Chapter 7
Communicating Weather Risk in the Twenty-First Century: Approaches Using Video Games and Virtual Reality

Jase Bernhardt

Abstract Despite great advances in forecast accuracy and warning lead time in recent years, effective communication of risk from weather hazards to impacted individuals remains a challenge. One way to evaluate and improve public scientific literacy is to leverage engaging technologies such as virtual reality (VR). A VR simulation of a tropical cyclone (TC) landfall was developed for use in two separate studies to evaluate whether it could help convince individuals to evacuate in a hypothetical TC. The first study, conducted on a college campus with mainly younger participants, revealed that the VR simulation did in fact encourage individuals to take the TC more seriously. A follow-up survey, however, found that for a sample of mainly older participants, many of whom were directly impacted by TC Sandy, the VR discouraged evacuation in the hypothetical landfall scenario. The results of those two studies indicate that while VR may be useful in aiding TC hazard communication, more research is needed to better understand how best to leverage the technology, especially when considering different demographic groups.

Keywords Scientific communication · Weather risk · Video games · Virtual reality · Immersive technology

7.1 Introduction

Weather forecasters face dual challenges when serving the public. Predicting future weather conditions has always been recognized as a scientific problem, given uncertain initial conditions and an incomplete understanding of the atmosphere's governing equations. However, in recent years, increasing attention has been paid to how effectively weather forecasts are conveyed to the public. Despite clear gains in

J. Bernhardt (✉)
Department of Geology, Environment and Sustainability, Hofstra University, Hempstead, NY, USA
e-mail: Jase.E.Bernhardt@hofstra.edu

S. D'Amico, F. De Pascale (eds.), *Geohazards and Disaster Risk Reduction*, Advances in Natural and Technological Hazards Research 51,
https://doi.org/10.1007/978-3-031-24541-1_7

the accuracy of hazardous weather forecasts (e.g., National Hurricane Center 2021a), it is more difficult to ascertain whether public understanding has made commensurate gains. Yet, in seeking to reduce risk from weather-related geohazards, the efficacy of a weather forecast is limited by its reception from the public. For example, even a perfect forecast for a hazardous weather event such as a tropical cyclone can be seen as ineffective if recipients do not properly act on it to reduce personal vulnerability. Further compounding the disconnect between a weather forecast and its interpretation are the innumerable personal factors which control personal decision-making. Age, previous experience with hazardous weather, political identity, and primary language spoken are just a few of the many characteristics that cause individuals to act upon hazardous weather alerts in starkly contrasting ways (e.g., Schumann et al. 2018; Ngo et al. 2020). While there is no single method for gaining a full understanding of this multifaceted issue, simulations offer one promising approach. Simulations allow a researcher to place study participants in a controlled but realistic environment, resulting in authentic responses to the hazardous weather faced and an objective way to measure the efficacy of the hypothetical weather forecasts and alerts provided. In the following case study, I discuss how this approach was leveraged to gain insight into behavioral responses to a key weather hazard occasionally impacting the Northeastern United States, tropical cyclones (TCs).

TCs are among the costliest and deadliest geohazards globally (World Meteorological Organization 2021). They typically form in lower latitude regions of global oceans, particularly in the Northern Hemisphere, and frequently impact adjacent land areas. TCs are a multifaceted hazard, bringing serious threats from water, wind, and even tornadoes. TC forecasts have experienced marked improvements over time, especially their tracks. Moreover, given the slow forward motion of TCs, on average 10 to 15 knots when in and near the tropics (Atlantic Oceanographic and Meteorological Laboratory 2021), there is often sufficient advance notice of an impending storm. Yet convincing impacted individuals to evacuate from the path of a TC remains fraught with difficulty, owing to the complexity of such a decision. A variety of deeply personal factors can influence willingness to leave. Further compounding these issues for a place like New York is the infrequency with which TCs strike, and even when one does strike, it can be dismissed as a single, anomalous event. Such is the case for Long Island, New York, an area that experienced severe impacts from TC Sandy in 2012, but otherwise has not been directly impacted by a TC at hurricane strength since 1985 and a storm at "major hurricane" strength (sustained winds of at least 96 knots) since 1938. In any given year, however, a major hurricane could make landfall on Long Island, and when it does happen, it could "result in a catastrophic natural disaster" (Shepard et al. 2012). Thus, it is imperative to understand how people on Long Island will respond in that hypothetical situation. Leveraging a virtual reality (VR) simulation of a TC landfall provided a means for doing so in a realistic way.

