryland, New Jersey, New York, and Virginia. Data on the demographics of each sample can be found in Table 1. For Earl, there were 633 respondents, for Irene 805 respondents, for Isaac 355, and for Sandy 538. Details about the methodology and response rates for the Isaac and Sandy surveys can be found in Meyer et al. [3], pages 1390–1392. The samples were similar across hurricanes, with the exception of the percentage of respondents who had experienced previous hurricane damage, with Hurricane Isaac respondents having experienced damage in much greater numbers than those surveyed during the other three hurricanes.

**Table 1.** Demographics for the four hurricanes.

| Demographic Variable | Earl Survey Respondents (%) N = 633 | Irene Survey Respondents (%) N = 805 | Isaac Survey Respondents (%) N = 355 | Sandy Survey Respondents (%) N = 538 |
|---|---|---|---|---|
| **Gender** | | | | |
| Female | 67 | 67 | 64 | 59 |
| Male | 33 | 33 | 36 | 40 |
| **Age** | | | | |
| under 30 | 4 | 6 | 3 | 4 |
| 30–45 | 15 | 17 | 11 | 14 |
| 46–60 | 27 | 26 | 41 | 27 |
| 61–70 | 23 | 24 | 22 | 23 |
| 71–80 | 17 | 14 | 12 | 18 |
| over 80 | 8 | 8 | 5 | 8 |
| Refused to Answer | 6 | 5 | 5 | 6 |
| **Ethnicity** | | | | |
| White/Caucasian | 83 | 78 | 83 | 83 |
| Black/African American | 9 | 10 | 13 | 8 |
| Other | 4 | 7 | 2 | 4 |
| Refused to Answer | 4 | 5 | 2 | 4 |
| **Income** | | | | |
| Less than $25,000 | no data collected | 9 | 11 | 5 |
| $25,000–$79,000 | | 29 | 34 | 21 |
| More than $80,000 | | 21 | 21 | 23 |
| Don't Know/Refused | | 41 | 34 | 50 |
| **Education** | | | | |
| Some high school/high school graduate | 26 | 26 | 25 | 26 |
| Some college/college graduate | 52 | 53 | 53 | 48 |
| Postgraduate | 16 | 14 | 14 | 20 |
| Other/refused | 6 | 7 | 8 | 5 |
| **Homeowner Status (%)** | | | | |
| Own | 87 | 82 | 94 | 89 |
| Rent | 11 | 17 | 5 | 9 |
| Other | 2 | 1 | 1 | 2 |
| **Home Type** | | | | |
| Single Family Home | 77 | 74 | 93 | 81 |
| Duplex or Triplex Home | 4 | 5 | 1 | 7 |
| Multi-family building (4 stories or less)—apartment/condo | 7 | 10 | 3 | 6 |
| Multi-family building (4 stories or more)—apartment/condo | 1 | 6 | 1 | 3 |
| Mobile or Manufactured Home | 10 | 4 | 2 | 3 |
| Don't Know/Refuse | 1 | 1 | 0 | 0 |
| **Previously Experienced Hurricane Damage, in current or previous home** | 49 | 39 | 83 | 27 |

Note: Sometimes percentages do not add to 100 because not all respondents answered every question.

## 3. Results

People do not always approach decisions in an analytic fashion. The reliance on heuristics, or mental shortcuts [5–7], allows people to make many decisions quickly, freeing up their attention for more mentally taxing activities. In many facets of life this serves us quite well, particularly for decisions with which we have repeated experiences and can benefit from trial-and-error learning. However, these heuristics—which are often used under time pressure, or when motivation is low, or when people are distracted—can sometimes lead to sub-optimal decisions.

In the case of hurricanes, we find that decisions made before the onset of the hurricane season and during the approach and landfall are subject to multiple cognitive biases and other challenges. Below we describe some of the biases and challenges we observed in hurricane decisions. This is not meant to be an exhaustive review of all cognitive biases or a comprehensive account of human behavior during these four hurricanes. Rather, we are identifying some consistencies in human behavior before and during these hurricanes, which build on earlier findings reported in the literature, and which could be of use to others who work on vulnerability reduction and forecast communication.

### *3.1. Temporal and Spatial Myopia*

There is a well-documented tendency of people to discount distant future outcomes, leading to decisions that prioritize short-term benefits at the expense of long-term gains or security (see [8] for a review). Construal-level theory [9–11] offers an explanation for the tendency to discount future events in ways that lead to low levels of storm preparation. According to this theory, events that seem distant—in time, space, and/or likelihood—are perceived in an abstract way, in terms of higher-level features that convey the general essence of the event. Events that seem close are perceived in more concrete terms, with a focus on the details of the event. This can lead to an intention to take action towards a future goal (e.g., giving a conference presentation, safeguarding one's house against a big storm), but then a failure to follow through on the specific steps that would enable a person to reach that goal.

Data from Hurricane Sandy reported by Meyer et al. [3] provide a good illustration of the short-sightedness that can be explained by construal-level theory. When people living in threatened areas were asked whether they would evacuate prior to evacuation orders actually being issued, almost 60% indicated they would. But when the orders actually came, this percentage dropped to less than 40% and continued to diminish over time. The likely explanation is that when residents viewed evacuation as an abstract action in the future, they were open to the virtuous prospects of leaving, but when the orders actually came—and the costs of leaving became more vivid and specific—this willingness dropped precipitously, and people began to focus on the lower-level, concrete obstacles to leaving, such as the cumbersome logistics of actually leaving.

Similarly, during Irene, the percentage of respondents in each survey time block in North Carolina who reported having put up shutters hovered around 10–18% for the first seven survey periods. Only during the last two survey periods did we see an increase in the percentage of respondents who reported having put up window protection, but it was still low (22–32%). (Reports of window protection in New York never reached above 14%). Meyer et al. [3] reported that when Hurricanes Isaac and Sandy were fewer than six hours away from landfall, fewer than 55% of residents reported having put up removable window protections, such as shutters.

We find evidence of myopia in the reasons respondents gave for not putting up storm shutters during Hurricanes Irene and Isaac. The most common reason given was that it was "too soon" (Irene: 56%; Isaac: 53%) suggesting people were going to wait until the storm moved closer. This question was not asked in the Earl survey. The vast majority of respondents during Irene (89%) believed they had at least seven hours, with many believing they had 1–3 days, until the storm would affect their home with wind and flooding. Even in the last survey period for Irene, almost twice as many residents thought they had seven or more hours until the storm caused serious damage, compared to those who thought they had fewer than seven hours. Residents appeared to succumb to the "planning fallacy" [12], underestimating both the time it might take to install window protection before the onset of dangerous conditions (which can start many hours before the closest approach of the center) as well as unexpected preparedness actions that might preclude putting up shutters—such as a last-minute order to evacuate. For Isaac, 78% thought they had at least seven hours.

