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Is It Scientific? Viewer Perceptions of Storm Surge Visualizations

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Is it scientific? Perceptions of hybrid Landscape-Data-Visualizations of storm surge.

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Abstract

Scientists and coastal and risk managers are using semi-realistic visualizations of storm-surge connected to hydrodynamic models. These visualizations may make depictions of forecast impacts more engaging and accessible. However, they do not fit within established frameworks for visualizing risk because they add representational detail that exceeds current guidance. This study explores how audiences regard these visualizations in relationship to perceived representational norms. Survey respondents were asked about characteristics that make a representation "scientific." Results suggest that audiences may perceive semi-realistic visualizations of real places as scientific providing some conventions are met. It demonstrates that the persons and institutions behind the visualization may influence perceptions of legitimacy more than the style of the visualization. Although this opens new representational possibilities, it also may increase the potential of visualizations to be misleading and may foster perceptions that scientists are engaged in advocacy.

Keywords

storm surge; visualization; risk communication; visual rhetoric; argumentation; data visualization

1.0 Introduction

Coastal communities are subject to increasing but uncertain risks from storm surge, wind and precipitation (Romero and Emanuel 2017; Rosowsky 2018; Woodruff et al. 2013). Emergency managers and risk communicators fear that people underestimate these hazards. (Bostrom et al. 2018; Morrow et al. 2015). Although current emphasis is placed on map based representations created with Geographic Information Systems (GIS) (NOAA 2013), scientists and researchers are developing novel visualization technologies to better communicate risks to policy makers and the public (Fenech et al. 2017; Spaulding et al. 2016).

This paper considers one such approach, model-driven semi-realistic 3D visualizations of recognizable places (Figure 1). These visualizations combine aspects of Landscape Visualization and Data Visualization. Landscape Visualization "represents actual places and on-the-ground conditions in 3D perspective views, often with fairly high realism" (Sheppard and Salter 2004). Data visualization is concerned with "the representation and presentation of data to facilitate understanding." (Kirk 2016). Although this definition of data visualization does not directly exclude the notion of representing landscapes, norms of data visualization exhibit a preference for emphasizing essential aspects of the data (e.g., Harold et al. 2016; Tufte and Weise Moeller 1997). The level of detail and scenography included in many landscape visualizations contradicts this norm. We thus define these visualizations as a hybrid for purposes of exploration and discussion.

Landscape Data Visualizations (LDVs) are here defined as: realistic and semi-realistic 3D visualizations of real places distinguished by their integration of numerical models (e.g., ADvanced CIRCulation model) and 3D visualization platforms (e.g., game engines, custom software) that make visualization outcomes a direct product of underlying modelling, such as the implementation of fragility curves and damage functions (e.g., Spaulding et al. 2016). Some Landscape Data Visualizations have the capacity to display results from forecast models in near real-time, and real-time use is being considered (Stempel et al. 2018).

Development and use of LDVs by ocean scientists and planners coincides with a broader recognition that visualizations in multiple arenas (e.g., species diversity) are playing increasingly important role in communicating between scientists, policymakers and the public (McInerny et al. 2014). Guidance for such visualizations (e.g., McInerny et. al. 2014, Harold et. al., 2016) rejects presumptions that scientific graphics are necessarily plain, unadorned or inscrutable, but maintains a preference for emphasizing essential aspects of the underlying data and avoiding extraneous stylistic elements that may distract or obscure underlying meanings (Smallman and John 2005). The boundary of when a visualization is a product of science or a product of art or journalism, however, is not explicit.

LDVs arguably seek to leverage a more dramatic rhetorical style while maintaining claims of legitimacy that stem from their basis scientific and technical processes. Although experts tend to overestimate the role of simulations or technical processes in evaluations of legitimacy (Fogg and Tseng 1999), the explicit (as opposed to tacit) use of persuasive imagery directly challenges norms that favor essential rhetorical styles and presumptions on the part of some experts and audiences that scientific graphics are somehow devoid of argumentation (Muehlenhaus 2012; Walsh 2014).

LDVs of storm surge thus form a potent case to explore the perceived boundaries of representational norms because they obviously do not fit within accepted paradigms for risk communication or scientific data visualization. This research thus uses these visualizations as a basis to explore characteristics that contribute to whether a visualization is perceived as being "scientific". Respondents to an online survey evaluating semi-realistic visualizations (n-=735) were asked:

"What characteristics make a graphic or visualization scientific?".

Although the question can hypothetically stand on its own and be asked in the abstract, responses are grounded in the context of the survey and the nature of visualizations being tested therein. They thus provide insight into the ways in which audiences evaluate LDVs, providing a starting point for further research into the use of these visualizations for risk communication.

1.1 Paradigms for using semi-realistic visualizations

Semi-realistic visualizations of storm surge (even without the model driven component) intended for direct use with the public currently fall into a neither-world outside of both disciplinary frameworks (e.g., cartographic frameworks for visualizing risk such as Kostelnick et. al., 2013), and transdisciplinary paradigms that use combined models and visualizations in climate communication or landscape and urban planning (e.g., Schroth, Pond, & Sheppard 2011).

As it pertains to risk communication frameworks, there are acknowledged research gaps as to how realistic visualizations of probabilistic risk are perceived (Bostrom et al. 2008). The use of realism (or even 3D graphics) for risk communication is thus discouraged because detailed realistic imagery may increase affective (instantaneous, subconscious, emotional) responses that are difficult to account for (Bostrom et al. 2008; Kostelnick et al. 2013). Although more recent research suggests that the effects of dual-process theory (distinct affective and cognitive pathways) may be overstated (Kahan 2012), the crystalizing effects of detailed imagery and the possibility that graphic features distract from meaning persist. Detailed imagery overstates the resolution of the underlying data and makes outcomes appear more certain than they are (Kostelnick et al. 2013). This creates the impression that there is greater knowledge than exists. Moreover, the use of realism and other dramatic elements can distract from the intended meaning of the communication (Smallman and John 2005).

The case for using visualizations with varying degrees of realism to communicate risks has largely been made in the context of landscape and urban planning and climate communication (Sheppard 2005). Realistic visualizations of future climate impacts such as sea level rise have a unique capacity to engage the public by contextualizing information in immediately recognizable and relatable contexts (Sheppard 2015; Sheppard et al. 2008). Depictions of recognizable contexts may further stimulate feelings of place attachment and *potentially* increase risk perception (Sheppard 2005). The question of how one appropriately calibrates these visualizations such that they are perceived by the viewer as being salient, credible, and legitimate has lead researchers to emphasize reflexive processes in which the audience assists in shaping the physical and temporal scope of what is visualized (Schroth et al. 2011; White et al. 2010). This may include providing inputs to predictive models, such as data derived from expert stakeholders (Schroth et al. 2011). For instance, impact visualizations that incorporate qualitative data from emergency managers (e.g. Witkop et al. In Press) , or data for hydrological models (e.g. White et al. 2010).