7.2 Data and Methodology

In 2017, a VR simulation of a Category 3 TC landfall was developed (a link to the non-VR, YouTube video version is included in the appendix). TCs are assigned a category on the Saffir-Simpson scale, based on maximum sustained wind speed, varying from Category 1 (the weakest) to Category 5 (the strongest). TCs of Category 3 strength or greater (sustained winds of at least 96 knots) in the North Atlantic and East Pacific Oceans are frequently referred to as "Major Hurricanes," given their ability to inflict substantial damage when impacting land. A Category 3 TC was selected because climatologically it was the strongest type of storm that has ever been observed to strike Long Island. The simulation, which lasted around 75 seconds, depicted landfall in a low-lying residential coastal community, of which there are many on Long Island. Participants stood in the family room of the first floor of a standard suburban home (Fig. 7.1a). While viewers were unable to physically change their position in it, they were able to move their head around, both vertically and horizontally, to view the full scale of storm hazards in the immersive environment. Throughout the experience, simulation users saw and heard strong winds, torrential rain, lightning, and sirens. Moreover, those heavy winds blew debris into the room's window, smashing it open, and then proceeded to blow household objects around, such as knocking a television over (Fig. 7.1b). In addition to hazardous wind, the power of storm surge was also demonstrated in the VR simulation (Fig. 7.1c). Storm surge is the excess water rise caused by TCs, and other storms, on top of the normal astronomical tides (National Hurricane Center 2021b), due to their strong winds and low pressure. Wind speed is often the most-discussed aspect of TCs and determines its Category; however, storm surge is frequently deadlier. Storm surge can rise many feet above normal tidal levels, causing catastrophic

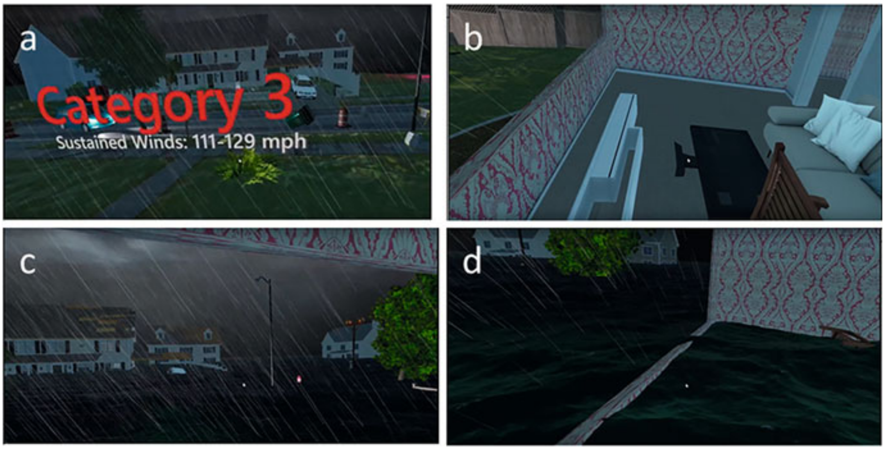

Fig. 7.1 Screenshots of various stages of Category 3 tropical cyclone landfall virtual reality simulation (**a**–**d**). Image source: Bernhardt et al. (2019), their Fig. 1

flooding of coastal locations, and may extend well inland. Throughout the simulation, the water outside of the home consistently rose due to the storm surge, and towards the end, it flooded the home and completely submerged the participant (Fig. 7.1d).

