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DEPICTING THE CONSEQUENCES OF STORM SURGE RISK COMMUNICATION OPPORTUNITIES AND ETHICS

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DEPICTING THE CONSEQUENCES OF STORM SURGE

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ABSTRACT

To better communicate the risks of storm surge, scientists and engineers are employing novel 3d visualizations. In many cases, these visualizations are deliberately used in, or leak into mass media contexts that are not addressed by current frameworks for hazard communication. These frameworks discourage the use of 3d visualizations due to a long-standing gap in basic research as to how graphics and visualizations alter perceptions of risk.

. A survey (n=735) was employed to assess how 3d visualizations of storm surge depicted in recognizable contexts were perceived and altered perceptions of risk. Results of the survey demonstrate that place recognition and affective responses (instantaneous subconscious emotional judgements that have been shown to alter risk perception) contribute to the likely effectiveness of visualizations.

This effectiveness, however, is tempered by a range of “backfire” effects such as the discounting of the legitimacy of the visualizations based upon their style, or the discounting of risks based on the nonconformity of the visualization to the viewers previous assumptions regarding the extents of storm surge.

Alternate models of the persuasive effects of visualizations are presented, together with a recommendation that visualization research continue to investigate how the assumptions of audiences (e.g., expectations for how graphics should appear), alter perceptions to foster the development of shared assumptions, and thus improved risk communication.

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PREFACE

USE OF THE MANUSCRIPT FORMAT

This dissertation adopts the manuscript format. The text following this paragraph introduces and contextualizes the chapters in relationship to each other. All manuscripts are being prepared for submission. A conclusion is provided as a fifth chapter. References are provided for this preface, and in line with each chapter.

INTRODUCTION TO THE CHAPTERS / MANUSCRIPTS

The eastern seaboard of the United States faces increasing but uncertain risks from storm surge and sea level rise (Woodruff et al., 2013, Romero and Emanuel, 2017). Even modest increases in sea level magnify the effects of storm surge such that a storm that has a 1% probability of occurrence today may be equivalent to a storm with a 10% probability of occurrence by midcentury (Miller et al., 2013). Probabilities of occurrence may already be undercalculated. For instance, Hurricane Harvey which was broadly regarded as an outlier event may have a current probability of occurrence as high as 6% (Emanuel, 2017). The need to communicate increasingly impactful events with experts (e.g., emergency managers) and the public conflicts with guidance in the climate communication literature that emphasizes the effectiveness of depictions of climate impacts that are modest in both physical and temporal scale. Depictions of extreme events that seem remote in time tend to be discounted (Weber, 2010), and decrease feelings of self-efficacy (feeling one has the ability to take action) (O'Neill and Nicholson-Cole, 2009, O’Neill et al., 2013, Sheppard, 2012). Given this conflict, the question thus arises as how to effectively communicate these increasing risks. Some scientists and engineers are turning to novel 3d visualizations (Ginis et al., 2017, Spaulding et al., 2016).

The fundamental assumption that undergirds the use of realistic and semi-realistic 3d visualizations to communicate risks associated with storm surge and other climate related risks is that they are more effective tools to influence behavior change (e.g., the implementation of adaptation measures by the public and policy makers) because they evoke emotional responses by contextualizing risks in recognizable contexts (Sheppard et al., 2008, Sheppard, 2005, Sheppard, 2015). It is incorrect to assume, however, that “more = more”. The same literature that predicts the effectiveness of these visualizations also suggests that increasingly dramatic depictions are disbelieved or are easily discounted (Sheppard, 2005, Weber, 2010).

Realistic and semi-realistic visualizations have been shown to play an important role in making seemingly abstract risks like future sea level rise seem tangible (Sheppard, 2015). They connect seemingly abstract and expansive phenomena (e.g., sea level rise) with immediately recognizable and meaningful contexts (Sheppard et al., 2008). They have become an important part of engaging the public and communicating risks and are often used in combination with other exhibits and interactions in workshop processes (e.g., Becker 2016). They are thus commonly viewed to overcome barriers to understanding risks by demonstrating that “it can happen here” (Sheppard et al., 2008). Although these practical applications of visualizations are well studied, there is a gap in basic research regarding the effects of visualizations on risk perception (Kostelnick et al., 2013, Bostrom et al., 2008).

The emergence of climate communication as a community of practice over the last two decades, while highly productive, has steered visualization research in increasingly qualitative directions that emphasize practical application over basic research (Moser, 2016, Sheppard, 2005). Guidance developed in the context of climate communication addresses the possibility that visualizations may mislead the public or demotivate action (i.e., cause people to discount risks) by emphasizing co-creation of outputs (e.g., through workshop processes) and incorporating inputs to models from stakeholders (Moser, 2016, Schroth et al., 2011b, Schroth et al., 2011a). As effective as these approaches to engaging stakeholders are, they leave the fundamental questions unanswered. There is research into the effects of imagery on risk perception (Keller et al., 2006), and the effects of climate-related imagery on feelings of self-efficacy (Nicholson-Cole, 2005), and affective effects of climate-related imagery on perceptions of climate change generally (Leiserowitz, 2006) (These understandings underpin the current guidance). However, none of these studies address the effects of familiarity with or recognition of a place on audience's perceptions of risk. Concerns that visualizations may overstate the certainty of risks, and other critiques of the use of visualizations are similarly unaddressed by researchers insofar as basic research is concerned (Kostelnick et al., 2013, Bostrom et al., 2008).

This research therefore seeks to test fundamental underpinnings of the current guidance in landscape and urban planning and climate communication regarding the roles of affective response (instantaneous subconscious emotional judgements (Zajonc, 1984, Slovic et al., 2002)), place recognition, and the perceived status of visualizations (i.e., whether 3d visualizations used as scientific outputs are perceived as products of science by experts and the lay public).

The choice of these foci reflects the role that these factors play in models of risk perception (van der Linden, 2015, Slovic et al., 2005), and in arguments that underpin the use of visualizations (as argued above).

My research agenda is defined in the first chapter: "Visualizations out of context. Implications of using simulation-based 3d hazard visualizations".

As originally outlined, this research identified realistic visualizations based on numerical simulations as a new type of visualization. Further, it sought to create an ethical framework for their creation. Although the technical concerns raised regarding these specific visualizations are not directly related to risk perception per-se, issues that were exposed regarding the implications of point quality, and the type of data utilized for analysis (e.g., qualitative inputs from stakeholders vs. statistically aggregated data) are significant enough to model predictions that they warrant discussion.

These issues and aspects of methods used to create the visualizations tested in this dissertation are described in the second chapter: "Real-time chronological hazard-hazard impact modeling".

Many of the issues that arise in the second chapter, such as issues arising from the quality of points used in impact analysis, are compounded by the interdisciplinary nature of the work being undertaken. Impact analysis that is necessary to create visualizations necessarily combines data that is gathered in multiple disciplinary contexts (e.g., qualitative data gathered by social scientists, location data generated by first responders) that have different standards of validity and reliability. These differing standards (which heretofore have been largely ignored) can introduce errors averaging over 1 meter and up to 5 meters vertical distance into inundation analysis. This technical illustration, however, is a microcosm of a larger set of epistemic questions that arise when moving between disciplines, specifically, how recognizable are the issues raised in one disciplinary context in another, and what does one do to make them recognizable (Latour, 1987)?

This question is being raised in climate communication, rhetoric of science, and science technology studies (Graham, 2018, Moser, 2016). This research, by addressing the relationship between guidance in climate communication and common assumptions about the use of visualizations (the "more = more" question), weighs firmly in that fray. It deliberately adopts quantitative methods and statistical analysis as a means of testing and making qualitative findings more recognizable in quantitative contexts (e.g., climate science and physical oceanography).

This approach is further detailed in the third chapter: "Are visualizations scientific? How viewer expectations for scientific graphics shape perceptions of storm surge visualizations".

This chapter is written for an interdisciplinary audience including persons in the disciplines of rhetoric and science and technology studies. The arguments regarding making findings recognizable is overlaid on basic research as to how viewer assumptions regarding scientific graphics and visualizations alter the perceived authority of graphics and visualizations. In addition to addressing aspects of the research agenda such as perceived status of visualization, this chapter arises out of the suspicion that aspects of the graphic presentation and visual cues provided graphics alter the perceived authority and persuasiveness of visualizations. This work updates and extends seminal findings regarding perceptions of computer models (Fogg and Tseng, 1999). It culminates with a revised model of the persuasive effects of visualizations.

The last chapter, "Affective response and place recognition effects on perceptions of storm surge visualizations: the limits of drama and the power of recognition" addresses the questions raised at the beginning of this introduction.

The purposive sampling method used for the survey (n = 735) conducted as part of this research was designed to maximize both different degrees of physical and professional proximity to the visualizations tested and places visualized. As outlined in the research agenda developed in chapter 1, these cross-sectional characteristics include differing degrees of familiarity with the visualizations, different types of expertise, different degrees of physical proximity, and different degrees of familiarity with the place. These measures were compared with different dimensions of risk perception (perceptions of severity and likelihood of the depicted consequence (Yates and Stone, 1992)) In addition to demonstrating some of the effects predicted by the literature, this chapter provides insight into how different aspects of visualizations (e.g., the depiction of consequences) alters perceptions. Moreover, it suggests that different factors (e.g., social and cultural factors) effect different aspects of risk perception (e.g., perceptions of probability vs. perceptions of severity of a consequence). The last chapter thus demonstrates:

- A standardized set of metrics is applied that can be applied to any visualization regardless of the method used in its creation. This addresses the difficulty in comparing visualizations in more qualitative analyses that arises from the heterogeneity of visualizations (Lovett et al., 2015). This is essential to continuing basic visualization research.

- A more complete understanding of the role of personal stakes and the depiction of consequences in perceptions of visualizations that may inform practice.

These and previous findings are combined in the conclusion of this dissertation to provide clear guidance for risk communication and the continued development and creation of visualizations. The conclusion also proposes a series of “next steps” for the continuation of basic research (e.g., applying the proposed metrics to comparing maps and visualizations). These recommendations are framed in a way that allows them to be adopted across a range of practices (e.g., risk communication, climate communication, rhetoric of science).

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER 1

VISUALIZATIONS OUT OF CONTEXT

IMPLICATIONS OF USING SIMULATION-BASED 3D HAZARD VISUALIZATIONS.

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ABSTRACT

Realistic 3d hazard visualizations may be directly driven by hydrodynamic and wind model outputs (e.g., ADCIRC, Advanced Circulation Model) and hazard impact modeling (e.g., predicting damage to structures and infrastructure) (Stempel, 2017). These methods create new possibilities for representing hazard impacts and support the development of near real-time hazard forecasting tools (Stempel, 2017, Brecht, 2007). This paper considers the wider implications of using these storm visualizations in light of current frameworks in the context of landscape and urban planning and cartography that have addressed the use of realistic 3d visualizations (e.g., Sheppard 2012). This suggests that use of realistic simulation-based 3d visualizations, outside of local workshop processes organized by experts, could mislead the public about potential storm impacts (Kostelnick et al., 2013). It could further have consequences in regard to the public's perception of their own efficacy in addressing problems scientists might otherwise seek to draw attention to (Nicholson-Cole, 2005, O'Neill and Nicholson-Cole, 2009). More broadly, this effort exposes gaps in the literature regarding the effects of visualizations on risk perception (Bostrom et al., 2008, Kostelnick et al., 2013), and the perceived status of visualizations produced by scientists as compared to visual rhetoric more generally (Deitrick and Edsall, 2009). These gaps have implications for science communication more generally. A research agenda is proposed to address these gaps that will further inform existing frameworks in landscape and urban planning and cartography.

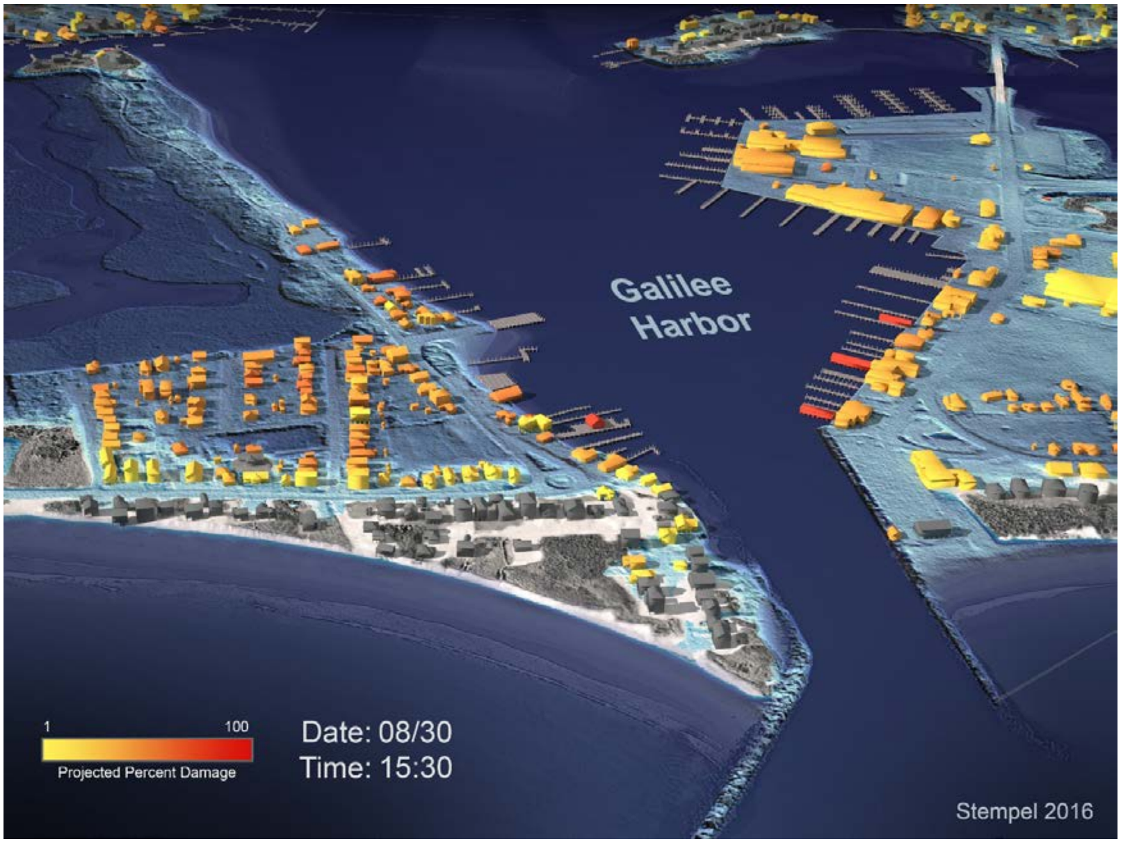


Figure 1, Excerpt from time incremented 3d hazard visualization series of Galilee Harbor, South Kingstown, RI, USA, depicting the progressive impacts (%structural value) of Hurricane Carol (1954) at current sea level on present build-out (Stempel, 2017). These visualizations may have the capacity to stimulate place attachment and elicit strong affective responses (Sheppard, 2005), without proper contextualization, however, they may be misleading or have unintended consequences (Kostelnick et al., 2013).

KEY POINTS

- The status of realistic simulation-based visualizations used outside of local workshop processes is ambiguous. The potential lack of distinction between these visualizations and other forms of visual rhetoric may undermine their utility.
- Considering the use of these visualizations outside of the context of local workshop processes draws attention to broader research gaps as to the effects

of realistic visualizations on perceptions of risk, and public perceptions of the status and legitimacy of those visualizations.

- There is a need for a research agenda to address the exposed gaps to support further use of these visualization methods if they are to be used outside of workshop processes.

KEYWORDS

legitimacy, realism, risk perception, simulation, storm surge, visualization

INTRODUCTION

The combination of hurricanes and increasing sea levels will subject low lying coastal areas to increased but uncertain risks from flooding, wave related damage and erosion (Woodruff et al., 2013, Romero and Emanuel, 2017). This creates a range of problems for coastal and emergency managers, who have identified gaps regarding how the impacts of hurricanes (e.g., flooding from heavy rains, storm surge) and sea level rise are communicated to the public (Lindeman et al., 2015, Morrow et al., 2015). Research suggests that the public, for instance, tends to underestimate the power of storm surge, potentially causing them to discount the risk (Morrow and Lazo, 2013).

To respond to this gap, researchers are employing visualization architectures that allow outputs from simulations such as hydrodynamic models (e.g., ADCIRC, Advanced Circulation Model) and hazard impact modeling (e.g., damage to structures) to be linked directly to realistic 3d hazard visualizations (Stempel, 2017). This allows for rapid visualization of multiple time incremented storm scenarios and creates the potential for the creation of real time impact forecasting systems that use realistic visualizations as primary outputs (Stempel, 2017) (Figure 1 & Figure 2).

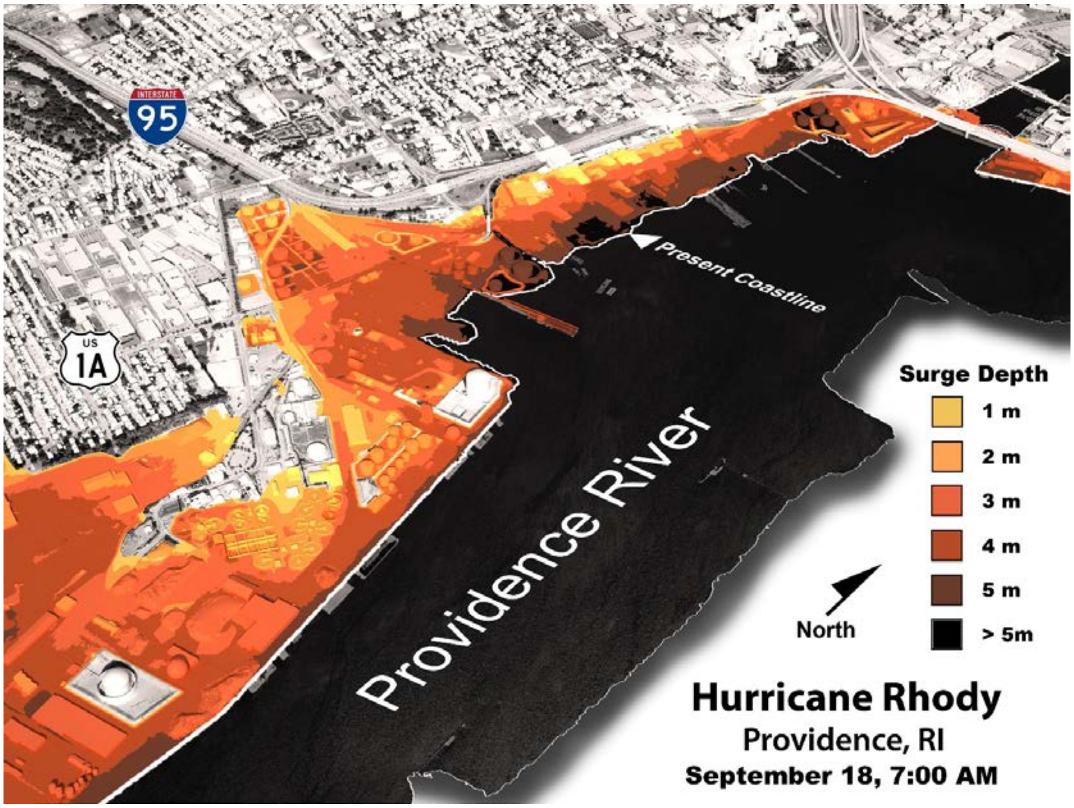


Figure 2. Visualization depicting inundation of energy infrastructure in Providence, RI, USA, used for a training exercise (FEMA IEMC) that took place in June of 2017. This training exercise used time incremented 3d models of coastal communities and infrastructure to depict the landfall of a modeled extreme storm event (Stempel, 2017, UNC-CRC, 2017, Ullman et al., In press) Although structures were individually modeled and tested, specific representations of damage were not included to avoid creating misleading impressions (Stempel, 2017).

Images of flood consequences have been shown to enhance risk perception by stimulation of instantaneous subconscious emotional reactions known as affective response (Keller et al., 2006). These effects, combined with affective response based on place attachment (Sheppard, 2005), may make realistic visualizations of hazard impacts set in local contexts powerful tools for risk communication. The utility of this increase in risk perception, however, largely hinges on the ability to evaluate the effect of the visualizations on perceptions of probability (Kostelnick et al., 2013, Bostrom et al., 2008). Absent a means of evaluation, it is extremely difficult to determine whether these representations of risk are appropriate (overstating or understating risk) or effective (achieving their desired communication effect) (Bostrom et al., 2008, Morgan, 2002). Moreover, evoking an affective response in and of itself does not necessarily motivate action and can be counterproductive (e.g., by overwhelming the viewer and demotivating action) (Weber, 2010, Nicholson-Cole, 2005, O'Neill and Nicholson-Cole, 2009).

Means of evaluation may be provided by workshops and other processes that allow for iterative interactions between stakeholders and experts (Morgan, 2002). In such situations, visualizations are not used in isolation, but in concert with other exhibits and direct interpersonal interactions (Becker, 2016, Schroth, 2010). Through these processes individuals incorporate perceptions of visualizations with their own experience to form new conceptions of risk (Schroth, 2010, Morgan, 2002). This approach to risk communication reflects a larger understanding of risk perception as being dependent on a variety of social, cultural and situational factors (Morgan, 2002). It also reflects a recognition that factors like relative expertise, affective response and numeracy inherently complicate the understanding of any graphic or image that attempts to communicate uncertain events such as storm surge and sea level rise (Kostelnick et al., 2013).

What then, are the implications of using these visualizations outside of the context provided by local workshops? This question is provoked by the recent use of visualizations in feature newspaper articles (e.g.,Kuffner 2017), and potential deployment of forecasting applications described above online (e.g., Stempel 2017, Sneath 2017). These uses, which fall outside of the bounds of traditional workshops, potentially place visualizations in the hands of unfamiliar users. This raises a series of related issues that researchers should consider before deliberately distributing realistic simulation-based 3d hazard visualizations to the public at large (see Table 1):

1) **Questions of status and perceived legitimacy.** To the extent that these storm visualizations are indistinguishable from other forms of visual rhetoric (Deitrick and Edsall, 2009), any effect on risk perception is likely moot. Without establishing the efficacy and perceived legitimacy of realistic simulation-based visualizations, the effort placed into creating them may be questionable.

2) **Uncertainty and effect.** Realistic 3d hazard visualizations have been criticized for potentially misleading the public when used for hazard communication (Kostelnick et al., 2013). The use of realism, for instance, can imply that outcomes are more certain than they are (Kostelnick et al., 2013). As previously argued, however, the relevance of effects on the perception of probability depends to a large degree on assessing response to the visualizations (Bostrom et al., 2008). It is thus unclear to what extent these visualizations may be misleading, and if they are more or less misleading than other forms of visualization.

3) **The use of persuasive visualizations.** Current paradigms for the use of realistic visualizations that otherwise accommodate realistic visualizations advocate the use of iterative processes that allow stakeholders to shape the focus of the visualization and in some cases the underlying modeling (Sheppard, 2015, Sheppard, 2012, Schroth et al., 2011b, White et al., 2010). While these paradigms create clear pathways for the use of these visualizations, it is unclear

how such processes could be scaled beyond local contexts to accommodate broader distribution.

These issues raised by realistic simulation-based 3d visualizations surface questions that are fundamental to the use of visualizations, and visual rhetoric made by scientists more generally. Namely:

- What is the perceived status of visualizations used outside of workshop processes and how does this affect perceptions of legitimacy? The question of status includes whether viewers perceive these visualizations as products of scientific or technical processes, and how factors such as labeling, association with an institution, or visual quality affect those perceptions (Deitrick and Edsall, 2009, Fogg and Tseng, 1999).
- What are the effects of visualizations on perceptions of probability and risk? (Risk is defined as a judgement as to the probability and severity of a consequence (Yates and Stone, 1992)) (Bostrom et al., 2008, Kostelnick et al., 2013).

These questions correspond to larger identified research gaps (Leshner et al., 2016). As has been the case for many years, the advancement of visualization technology outstrips understanding of its application (Sheppard and Cizek, 2009, Lovett et al., 2015). While technologies may change and continually provoke new questions, addressing fundamental questions raised by realistic simulation-based visualizations is likely to benefit the understanding of visualization practices more generally.

Table 1. Summary of issues raised by use of realistic simulation-based visualizations outside of expert-led workshop processes. These issues may apply more broadly to other types of visualizations.

	Status & Legitimacy	Uncertainty & Effect	Use
Outside of workshop process	Unclear whether visualizations are distinguishable from other visual rhetoric (Deitrick 2009). Factors influencing perceptions of legitimacy not defined.	Detail and realism may overstate certainty of outcomes and mislead the public. (Kostelnick 2013) Potential unintended consequences (e.g., demotivating public action) (Nicholson-Cole 2005).	Exceeds the boundaries of existing cartographic frameworks (e.g., Kostelnick 2013).
Inside of workshop process	Participants gain understanding / provide inupt to technical processes through interaction with experts, creating a basis for perceived legitimacy of modeled outputs (Schroth 2011).	Perceptions of probability and effect of affective response qualified through interactions between participants and experts (Morgan 2002). Effects may be measured before and after treatment (Bostrom 2008)	Guided by well established practices and guidelines (e.g., (Schroth 2010), (Sheppard 2012))

BACKGROUND

Realistic simulation-based visualizations connect realistic 3d virtual contexts (e.g., 3d representations of real places) with predictive models created by scientists (Stempel 2017, UNC-CRC 2017). Once the virtual context is created, content represented in that context may be continually updated as the underlying simulation changes (Stempel 2017). This allows for the rapid production of still visualizations and the creation of interactive tools using game engines (e.g., UPEI 2014).

Visualizations meeting this definition have been utilized as part of a recent US Federal Emergency Management Agency Community Specific Integrated Emergency Management Course (FEMA-IEMC) conducted by the Emergency Management Institute and institutions associated with the US Department of Homeland security

Center of Excellence at UNC Chapel Hill, (North Carolina, USA) (UNC-CRC, 2017). The Water Institute and Deltares, a Dutch consulting firm, have announced a project to depict model outputs in Louisiana, USA (Sneath, 2017). This tool combines model outputs with 3d terrain and representations of structures (Sneath, 2017). The Massachusetts Institute of Technology (MIT) (USA) and the University of Prince Edward Island (Canada) have announced CLIVE, an interactive tool to visualize sea level rise scenarios (UPEI, 2014). This tool uses a game engine to display model outputs (UPEI, 2014).

While none of these tools is in broad distribution currently, their existence minimally suggests that multiple research teams are working to combine the persuasive power of realistic 3d hazard visualizations with storm model outputs. They are also being used to depict outputs of the Coastal and Environmental Risk Index (CERI). CERI is a GIS based tool that combines ocean simulations, databases of structures and their attributes, and building performance studies to predict damage outcomes for multiple storm surge, wind, and sea level scenarios as a means to better quantify risk (Spaulding et al., 2016).

Realized applications of simulation-based visualizations emphasize the use of local workshops (Stempel, 2017, UPEI, 2014). Processes used in FEMA IEMC, for instance, included multiple meetings with end users as part of developing the basis of impact assessments and damage visualizations (Stempel, 2017). CERI outputs are currently used in local stakeholder processes conducted by Rhode Island Shoreline Change Special Area Management Plan in Rhode Island, USA (Beach SAMP) (McCann et al., 2013, Crean, 2017). Embedding the use of these visualizations provides opportunities for interaction between the audience and the expert teams (e.g.,(Stempel, 2017)).

These interactions resemble broadly recommended practices that embed communication processes in local contexts (e.g., Sheppard 2012, Trumbo 2000). This allows for critical interactions between the science communicators (persons responsible for creating the visualizations), the audience, and scientists, which allows for the calibration of messaging and consideration of local cultural issues pertinent to the visualizations (Morgan, 2002, Trumbo, 2000, Sheppard, 2015). To the extent that these interactions allow for user input into the underlying models, they likely have effects on the perceived legitimacy of those models, and the process as a whole (Salter et al., 2010, White et al., 2010). These processes thus not only affect perceptions of the visualizations, they affect perceptions of the underlying science (Trumbo, 2000).

What, however, is the status of these simulation-based realistic 3d hazard visualizations absent this contextualization? This question is provoked by a recent newspaper article on CERI. Newspaper editors juxtaposed a null scenario (one without any impacts shown) with the most extreme scenario produced by the index, and further chose to combine and crop both so that the extreme scenario showed only devastation. This comparison was featured on the front page with a bold “Rising Seas Rising Stakes” headline in red (Kuffner, 2016) (Figure *3*).

This emphasis on the dramatic and the extreme comparison may have potentially negative effects on people’s feelings of self-efficacy in confronting theses hazards and cause them to discount or dismiss the risk due to feeling overwhelmed (Nicholson-Cole, 2005; O'Neill & Nicholson-Cole, 2009). This is contrary to the stated intentions of the

Beach SAMP, which aspires to provide useful information to the public to support constructive engagement with issues that arise out of the impacts of storm surge and sea level rise (McCann et al., 2013, Crean, 2017).These unintended consequences, however are only the tip of the iceberg when one considers the broader potential for uncontextualized realistic 3d hazard visualizations to mislead the public. Visualizations that make outcomes appear more certain than they are may, for instance, impact property values or imply support for a particular political outcome (Crampton and Krygier, 2005, Kostelnick et al., 2013). (See for instance, Figure 4).

