Expert Perceptions of Uncertainty Communication in 3D Visualizations of Coastal Hazards

Peter Stempel[1], Austin Becker[2], Ellie Nasr-Azadani[3]

[1]Penn State University, Pennsylvania/USA · pjs6035@psu.edu
[2]University of Rhode Island, Rhode Island/USA
[3]Penn State University, Pennsylvania/USA

Abstract: Guidance for visualizing coastal hazards has discouraged the use of 3D visualizations because of a lack of experimental testing accounting for their effects on audiences and the potential of these visualizations to be misleading by making outcomes appear more certain than they are. Some experts continue to use model-driven 3D visualizations despite this guidance. We thus conducted a survey to better understand expert perceptions of uncertainty communication related to 3D visualization of storm impacts (flooding and damage to structures). The survey included 115 experts drawn from the Northeast USA. We selected experts with differing levels of familiarity with the visualizations tested, including experts engaged in their creation, to explain how their relationship to the process affects perceptions. We found that the experts overwhelmingly support using 3D visualizations for risk communication providing that adequate attribution, labelling, and background is provided to contextualize the visualizations. The evolution of real-world use and practice suggests further research is needed to better understand the audience interpretations of the visualizations and revise expert guidance.

Keywords: Uncertainty, visualization, realism, storm surge, 3D

1 Introduction

Coastal Communities face increasing uncertain risks posed by storm surge, and storm surge combined with flooding from rainfall (TRENBERTH et al. 2018, TRENBERTH 2011, ROMERO & EMANUEL 2017). Coastal managers and other experts use 3D visualizations that combine outputs from hydrodynamic and hydrological models with realistic depictions of recognizable landscapes for public engagement, disaster risk reduction and training and informing decision makers, such as emergency managers. While disciplines such as landscape and urban planning like employing participatory frameworks of science communication to easily accommodate 3D visualizations (e. g. SHEPPARD 2012), dissemination-based frameworks commonly applied to hazard and risk visualization discourage their use (e. g. KOSTELNICK et al. 2013). This guidance emphasizes the use of 2D visualizations, management of level of detail, and knowledge of audiences such that added detail or dimensions do not imply more knowledge than exists (KOSTELNICK et al. 2013, BOSTROM et al. 2008). Scholars rightly worry that realistic 3D visualizations reify physical models by transforming the abstraction of assumptions, equations, and nodes (places where calculations are made) into highly detailed images that imply higher degrees of certainty regarding outcomes than exist (DEITRICK & EDSALL 2009, KOSTELNICK et al. 2013). We believe that landscape architects should be cognicent of these issues given that tools traditionally associated with the discipline are being applied in this way.

We conducted a survey that shows that coastal managers and experts perceive 3D visualization to be effective at relating complex information to interested parties. These visualizations in themselves, however, do not conform to guidance and flood mapping practices that dis-

Journal of Digital Landscape Architecture, 8-2023, pp. 564-573. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-740-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537740059.

courage use of 3D and emphasize the clear expression of technical uncertainty (e. g. PADILLA et al. 2020, SEIPEL & LIM 2017, BEVEN et al. 2015). The term "technical uncertainty" is used to distinguish this form of uncertainty from other forms of uncertainty such as personal uncertainty and public (political) uncertainty that also shape risk perception, but are not discussed here (WALSH & WALKER 2016). All flood hazard models involve technical uncertainty that includes both epistemic uncertainty of the model (our ability to know) and aleatory uncertainty associated with the stochastic nature of events like storms (MERZ & THIEKEN 2009). These issues are made more complex by increasing emphasis on "deep uncertainty" where decision makers cannot know the likelihood of an outcome (RUCKERT et al. 2019).

The use of 3D visualizations in diverse contexts thus poses a potent case to explore how coastal managers and other experts employing them in communicating risk from coastal hazards perceive *the need* for uncertainty communication when using 3D visualizations for risk communication. We also investigated how proximity to the visualization project affected the results to determine whether being involved or familiar with aspects of the visualization process altered perceptions of their use in addition to observing other factors, such as type of expertise that may influence perceptions. This work is closely related to our other investigations of whether 3D visualizations are perceived as being "scientific" (STEMPEL & BECKER 2021), and the effects of context on perceptions of 3D visualizations (STEMPEL & BECKER 2019).