Although these practices are highly evolved (Sheppard et al. 2013), they primarily address limited audiences such as persons involved in local visioning workshops (e.g., Becker 2017). As previously discussed, the question of how uninitiated audiences perceive these visualizations (e.g., effects on risk perception, perceived legitimacy) outside of managed processes is largely unanswered (Edsall and Deitrick 2009). Moreover, research addressing graphics and visualizations used in risk communication suggests proponents of using semi-realistic visualizations should be concerned with how visualizations may be dislocated in time as they are shared, decontextualized, and recast for other purposes such as political advocacy. (Bica et al. 2019).

1.2 Use of imagery to communicate risk

Imagery of storm impacts stimulates individual’s ability to call to mind exemplars of an event (the availability heuristic). Images of flood damages accompanying flood projections (Keller et al. 2006), or of storm surge impacts accompanying hurricane forecasts enhance risk perception (Rickard et al. 2017). For example, in a comparison of hypothetical forecast images, photographs of impacts showed the greatest effects on risk perception as compared to maps depicting inundation (Rickard et al. 2017).

It is unlikely that LDVs that include qualities of both photographs and maps operate in the same way. Photographs, despite advances in fakery, demonstrate that something exists, and have a difficult time proving something does not exist (Messaris 1994). In contrast, the notion of artifice and potential for disbelief is inherent to a visualization, and has been a long preoccupation of visualization proponents (Orland et al. 2001). The perceived status of semi-realistic visualizations, whether they are regarded as representations of underlying scientific or technical processes, is thus highly relevant to whether other benefits such as making impacts relatable in context are relevant. Research that shows a legitimacy bias favoring stripped down or unadorned visualizations as somehow being more “scientific” (e.g. Walsh 2014) reinforces the concern that there may be a ‘style penalty’ for using advanced semi-realistic visualizations.

Exploring how these visualizations are understood, and the characteristics that make a visualization appear to be “scientific” is thus highly relevant to any use of semi-realistic 3D visualizations for risk communication. To the extent that boundaries are malleable enough to admit the use of these visualizations it may be possible to realize benefits such as making impacts more relatable to local contexts and thus more salient to audiences (Lewis and Sheppard 2006). Conversely, it’s also possible that scientists and experts considering use of these visualizations are simply falling prey to a false presumption that advanced visualizations are necessarily more effective (Harold et al. 2016; Smallman and John 2005). In the worst case, well intentioned efforts to engage the public may be misleading or perceived as fear appeals and undermine credibility of scientists and planners (O'Neill and Nicholson-Cole 2009).

2.0 Methods

The question, **“What characteristics make a graphic or visualization scientific?”**, was incorporated into a larger survey evaluating semi-realistic visualizations in order to assess how audiences perceive the status of model-driven semi-realistic visualizations. The survey was distributed between June and August of 2017 and was open to all persons in the United States over the age of 18. The study presented minimal risk and was anonymous, and thus was granted “exempt” status by the University of Rhode Island Institutional Review Board. Participants provided online consent at the start of the survey.

The survey included two primary instruments. The first, an expert survey, was distributed to respondents using the email lists used by experts in the region such as the Rhode Island Shoreline Change Special Area Management Plan, the Department of Homeland Security Center of Excellence at the Coastal Resilience Center at the University of North Carolina, and an internal mailing list for the Rhode Island Emergency Management Agency / Federal Emergency Management Agency Integrated Emergency Management Course. The expert survey contained questions regarding the depiction of probability and the appropriateness of using visualizations for risk communication. The second, a public survey, was distributed via email and social media to explore the broader perceptions of these visualizations.

There were a total of 115 responses to the expert survey and 620 responses to the public survey instrument. 87 expert survey respondents and 362 public survey respondents answered the question: **What characteristics make a graphic or visualization scientific?"** (76% and 58% respectively). As the sample for the public responses was distributed via a shareable link, the survey sample of not statistically representative of the broader population. Moreover, the respondents to the "public" survey had disproportionately high levels of education and income, and in some cases were self-reported experts.

All surveys included three visualizations made for the Coastal and Environmental Risk Index (CERI) (Spaulding et al. 2016). These visualizations depicted three communities in coastal Southern Rhode Island USA and incorporate depictions of storm surge and of projected structural damages (Spaulding et al. 2016) (Figure 2). Damage estimates are based on functions developed by the US Army Corps of Engineers North Atlantic Coast Comprehensive Study (NACCS) (Coulbourne et al. 2015). CERI models combine models for inundation, wave, and erosion (Spaulding et al. 2016). Subsequent variations of CERI have been modified to depict wind and a more generalized quantification of risk. The expert survey included an additional visualization depicting inundation of coastal port infrastructure made for Federal Emergency Management Agency Integrated Emergency Management Training Course (Stempel et al. 2018). This visualization depicted inundation (maximum envelope of water – MEOW) only (Figure 1).

The following introductory statement was included:

> "On the next three pages, you will see visualizations that show both the extent of storm surge and the potential impact to houses in coastal Rhode Island communities. The projected surge and damage to houses are based on computer simulations that incorporate flooding, waves, and erosion. The names of the communities are omitted from the visualizations so that we can test whether they are recognizable to people who are familiar with them.
>
> Damage to structures is represented as a percent of damage to the structure between 1% and 100%. Structures that are colored red are destroyed. Structures that are colored green are not damaged by storm surge. There is also an indication of the likelihood of the depicted storm surge and damage event. In all examples used in this survey, this is a 1% chance in any single year at present sea levels. The style and position of the labels may vary slightly. Enlarged examples of the labels are shown below. When you press continue, you will be taken to the first visualization to evaluate."

The question regarding characteristics that make visualizations scientific was included in a summary page following the randomized evaluation of individual visualizations. Large numbers of responses directly referencing the visualizations confirm that the question was understood in relationship to the visualizations being tested.

Responses to the question were organized into a spreadsheet and inductively coded by the research team (Thomas 2006). This process was made more straightforward by the strength of scientific conventions of representation that clearly shaped responses. Answers often included repeated phrases such as, “citation of data and sources”. Initial groupings were based on obvious similarities, taking care to discern when the intent of a phrase was altered by other aspects of the text. From these groupings a set of four major themes was identified. 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.

3.0 Results

The hybrid nature of LDVs, having both characteristics of maps and of realistic scenography, is evident in the responses. A small number of the respondents used the term “picture”. Many answers, however, suggest that respondents place the visualizations in the category of maps and other geographic information products they are familiar with:

> “I am a commercial fisherman and rely on satellite images and have found them invaluable in my industry and in protecting my property on the coast” (author’s emphasis).