For Sandy, 23% of survey respondents reported the hurricane had already affected their location, and another 7% reported that they had fewer than six hours left to prepare. Of these 164 respondents reporting the storm had already hit or was likely to affect them within six hours, only three reported having put up window protection for this storm (another 18 reported having permanent window protection). Unfortunately, data are missing from this survey regarding why the rest of the residents had not put window protection in place.

Our data also reveal a lack of evacuation plans. For Earl, only 16% of respondents reported planning to evacuate. For Hurricane Irene, only 26% of coastal residents who took our survey indicated an intention to evacuate. Richetti-Masterson and Horney [13] similarly found compliance with evacuation orders during Irene to be only 27%. These findings mirror those from Isaac and Sandy, in which 28% and 19%, respectively, reported intending to evacuate. When hurricanes actually threatened, compliance with evacuation orders was found to be minimal. During 2010's Hurricane Earl, of the 3% of respondents who indicated that they lived in an evacuation zone, 22% indicated an intention to comply with evacuation. For Irene, of the 16% who reported living in an evacuation zone, 38% intended to evacuate—a little higher than for Earl, but still fewer than half of all respondents. For Isaac and Sandy, Meyer et al. [3] similarly found little evidence of compliance with evacuation orders, as indicated by no noticeable decrease in people who were home to answer the telephone surveys once the evacuation orders had been issued. (30% of Isaac respondents and 38% of Sandy respondents who reported living in an evacuation zone intended to evacuate).

### *3.2. Mental Models*

A mental model is a cognitive representation of a process or phenomenon. Mental models shape how we understand the world and how we make inferences and predictions about future events [14,15].

Storms are complex systems that are poorly understood by the general public. Hurricanes bring strong winds, rain, and flood hazards. Most people have trouble understanding the interplay of factors such as land topography, drainage systems, and other factors that influence storm surge, such as timing with tides. As a result, residents often focus on wind and rain. This tendency to focus on wind, in particular, is reinforced by some of the forecast imagery, such as the cone of uncertainty [16]. Water is the big threat in hurricanes in most cases, yet all of the signals in warnings focus on wind: the Saffir–Simpson scale is a wind scale, the word "hurricane" connotes "hurricane-force wind" as the next step up from "gale-force," and people routinely experience wind and therefore can mentally visualize it, but not flooding.

Emergency managers and broadcasters are aware that the public does not adequately understand the nature of storm surge or their own storm surge vulnerability [17]. In a hurricane mental-models study conducted with forecasters, broadcasters, and public officials from Miami-Dade County, Florida, all participants mentioned high wind speeds and storm surge as hurricane threats. However, the professionals varied in how they discussed storm surge, and one broadcaster acknowledged that the general public most commonly thinks of wind as the main destructive force associated with hurricanes [18].

A study comparing perceptions of hurricane threats and evacuation during Hurricanes Ike (2008) and Rita (2005) found that people had a relatively low expectation of storm surge damage, compared to wind damage. Even a "certain death" warning linked to storm surge during Ike had relatively little impact on concern about storm surge [19]. Although other studies of Hurricanes Katrina, Rita, and Ike have found some evidence that evacuation decisions are based on both wind and storm surge threats [20,21], these studies were retrospective, relying on surveys of residents 4–5 months after the hurricanes had struck. Particularly in the case of Katrina, the media images of flooding and of the levees being breached were vivid and widespread. It is possible this confounded residents' memories of which factors actually influenced their preparation decisions. In contrast, the results presented here for Earl, Irene, Isaac, and Sandy are from real-time surveys conducted in the days leading up to the hurricanes and provide insight into how residents might be weighing the relative risks of wind and storm surge as the storms bear down on their regions.

In each of the storms we studied, the primary threat residents faced was from flooding either due their home's close proximity to the coast or, in the case of Isaac, a forecast of sustained heavy rains.

Proximity to the coast was determined by geo-coded calculated distance between either the ocean or, in some cases, an open bay. Nevertheless, in the period leading up to Hurricane Earl, 79% of respondents were most concerned about wind, with only 6% viewing flooding as the greatest threat to their homes and 10% reporting a combination of wind and flooding as the greatest threat. For Irene, a majority of respondents polled (61%) thought the greatest threat to their homes would be wind. An additional 20% thought the greatest threat would be a combination of wind and flooding from storm surge. Only 31% of respondents thought the greatest threat was either flooding (11%) or a combination of wind and flooding (20%). Moreover, residents had trouble recalling the predicted storm surge for their area, with approximately half of all respondents (49% for Earl and 51% for Irene) saying they did not know or were unsure how high the storm surge would be along the coast near their location if and when the storm made landfall. Meyer et al. [3] found a similar preoccupation with wind. For Hurricane Isaac, 56% of their respondents identified wind as the greatest threat they faced, despite living in zone A or category 1 surge zones. Even when Meyer et al. [3] analyzed responses based on proximity to water, 40% of those who lived within 500 feet of water believed their primary risk was wind. Meyer et al. reported a similar wind bias for Sandy respondents.

Given the proliferation of media information available, one plausible explanation of incomplete or erroneous mental models is that people did not pay sufficient attention to evacuation warnings—i.e., because they misunderstood the nature of the threats from hurricanes, residents had trouble interpreting evacuation notices and other warnings. In the aftermath of Hurricane Katrina and in a focus group study of tsunami warnings, people reported confusion over whether evacuation was "ordered" or "recommended" [22,23]. Baker [24] showed that official evacuation recommendations were the single most important predictor of evacuation, with the possible exception of "risk area" (low-lying, exposed areas). Although Baker suggested that the distinction between evacuation orders and advisories may be inconsequential, he pointed out that the wording and dissemination of the message can convey more or less urgency, which will impact perceptions of risk and beliefs about the value of evacuation. A more recent meta-analysis of hurricane evacuation decisions [25] supported this, showing that official warnings impacted evacuation decisions both directly and indirectly, by also impacting residents' perceptions of the personal impact the storm will have on them. Another recent study [26] found a modest increase in evacuation rates when evacuation was ordered, versus only recommended.

Only 11% of the Earl survey respondents reported that an evacuation notice was issued for their community, and there was confusion about whether the message was that evacuation was recommended or ordered. Of those who reported an evacuation notice being issued, 16% indicated they were unsure whether evacuation was recommended or ordered. During Irene, of those respondents who reported an evacuation notice being given for their community (n = 235), 9% were unsure whether evacuation was ordered or recommended. Isaac and Sandy respondents were more certain of the nature of the orders, with only 5% of Isaac respondents who reported an evacuation notice being issued (n = 189) being unsure of the nature of the notice, and only 5% of the comparable Sandy respondents (n = 100). Meyer et al. [3] reported underestimation of the duration of the storm's impact during Hurricane Sandy, even in New Jersey and Delaware, where residents were warned they could be without power for 7–10 days.