2 Methods

We asked three questions of 115 U.S. experts participating in an online survey evaluating four semi-realistic 3D visualizations of storm surge (STEMPEL & BECKER 2021):

- Are visualizations such as the ones you've just seen appropriate tools for risk communication? (Yes / No question)
- What concerns, if any, do you have about using visualizations like you've seen here for risk communication? (Open ended question)
- Should visualizations of storm surge distributed to the public include labels describing the scientific uncertainty of predictions? Please provide a brief explanation. (Open ended question)

The survey instrument was approved by the University of Rhode Island Institutional Review Board (1047179–2), and participants provided online consent at the start of the survey. It was distributed to respondents using email lists used by experts in coastal resilience in Rhode Island USA. These included: an internal mailing list for the Rhode Island Emergency Management Agency / Federal Emergency Management Agency Integrated Emergency Management Course, the Rhode Island Shoreline Change Special Management Plan, and the Department of Homeland Security Center of Excellence at the Coastal Resilience Center at the University of North Carolina that reaches a wider audience of experts. The inclusion of persons outside of Rhode Island reflects an interest in exploring the possibility that proximity to the visualization process or locale depicted might influence the appraisal of the visualizations. Additional data collected included demographic information and experience with storm surge.

A total of four visualizations were used in the survey. All surveys included three visualizations made for the Coastal and Environmental Risk Index (CERI), a system developed and applied within the State of Rhode Island. These visualizations depicted three communities in Rhode Island USA and incorporated depictions of storm surge and of projected structural damages (visualizations dynamically updated). Damage estimates were based on functions developed by the US Army Corps of Engineers North Atlantic Coast Comprehensive Study (NACCS) (COULBOURNE et al. 2015 (https://www.nad.usace.army.mil/CompStudy/)). CERI models combine models for inundation, wave, and erosion (SPAULDING et al. 2016). Subsequent evolutions of CERI have been modified to depict wind and a more generalized quantification of risk and is now deployed as an app (SPAULDING et al. 2020). The fourth visualization depicted flooding of coastal port infrastructure made for Federal Emergency Management Agency Integrated Emergency Management Training Course (STEMPEL et al. 2018). (Figure 1).

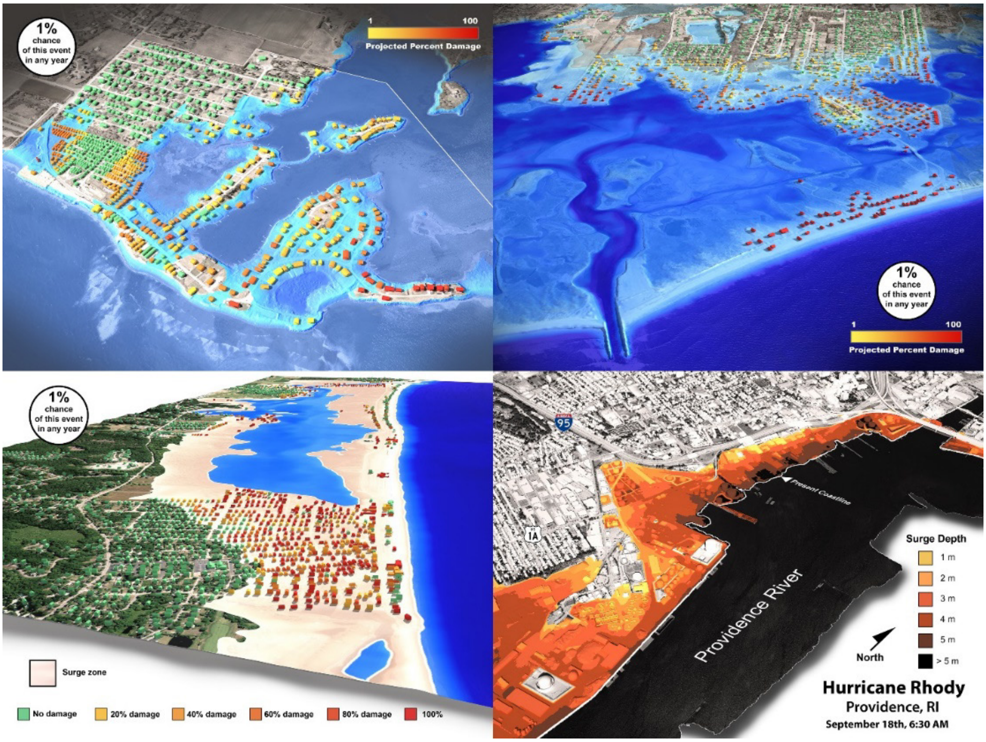

Fig. 1: Four visualizations that were used in the survey. Clockwise from lower left, Misquamicut, RI, USA, Matunuck, RI, USA, Charlestown, RI, USA, and Providence, RI, USA. Each visualization exhibited different stylistic characteristics such as the distance at which the view was framed, and the color schema used.