> “Whether the map is depicting possible events…..” (author’s emphasis).

One respondent was critical of the notion that these visualizations were scientific or necessary:

> “Pretty pictures belie the science beneath them; Science data traditionally is shown in a less aesthetic manner. "Being pretty" doesn't help sell the data.”

Most respondents, however, exhibited a high degree of flexibility as to the style of the visualizations presented and necessary characteristics provided that the sources of the data were appropriately cited (103 mentions), background or methods elaborated (37 mentions), and from a reputable source such as a research university, National Oceanic and Atmospheric Administration (NOAA) or National Weather Service (NWS) (47 mentions).

> “The fact that they are created by the University of Rhode Island and by qualified scientists.”

> “A clear description of the data that were used and the process followed to generate the visualization. Preferably. these visualizations would be peer reviewed and published in a scientific journal.”

> “I would want to see something from NWS/NOAH [sic] blessing the program. I'm not going to trust a graphic because of how it looks.”

> “Explanation of the data it is based on; understandable legends; university logos; references to "behind the scenes" work to create model (i.e. scientific papers).”

These responses were coded into the larger theme of **"Transparency of sources, data and methods" (181 mentions)**. Validation and integrity of the data based on replication, Quality Assurance and Quality Control, and peer review were regarded as a component of this theme (36 mentions).

> "Does the study conform to previous estimates by other organizations not associated with study creators. Do goals of the study reflect a common good or is it the insurance industry and/or government trying to influence a program. e.g. NFIP" (National Flood Insurance Program).

Historic storms were mentioned as means of validation or a basis for damage assessments (16 mentions), which is logical given the extent to which comparisons to historic events are used to evaluate model performance. **Error! Reference source not found.** presents the major themes that were identified.

The **"Ability to discern underlying data and outcomes" (74 mentions)** was regarded as a separate theme because it pertained to representation. Respondents cited the presence of labelling, legends, and use of color gradients (51 mentions), and the ability to discern quantifiable values (e.g., percent of damage) or detailed outcomes (26 mentions). The juxtaposition of specific outcomes, for instance an undamaged structure depicted next to a destroyed structure or not apparently aligned with the level of inundation) (23 mentions) was cited as making the visualizations seem less scientific (Figure 3). Those with specific experience of storm surge, however, were more likely to cite the juxtaposition positively.

> "I did not understand how houses could be green and unthreatened while they were directly next to red houses which were threatened. This made me feel the visualizations were not totally accurate."

> ". . . Inland public at large may believe storm surge hits the coast with uniform damage to all houses adjacent to body of water, unless elevation is readily apparent."

> "Is it believable - there are always survivor structures, and they appear appropriate to terrain."

> "Consistency--for example. in several of the visualizations. some of the houses in the "surge zone" or "danger zone" were shown as being likely to suffer heavy damage. while another next door to it was shown as being likely to suffer no damage at all. This does not make sense."

"Style and Quality" (87 mentions) also emerged as an important theme. Visualization style (38 mentions) included the degree of abstraction, illustrative quality, and nature of the colors chosen.

> "It's an illustration not an actual picture."

> "The color coding and graphic visualization of the potential impact with 3D structures really helps."

> "It obviously took time to make, it's not some quick journalist work. The 3D models and the continuous color scale look like there's some real work (math, computer simulation) behind this. It looked scary but didn't use flashy things to increase the "alarming" feeling."

> "Lack of superfluous anesthetics [sic]. Inclusion of topology [sic]."

Comparatively few respondents cited the visualization style with a negative valence, for instance being "too pretty" for the subject or being cartoonish:

> "The more realistic it looks the better. The second example looked too much like a cartoon." (referring to the Misquamicut visualization).

Only one respondent specifically excluded visualizations from the notion of being scientific in their response, preferring graphs and charts over visualizations:

> "Graphs, charts. and numbers with source data listed at the bottom. The visualizations and rainbow colors seem more like a computer generation from a movie."

Related to visualization style, the quality and professionalism of the visualizations was cited positively (16 mentions) as was the use of geographic information (e.g., air photos, LiDAR) and accurate depiction of geographic areas in terms of appearance of features and scale (25 mentions.

Although the survey overall reflects the high degrees of expertise present in both the expert and public cohorts, some respondents were forthright about the influence of their own personal experience, enough so that **"Personal Knowledge or experience" (40 mentions)** became the fourth and smallest theme. In a few cases this included respondents who had direct knowledge of the project or similar data (4 mentions). More frequently, however, respondents evaluated stated that their evaluation depended on whether or not is seemed believable (15 mentions), or conformed to their personal experience of the place (23 mentions).

> "My personal experiences as an aquaculturalist [sic] and living for 37 years in a house within site [sic] of a shoreline evacuated 13 times for 'hurricanes' thus witnessing first hand tidal surges. My home is also 200 years old."

> "Knowledge of damages along NJ coast for storms."

Given the level of expertise, surprisingly very few respondents mentioned the quantification or inclusion of uncertainty as being a characteristic of a visualization being scientific. (16 mentions). Moreover, there is some evidence that at least some respondents assumed analyses conducted were more complex than they were (e.g., including modelling of soil types in relationship to structural damages).

Lastly, as compared to the number of respondents who sought transparency of data and methods and the ability to decipher and engage with that data through the visualizations, comparatively few respondents cited the use of data in and of itself (16 mentions), the use of computer generated models (18 mentions), and notions of facts and objectivity (11 mentions).

The brevity of the answers associated with these mentions and other contextual information in the answers did not support development of a theme.

3.1 Limitations

The primary limitation of the findings is the disproportionately high level of education and wealth (as compared to census data) of survey respondents to the "public" survey instrument, the data gathering method for this cohort was not rigorous enough to be regarded as anything other than exploratory. Biases of wealth and expertise exist in the expert cohort; these biases accord with the nature of the group surveyed.

A subsequent survey more narrowly designed and distributed to a statistically representative sample of participants is necessary to make any inferences regarding the perceptions of the lay public. The response rates to the question also do not provide any insight as to why the question was skipped (e.g., survey fatigue, feeling the question is inappropriate). It is therefore possible that a disproportionate number of people who felt positively about the visualizations answered the question.

Despite these limitations, the survey does have a comparably high number of respondents and provides valuable insight into the attitudes of persons likely to be engaged in activities around risk communication, coastal resilience and other related topics that may employ visualizations like those tested here. It similarly provides insight into how this audience regards and evaluates such visualizations. A significant number of people who responded resided in coastal communities depicted, in total. 131 respondents reported recognizing Matunuck, RI, USA, 187 reported recognizing Charlestown, RI USA, and 168 reported recognizing Misquamicut, RI USA in the visualizations. Numerous personal testimonies are evidenced in the responses. Moreover, the extent to which the survey cohort (especially the expert cohort) is directly engaged in risk assessment and communication provides valuable insight as to how experts may perceive the use of advanced visualizations.