Residents also reported confusion over insurance coverage: for Irene, 12% of residents were not sure if their insurance policy included flood protection; for Isaac 4% were unsure; and for Sandy, 11% were unsure. While knowledge of one's insurance coverage is not directly related to their mental model of a storm, it is an important component of individuals' understanding or confusion over personal storm impacts. How this uncertainty influenced their decision making process is not clear but worthy of future study. Insurance questions were not included in the Earl survey.

### 3.3. Objective versus Subjective Probability Estimates

Probabilistic forecasts are not easily interpreted by most members of the lay public [27]. Sometimes people confuse the probability of a forecasted event with forecast confidence [28]. Sometimes people conflate the uncertainty of an event with the ambiguity of it (e.g., uncertainty about a hurricane's arrival versus ambiguity about the magnitude of the potential impact). Budescu et al. [29] recommend as much precision as possible in descriptions of events; they recommend avoiding ambiguous terms like "large," "significant," or "damaging" and using probabilistic estimates only for clearly defined events, to the extent possible. To work around the challenges of probabilistic forecasts, some forecasters have shifted to verbal descriptors of likelihood, but there is tremendous variability in how people interpret verbal descriptors of probability, such as "very likely," "likely," "unlikely," and "very unlikely" [30,31].

While people in general have trouble using probabilities to make optimal decisions, low-probability events can be especially challenging. According to Kahneman and Tversky's seminal work on prospect theory, people overweight rare events, unless the probability is close to zero, and then people tend to treat the probability as if it actually were zero [32]. However, there is some evidence that when people have personal experience with a rare event, they tend to underweight its likelihood in future decisions [33] (see Section 3.4 *Prior Storm Experience* in this article for a more detailed discussion). While hurricanes may be relatively rare, an over-focus on their low likelihood at the expense of focusing on and preparing for the severity of their impact can be disastrous.

Further complicating storm preparation decisions is the challenge of visually communicating probabilistic storm information [34,35]. Images such as the "cone of uncertainty," used by the National Hurricane Center, attempt to communicate a range of paths the storm might take; there is a 2/3 chance that the eye of the hurricane will fall within the cone [36]. However, the graphic is confusing and—at least in the high-profile case of Hurricane Charley—can lead people to assume they are out of harm's way, when in fact they are not [16].

There is often a tendency for residents to focus on the center, or eye, of the storm, not realizing that when a graphic displays the predicted path of the eye of the storm, impacts will be felt beyond [16]. The findings from two lab-based studies by Wu et al. [37,38] support the finding that people tend to focus on the forecast track, gleaning little information from the rest of the graphic. Other challenges with maps include confusion between probability maps and scenario maps [39] and misjudgment of risk when polygons are used to show risk zones [40,41]. Although people at least sometimes are able to infer that the edge of a polygon does not indicate a divide between an area at risk and an area completely not at risk [38,41], there is some evidence that people infer a higher risk at the center of the polygon [41].

Our surveys reveal a substantial gap between the objective forecasts and the concern of residents living in those threatened areas. These concerns are a kind of forecast, a subjective estimate. For Earl, residents were asked, "How personally worried are you about the storm hitting your area?" For Irene, residents were asked, "How personally worried are you that the storm might cause significant damage to your home or possessions?" For Earl and Irene, respondents indicated their worry on a scale from 0 to 100, where 0 = not at all and 100 = completely worried. For Earl, 66% of respondents reported a worry level at below 50%, with 20% rating their worry at 0. Irene respondents reported greater worry, with 61% rating their worry at 50% or higher.

The Isaac and Sandy surveys assessed concern with different questions about significant damage from wind and flooding (see Meyer et al. [3], p. 1394, for more details). During Hurricanes Isaac and Sandy, residents overestimated the likelihood that they would experience hurricane-force winds—on average by five times as much as the scientific estimates—but they were relatively unconcerned about the storms. Only 13% of the people threatened by Isaac and only 17% of those threatened by Sandy thought they would experience any personal harm [3].

### *3.4. Prior Storm Experience*

Prior experience with hurricanes also influences probability judgments and preparation decisions. The availability heuristic is a tool people use to make probability judgments based on the ease with which they can call to mind similar instances [5]. However, this can lead to erroneous judgments because the availability of relevant examples is influenced not only by frequency, but also by how recent the recalled event was and by how emotionally evocative it was (see also [33]). For example, people who had recently suffered damage in a wildfire gave higher estimates of the likelihood of a future fire, compared to those who had not suffered damage [42]. In the case of hurricanes, Trumbo et al. [43] found that during the quiescent three-year period after the 2005 hurricane season, when Katrina and Rita struck, hurricane risk perception declined and optimism bias (believing others are more likely to suffer harm than oneself) increased. Additional evidence of a recency effect on preparation decisions can be found in voluntary flood insurance purchases, which were predicted in one study by peak storm surge heights during the most recent hurricane [44]. The availability heuristic can also make it difficult for people to imagine that future hurricanes may behave differently from past ones (Kates [45] referred to the participants of his study as "prisoners of experience").

In the case of natural hazards, the evidence is mixed. Earthquake experience has been linked to increased risk perception for future earthquakes and greater preparation for them [46]. But having previously experienced a hurricane has been linked to lower levels of concern about future hurricanes and less preparedness [47]. A meta-analysis of 21 actual hurricane evacuation studies and two hypothetical ones found no correlation between previous hurricane experience and evacuation [25]. However, the authors did not specify what "previous experience" means and acknowledged (p. 1018) that different authors may characterize "previous experience" in different ways (e.g., different categories of hurricanes and different levels of damage suffered), an issue first noted by Baker [24]. Indeed, for a range of natural hazards, it has been suggested that the ambiguity of the role of prior experience in estimation of future events may have to do with the different ways "prior experience" has been defined—ranging from 'witnessing an event' to 'experiencing severe damage' [48]. Additionally, there are different kinds of preparedness (purchase of insurance, purchase of basic supplies, evacuation plan, etc.), which may explain why it is challenging to draw a single conclusion from a range of studies about the relationship between prior experience and preparedness [49,50]. Huang et al. [25], for instance, focused on evacuation but not other kinds of preparation.