Responses to open ended questions were organized into a spreadsheet and inductively coded by the research team (THOMAS 2006). To validate the coding, codes were applied to a random subset of the data (n = 100) by an independent coder. That coded sample was then compared and found to be 84 % in agreement with the coded data.

As initially designed, the yes/no question as to whether the tested visualizations were suitable for risk communication was intended for use in a logistic regression to determine if proximity and expertise, among other factors, influenced the perceived acceptability of using the tested visualizations for risk communication. As will be discussed in the results, however, the one-sided nature of the responses made this analysis moot (additional details regarding methods of the larger survey project can be found in Stempel and Becker 2021, "Is it Scientific, Viewer Perceptions of Storm Surge Visualizations).

3 Results

3.1 Respondents

Half of survey respondents were unfamiliar with the visualizations and the other half exhibited varying degrees of proximity to the labs that created the visualizations. Type of expertise and familiarity with the visualizations and visualization team are summarized in Table 1 and Table 2.

Table 1: Responses broken down by expertise. Note that respondents could choose more than one category (e. g. a government official that is also an emergency manager).

Type of expertise	Respondents
Emergency management	34
Natural or physical Science	29
Engineering or technical	23
Public policy	25
Public engagement	29
Government or elected official: federal	15
Government or elected official: state	20
Government or elected official: local	20

Table 2: The proximity of respondents to the research team and visualizations

Degree of familiarity	Respondents
Worked with or near the science and visualization team	17
Have seen the tested visualizations previously	31
Have encountered the tested visualizations in training	13
Unfamiliar with the visualizations tested	57

The cohort is overwhelmingly white, comparatively wealthy, and well educated. This lack of diversity reflects the underlying condition of the selected expert cohort. 25% of the cohort noted their gender as female. Virtually all respondents had direct experience with storm surge, which is not surprising given the expertise and career focus of respondents. The personal experience of respondents with storm surge is summarized in Table 3.

Table 3: Respondents experience with storm surge (respondents were able to select more than one)

Experience with storm surge	Respondents
Directly impacted	14
Family or friend impacted	26
Witnessed impacts first-hand	96

3.2 Use of Visualizations for Risk Communication

The answer to the question "Are these visualizations appropriate tools for risk communication" was overwhelmingly one-sided. Of 115 respondents, 97 answered Yes, three answered No, and 15 did not answer the question (87 % response rate). The sentiments expressed in the question "what comments do you have regarding these visualizations" provided insight into the positive assessment, mostly emphasizing the ability of the images to place surge information in recognizable contexts and the ability to convey complex information concisely in an easy-to-understand format. Examples of comments include:

- "The oblique view of a 3D representation of each community is similar to images that the public sees in the media following a storm surge event. This visualization choice puts this information in a context familiar to the public."
- "It helps to know the area being shown to really understand the effect."
- "I am impressed as to the synthesis of very complex scientific data that these visualzations are able to express in a relatively easy-to-understand presentation."

There was, however, a consistent sentiment that more context was required in the form of text, supplemental images to provide a means of interpreting images (e. g. what every level of damage represents in real terms), and background information.

3.3 Concerns Regarding Use for Risk Communication

The answer to "what concerns you regarding the use of these images for risk communication" was revealing. 85 respondents answered the question (74 % response rate). 29 respondents were concerned about the potential that the visualizations could mislead the public by being inaccurate, overstating or understating risk, or being used in misleading ways. Of those respondents, 15 were concerned about understating risk, and the remainder (14) expressed concern about overstatement or inaccuracy. 15 respondents expressed concern with adequately communicating the scientific basis for the visualizations and providing adequate background. 15 respondents expressed concerns with representational choices. There was an expressed preference for a yellow-rust color palette, the way results were binned (the color choices were the result of a need to make the visualization color-blind accessible), and the clarity of the features represented. The least favourite visualization was the Misquamicut visualization that used a tan color to mark the surge zone.