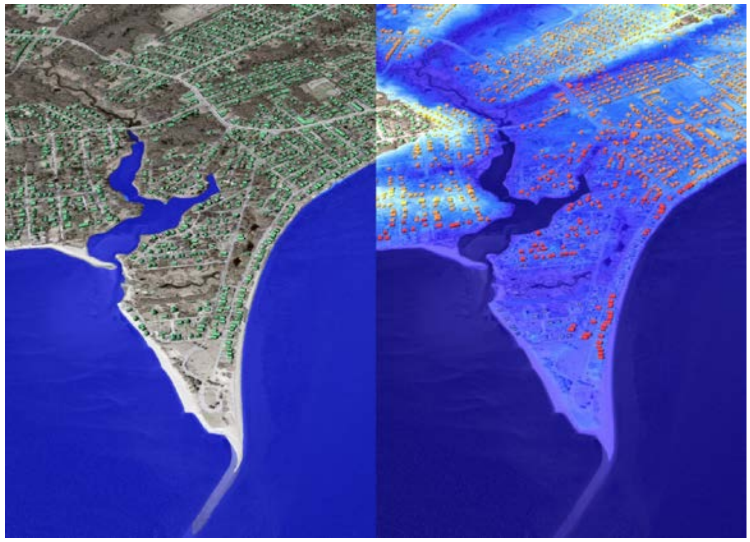


Figure 3, *Cropped comparison of Warwick, RI, USA, as used on the front page of the Providence Journal newspaper juxtaposing the no inundation scenario with a scenario depicting 7' of sea level rise and a storm event with a 1% chance of occurrence (Spaulding et al., 2016). The comparison and cropping of the image emphasizes the already extreme scenario.*

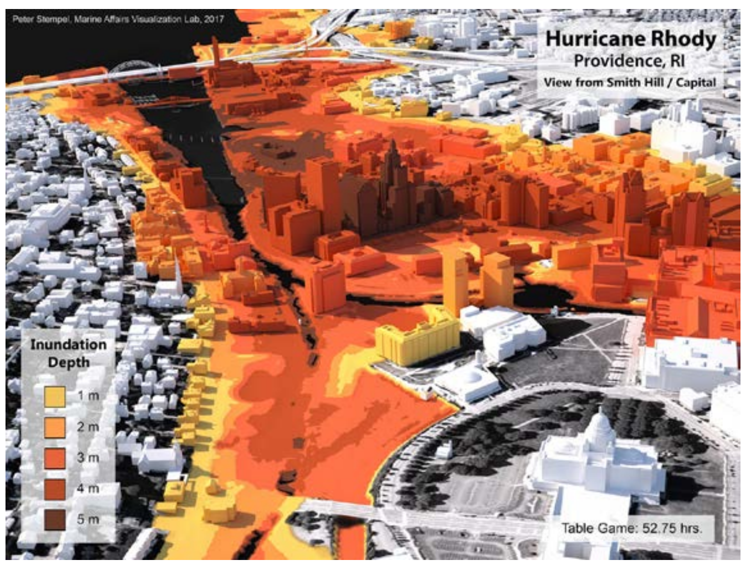


Figure 4, A visualization of downtown Providence, RI, USA as a result of failed flood control systems and 46" of rainfall (Ullman et al., In press, Stempel, 2017). The unfolding of this scenario requires the alignment of several events (failure of flood control measures and a two-hit storm); without this qualification, this visualization could foster a range of misleading interpretations. The term "Table Game" used in the visualization is a reference to the specific time increments of the exercise (visualizations made in series).

PERCEIVED STATUS AND ITS INFLUENCE ON PERCEPTIONS OF LEGITIMACY

Simulation-based realistic 3d hazard visualizations may be distinct from map-based tools involving simulations (e.g., Stephens et. al., 2015) by virtue of employing realistic perspectival 3d representations (Figure 5). Unlike realistic 3d hazard visualizations, map-based tools benefit from the strength of cartographic conventions, which address a range of representational questions such as the management of uncertainty based on the specific role to be played by a particular visualization in advancing the understanding of data (MacEachren, 1992). Cartographic approaches emphasize the clear, nondramatic presentation of probability (Bostrom et al., 2008, Kostelnick et al., 2013). They further emphasize selecting the type of the representation based on the nature of the underlying data, the intended purpose of the representation, and the intended audience (Kostelnick et al., 2013).

In the case of realistic simulation-based 3d hazard visualizations, the presumed use of realism establishes a style and high level of resolution that contradicts the cartographic approach. While this might seem to place these visualizations into a separate and distinct category of visual rhetoric, it is as of yet unclear to what degree the public perceives distinctions among different typologies of representation (Deitrick and Edsall, 2009, Walsh, 2015). Whether viewers distinguish these visualizations from other realistic imagery and graphics depicting sea level rise, for instance, may hinge on whether they are perceived as direct outputs of technical processes as opposed to an artist's interpretation.

Figure 5. Comparison of map based NOAA Sea Level Rise Viewer and Semi-realistic 3d model output based on the Coastal and Environmental Risk Index (CERI) demonstrating the distinction between them. Both depict Matunuck, RI, USA (2017, Spaulding et al., 2016).

While a direct connection to technical processes may seem to ascribe a greater level of legitimacy to these visualizations, what scarce evidence there is about the way simulations are perceived suggests that a range of factors unrelated to underlying technical processes may have a greater effect, and that the perceived credibility of computers is overstated (Couture, 2004, Fogg and Tseng, 1999). In fact, it is possible that the visual quality and level of detail displayed in realistic visualizations may have a substantial effect on perceived legitimacy (Couture, 2004, Orland et al., 2001).This suggests that a well-made but misleading visualization may be judged by the viewer as credible (Sheppard and Cizek, 2009, Liu and Palen, 2010). Research in the context of still visualizations and virtual environments seems to support the importance of level of detail, and conformance to observed conditions as significant factors (Appleton and Lovett, 2003, Lange, 2001, Orland et al., 2001). It is therefore important to determine how viewers perceive the connection to the underlying simulation in relation to other factors influencing perceptions of legitimacy.

In the context of expert-led workshop processes, the questions of status and legitimacy are addressed, at least in part, through interaction (Sheppard, 2012). For example, climate visioning workshops conducted by the Center for Advanced Landscape Planning at the University of British Columbia (CALP), used a combination of diverse stakeholder input, expert elicitation and mathematical modeling (a form of simulation) to predict future conditions using multiple climate scenarios (Schroth et al., 2011b, Schroth et al., 2011a). This process, which is described under the larger umbrella of integrated assessment (Schroth et al., 2011b), included:

- Using stakeholder input gathered through workshops to guide mathematical modeling priorities, such as particular issues or locations that require attention (Schroth et al., 2011b).
- Use of stakeholder feedback and qualitative knowledge to continually improve the models through an iterative workshopping process (Schroth et al., 2011b).

The use of stakeholder input in the creation of models tempered the impression that models created by experts were "black boxes" (Schroth et al., 2011b, Salter et al., 2010). This kind of engagement in the creation of simulations and technical processes has further been shown to enhance the perceived legitimacy of those models and outcomes (White et al., 2010). Perceptions of legitimacy may thus depend on interactions between experts and the public and the ability to shape inputs to the underlying models.

To the extent that modeling and visualization processes are linear and do not allow for direction on the part of stakeholders there is a danger of bias. (MacFarlane et al., 2005). Simulation-based visualizations, through their emphasis on complex scientific processes and use of advanced visualization methods, are inherently not transparent to the public and favor expertise (MacFarlane et al., 2005, Sheppard, 2001). This bias potentially affects every aspect of what is visualized, from the determination of what areas are focused on to the specific hazard scenario chosen (MacFarlane et al., 2005). It is therefore necessary to consider how the development of simulation-based visualizations used outside of local workshop processes may incorporate direction from stakeholders.

OBSCURING UNCERTAINTY

Like other visual rhetoric (e.g., graphics, maps) used to communicate with the public regarding climate change, realistic 3d hazard visualizations concretize science in a way that can obscure uncertainty (Deitrick and Edsall, 2009). These effects are magnified in the case of realistic visualizations (Kostelnick et al., 2013), especially those that incorporate the depiction of hazard impacts. The inclusion and aggregation of multiple kinds of modeling (such as wave, inundation, erosion, and damage modeling) compounds multiple kinds of uncertainty (MacEachren, 1992, Kostelnick et al., 2013). Erosion and inundation, for example, are predicted using different methods (Spaulding et al., 2016), and thus have differing levels of uncertainty associated with the prediction (Figure 6). Similarly, expressing the temporal uncertainty of the storm event (a 1% chance of occurrence), is fundamentally different than expressing a likelihood that the water and terrain will interact in a particular way (natural uncertainty) (Kostelnick et al., 2013).

The use of realism in visualizations compounds this problem because it can imply higher levels of resolution than exist by contextualizing abstract modeling in highly detailed 3d representation (Kostelnick et al., 2013). Although the high resolution of modeling used in some visualizations (e.g., Spaulding 2016, Stempel 2017) avoids some of the gravest pitfalls of mismatching data scales and types (e.g., areal and point data) (Liu and Palen, 2010, Sheppard and Cizek, 2009), there is still the problem of reification: the potential that an abstract scientific model is treated as equivalent to reality (Kostelnick et al., 2013, Wynne, 1992). Regardless of resolution, the level of detail and exactitude of realistic visualizations implies levels of certainty beyond the capability of the underlying model.

In cartographic contexts, these problems are addressed in several ways, including careful evaluation of the intended audience, modulating the level of detail, emphasizing the non-dramatic depiction of uncertainty, and avoiding realism or visualizations with an excessive "wow" factor that might otherwise distract from the intended risk messaging (Bostrom et al., 2008, Kostelnick et al., 2013). Even with these steps, however, there is still the fundamental question of how these visualizations are perceived, and whether they are effectively communicating probability (Bostrom et al., 2008). This surfaces a research gap regarding the perception of graphics used for risk communication (Bostrom et al., 2008).

Without testing the effects of realistic visualizations, it is difficult to assess to what extent that this masking of uncertainty alters perceptions of the probability of events. While it is very likely that these misleading effects exist, it is unclear whether realistic visualizations are in practice necessarily more or less misleading than maps or other forms of less dramatic representation. For instance, to the extent that maps are viewed as having a higher degree of authority (Crampton and Krygier, 2005), it is entirely possible that the crystalizing effects of maps may have a greater capacity to mislead (Monmonier, 2014).

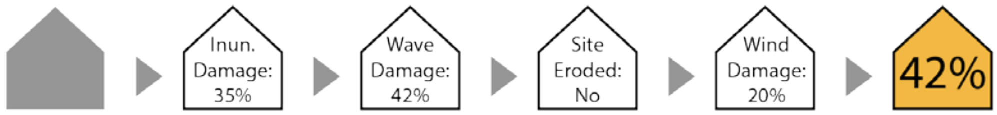


Figure 6, an example of damage modeling (similar to methods used in CERI (Spaulding et al., 2016)), in which a final level of damage is determined by testing building characteristics against a series of models to determine which model produces the highest and therefore controlling level of damage. Each model introduces unique assumptions and uncertainties. Unmodeled or unknowable conditions and interactions between the model create additional uncertainties (Couclelis, 2003, Kostelnick et al., 2013). In addition to this, the use of forensic studies introduce the problem of making calculations with vague data—that is data that is expressed in ranges rather than as a single figure (Kruse et al., 2012, Coulbourne et al., 2015). The specificity of the numerical outcome for a specific structure, thus may create an inappropriate impression of certainty, which is further compounded by the level of detail in a realistic visualization (Kostelnick et al., 2013).

It is also worth considering that choice of representation may signal intentions of the designer that alter the way information is understood and assessed (Elzer et al., 2004). A realistic representation may signal a degree of deliberate dramatization that makes the resulting visualization seem less authoritative. The degree to which such a visualization is misleading may thus be a question of whether other factors, such as institutional affiliation or being perceived as the product of a technical process, are perceived to confer legitimacy. If this is the case, the question of whether or to what degree realistic visualizations are intrinsically misleading is closely connected to both questions of status and how questions of how visualizations alter perceptions of probability and risk.

While the desire to leverage the effects of affective response and place attachment to elicit a response from an audience would seem to place these visualizations firmly in the category of persuasive media (Nicholson-Cole, 2005), the notion of dividing persuasive media from other forms of representation may be a matter of degrees. All representation, at some level, aspires to persuade in order to be an effective communication tool (Tufte and Weise Moeller, 1997, Latour, 1990). It may therefore be a mistake to view conventional disciplinary approaches to representation as somehow less transformed by perception and outside of the bounds of rhetoric (Walsh, 2015). Maps and graphs are not immune from the problem of being decontextualized, misunderstood, and potentially misused (Deitrick and Edsall, 2009).

USE OF PERSUASIVE MEDIA TO COMMUNICATE UNCERTAIN FUTURE EVENTS.

Guidance for the creation and use of visualizations in the context of landscape and urban planning has explicitly evolved to accommodate potentially persuasive imagery including realistic 3d hazard visualizations (Sheppard, 2012). The judicious use of drama, and the capacity of realistic and semi-realistic visualizations to elicit emotional responses is cited as a reason that visualizations may be more effective at engaging the public and potentially inspiring behavior change (Sheppard et al., 2008, Sheppard, 2005). In this context, visualizations are seen as an important means to localize, and make tangible the abstract effects of climate change that are otherwise difficult to imagine (Moser and Dilling, 2011, Sheppard, 2015).

The use of visualizations in this way is a departure from earlier standards that were proposed in the context of landscape and urban planning (Sheppard et al., 2008).

Those standards emphasized dispassionate representation and were imagined in the context of representing more conventional planning alternatives (e.g., a proposed bridge) (Sheppard, 2001). While such standards were useful for near term planning alternatives, they did not accommodate the broader range of uncertainty regarding outcomes associated with climate change (Sheppard et al., 2008, Sheppard, 2005). To the extent that visualizations are used to promote positive responses to climate change they further depart from the notion of a dispassionate representation by virtue of advocacy (Sheppard et al., 2008, Sheppard, 2005), a new framework was therefore necessary.

The practices that subsequently evolved in the context of landscape and urban planning are exemplified by the special role Sheppard, a leading proponent of the use of visualizations, imagines for landscape architects (Sheppard et al., 2008, Sheppard, 2015). He proposes that landscape architects, through their capacity to "visualize and spatialize future conditions", act as connectors that facilitate the integration local cultural knowledge and technical knowledge provided by experts (Sheppard, 2015, Sheppard, 2012). This approach conforms to a larger view of science communication that suggests that science communication is best accomplished by collaborative mixed teams that involve scientists, stakeholders, and visual communicators (Trumbo, 2000). Such an approach recognizes that the process of creating visual media often involves decisions by visual communication experts that profoundly affect the resulting communication, and that engagement provides an important means to calibrate these decisions among scientists, visual communicators, and stakeholders (Trumbo, 2000, Sheppard, 2012).

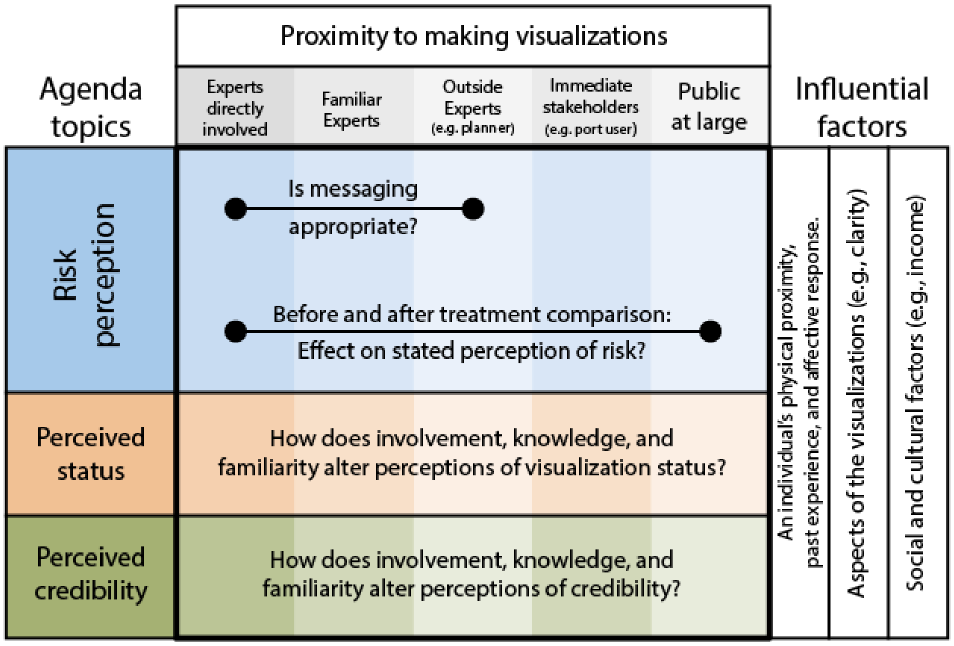
Sheppard and others have provided clear roadmaps for the use realistic visualizations (Sheppard et al., 2011, Sheppard et al., 2013, Sheppard, 2015), including the use of simulations (Schroth et al., 2011b). As previously indicated, this involves engaging stakeholders in the formation of the models and visualizations using an iterative workshopping process. The challenge, insofar as supporting the broader distribution of realistic simulation-based visualizations, is the emphasis on locality (Sheppard, 2012, Star, 2010).

Work undertaken in support of FEMA IEMC, for instance, enlisted local emergency managers to identify specific modeling priorities, including quantifiable thresholds at which a hazard compromised a site or piece of infrastructure. These local priorities were then combined with other statewide databases to produce a real-time training exercise that was relevant at multiple scales (Stempel, 2017). Although the geographic scope of the exercise encompassed an entire state, the population reached was fewer than 200 emergency managers and officials in related fields (Stempel, 2017).

STEPS TO MORE BROAD USE OF SIMULATION-BASED 3D HAZARD VISUALIZATIONS

Contemplating the broader dissemination of realistic simulation-based 3d hazard visualizations, whether by mass media such as a newspaper or deliberate distribution, raises fundamental questions about the perceived status of visual rhetoric, perceptions of legitimacy, and the ways in which visualizations alter perceptions of probability and risk. This suggests that, despite the existence of clear and practical roadmaps for some uses, research needs to address fundamental questions regarding the ways in which viewers perceive visualizations.

Table 2, Research agenda for realistic simulation-based visualizations, including evaluation of how proximity to how processes influences perceptions.



A research agenda to address these questions should thus include (See also Table 2):

1. <u>Develop a framework to understand the perceived status of simulation-based realistic visualizations</u>. Are these visualizations regarded in the same way as other visual rhetoric (Deitrick and Edsall, 2009), or is there a distinction based on their underlying connection to scientific and technical processes? How are these perceptions altered by an individual's familiarity with the process? The considerable effort placed into developing fine grained simulations (Spaulding et al., 2016), and visualization architecture more generally, is potentially misplaced if the resulting visualizations are indistinguishable from more arbitrary visualizations.

2. Develop a framework to understand factors that influence (positively or negatively) the perceived legitimacy of simulation-based realistic visualizations. To what extent do ease of understanding, visual appearance, or other factors such as reputation of the sponsoring institution, account for perceptions of legitimacy? If viewers do not perceive visualizations as legitimate, any effect they have on risk perception is likely moot.
3. Determine the effect of realistic visualizations and graphics more generally on perceptions of probability and risk. Affective response, instantaneous emotional reactions to a stimulus, has long been cited in both visualization (e.g., Nicholson-Cole 2005, Sheppard 2005) and risk perception literature (Slovic, Peters, Finucane, & MacGregor, 2005), yet our knowledge of the effects of visualizations of specific places on risk perception is largely unexplored, outside of case studies that explore the potential role of affective response (e.g.,(Lewis and Sheppard, 2006)).

Answering these questions does not in and of itself offer a path to the broader application of realistic simulation-based visualizations. It is clear from other work that distributions are complicated by a range of factors, including interface design and supplemental information (Stephens et al., 2015), as well as questions of user familiarity, navigation, and other factors that likely affect whether interactive tools are effective (Schroth et al., 2015).

These questions do, however, inform the continued development of existing frameworks in the context of risk communication, cartography, and landscape and urban planning by taking up longstanding questions such as the effect of a particular type of representation on risk perception (even considering that the original intention of the question was to study graphics, not realistic visualizations) (Bostrom et al., 2008). Asking fundamental questions about these specific aspects of visual communication further supports a more broadly identified national agenda for research into the way that science communication is perceived (Leshner et al., 2016).

CONCLUSION

If researchers and creators of visualizations can understand the dimensions of these issues, it may be possible to expand the boundaries of current guidelines for the use of realistic visualizations, including realistic simulation-based 3d visualizations. If for instance, the potentially misleading effects of realistic visualizations can be understood and mitigated, it may be possible to hybridize the uses of these visualizations with existing applications of 2d map representations (e.g., Stephens et. al. 2015). It is similarly conceivable that better understanding factors contributing to perceived legitimacy of visualizations may suggest ways of expanding current workshop processes.

Beyond these practical considerations, however, this research has broader implications.

It is unclear to what degree the public perceives a difference between one form of visual rhetoric and another (e.g., realistic visualizations and maps) (Deitrick and Edsall, 2009). Although realistic visualizations introduce detail and assumptions that are extraneous to the presentation of the underlying data, (Kostelnick et al., 2013), the degree to which this distinction is perceived or has an effect on perceptions of probability is currently unknown and warrants further research. Developing a more thorough understanding of public perception of realistic simulation-based visualizations thus not only has the potential to inform the development of that technology, (either supporting or discouraging use), it has the potential alter our understanding of existing paradigms of communication.

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CHAPTER 2

REAL TIME CHRONOLOGICAL HAZARD IMPACT MODELING

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ABSTRACT

The potential of ocean models such as the ADvanced CIRCulation model (ADCIRC) to be used asses hazard impacts on individual critical facilities (e.g., inundation of a hospital) has long been recognized (e.g., Brecht, 2007). This includes creating time incremented assessments that illustrate the progression of hazard impacts during a storm (Brecht, 2007, Aerts et al., 2018). While methods for creating aggregate hazard models depicting large regions are well known (e.g., HAZUS), methods for creating highly granular impact models of individual points that take advantage of the time incremented aspect of ADCIRC models are not thoroughly elaborated (Brecht, 2007, Aerts et al., 2018). This may become increasingly important as researchers propose increasing integration of highly specific qualitative data to models (Aerts et al., 2018).

One means to realize this capability and enable forecasting of impacts to be run concurrently with or immediately following an ADCIRC model run is use of an all numerical process in which elevation and vulnerability data inheres with individual geographic points (representing individual facilities or objects) in a tabular format. Combining elevation and facility-based data into tables makes it possible to link geographic databases and ocean models using a variety of programming languages and eliminates the need for translation of data between formats (e.g., unstructured grid to raster or polygon in GIS).

The implementation of this method makes it possible to use ADCIRC as a rapid hazard impact forecasting tool, and further supports the development of near-real-time

visualization of modeled impacts (Figure 7). The application of these methods, however, raises questions regarding potential pitfalls such as the inadequacy of data to support the resolution of proposed outputs (Liu and Palen, 2010, Couclelis, 2003). Addressing these pitfalls and employing this method opens the prospect of providing a new tool for better understand the progression of impacts during modeled storm surges.

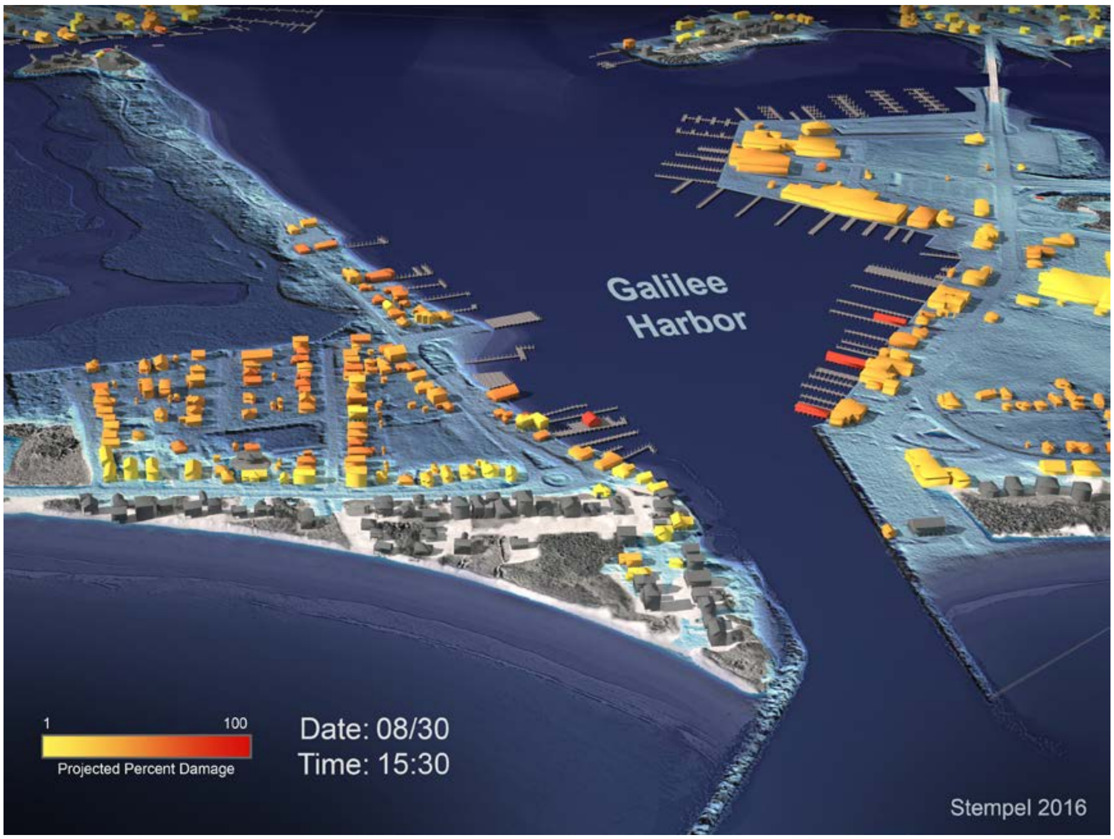

Figure 7, rendering made during development of the real-time methodology depicting impacts of hurricane Carol (1954) on the port of Galilee, RI, USA at current (2016) buildout.

KEY POINTS

- A numerical architecture allows for direct programming of hazard impact models outside of geographic information systems.
- The evaluation of impacts to individual data points places increased demands on ground truthing and data quality.

- The implementation of fine scale hazard impact models is enhanced by involving model users in the creation of model inputs.
- Realizing the potential of time incremented hazard impact models and visualization requires further research so as not to create misleading outputs.

KEYWORDS

Hazard, impact, modeling, ADCIRC, real-time, 3d, damage

INTRODUCTION

Hurricanes place critical facilities such as hospitals, electrical systems, and transportation links at risk (Haraguchi et al., 2016). The potential of ADCIRC as a tool to analyze vulnerabilities of specific geographic points has long been recognized (Brecht, 2007). This includes the potential for real time analysis of impacts and showing the chronological effects of a storm surge (Brecht, 2007, Aerts et al., 2018). In this case, "real-time" refers to the ability to generate reports of hazard impacts (e.g., effects of the surge at an individual geographic point) as the underlying ADCIRC simulation is run or immediately after. "chronological effects" refers to the ability to calculate hazard impacts for each time increment of the underlying ADCIRC model. Achieving a reliable real-time method to evaluate chronological hazard impacts at specific points may provide a new way to assess potential hazard impacts in the days and hours preceding landfall to adjust and improve preparation and response. (Brecht, 2007, Ginis et al., 2017). Researchers are also calling for improved methods for the integration of qualitative data into time incremented hazard impact models (Aerts et al., 2018).

Methods to achieve real-time connection of hazard impact models to ADCIRC are generally not elaborated in the literature. Methods for hazard impact modeling that have been elaborated largely rely on GIS, and effects are typically aggregated to show maximum possible impacts. (Brecht, 2007, Allen et al., 2013, Allen et al., 2010, Vickery et al., 2006). There is a recognition more generally that as modeling of phenomena such as sea level rise improves, that hazard impact models will need to be similarly improved to realize planning benefits for coastal communities (Kopp et al., 2014, Aerts et al., 2018).

One means to create time incremented hazard impact models is to use an all numerical approach that indexes individual geographic points (e.g., representing an object or facility) to grid nodes of the ADCIRC model. Using this method, elevation data such as ground elevation inheres with the geographic point in a table with other necessary information to perform the analysis. This all numerical method makes it possible to program the hazard impact model in multiple programming languages that can run independently of GIS software (e.g., ArcMap). This allows the hazard impact model to be run on the same platform as the ocean model, eliminating the “air gap” between processes. If further has the potential to eliminate errors of resolution that can result from multiple transformations of data. Possible implementations include running the ADCIRC model in a cloud based system (e.g., Amazon Web Services, Microsoft Azure), with a hand-off to the hazard impact model programmed in R (Hazard impact models at the University of Rhode Island (URI) currently employ this language). Alternately, the hazard impact model can be directly installed on a super-computer running the ADCIRC model.

The use of a method to evaluate individual points also raises questions. Hazard impact modeling typically relies on statistically aggregated data (e.g., Vickery et. al., 2006) and point data that was originally generated for other purposes (e.g., e911 databases) (e.g., Spaulding 2016) While the application of these methods is appropriate over wider geographic regions to produced comprehensive and aggregated reports (Vickery et al., 2006, Aerts et al., 2018), the application of statistically aggregated methods to derive outcomes for individual localized points becomes questionable (Sheppard and Cizek, 2009). Issues include the use of data of different types (e.g., point vs. areal) or derived at different scales (Liu and Palen, 2010). This is in addition to problems associated with the imperfection of geographic data, or the impossibility of obtaining sufficient data for the intended purposes (Couclelis, 2003).

A point located at the centroid of a land parcel for instance, may not reflect a specific vulnerability and could thus yield a false positive or negative (e.g., the facility in question is at lower or higher elevation than the point). To the extent that highly specific outcomes are predicted and potentially visualized using data made for other purposes there is a danger that the certainty of outcomes is overstated and misleading (Kostelnick et al., 2013, Liu and Palen, 2010, Sheppard and Cizek, 2009). The implementation of this approach thus requires careful attention to issues of data quality and the representation of outcomes.

This paper further elaborates the numerical approach to hazard impact modeling and methods to contend with the questions it raises. It includes:

1. Overview of the storm surge modeling system, including: generation of the meteorological forcing, the hydrodynamic simulation model, and steps taken to

validate the model using a historic storm (Hurricane Carol, 1954) and tide gauge data.

2. Architecture of the all numerical method, including steps taken to avoid errors of interpolation, or that might otherwise be introduced in more conventional processes by downscaling or translation of data between data types (e.g., point, raster and polygon) (Allen et al., 2013, Gesch, 2009, Liu and Palen, 2010).

Quality of spatial data, including issues such as positioning of geographic points to coincide with specific vulnerabilities to minimize errors resulting from use of data created for different purposes (e.g. e911) (Liu and Palen, 2010, Sheppard and Cizek, 2009).