People who have experienced a hurricane in the past but managed to avoid property damage tend to underestimate the likelihood of experiencing damage during a future hurricane, even if their prior experience was due to good luck rather than any action they took [22,51,52]. "Near-miss" and "false alarm" storm warning experiences also impact judgments of the likelihood of future events. There is some evidence that residents who had previously evacuated based on a warning for a tropical cyclone that never arrived were less likely to evacuate in the future, although a review of seven other hurricane evacuation studies found mixed evidence of a relationship between "unnecessary evacuations" and subsequent evacuation rates [25]. It was also unclear from the discussion of false alarms in the meta-analysis whether the false alarm studies involved people who had actually evacuated or people who had heard an evacuation warning and chose not to evacuate [25]. More importantly, most studies of past experience have relied on vague questions ("Have you experienced a hurricane?" "Have you personally been affected by a hurricane?"), which fail to capture the range of ways people may experience a hurricane and the range of impacts a hurricane can have (not only property and financial damage, but a psychological toll as well) [53]. See Demuth et al. [53] for a comprehensive examination of the different cognitive and emotional factors that mediate the relationship between previous experience and evacuation intentions. Of particular note is their finding that previous emotional experience increased negative feelings (worry, fear, dread), which increased evacuation intentions. However, these same negative feelings *decreased* respondents' confidence in their being able to evacuate from a future hurricane. This cancelation effect may be one reason that previous studies have found mixed and non-significant results for a relationship between experience and intentions [53]. The nature of previous evacuation is also important: A previous negative evacuation experience can reduce the likelihood of future evacuation [48].

Although 49% of Earl respondents reported having experienced damage from a previous hurricane, only 24% of those reported having window protection for the current hurricane. For the 39% of Irene respondents who reported having experienced damage from a previous hurricane, only 25% reported owning window protection and only 33% reported having made other modifications to their homes to minimize damage from another hurricane. For Isaac, of the 83% of respondents who had previously experienced hurricane damage, 59% had window protection and 36% reported making other modifications to their homes. For the 27% of Sandy respondents who reported having experience prior damage, only 13% reported owning window protection, although 21% reported making other modifications to their homes. (Earl respondents were not asked about other home modifications). Without follow-up questions, it is hard to know why the previous experience of Isaac respondents led more of them to be proactive compared to people in other survey areas. In terms of demographics, the only distinguishing feature of Isaac respondents was their much higher rate of previous hurricane damage experience. Perhaps Isaac respondents had previously experienced more severe damage than respondents for the other hurricane surveys. It is also possible that the similarity of Isaac's track to that of Katrina led to greater preparation, as vivid images of the devastation from Katrina may have motivated people to be more proactive during Isaac.

### *3.5. Social Factors*

During times of crisis, people often turn to their friends, family, and neighbors for clues as to what they should be doing. Wood et al. [54] have found that observing that others had taken preparatory actions was the best predictor of individual household preparedness (see also [55,56]). Mileti and Peek [57] noted that evacuation orders are more likely to be ignored if people observe others ignoring them. This is a robust phenomenon with people frequently placing uncritical weight in the actions (or inactions) of trusted others. Seeing others take precautionary measures communicates that these measures are effective and makes it more likely that others will take precautionary measures as well. Of course, the action observed may not be the most effective one, and seeing others prepare may lead people to do just one thing to prepare to relieve the psychological burden of inaction, neglecting other important precautionary measures (a phenomenon referred to as "single-action bias" [58]).

The evidence from our field studies, however, does not support social factors as a major driver of decisions about how and when to prepare against immediate hurricane threats. Few respondents (13% for Earl and 9% for Irene) reported friends or neighbors as a recent source of information about the storms. For Isaac, 5% reported friends and neighbors with an additional 3% reporting social media. For Sandy, 3% reported friends and neighbors as a recent source of information, with an additional 1% reporting social media. It appears that instead of friends and neighbors, residents were relying a great deal on television for news. When respondents were asked to list their most recent sources of information on the approaching storms, 89% of Earl respondents and 88% of Irene respondents named television, and 18% of Earl respondents and 14% of Irene respondents said radio. Television was also a primary source of storm information for Isaac respondents (90%) and Sandy respondents (87%) [3].

Likewise, very few cited friends or relatives as reasons to evacuate or reasons not to evacuate. During Earl, only 10% cited friends/relatives as the main reason they were planning to evacuate, and 1% of those not planning to evacuate cited friends/relatives as the main reason for their decision. During Irene, only 13% cited advice from friends or relatives as the main reason they were planning to evacuate and just 3% cited friends/relatives as the main reason why they were not evacuating. For Isaac, 14% cited friends/relatives as the main reason they were evacuating, and fewer than 1% of respondents cited friends/relatives as the main reason why they were not evacuating. For Sandy, 23% of people planning to evacuate cited friends/relatives as the main reason for their decision, and 1% of those not planning to evacuate cited friends/relatives as the main reason for their decision.

There are a few ways to reconcile the apparent contrast between our findings and prior work on social factors. For coastal residents, hurricane warnings are a much more familiar threat than, for instance, wildfires or tsunamis, and warnings are typically accompanied by a plethora of information over multiple media channels that precludes the need to rely on friends and neighbors as a source of guidance. It is also possible that our social factors findings are in part an artifact of the question wording. Simply because social factors are not reported as the main reason for residents' evacuation decisions, does not mean they are not a contributing factor to those decisions. It is also possible that social influences operate at a more subconscious level, and hence are difficult to measure through overt questioning. For instance, people may not consciously register as they drive through their neighborhood that shutters are being put up or that businesses are closing [25], yet at some level, the lack or presence of neighbors' shutters and closed businesses may be influencing their actions. Finally, respondents may be reluctant to cite friends' behavior as a major driver of their own choices because this may threaten their self-image as autonomous actors.

Another reason residents may not worry much about hurricane damage is because of over-trust in societal safeguards or protections, sometimes called the "levee effect" [59–63]. Here, characteristics of institutional design may underlie perceptions of vulnerability. Protections built to reduce damage to existing structures can lead to overconfidence in their efficacy, which in turn may promote overdevelopment in hazard-prone areas and reduce individuals' sense of responsibility for personal preparation and safety.

## 4. Discussion

We have presented evidence across four storms during the 2010–2012 Atlantic hurricane season showing that individuals and households are vulnerable to several cognitive and decision biases that interfere with their optimal preparation for hurricanes. One of the strengths of our methodology is that these surveys were conducted in real time, as the hurricanes were approaching residents' coasts. However, there are some limitations. Because the surveys were administered over three years, they were revised slightly from storm to storm to improve the usefulness of the data collected. Thus, we are missing data for some questions for some storms, as noted above. Additionally, we did not have the resources to conduct physical house-by-house risk assessments that incorporated other factors affecting hurricane risk, such as a home's building materials or whether it was built on stilts.