7.3 Results

The VR simulation developed was used for two pilot studies involving field surveys in 2017 and 2018, with the goal of understanding how the simulation impacted behavioral response. For the first study, undertaken in fall 2017 and described in Bernhardt et al. (2019), 124 individuals were randomly selected from Hofstra University's student center, over several sessions, and split into two even groups (i.e., 62 in each). Both groups received basic information about a hypothetical TC landfall, including the forecast track and wind speeds. Only one group, however, was shown the VR simulation, in an attempt to isolate its impacts on individual risk perception and resultant actions. It was found through Likert-scale questions that participants who experienced the VR were more likely to report that they would evacuate and take other preparedness measures (Fig. 7.2). Importantly, qualitative

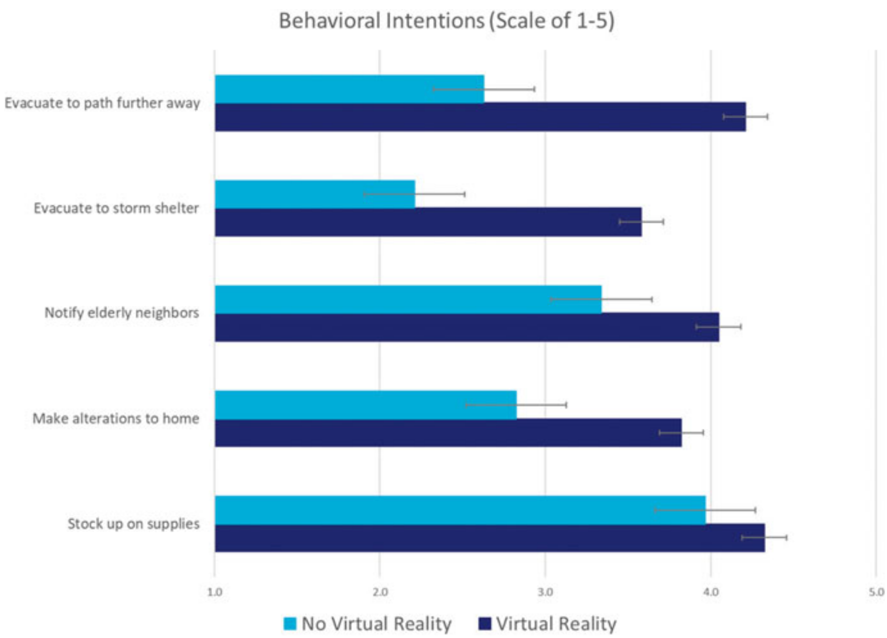

Fig. 7.2 Behavioral intentions, in response to Likert-style questions, where 1 is very unlikely and 5 is very likely, of 124 individuals surveyed. Image source: Bernhardt et al. (2019), their Fig. 4

responses also indicated that those viewing the VR took the storm surge threat more seriously.

The second, follow-up, study was conducted in Long Beach, New York, in 2018 and is presented for the first time in this chapter. Long Beach is a small, densely populated city located on a barrier island immediately south of Long Island. Being situated on a barrier island just above sea level, Long Beach is exceptionally vulnerable to storm surge flooding from both TCs and non-tropical storms. During Sandy, which struck the Northeast United States in October 2012, Long Beach sustained extensive damage, including the destruction of its boardwalk and damage to many homes and businesses. When this study was conducted in early 2018, it was hypothesized that while Sandy was over 5 years in the past, its extensive impacts would still be well recalled and thus influence hypothetical actions in a future TC landfall. Previous experience with a weather hazard, however, has conflicting effects on risk perception, and some studies have shown there is insufficient evidence to support the idea that individuals and organizations will be more prepared for a severe weather event after already facing one (e.g., Keul et al. 2018; Zhang and Maroulis 2021).