4.0 Discussion

Visual rhetoric such as maps all aspire to persuade even if the object of argumentation is simply the veracity of the map and the cultural context that created it (Harley 1989). Minimalist displays with spare high contrast graphics popularized in the 20th century may have aspired to universality, but are nonetheless still transformed by the skills, interests, and interpretations of diversifying audiences (Kostelnick 2008). These issues affect even the most narrowly configured representations and are here revealed by the extent to which audiences brought their own interpretation. For instance, differences in how the juxtaposition of damages was questioned by respondents to this survey demonstrate likely differences between coastal and inland residents based on their experience with storm damages. References to other maps and graphics that audiences are familiar with further remind us that these interpretations are shaped by expectations set by other graphics depicting storm surge, sea level rise, or geographic data with which the audience is familiar. Whether intended or not, these graphics set expectations and form the basis of conventions and norms (Kostelnick and Hassett 2003).

LDVs, however, likely stretch beyond these issues into territories of persuasion similar to persuasive maps—maps that have a defined persuasive purpose (Muehlenhaus 2012, 2013): in the case of LDVs, convincing coastal residents of the potential severity of damages in the context of their coastal communities. LDV's differ from many persuasive maps in that they do not use omission of data for their persuasive purposes (Muehlenhaus 2013), but rather rely on portrayal of damages in context as means to enhance risk perception. Whether this is warranted or not, largely depends on the communication objective.

This complicates the management of these graphics as compared to other graphics that are used to depict storms in real-time or near-real-time. Hurricane track diagrams, for instance, can be optimized based on cognitive factors, such as the salience of relevant information (Hegarty 2011), the "naturalness" with which graphic features are mapped to dimensions of the data (Boone et al. 2018), and the relative efficiency (e.g., ink to information ratio, Tufte and Graves-Morris 1983). These optimizations, however, are only possible where the variables and complexities are suitably controlled and use-case clear (Hegarty 2011).

Yet these restrained visualizations do not communicate the potential severity of damages. The desire to more effectively communicate damages has led researchers to explore the effects of supplemental imagery on risk perception (e.g.,Keller et al. 2006; Rickard et al. 2017). LDVs potentially used in real-time arguably combine the role of forecasting tools with supplemental imagery. The use of LDVs thus strains the conceit of limiting persuasion to effective communication of data that governs more typical risk communication tools.

It is arguably the use of persuasion (e.g., promoting behavior change, Sheppard 2005) related to climate change that lead to evolving paradigms for visualization use in landscape and urban planning and climate communication. The term "permissible drama", for instance, was used to address the extent to which landscape visualizations incorporated some degree of speculation and dramatization (Sheppard 2001; Sheppard et al. 2008). The uncertainty of future conditions (Sheppard et al. 2008) and potential bias of experts (MacFarlane et al. 2005), however, ultimately lead practitioners to increasingly emphasize skilled local visualizers such as landscape architects who also served to relate science to the cultural context (Sheppard 2015). This conforms to the larger drive in the context of climate communication to engage in co-creation of outputs by communities and experts (Moser 2016).

The integration of model and visualization in LDVs attenuates these practices that evolved to support the use of landscape visualizations. Even if the initial programming of these systems is onerous, the development and use of these systems foreshadows more direct access to increasingly dramatic forms of persuasive visual rhetoric by scientists.

This research into how these visualizations are perceived by audiences makes several things clear.

1. **The style of a visualization is less important than the people that stand behind it.** Audiences seem willing to accept LDVs as being "scientific" (or representations of science) providing that certain conventions are adhered to such as transparency of data and sources, and that those sources are reputable. Scientists who employ LDVs as tools

to communicate their work should thus not presume that the visualization will be regarded differently than other maps or representations they stand behind. Moreover, in media situations where visualizations are available, they are likely to become the emblems of any project. For instance, newspaper coverage of the Coastal Environmental Risk Index emphasized the most extreme and dramatic visualizations made available (e.g.,Kuffner 2016). This emphasis of the dramatic not only risks demotivating audiences, it likely undermines the credibility of the team (O'Neill and Nicholson-Cole 2009).

2. **Realism and 3D are not equivalent.** The distorting effects of realism are not unique to 3D representations, and have been observed in 2D representations (e.g., using air photos)(Zanola et al. 2009). It’s notable that one respondent stated “the fewer graphic 'enhancements' applied. the more scientific it appears (no animated waves, etc.)” (Several semi-realistic systems use animated water surfaces). This comment had less to do with three dimensionality or perspective than the type of 2D texturing strategy used. Moreover, audiences are sensitive to seemingly minor graphic differences of style or coloration in LDVs that are categorically similar in terms of being perspectival and 3D. Colors in some cases were perceived as appropriate, in others cartoonish. This suggests that three-dimensionality in the landscape may be less important than other graphic treatments.
3. **Overstatement**. As has been elsewhere observed, sophistication was associated with professionalism and legitimacy (Kostelnick 2008). Some audience members presumed the underlying models were more sophisticated than they were. One respondent, for instance, presumed that structural damage models accounted for the soil type in calculating damages (damages were calculated with fragility curves based on type of construction), and erosion calculations were based on projected shoreline change (Spaulding et al. 2016). This suggests that some criticisms of realistic 3D visualizations (e.g., Kostelnick et al. 2013) are well placed but likely applicable to other sophisticated visual rhetoric or 2D visualizations.

Although these observations would seem to disqualify these visualizations from certain uses, they are also indicative of the limitations of categorical distinctions and the need to re-think how we organize the discussion of visualizations more generally. The ability to orient audiences and persuade them to evacuate, for instance, may be aided by the judicious use of 3D landscapes and landmarks that make the potential extent of a hazard less abstract. As it pertains to geographic contexts there may be a very good argument for inclusion of realistic 3D elements to contextualize data. The extent to which these features make information engaging and salient do not necessarily contradict guidance for more restrained, cognitively justified visualizations (e.g., Hegarty 2011).

In the preceding example, however, the level of detail included in some of the visualizations tested here (e.g., damage calculations), is irrelevant to this purpose. One respondent made exactly this point regarding the elaborate nature of the modeling shown. Showing high levels of detail or complex outcomes may be secondary to displaying a generalized indication of the hazard in a recognizable context. Moreover, providing indication of wind or other hazard may be equally important so as not to understate risks faced in adjacent areas. If the real-time capabilities of LDVs are to be relevant, these use-cases should be identified in advance and appropriate design processes initiated to shape the visualizations.