Participant input. Developing a credible non-aggregated basis for modeling specific impacts requires facility level vulnerability information (Vickery et al., 2006). Participating emergency managers assisted with the development of highly specific granular data (e.g., the wind velocity at which a communication tower may be compromised) for the IEMC. Incorporation of stakeholder input has been shown to increase transparency of processes as well as enhance trust and perceived legitimacy of model outputs (Schroth et al., 2011b, White et al., 2010).

The methods described were recently tested as part of developing time incremented hazard impact reports and visualizations to support a Federal Emergency Management Agency, Community Specific Integrated Emergency Management Course (IEMC) conducted by the Emergency Management Institute (EMI) and the Rhode Island Emergency Management Agency (RIEMA) in June of 2017. Where appropriate, examples used in this paper are drawn from this work. After expanding the four points above, this paper concludes with a reflection on the benefits of this work to the IEMC exercise and hazard impact modeling more generally.

OVERVIEW OF THE STORM SURGE MODELING SYSTEM

GENERATION OF THE METEOROLOGICAL FORCING

This study used a newly developed high-resolution hurricane boundary layer (HBL) model to provide physics-based simulations of surface winds during hurricane landfall. At landfall, the hurricane usually encounters a rougher surface with increased friction. The roughness length of the sea is of the order of a few millimeters, while land roughness lengths are typically several centimeters for open fields, and greater for forested or urban areas. This change in the surface friction affects the near-surface wind structure. The Gao and Ginis (2016) hurricane boundary layer (HBL) model, originally designed for open ocean studies, has been recently adopted for landfalling storms (hereafter URI HBL) as part of the coastal resilience project at URI funded by the U.S. Department of Homeland Security. The new HBL model is a dynamical approach that utilizes the physical balances in the dynamic equations to determine how a hurricane responds to local variability in the surface conditions (primarily topography and surface roughness). Figure 8 depicts an example of the coastal wind swath (maximum sustained wind experienced during the storm passage) produced by the URI HBL model for Hurricane Carol (1954), the most destructive hurricane to strike southern New England since the Great New England Hurricane of 1938. The National Weather Service in Warwick, Rhode Island recorded sustained winds of 90 mph, with a peak gust of 105 mph.

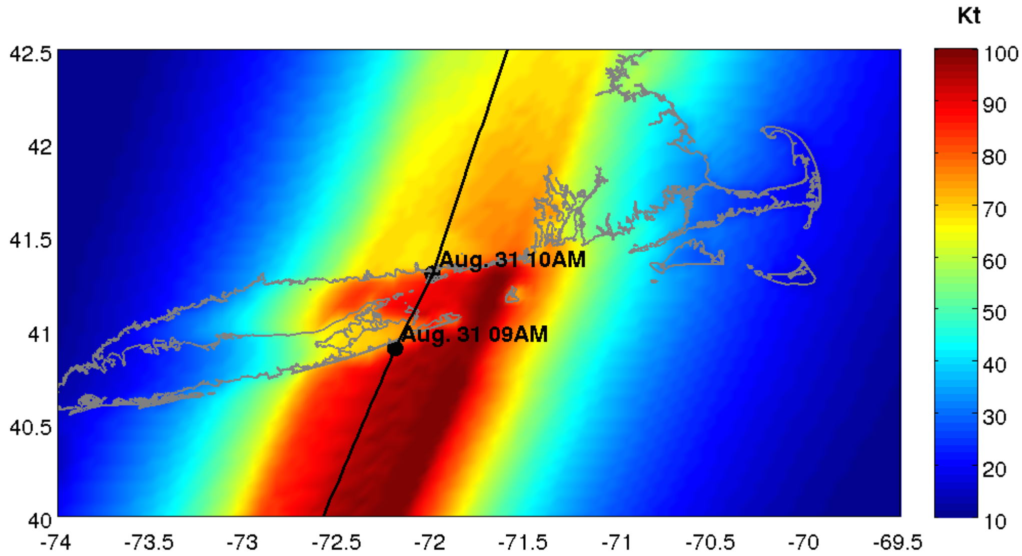

Figure 8, Maximum sustained winds (kt) simulated to have occurred during landfall of 1954's Hurricane Carol, as obtained from the URI hurricane boundary layer model.

A hypothetical yet plausible hurricane scenario was created to simulate the effect of a high-impact storm in Rhode Island named "Hurricane Rhody" (Figure 9). This scenario involves a major hurricane that starts near the Bahamas and propagates northward close to the U.S. East Coast. While staying close to the coast (like Hurricane Carol in 1954) it moves much more quickly (like the Great New England Hurricane of 1938). Ultimately, the storm makes landfall in central Long Island and then in Connecticut (like the hurricanes of 1938 and Carol), as a strong Cat 3 hurricane with peak winds of 132 mph causing a huge storm surge in Narragansett Bay and along the south shore of Rhode Island. Then, shortly after its landfall near Old Saybrook, Connecticut, the storm slows down, stalls, and loops over Southern New England, somewhat similar to Hurricane Esther in 1961. Rhody makes the second landfall as a Category 2 hurricane in Rhode Island, producing strong winds and heavy rainfall. The total rainfall reaches more than 10 inches in some areas causing massive river flooding, similar to Hurricane Diane (1955) and the Rhode Island March 2010 floods.

HYDRODYNAMIC SIMULATION MODEL

Storm surge response to the modeled hurricane wind and atmospheric pressure fields was computed using the ADCIRC model coupled with the Simulating Waves Nearshore (SWAN) model. ADCIRC is a finite element model that, in the 2-dimensional mode employed here, solves for water level using the generalized wave continuity equation (GWCE) and depth-averaged current using the shallow water momentum equations (Luettich Jr et al., 1992). SWAN is a third-generation, phase-averaged wave model for simulating wind waves in coastal and open ocean regions (Booij et al., 1999). ADCIRC and SWAN are coupled by passing the wave radiation stress computed from the SWAN wavefield to ADCIRC and passing the water levels, currents, and frictional parameters from ADCIRC to SWAN (Dietrich et al., 2011). Both models are run on the same unstructured mesh using triangular elements. Further details of the storm surge simulation model are described in Ullman et al. (In press).

The unstructured model mesh covers the northwest Atlantic, the Caribbean Sea, and the Gulf of Mexico with an open boundary at the 60° W meridian. It provides highest spatial resolution in key areas of interest and lower resolution in other areas, with triangular elements of the order of 50-100 km in size over deep ocean areas, decreasing to kilometer scale over the continental shelf. The mesh is highly refined in the region of interest (southern New England) where element sizes decrease further to 30 m along the coastline. The mesh extends inland of the coastline, to the 10 m elevation contour, in order to enable the simulation of overland inundation. The Fox Point Hurricane Barrier, constructed in southern Providence after devastating flooding during the 1938 hurricane and Hurricane Carol in 1954, was represented in the model mesh as a weir (dam) with a height of 7 m (Ullman et al., In press). The height of 7 meters and alignment of the barrier was verified using LiDAR elevation data.

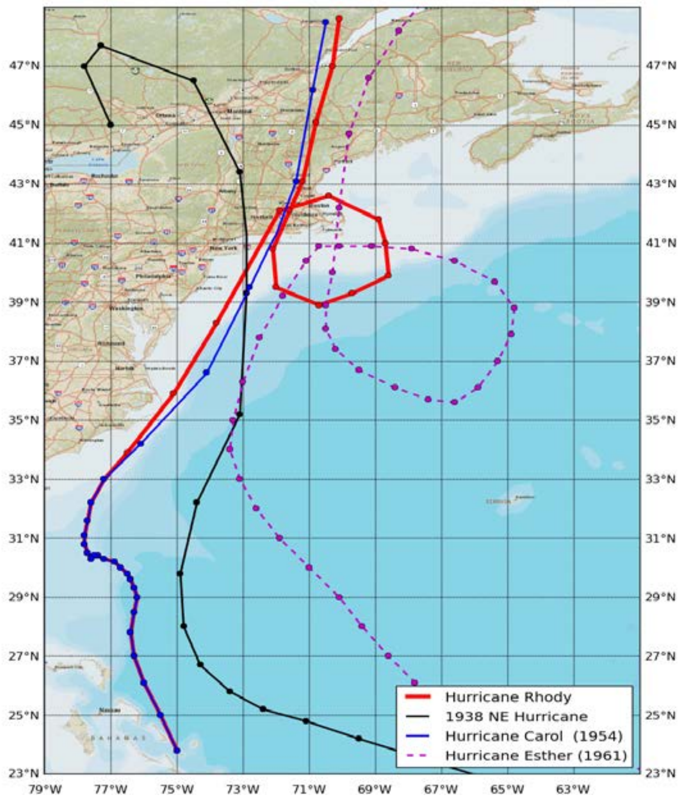

Figure 9, Hurricane Rhody track. Historical tracks of the 1938 New England Hurricane, Hurricane Carol (1954) and Hurricane Ester (1961) are shown as well.

A key input to any storm surge model is the bathymetry/topography of the region to be simulated. The bathymetry/topography of the Rhode Island region was interpolated from a digital elevation model (DEM) of the area provided by the Rhode Island Geographic Information System (RIGIS) with the vertical reference datum converted from NAVD88 to mean sea level (MSL), which is the natural datum of an ocean model. This adjustment, based on the NAVD88-MSL difference at the National Ocean Service tide gauge at Newport RI (NOS station 8452660), was 0.093 m. As this difference is small compared to the simulated storm surge elevations reported here and in Ullman et al. (2017), it is ignored in some subsequent analyses.

The coupled ADCIRC/SWAN modeling system was verified in the Rhode Island region with a simulation of Hurricane Carol, which impacted the area in the late summer of 1954. The water level time series from this simulation, performed using a mesh lacking the Hurricane Barrier which was not present at the time, were compared to observed water levels at Providence and Newport (Figure 10). The results indicate that the model accurately simulates the maximum water level during the storm surge, but that the duration of the model surge is too short relative to the observed storm surge. The reason for this is likely imperfect model wind forcing at the edges of the hurricane where the interaction of the hurricane and the mesoscale meteorology are not captured.

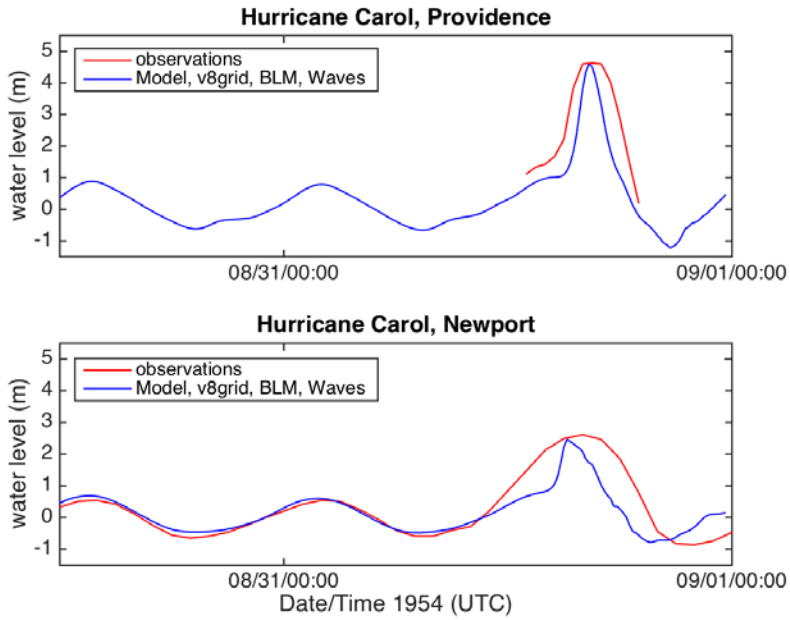

Figure 10, Time series of water level at Providence (top) and Newport (bottom) during Hurricane Carol. Observations are shown in red and model output is denoted by the blue lines.

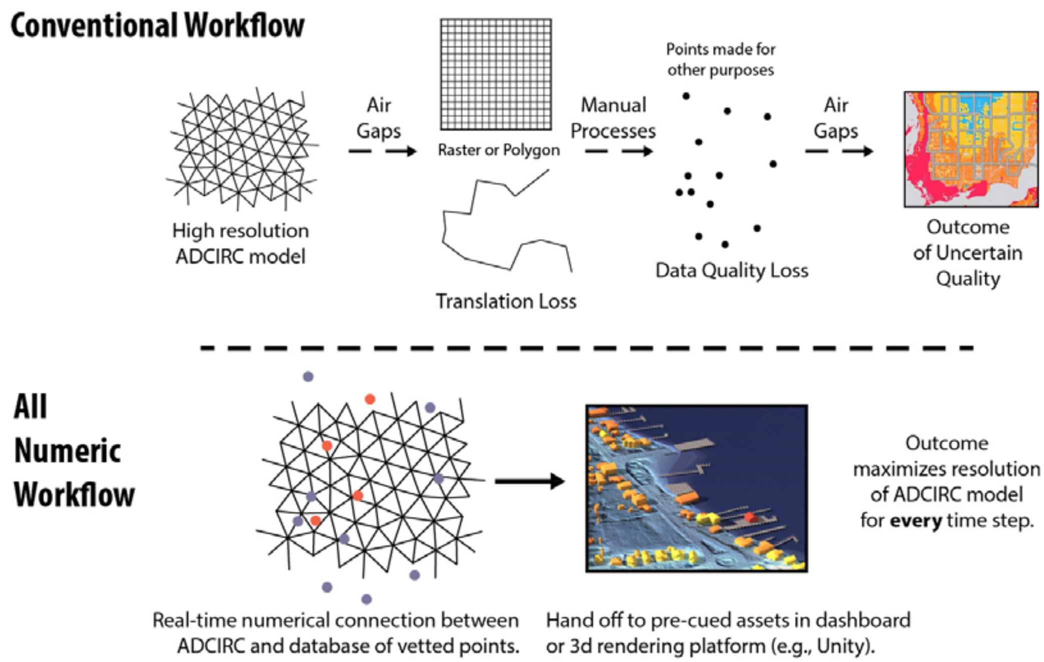

Figure 11. Comparison of conventional workflow and all numeric workflow.

ARCHITECTURE OF THE ALL NUMERICAL METHOD

OVERVIEW

Parallel of the HBL wind model and hydrodynamic simulations, the URI Department of Marine Affairs (MAF) has been developing hazard impact modeling and visualization methods based on the previously described all numerical connection to underlying models. Although this paper focuses primarily on connection to ocean models such as ADCIRC, the fundamental architecture can be applied to wind models or other simulations. Using these methods, geographic points representing specific pieces of infrastructure are indexed directly to multiple nodes of the simulation (Stempel, 2016).

Traditional GIS workflows typically involve transforming outputs of the ADCIRC or other model into raster maps or polygons that can be compared to geographic points using ArcMap or other applications (Figure 11). Depending on how this is accomplished, such procedures may involve multiple manual steps for each timestep tested, or compilation of maximum values. By contrast, the all numerical method pre-indexes each geographic point to nodes of the ADCIRC model (methods for interpolation are discussed in a subsequent paragraph). This indexing allows the values from the ADCIRC model to be associated with the geographic point, and for operations (calculating inundation depth at the point for instance), to be carried out continuously for each point for every time step without manual intervention.

The initial implementation of the all numerical method tested structures in the area around Galilee, Rhode Island, USA, and implemented damage functions developed by the U.S. Army Corps. Of Engineers as part of the North Atlantic Coast Comprehensive Study (Coulbourne et al., 2015). Once indexed to the unstructured grid, the structures and visualizations of those structures could be automatically updated based on adjustments to the model run, or tested against other storms (e.g., hurricane Bob) that was run on the same grid (*Figure 12*). In addition to cataloging attributes of structures, extensive data was gathered for testing of debris objects and infrastructure such as electrical transmission poles.

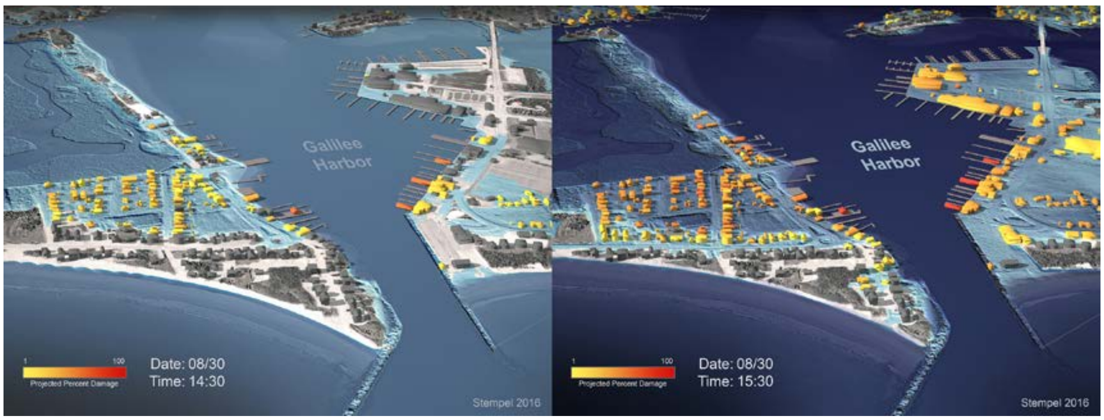

Figure 12. Progressive hazard impact model depicting the landfall of hurricane Carol at the port of Galilee, Rhode Island, USA, at present sea level and build out. Hazard impacts for each structure are calculated using the all numerical method. Outputs are configured to be directly used by the 3d visualization platform such that damage levels may be displayed for any timestep.

The fundamental architecture used to depict Galilee, Rhode Island USA, formed the conceptual basis for developing the all numerical method into a rapidly updatable method for hazard impact modeling in which tabular databases of information of geographic information are pre-indexed to the nodes of ocean models. Outputs from the hazard impact models are formatted to drive visualization and rendering platforms (e.g. Unity) such that outputs may control pre-established 3d model content. Simpler outputs may include dashboards, or, in the case of the IEMC, time incremented tabular impact reports (Figure 13).

INTERPOLATION

The fundamental innovation of the all numeric method is relating the geographic point and its attributes to the sea surface as described by the unstructured grid and interpolating values where necessary. The advantage of not using interpolation is speed of analysis over multiple timesteps. To determine the necessity of interpolation between points, a sensitivity test was performed in an area of concern in analyses, the Port of Providence. This analysis entailed 12,176 nodes. The first, second and third nearest neighboring points ranged between 22.8m apart and 73.9 meters. The variation reflects the optimization of the unstructured grid to fit the topography (e.g., greater node separation where less detail is required).

Most adjacent nodes vary by less than .003 meters (+/- 1/10th of an inch). The maximum variation between adjacent nodes in the sample set is .015 meters (.5 inch) (Figure 14). Given the small variation between relevant nodes, it was decided that interpolation was un-necessary. Similar tests in other sites yielded similar results. The maximum variation between nearest nodes across the State of Rhode Island for these timesteps is 2.47 meters, reflecting adjacent nodes in Block Island Sound.

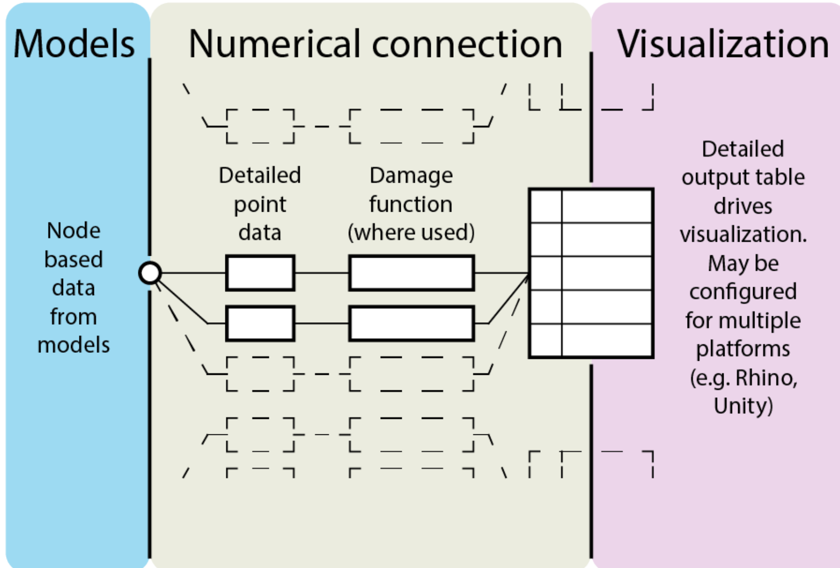

Figure 13. Basic workflow from model(s) to visualization. Output tables may be directly linked to information dashboards or designed to be ingested by visualization platforms such as Unity.

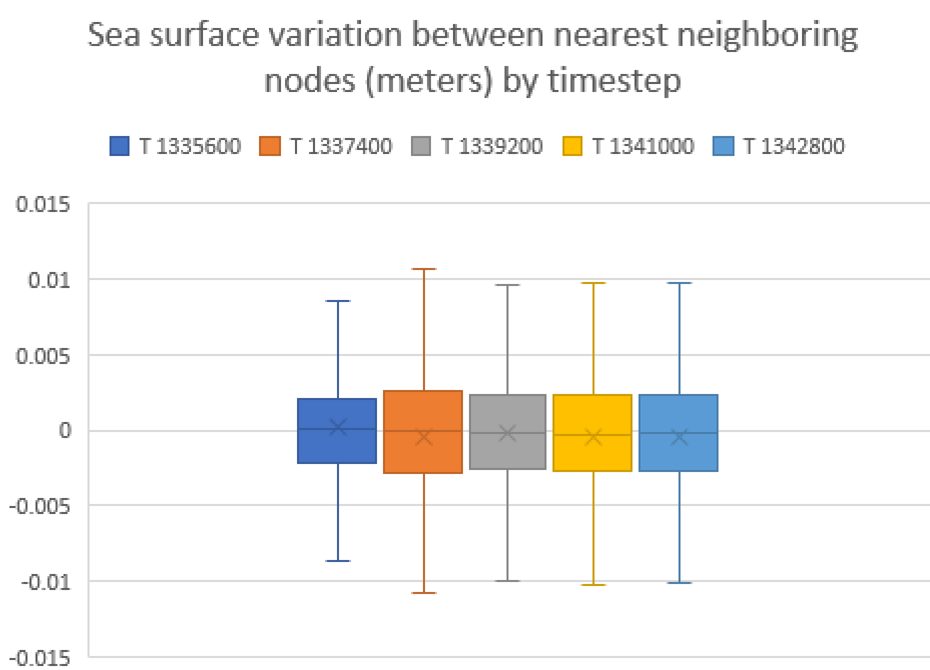

Figure 14, variation in sea surface for nearest adjacent nodes for timesteps during maximum storm surge of Hurricane Rhody in the Port of Providence.

Interpolation, where necessary, may be accomplished by indexing the geographic points to multiple adjacent nodes and using geometric interpolation, or processes such as inverse distance weighting. It's unlikely, however, that in situations where nodes are closely spaced such interpolation will be required. The indexing and associated interpolation or extraction methods include:

Geographic point with three adjacent wet nodes (nodes which are reported to be inundated by the ADCIRC model): interpolate sea surface elevation, water direction and velocity based on the geometric relationship of the point to the planar surface described by the three points. Geographic point beyond the last wet node: use nearest adjacent node without interpolation (Figure 15).

This interpolation method presumes that sea surface is described by the z of each node as a Delaunay triangulation. This is the optimal triangulation for the unstructured grid and thus identical to the ocean model grid with the exception of reflecting z elevation of the water surface (Chen and Xu, 2004) (Figure 16). The interpolated value is understood to be measured where it intersects with the plane described by the three points. Interpolation between node points is thus optimized for each geographic point based on the available data (Chen and Xu, 2004). The evaluation of points beyond the model grid accounts for situations where small-scale topographic conditions would cause inundation to extend beyond the last wet point of the ADCIRC model. All points are constrained by a basin analysis, such that points outside of the basin are not included. Vertical data, such as LiDAR derived ground elevation, inheres with the geographic point. Registration is accomplished by referencing a common datum.

Figure 15. Example of a point with three adjacent nodes (green) and point beyond the nearest wet node (blue). The red lines represent wet portions of the unstructured ADCIRC grid. Points tested are both inside and outside of the grid, and constrained by a basin analysis.

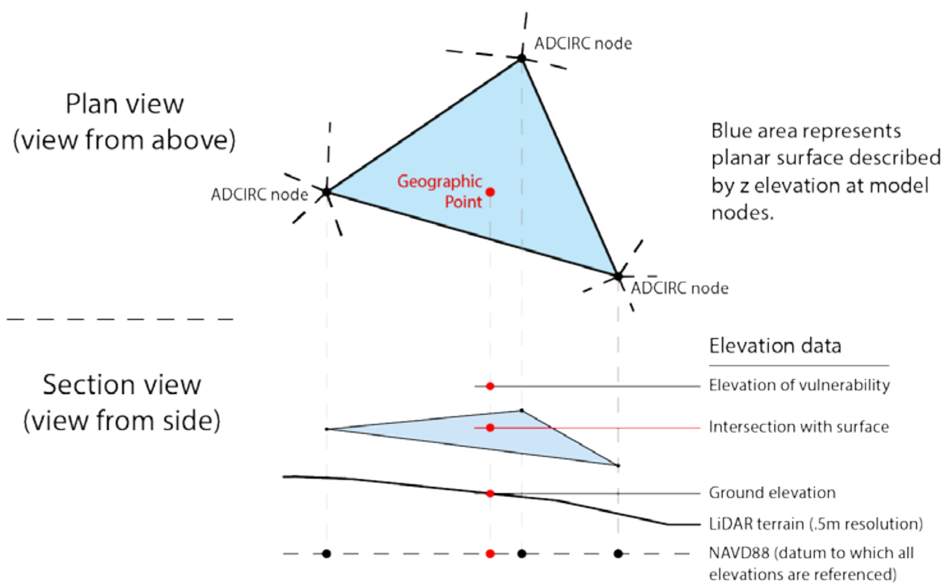

Figure 16. Interpolation between three points. A geographic point representing a facility is shown in red. The plan view is juxtaposed with a section view showing examples of elevation data related to the point.

The use of this method avoids compromises in speed and resolution associated with the translation of node-based data into raster maps. It allows outcomes for multiple timesteps to be easily determined and updated, and also preserves the elevation of the sea surface. Determining whether points are inundated based on transforming the wet portions of an ADCIRC model into a polygon defining inundation extent, by contrast, effectively transforms the middle areas of the simulation into a bathtub model (geographic points wet or not wet) even if the edges of the polygon capture elevation variation (e.g., if the polygon is determined through the comparison of two raster maps). In locations where there is significant change of geography, such as the narrowing of a river, the elevation of sea surface can vary by measurable amounts even in small geographic areas. (Figure 17).

Additional data, such as finish floor elevation of a structure, freeboard (clearance to vulnerable portions of a structure) details of its construction, or the presence and elevation of protective barriers such as flood walls inheres with the geographic point so that all calculations relevant to its involvement may be accomplished in a single process. Hazard impact assessments made with this method may thus combine a high degree of intricacy with speed, and potential improvements in resolution associated with interpolation.

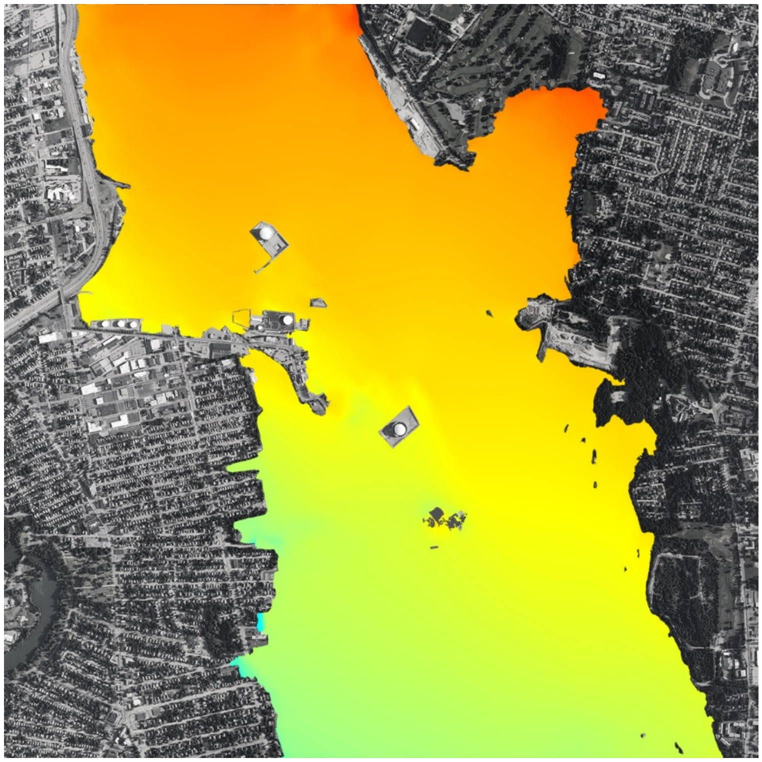

Figure 17. Variation in sea surface during a modeled inundation event. Total variation +/- 1 meter; total area shown 14km^2. Lowest relative elevation shown in blue, highest relative elevation shown in red.

QUALITY OF SPATIAL DATA

The improvements to resolution and intricacy referenced above are highly dependent on the quality of underlying data. A fractional improvement to methodology is meaningless if there are gross errors in underlying points. The resolution of data often depends upon the purpose for which it was created (Liu and Palen, 2010, Couclelis, 2003). Developing highly specific predictions based on generalized data that has not been vetted for that purpose is thus problematic, and create misleading results that imply a level of precision that is not supported (Liu and Palen, 2010, Sheppard and Cizek, 2009). Ground truthing of geographic points, a process of determining whether point data is sufficiently detailed or accurate, is thus essential if highly specific predictions are to be made.

Points associated with databases made for other purposes, such as e-911 databases, while sufficiently accurate at geographic scales may have limited utility at granular impact modeling scales. A single point representing a wastewater treatment facility, for instance, may be located arbitrarily or at the centroid of the land parcel that the facility occupies. The elevation of this point may be at a significantly different elevation than vulnerable portions of the facility. Moreover, facilities may include multiple vulnerabilities with distinctly different hazard exposures (e.g., inundation vs. wind). For this reason, individual points in here to individual structures within a facility, or minimally, are located based on vulnerability (Figure 18).