In February–April 2018, researchers visited a local coffee shop and public library, both in Long Beach, to replicate the Bernhardt et al. (2019) study on Hofstra's campus, but for individuals living in Long Beach, many of whom were directly impacted by Sandy's hazards in 2012. Based on that survey audience, it was thought that much like the Hofstra campus study, individuals viewing the VR simulation would be significantly more likely to take the hypothetical TC seriously than those not seeing it. However, that was not the case in the Long Beach survey (Fig. 7.3b, below the Hofstra results in Fig. 7.3a, for comparison), as the VR was shown to be a less effective risk communication tool for that audience. For example, in the campus survey, in four of the five Likert-scale questions regarding behavioral intentions in the hypothetical TC, those viewing the VR were significantly more likely to take preparedness actions in response to the storm. For the Long Beach survey, though, there were only significant differences between two of those five questions. Further, in both surveys, a dichotomous, "yes or no" question was posed, simply asking if participants would evacuate from the predicted TC or not. A strong majority of respondents in the Hofstra study said yes, 55 of 62 viewing the VR and 45 of the 62 who did not. That result showed most individuals found a Category 3 TC to be sufficient for warranting evacuation, but the VR simulation provided extra assistance in conceptualizing and acting on the risk. Conversely, in the Long Beach survey, participants viewing the VR were *less* likely to say that they would evacuate, with 73.3% saying they would evacuate, while 81.0% of those not seeing the VR reported the intention to evacuate.

The fact that participants experiencing the VR in the Long Beach study took the projected TC less seriously seemed counterintuitive, especially when compared to the opposing and more expected result in the analogous survey on Hofstra's campus. Further investigation, though, revealed multiple explanatory factors for the apparent discrepancy. As expected from a college campus, the Hofstra survey sample skewed younger, as 80.6% of the individuals were under the age of 25 (Bernhardt et al.

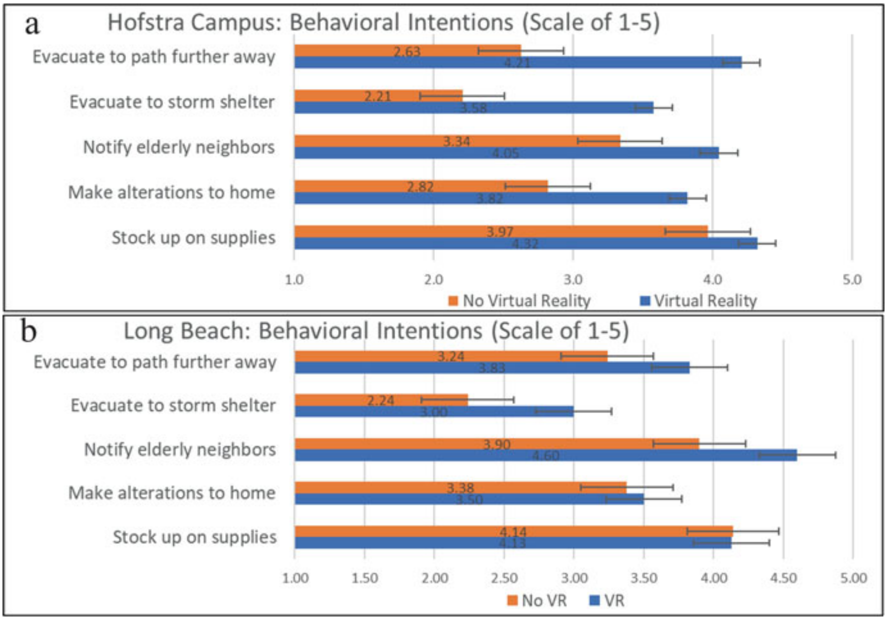

Fig. 7.3 Comparison of Likert-scale question results in the (**a**) Hofstra survey and (**b**) Long Beach survey (**b**)

Fig. 7.4 Long Beach survey results for age range versus evacuation intention ("Yes" or "No")

Age	Yes	No
<25 (9)	100%	0%
25-40 (11)	82%	18%
40-60 (10)	70%	30%
>60 (18)	61%	39%
NA (3)	100%	0%