Despite some limitations, our findings shed light on areas of intervention to improve individual and household preparedness. One approach to dealing with the cognitive and motivational obstacles outlined above is to structure the choice set for decisions so that the default option will increase the likelihood of the most beneficial decision being made [64]. In other words, decisions would be set up so that the default is taking some preparatory action, and an individual or household would have to purposefully decide to not take the action rather than having the default be doing nothing and then having to consciously decide to take action. This purposeful structuring of information is one of the characteristics of 'decision architecture' or 'choice architecture' and has proved effective in a wide range of public choice domains, including organ donation [65], individual savings [66], and green energy [67]. In fact, the U.S. and the U.K. have set up offices to coordinate incorporation of decision architecture, among other information on cognitive biases, into formal, regulatory approaches. Here we illustrate the concept with examples of the biases or obstacles we observed in the field. While we present data primarily related to actions during the short-term forecast/storm preparation phase, choice architecture approaches are equally applicable to the longer-term preparation phase, and we include examples below.

### 4.1. Forecast Phase

Though the internet is not the sole source of information or necessarily the primary source for many [68], media channels—especially TV—rely on the National Hurricane Center (NHC) website as a major source of graphical hurricane displays. To counteract the temporal and spatial myopia interfering with effective preparation decisions, the architecture of these sites could be set up to tailor information for the individual user, for example, by requiring a zip code to progress to the forecast. The most relevant forecast information could then be presented (wind, storm surge, or evacuation information), instead of an image that tries to show all information for all affected areas, making it difficult to interpret or masking other key vulnerabilities. For example, one of the most familiar NHC forecasts remains the cone of uncertainty (officially called the NHC Track Forecast Cone), but that image does not convey information on storm intensity nor storm surge threat. A storm surge forecast product does exist, but it takes several clicks to reach. If a coastal resident puts in their zip code, a 'smart' system would note they are in a vulnerable area and could bring up the storm surge product first.

However, finer grain forecasts come with challenges and potential for unintended consequences as well [69]. For example, in some rural areas, zip codes are very large and would necessitate additional detailed information (street address) to be able to identify the risk to different storm impacts. Such localized products are increasingly becoming available for other risks, such as sea level rise (see for example, the sea level rise maps provided by Climate Central, a scientific research and communication organization [70]), and being used for personal choices such as home purchases. While flooding during extreme weather events involves some different topographic and water management factors than sea level rise, efforts to characterize the flood risk from weather events at increasingly high resolution in urban areas are ongoing. While temporal and spatial myopia appear to play a role, the issue of inferring personal risk from synoptic displays is not fully understood. Further controlled testing with diverse subjects can help identify the utility of this approach.

To better communicate objective probabilities and improve mental models of storm risk, we recommend modifying the presentation of watch, warning, and evacuation information that our study found to be confusing to decision makers. Again, this could be handled by requiring entry into the websites by typing in some locator information that would provide the relevant warning along with suggested actions in a clear format. This information would have to be acknowledged, perhaps by answering a question, before moving on to the next characteristic. This approach could tailor information, reducing the confusion we observed with the official forecast's objective probabilities and people's subjective probability assessments.

Such routing of information could at least in part make up for biases from inadequate mental models of storm impact. Additionally, popular social media sites such as Facebook and Twitter are increasingly providing pertinent logistical information in times of crisis and could play a key role in providing tailored information based on pre-screening questions and links to the most relevant sites. The increasing use of social media of course is a double-edged sword with the increased capability of finding misinformation. The predispositions of information seekers based on any range of factors (e.g., ideological preferences) could lead them to information created with varying degrees of scientific rigor and validation.

The challenge of biases resulting from overweighing past experience could also be dealt with through a 'smart' interactive forecast system. For example, when a person's home zip code is entered, information on how strong the winds have become or how high the water level has risen during past events of similar scale in other areas would be visually displayed, triggering an affective reaction that can be more motivating than technical (analytic) information [71]. Objective data overcomes an excessive reliance on experience by showing actual rather than recalled historical frequency, also allowing for new residents and those who were away when a storm hit to appreciate them. This information should be presented in combination with advice regarding effective precautionary measures, so people are motivated rather than overwhelmed.

Presenting quantitative information to the general public, particularly in probabilistic formats, is challenging, and better formatting could reduce spatial and temporal myopia if strategically deployed. This challenge is two-fold: given probabilistic information for an area before an event (e.g., purchasing a home, deciding whether to buy flood insurance or not), people can underestimate risk due to the time horizon of the probabilities. Then during an actual event, or in the time period leading up to it, people have trouble interpreting the probabilities in the forecast. They may confuse forecast probability with forecast confidence; be unsure which geographic areas the probabilities refer to and over what time period; and/or over-focus on probability and pay less attention to potential impact. Developing alternative metrics that resonate with different groups has been shown to be effective in other domains, such as expressing fuel efficiency (e.g., instead of describing fuel efficiency in miles per gallon, specifying how many gallons of gas will be needed to drive 1000 miles leads to preferences for more fuel-efficient cars [72]). For hurricanes, communication could focus on the impacts (how many feet of water one might find in their house) rather than probabilities [73].

### 4.2. Preparation Phase

Challenges remain with regard to providing incentives to purchase the proper insurance and informing the public about the nuances of various types of policies. Although flood insurance is carried by all coastal residents with federally-backed mortgages in high-risk areas, it is challenging to promote insurance purchases among those not obligated to carry it. One approach might be to exploit people's tendency to choose default options by making flood insurance something one needs to opt out of rather than opt into. For example, insurers in flood-risk areas could routinely offer flood insurance in a package with regular homeowners' policies, but allow residents to opt out of that coverage if they desire. In a similar way, defaults also could be used to encourage other kinds of preparedness measures. For example, communities in hurricane risk areas might distribute annual preparation kits to homeowners that are paid for by property tax revenues, but those who want to opt out of the program can apply for rebates.

Developing and filing preparation checklists and filing evacuation plans prior to the season's start can also be helpful. Care must be taken to prevent people succumbing to single-action biases when completing such lists. To this end, planners might work to develop lists that offer prioritization schedules; e.g., if one were to take only one preparatory action, what would it be? Increasingly, web resources that allow you to 'personalize' and track your risk exposure are becoming available. For example, the "Know Your Hazards" website run by San Diego County allows users to see neighborhood-specific risks for earthquakes, tsunamis and wildfires as they unfold [74].

Some preparatory actions may play out years before an actual event, such as investment in hurricane-proof windows and doors and, most importantly, home location choices. Again, there can be certain choices that could be made the default during home purchases and loan processes, and these could incentivize more resilient choices. Given the relatively short-term time frame of home ownership, people may be understandably reluctant to invest thousands of dollars in protections such as stormproof windows and elevating structures. Thus, it is up to policymakers to incentivize citizens, through subsidies, code changes, or other insurance-related mechanisms [75]. Although people do not always take advantage of incentives when offered, incentives combined with repeated messages of the severe negative impacts of hurricanes could be effective [76]. Tables 2 and 3 summarize the different decision barriers and proposed solutions during the pre-season preparation and forecast phases.