A sensitivity test comparing elevations of existing point data (obtained from Rhode Island GIS, e911, and Department of Homeland Security Office of Cyber and Information Security) was performed to compare the existing points used in analyses (e.g., points marking structures or the centroid of the property) with the elevation of the vulnerability (e.g. a clarifier that will be damaged if water exceeds an elevation). This analysis revealed the difference between the lowest existing point and lowest point of vulnerability had a mean of 2.33 meters. In the analysis, least elevated points for each site were compared with least elevated vulnerabilities, and most elevated points were compared with the most elevated vulnerabilities (

Table *3*). Thus, this assumes that when existing points are used in an analysis that the "worst case" is utilized. Had highest been compared to lowest, the variations would have been more extreme. Waste water treatment facilities, which employ gravity as part of processes, often feature elevation changes on site, and are therefore acute examples, however they are not unique.

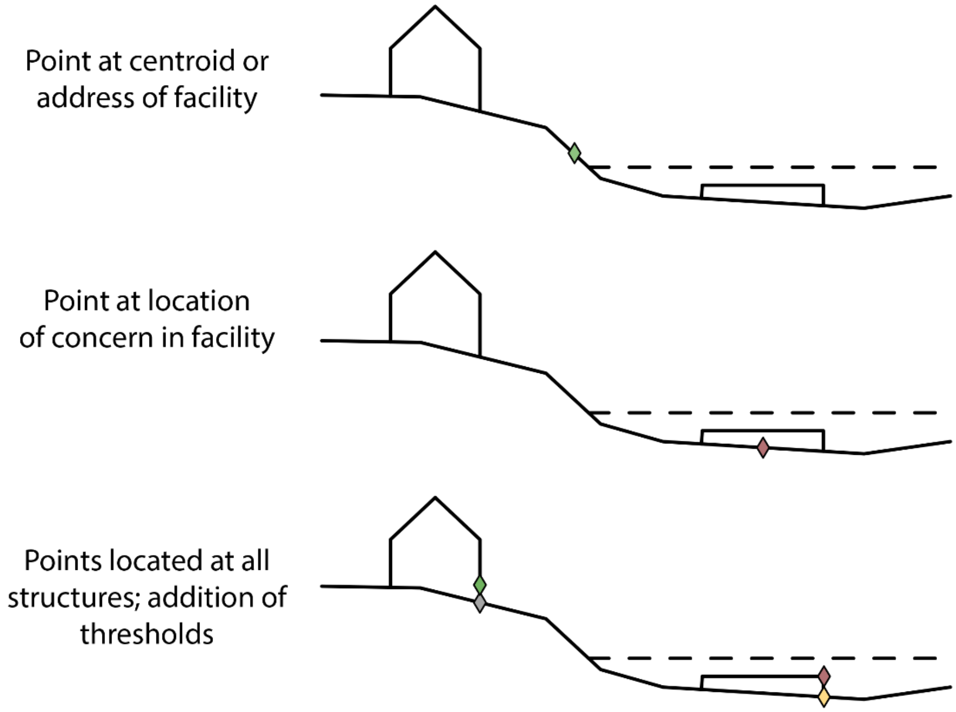

Figure 18. Implications of point location. Points used without verifying location in relationship to a vulnerability risk the creation of misleading results. While this may be less of a problem at geographic scales, specific impact assessments require specific data regarding individual vulnerabilities. The concept of "thresholds" is subsequently detailed in this paper.

Table 3, summary of sensitivity test of 14 Waste-water treatment facilities in Rhode Island. "Existing - lowest" refers to the lowest existing point tested minus the lowest elevated vulnerability on site.

	Range	**Existing - lowest**	**Highest - existing**
Max	14.18	5.42	0.82
Mean	4.54	2.33	-0.92
Median	3.34	1.55	-0.73

Bridges, similarly create complex analytical problems, as they are subject to multiple forces (e.g., scour, shear) (Robertson et al., 2007, Padgett et al., 2008), and often involve structures at multiple elevations. Representing a bridge as a single point is therefore problematic. In addition to the question of structural damage, there is a larger question of the role the bridge plays in emergencies in providing access. For this reason, special attention was paid to the elevation of highway access points in analyzing data for the IEMC (Figure 19). These access points play a significant role in transportation to and from a major Hospital.

Ground truthing is also necessary where micro-topographical conditions are invisible to the ocean model. Such is the case with armored concrete reinforced protective dikes that surround liquified natural gas storage tanks in the Port of Providence (Figure 20). These types of conditions have necessitated the development of special attributes within databases developed for the IEMC and other projects. The presence of these dikes, including the threshold at which they are overtopped, is included in the point data representing the tank. Although wind damage to petroleum storage tanks was not specifically modeled for IEMC, these facilities serve as a primary example of points that can have multiple damage modes (e.g., buoyancy, wind damage) (Chang and Lin, 2006), and thus may require data for multiple analyses.

Beyond obvious issues of accuracy associated with using granular data, attention to observed conditions likely plays a significant role in the perceived credibility of visualization outputs (Lange, 2001, Schroth et al., 2011a, Hayek et al., 2010). To the extent that abstract simulations like ocean models are treated as equivalent to reality without sufficiently accounting for these conditions there is a danger that inconsistencies between the model outputs and observed reality undermine the credibility of the models when they do not agree with observed reality (Wynne, 1992).

Figure 19. Comparison of points located at highway access ramps compared to span centers (green). Before being corrected, span elevation was recorded as the channel bottom (bathymetry). A more logical way to determine whether a span would be compromised would be to ascertain elevation based on the underside of the span (direct impact/shear failure) or at pier locations (scour) (Robertson et al., 2007, Padgett et al., 2008).

Figure 20. Example of micro-topographical condition. The gasometer is protected by an armored concrete dike that is not 'visible' to the ocean model. Determining inundation extents without accounting for this dike will lead to misleading results.

PARTICIPANT INPUT

The role of experts in developing hazard impact models is widely recognized, and is, for instance, specifically cited in the recommended methods for developing impact models beyond level 1 models as part of HAZUS (Vickery et al., 2006, Schneider and Schauer, 2006). As previously argued however, there are logical questions regarding the application of generalized statistically derived damage curves to highly specific structures. Even in situations where appropriate ground truthing has taken place regarding the geometry of a vulnerability, the application of a generalized curve may not be appropriate. The description of highly specific outcomes based on vague data, for instance, can make highly uncertain outcomes appear certain (Kostelnick et al., 2013). This issue was particularly concerning as it pertained to the IEMC because of the need for highly specific outcomes (e.g., disruption of a generator or communication tower) to be reported as prompts used during the exercise.

To address this, a process to engage emergency managers was initiated at the outset of the process in collaboration with RIEMA. This process enlisted local emergency managers in the development of model inputs that would be used in generating the hazard impact models. These inputs primarily included the development of a "thresholds database" that included specific facilities of concern and quantifiable thresholds at which described outcomes could be expected.

The concept of using thresholds or triggers to define inter-related impacts of storm events is drawn from approaches to planning that seek to organize responses to uncertain future conditions and interdependencies (Ranger et al., 2013, Brown et al., 2011). In these planning processes, thresholds are identified for different levels of future hazards to assess future vulnerability (Brown et al., 2011, Ranger et al., 2013). As it pertains to the methods used by URI, quantifiable triggers related to measurable effects of wind, rain, and inundation were collected to be used as model inputs to be tested against storm scenarios and incorporated into databases tested against the relevant models. Where multiple factors contributed to a specific impact (e.g., the combination of wind and ground saturation from rainfall), connection between models was made manually. In future iterations, it is conceivable that such hand offs could be made automatically between parallel models referencing a common point database.

The adaptation of these methods made it possible to extend impact modeling to facilities for which there were not existing damage functions (e.g., communications towers compromised by wind or inundation, or cascading effects of communications outages). If further provided a credible basis for including areas of concern not conventionally captured by point based analysis (e.g., needed evacuation of a trailer park based on ground saturation and wind, creating a treefall hazard).

It also provided an opportunity for local emergency managers, and emergency managers overseeing the process to participate in the development of the hazard impact modeling, such that outcomes tested in the models reflected ongoing stakeholder input. This involvement of participants has the potential to increase transparency and make the technical aspects of the process less of a “black box” (Schroth et al., 2011b). This participation may serve to enhance the perceived legitimacy of the outputs and build faith in the process (White et al., 2010). The further development of these methods thus not only expands the range of impacts that can be credibly modeled at a granular scale, it may be critical to the perceived credibility of the underlying processes (White et al., 2010).

NEXT STEPS

The all numerical approach to hazard impact modeling has been developed as part of a larger effort to connect high resolution ocean models to detailed 3d visualizations. This is accomplished by indexing 3d model assets of structures and objects such as buildings bridges, telephone poles, and debris objects to the previously described geographic points. In the context of the IEMC, the use of these visualizations was confined to depicting inundation (Figure 21) for two reasons:

- While the potential of 3d visualizations to make difficult to imagine impacts seem more tangible is widely acknowledged (Moser and Dilling, 2011, Sheppard, 2015), the effects of such visualizations on perceptions of risk, however, is less clear (Kostelnick et al., 2013, Bostrom et al., 2008). There are concerns that highly detailed depictions of impacts may make uncertain outcomes appear more certain than they are by virtue of contextualizing less detailed information in highly specific contexts (Kostelnick et al., 2013). Further research is needed to better understand the effects of these visualizations on risk perception. There is more generally, a lack of understanding of how 3d graphics and visualizations may influence perception of risk (Kostelnick et al., 2013). The development of the thresholds database, and the implementation of iterative processes involving end users is based in part on practices intended to contextualize and support the use of visualizations (Schroth, 2010). These practices will be further developed and refined based on the outcome of these surveys.

- At the time of the IEMC databases had only been developed for a limited number of sites and facilities. Representations that mix structures for which there is highly detailed information available with structures for which there is no data may create misleading impressions due to the absence of reported effects. To the extent that specific vulnerability information is gathered from multiple emergency managers, there is also a concern regarding the consistency of the reported data for modeling purposes. This requires further development of consistent methodologies to elicit vulnerability data. The implementation of the databases as part of the IEMC has led to an ongoing collaboration between RIEMA and URI to develop more comprehensive databases for critical facilities in the state.

CONCLUSION

The implementation of these methods as part of the IEMC suggested that there was merit in the use time incremented impact analysis to better understand the progression of storm impacts. For instance, impacts of the 1938 Long Island Express hurricane which is often referenced by citizens and emergency managers in Rhode Island unfolded with particular swiftness for much of the state (Allen, 1976, Blake et al., 2007). The simulated storm used for the IEMC, by contrast, combined rapid storm surges and lingering rain and wind effects over multiple days (Ullman et al., In press). The volume of rainfall (46”) generated by the storm was more similar to Hurricane Harvey which made landfall two months after the exercise than it was to the Long Island Express (Pérez-Peña et al., 2017, Allen, 1976). The catastrophic effects of rainfall of Hurricane Harvey are a stark reminder that Hurricanes may do damage through means that are not anticipated by the public or emergency managers (Pérez-Peña et al., 2017), and that may be very different from previously experienced storms. This may be especially important at a time when, through the use of high resolution modeling, we can anticipate the possibility of highly unlikely but catastrophic events (Lin and Emanuel, 2016).

The use of time incremented hazard impact modeling also raises questions regarding the compression of events in training exercises. Damage modeling provided by the Department of Homeland Security Office of Information and Cyber Security (DHS OICS) that was also used in the exercise, indicated substantial wind impacts (80-100% of the state without power) 24 hours before the first storm surge made landfall. This placed substantial impacts prior to the bulk of the exercise, which was centered on the first of two storm surges. Furthermore, maximum rainfall occurred in the days following the first surge, prior to a second lesser surge making landfall. This points to a what may be a larger issue to be aware of during training: the compression and potential mis-ordering of anticipated effects. To the extent that storm impacts can vary widely, chronological impact assessment may be a valuable tool to better anticipate and train for the impacts of hurricanes. These experiences, although limited in scope, suggest that further development of these methods is warranted to improve the capacity to predict and depict impacts of modeled storms.

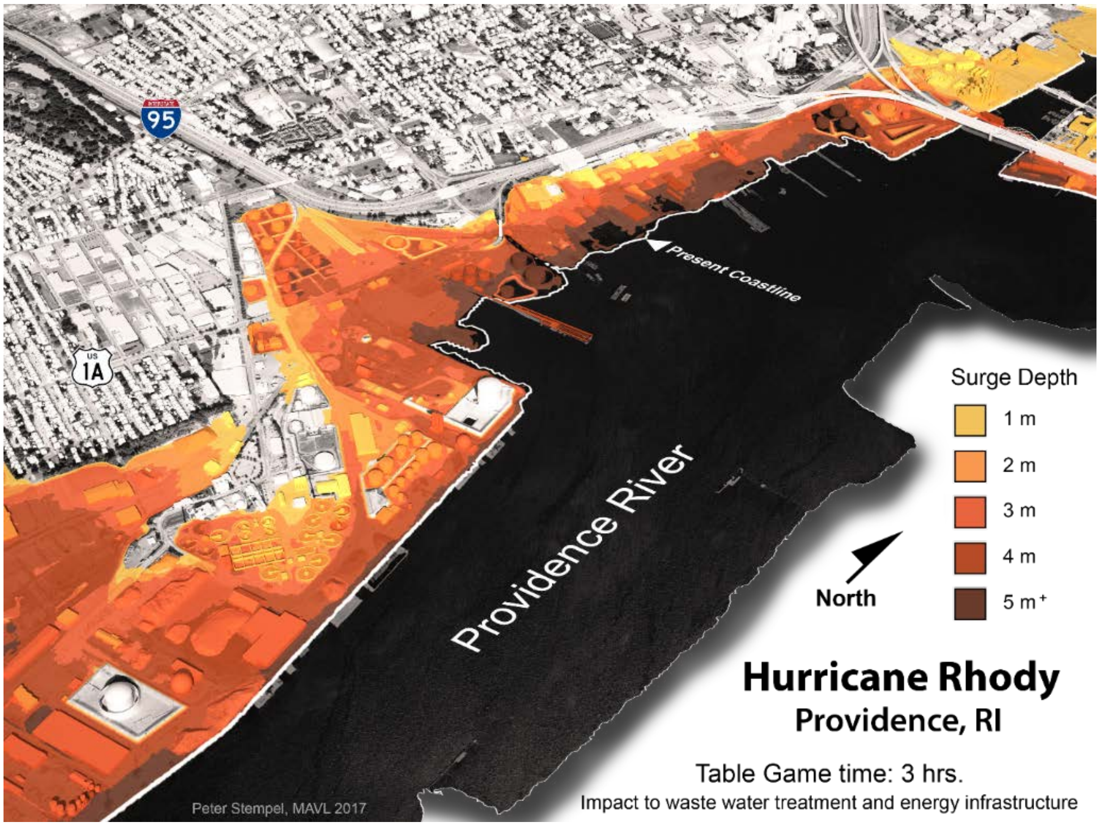

Figure 21. Inundation of waste water treatment and petroleum infrastructure near the height of the first surge of the simulated storm (Hurricane Rhody). Structures depicted in the visualizations are individual 3d models that are linked to hazard impact model output tables.

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CHAPTER 3

ARE VISUALIZATIONS SCIENTIFIC?

HOW VIEWER EXPECTATIONS FOR SCIENTIFIC GRAPHICS SHAPE PERCEPTIONS OF STORM SURGE VISUALIZATIONS

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ABSTRACT

This research uses semi-realistic 3d visualizations of storm-surge to explore the way viewer expectations of scientific graphics influence ratings of visualizations, and the characteristics that contribute whether they regard those visualizations as being “scientific”. Expectations may be shaped by a range of social, cultural, and contextual factors such as experience with past visualizations or events and expertise.

An online survey (n = 735) provided semi-realistic visualizations of storm surge and asked respondents to rate the degree to which they regarded the visualizations as being “scientific”. A separate question asked what characteristics made a graphic or visualization “scientific.” Responses were coded and compared to respondent ratings and other social, cultural, contextual factors and comments. Results suggest that some scientists and members of the lay public believe that scientific graphics are plain, unadorned presentations of data (Walsh, 2017, Walsh, 2014). These perceptions, however, are not monolithic: people bring with them expectations that are conditioned on their experiences with similar graphics (e.g., maps depicting storm surge) (Kostelnick and Hassett, 2003), and other social and cultural factors commonly associated with risk perception (e.g., income) (Morgan, 2002). Differences also arise based on expertise (e.g., between emergency managers, planners and academics), and different ways of “knowing” expressed by scientists, academics, and the lay public. Absent a means to access the underlying technical information, for instance, survey results show that respondents openly admit to making determinations based on whether the depicted result matches their own personal experiences and expectations.

The degree to which a visualization is regarded as 'scientific' is thus conditioned on what new information is being added to a basis of shared assumptions. By embedding these concerns in practical guidance for ocean scientists and coastal managers, this research models a path to better addressing questions of argumentation in semi-realistic visualizations, and scientific graphics more generally.

KEYWORDS

storm Surge, visualization, risk communication, visual rhetoric, argumentation

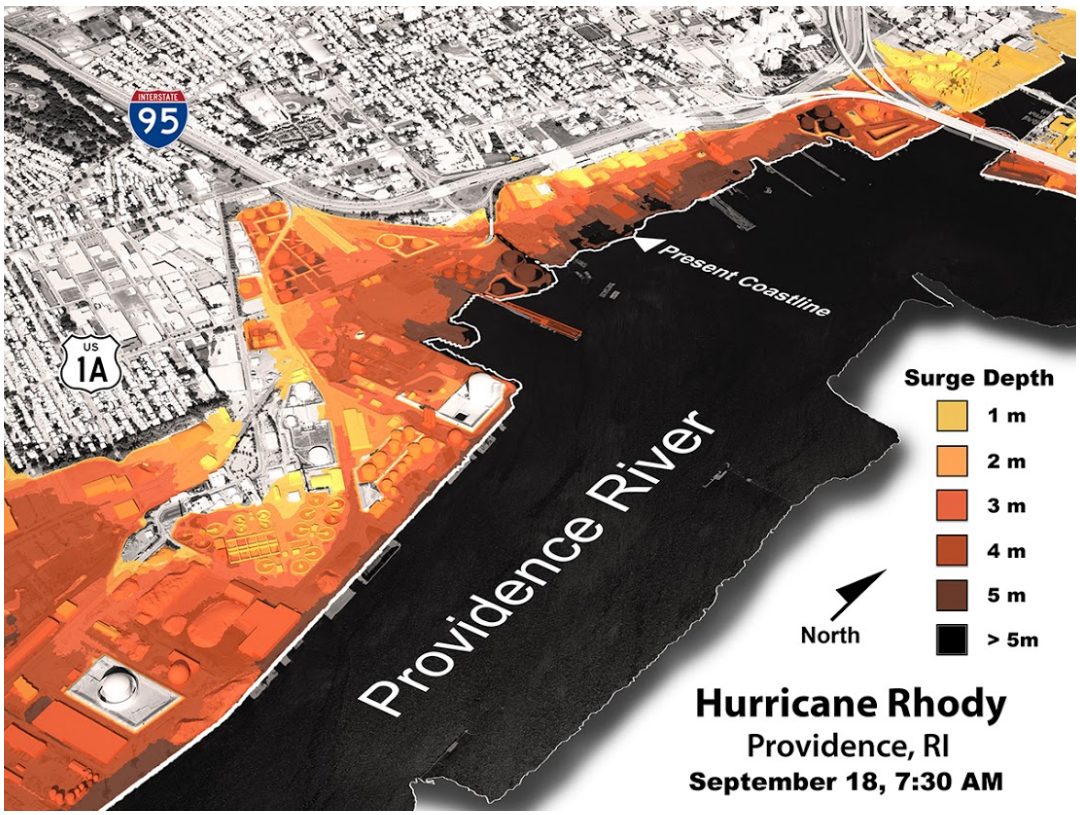

Figure 22, a semi-realistic visualization of a modeled extreme hurricane striking Providence, Rhode Island, USA. Image: Author

INTRODUCTION

Coastal communities are subject to increasing but uncertain risks from storm surge and sea level rise (Woodruff et al., 2013, Romero and Emanuel, 2017). Scientists and researchers employ novel visualization technologies to better communicate these risks to policy makers and the public, including semi-realistic 3d visualizations of recognizable places (Spaulding et al., 2016, Sneath, 2017, Fenech et al., 2017) (Figure 22). Although these visualizations are typically used in planning and training contexts, they are also used in mass media such as newspapers and on the web (Spaulding et al., 2016, Fenech et al., 2017, Kuffner, 2016). In addition to depicting inundation, the visualizations tested in this study include individually controllable 3d structures that can reflect modeled damages and sophisticated visualization architectures that allow for rapid visualization of multiple scenarios (Figure 23) (Spaulding et al., 2016, Ginis et al., 2017b).

Semi-realistic visualizations fall outside of conventional frameworks that might otherwise guide visual rhetoric produced by ocean scientists and engineers. Cartographic frameworks for visualizing risk, for instance, discourage the use of realistic representations because the level of detail typically overstates the resolution at which the underlying models are predictive and obscures uncertainties (Kostelnick et al., 2013, Bostrom et al., 2008).

This research challenges and expands current frameworks for visualizing risk by asking how viewers' expectations shape their own perceptions. Although existing frameworks acknowledge the role of affective response and social and cultural factors, they tend to emphasize these factors as complications that disrupt the viewers' understanding of the underlying probabilistic models (Bostrom et al., 2008, Kostelnick et al., 2013). This work seeks to better define the effects of expectations of scientific graphics; social, cultural and contextual factors; to inform the current practice of ocean scientists and engineers who employ these visualizations; and explore approaches that may yield generalizable frameworks that better account for these effects.

> Argumentation:
>
> At some level, every graphic or visualization is designed to persuade, even if only by arranging data and putting it in an order so as to make meaning apparent (Tufte and Weise Moeller, 1997, Latour, 1990a). The ordering and presentation of data to make it more persuasive is argumentation.

OBVIOUS ARGUMENTATION

Semi-realistic visualizations, like the ones tested in this study, employ obvious argumentation: representational decisions, such as use of simulated light and shadow and evocative colors, are designed to make the visualizations more appealing and thus more persuasive (Sheppard et al., 2008, Sheppard, 2001, Sheppard, 2005). The extensive use of argumentation contradicts popular notions held by some scientists and members of the lay public that the graphics produced by scientists and technical experts are plain, unadorned presentations of data that eschew obvious argumentation (Walsh, 2014, Walsh, 2017). Visualizations of storm surge thus form a particularly potent case to explore the relationship between expectations of scientific graphics on the part of scientists, experts, and the lay public and the way those expectations influence ratings of visualizations.

Two questions were asked in an online survey (n = 735) that more broadly addressed perceptions of risk and credibility associated with semi-realistic visualizations (Figure 23). Respondents rated the degree to which they regarded visualizations as being "scientific", and then identified characteristics they felt made a graphic or visualization "scientific".1 Regression analysis determined which of the subsequently coded factors identified were most predictive of the rating. Although it would be possible to define the word scientific (e.g., something related to scientific principles or processes), for purposes of this research, respondents to the survey were allowed to define for themselves what was implied by the word "scientific". This is elaborated in the background section.

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[1] The question of being scientific is particularly relevant to the visualizations being tested here because they are made using a visualization architecture that allows visualization outputs to be directly linked to and controlled by ocean models GINIS, I., KINCAID, C., HARA, T., ROTHSTEIN, L., ULLMAN, D. S., HUANG, W., ROSA, K., CHEN, X., ZHOU, X., RUBINOFF, P., BECKER, A., STEMPEL, P., WITKOP, R. & HASHEMI, M. R. 2017b. Modeling the combined coastal and inland hazards from high-impact hypothetical hurricanes. Appendix to the annual project performance report prepared for the DHS Coastal Resilience Center.: University of Rhode Island.. This approach bypasses traditional methodologies that emphasize the interpretive role of intermediary communicators TRUMBO, J. 2000. Essay: Seeing science: Research opportunities in the visual communication of science. *Science Communication,* 21**,** 379-391, SHEPPARD, S. R. 2015. Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning,* 142**,** 95-105., and emphasizes the visualization as a product of a scientific and technical process.

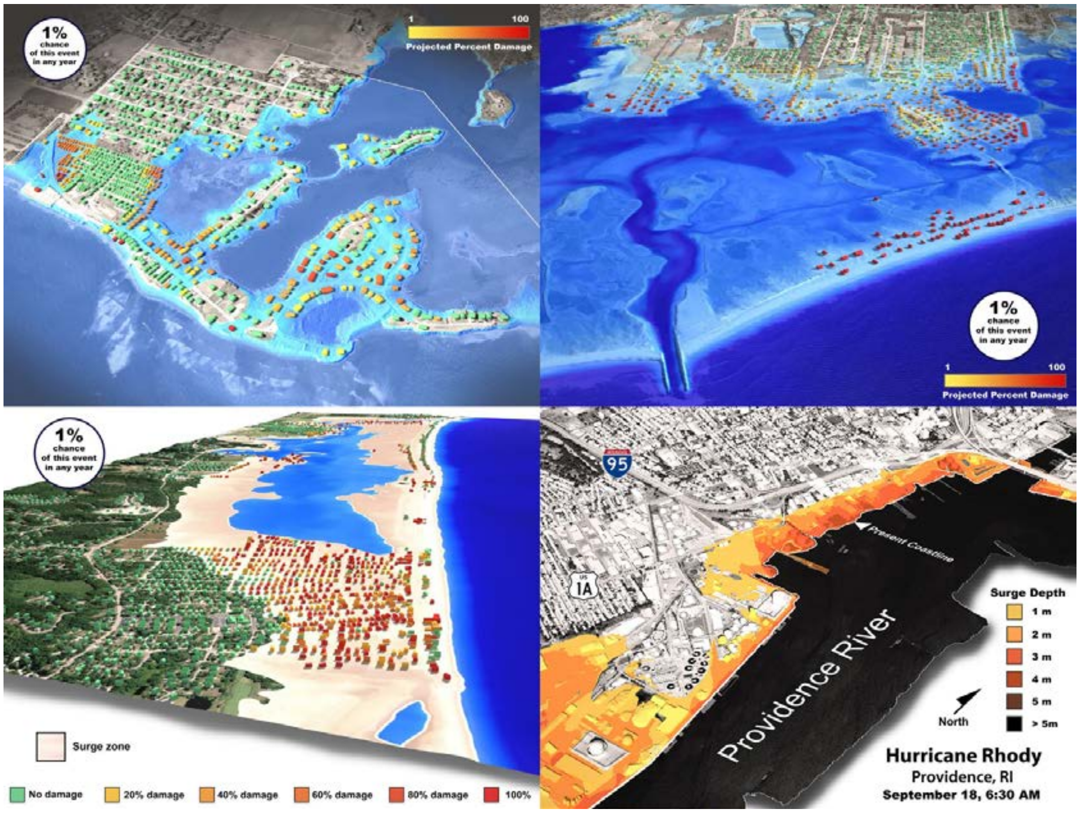

Figure 23, four visualizations that were developed by the author and used in the survey. Each visualization exhibited different stylistic characteristics such as the distance at which the view was framed, and the color schema used. The image in the lower right is similar to figure 22, but with a lower level of inundation shown. Image: Author

RELEVANCE TO THE SPECIAL ISSUE

There is no shortage of guidance relevant to the use of realistic and semi-realistic visualizations developed in small-scale case studies using qualitative methods. These have largely taken place in the context of landscape and urban planning and other adjacent fields (e.g., Sheppard 2012). Whether these results are applicable, recognizable and acceptable to ocean scientists and engineers who employ semi-realistic visualizations of storm surge, however, is an open question (Graham, 2018). For these reasons, this work aspires to create specific, practical, and actionable conclusions using methods with standards of reliability and validity (large scale quantitative survey and linear regression) that are recognizable to the intended audience. In so doing, this research seeks to model an approach to "durability" and "portability" by extending and testing largely qualitative knowledge derived from case studies and interpretive research (Latour, 1987). It further confronts apparent epistemic incompatibilities between disciplines (e.g., social scientists using qualitative or interpretive methods, physical scientists using quantitative methods) by embedding practical and epistemic concerns of rhetoric in practical guidance for ocean scientists and technical experts. The format of this paper thus follows a traditional format for an experimental paper (introduction, background, methods, results, discussion, conclusion) and to the extent possible frames concepts in plain language.

BACKGROUND

WHY USE SEMI-REALISTIC VISUALIZATIONS?

The case for using realistic and semi-realistic visualizations to better communicate risks2 has largely been made in the context of landscape and urban planning. In that context it is understood that 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 et al., 2008, Sheppard, 2015). Depictions of recognizable contexts may

[2] The literature in landscape and urban planning frames the utility of realistic visualizations in terms of engaging the public and motivating behavior change SHEPPARD, S. R., SHAW, A., FLANDERS, D. & BURCH, S. 2008. Can visualization save the world? Lessons for landscape architects from visualizing local climate change. *Digital Design in Landscape Architecture*, 29-31, SHEPPARD, S. R. 2005. Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science & Policy,* 8**,** 637-654, SHEPPARD, S. R. 2015. Making climate change visible: A critical role for landscape professionals. *Landscape and Urban Planning,* 142**,** 95-105.. The construction of the argument, however, fundamentally hinges on the literature in risk perception (e.g., Slovic and Peters), and is framing climate-related risks (particularly Sheppard, 2005). Although the construct avoids discussing these visualizations as tools of risk communication, that is what is taking place.

further stimulate feelings of place attachment, thus increasing instantaneous subconscious emotional reactions, known as affective response, and potentially increasing 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., 2011b, White et al., 2010). This may include providing inputs to predictive models (Schroth et al., 2011b). As will be subsequently argued, this reflexive engagement also provides a means to manage argumentation (e.g., the use of drama to make a visualization more engaging or persuasive).

These reflexive processes typically involve multiple workshops or other gatherings of less than 50 people that facilitate interaction between stakeholders and technical experts (e.g., Schroth, Hayek, Lange, Sheppard & Schmid 2011). Although practices and methods for using realistic and semi-realistic visualizations in these contexts are highly evolved (Sheppard et al., 2013), the question of how audiences perceive visualizations (e.g., effects on risk perception, perceived legitimacy) outside of such processes, such as in a newspaper or online publication, is largely unanswered (Deitrick and Edsall, 2009). There are widely acknowledged research gaps as to how visualizations of probabilistic risk, and visual rhetoric produced by scientists more generally, are perceived (Leshner et al., 2016, Bostrom et al., 2008, Kostelnick et al., 2013). Semi-realistic visualizations, such as those tested here, thus fall into a kind of neither-world outside of both disciplinary frameworks (e.g., cartographic frameworks for visualizing risk such as Kostelnick et. al., 2013), and paradigms that rely on workshop processes like those described above.