Those processes will result in a different set of 3D depictions than those used in this study. The visualizations tested here conform more closely to the parameters of visualizations used in Disaster Risk Reduction or climate adaptation processes, for which guidance has been established (e.g., Schroth et. al. 2011), and the rapid real-time aspects are irrelevant. LDVs in this context are likely effective. For instance, the extent to which juxtaposition of outcomes was associated with both increases and decreases in perceived credibility of modelled outcomes suggests the discernible model details fostered engagement. Had these visualizations been coupled with more in-depth explanations of the effects of building elevation (as they would be in a DRR or climate communication process), they could leverage this curiosity regarding unexpected effects into an educational opportunity (Kahan et al. 2017). The challenge then becomes to convince ocean scientists and persons who are not DRR or Climate Communication practitioners to employ climate communication practices (Moser 2016).

One logical conclusion of these critiques is that the capacity to produce LDVs is a technology in search of a purpose; like other preceding visualization advancements, the development of the technology has likely outpaced our understanding of its best use (Lovett et al. 2015; Sheppard and Cizek 2009). The logic of this conclusion, however, is subject to changing expectations and evolving norms. It’s reasonable to speculate that the elasticity of norms observed in this study reflects the robustness of scientific conventions and the familiarity of the respondents with those conventions (Kostelnick and Hassett 2003). However, the apparent acceptability of LDVs within these conventions may also reflect the evolution of norms based on the increasing use of advanced visualizations across the breadth of the sciences. Scientists, planners, and policy makers are shaping audiences (Kostelnick and Hassett 2003).

5.0 Conclusion

This research suggests that the boundaries of what is perceived to be scientific are malleable, providing certain conventions for disclosure and transparency are met. These shifting boundaries are indicative of the larger set of value judgements that scientists and consumers of scientific graphics make every day (Walsh 2017). LDVs surface these judgements because they include elements such as light and shadow and perspective that are clearly extraneous to the underlying data but may nonetheless contribute to the ergonomics of the presentation and the impression it creates. This forefronts a range of decisions, color choice, emphasis, that can make even the simplest presentation of data into a dramatic and iconic image (Schneider 2016). It is therefore understandable that the use of semi-realistic visualizations would be roundly discouraged in the context of existing frameworks for risk communication.

As it pertains to the presentation of data that is spatially relevant to specific audiences, however, there is an at least reasonable case for the consideration of perspectival presentations and inclusion of recognizable landmarks that make outcomes less abstract (Lewis and Sheppard 2006). These uses, however, require new and more careful designs. Use-cases such as communicating the effects of building elevation where these visualizations may be highly effective are possible within existing paradigms of climate communication.

Further research is necessary on three counts.

1. A visualization that a scientist may perceive as being accessory, or ‘just an illustration’ may be nonetheless be perceived as the primary means of interface by audiences. A more refined version of this research question should be repeated with a statistically representative sample to determine whether the elasticity observed in this exploratory research is confined to highly educated expert audiences, or if it is more widespread.
2. The role of visualizations should be clarified with the scientists seeking to use them such that the precise use case can be tested. This begins by surveying those that would seek to use visualizations and determining their specific objectives, and similarly requires surveying or querying intended audiences such that visualizations can be developed not based on the emergence of the technology but based on the purposes set forth and needs of the intended audience. The use of 3D representations of recognizable places may be suited to some use cases.
3. Categorical distinctions that place realistic and semi-realistic visualizations apart from other sophisticated visualizations or 2D visualizations employing realism likely create false distinctions. Highly diagrammatic 3D visualizations, for instance, may have more in common with 2D data visualizations than is currently acknowledged by the ways in which visualizations are categorized. More testing with real audiences is thus warranted.

The development of semi-realistic and realistic visualizations in real-time connection with storm models follows a larger pattern of technology driving representational decisions (Lovett et al. 2015; Sheppard and Cizek 2009). The desire to use the best and most advanced tools, even before the evidence exists to support their use, is understandable given the desire of many scientists to connect to audiences. Doing this blindly, however, risks distracting or misleading the public. The extent to which reputation is a factor in assessments should give scientists pause, lest they undermine their own credibility (O'Neill and Nicholson-Cole 2009). This study is a modest step to inverting the technology first paradigm and better directing the development of these visualizations.

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References

Becker, A., 2017: Using boundary objects to stimulate transformational thinking: storm resilience for the Port of Providence, Rhode Island (USA). *Sustainability Science*, **12,** 477-501.

Bica, M., J. L. Demuth, J. Dykes, and L. Palen, 2019: Communicating Hurricane Risks: Multi-Method Examination of Risk Imagery Diffusion. *Manuscript submitted for publication*.

Boone, A. P., P. Gunalp, and M. Hegarty, 2018: Explicit versus actionable knowledge: The influence of explaining graphical conventions on interpretation of hurricane forecast visualizations. *Journal of experimental psychology: applied*, **24,** 275.

Bostrom, A., L. Anselin, and J. Farris, 2008: Visualizing seismic risk and uncertainty. *Annals of the New York Academy of Sciences*, **1128,** 29-40.

Bostrom, A., R. Morss, J. K. Lazo, J. Demuth, and H. Lazrus, 2018: Eyeing the storm: How residents of coastal Florida see hurricane forecasts and warnings. *International Journal of Disaster Risk Reduction*, **30,** 105-119.

Coulbourne, B., and Coauthors, 2015: North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk; Physical Damage Function Summary Report.

Edsall, R. M., and S. Deitrick, 2009: Case Studies Demonstrating the Utility of Unconventional Designs for Geographic Problem-Solving. *Proceedings of the 24th International Cartographic Congress*.

Fenech, A., A. Chen, A. Clark, and N. Hedley, 2017: Building an adaptation tool for visualizing the coastal impacts of climate change on Prince Edward Island, Canada. *Climate change adaptation in North America*, Springer, 225-238.

Fogg, B., and H. Tseng, 1999: The elements of computer credibility. *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, ACM, 80-87, doi 10.1145/302979.303001.

Harley, J. B., 1989: Deconstructing the map. *Cartographica: The international journal for geographic information and geovisualization*, **26,** 1-20.

Harold, J., I. Lorenzoni, T. F. Shipley, and K. R. Coventry, 2016: Cognitive and psychological science insights to improve climate change data visualization. *Nature Climate Change*, **6,** 1080.

Hegarty, M., 2011: The Cognitive Science of Visual-Spatial Displays: Implications for Design. *Topics in Cognitive Science*, **3,** 446-474.

Kahan, D. M., 2012: Ideology, motivated reasoning, and cognitive reflection: An experimental study. *SSRN Electronic Journal*.

Kahan, D. M., A. Landrum, K. Carpenter, L. Helft, and K. Hall Jamieson, 2017: Science curiosity and political information processing. *Political Psychology*, **38,** 179-199.