Other issues raised included concern for the public's understanding of probability and statistics (5 respondents), Accessibility of the visualizations to lay audiences (4 respondents) and the inclusion of scientific uncertainty or quantification of risk (4 respondents). Four respondents stated that they had no concerns. The main themes are shown in Table 4.

Table 4: Summary of concerns expressed in response to the question “What concerns, if any, do you have about using visualizations like you've seen here for risk communication?”

Concern	Respondents
Misleading the public by being inaccurate (no indicated valence) or overstating risk	14
Understating Risk	15
Adequately communicating the scientific basis for visualizations and providing adequate background.	15
Representational choices that alter perceptions of the visualization such as colour palette.	15
n = 87	

3.4 Labels Describing “Scientific Uncertainty”

The answer to the question “Should visualizations of storm surge distributed to the public include labels describing the scientific uncertainty of predictions? Please provide a brief explanation.” Yielded a diverse response. Of 91 responses (79 % response rate), 61 answered yes (67 % of those who answered). Six respondents suggested that representations of uncertainty should be simplified, and 14 indicated that it should not be included. The remaining ten responses discussed the issue without a clear indication of yes or no (Table 5).

Table 5: Responses to the question ““Should visualizations of storm surge distributed to the public include labels describing the scientific uncertainty of predictions? Please provide a brief explanation” categorized in yes/no terms.

Response categorized in yes/no terms	Respondents
Yes	61
Simplified	6
No	14
Answered but no clear indication of whether uncertainty should be included	10
n = 91	

In discussing uncertainty, several respondents made comments regarding the improbability of the depicted storm event; two respondents, for instance, indicated that a 1 % storm was too unlikely. Most of the comments, however, appeared to reference aleatory uncertainty (the predictability of the depicted event), and fifteen respondents explicitly distinguished aleatory uncertainty from epistemic uncertainty; for instance, suggesting that uncertainty regarding models be excluded. One respondent referenced compounding uncertainties. 23 respondents expressed concern for the public’s understanding of statistics and probability. 14 suggested communicating uncertainty was best done using extended background and supporting information. 13 suggested that disclosure of uncertainty was essential to establish the credibility of the visualizations.

Only one respondent suggested that including uncertainty would undermine efficacy. Respondents expressed other concerns in the response blank. For instance, six respondents expressed concern that the visualizations could cause panic, cause people to have misplaced feelings of safety, or be misused. Concerns related to the expression of uncertainty are summarized in Table 6.

Table 6: Summary of concerns expressed in response to the question "Should visualizations of storm surge distributed to the public include labels describing the scientific uncertainty of predictions? Please provide a brief explanation."

Coded category	Responses
Concern for public understanding of statistics and probability.	23
Inclusion of scientific uncertainty (confidence).	15
Provide extended background and supporting information.	14
Disclosure of uncertainty is essential for the credibility of the visualizations.	13
n = 69	

3.4 Effects of Familiarity

There was a correlation between concerns that risks could be understated and those persons who reported working with or near the science and visualization team. Conversely, persons who had seen the visualizations but not otherwise engaged with the team or trainings using the visualizations were concerned about overstatement. Whether this is a result of familiarity with the data or investment in the process of creating it cannot be determined. Other considerations, such as political leaning, gender, experience with storm surge and type of expertise were examined with no clear correlations explaining this difference.

There was a strong correlation between persons who were familiar with the work and an indication of the need to communicate uncertainty. Although it would seem logical that there might be other correlations in the data, few if any other strong signals emerged across types of expertise.

4 Discussion

4.1 Use of 3D Visualizations for Risk Communication

Conventional 2D Visualizations of storm surge and sea level rise are among the most common visualizations of climate related hazards, and clear guidance has emerged for their use. The overwhelmingly positive response to the question "Are visualizations such as the ones you've just seen appropriate tools for risk communication?" would seem to contradict this guidance in the literature favoring 2D, rather than 3D, representations (KOSTELNICK et al. 2013). This guidance, however, partly stems from a lack of experimental testing to account for effects of 3D visualization on risk perception. Use of 3D visualizations is discouraged, in part, because we do not fully understand their effects on audience perceptions of risk (BOSTROM et al. 2008, SHEPPARD & CIZEK 2009, KOSTELNICK et al. 2013).