EVOLUTION OF CURRENT PRACTICES

Practical and ethical guidance for the use of realistic and semi-realistic visualizations has not always been so dependent upon reflexive processes. In the early 2000's, much of the visualization research in landscape and urban planning was more generalizable. It emphasized the validity of visualizations for decision making purposes (e.g., whether visualizations were sufficient surrogates for reality (Lange, 2001) and identifying appropriate levels of realism (Appleton and Lovett, 2003)). This focus reflected the primary use of visualizations as tools to make near-term planning decisions (e.g., forest management, a proposed bridge alignment) (Sheppard, 2001). Proposed ethical principles emphasized the "representativeness" of views in relationship to the landscape, and their conformance to expected conditions to avoid manipulation of the form or presentation of a proposal to favor a desired outcome (Sheppard, 2001).

Depicting potential climate change in visualizations introduced additional problems of spatial and temporal uncertainty that made it difficult to measure "representativeness", inviting dramatization and advocacy (Sheppard, 2005, Sheppard et al., 2008). Sheppard proposed the notion of "permissible drama" as one way to manage this problem. "Permissible drama" suggests that there is a discernable qualitative distinction between an appropriate level of argumentation and what could be considered "persuasive imagery" (e.g., advertising)(Nicholson-Cole, 2005, Sheppard, 2005).

That distinction, however, was difficult to discern (Sheppard et al., 2008). There were also situations in which drama was highly problematic and created backfire effects. Visualizations depicting extreme scenarios, for instance, were shown to overwhelm audiences and reduced feelings of individual self-efficacy in taking action to mitigate climate change: precisely the opposite of what some proponents of visualizations hoped to accomplish (O'Neill and Nicholson-Cole, 2009, Sheppard et al., 2008). These and other complexities led proponents of realistic and semi-realistic visualizations (e.g., Sheppard, Schroth) to develop techniques in which stakeholders are consulted throughout the visualization process.

Stakeholders or skilled communicators sensitive to local conditions assist with defining the scope of uncertain parameters as well as physical and temporal extent of the visualization (Sheppard et al., 2013, Sheppard et al., 2008, Sheppard, 2015, Schroth et al., 2011a). Stakeholders thus play a role in managing aspects of the visualization that could otherwise be manipulated for purposes of argumentation (e.g., choosing a timeframe or scenario that creates a more extreme and dramatic outcome). The evolution of this paradigm suggests that one way to manage persuasive aspects of visualizations used outside of such processes is to query and understand the ways in which user expectations inform perceptions, as is proposed in this study.

IS IT SCIENTIFIC?

Practices for creating realistic and semi-realistic visualizations are heterogeneous (Lovett et al., 2015), as are practices for creating scientific graphics more generally (Walsh, 2017). Practices depend upon a range of factors including local disciplinary culture and the availability of skills or expertise and tools (e.g., software) (Lovett et al., 2015, Walsh, 2017). In the context of the sciences, notions of what makes a representation valid are also varied and largely depend upon standards that are culturally determined by disciplinary practice (Van Fraassen, 2008, Mansilla, 2006). What is included or excluded, what constitutes appropriate scales and types of representation are often determined individually, or informally among small communities of practice (Van Fraassen, 2008, Walsh, 2017). It is thus difficult to categorically define what constitutes a scientific visualization or graphic.

For purposes of this study, it is assumed that anything that is the product of scientific or technical process involving scientists is in some way scientific. The lack of a standardized definition of what constitutes a scientific visualization or graphic does not inherently prevent a comparing a respondent's assessment of the degree to which a visualization is "scientific" to their stated expectations. If anything, the degree to which respondents define for themselves what "scientific" means allows for a wider range of expectations regarding perceived scientific authority and practice to be revealed and tested. The rating of the degree to which visualizations are "scientific" was thus paired with a question to elicit characteristics against which it can be analyzed:

What characteristics contribute to your assessment of whether a visualization, representation, or graphic is scientific?

The rhetorical framing of that question, and the rating question were designed so as not to presuppose the visualizations tested were scientific, or to assume distinctions between visualizations and scientific graphics. Consider the difference between the rating question that was used in the survey:

The visualizations you reviewed incorporate scientific data, do you regard the visualizations as scientific? (Rating scale of 0-100, not scientific at all – very scientific)

And an alternate wording that was proposed by more than one colleague:

The visualizations you reviewed incorporate scientific data, do you regard the visualizations as accurate depictions of scientific data?

The question as used in the survey leaves open the possibility of responding that the visualizations are not scientific at all (by setting the response slider to 0), or to consider degrees of "scientific-ness" by adjusting the slider to any of 99 other possible positions.

The alternate construction of the question draws a distinction between data and visualization and ignores the degree to which choices made in the underlying science are also subject to argumentation (e.g., scenario selection-choosing a worst case as opposed to a more likely case) (Walsh, 2014).

This research therefore takes the epistemic position that representation is a fundamental act of science, and that all science exists in representation. A recorded observation fundamentally represents phenomenon, and thus transforms it (Van Fraassen, 2008). We may describe a measurement of the tide as "the tide", but this conflation of the phenomenon and the measurement that represents it is an act of convenience (Van Fraassen, 2008). The degree to which charts, graphs and other graphics transform data by making it persuasive is thus but one of many transformations used to distil and communicate meaning, and one of many layers that are subject to argumentation (Walsh, 2015, Latour, 1990a, Walsh, 2014).

The question is thus not whether persuasion and argumentation are at play, but rather how to manage that argumentation, especially as revealed in graphics and visualizations that are used outside of communities of practice and or disciplinary boundaries where common cultural practices set mutual expectations (Walsh, 2014, Van Fraassen, 2008). This research proposes that understanding audience expectations of graphics and visualizations may play a role in answering this question.

METHODS

SURVEY INSTRUMENTS AND RESPONSES

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. Distribution was designed to maximize the cross section of expertise, degrees of familiarity with the visualizations, and degrees of familiarity with the locations depicted. This resulted in a purposive sampling method that utilized a variety of email lists, social networking sites, word of mouth, and other similar means to achieve these cross-sectional characteristics. Venues included email lists (e.g., Department of Homeland Security, Center for Excellence, local business groups), social media, and a purpose-built website for the survey that could be easily shared by members of the public (www.vissurvey.com). Sharing was encouraged. No personal identifying data was collected. All responses were anonymous. To the extent practical, question randomization was employed (e.g., the order of visualizations and some questions was changed randomly).

There were a total of 735 responses to four closely-related survey instruments as summarized in Table 4. The primary distinction in survey instruments was between the expert survey and the public survey. The expert survey included additional questions about how probability and uncertainty should be represented as part of another aspect of this research not discussed in this paper. Additional minor variants of the expert survey were created with text and additional questions that better acknowledged identified populations of experts. For instance, the maritime survey instrument included an additional question that allowed respondents to indicate credentials such as a pilot's license in addition to traditional questions regarding education. This sign of respect was regarded as important to encouraging participation.

Table 4, survey instruments, number of responses.

Survey instrument	Number of responses
Expert survey	115
Public survey	598
Planner's survey	11
Maritime survey	11

Qualifying questions were included in all surveys identify multiple types of expertise. This included categorical questions and open-ended questions (e.g., job title/role). This approach allowed for distribution of the public survey instrument without having to use exclusionary statements or qualifiers that might discourage participation. The breakdown of respondents based on these classifications is summarized in

Table *5*. Further subdivisions of expertise (e.g., among scientists and academics), were also recorded for use in other analyses not presented here. Differing degrees of familiarity were similarly recorded and are summarized in

Table *6*. The differing numbers reported reflect absent responses. Responses for which question data was incomplete were disregarded in the analysis. Simulated data was not used.

Table 5, summary of respondents by category of expertise. The remainder of respondents did not complete sufficient questions for categorization. In some cases, respondents fit more than one category.

Expertise	**Respondents**
Scientists and academics	119
Government and elected officials	73
Emergency managers	48
Planners	39
Maritime industry	12
Non-experts (persons not fitting into the above categories)	418

Table 6, degrees of familiarity with the visualizations being tested.

Degree of familiarity	**Respondents**
Worked on or near the team responsible for the visualizations being tested	25
Encountered the visualizations being tested in a training session	33
Have seen the visualizations being tested (e.g., in media)	89
Not familiar with the visualizations being tested	586

SUPPORTING INFORMATION PROVIDED

In addition to the epistemic considerations discussed in the background, the survey design was also informed by the practical realities of the ways visualizations are decontextualized and disconnected from underlying processes when used in mass media (Deitrick and Edsall, 2009). For this reason, supporting information and descriptions were deliberately concise and limited. Overly technical explanations that might in and of themselves serve as symbols of scientific legitimacy were avoided. Statements thus included:

- A statement that the visualizations were the product of computer simulations of hurricanes that in some cases included simulation of damages to structures.
- A statement of probability indicating that the depicted event had a 1% chance of occurrence in any year. Probability was also restated in an example of the labeling, and in labels included in the visualizations. Related to this:
    - References to historic storms, or the "100-year storm" were deliberately avoided and not included anywhere in the survey. The construction utilized (1% of occurring in any year) is easily understood, and less likely to create mis-impressions of probability (Keller et al., 2006).
    - The effects of sea level rise were not included in any of the presented scenarios due to the ambiguity of compounding uncertainties.
- Attribution to the University of Rhode Island, Rhode Island USA.

An enlarged graphic showing an example of the probability label and legends was also included in the introductory materials, and the visualizations and labels were pre-tested to ensure clarity on mobile devices. Further keeping with this approach, the length of the survey was minimized to encourage participation and completion.

ANALYSIS

After initial coding of the expert and non-expert cohorts, answers to the "what factors contribute to your assessment of whether a graphic or representation is scientific" question were coded using NVIVO software. NVIVO was chosen for the ease of viewing coded responses in context and by coded group to ensure consistency among groups. To the greatest extent possible, literal groupings of identical phrases (which were predominant) were used as codes. A response that cited a basis in data as essential to something being regarded as scientific was therefore regarded as being distinct from a response that indicated that the source of data be disclosed. Coded themes were combined into the most concise groups possible based on these literal alignments. In cases of ambiguity, answers in other sections of the survey were consulted for clarification. Where relevant to aspects of this analysis, comments made in response to the question "Do you have any other comments regarding these visualizations" were also marked for future reference during the analysis (these comments were not included in the coded analysis).

Identified themes were then incorporated into linear regression models that used an individual's rating of the visualizations they reviewed as the response variable to determine whether any of the identified themes had a significant statistical correlation with the rating of the visualizations. The use of a continuous 1-100 scale, although shown to be slightly less reliable than 1-10 scales, was used to facilitate having a continuous response variable (Allen and Seaman, 2007). In addition to the coded predictive variables, the regression models included variables for types of expertise, experience with storm surge, and social and demographic factors. The inclusion of these factors was based on the larger understanding that perceptions of depictions of risk are influenced by these factors (Morgan, 2002, Weber, 2010). Accounting for all necessary factors, 528 responses were complete enough for regression.

Regressions were performed with the full cohort, non-familiar expert cohort only, and non-familiar-non-experts only to account for sensitivity of the results to the effects of familiarity and expertise. All regression modeling was performed using the open source programming language ‘R’. Model fit was influenced by the distribution of the ratings which favored one end of the rating scale. Even accounting for this, the number of significant results revealed within the original model designs, the alignments of the three models, and their conformance with other smaller scale case study research, suggest that the results are robust.

RESULTS

OBSERVATIONS OF THE COMMENTS

Upon reading the comments made by some respondents, it became immediately clear that in several cases evaluations of the visualizations were based on information and attitudes external to the survey and the visualizations, and that in some cases the introductory statements were either skipped or discounted, as were labels. For instance, respondents who questioned the extremity of the scenario questioned “the sea level rise scenario used” despite clear statements that visualizations were of a storm event at present sea levels. Although these comments were not conclusive in and of themselves, correspondences between these comments and other questions (e.g., politics, income) suggest that biased assimilation is taking place where people have strong feelings (Lord et al., 1979, Corner et al., 2012). At the extremes of the evaluations, for instance, there are corresponding statements that are highly supportive (e.g., praising the utility of the visualization) or accusatory (e.g., suggesting that the visualizations are highly manipulative: "I feel raped by the visualization"). Comments that were critical of the visualizations suggested that respondents did not separate underlying choices regarding scenario selection from graphic choices when considering the visualizations. Three respondents felt the scenarios were not extreme enough.

VALIDATING THE QUESTION

Despite evidence of biased assimilation and some criticism of the scenarios, the overall ratings of whether visualizations are regarded as being scientific occupy the high side of the arbitrary rating scale. The mean evaluation is 81, the median is 85. Ratings were validated by comparing them to ratings for stated perception of risk and the degree to which visualizations were regarded as trustworthy. That comparison indicates that no single score is a direct proxy for another, and that the ratings are considered separately (The correlation coefficients between these scores is summarized in Table 7). An analysis of the differential between scores shows that scores for trustworthiness, stated perception of risk, and whether the visualizations are regarded as being more scientific shows the least difference among those visualizations rated as most scientific, and most difference among those regarding the visualizations as being less scientific (Figure 24). For example, someone who does not regard the visualization as being very scientific may nonetheless perceive a higher level of risk, but only somewhat trust the visualization. In some cases, there are respondents who regarded the visualizations as being very scientific and trustworthy and had reduced perceptions of risk because the area occupied by their home was shown as not being inundated.

Table 7, coefficients of correlation between the degree to which respondent's regard visualizations as being scientific and other evaluated terms. 1 indicates perfect positive correlation, 0 indicates no correlation, and -1 indicates perfect negative correlation.

Stated level of trust	.49
Stated perception of risk	.58

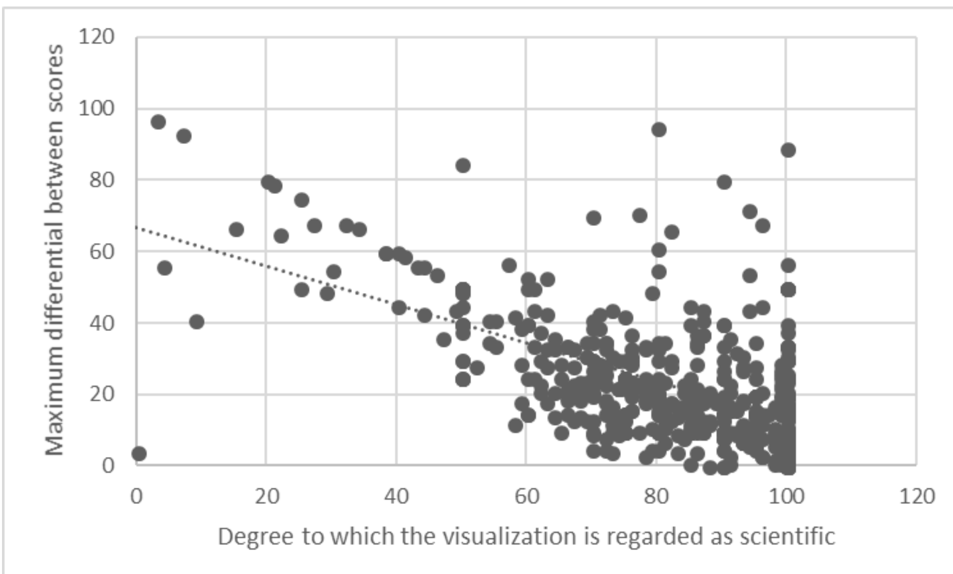

Figure 24, the differential between ratings of trustworthiness and stated perception of risk after viewing the visualizations (y axis), compared to the rating of whether the visualizations were regarded as being scientific (x axis).

Clear and easily identifiable themes emerged in the analysis of the responses to the “what characteristics contribute to your assessment of whether a visualization, representation, or graphic is scientific” question (Table *8*). Notably, the most frequently cited themes pertained to the visualization being based on data (n = 100), or disclosure of data and sources (n = 99). Taken together with other themes that relate to the expression of quantitative data (e.g., the use of color scales (n = 37), labels and legend (n = 45), there is strong sense among respondents that a basis in quantifiable data and its clear attribution is fundamental.

Although the strength of responses regarding the presence of data may have been prompted by the mention of data in the question, the overwhelming number of responses that included references to data suggest that this is a robust result. Related to this, and the observations regarding biased assimilation, very few respondents cited objectivity (n = 8) as a characteristic of a graphic or visualization being scientific.

*Table 8, Coded categories, number of responses, and whether the responses are positively or negatively correlated with a rating of realistic visualizations. +/- indicates variation between cohorts. * indicates that a similar question located elsewhere in the survey may have primed these responses.*

Coded Category	Number of responses	+/- correlaton with evaluation of realistic visualizations
Data and related factors		
Based on Data	100	-
Based on Computer Simulation*	18	+
Reference to Historical Storms	23	+/-
Validation, peer review of results	21	+/-
Includes probability or uncertainty	20	-
"Objectivity"	8	-
Visual Cues		
Visualization style	54	-
Clarity and ease of understanding*	26	+/-
Overall quality and aesthetics	29	+
Use of color scales / gradiations	37	+
Use of labels or legend*	45	-
Represents geography accurately, is recognizable	36	+
Transparency		
Disclosure of data and sources	99	+/-
Disclosure of methods	41	+/-
Provision of background /context	47	+/-
Other factors		
Personal judgment	49	+/-
Reputation*	69	+
Don't get it	2	+/-

Visualization style (n = 54), although seemingly distinct from the question of a basis in data, is in some senses an aesthetic corollary to visualizations being based in quantifiable data, as it includes stylistic preferences for diagrammatic representations. Some respondents went so far as to suggest that to be scientific a representation should be a chart or a graph. Others invoke the concepts that scientific representations should not be overly dramatized or cartoonish, often in reference to a visualization of unusual style. In most cases, comments regarding visualization style were negatively correlated with ratings of the visualizations in the study, meaning people who cited visualization style being an important characteristic generally evaluated the visualizations as being less scientific (Figure 25).

In the regression analysis, clarity and ease of understanding (n = 26) was a significant factor (p = .017) among the full cohort. It is unclear how respondents' understanding of this term (potentially prompted by questions in other parts of the survey) relates to visualization style (54), which was significant among non-familiar non-experts (p = .089). Indications of visualization style related primarily to the visualizations being more diagrammatic and less dramatized. It is possible that these responses are in fact two sides of the same coin, in the sense that people with a positive evaluation of the visualizations may regard them as being clear and easy to understand, and those with a negative evaluation of the visualizations may regard them as being unclear, or stylistically inappropriate. The degree to which representing geography accurately (n = 36) is significant (p = .032) may be reflective of one way in which the unique aspects of perspectival representation may positively influence perceptions of visualizations.

Despite being prompted by an introductory statement regarding computer simulation, few people cited based on computer simulation (n = 18) as being an important factor in the assessment of whether the visualizations were scientific. The relative low mention of simulation, and the high mention and statistical significance of reputation (n = 69) (p = .003. p = .005, p = .512) in all of the regression analyses suggests that contextual factors that are distinct from the underlying modeling have a greater influence on perceived legitimacy than the model characteristics themselves (Fogg and Tseng, 1999).

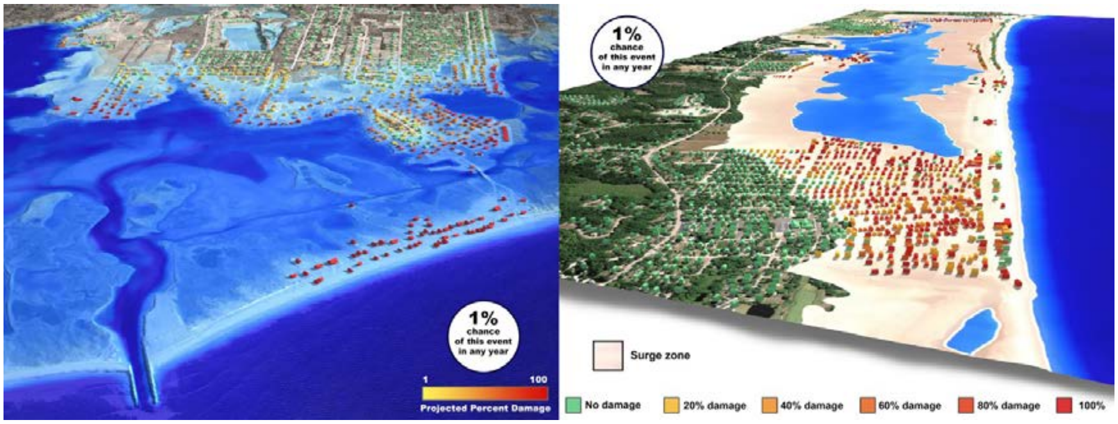

Figure 25, a comparison between a visualization that a respondent complimented for its style (left) and a visualization that some respondents found to be "cartoonish" or "like something from a Hollywood movie" (right). Multiple aspects of the visualization on the right were cited in comments as making it less scientific including the use of an unconventional color scale (inundation area marked by a sandy color), and the apparent inconsistency in the color of the damaged houses. Some respondents felt the coloration was illogical (e.g., a green house shows next to a red house). These differences in colors were related to differences in construction (e.g., elevated vs. on grade). Image: Author

Among non-experts, the provision of background (n = 47) (or absence thereof) was significant (p = .042). In this case background includes exposition of not only the methods, but the story of the people and the process behind the visualizations. Thus, being exposed to the people and processes used are likely to reflect positively on the rating of the visualizations as being scientific. In one instance, a respondent noted that they did not trust anything done by students: this and similar statements suggest that that who is doing the work is important.

In many cases, the characteristics cited as making a visualization or representation scientific were closely tied with expectations for flood mapping, especially including the notion that inundation mapping should be based upon historic storms (n = 23). Several participants presumed that the visualizations were based on historic data and indicated that this contributed to them considering the visualizations as being more scientific. These statements were made even though no reference was made to historic events in the materials provided through the survey.

Similar effects of expectations can be observed in the negative correlation of a person having been personally damaged by storm surge (among the other social and contextual factors gathered through other questions) and their rating of the visualizations as being (more or less) scientific (p = .094 among non-familiar non-experts, .025 among experts). These effects are particularly strong with residents living on the coast, emergency managers and government officials. Scientists and academics (p = .079 among the full cohort, p = .098 among experts) and planners (p = .036 among the full cohort, p = .065 among experts) show a statistically significant higher rating of the visualizations while emergency managers and persons engaged in maritime related professions are likely to rate the visualizations as being less scientific. Non-experts were significantly more likely to rate the visualizations as being more scientific (p = .030). Retired persons also showed a statistically higher response, however, there is no way to verify the completeness of this category, as it is based entirely on volunteered information.

LIMITATIONS

These results reflect cognitive biases based on respondents' personal circumstances and factors that influence risk perception. In the context of the full cohort, for instance, income is shown to be negatively correlated with rating of the visualizations being scientific. People indicating that they prefer not to answer (p =

.086 among the full cohort, p = .034 among non-familiar non-experts), or, choosing to leave the response blank (p = .019 among the full cohort, p = .064 among experts), show the largest negative correlation. Being a liberal is significantly correlated (p = .039 among the full cohort, p = .050 among non-familiar, non-experts) with rating the visualizations as being more scientific. This likely supports the presence of biased assimilation. In some cases, political biases may be inherent to the types of expertise queried. For instance, emergency managers and first responders in the cohort are more conservative, academic scientists in the cohort are more liberal. This distinction in and of itself is not inherently problematic because it may be reflective of a bias within these categories more broadly.

While the number of participants is high, and representative in some respects (e.g., gender) the purposive sampling method has resulted in some biases. Persons of color are underrepresented overall, and persons identifying as conservative are underrepresented in the non-expert cohort. It is thus difficult to make extensive conclusions regarding race for instance, even though it is shown to be a significant factor among the expert cohort, where there were the most respondents of color. For that reason, observations regarding these factors are deliberately limited.

Geographically, the sample is concentrated in the northeastern USA, with most respondents in and around the state of Rhode Island. Given this, the specific findings of this research are most relevant to the type of visualization and region at hand. This does not undermine the potential of this investigation to suggest avenues and approaches to research that may be extended and replicated. The extensive degree to which the results of this quantitative survey align with diverse findings from extensive case studies and research in other arenas (e.g., computer credibility, landscape and urban planning), as will be elaborated in the discussion, also suggests that the findings are likely robust.

DISCUSSION

CURRENT BEST PRACTICES

The degree to which respondents evaluate visualizations as being scientific is contingent on a range of expectations and social and contextual factors (e.g., reputation). These factors may not be internally problematic in the context of individual disciplines which have established cultural conventions for representation (Van Fraassen, 2008), but clearly need to be accounted for in situations where scientists and technical experts aspire to communicate beyond those boundaries.

The alignment of several factors, including the preponderance of responses regarding a basis in data and description of factors related to visualization style suggest that a number of participants subscribe to the notion that scientific graphics are characterized by being plain, unadorned presentations of data. It is important to temper this finding by recognizing that very few persons suggest that scientific visualizations and graphics are characterized by being "objective". This suggests that while there is some discomfort with the use of obvious argumentation in graphics that are purported to be scientific, respondents don't subscribe to the notion that it is absent from scientific graphics.

It is also clear from comments that respondents do not separate the argumentation inherent in scenario choice and modeling outcomes chosen for visualization from the argumentation made through graphic decisions. This confirms and reinforces approaches in landscape and urban planning and other disciplines that allow audience input into scenario selection and model inputs (e.g., Schroth, Pond, et. al., 2011, White., 2010), and casts further doubt on models of communication that emphasize the exclusive authority of science to determine the basis for analysis and outcomes (Walsh, 2015).

This finding is reinforced by the limited mention of the role of computer simulation, which is often emphasized to suggest technical authority (e.g., Sneath 2017). Although there is limited research on the perceived credibility of computer simulations, Fogg and Tseng, in their broad analysis of the topic found that the relative importance of simulations is likely over stated, and that computers are not evaluated as being necessarily more credible (Fogg and Tseng, 1999). The overwhelming significance of reputation as significant factor aligns with Fogg & Tseng's finding that contextual factors exert more influence on perceived credibility than the nature of technical processes that opaque and difficult for audiences to decode from limited information (Walsh, 2015).

This alignment lends additional credence to the role of extended background information and other narrative materials, as is also found to be significant in this analysis. These findings conform with the most fundamental guidance that suggests that science communicators and communication facilitates a relationship between scientists, other experts and lay persons (Trumbo, 2000, Sheppard, 2015).

STYLE AND ARGUMENTATION

Results suggest that factors unique to 3d visualizations, such as the accurate and recognizable depiction of the context, may positively influence ratings. This, taken together with the case study evidence suggesting that 3d visualizations are more effective tools for engagement (e.g., Sheppard, Shaw, Flanders, Burch & Schroth, 2013), suggests that there may be a trade-off between the benefits of recognition and engagement found in visualizations and a penalty in terms of perceived legitimacy based on visualization style.

The apparent penalty for visualization style is not absolute, as evidenced by responses to the visualizations presented in Figure 25. The broader, more generalized view in a conventional color scheme was more highly regarded than the unconventional view. This suggests that it is possible to leverage some of the engagement and place identification aspects of 3d visualization within bounds that are regarded as being “scientific”. These findings are significant in light of frameworks that discourage the use of 3d visualizations due to potentially misleading characteristics (e.g., Kostelnick et. al., 2013), as they suggest that there may be constructive benefits to judiciously use 3d visualizations to orient audiences. To the extent that more naturalistic perspectival views conform to ways people are accustomed to experiencing the landscape (even from unique vantage points) such views may be less disorienting than maps (Lewis and Sheppard, 2006, Sheppard, 2005).

At the same time, concerns regarding the ways in which 3d visualizations are misleading may presume incorrectly that these visualizations carry the same authority of maps or other types of representation. Although no comparative test was made in this study, the existence of the style penalty seems to suggest that there are likely higher degrees of perceived authority and legitimacy inherent to maps, the crystalizing effects of which may be no less problematic than those ascribed to visualizations (Crampton and Krygier, 2005). Comparative testing is thus required to examine the effects and tradeoffs of using these visualization types that encompasses questions of perceived authority and legitimacy.

It is difficult to separate discussions of visualization style and effective argumentation (e.g., better orienting audiences) from notions of scientific authority and legitimacy. To the extent that visualizations such as those tested here allow access to complex data they may invite scrutiny. For example, respondents sometimes questioned the juxtaposition of houses shown as structurally undamaged in the visualizations that were shown as being adjacent to homes that were damaged (this was largely due to the use of elevation to mitigate flood damage in some homes). Although these juxtapositions were associated with criticisms of the visualizations (and thus apparently decreased authority), their identification demonstrates the capacity of visualizations to simultaneously quickly orient the viewer and communicate multiple dimensions of data such as inundation extent and damage effectively.

This raises fundamental questions regarding argumentation and the intention of the authors of visualizations. If the intention is to promote transparency and engagement with the underlying data to inform policy and stakeholders, the questions raised regarding juxtapositions in Figure 26 suggests that the visualization is successful. If the intention, however, is to promote a singular message (e.g., there is a serious problem and action needs to be taken), these questions may be seen as problematic. These questions regarding the role of argumentation in scientific graphics are not without precedent or consequences, and their existence here suggests that the intention or role of visualizations should be clarified as part of their creation (Walsh, 2014) (The extent to which color scales are mentioned in the results may reinforce this finding, as it may indicate that audiences responded positively to being able to interpret the granular nature of data presented for structural damage).

Extreme argumentation to make a singular point is illustrated by a pair of visualizations published in a newspaper article (*Figure 27*). Visualizations provided by the author were selected from a range of scenarios and selectively cropped by the editors so as to juxtapose a maximized 2-meter (7 foot) sea level rise scenario with a null scenario. Images that employ iconic imagery (e.g., the flood), may behave more like symbols and in essence become an argument in themselves apart from the underlying data (Schneider, 2016). In the context of the sciences (apart from this example which is the result of editorial decisions), fear-based appeals often seek to leverage scientific authority while being opaque to scrutiny (Walsh, 2015). There is ample evidence that such extreme argumentation (the use of cropping and extreme scenario to emphasize devastation in the image) is ineffective and discounted by audiences because it is easy for them to dismiss as a remote possibility and favor consideration of more immediate risks (Walsh, 2015, O'Neill and Nicholson-Cole, 2009, Weber, 2010).