Keller, C., M. Siegrist, and H. Gutscher, 2006: The role of the affect and availability heuristics in risk communication. *Risk analysis*, **26,** 631-639.

Kirk, A., 2016: *Data Visualization, A Handbook for Data Driven Design.* Sage.

Kostelnick, C., 2008: The visual rhetoric of data displays: The conundrum of clarity. *IEEE Transactions on Professional Communication*, **51,** 116-130.

Kostelnick, C., and M. Hassett, 2003: *Shaping information: The rhetoric of visual conventions.* SIU Press.

Kostelnick, J. C., D. McDermott, R. J. Rowley, and N. Bunnyfield, 2013: A cartographic framework for visualizing risk. *Cartographica: The International Journal for Geographic Information and Geovisualization*, **48,** 200-224.

Kuffner, A., 2016: Rising Seas, Rising Stakes. *Providence Journal*, Sunday ed., Gatehouse Media.

Lewis, J. L., and S. R. J. Sheppard, 2006: Culture and communication: Can landscape visualization improve forest management consultation with indigenous communities? *Landscape and Urban Planning*, **77,** 291-313.

Lovett, A., K. Appleton, B. Warren-Kretzschmar, and C. Von Haaren, 2015: Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. *Landscape and Urban Planning*, **142,** 85-94.

MacFarlane, R., H. Stagg, K. Turner, and M. Lievesley, 2005: Peering through the smoke? Tensions in landscape visualisation. *Computers, Environment and Urban Systems*, **29,** 341-359.

McInerny, G. J., and Coauthors, 2014: Information visualisation for science and policy: engaging users and avoiding bias. *Trends in ecology & evolution*, **29,** 148-157.

Messaris, P., 1994: *Visual" literacy": Image, mind, and reality.* Westview Press.

Morrow, B. H., J. K. Lazo, J. Rhome, and J. Feyen, 2015: Improving storm surge risk communication: Stakeholder perspectives. *Bulletin of the American Meteorological Society*, **96,** 35-48.

Moser, S. C., 2016: Reflections on climate change communication research and practice in the second decade of the 21st century: what more is there to say? *Wiley Interdisciplinary Reviews: Climate Change*, **7,** 345-369.

Muehlenhaus, I., 2012: If looks could kill: The impact of different rhetorical styles on persuasive geocommunication. *The Cartographic Journal*, **49,** 361-375.

——, 2013: The design and composition of persuasive maps. *Cartography and Geographic Information Science*, **40,** 401-414.

NOAA, 2013: Hurricane/Post-Tropical Cyclone Sandy, October 22–29,

2012., N. W. Service, Ed., 66.

O'Neill, S., and S. Nicholson-Cole, 2009: "Fear Won't Do It" Promoting Positive Engagement With Climate Change Through Visual and Iconic Representations. *Science Communication*, **30,** 355-379.

Orland, B., K. Budthimedhee, and J. Uusitalo, 2001: Considering virtual worlds as representations of landscape realities and as tools for landscape planning. *Landscape and urban planning*, **54,** 139-148.

Rickard, L. N., J. P. Schuldt, G. M. Eosco, C. W. Scherer, and R. A. Daziano, 2017: The proof is in the picture: The influence of imagery and experience in perceptions of hurricane messaging. *Weather, climate, and society*, **9,** 471-485.

Romero, R., and K. Emanuel, 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.

Rosowsky, D. V., 2018: Assessing Climate Change Impacts on Hurricane Hazards. *Climate Change and Its Impacts*, Springer, 93-107.

Schneider, B., 2016: Burning worlds of cartography: a critical approach to climate cosmograms of the Anthropocene. *Geo: Geography and Environment*, **3,** e00027-n/a.

Schroth, O., E. Pond, and S. R. Sheppard, 2011: Integration of Spatial Outputs from Mathematical Models in Climate Change Visioning Tools for Community-Decision Making on the Landscape Scale. *DLA-Digital Landscape Architecture*, Dessau and Bernburg, Germany, Offenbach: Wichmann Verlag, 246-255.

Sheppard, S., and J. Salter, 2004: The role of visualization in forest planning. *Encyclopedia of Forest Sciences***,** 486-498.

Sheppard, S. R., 2001: Guidance for crystal ball gazers: developing a code of ethics for landscape visualization. *Landscape and urban planning*, **54,** 183-199.

——, 2005: Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science & Policy*, **8,** 637-654.

——, 2015: Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning*, **142,** 95-105.

Sheppard, S. R., and P. Cizek, 2009: The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation. *Journal of environmental management*, **90,** 2102-2117.

Sheppard, S. R., A. Shaw, D. Flanders, and S. Burch, 2008: Can visualization save the world? Lessons for landscape architects from visualizing local climate change. *Digital Design in Landscape Architecture*, Anhalt University of Applied Sciences, Dessau, Germany, Herbert Wichmann, 29-31.

Sheppard, S. R., A. Shaw, D. Flanders, S. Burch, and O. Schroth, 2013: Bringing Climate Change Science to the Landscape Level: Canadian Experience in Using Landscape Visualisation Within Participatory Processes for Community Planning. *Landscape Ecology for Sustainable Environment and Culture*, Springer, 121-143.

Smallman, H. S., and M. S. John, 2005: Naive Realism: Misplaced Faith in Realistic Displays. *Ergonomics in Design*, **13,** 6-13.

Spaulding, L. M., A. Grilli, C. Damon, T. Crean, G. Fugate, A. B. Oakley, and P. Stempel, 2016: STORMTOOLS: Coastal Environmental Risk Index (CERI). *Journal of Marine Science and Engineering*, **4**.

Stempel, P., I. Ginis, D. Ullman, A. Becker, and R. Witkop, 2018: Real-Time Chronological Hazard Impact Modeling. *Journal of Marine Science and Engineering*, **6,** 134.

Thomas, D. R., 2006: A general inductive approach for analyzing qualitative evaluation data. *American journal of evaluation*, **27,** 237-246.

Tufte, E. R., and P. Graves-Morris, 1983: The visual display of quantitative information.

Tufte, E. R., and E. Weise Moeller, 1997: *Visual explanations: images and quantities, evidence and narrative.* Vol. 36, Graphics Press Cheshire, CT.

Walsh, L., 2014: ‘Tricks,’Hockey Sticks, and the Myth of Natural Inscription: How the Visual Rhetoric of Climategate Conflated Climate with Character. *Image politics of climate change: Visualizations, imaginations, documentations*, B. schneider, and T. Nocke, Eds., 81-104, doi: 110.14361/transcript.9783839426104.9783839426181.

——, 2017: Visual Invention and the Composition of Scientific Research Graphics: A Topological Approach. *Written Communication*, 0741088317735837.