Responses to this survey indicate that expert respondents are aware of the pitfalls and limitations of these visualizations elaborated by frameworks but see a role for 3D visualizations providing that adequate qualification is provided. Issues of numeracy, concerns about perceived overstatement or understatement of risk, all align with factors referenced in exiting frameworks (KOSTELNICK et al. 2013). Respondents are also aware that visualizations might backfire and make people feel safer because they only show effects in flooded areas. This aligns with findings elsewhere in the literature and speaks to the limitations of localized flood visualizations during multi-hazard events (MILDENBERGER et al. 2019, SCHULDT et al. 2018, RETCHLESS 2018).

Respondents envision visualizations like those being tested as being used with contextual information that elaborates a breadth of information that spans from the technical underpinnings of the visualizations to tangible examples of the damages symbolized. This makes the visualizations part of a larger information portfolio that approximates the effects attributed to participatory processes. This tracks closely with our findings that suggest audiences perceive 3D landscape visualizations as “scientific” products based on the presence of appropriate attribution, labeling, and background (STEMPEL & BECKER 2021).

4.2 Familiarity

Experts unfamiliar with the visualizations or team were concerned about overstatement of risks and those more familiar with the visualizations or participated in the team were concerned about understatement. This suggests that there may be a relationship between the proximity of an expert to a process and perceptions of scenarios. We can speculate, for instance, that those familiar with the place feel more urgency in communicating risks based on their experience or investment in the process (or place), but it is impossible to know from the data collected why this was observed. It is the mirror of known heuristic of risk perception, “local optimism bias” that describes how those closest to a risk are most likely to discount it (RETCHLESS 2018). Could it be that local experts feel increased urgency to communicate risk in situations where audiences discount it? This warrants investigation.

It is also notable that those same familiar experts were also most concerned with the communication of uncertainty—likely reflecting intimate knowledge of the models and their limitations and the need for qualification to prevent audiences from being misled. This also supports the use of labeling, background, and supporting material to ensure transparency, mitigate bias, and foster perceptions of legitimacy as previously discussed, and found in our other research (STEMPEL & BECKER 2021). Where preferences were expressed, they supported visualizations that most closely followed conventions, with clearly binned outcomes and the most legible color ramps, further reinforcing the application of conventions and standards familiar to experts and audiences alike.

5 Conclusion

Comments such as “It helps to know the area being shown to really understand the effect”, reflects experts’ perception of the unique capacity of these localized visualizations to orient audiences and communicate impacts. The insight expressed by one respondent that the visualizations were not necessarily communicating risk also draws attention to the extent to which the visualizations emphasize the depiction or indication of impacts in context. This, taken with the discussion suggests to us that it may be possible to realize these benefits and clarify usage of 3D visualizations for hazard and risk communication by appropriately qualifying them as visualizations of impacts. Flood visualizations are among the most common climate visualizations in use, and audiences are accustomed to seeing them. We conclude that experts are comfortable with using these visualizations providing that recognizable conventions of flood visualization are applied, and sufficient context is provided. More testing is required to determine what, if any differences exist between perceptions of 2D and 3D visualizations and to address the lack of knowledge that have led experts in risk communication to discourage their use. Pursuing this is the next step to refining guidance.

References

BEVEN, K., LAMB, R., LEEDAL, D. & HUNTER, N. (2015) Communicating uncertainty in flood inundation mapping: a case study. International Journal of River Basin Management, 13, 285-295, doi:10.1080/15715124.2014.917318.

BOSTROM, A., ANSELIN, L. & FARRIS, J. (2008), Visualizing seismic risk and uncertainty. Annals of the New York Academy of Sciences, 1128, 29-40,doi:10.1196/annals.1399.005.

COULBOURNE, B., HEADEN, F. L., JONES, C., KENNEDY, A., PAGANO, M., RAMANATHAN, K., ROGERS, S., SOUCY, J. & YOUNG, J. (2015), North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk; Physical Damage Function Summary Report. United States Army Corps of Engineers. https://www.nad.usace.army.mil/CompStudy/ (10.03.2023)

DEITRICK, S. & EDSALL, R. (2009), Mediated Knowledge and Uncertain Science: Maps in Communicating Climate Change in Mass Media. 24th International Cartographic Conference, November 15-21, Santiago, Chile.

KOSTELNICK, J. C., MCDERMOTT, D., ROWLEY, R. J. & BUNNYFIELD, N. (2013), A cartographic framework for visualizing risk. Cartographica: The International Journal for Geographic Information and Geovisualization, 48, 200-224. doi:10.3138/carto.48.3.1531.