2019). In the Long Beach survey, meanwhile, participants tended to be older, with only 17.6% under the age of 25 and 35.3% over the age of 60. The Long Beach study further demonstrated the importance of age to evacuation intention (Fig. 7.4). In that survey, all 9 of the respondents under the age of 25 (100%) stated they would evacuate from the hypothetical TC, but the percentage willing to evacuate dropped with each successive age group (25–40; 41–60; >60), with only 61% of the individuals over the age of 60 stating they would evacuate. Additionally, prior experience with TCs also likely played a similar role in reducing perception of risk (Fig. 7.5). In the Hofstra survey, 71.8% of the participants reported having previously experienced a TC (Bernhardt et al. 2019), while in Long Beach, that number was 78.0%. In the latter study, much like older age, previous experience was shown to reduce willingness to evacuate. Of the Long Beach individuals surveyed who mentioned previous experience with a TC, only 69.2% said they would

Fig. 7.5 Long Beach survey results for previous TC experience versus evacuation intention ("Yes" or "No")

Previous Experience	Yes	No
Yes (39)	69%	31%
No (11)	100%	0%
NA (1)	100%	0%

evacuate, while 100% of those without previous experience said yes. Clearly, further investigation of the underlying demographics of each survey group helped explain why they showed opposing results, that is, why VR encouraged individuals in the Hofstra study to take the projected TC seriously but discouraged those in the Long Beach study.

7.4 Discussion

The divergent results across the two studies and their demographic groups indicate that much nuance must be used when understanding how novel technologies can be applied to the problem of weather hazard risk communication. When initially framing this line of inquiry, it was hypothesized that a VR simulation could be a useful asset in real-time warning communication, by providing a short, dramatic, immersive, and easily relatable demonstration of a TC's many hazards. It was thought, therefore, that including the VR simulation with an advisory message 2 to 3 days in advance of a predicted TC landfall would help convince individuals to evacuate. The findings of the first study at Hofstra University, which matched that scenario, were encouraging, as those viewing the simulation were significantly more likely to report the intention to evacuate and take other preparedness measures in response to the hypothetical threat. Supporting that conclusion were qualitative responses containing several comments about the water in the simulation being frightening and helping to motivate action, especially when it rose to the viewer's eye level. That result in particular underscored the potential VR holds for enhancing scientific literacy of weather hazards while also motivating appropriate action in real time. The findings from the Long Beach survey, meanwhile, force a more rigorous evaluation of VR's value in conveying weather hazard risk, as the simulation may have made individuals less likely to take a TC seriously. Factors such as the realism of the simulation, the viewer's previous experience with the hazard being shown, and other personal characteristics, all seem to influence risk perception.

Regarding the accuracy of the VR simulation, if it is found to be unrealistic by a user, the simulation might cause them to ignore it as a risk communication tool or perceive less risk from a TC landfall. To the first point, in the VR experience developed for this project, the power did not go out. One participant in the Long Beach study mentioned this in qualitative feedback, implying that would be a reason to not worry as much about the storm. Further comments from that study were critical of the lack of other people in the simulation, as there were no family members, neighbors, or first responders in it, and additional individuals pointed out the inability to physically move and attempt to escape as unrealistic. Previous experience with a TC was also shown to be an important driver of behavioral response in the two surveys. Particularly for the Long Beach participants, Sandy represented a catastrophic event, as their homes and neighborhoods endured extensive flooding while also sustaining wind damage. Nevertheless, all those individuals physically survived Sandy, so the notion of another TC, especially in a hypothetical sense, may not have been sufficient to motivate evacuation, even with the scenario being enhanced by a VR simulation. For those never impacted by a TC, or not significantly affected (i.e., not forced to evacuate), though, the VR can be instrumental in conveying the dangers of a TC. The efficacy of an immersive simulation is especially apparent in that case, as it can resonate more strongly than a standard video or simple text description of a TC's hazards. In addition, to further enhance its value, future simulations should also be more localized. For instance, if the survey were to be repeated in Long Beach, the VR simulation could depict the City of Long Beach Boardwalk and Beach Park, which would be a recognizable landmark for local residents. Damage to the boardwalk and beach in the simulation could elicit a more emotional response, potentially triggering flashbacks to Sandy and compelling participants to take the present hazard more seriously. Intentionally forcing such a response, however, can be morally ambiguous. During the two studies, in Long Beach especially, several participants asked to remove the VR headset prior to the simulation concluding. The stated reason was because the VR experience, primarily the water rising and sounds of the storm, did in fact trigger flashbacks to Sandy, resulting in sudden fear. This finding poses a difficult question for hazard researchers and communicators. In order to better understand risk perceptions and motivate protective actions during a storm event, is it ethical to intentionally frighten individuals by attempting to elicit a deep emotional response rooted in past dangerous interactions with that hazard? Coming to terms with this conundrum will be of utmost importance as immersive technology, including VR and other tools such as augmented reality (AR), becomes more lifelike and realistic.