**Table 2.** Decision biases and solutions during pre-season preparation phase.

| Problem | Example | Associated Decision Bias/Obstacle | Solution |
|---|---|---|---|
| Insurance | Lack of insurance and lack of knowledge of insurance coverage | Myopia; Inappropriate mental models | Make having flood insurance the default, requiring uninterested people to opt-out, rather than opt-in |
| Investment in hurricane preparation | Shutters, roof secure | Myopia; Single-action bias | Making hurricane preparation (e.g., having emergency kit, shutters) the default; providing incentives |
| Post-event plan | evacuation plan | Myopia; Construal-level theory | Track-your-risk websites that encourage (and explain) making evacuation plan |

**Table 3.** Decision biases and solutions during forecast phase.

| Problem | Example | Associated Decision Bias/Obstacle | Cause/Solution |
|---|---|---|---|
| Misplaced attention to select hazard characteristic | Over-focus on wind speed, under-focus on flooding | Inappropriate mental model; Outsized influence of prior experience (availability bias) | Current products sometimes lack appropriate information or have too much information; need to automatically tailor information for specific locales/situations |
| Disconnect between hurricane landing risk probability vs. personal risk probability | Buying shutters, but not putting up; overestimate likelihood of strike early but underestimate as event unfolds | Objective vs. subjective probability | Different formats for expressing risk probability (damage vs. likelihood of landfall); visual displays of risk combined with verbal explanations |
| Limited preparatory actions | Some water, batteries, but not many other possible actions | Social factors; Single-action bias | Checklist |
| Poor impact duration estimate | Extended power outage | Inappropriate mental models | Checklist, narratives (examples of likely impacts from previous similar storms) |

## 5. Conclusions

Encouraging adoption of emergency preparedness measures will require actions at multiple levels—from individual decision makers to local government to global re-insurance companies. Here we focused on the persistent challenges facing individual and household decision makers and identified consistent biases that likely contribute to poor planning. There are, of course, multiple factors outside of the household decision making realm—from socioeconomics to zoning to cultural preferences—that constrain decisions and subsequent storm impact. These individual biases, however, can provide some guidance for developing communication approaches: low-hanging fruit for improving resilience to tropical storms. As the use of simulations, virtual reality, and other technological advances become more mainstream, there will be increased opportunities to draw on choice architecture to minimize the negative effects of decision biases.

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## References

1. Pielke, R.A., Jr.; Landsea, C.W. Normalized hurricane damages in the United States: 1925–1995. *Weather Forecast.* **1997**, *13*, 6216–6231. [CrossRef]
2. Baker, E.J.; Broad, K.; Czajkowski, J.; Meyer, R.; Orlove, B. *Risk Perceptions and Preparedness among Mid-Atlantic Coastal Residents in Advance of Hurricane Sandy*; Working Paper #2012-18; Risk Management and Decision Processes Center, The Wharton School, University of Pennsylvania: Philadelphia, PA, USA, 2012.
3. Meyer, R.J.; Baker, J.; Broad, K.; Czajkowski, J.; Orlove, B. The dynamics of hurricane risk perception: Real-time evidence from the 2012 Atlantic hurricane season. *Bull. Am. Meteorol. Soc.* **2014**, *9*. [CrossRef]

4. Thaler, R.H.; Sunstein, C.R. *Nudge: Improving Decisions about Health, Wealth, and Happiness*, 1st ed.; Yale University Press: New Haven, CT, USA, 2008; ISBN 9780300122237.
5. Tversky, A.; Kahneman, D. Availability: A heuristic for judging frequency and probability. *Cognit. Psychol.* **1973**, *5*, 207–232. [CrossRef]
6. Tversky, A.; Kahneman, D. The framing of decisions and the psychology of choice. *Science* **1981**, *211*, 453–458. [CrossRef] [PubMed]
7. Tversky, A.; Kahneman, D. Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychol. Rev.* **1983**, *90*, 293–315. [CrossRef]
8. Frederick, S.; Loewenstein, G.; O'Donoghue, T. Time discounting and time preference: A critical review. In *Time and Decision: Economic and Psychological Perspectives on Intertemporal Choice*, 1st ed.; Loewenstein, G., Read, D., Baumeister, R., Eds.; Russell Sage Foundation: New York, NY, USA, 2003; pp. 13–86, ISBN 0-87154-549-7.
9. Trope, Y.; Liberman, N. Temporal construal and time-dependent changes in preference. *J. Pers. Soc. Psychol.* **2000**, *79*, 876–889. [CrossRef] [PubMed]
10. Trope, Y.; Liberman, N. Temporal construal. *Psychol. Rev.* **2003**, *110*, 403–421. [CrossRef] [PubMed]
11. Trope, Y.; Liberman, N. Construal-level theory of psychological distance. *Psychol. Rev.* **2010**, *117*, 440–463. [CrossRef] [PubMed]
12. Buehler, R.; Griffin, D.; Ross, M. Exploring the "planning fallacy": Why people underestimate their task completion times. *J. Personal. Soc. Psychol.* **1994**, *67*, 366–381. [CrossRef]
13. Richetti-Masterson, K.; Horney, J. Social factors as modifiers of Hurricane Irene evacuation behavior in Beaufort County, NC. *PLoS Curr. Dis.* **2013**. [CrossRef] [PubMed]
14. Gentner, D. Psychology of mental models. In *International Encyclopedia of the Social and Behavioral Sciences*; Smelser, N.J., Bates, P.B., Eds.; Elsevier Science: Amsterdam, The Netherlands, 2002; pp. 9683–9687, ISBN 978-0-08-043076-8.
15. Johnson-Laird, P.N. The history of mental models. In *Psychology of Reasoning: Theoretical and Historical Perspective*, 1st ed.; Manktelow, K., Chung, M.C., Eds.; Psychology Press: New York, NY, USA, 2004; pp. 179–212, ISBN 9781841693101.
16. Broad, K.; Leiserowitz, A.; Weinkle, J.; Steketee, M. Misinterpretations of the "Cone of Uncertainty" in Florida during the 2004 hurricane season. *Bull. Am. Meteorol. Soc.* **2007**, *88*, 651–667. [CrossRef]
17. Morrow, B.H.; Lazo, J.K.; Rhome, J.; Feyen, J. Improving storm surge risk communication: Stakeholder perspectives. *Bull. Am. Meteorol. Soc.* **2015**, *12*, 35–48. [CrossRef]
18. Bostrom, A.; Morss, R.E.; Lazo, J.K.; Demuth, J.L.; Lazrus, H. A mental models study of hurricane forecast and warning production, communication, and decision-making. *Weather Clim. Soc.* **2016**, *8*, 111–129. [CrossRef]
19. Wei, H.-L.; Lindell, M.K.; Prater, C.S. 'Certain death' from storm surge: A comparative study of household responses to warnings about Hurricanes Rita and Ike. *Weather Clim. Soc.* **2014**, *6*, 425–433. [CrossRef]
20. Huang, S.-K.; Lindell, M.K.; Prater, C.S.; Wu, H.-C.; Siebeneck, L.K. Household evacuation decision making in response to Hurricane Ike. *Nat. Hazards Rev.* **2012**, *13*, 283–296. [CrossRef]
21. Huang, S.-K.; Lindell, M.L.; Prater, C.S. Multistage model of hurricane evacuation decision: Empirical study of Hurricanes Katrina and Rita. *Nat. Hazards Rev.* **2017**, *18*. [CrossRef]
22. Eisenman, D.P.; Cordasco, K.M.; Asch, S.; Golden, J.F.; Glik, D. Disaster planning and risk communication with vulnerable communities: Lessons from Hurricane Katrina. *Am. J. Public Health* **2007**, *97*. [CrossRef] [PubMed]
23. Sutton, J.; Woods, C. Tsunami warning message interpretation and sense making: Focus group insights. *Weather Clim. Soc.* **2016**, *8*, 389–398. [CrossRef]
24. Baker, E.J. Hurricane evacuation behavior. *Int. J. Mass Emerg. Disasters* **1991**, *9*, 287–310.
25. Huang, S.-K.; Lindell, M.K.; Prater, C.S. Who leaves and who stays? A review and statistical meta-analysis of hurricane evacuation studies. *Environ. Behav.* **2016**, *48*, 991–1029. [CrossRef]
26. Sadri, A.M.; Ukkusuri, S.V.; Gladwin, H. The role of social networks and information sources on hurricane evacuation decision making. *Nat. Hazards Rev.* **2017**, *18*. [CrossRef]
27. Gigerenzer, G.; Hertwig, R.; van den Broek, E.; Fasolo, B.; Katsikopoulos, K.V. 'A 30% chance of rain tomorrow': How does the public understand probabilistic weather forecasts? *Risk Anal. Int. J.* **2005**, *25*, 623–629. [CrossRef] [PubMed]