White, D. D., A. Wutich, K. L. Larson, P. Gober, T. Lant, and C. Senneville, 2010: Credibility, salience, and legitimacy of boundary objects: water managers' assessment of a simulation model in an immersive decision theater. *Science and Public Policy*, **37,** 219-232.

Witkop, R., P. Stempel, and A. Becker, In Press: Incorporating critical facility managers' knowledge into hazard impact models: A case study of Westerly, Rhode Island. *Frontiers in Citizen Science: Reducing Risk and Building Resilience to Natural Hazards.*

Woodruff, J. D., J. L. Irish, and S. J. Camargo, 2013: Coastal flooding by tropical cyclones and sea-level rise. *Nature*, **504,** 44-52.

Zanola, S., S. I. Fabrikant, and Çöltekin, 2009: The effect of realism on the confidence in spatial data quality in stereoscopic 3D displays. *24th international cartography conference*, Santiago, Chile, 15-21.

Tables

Table 1, themes identified in response to: What characteristics make a graphic or visualization scientific?

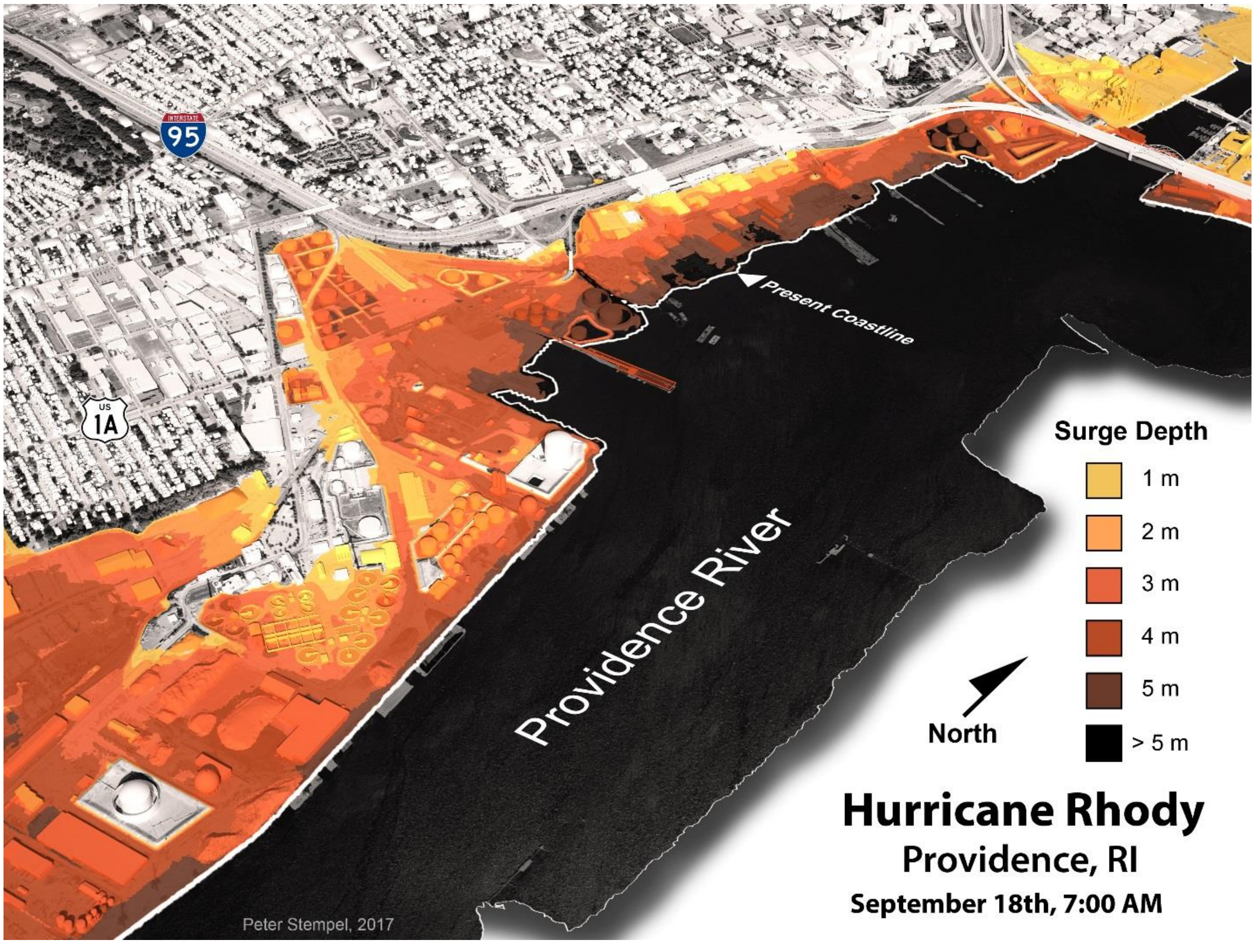
Theme	**Total**
Transparency of sources, data and methods.	181
Ability to discern underlying data and outcomes.	74
Style and quality.	87
Personal knowledge or experience.	40

Figure Captions

Figure 1, a model driven, semi-realistic depiction of the Port of Providence during an extreme hurricane event. Image: Authors

Figure 2, four visualizations that were developed by the author and used in the survey. Clockwise from lower left: Misquamicut, Westerly, RI USA, Matunuck, South Kingston, RI USA, Charlestown, RI USA, and Providence, RI USA. The Providence visualization was only included in the expert survey. Each visualization exhibited different stylistic characteristics such as the distance at which the view was framed, and the color schema used.

Figure 3, respondents raised questions regarding apparent discrepancies in damage between adjacent structures in this visualization of Matunuck, Rhode Island, USA. Image: Authors.