Figure 26, respondents raised questions regarding apparent discrepancies in damage between adjacent structures in this visualization. Image: author.

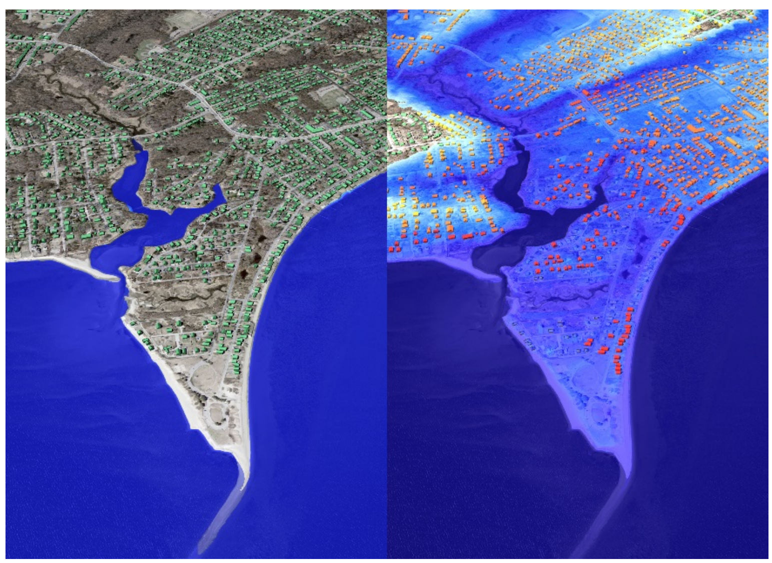

Figure 27, images cropped to simulate an image pair used in a Providence Journal article. Editor's emphasized extreme destruction in the headline, a portion of which read: "A once in a century hurricane would wreak havoc in R.I. Raise the sea level 7 feet and things get really ugly." Note the language misinterprets the 1% chance of occurrence, further emphasizing the remoteness of the scenario. (Kuffner, 2016) Image: author.

"PERMISSIBLE DRAMA"

The previous examples suggest that the concept of "permissible drama"3 and assumptions regarding the use of obvious argumentation in visualizations may need to be elaborated to better account for the evident diminishing effectiveness of extreme argumentation. The effects of increasing argumentation are likely not an inclining line as shown in Figure 28. Although nobody explicitly argues for a continuously increasing line or curve, the notion that there is a point at which images become "persuasive imagery" as used in advertising suggests this (Sheppard et al., 2008, Sheppard, 2005, Nicholson-Cole, 2005). This is further reinforced by assessments of the dangers of persuasive imagery that do not account for the likelihood that such imagery is easily discounted and dismissed.

In practical terms, however, the use of argumentation appears to have non-linear effects. This is experimentally confirmed at the extreme (e.g., O'Neill and Nicholson-Cole 2009, etc.). The existence of the "style-penalty" may also lend credence to this assertion. This decrease in persuasiveness, as measured for instance in effects on risk perceptions, owes to discounting based on being overwhelmed (O'Neill and Nicholson-Cole, 2009, Weber, 2010), or discounting of legitimacy (e.g., challenging the chosen scenario in the results of this research based on personal experience). While it's difficult to identify a precise shape, this suggests the diagram should look more like Figure 29.

[3] The term "permissible drama" is not in current use and was largely confined to two papers by Sheppard (2005, 2008). It is being rekindled here because it is a useful way to describe some degree of obvious argumentation that is appropriate.

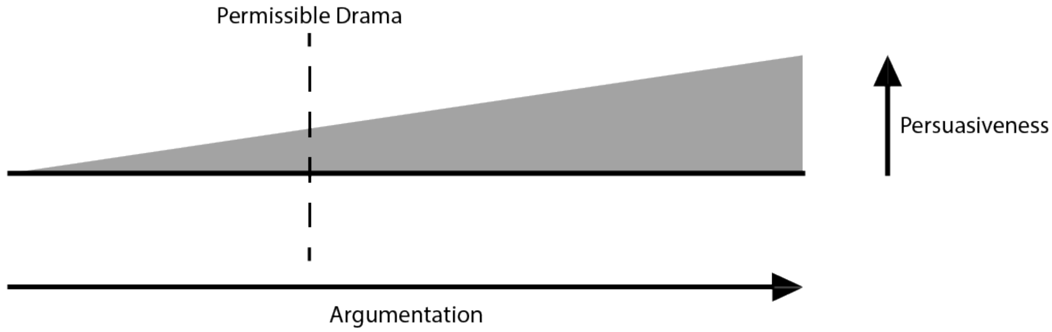

Figure 28, an imagined model of obvious argumentation and persuasiveness based upon the literature. Diagram: Author

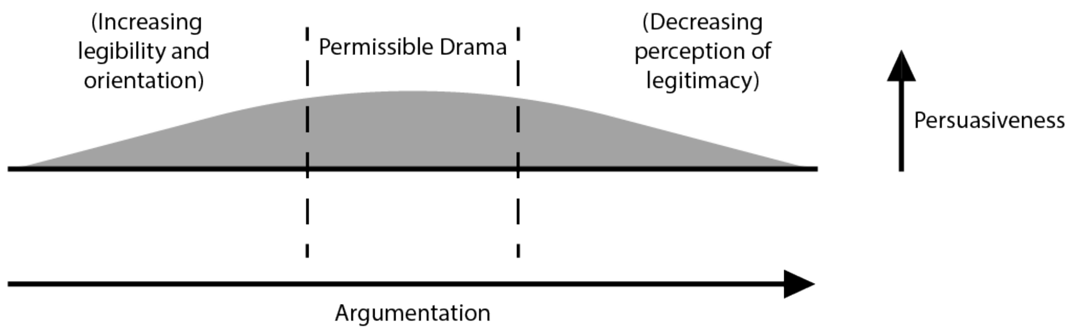

Figure 29, a model of obvious argumentation and persuasiveness that better accounts for the discounting of perceived legitimacy. Diagram: Author

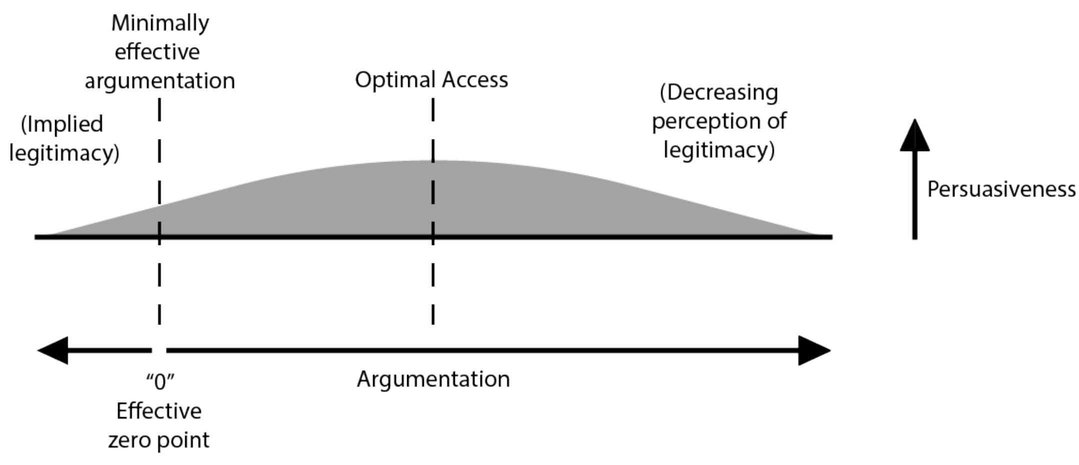

Figure 30, a speculative model of argumentation that accounts for a level of "minimally effective argumentation" that is required to make a graphic or visualization persuasive enough to serve a purpose beyond signaling implied legitimacy. Diagram: Author

Speculatively, the area under the curve may correspond to access to meaningful aspects of the underlying data (e.g., Figure 26). The larger emphasis on transparency and data in the results lend credence to this speculation. To the extent that scientists and technical experts also use inscrutable or deliberately banal graphics to signal authority, and even prevent scrutiny this explanation also makes sense (Walsh, 2015, Walsh, 2017). A more generalizable, speculative model is presented in Figure 30. Although this model is speculative, it conforms to Tufte et. al.'s approach to displaying quantitative information that generally emphasizes the "sense and substance of the data" and not underestimating the audience's ability to understand and engage with it (referred to here as "access") (Tufte and Graves-Morris, 1983).

At the extreme left of Figure 30 are graphics that are made to be deliberately inscrutable to imply authority or scientific legitimacy. The "0" point marks a minimum level of persuasiveness to convey meaning effectively. Optimal access mark the level of argumentation at which meaningful aspects of the underlying data are accessible by the audience. At the far right are graphics that are unpersuasive due to the extremity of their argumentation (e.g. Figure 27).

CONVENTIONS

Based on anecdotal experience of the author, some ocean scientists and engineers will be alarmed by the notion that scenario selection is a form of argumentation that should be set in consultation with stakeholders. The concern being that in situations where climactic forcing of models is changing, past conventions of using historic return periods and the 1% chance of occurrence as a standard are questionable (Ginis et al., 2017a, Lin and Emanuel, 2016). Moreover, analysis of paleorecords suggests that there are larger variations in storm intensity and activity than are currently captured (Mann et al., 2009). Using lesser, more likely to recur storms in addition to or in lieu of extreme events, while empirically shown to be likely more effective in communication (O'Neill and Nicholson-Cole, 2009), may raise concerns that communities will be inadequately prepared and fail to mitigate risks.

Results of this research also suggest that significant differences in perception exist between the academic and scientific community and persons engaged in emergency management and government. This may reflect differences in personal experience4, a bias of scientific and technical experts (MacFarlane et al., 2005), or other social and situational factors related to job function as discussed subsequently in the limitations section. Regardless of their cause, these differences should be of concern to scientists and academics who aspire to inform policy. This is especially true in regard to extreme, seemingly unprecedented events that are well within the bounds of probability and predicted through modeling (e.g., Hurricane Rhody in Figure 22) (Ginis et al., 2017a, Lin and Emanuel, 2016).

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[4] Although personal experience has been shown to be a strong influence on risk perception in situations where people have experienced flood damage KELLER, C., SIEGRIST, M. & GUTSCHER, H. 2006. The role of the affect and availability heuristics in risk communication. *Risk analysis,* 26**,** 631-639., the nature of the recent exposure in Rhode Island, USA has been comparatively small. Superstorm Sandy, for instance, exhibited effects at a far lower level than historic events like Hurricane Carol MANN, M. E., WOODRUFF, J. D., DONNELLY, J. P. & ZHANG, Z. 2009. Atlantic hurricanes and climate over the past 1,500 years. *Nature,* 460**,** 880-883, HALVERSON, J. B. & RABENHORST, T. 2013. Hurricane Sandy: The Science and Impacts of a Superstorm. *Weatherwise,* 66**,** 14-23.. In such situations, small perturbations can build a false sense of security or confidence WEBER, E. U. 2010. What shapes perceptions of climate change? *Wiley Interdisciplinary Reviews: Climate Change,* 1**,** 332-342, KELLER, C., SIEGRIST, M. & GUTSCHER, H. 2006. The role of the affect and availability heuristics in risk communication. *Risk analysis,* 26**,** 631-639..

The question thus becomes how to bridge this gap in the perceived legitimacy of scenarios. The role informal and formal conventions as revealed by this research may offer one possible path forward:

The stated emphasis on historic events on the part of some emergency managers and officials may reflect the degree to which years of creating maps and visualizations has established conventions of flood and storm surge mapping. This effect is revealed most obviously in the preference for blue color schemes, and the more generalized (most conventional) view expressed in the results of this research. The extent to which past risk communication processes and the nomenclature of risk have relied upon historic storms has likely established a similar informal convention. Understanding these informal conventions may form a basis for constructively addressing some of the issues raised by this research (Kostelnick and Hassett, 2003). For instance, it is possible that meeting expectations of viewers by displaying lines of historic inundation (e.g., Hurricane Carol and Superstorm Sandy) alongside projected future inundation may increase perceived legitimacy of those projections by acknowledging viewer expectations and experiences.

Applying these concepts to the semi-realistic visualizations tested here suggests that projected storm surge scenarios be include lines of inundation from past events that are recognizable to the participants, allowing them to understand the new information in relationship to their lived experience. This contextualization draws attention away from a singular extreme and draws attention to a range of potential outcomes between the lived experience and maximal scenario. This approach conforms to the speculative framework that is proposed in the previous section by enhancing the relevant information in order to provide access: the ability to effectively gauge the quantifiable data (the presented scenario).

While it would be difficult to prove conclusively using this research, the results suggest it is likely that viewer expectations are directly or indirectly shaped by formal conventions and frameworks they have encountered through visual representations. This can be seen in the emphasis on labels and legends. There are multiple alignments between characteristics expressed by respondents, and existing and past frameworks. The degree to which people emphasized aspects of transparency regarding data and sources, for instance, tracks very closely with component criteria of legitimacy as cited by Sheppard (Sheppard, 2001). This suggests that future conventions that may be adopted by scientists and technical experts have the capacity to shape those expectations. Thus, as messy as it may be to contend with questions of argumentation, creating guidance may eventually have tangible effects that improve the effectiveness of communication by scientists and technical experts.

Recommendations for continued use of semi-realistic visualizations

1) Emphasize narrative background information that illuminates the motivations for undertaking the research (such relevant experiences of persons engaged in research), and narrative explanations of the process of developing models (e.g., reasons for scenario selection). Reduce emphasis on technical explanations.
2) Clarify the intent of utilizing visualizations. Is the intention of the visual rhetoric to clearly communicate meaningful aspects of the data, or is it intended to deliver a singular message such as a fear-appeal? Recognize the limited utility of fear-appeals.
3) Set levels of argumentation in visualizations by optimizing the legibility of meaningful aspects of underlying data.
4) Leverage existing informal and formal conventions to aid in rapid uptake of information and orientation. Provide relatable references to historic storms to better contextualize projected inundation levels.

CONCLUSION

This research demonstrates the relevance of processes that have evolved in the context of landscape and urban planning and concerns raised in the context of rhetoric to current practice by teams of ocean scientists and engineers employing novel visualizations. It emphasizes the development actionable approaches to addressing issues of argumentation. It further addresses the popular conception of graphics as mere presentations of scientific data and elaborates in plain terms the complex way that argumentation that alters interpretation and is imbedded throughout the modeling and visualization process (e.g., scenario selection). The provided recommendations are recognizable to anyone who is familiar with the existing literature on climate communication spread across several disciplines (Moser, 2016). What distinguishes these recommendations, however, is that they are grounded in direct experimentation with the visualizations in question and offer concrete approaches to addressing the issues raised.

Although the use of an experimental framework was initially intended to make existing research more tangible and relevant to the intended audience, its application has implications beyond this purpose. The application of the experimental framework raises legitimate questions about the use of visualizations that are not fully elaborated within current literature. For instance, this research plainly suggests that the engaging properties of visualizations and their effects are not necessarily an unalloyed good (e.g., effects of the "style penalty", biased assimilation). Understanding and addressing the ways in which argumentation is used within visualizations may enhance processes at all scales by making visualizations more effective. This research clarifies the role of reflexive stakeholder processes in setting levels of argumentation and explores the effects of using visualizations outside of these contexts. It makes a step to addressing larger research gaps regarding visualizations (Deitrick and Edsall, 2009, Leshner et al., 2016), and the identified need to understand prevailing methods of communication that are in use (in this case, visualizations employed by ocean scientists and engineers) (Leshner et al., 2016).

In the context of rhetoric this research requires further development, especially regarding the relationship between the term “scientific” and other aspects of perceived authority and legitimacy. This relationship is referenced but not fully elaborated or explored. This owes in part to the acceptance that respondents will define for themselves what “scientific” means, and the nature of the questions asked. A better understanding of this question could be gleaned using a more extensive interview process and qualitative analysis. This limitation was accepted as a consequence of the method. Although it would have been possible to study legitimacy in and of itself (of which there are examples, e.g., White et. al., 2010), that approach does not attend to the intersection of expectations for scientific graphics and obvious argumentation that this work is focused on. Thus using the term “scientific” provided a short-hand to discuss an elaborate set of intersections.

With that caveat, this research does effectively illuminate the relationship between concerns raised in the context of rhetoric and demonstrates their practical application to a specific audience (ocean scientists and engineers). Moreover, it characterizes the results of the research and recommendations in a way that is sensitive to the practical preoccupations and needs of those scientists, who, by the nature of their practice need to compartmentalize and separate the immediate concerns of their research from other technologies and tasks (e.g., visualization) in order to simply manage their portion of a larger scientific endeavor (Latour, 1990b).

This reflects the degree to which we all accept certain foundational concepts and technologies as givens without scrutiny so as to allow ourselves to explore in detail aspects of a problem, often forgetting that each of those technologies and concepts is or was in itself a scientific project (Latour, 1990b). It falls to persons who create visualizations or visualization technologies to illuminate concerns regarding their use or potential misapplication, lest we be complicit in misleading the public or producing counterproductive graphics and visualizations.

"Portability" is thus conceived of as the embedment of the epistemic and practical concerns of one discipline in another. "Durability" is conceived in the literal sense, through the creation of recommendations, models, and hypotheses that can be tested and made more precise through further research and experimentation (Latour, 1987). This research provides both topics for further investigation (e.g., speculative models related to optimizing argumentation) and testing (e.g., the effects of marking historic inundation levels in addition to projected inundation levels). It invites scrutiny, and further testing.

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CHAPTER 4

EFFECTS OF AFFECTIVE RESPONSE AND PLACE RECOGNITION ON VISUALIZATIONS OF STORM SURGE

THE LIMITS OF DRAMA AND THE POWER OF RECOGNITION

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ABSTRACT

In response to increasing but uncertain risks posed by storm surge (Romero and Emanuel, 2017), scientists, engineers and experts employ novel 3d visualizations as tools for risk communication (e.g., Fenech 2017, Sneath 2017, Spaulding 2016). The effectiveness of these semi-realistic visualizations depends on their ability to elicit stronger affective responses, instantaneous subconscious emotional judgements, to depictions of recognizable locales (Sheppard et al., 2008, Zajonc, 1984). Although potentially effective, researchers have expressed concerns regarding the way in which semi-realistic visualizations may distort perceptions of probability and uncertainty, misleading the public (Kostelnick et al., 2013). This study employed a survey (n = 735) and quantitative analysis to understand how affective response and place recognition, as experienced through semi-realistic visualizations, alter perceptions of storm surge risk.

Results confirm findings from the case study literature in the context of climate communication and landscape and urban planning regarding the potential effectiveness of realistic visualizations, especially as it pertains to the localization of climate impacts (Sheppard, 2015, Sheppard et al., 2013, Moser and Dilling, 2011). The results expand these findings, however, by suggesting that affective response may have greater effect on perceptions of the severity of a consequence as opposed to the likelihood of a consequence, and that perceptions of probability are more strongly influenced by other social and cultural factors such as expertise. Moreover, this research demonstrates that visualizations have the capacity to both increase and decrease risk perception, and that it is incorrect to presume that dramatic visualizations

necessarily increase perceptions of risk. This suggests that the potential of visualizations to mislead the public is moderated by the effects of discounting the depicted risks.

Key points

- Affective responses, instantaneous subconscious emotional judgements, may be in reaction to multiple aspects of the visualization and not necessarily to the content depicted. A reaction to aspects of the presentation may thus result in discounting of risks.
- Increased effectiveness of visualizations associated with place recognition and increased affective response may also be associated with increased levels of discounting of risks by some stakeholders.
- Claims that visualizations make the effects of climate change local and tangible (Moser and Dilling, 2011) are born out in models of risk perception. These models show that the affective response has a greater effect on perceptions of the severity consequences, whereas place recognition appears to alter both perceptions of the likelihood and severity of a consequence.

Introduction

Coastal communities are facing growing, but uncertain risks from storm surge (Romero and Emanuel, 2017). Scientists, engineers, and coastal managers are increasingly using advanced visualizations as tools to communicate these risks to the public (Spaulding et al., 2016, Fenech et al., 2017). Some of these visualizations employ sophisticated visualization architectures to present model-derived data such as damage to structures and inundation depths in semi-realistic portrayals of recognizable places (Fenech et al., 2017, Ginis et al., 2017, Spaulding et al., 2016). The primary rationale for using these depictions is that they are more effective tools for orienting and engaging the public (Sheppard, 2015, Sheppard et al., 2008), and thus presumably for communicating risks from natural hazards such as storm surge.

A key aspect of this potential effectiveness is the ability of a semi-realistic visualization to evoke an “affective response”: an instantaneous subconscious emotional judgement that shapes risk perception (Zajonc, 1984). Affective response influences the perception of any map, graphic or visualization (Bostrom et al., 2008). It has been argued that affective response increases audience engagement with visualizations of recognizable places and the likelihood of behavior change (Sheppard, 2005) . The seminal literature that argues for the role of affective responses to depictions of recognizable places as being essential to the effectiveness of visualizations also warns against potential backfire effects of these representations (Moser and Dilling, 2011, Sheppard et al., 2008, Sheppard, 2005). Depictions of extreme events may overwhelm and demotivate constructive action by individuals who feel that their actions will have no effect or may simply be disbelieved (Sheppard, 2005, Nicholson-Cole, 2005, O'Neill and Nicholson-Cole, 2009).

Guidance that has evolved in the context of climate communication and landscape urban planning is designed (among other things) to mitigate these potential backfire effects. Practices emphasize use of dialogic processes where the use of visualizations is guided and contextualized by interaction between experts and stakeholders who in some cases directly shape inputs to modeling and visualization processes (Schroth et al., 2011a, Sheppard et al., 2013, Schroth et al., 2011b, Moser, 2016). This type of engagement, where audiences shape inputs, has been shown to increase the perceived saliency credibility and legitimacy of models and visualizations, and thus reduces the likelihood that they are disbelieved (White et al., 2010, Schroth et al., 2011b). Other guidance is practical, for example: emphasize contexts and timescales relevant to individual stakeholders, emphasize constructive responses to climate change (as opposed to only depicting impacts), employ culturally attuned local communicators, etc. (Sheppard, 2015). Visualizations and imagery are thus most effective at promoting efficacy (e.g., the sense that mitigation efforts are possible and worthwhile) when they engage audiences in practical and constructive responses, rather than emphasizing fear appeals (O'Neill et al., 2013).

As valuable as this guidance is, it does not address the knowledge gaps identified in frameworks for visualizing probabilistic risk regarding perceptions of 3d graphics and visualizations (e.g., Bostrom et al., Kostelnick et. al.). These frameworks are more precisely aimed at risk communication regarding natural hazards (e.g., storm surge, earthquakes) (Kostelnick et al., 2013, Bostrom et al., 2008). Absent a means to consistently measure the effects of visualizations on audiences it is difficult to comparatively assess relative effects of visualizations (e.g., how aspects of the visualization or visualization type increase or decrease risk perception) (Bostrom et al., 2008). This research suggests that lack of effective measurement also makes it difficult to weigh factors altering perceptions of visualizations (e.g., how much of an effect does place recognition have compared to other factors?). It is thus difficult to determine whether and to what degree a visualization may be misleading (e.g., making outcomes appear overly certain (Kostelnick et al., 2013)), or to balance the benefits of orientation and engagement with clear and concise communication of risks (for instance, addressing the need to better inform stakeholders regarding the depth and power of present day surge hazards (Morrow et al., 2015)). Frameworks for visualizing risk (e.g., Bostrom 2008, Kostelnick 2013) thus discourage the use of 3d graphics and visualizations for the uses scientists and engineers communicating storm surge risk are now contemplating (Kostelnick et al., 2013, Bostrom et al., 2008). This research therefore seeks to account for the effects of affective response to visualizations of recognizable places and ground fundamental arguments for the use of visualizations in heuristics of risk perception. In so doing, this research seeks to further ground current guidance in climate communication and make that guidance more broadly recognizable to persons engaged in communicating natural hazard risks.

To accomplish this, a quantitative survey (n = 735) was conducted among persons over the age of 18 living in the United States. The survey design employed a purposive sampling method to maximize the cross-sectional characteristics of the cohort in terms of familiarity with the place visualized and relevant expertise. In addition to asking questions to assess risk perception, familiarity with the place visualized, and a range of social and cultural factors, one-word answers regarding how visualizations made respondents feel were solicited. These answers were analyzed using a system that quantifies the emotional content of language, the affective norms of English words (ANEW) as a measure of affective response.

BACKGROUND

THE NEED FOR BASIC RESEARCH

The fundamental arguments for how visualizations may be effective tools for fostering engagement and behavior change draw on literature in risk perception (e.g., Kahneman, Slovic) and image studies (e.g., Lieserowitz, Nicholoson-Cole) (Sheppard, 2005, Sheppard et al., 2008). Even as these arguments were being made, the leading proponent of visualizations as tools to engage the public regarding climate change, Sheppard, noted that studies of visualizations tended to focus on applications (e.g., using visualizations in workshops) rather than on basic research into how visualizations are perceived (Sheppard, 2005). As practices have evolved, and climate communication has evolved as a community of practice in its own right, the emphasis on practical application of visualizations within dialogic processes, and on in depth qualitative research has increased (Moser, 2016, Sheppard, 2015). This has left a gap in basic research into perceptions visualizations as visual rhetoric largely unfilled (Bostrom et al., 2008, Kostelnick et al., 2013).

Among current concerns in climate communication is whether the insights gained through the practice of climate communicators can be effectively transferred to other scientists and experts (Moser, 2016). This concern mirrors concerns on the part of scholars in science and technology studies and rhetoric of science that seek to inform the practice of scientists and technical experts (Graham, 2018). Outside of climate communication practice, deficit model approaches to communication persist, sometimes under the guise of scientists who are skeptical of the public or feel under threat (Welsh and Wynne, 2013). Resistance to participating in dialogic processes may also relate to epistemic issues. Some scientists and experts, for instance, are reluctant to acknowledge their own role in argumentation (aspects of rhetoric that are intended to be persuasive) (Walsh, 2014, Walsh, 2017). They may thus limit choices as to potential scenarios (e.g., emphasizing only the worst case) while claiming technical neutrality (acting as "stealth advocates") (Pielke Jr, 2007). In these situations, scientists and experts may employ argumentation (e.g., dramatized colors) (Schneider, 2016), that risk the previously described backfire effects. Even in situations where skilled science or climate communicators are employed, graphics visualizations may leak beyond the boundaries of a process, be decontextualized, and used in fear-appeals (Stempel, 2018).

This research thus deliberately tests visualizations in a way that simulates their decontextualization, offering only modest supporting information to: 1) understand the effects of visualizations as they are encountered and 2) to gain insight into how the visualizations of recognizable places in and of themselves influence risk perception. It further revisits, tests and consolidates the understanding of the effect of visualizations that heretofore has been assembled from a combination of image studies and basic research in risk perception (Sheppard 2005, 2008). In so doing, this research seeks to make these findings more broadly recognizable and applicable to other contexts that emphasize quantitative methods and probabilistic understandings of risk (e.g., expert driven risk communication regarding natural hazards) (Latour, 1987).

Risk is a judgement as to the likelihood and severity of a consequence (Yates and Stone, 1992).
Affect “refers to a person’s good or bad, positive or negative feelings about specific objects, ideas, or images” (Leiserowitz, 2006, Kahneman and Tversky, 1982)
Affective response is an instantaneous subconscious emotional reaction to a stimulus (Slovic et al., 2005, Shumaker and Taylor, 1983), that automatically guides judgement (Zajonc, 1980).

Sheppard (2005) articulated the nexus between risk perception and visualization research, arguing that visualizations would effectively spur behavior change because of their capacity to elicit a combination of aligned affective and analytical (cognitive responses)(Sheppard, 2005). This understanding draws upon the affect heuristic, which argues that misalignments between affective and analytical responses explain the discounting of some risks, and the overemphasis on others (Slovic et al., 2005). Dread risks, such as nuclear meltdown or terrorist attacks, for instance, evoke disproportionately high affective responses, and thus tend to be overemphasized (Weber, 2010). Similarly, the pleasure derived from a risky behavior can cause someone to discount risks of some activities such as smoking or skiing (Slovic and Peters, 2006). Sheppard thus argued that aligning the affective response to a visualization of a meaningful local place with a cognitive understanding of risk potentially made visualizations effective communication tools that may foster behavior change (Sheppard, 2005).

Proponents of visualizations who cite the risk perception literature are careful not to suggest that visualizations alter perception of risks. A claim that visualizations alter risk perception may be inherently problematic. Beyond ethical issues that come with using images to influence behavior (Sheppard, 2005, Nicholson-Cole, 2005, Sheppard, 2001), the question immediately arises as to the level of risk that is appropriate to communicate, and how to evaluate whether that risk is being effectively communicated (Bostrom et al., 2008). Given that perception of risk is predicated on social and cultural factors, the biases of expertise are also concerning (MacFarlane et al., 2005).

Regardless of whether the claim that a visualization alters risk perception is problematic, it has been experimentally demonstrated that visualizations or imagery (e.g., imagery of flooding) have the capacity to alter risk perception (Keller et al., 2006). This research thus takes the position that risk perception is a useful metric against which to compare the relative effects of affective response, place recognition, and social and cultural factors (e.g., gender, race, income).

AVAILABILITY, PLACE RECOGNITION, AND WHY THE TERM PLACE RECOGNITION IS USED INSTEAD OF "PLACE ATTACHMENT".

Availability is the "ease with which one can bring to mind exemplars of an event" and may alter perceptions of how likely that event is to occur (Folkes, 1988, Kahneman and Tversky, 1982).

The discussion of affective response is closely related to the topic of place recognition through another concept drawn from the risk perception literature: availability. The influence of personal experiences with hazards such as storm surge is an example of availability; persons who have experienced and can recall severe impacts from past storm surge events are likely to have increased levels of risk perception (Keller et al., 2006, Becker and Caldwell, 2015). Experience of storm surge, however, does not necessarily increase risk perception. In situations where persons have experience with lesser effects, these experiences can undermine risk perception (Weber, 2010). This is likely the case with the locations visualized as part of this research. The effects of Superstorm Sandy were comparatively weak in Rhode Island (Halverson and Rabenhorst, 2013), the extents of that storm surge appears to have lowered the expectations for the extent of an extreme event (Stempel, 2018).