Beyond the moral quandaries surrounding the application of immersive technology to hazard communication, deeply held personal convictions should also be considered. Several such factors emerged during the Long Beach study in particular. In the Hofstra survey, when explaining their resistance towards evacuating, participants primarily cited technical information. A lack of specific information about evacuation routes and precise wind speeds, confusion over the forecast map and TC category, and imprecise timing of the event were among the limitations mentioned. In the Long Beach study, while those issues were mentioned by some, the single greatest concern brought up was mistrust – of actors including governmental authorities, the news media, and meteorologists. The inclusion of VR, being a relatively novel and untested technology, may have helped bring rise to those barriers to action mentioned, especially given the older skew of the population, where feelings of distrust may be most acute. This conclusion further cautions against the appropriateness of using VR and similar tools in hazard communication for all audiences, unless it is done so intentionally. One way of doing so could be asking local authorities and civic associations, who might be viewed as more trustworthy, to leverage VR as part of a suite of risk communication tools. That strategy builds upon the findings of Ploran et al. (2018), who also studied hurricane evacuation decision-making in Long Beach. The Ploran et al. study determined that local informational sources, such as police officers, fire departments, and community organizations, would likely be the most persuasive sources of information in future storms. Beyond distrust, other factors revealed as deterrents to evacuation in the Long Beach study included concerns about whether a storm shelter could accommodate people with disabilities and the presence of pets in a household. All of those factors can be challenging to overcome when working to change behavioral outcomes in a hazard. They do, however, motivate an expansion of VR into the realm of video games. The combination of immersive VR and an interactive game could result in a powerful tool for outreach and potentially real-time hazard awareness too. The video game approach could reduce the uncertainties arising from the present studies, particularly limitations involving hazard realism and personal relatability to the simulation.

In the future, a VR TC simulation could allow for several personalization options to increase its authenticity. Users could select a simulation location most impactful to them, whether it be a beach, their own neighborhood, or somewhere else. Moreover, they could choose a personal avatar (i.e., character), specify other members of their household (or pets) who should be included in the scenario, and also be allowed to physically evacuate from the location, if they so choose. Those enhancements would be expected to provide more authentic reactions and follow-up survey responses when investigating hypothetical behavioral responses to a hazard and also potentially resonate more in advance of an actual hazard. The former has already been successfully demonstrated in Bernhardt et al. (2020), where a VR video game of a rip current was created. In that simulation, participants were trained in how to swim in the ocean and wave for help in the game and then unexpectedly placed in a rip current. Most participants were able to apply that training in escaping the rip current and reported that physically taking the action in the game was meaningful in teaching them what to do in that hazard. It stands to reason, therefore, that asking participants in a VR TC landfall video game to take similar risk avoidance actions would result in a more memorable lesson. While there are undoubtedly more complexities in reducing TC risk than rip current risk, the flexibility of the video game approach permits both the researcher and the user to tailor the experience to a preferred location and type of TC.