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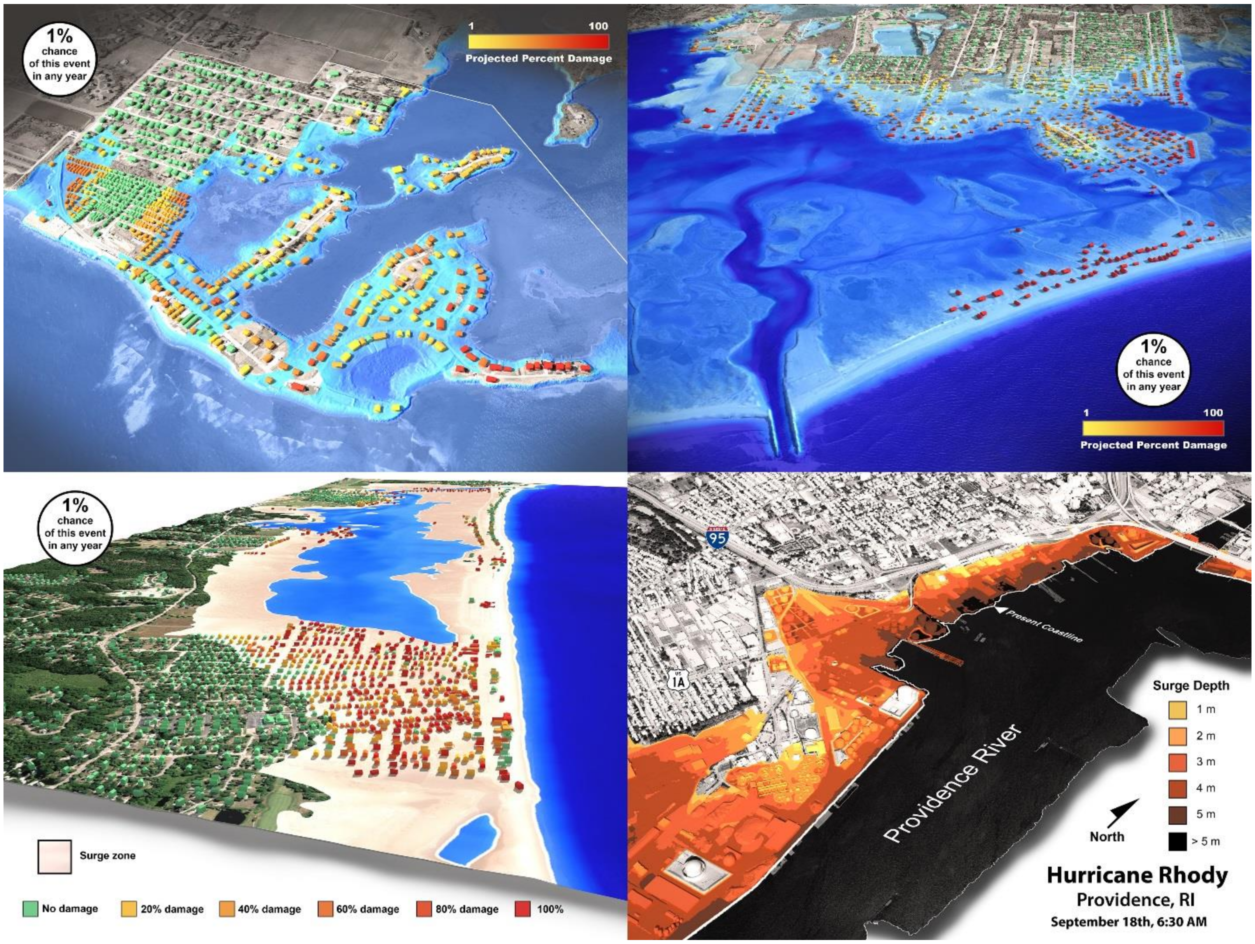

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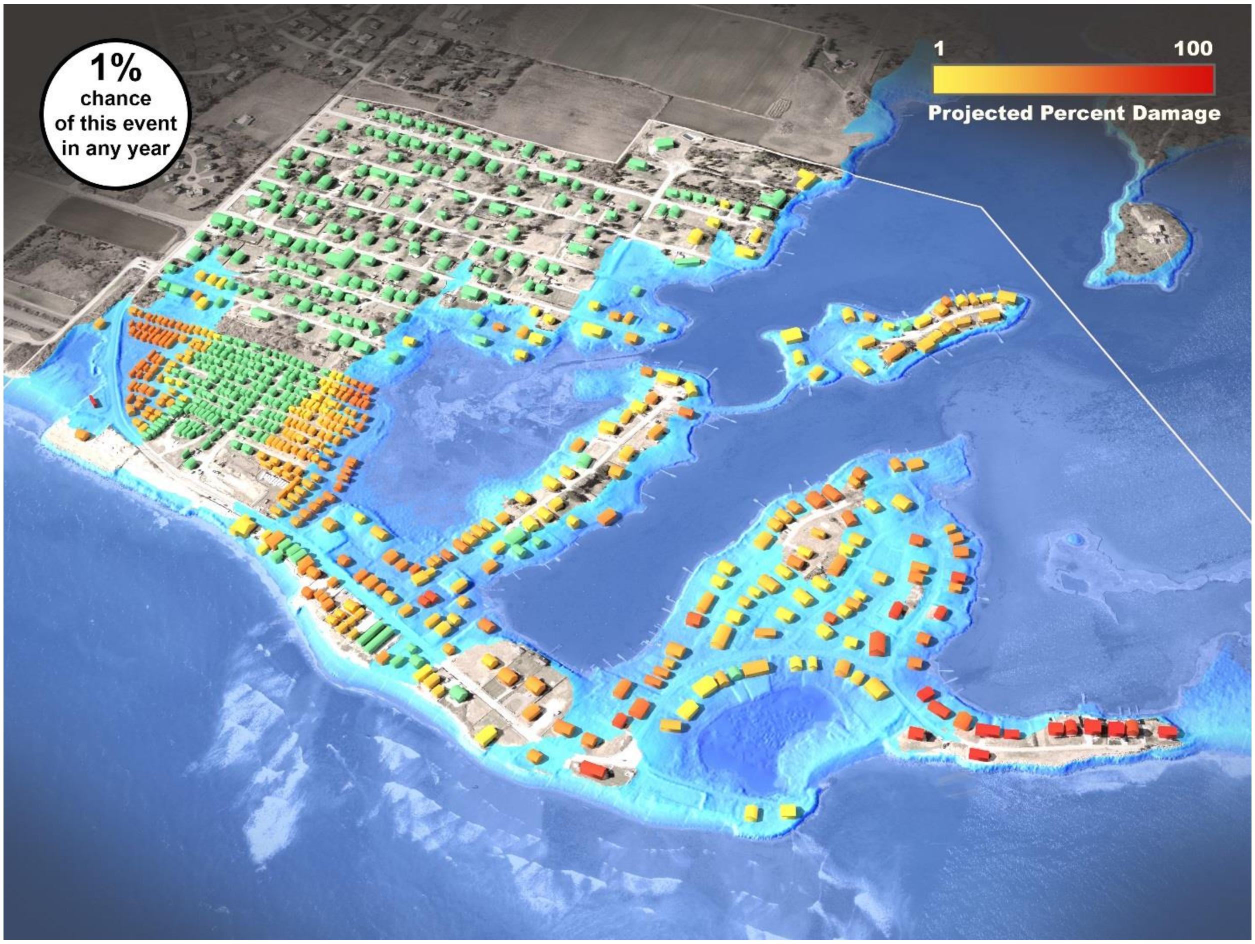

Figure 3, respondents raised questions regarding apparent discrepancies in damage between adjacent structures in this visualization of Matunuck, Rhode Island, USA. Image: Authors.