As previously described, viewing images of flood impacts has been shown to increase respondents stated level of risk perception when evaluating flood risks by making it easier to imagine the occurrence and effects of the event (Keller et al., 2006). To the extent that visualizations seek to localize the effects of climate change (or storm surge in the case of this study), they are seeking to make the consequences more “available”. They demonstrate that “it can happen here” and in so doing not only provoke affective responses but serve to make abstract impacts or responses imaginable (Sheppard, 2015, Sheppard et al., 2008, Moser and Dilling, 2011). In terms of availability, the strength of these effects is likely much weaker than the effects of direct experience (e.g., losing one’s home to storm surge, or the countervailing effect of having experienced a lesser surge); it’s unclear to what degree visualizations can act as a surrogate for experience.

In the context of the visualization literature, the effects affective response to visualizations of recognizable places are described in terms of “emotional attachment to place” (Sheppard et al., 2008). This choice of words disambiguates the localizing effects of visualizations from the concept of “place attachment” that speaks to a wider range of place based social and cultural meanings (Hidalgo and Hernandez, 2001). As it pertains to visualization, there is increased interest in effectively mapping and understanding the role of place attachment, and better understanding the relationship between visualizations and place attachment so as to better inform decisions (e.g., resource management, barriers to climate adaptation) (Newell and Canessa, 2018). The range of definitions used for place attachment, which can reflect both physical and social contexts operating at a wide range of scales, however, hinders this effort. (Brown et al., 2015, Hidalgo and Hernandez, 2001). Given these complexities, this survey was confined to measuring the effects of place recognition, and the effects of various kinds of proximity (e.g., physical distance, whether a person spends time in a coastal community). While the results of this research have the potential to inform efforts around place attachment, the immediate purpose is more confined by understanding effects of the research in as it pertains to heuristics of risk perception (e.g., affect, availability).

MEASURING AFFECT

Valence is “the pleasantness of a stimulus” (e.g., sad to happy) (Bradley and Lang, 1999, Warriner et al., 2013).
Agitation (arousal) is “the intensity of emotion provoked by a stimulus” (Warriner et al., 2013, Sheppard, 2015).
Dominance is the “degree of control exerted by the stimulus” (Warriner et al., 2013).

Concepts of validity related to representational practice vary between disciplines (Van Fraassen, 2010), as do methods for creating visualizations (Lovett et al., 2015). This heterogeneity combined with the rapid pace of evolving technologies has made it difficult to define visualization practice and ethics (Sheppard and Cizek, 2009, Lovett et al., 2015). Moving beyond mere recognition that affective response may enhance or complicate the understanding of graphics and visualizations thus requires metrics that can be reliably applied and understood in multiple contexts. For that purpose, this research adopts the "Affective Norms of English Words" (ANEW), to quantify affective response as indicated verbal reactions to visualizations.

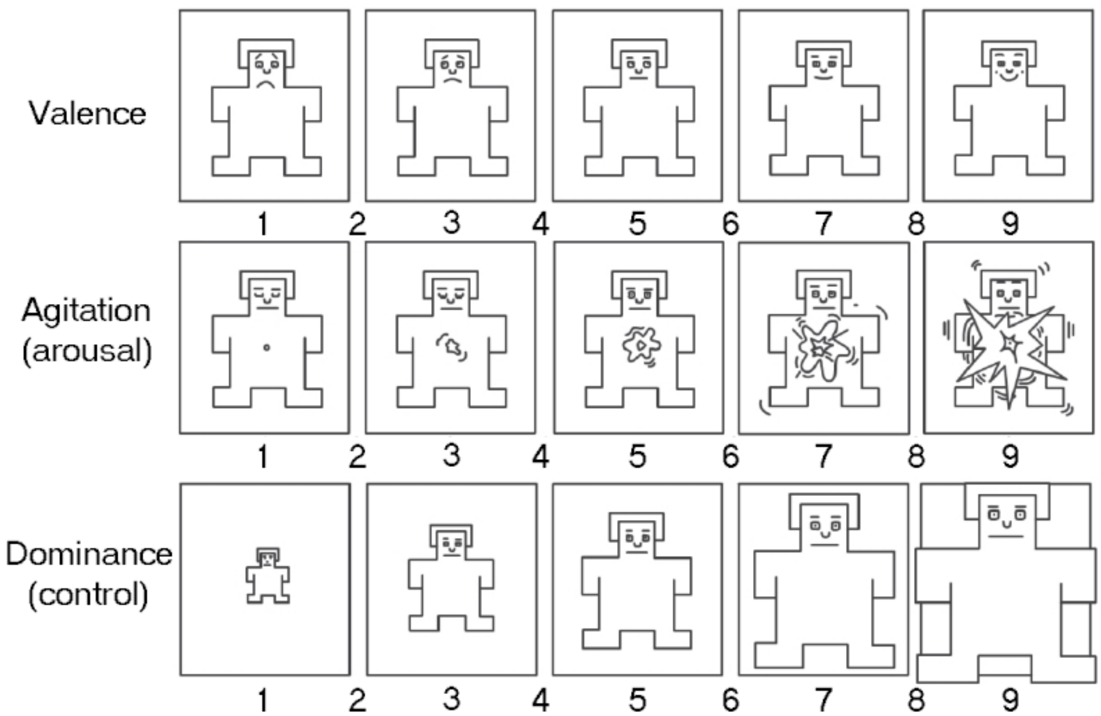


Figure 31, the self-assessment manikin. Figure adopted from Bradley and Lang 1999.

This system is based upon the a "self-assessment manikin" (SAM), a series of pictograms on which people rate three aspects of the emotional content of words: valence, agitation (arousal), and dominance. Although earlier ANEW databases were confined to 1134 words (Bradley and Lang, 1999), the application of the original methods using crowd sourcing has recently expanded to 13,915 English words

(Warriner et al., 2013). These tools have been used in a wide array of text-based research, including analysis of text for emotional content (Leveau et al., 2012). Although the recent expansion of the project had depended upon technology (crowd sourcing via Amazon's Mechanical Turk), aspects of the method date to the late 1950s (Warriner et al., 2013). It thus represents a consistently utilized and recognizable standard by which to measure affective content.

Affective response is (by definition) a subconscious judgement. It is thus inherently difficult to capture. Writing a response to a question may involve reflection or other less immediate considerations. As utilized in this research, ANEW quantifies the affective content of a word that was used to describe a visualization. It is therefore not a direct measure of affective response to the visualization, but a measure of a written reaction that may capture the subconscious affective judgment. The method may be useful nonetheless given the difficulty of quantifying affective response. Past methods have mainly relied on observation of respondents (e.g., Lewis and Sheppard 2006). These methods, although compelling, rely on the observations and interpretations of the research team (Lewis and Sheppard, 2006), and are thus impossible to implement in a digital survey that respondents fill out remotely. Moreover, using a standardized method, such as applying ANEW makes it possible to compare responses across multiple surveys.

Another distinct advantage of using ANEW over more conventional coding is that the researcher does not have to make decisions as to the sentiment to perform the initial analysis: the ANEW database provides values based on different social and cultural factors (e.g., gender) for each word. This also eliminates the need for the researcher to discern whether the respondent is responding to the content of the visualization, or to aspects of the visualization as an artifact (e.g., legends or colors). Even in situations where a respondent is simply ‘put off’ by the visualization, that distance would theoretically be captured in their response.

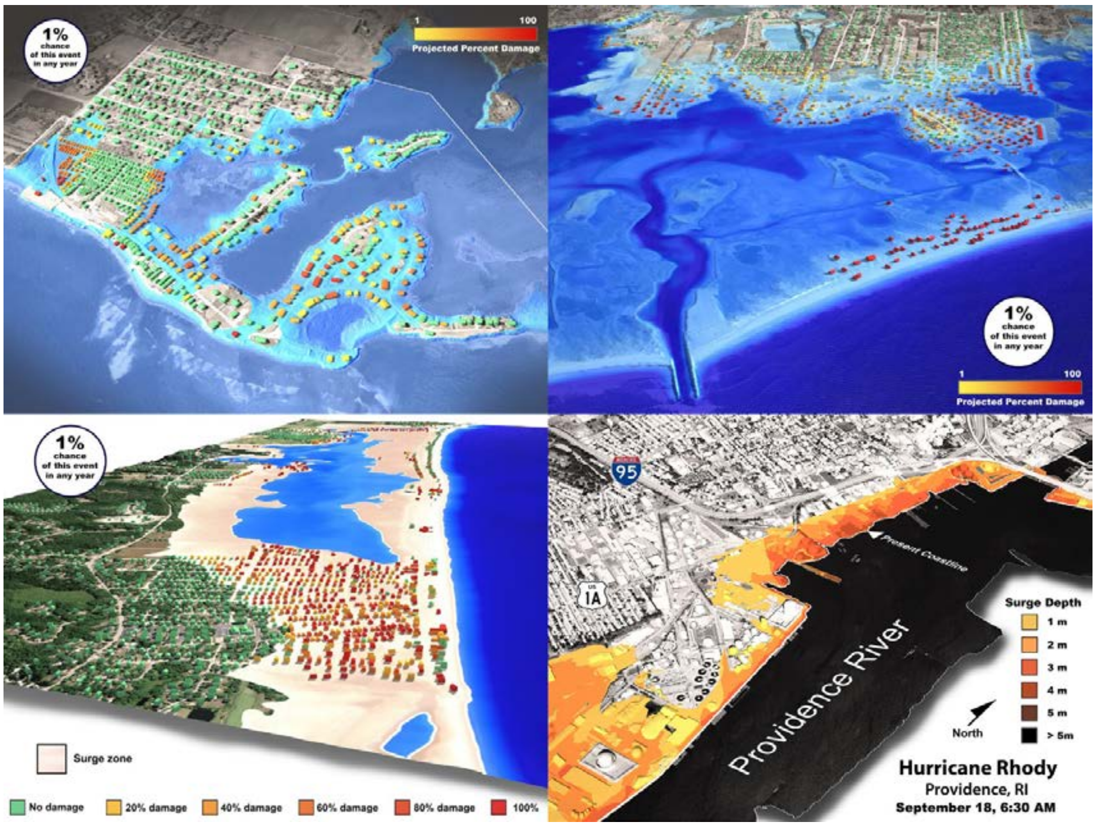


Figure 32, examples of visualizations featured in the survey, some images related to portions of the survey not included in this study. Images: Author.

METHODS

SURVEY INSTRUMENTS AND RESPONSES

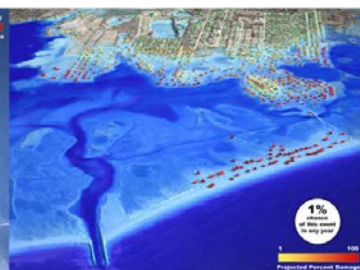
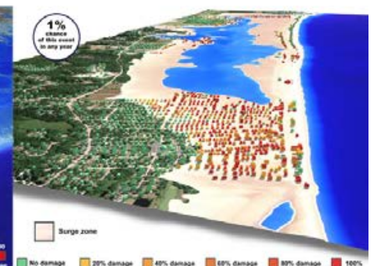
Four survey instruments were created that contained variations of visualizations of Rhode Island’s coastal communities (Figure 32), as follows: expert, public, planners, maritime. The primary distinction in instruments was between the expert survey, which contained additional questions regarding the depiction of probability and uncertainty, and the public survey which did not include these questions. Two additional variants of the expert survey were created to address specific audiences (e.g., maritime industry). These instruments included additional questions regarding expertise to acknowledge qualifications such as having a marine pilot's license or other maritime qualification in addition to more traditional educational credential. None of the questions regarding expertise were disqualifying, and additional open-ended questions (e.g., job title) were used to further categorize responses such that the composition of the cohort and relevant responses could be understood regardless of which survey was taken. Responses were anonymous, and no personal identifying data was collected.

The survey was open to all persons in the United States and was conducted between June and August of 2017. A purposive sampling technique was employed to maximize different degrees of familiarity with the place recognized and to account for differences in expertise as well as different degrees of familiarity with visualizations (e.g., people who encountered the visualizations in a training session, people who never had seen them). Distribution utilized email, social media, and word of mouth. A website was created to facilitate sharing of the survey (www.vissurvey.com) and sharing was encouraged. A total of 735 responses were collected using the four survey instruments (Table 9).

Table 9, survey instruments and number of responses.

Survey instrument	**Number of responses**
Expert survey	115
Public survey	598
Planner's survey	11
Maritime survey	11

Table 10, visualizations tested as part of this study, with qualitative distinctions in graphic representations. Comments suggest a preference for the color and point of view and style shown in the Charlestown visualization. The Misquamicut visualization was most criticized. As is subsequently shown by the analysis, the Matunuck visualization showed the most statistically significant responses for place recognition and affect.

		
Matunuck, R.I., USA	Charlestown, R.I., USA	Misquamicut R.I., USA
Rendered to make damage to individual homes easily discerned. ("sharpness")	Employed deliberate blur and greater distance from subject to make it more difficult to discern individual homes, emphasizing community.	Damage to foreground properties is discernable, but not background properties.
Conventional color scheme (water is blue)	Conventional color scheme (water is blue)	Surge areas represented as sandy color.
View predominantly from land.	View predominantly from ocean.	View along coast.

VISUALIZATIONS

The visualizations tested in the survey represent Matunuck (part of South Kingstown), R.I., USA, Charlestown, R.I., USA, and Misquamicut (part of Westerly), R.I., USA (Table 10). For brevity, these places will subsequently be referred to as Matunuck, Charlestown and Misquamicut. These communities were chosen based on common characteristics, such as a mix of residential and shoreline commercial and recreational uses with which respondents would be familiar (e.g., popular bars and restaurants, areas for recreational boating). These locations also share a common shoreline morphology: a combination of barrier beach and coastal salt pond (lagoon). Aligning these characteristics made it more likely that effects of differences in the visualization could be detected (e.g., as opposed to comparing a highly urbanized environment to a coastal barrier). Relevant differences in the visualizations are summarized in Table 10.

The visualizations were created by the author as part of his role in the Marine Affairs Visualization Lab at the University of Rhode Island, Rhode Island USA, and they were used in public engagement, publications (physical and online). Similar visualizations have been used in emergency management training processes (e.g., US Federal Emergency Management Agency (FEMA) Integrated Emergency Management Training Course). They were created using a script driven numerical-model-based architecture that places 3d assets (e.g., buildings, tanks, bridges) in a rendering environment (in this case Rhino, but also may be utilized in Unity or other platforms such as Maya or any software that allows script-based control) and alters the placement and appearance of the content based on model parameters. Examples are shown in Figure 33. The three visualizations used in this study all include damage modeling developed by the University of Rhode Island Department of Ocean Engineering (Spaulding et al., 2016). The architecture is currently used in combination with a variety of ocean and impact models (e.g., ADvanced CIRCulation model: ADCIRC, impact models developed by the author/Marine Affairs Visualization Lab) and can drive renderings of a variety of styles and levels of detail.

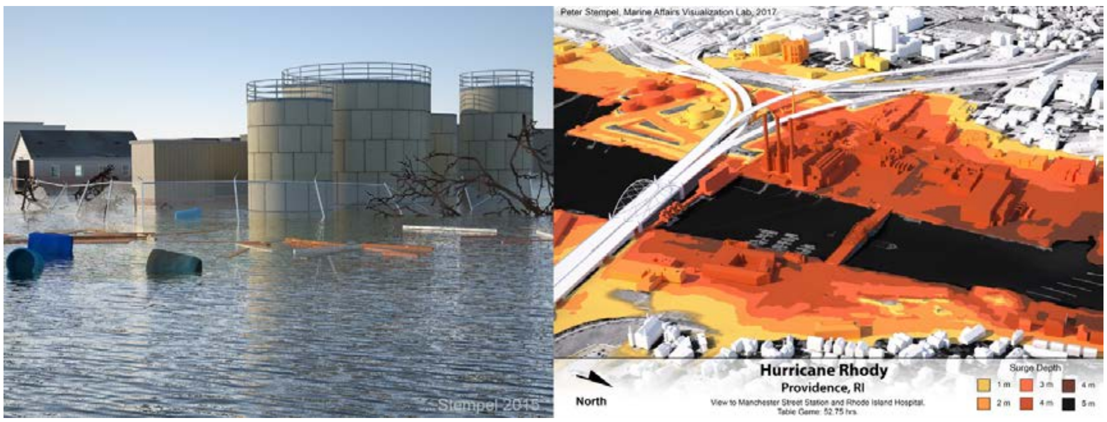


Figure 33, examples of visualizations made using the same model architecture as the visualizations tested in this survey. Highly realistic visualization of water treatment tanks, Galilee, Narragansett, R.I., USA, and a visualization used by FEMA IEMC, depicting Providence, R.I., USA. Images: author.

BACKGROUND INFORMATION PROVIDED IN SURVEY

The online survey was designed to maximize participation by minimizing its length and not requiring respondents to enter a response. The design approximated a situation in which visualizations are partially decontextualized, as they might be when encountered online or in a newspaper article or other publication (Stempel, 2018). The introductory statement was thus brief. In addition to emphasizing the basis of the visualization in underlying simulations (which is frequently stated in newspaper articles, e.g., Kuffner 2016), the text also highlighted that the evaluations were made at present sea levels (in bold face type). The full background statement is as follows:

“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 (Figure 34). When you press continue, you will be taken to the first visualization to evaluate.”

The minimization of supporting information, deliberate absence of place labels frustrated a few respondents, who requested them, and “letting the person taking the survey know where the place is instead of trying to guess.” Another reported deliberately not reading the background information because they felt the visualizations should “stand on their own”.

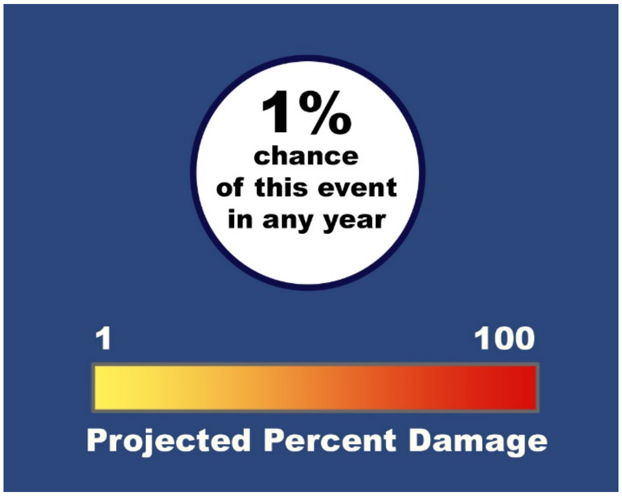


Figure 34, enlarged version of the legend included in the survey background information, prior to evaluation of the visualizations.

QUESTIONS RELATED TO AFFECT AND PLACE RECOGNITION

Respondents evaluated three visualizations that were pertinent to the research presented here. The visualizations were presented in random order. A series of questions were presented on the ‘page’ with each visualization so that respondents could easily scroll back to the visualization if they were viewing it on a mobile device, etc. (Legends and other details were optimized on multiple devices, one respondent indicated difficulty with using a mobile phone). Respondents were asked to provide a one-word answer as to how the visualization made them feel, and to indicate whether they recognized the place visualized:

What one word would you use to describe how this visualization makes you feel? (word blank)

Do you recognize the coastal community depicted in the visualization above? (yes / no)

The concept of risk was measured using two component questions based on the definition of risk as a judgement as to the severity and likelihood of a consequence:

How likely do you think it is that the community depicted here will experience an event like this in the next 30 years? (visual analog scale, 1:100, not likely – very likely)

How severe do you think the consequences of this event would be for this community? (visual analog scale, 1:100, not likely – very likely)

Separating the question in this way avoided confusion as to the definition of risk (e.g., equating risk with probability alone). The use of a continuous 1-100 scale, although shown to be slightly less reliable than 1-10 scales, was used to facilitate having a continuous response variable (Allen and Seaman, 2007). These scores were analyzed separately, and combined into a single composite risk score:

$$Risk\ score = (Severity * Likelihood)/100$$

In addition to the assessment of risk for each visualization, respondents were asked directly about their perception of the risk of storm surge to properties, homes and businesses both before and after viewing the visualizations:

How significant of a risk do you feel storm surge poses to properties, homes, and businesses near the coast? (1:100, not likely – very likely)

After reviewing this set of visualizations, how significant of a risk do you feel storm surge poses to properties, homes, and businesses near the coast? (1:100, not likely – very likely)

In addition to asking whether respondents recognized the place visualized, respondents were asked to identify whether they had relationships with several communities in Rhode Island, USA, as well as whether they had a relationship with another coastal community not listed prior to evaluating the visualizations. A relationship was defined as visiting or living in a community more than seven days a year. This made it possible to determine whether a person recognized or did not recognize a place they visited or lived in, and for non-recognition to be analyzed as a factor.

Additional questions addressed other aspects of the visualization (e.g., believability, trustworthiness) and topics not covered in this paper. In addition to questions specific to the visualizations, respondents were asked a series of questions about their experience with storm surge in addition to social and demographic questions designed to account for factors known to influence perceptions of risk (e.g., gender, income). Separate analyses not associated with this research addressed questions of expertise and the extent of familiarity with the visualizations (Stempel, 2018). Factors regarding expertise and familiarity were included to discerning experts from non-experts and to discern those familiar with the visualizations from those who had never seen them).

ANALYSIS

One-word responses were conditioned for spelling and capitalization, statements and phrases identified through that process were set aside for other analyses. The conditioned words were associated with affective normative response word scores for valence, agitation, and dominance based on the word used and the gender of the respondent to account for gender differences in the perceived affective content of words. ANEW breaks down scores based on factors like gender and age, because these factors affect the ANEW ratings. As gender was the most demographically representative factor in the study cohort and is also a factor that has been understood to shape risk perception, gender was accounted for in assigning values. This was accomplished through simple conditional matching (e.g., assign ANEW values to the respondent's answer based on matching the ANEW word to the response word and the gender of the respondent) in the open source programming language 'R' (*Table 11*).

Table 11, the first three lines of the table used to assign ANEW values to words. Values are based on compiled crown sourced responses to the self-assessment manikin (SAM), scoring words on a scale of 1 to 9 (Warriner et al., 2013).

	Gender male			**Gender female**		
Word	Valence (+/-)	Agitation (arousal)	Dominance (control)	Valence (+/-)	Agitation (arousal)	Dominance (control)
aardvark	6.18	3	4	6	2.07	4.4
abalone	5.71	2.56	5.33	5.08	2.73	4.81
abandon	2.45	4.5	4	3.57	3.29	3.06

Answers related to place recognition were analyzed to identify persons who indicated being familiar with a place but did not recognize the place, as well as identifying the distance of the respondent's U.S. zip code (postal code) from the place. These conditioned factors, together with other social and demographic factors and factors related to expertise were used in a series of linear regressions. The first analysis was performed with the risk score as the primary response variable. A subsequent set of regressions was performed using likelihood and severity as response variables, both to test how sensitive the results were to removal of one of the components, and to explore how the different components shaped the results. In all regressions, visualizations were evaluated separately so that no more than one response per respondent was included in any regression. All regression modeling was performed using the open source programming language ‘R’.

Results

1. ANALYZING ONE-WORD RESPONSES AND APPLYING AFFECTIVE NORMS OF ENGLISH WORDS (ANEW).

ANEW values for valence (positivity or negativity), agitation (how engaged or activated the respondent is), and dominance (how in control the respondent feels), were applied to one-word responses. Overall, 1694 word responses to individual visualizations (each respondent had the opportunity to evaluate multiple visualizations) were complete enough for analysis. After accounting for spelling, capitalization and repetition, there were 302 unique words, and 66 phrases and comments inserted into the word bank. Although in some cases, a word could be identified from the phrases and comments, e.g., “very concerned for those effected [sic]”, it is unclear how interpreting a word from the response might influence the affective content. In light of the relatively small number of instances of this occurring (< 4%) these answers were set aside with the other comments. This reduced the total one-word responses to 1628. The proportion of words appearing in the ANEW database is summarized in Table 12. A summary of words, totals of words appearing from the ANEW database, and words not present in the ANEW database is included in the supplementary materials. As words without an exact or very near corollary made up only 8.5% of the analyzable responses, they were set aside in the analysis.

Table 12, corollaries between one-word responses and the ANEW database

One-word responses:	**Number of responses**	**Percentage of total**
Responses with an exact corollary in affect list	1247	76.5%
Responses with a near corollary in affect list	244	15%
Responses with no corollary in affect list	137	8.5%
Total one-word responses	1628	100%

The most frequently used word was Concerned (n = 252). The range of words used to describe how the visualizations made respondents feel suggest that respondents were in some cases responding to the artifact of the visualization, and in others responding to what was depicted. For instance, some respondents used words like “blue” (n = 4) or “beach” (n = 3). These words were used to describe visualizations that used a blue color and a brown color to indicate inundation zones respectively. In other cases, words like “devastating” (n = 10) and “devastated” (n = 19) seem to clearly reflect engagement with the content of the visualization.

Some words such as “confused” (n = 89) and “disoriented” (n = 6) clearly reflect disengagement with the content and uncertainty as to what is being examined or asked of the respondent. In some cases, words could reflect different sentiments, for example, “curious” (n = 35) could mean that the respondent wants to learn more, or that the respondent finds the result curious. Words like “resigned” (n = 11) and “expected” (n = 7) and “unsurprised” (n = 9), suggest that the visualizations are confirming respondents’ expectations, this likely indicates that biased assimilation is also likely taking place (Lord et al., 1979).

Overall, the words utilized reflect a range of sentiments and differing degrees of engagement with the content. Interpretation of visualizations may thus be in response to both the content and / or the artifact of the visualization and other aspects of the presentation.

2. EVIDENCE OF BACKFIRE EFFECTS IN THE WORD RESPONSES.

The effect of viewing the visualizations resulted in both increases and decreases in stated perception of risk. These changes are summarized in Table 13. Among the word responses, several respondents reported feeling safe or safer. These responses were associated with decreased stated perception of risk, and lower risk scores for the associated visualzation. Observations of words and comments suggest that decreases in perceptions of risk are also associated with:

- The extents of storm surge being less than the viewer imagined or expected.
- Seeing that one's home is outside of the surge zone depicted.
- Questioning the severity of the damage or extents of the surge based on experience with less severe storms (e.g., Hurricane Sandy, which had a comparatively low impact in Rhode Island USA as compared to New Jersey USA (Halverson and Rabenhorst, 2013)).

Table 13, changes in stated perception of risk.

	Percent of respondents	Mean change (scale of 100)	Median change (scale of 100)
Increased stated perception of risk	40%	11.6	9
No change in stated perception of risk	27%	0	0
Decreased stated perception of risk	33%	-12.1	-9

Given other evidence of biased assimilation, a close examination of the relationship between politics and changes in stated perception of risk was performed. Virtually no correlation was found between political affiliation and changes in stated perception of risk, which suggests these changes reflect other factors (e.g., personal stakes). This analysis is included in the supplemental materials.

EFFECTS OF PLACE RECOGNITION AND AFFECT.

In all but one of the visualizations, more people reported recognizing a place than reported visiting or living in the place. 73 people reported visiting or living in Matunuck, but did not recognize the visualization. The high number of reported visitors overall may owe in part to a popular local bar (the Ocean Mist) that attracts many visitors who may or may not recognize the place. The other complicating factor in the Matunuck visualization was the deliberate choice of an unconventional point of view, looking from land to ocean (an orientation criticized by some respondents: ”bad angle”). Numbers of persons reporting visiting or recognizing a place are summarized in Table 14.

*Table 14, summary of persons reporting visiting a place, recognizing a place, and those not recognizing a place. * The repeated number of 131 is coincidental.*

Place visualized:	**Visited or lived in the place more than 7 days per year.**	**Reported recognizing the place in a visualization.**	**Did not recognize a place visited or lived in.**
Matunuck, R.I. USA	131	131*	73
Charlestown, R.I. USA	95	187	13
Misquamicut (South Kingstown), R.I. USA	57	168	19

Responses reflected a range of physical distances from the places visualized. Distances ranged from 0 to 8162km (Hawaii, USA), with a mean distance of 630km, and a median distance of 57km. Most of the responses were concentrated in the State of Rhode Island, USA, and the area around the places visualized. These distances were shown to be correlated with risk perception, but were in most cases shown not to be statistically significant predictors as compared to other factors.

Regression analyses were performed for both the composite risk score, and for likelihood and severity separately in order to determine whether aspects of risk perception were affected differently by place recognition, affect, and other social and cultural factors that were accounted for. In all of the regression analyses, place recognition was a significant factor. In the regression of the risk score (which composited severity and likelihood) social and cultural factors such as gender or expertise were shown to be significant. For example, being a scientist or academic was shown to be significant in all analyses (p = .029*, p = .038*, p = .035* for Matunuck, Charlestown, and Misquamicut respectively). With the exception of the valence scores for the Matunuck (p = .001***), and Charlestown (p = .068 .) visualizations the

ANEW variables were not shown to be significant when regressed against the composite score.

The significance of the ANEW factors, however, was more significant when the components of the risk score (severity and likelihood) were regressed separately. Social and cultural factors and factors related to expertise were shown as significant to evaluations of likelihood, whereas factors related to the ANEW scores were shown as being more significant to evaluations of severity. Valence is shown to be significant for both the Matunuck and Charlestown visualizations (p =*** , and p = .032* respectively). Agitation is shown to be significant for the Charlestown visualization (p = .008*). The pattern shown for the Matunuck and Charlestown visualizations is not repeated for the Misquamicut visualization however. Non-recognition of a place lived in or visualized (p = .012) is significant for the assessment of severity as it pertains to the Misquamicut visualization. Taken together, these analyses suggest that aspects of the visualization are altering perceptions of severity, and that differences in distribution of the scores for severity may be explained by these factors.