MERZ, B. & THIEKEN, A. H. (2009), Flood risk curves and uncertainty bounds. Natural Hazards, 51, 437-458. doi:10.1007/s11069-009-9452-6.

MILDENBERGER, M., LUBELL, M. & HUMMEL, M. (2019), Personalized risk messaging can reduce climate concerns. Global Environmental Change, 55, 15-24. doi:10.1016/j.gloenvcha.2019.01.002.

PADILLA, L., KAY, M. & HULLMAN, J. (2020), Uncertainty visualization. doi:10.31234/osf.io/ebd6.

RETCHLESS, D. P. (2018), Understanding Local Sea Level Rise Risk Perceptions and the Power of Maps to Change Them: The Effects of Distance and Doubt. Environment and Behavior, 50, 483-511. doi:10.1177/0013916517709043.

ROMERO, R. & EMANUEL, K. (2017), Climate Change and Hurricane-Like Extratropical Cyclones: Projections for North Atlantic Polar Lows and Medicanes Based on CMIP5 Models. Journal of Climate, 30, 279-299. doi:10.1175/jcli-d-16-0255.1.

RUCKERT, K. L., SRIKRISHNAN, V. & KELLER, K. (2019), Characterizing the deep uncertainties surrounding coastal flood hazard projections: A case study for Norfolk, VA. Scientific Reports, 9. doi:10.1038/s41598-019-47587-6.

SCHULDT, J. P., RICKARD, L. N. & YANG, Z. J. (2018), Does reduced psychological distance increase climate engagement? On the limits of localizing climate change. Journal of Environmental Psychology, 55, 147-153. doi:10.1016/j.jenvp.2018.02.001.

SEIPEL, S. & LIM, N. J. (2017), Color map design for visualization in flood risk assessment. International Journal of Geographical Information Science, 31, 2286-2309. doi:10.1080/13658816.2017.1349318.

SHEPPARD, S. R. (2012), Visualizing climate change: a guide to visual communication of climate change and developing local solutions, Abingdon Oxon, UK, Routledge.

SHEPPARD, S. R. & CIZEK, P. (2009), The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation. Journal of environmental management, 90, 2102-2117, doi:10.1016/j.jenvman.2007.09.012.

SPAULDING, M. L., GRILLI, A., DAMON, C., CREAN, T., FUGATE, G., OAKLEY, B. & STEMPEL, P. (2016), STORMTOOLS: Coastal Environmental Risk Index (CERI). Journal of Marine Science and Engineering, 4, 54, doi:10.3390/jmse4030054.

SPAULDING, M. L., GRILLI, A., DAMON, C., MCKENNA, B., CHRISTENSEN, M., VINHATEIRO, N., BOYD, J. & FUGATE, G. (2020), STORMTOOLS, Coastal Environmental Risk Index (CERI) Risk and Damage Assessment App. Journal of Marine Science and Engineering, 8, 129, doi:10.3390/jmse8020129.

STEMPEL, P. & BECKER, A. (2019), Visualizations Out of Context: Addressing Pitfalls of Real-Time Realistic Hazard Visualizations. ISPRS International Journal of Geo-Information, 8, 318. doi:10.3390/ijgi8080318.

STEMPEL, P., GINIS, I., ULLMAN, D., BECKER, A. & WITKOP, R. (2018), Real-Time Chronological Hazard Impact Modeling. Journal of Marine Science and Engineering, 6, 134. doi:10.3390/jmse6040134.

STEMPEL, P. J. & BECKER, A. (2021), Is It Scientific? Viewer Perceptions of Storm Surge Visualizations. Cartographica: The International Journal for Geographic Information and Geovisualization, 56, 120-136. Doi:10.3138/cart-2020-0004.

THOMAS, D. R. (2006), A general inductive approach for analyzing qualitative evaluation data. American journal of evaluation, 27, 237-246, doi:10.1177/1098214005283748

TRENBERTH, K. (2011), Changes in precipitation with climate change. Climate Research, 47, 123-138. doi:10.3354/cr00953.

TRENBERTH, K. E., CHENG, L., JACOBS, P., ZHANG, Y. & FASULLO, J. (2018), Hurricane Harvey links to Ocean Heat Content and Climate Change Adaptation. Earth's Future. https://doi.org/10.1029/2018ef000825.

WALSH, L. & WALKER, K. C. (2016), Perspectives on Uncertainty for Technical Communication Scholars. Technical Communication Quarterly, 25, 71-86. doi:10.1080/10572252.2016.1150517.