28. Carr, R.; Montz, B.; Maxfield, K.; Hoekstra, S.; Semmens, K.; Goldman, E. Effectively communicating risk and uncertainty to the public: Assessing the National Weather Service's flood forecast and warning tools. *Bull. Am. Meteorol. Soc.* **2016**, *97*, 1649–1665. [CrossRef]
29. Budescu, D.V.; Broomell, S.; Por, H. Improving communication of uncertainty in the reports of the Intergovernmental Panel on Climate Change. *Psychol. Sci.* **2009**, *20*, 299–308. [CrossRef] [PubMed]
30. Budescu, D.V.; Wallsten, T.S. Consistency in interpretation of probabilistic phrases. *Organ. Behav. Hum. Decis. Process.* **1985**, *36*, 391–405. [CrossRef]
31. Patt, A.G.; Schrag, D.P. Using specific language to describe risk and probability. *Clim. Chang.* **2003**, *61*, 17–30. [CrossRef]
32. Kahneman, D.; Tversky, A. Prospect theory: An analysis of decision under risk. *Econometrica* **1979**, *47*, 263–291. [CrossRef]
33. Hertwig, R.; Barron, G.; Weber, E.U.; Erev, I. Decisions from experience and the effect of rare events in risky choice. *Psychol. Sci.* **2004**, *15*, 534–539. [CrossRef] [PubMed]
34. Ruginski, I.T.; Boone, A.P.; Padilla, L.M.; Liu, L.; Heydari, N.; Kramer, H.S.; Hegarty, M.; Thompson, W.B.; House, D.H.; Creem-Regehr, S.H. Non-expert interpretations of hurricane forecast uncertainty visualizations. *Spat. Cogn. Comput.* **2016**, *16*, 154–172. [CrossRef]
35. Spiegelhalter, D.; Pearson, M.; Short, I. Visualizing uncertainty about the future. *Science* **2011**, *333*, 1393–1400. [CrossRef] [PubMed]
36. Definition of the NHC Track Forecast Cone. Available online: http://www.nhc.noaa.gov/aboutcone.shtml (accessed on 31 August 2017).
37. Wu, H.-C.; Lindell, M.K.; Prater, C.S. Strike probability judgments and protective action recommendations in a dynamic hurricane tracking task. *Nat. Hazards* **2015**, *79*, 355–380. [CrossRef]
38. Wu, H.-C.; Lindell, M.K.; Prater, C.S.; Samuelson, C.D. Effects of track and threat information on judgments of hurricane strike probability. *Risk Anal.* **2014**, *34*, 1025–1039. [CrossRef] [PubMed]
39. Zarcadoolas, C.; Vaughon, W. *NSHM Product Usability Testing—Public Map and Web Content*; How to Health Literacy, LLC: New York, NY, USA, 2016.
40. Ash, K.D.; Schumann, R.L.; Bowser, G.C. Tornado warning trade-offs: Evaluating choices for visually communicating risk. *Weather Clim. Soc.* **2014**, *6*, 104–118. [CrossRef]
41. Lindell, M.K.; Huang, S.-K.; Wei, H.-L.; Samuelson, C.D. Perceptions and expected immediate reactions to tornado warning polygons. *Nat. Hazards* **2016**, *80*, 683–707. [CrossRef]
42. Martin, I.M.; Bender, H.; Raish, C. What motivates individuals to protect themselves from risks: The case of wildland fires. *Risk Anal.* **2007**, *27*, 887–900. [CrossRef] [PubMed]
43. Trumbo, C.; Meyer, M.A.; Marlatt, H.; Peek, L.; Morrissey, B. An assessment of change in risk perception and optimistic bias for hurricanes among Gulf Coast residents. *Risk Anal.* **2014**, *34*, 1013–1024. [CrossRef] [PubMed]
44. Shao, W.; Xian, S.; Lin, N.; Kunreuther, H.; Jackson, N.; Goidel, K. Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior. *Water Res.* **2017**, *108*, 391–400. [CrossRef] [PubMed]
45. Kates, R.W. *Hazard and Choice Perception in Flood Plain Management*; University of Chicago Department of Geography Research Paper No. 78; University of Chicago: Chicago, IL, USA, 1962.
46. Dunn, P.T.; Ahn, A.Y.E.; Bostrom, A.; Vidale, J.E. Perceptions of earthquake early warnings on the U.S. West Coast. *Int. J. Disaster Risk Reduct.* **2016**, *20*, 112–122. [CrossRef]
47. Meyer, R.; Broad, K.; Orlove, B.; Petrovic, N. Dynamic simulation as an approach to understanding hurricane risk response: Insights from the Stormview lab. *Risk Anal.* **2013**, *33*, 1532–1552. [CrossRef] [PubMed]
48. Sharma, U.; Patt, A. Disaster warning response: The effects of different types of personal experience. *Nat. Hazards* **2012**, *60*, 409–423. [CrossRef]
49. Lindell, M.K.; Perry, R.W. Household adjustment to earthquake hazard: A review of research. *Environ. Behav.* **2000**, *32*, 461–501. [CrossRef]
50. Lindell, M.K. North American cities at risk: Household responses to environmental hazards. In *Cities at Risk: Living with Perils in the 21st Century*; Joffe, H., Rossetto, T., Adams, J., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 109–130.