7.5 Conclusions

The pilot studies described in this chapter demonstrate, in a preliminary way, that while VR simulations can potentially be an asset in conveying risk from TCs, there are several key caveats when deploying them. When surveying a younger audience at Hofstra University, VR was shown to be effective in helping participants to take a hypothetical TC landfall more seriously. When that same survey was replicated with an older demographic in Long Beach, however, efficacy of the VR in communicating risk decreased substantially. The reduced effectiveness is hypothesized to have been caused by (1) the direct impacts of 2012 TC Sandy in Long Beach, which counterintuitively lowered fear of a future storm, and (2) increased distrust of information and authorities in the older population. Moreover, in both studies, issues with the simulation's realism, and highly personal factors such as having dependents to care for, also limited willingness to evacuate in a hypothetical TC landfall. These findings confirm the long-standing notion that individual risk perception is complex and multifaceted. Although all factors influencing risk communication and how individuals act on hazard threats cannot be controlled, the immersive nature of VR shows promise in resonating on a personal level with at least some individuals, particularly younger ones. A VR simulation could further be enhanced by personalization options to make it more relatable and memorable. Last, to overcome the obstacles found in the Long Beach study, it is clear that the way in which a VR hazard outreach tool is framed and presented is crucial to its success with more hesitant populations. For example, asking local officials, friends, and family to share a simulation within their personal networks could be most effective for leveraging VR to help build community-level resilience. Future research can utilize methods including surveys and interviews to confirm and refine such applications of VR simulations to hazard risk reduction.

Acknowledgments The work described in this chapter would not have been possible without the devotion of Jackson Snellings in developing the tropical cyclone virtual reality simulation. Further assistance was also provided by Alexander Smiros. Last, several undergraduate research assistants supported collection of the survey data, including Angela Rienzo, Ivan Bermejo, Carys Swan, James Eager, Kaitlyn Shire, Sally Roscoe, and John Van Fossen.

Appendix

Link to low-resolution YouTube version of the VR simulation used for the studies: https://youtu.be/5VMCNWpuBdM

References

Atlantic Oceanographic and Meteorological Laboratory (2021, October 31) Frequently asked questions. https://www.aoml.noaa.gov/hrd-faq/#avg-forward-speed

Bernhardt J, Snellings J, Smiros A, Bermejo I, Rienzo A, Swan C (2019) Communicating hurricane risk with virtual reality: a pilot project. Bull Am Meteorol Soc 100(10):1897–1902

Bernhardt J, Dusek G, Hesse A, Santos W, Jennings T, Smiros A, Montes A (2020) Developing a virtual reality video game to simulate rip currents. J Vis Exp (JoVE) 161:e61296

Keul AG, Brunner B, Allen J, Wilson KA, Taszarek M, Price C et al (2018) Multihazard weather risk perception and preparedness in eight countries. Weather Clim Soc 10(3):501–520

National Hurricane Center (2021a, October 31) Forecast verification. https://www.nhc.noaa.gov/verification/verify5.shtml

National Hurricane Center (2021b, October 31) Glossary of terms. https://www.nhc.noaa.gov/aboutgloss.shtml

Ngo CC, Poortvliet PM, Feindt PH (2020) Drivers of flood and climate change risk perceptions and intention to adapt: an explorative survey in coastal and delta Vietnam. J Risk Res 23(4):424–446

Ploran EJ, Trasciatti MA, Farmer EC (2018) Efficacy and authority of the message sender during emergency evacuations: a mixed methods study. J Appl Commun Res 46(3):291–322

Schumann RL III, Ash KD, Bowser GC (2018) Tornado warning perception and response: integrating the roles of visual design, demographics, and hazard experience. Risk Anal 38(2):311–332

Shepard CC, Agostini VN, Gilmer B, Allen T, Stone J, Brooks W, Beck MW (2012) Assessing future risk: quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, New York. Nat Hazards 60(2):727–745

World Meteorological Organization (2021) WMO atlas of mortality and economic losses from weather, climate and water extremes (1970–2019). WMO, Geneva. WMO-No. 1267, https://library.wmo.int/doc_num.php?explnum_id=10989

Zhang F, Maroulis S (2021) Experience is not enough: a dynamic explanation of the limited adaptation to extreme weather events in public organizations. Glob Environ Chang 70:102358