51. Halpern-Felsher, B.L.; Millstein, S.G.; Ellen, J.M.; Adler, N.E.; Tschann, J.M.; Biehl, M. The role of behavioral experience in judging risks. *Health Psychol.* **2001**, *20*, 120–126. [CrossRef] [PubMed]
52. Dillon, R.L.; Tinsley, C.H.; Cronin, M. Why near-miss events can decrease an individual's protective response to hurricanes. *Risk Anal.* **2011**, *31*, 440–449. [CrossRef] [PubMed]
53. Demuth, J.L.; Morss, R.E.; Lazo, J.K. The effects of past hurricane experiences on evacuation intentions through risk perception and efficacy beliefs: A mediation analysis. *Weather Clim. Soc.* **2016**, *8*, 327–344. [CrossRef]
54. Wood, M.M.; Mileti, D.S.; Kano, M.; Kelley, M.M.; Regan, R.; Bourque, L.B. Communicating actionable risk for terrorism and other hazards. *Risk Anal.* **2012**, *32*, 601–615. [CrossRef] [PubMed]
55. Mileti, D.S.; Fitzpatrick, C. The causal sequence of risk communication in the Parkfield Earthquake Prediction Experiment. *Risk Anal.* **1992**, *12*, 393–400. [CrossRef]
56. Mileti, D.S.; Darlington, J.D. The role of searching in shaping reactions to earthquake risk information. *Soc. Probl.* **1997**, *44*, 89–103. [CrossRef]
57. Mileti, D.S.; Peek, L. The social psychology of public response to warnings of a nuclear power plant accident. *J. Hazard. Mater.* **2000**, *75*, 181–194. [CrossRef]
58. Weber, E.U. Perception and expectation of climate change: Precondition for economic and technological adaptation. In *Psychological and Ethical Perspectives to Environmental and Ethical Issues in Management*; Bazerman, M., Messick, D., Tenbrunsel, A., Wade-Benzoni, K., Eds.; Jossey-Bass: San Francisco, CA, USA, 1997; pp. 314–341.
59. Montz, B.E.; Tobin, G.A. Livin' large with levees: Lessons learned and lost. *Nat. Hazards Rev.* **2008**, *9*, 150–157. [CrossRef]
60. Bohensky, E.L.; Leitch, A.M. Framing the flood: A media analysis of themes of resilience in the 2011 Brisbane flood. *Reg. Environ. Chang.* **2014**, *14*, 475–488. [CrossRef]
61. Bradford, R.A.; O'Sullivan, J.J.; van der Craats, I.M.; Krywkow, J.; Rotko, P.; Aaltonen, J.; Bonaiuto, M.; De Dominicis, S.; Waylen, K.; Schelfaut, K. Risk perception—Issues for flood management in Europe. *Nat. Hazards Earth Syst. Sci.* **2012**, *12*, 2299–2309. [CrossRef]
62. Terpstra, T. Emotions, trust, and perceived risk: Affective and cognitive routes to flood preparedness behavior. *Risk Anal. Int. J.* **2011**, *31*, 1658–1675. [CrossRef] [PubMed]
63. Viglione, A.; Giuliano, D.B.; Luigia, B.; Linda, K. Insights from socio-hydrology modelling on dealing with flood risk—Roles of collective memory, risk-taking attitude and trust. *J. Hydrol.* **2014**, *518*, 71–82. [CrossRef]
64. Johnson, E.J.; Shu, S.B.; Dellaert, B.G.C.; Fox, C.; Goldstein, D.G.; Häubl, G.; Larrick, R.P.; Payne, J.W.; Peters, E.; Schkade, D.; et al. Beyond nudges: Tools of a choice architecture. *Market. Lett.* **2012**, *23*, 487–504. [CrossRef]
65. Johnson, E.J.; Goldstein, D.G. Defaults and donation decisions. *Transplantation* **2004**, *78*, 1713–1716. [CrossRef] [PubMed]
66. Beshears, J.; Choi, J.J.; Laibson, D.; Madrian, B.C. *Simplification and Saving*; Working Paper 12659; National Bureau of Economic Research: Cambridge, MA, USA, 2006.
67. Pichert, D.; Katsikopoulos, K.V. Green defaults: Information presentation and pro-environmental behaviour. *J. Environ. Psychol.* **2008**, *28*, 63–73. [CrossRef]
68. Lindell, M.K.; Lu, J.C.; Prater, C.S. Household decision making and evacuation in response to Hurricane Lili. *Nat. Hazards Rev.* **2005**, *6*, 171–179. [CrossRef]
69. Cuite, C.L.; Shwom, R.L.; Hallman, W.K.; Morss, R.E.; Demuth, J.L. Improving coastal storm evacuation messages. *Weather Clim. Soc.* **2017**, *9*, 155–170. [CrossRef]
70. Surging Seas: Maps & Tools. Available online: sealevel.climatecentral.org/maps (accessed on 19 January 2018).
71. Kasperson, R.E.; Renn, O.; Slovic, P.; Brown, H.S.; Emel, J.; Goble, R.; Kasperson, J.X.; Ratick, S. The social amplification of risk: A conceptual framework. *Risk Anal.* **1988**, *8*, 177–187. [CrossRef]
72. Larrick, R.P.; Soll, J.B. The MPG illusion. *Science* **2008**, *320*, 1593–1594. [CrossRef] [PubMed]
73. Bruine de Bruin, W.; Bostrom, A. Assessing what to address in science communication. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 14062–14068. [CrossRef] [PubMed]
74. ReadySanDiego Know Your Hazards Tool. Available online: http://www.readysandiego.org/know-your-hazards/ (accessed on 31 August 2017).

75. Meyer, R.; Kunreuther, H. *The Ostrich Paradox: Why We Underprepare for Disasters*, 1st ed.; Wharton Digital Press: Philadelphia, PA, USA, 2017; ISBN 978-1-61363-080-8.
76. Ge, Y.; Peacock, W.G.; Lindell, M.K. Florida households' expected responses to hurricane hazard mitigation incentives. *Risk Anal.* **2011**, *31*, 1676–1691. [CrossRef] [PubMed]