Place recognition was shown to be related to both, with variations in significance between the visualizations. For instance, recognizing the community depicted showed higher significance for evaluations of severity than likelihood as it pertained to the Matunuck visualization (p = .007** and p = .010* respectively). This is reversed in the Charlestown visualization p = .046* and p = .001**)

Prior to conducting the regression analyses, the measures of severity and likelihood for each visualization were compared and analyzed to ensure that these variables were independent (i.e., that people were making unique judgements for each score, and that scores were not auto-correlated). This analysis revealed that there was a wider range of scores for the Matunuck visualization. These variations suggested that there was additional discounting of risks taking place. (This analysis is included in the supplemental materials). Thus while it appears that place recognition and the affective scores of words used to describe the visualization are more significant as it pertains to the Matunuck visualization, this visualization also was associated with increased discounting.

The “sharpest” visualization in which damages to individual structures can be easily discerned, the Matunuck visualization, thus has the most significant results in terms of scores for dimensions of ANEW and place recognition but is associated with increased discounting of risks on the part of some participants. The least conventional visualization in terms of color scheme used shows virtually no effects for the ANEW variables and the least effect for place recognition but has a narrower and higher range of scores for severity. This suggests that while the visualization may be less successful in terms of localizing and making the effects of storm surge tangible to participants, that there is also less discounting taking place. It thus appears that there is a ‘cost for effectiveness’.

DISCUSSION

DRAMA IS NOT PERSUASION.

Affective response is subconscious and instantaneous (Zajonc, 1984, Slovic et al., 2004). It is therefore impossible to control and predict what aspect of the visualization the affective response will be to. That word responses reflected reactions to both the quality and graphic aspects of the visualizations (e.g.,”beachy”, “cartoonish”) and to the impacts of the storm depicted (e.g., Devastated), speaks to a fundamental conundrum of representation. A representation may be understood as the thing it represents, and a thing or artifact in and of itself (Van Fraassen, 2008). When asked to describe a picture of the titanic, some people might say “it’s the titanic”, while others would say “it’s a photograph” (Van Fraassen, 2008). As it pertains to affective response, an individual’s immediate subconscious emotional judgment may pertain to the loss of those who perished on the liner, or it could be based on a reaction to the picture frame used to display the photograph. Thus, while affective response plays a role in perceptions of visualizations, these responses may be to multiple aspects of the visualization other than the content depicted.

Comments, such as those that describe the visualizations as “like a Hollywood movie” speak to the fact that even highly engaging and graphicly sophisticated visualizations may be dismissed as screen-craft, and thus have their effects be discounted. Moreover, critical comments (e.g., “I feel mugged by the visualization”), suggest that efforts at creating more engaging and emotive visualizations may be viewed as being manipulative. While these comments are limited, they suggest that even when visualizations are regarded as being of very high quality, or as very engaging, they may be dismissed as fictions. The affective reactions in these cases is either one akin to disgust (as in the case of the respondent who feels manipulated) or in the situation where it is to the content, may be compartmentalized. Discounting may thus also be tied to affective responses. Creators of visualizations should not presume that affective response will be to the content of the scene depicted.

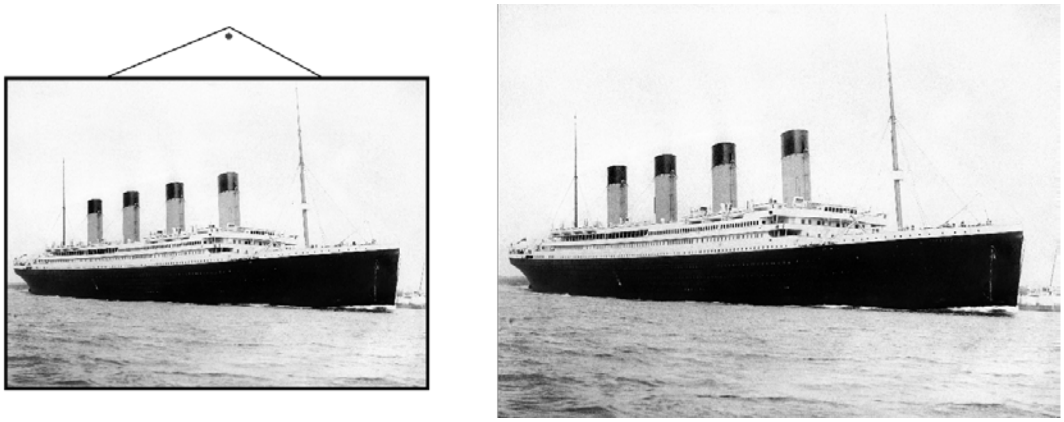


Figure 35, a unique conundrum of representation is that an image or visualization can be described as an artifact in and of itself (e.g., the "picture of the titanic" at left), or as the thing it represents (e.g., "the titanic" at right). Illustration: Author, based on a photograph by Francis Godolphin Osbourne Stuart, 1912, public domain (downloaded from Wikimedia Commons).

Therefore, increasingly dramatic visualizations may not necessarily evoke increasingly powerful affective responses. Concerns raised regarding “disbelief” in the seminal literature promoting the use of realistic visualizations (Sheppard, 2005, Orland et al., 2001), thus are not only supported by this research, this research suggests that they may be reinforced by affective responses. Insofar as there are concerns that increasing levels of drama are necessarily misleading (Bostrom et al., 2008, Kostelnick et al., 2013), this tendency to view the visualization as an artifact, may form a kind of “brake” on misleading effects by reducing the efficacy of the visualization (Figure 36). This issue also draws attention to issues of graphic quality, and ancillary aspects of graphics such as labels and legends. These items function as graphic cues and create impressions as to the legitimacy and intention of the graphic that alter perceptions of them (Stempel, 2018). It's therefore necessary to consider not only the effects of the depiction of content, but of the graphic presentation. Drama and persuasion should not be equated.

BACKFIRE EFFECTS.

Although the number of respondents who indicated feeling safe or safer in their word answers represented only a small portion (1%) of the cohort, the disposition of change in perception of risk indicates that nearly half of respondents showed decreased levels of risk perception after exposure to the visualizations. Persons who thus report feeling concerned (15%) or informed (4%) may nonetheless lower their stated perception of risk. Arguably, that perceptions of risk both increase, and decrease suggests that the visualizations may be effectively informing respondents. This would be true if the visualizations could holistically account for the risks brought about by the storm event. Among the long-predicted backfire effects associated with visualizations is that depictions of easily visualized events such as storm surge might distract from other more difficult to visualize effects such as precipitation (Moser and Dilling, 2011). This may be exacerbated by single-action bias, the tendency to focus on one action or effect and discount others (Weber, 2010). In the context of storm surge associated with hurricanes, the effects of wind are substantial (Figure 37), as are the hazards associated with disruption of services (e.g., ambulance response).

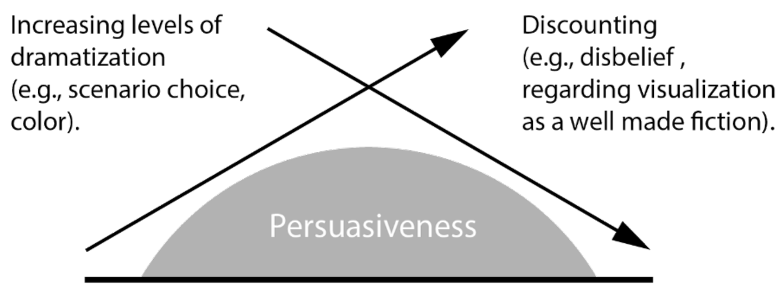


Figure 36, the "brake" effect: as visualized scenarios exceed audience expectations of impacts, discounting increases, and the persuasive effects of dramatization are counteracted. Diagram: Author.

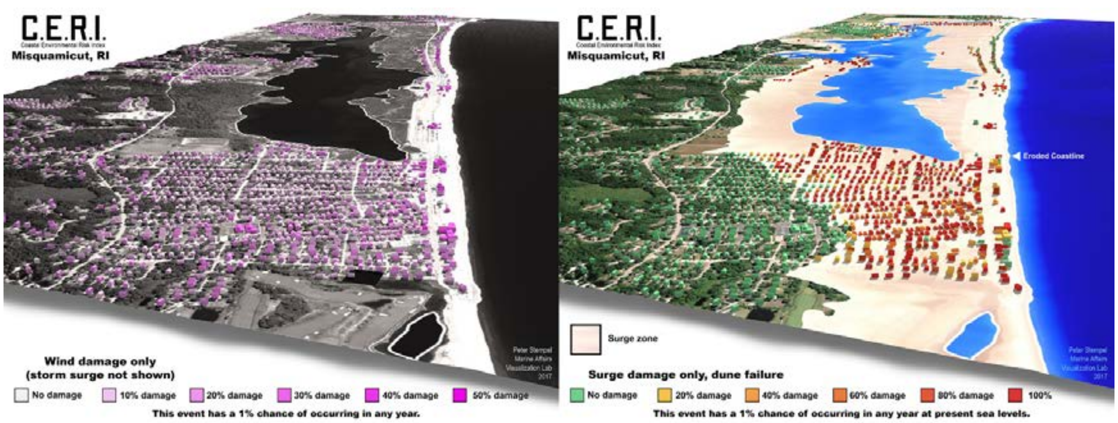


Figure 37, versions of the Misquamicut visualization that show projected wind damage (model in development) (left) and surge (right). Note that few structures are shown to escape the likelihood of wind damage (e.g., loss of roof shingles). These visualizations were made as part of the development of the Coastal and Environmental Risk Index (CERI). Images: Author

In addition to suggesting that these concerns are real, comments suggest that perceptions of the scenario presented as being extreme are triggering discounting. This discounting, taken together with the observed disbelief associated with the clear portrayal of consequences in the Matunuck visualization substantiate the ineffectiveness of scenarios that are perceived to be extreme (O'Neill and Nicholson-Cole, 2009). What the literature does not address in regard to these effects, however, is the likelihood that perceptions of what is extreme are likely set by the most recently experienced large storm event (Superstorm Sandy), and expectations may unrealistically low as it pertains to the impact of a 1% likelihood of occurrence event. This is even more concerning in situations where the likelihood of occurrence for some events may be unrealistically low. Hurricane Harvey, for instance, was regarded by many as an outlier event, but may have a present probability that is much higher (Emanuel, 2017).

As previously discussed, guidance in climate communication recommends the use of multiple visualization types (Sheppard, 2012), and different types of engagement (e.g., encounters with persons who have experienced storm impacts as in Becker 2016). The results of this research, however, suggest that the stakes for risk communicators using visualizations outside of the practices espoused by climate communicators are high. This brings new attention to the need to visualize more dimensions of climate impacts (Moser and Dilling, 2011), and to better acknowledge how future projections of impacts relate to audiences current expectations and experience.

Effects of place recognition on the perception of visualizations.

Place recognition was one of the most consistently significant factors in all of the regression analyses, and it influences appraisals of both likelihood of a depicted impact and severity of a depicted impact. The physical distance of a respondents place of residence from the place visualized, while correlated with the risk score, was not as predictive. This conforms to and confirms well-supported suggestions to visualize recognizable, culturally significant places at scales relevant to stakeholders (Sheppard, 2015, Sheppard, 2012). That both the Charlestown and Misquamicut visualizations are shown to be more frequently recognized by respondents that visited or lived in the place reinforces this. Both of those visualizations include landmarks (e.g., the distinctive breechway in the Charlestown visualization together with Charlestown Neck—the landform connecting the mainland to the barrier beach). Although not conclusive, the degree to which people who reported visiting or living in Matunuck that did not recognize the place visualized (n = 73) suggests that the unconventional view (from the land) may have undermined what is otherwise shown to be a highly effective visualization.

Some distinctions in results may in part reflect different dimensions of place attachment in addition to place recognition. Firstly, the presence of a widely known bar (the Ocean Mist Bar and Restaurant) and a popular restaurant (the Matunuck Oyster Bar) likely explain the comparatively high number of people who indicate having visited or lived in the visualized place. Secondly, a 2015 controversy over forced abandonment of a seawall, and construction of a new seawall behind the one of the businesses (the Ocean Mist Bar and Restaurant) has raised the stakes for both visitors, and persons who physically live or work in that community (O’Neil, 2016). The high significance of “valence” may thus reflect feelings about this controversy, or, as previously suggested, ambivalence or doubts regarding the scenario resulting from personal stakes. The wider distribution of responses as to both severity and likelihood and the lower evaluation of severity (potentially reflecting discounting of the scenario) for the Matunuck visualization likely reflects these differences.

EFFECTS OF AFFECTIVE RESPONSE AND THE DEPICTION OF CONSEQUENCES ON RISK PERCEPTION.

The disposition of the results between the likelihood and severity regressions suggest that the depiction and perception of consequences are closely related to the affective content of the word responses and place recognition. Conversely, it appears that affective response to the depiction of consequences has less effect on shaping perceptions of likelihood (probability), which is instead shaped more by social and cultural factors. These findings suggest that the primary role of visualizations insofar as risk perception is concerned is aligned with their stated role in communication processes: making impacts local and tangible (Sheppard, 2015).

Although more study is necessary to verify and elaborate these effects, these findings suggests that the visualizations may not necessarily be more distorting to perceptions of probability than any other form of graphic or visualizations, or, that if distortions are present, they largely relate to the perceived severity of the consequences. Further study using a similar study design with different types of visualizations (e.g., maps) and differing degrees of realism are necessary to confirm this finding. Minimally, this finding suggests greater precision be used when describing effects on risk perception, distinguishing stated perception of risk from perceived severity of consequences and probability (likelihood).

CONCLUSION

VISUALIZATIONS ARE NOT MAGIC

Climate communicators may take umbrage at the notion that the effects of visualizations on perceptions of risk are not well understood given their nearly two decades of practical experience in their application for the purposes of communicating risks of climate change (Moser, 2016, Sheppard, 2012). Anecdotal experience of the author, however, suggests that the enthusiasm of many scientists, policy makers, and experts engaged in hazard communication have for using visualizations has yet to be tempered and shaped by this guidance. Moreover, the lack of basic research that definitively describes the effects of visualizations of recognizable places in terms of their effects on risk perception is practically non-existent.

If this research did nothing other than convince scientists and technical experts that visualizations are not magical tools of persuasion, and to consult the practical guidance offered in the context of climate communication (e.g., Sheppard 2012), it would serve a purpose. Examining the effects of visualizations in terms of their effects on risk perception accomplishes much more than this however. For instance, this research plainly demonstrates that visualizations that clearly depict the consequences of storm surge show evidence of increased effects of affective response, but that these visualizations also are associated with increased discounting of risks on the part of some stakeholders. Engaging aspects of visualizations are thus tied to backfire effects: both can be explained in relationship to models of risk perception. This, however, does not suggest that the persuasive aspects of visual rhetoric should be abandoned, if anything, it suggests that the content is understood.

Lewis and Sheppard (2006) observed that even in situations where respondents indicated that they understood map-based depictions that their subsequent experience of visualizations suggested they had misunderstood the map-based visualization. That visualizations may assist with orientation and engagement of diverse populations is established (Sheppard, 2015, Lewis and Sheppard, 2006, Sheppard et al., 2013). By better understanding how visualizations alter perceptions of risk (e.g., the extent of effects on perceptions of likelihood of an event versus perceptions of the severity of impacts), this research suggests that there may be good reason to employ visualizations in expert driven risk communication processes (e.g., informing the public of storm surge extents). They may for instance, by virtue of effectively communication consequences, address a stated need to more effectively communicate the depth and power of storm surge (Morrow et al., 2015).

Before this expanded application of visualizations is made, however, more basic research must take place to adequately understand the trade-offs between conventional 2d representations, and visualizations such as those utilized here. This research proposes and pilots repeatable metrics for the assessment of visualizations, the Affective Norms of English Words (ANEW) and dimensions of risk perception (the severity and likelihood of a consequence (Yates and Stone, 1992)). In so doing, it proposes a parallel track to the current emphasis on in-depth qualitative research into climate communication (Moser, 2016): addressing the basic research gap pertaining perceptions of visual rhetoric as it is utilized (Leshner et al., 2016, Deitrick and Edsall, 2009).

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CHAPTER 5

CONCLUSION

THE EVOLUTION OF THE OBSERVED PROBLEM.

The observed problem identified in the proposal for this dissertation has evolved. As originally stated, this research sought to understand the implications of new technology that made it possible to rapidly and realistically visualize modeled impacts of hurricanes. This focus emerged from my development of innovations in this arena, and observations of innovations in this arena taking place in other institutions (e.g., C.L.I.V.E. at MIT and University of Prince Edward Island) (Fenech, Chen, Clark, & Hedley, 2017). A primary concern of this research was what occurred when these visualizations were decontextualized in mass communication and used outside of workshop processes.

As real and urgent as this observed problem is, it is symptomatic of a larger set of epistemic issues related to the use of visualizations, and scientific graphic issues more generally. The act of representation is so fundamental to science (a recorded observation is a representation of a phenomena) as to be both ubiquitous and invisible (Van Fraassen, 2008). Among the complications that emerges from this invisibility is that graphics and visualizations that ostensibly appear similar are understood differently within different communities of practice. As it pertains to this dissertation, the clearest distinction can be seen between expert-driven communication of natural hazards, that tends to focus on the probability of events and informing the public of hazards, and climate communication, which tailors communication to foster acceptance and constructive action on the part of participants.

These approaches are exemplified by cartographic frameworks for visualizing risk such as Kostelnick, et. al. (2013) that fundamentally view the heuristics of risk perception as distortions that alter the understanding of probabilistic information (e.g., overstating certainty), and the approach espoused by scholars like Moser (2016), that emphasize qualitative work, and the use of dialogic processes that foster bi-directional communication between experts and stakeholders, including policy makers and public officials. Both approaches are pragmatic. Cartographic frameworks fundamentally work from “science-out” and seek to describe standards for the portrayal of expert derived data, in some cases going so far as to suggest that certain kinds of representations be reserved for experts (Kostelnick, McDermott, Rowley, & Bunnyfield, 2013). Although climate communication is diverse and spread across many disciplines (Moser, 2016), the practices for applying visualization espoused in that context work back from understandings of heuristics of risk perception such as Kahneman (1982) and qualitative image studies such as O’Neill and Nicholson-Cole (2009). Guidance thus emphasizes constructive responses, scenarios that are relevant to individual stakeholders in temporal and physical scope and allowing stakeholders to interactively explore adaptation (Sheppard, 2012). Not adhering to this guidance risks reducing feelings of efficacy (that actions taken to adapt or mitigate are worthwhile)(O'Neill & Nicholson-Cole, 2009).

It’s all but impossible to argue that expert driven hazard communications don’t generate reductions of feelings of efficacy or disbelief of risks predicted in the context of climate communication (this research demonstrates that they do). The guidance developed in climate communication, however, does not easily accommodate the needs of experts engaged in hazard communications. First and foremost, climate communication research is dominated by practitioners, meaning that the research conducted largely references the communication practice of the researchers themselves (Moser, 2016). A further disconnect exists between the guidance in climate communication insofar as communicating the risks of extreme events with increasing probabilities (Emanuel, 2017). Even if such events may be demotivating to personal efficacy, it's arguable that there is a real need to inform the public of unlikely but plausible events (Lin & Emanuel, 2016).

This research thus identifies a fundamental issue with both pragmatic approaches to communications, namely, the extent to which pragmatic qualitative research into the application of visualizations has distracted from the development of fundamental understandings of how visualizations 'work' in regard to the heuristics of risk perception. This gap was first identified by Sheppard (2005) and has only grown as climate communication has become more evolved and sophisticated. This research thus exchanged the relatively tractable problem of defining problems of a visualization used in mass media, with a much more complex endeavor, grounding the use of the same visualizations in the heuristics of risk perception to inform their use by experts engaged in hazard communications.

THE INTENDED AUDIENCE.

Two weeks before handing in this dissertation, while discussing an analysis of point data, Professor Ginis asked who the audience of this research is. The answer was that he was the intended audience. Although it would seem to be a humorous comment regarding who needs to understand the quality of existing point data, it accurately reflects the motivation of this research. Professor Ginis presumed that the creators of the point data had attended to the quality of the data. The data, however, was made to standards suitable to one purpose (emergency response), but not to the purpose which we were applying it to, an issue that had been elaborated in the landscape and urban planning (e.g., Sheppard and Cizek (2009)), and GIS literature (e.g. Couclelis (2003)). This small issue reflects the complex epistemic issues that come about in interdisciplinary work when scientists and scholars are operating in parallel but distinct epistemic contexts. It also explains the alignment of the technical and social science aspects of this research, in the sense that understandings of technical data and social science are fundamentally necessary to allow the ethical and effective application of the technologies that have been developed as part of this research.

While this research could be seen to be critical of the practice of ocean scientists who disregard the advice of climate communicators regarding guidance for scenario selection or other practices, it is more critical of our collective failure to systematically understand the ways in which visual rhetoric is perceived sufficiently to inform practices that don’t conform to the current paradigms of climate communication. The choices of publishing venues, the Journal of Marine Science and Engineering, Technical Communication Quarterly, reflect the need to reach persons engaged in ocean modeling and technical communicators respectively.

FAILING FORWARD.

The origins of this research reflect a continuing and nagging doubt in pragmatic approaches to visualization research that repeats the importance of affective response and social and cultural factors without further explaining their relative effects. The acceptance of this status quo is the post-positivist equivalent of "it's complicated, be careful".

The fundamental criticism of this research as it has sought to better explain the effects of visualizations has been the lack of clear hypotheses, failure to adequately consolidate and define findings, and the tendency to sprawl across multiple disciplines without firmly grounding the research in a singular disciplinary context. Arguably, developing clear hypotheses, consolidating and defining findings, and grounding them in a discipline are the fundamental objectives of a doctoral education.

The shift in the observed problem, and the reactionary nature of this research is the source of the seeming lack of focus. It is also the source strength; shifts and periodic failings have fueled discovery. Writing a pragmatic paper dealing with audience perceptions of the visualizations would be a much more straightforward paper to write than trying to discern how the presumptions audiences make regarding scientific graphics inform their perception (chapter 3). The former falls within the boundaries of practitioners' evaluations that are common in the genre of climate communication. The latter seeks an explanation that can be more broadly applied to communication practice. Arguably, the outcomes of this research would have more utility for the broader research team (e.g. Marine Affairs Coastal Resilience Lab) had I taken the easier path. Within the survey comments praise and laudatory comments outweigh those critical of the visualizations. This would also firmly place the research within the existing paradigms of climate communication, thus more firmly grounding the research, and making it easier to publish. Doing this however, perpetuates the fundamental lack of basic research that has held back visualization practice. This research thus has been overtly critical of the use of visualizations, emphasized aspects that make them less effective (e.g., affective responses reflecting feelings of manipulation), and taken a path contrary to approaches by other scholars that seek to demonstrate the effectiveness of the tools they have created.

This approach, while intellectually satisfying, has maximized the amount of literature I have needed to master. In some cases, this has led me to over-cite texts for fear of walking on thin ice in unfamiliar genres, or in some case to rely more heavily on researchers I have an affinity with (e.g. Walsh). In other situations, however, the narrowness of the citations reflects the problem as it is observed, that is the over dependence on case studies, and the lack of basic research. In these situations, works (e.g., Kostelnick, Bostrom) take on outsized importance due to the dearth of resources.

VALIDITY, RELIABILITY AND NEXT STEPS.

Evolution and discovery comes at a cost. Many of the original models that were developed as part of the research design in the proposal are obsolete, as are the intentions that drove the choice of using continuous variables in the first place. This has created potential issues insofar as validity is concerned, namely, the use of a categorical lickert scale would have been regarded as more reliable for the models ultimately executed. Some of this is offset by the high number of respondents. In the worst case, this research may be regarded as exploratory and the source of hypotheses to test. As the chapters have been clarified, however, it’s clear that the emergence of the themes within the inductive coding, and the nature of the one-word responses in and of themselves is informative, and further work is being done to validate the results (e.g., additional tests, re-examination of underlying data to determine if descriptive statistics may also be used to make the argument).

The findings of this work form the basis of hypotheses for further testing using more concise survey instruments and statistically representative samples in lieu of the current purposive sample. For example:

1. Audience expectations inform perceptions of graphics and visualizations; deviations from audience expectations (e.g., graphic style, extents of surge) are associated with the discounting of risks.
    a. Expectations are defined as pre-existing judgements regarding aspects of the depicted content (e.g., likely extents of the storm surge) and / or graphic standards (e.g., presumptions regarding scientific graphics). Although heuristics of biased assimilation could be used to explain these effects (Lord, Ross, & Lepper, 1979), the concept of expectations is here used because creators of graphics, such as visualizations of storm surge, may play a role in "setting" expectations through continued practice (e.g., the repeated use of a blue color to represent inundation).
2. Affective responses to graphics and visualizations that affect risk perception may be to either the depicted content of the visualization, or the visualization itself as an artifact (Van Fraassen, 2008). Regardless of whether the response is to the content or the "container", these responses alter risk perception.
    a. Affective response is a subconscious emotional judgement based on a stimulus (Zajonc, 1984).

These two examples may seem to state the obvious, however, these fundamental aspects of the perception of visualizations are not established experimentally within the literature. As it pertains to existing models of hazard communication, e.g., Kostelnick (2013) the proof of these hypotheses would both support the use of existing frameworks. For instance, conventions may form a basis for effective communication by "setting expectations". Conversely, the proposed model of affective response and risk perception suggests that the misleading characteristics of 3d visualizations may be overstated. These hypotheses which are preliminarily supported by this research thus address the identified research gap by grounding the perception of visualizations in the heuristics of risk perception. This work therefore contributes an important new cornerstone to the development of visualization practice by providing a means to understand and apply the considerable practical knowledge gained in climate communication to other types of hazard communication processes engaged in by experts or through mass media.

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APPENDICES

APPENDIX 1

REGRESSION MODELS FOR CHAPTER 3

Regression models are presented in Table 15 and Table 16 on the following pages.

Table 15, Part one of the summary of regression models for Chapter 3 including social and cultural factors and familiarity with the visualizations.

Social and Cultural Factors

	Full cohort					Non-familiar-non-expert					Experts (not including team members)				
Term	**estimate**	**std.error**	**f-statistic**	**p.value**		**estimate**	**std.error**	**f-statistic**	**p.value**		**estimate**	**std.error**	**f-statistic**	**p.value**	
(Intercept)	86.15065	10.31516	8.351851	5.95E-16	***	75.95381	11.99966	6.329663	1.06E-09	***	100.7311	46.05273	2.187298	0.033842	*
Income															
Under 50,000	1.976349	3.078419	0.642001	0.521151		3.099598	4.002288	0.774456	0.439359		17.13886	16.41417	1.044151	0.301872	
Under $75,000 (+ median)	-1.94971	2.566673	-0.75963	0.447816		-3.61044	3.515262	-1.02707	0.305332		-3.67311	13.63306	-0.26943	0.788806	
Over $150,000 (+ double median)	-2.45994	2.273785	-1.08187	0.279804		-3.56466	3.047625	-1.16965	0.243204		-2.16322	8.542173	-0.25324	0.801211	
Choose not to respond	-4.16418	2.421411	-1.71973	0.086067	.	-6.84942	3.223681	-2.12472	0.034546	*	9.885199	11.00279	0.898427	0.373637	
Left blank	-14.9743	6.386686	-2.34461	0.019417	*	-3.53129	9.953592	-0.35478	0.723043		-34.5781	18.25358	-1.89432	0.06448	.
Education															
Associates degree or less	-8.53482	9.19761	-0.92794	0.353863		6.755559	13.04409	0.517902	0.604964		-19.3966	30.18107	-0.64268	0.523626	
Bachelor's degree or higher	-12.6694	9.003644	-1.40714	0.159975		-3.73831	12.8199	-0.2916	0.770822		4.012924	30.22433	0.132771	0.894953	
Graduate degree or higher	-11.8915	8.870577	-1.34056	0.18064		-2.51762	12.71065	-0.19807	0.843143		-2.80483	28.3394	-0.09897	0.92159	
Other political and demographic															
Liberal	4.516704	2.190849	2.061623	0.039733	*	6.552	3.341939	1.960539	0.050992	.	-1.20937	8.457018	-0.143	0.886913	
Conservative	-1.39529	2.923181	-0.47732	0.633333		4.271984	4.249542	1.005281	0.315689		-9.10432	9.810863	-0.92798	0.35826	
Female	-1.10372	1.628639	-0.67769	0.498263		-2.43909	2.165329	-1.12643	0.261015		6.997499	9.36339	0.747325	0.45867	
Under 40	1.122285	2.188421	0.512828	0.608286		-1.30017	2.966775	-0.43824	0.661571		16.65835	9.893197	1.683819	0.098992	.
Non-white	2.549097	3.00781	0.847493	0.397105		-1.15098	3.698506	-0.3112	0.755896		32.44158	15.95021	2.033928	0.047749	*
Home ownership															
Coastal home owner	0.043917	8.993792	0.004883	0.996106		5.802939	11.66949	0.497274	0.619413		-28.3936	28.54487	-0.9947	0.325085	
Home owner	3.105977	8.940742	0.347396	0.728432		6.418719	11.59811	0.553428	0.580442		-18.9344	28.80334	-0.65737	0.514221	
Not a home owner	-1.42292	9.070482	-0.15687	0.875404		4.197307	11.82702	0.354891	0.722956		-24.5028	30.6619	-0.79913	0.428323	
Experience with storm surge															
Personally expereinced damage	-3.03788	2.288225	-1.32761	0.18488		-5.1953	3.074352	-1.68988	0.09224	.	-22.936	9.917193	-2.31276	0.025262	*
Friend or family experienced damage	0.269697	1.890269	0.142677	0.8866		-1.51072	2.679143	-0.56388	0.573318		2.442588	9.567041	0.255313	0.79962	
Personally seen or witnessed	1.670312	1.789716	0.933283	0.3511		0.324548	2.546333	0.127457	0.898676		0.088719	8.807637	0.010073	0.992007	
Seen in media	2.008311	1.837692	1.092844	0.274961		2.9557	2.59723	1.13802	0.256152		-6.81804	8.664936	-0.78685	0.435402	

Familiarity with visualizations

	Full cohort					Non-familiar-non-expert					Experts (not including team members)				
Term	**estimate**	**std.error**	**f-statistic**	**p.value**		**estimate**	**std.error**	**f-statistic**	**p.value**		**estimate**	**std.error**	**f-statistic**	**p.value**	
Worked with or near science team	8.217569	5.384693	1.526098	0.127584		NA	NA	NA	NA		NA	NA	NA	NA	
Have seen the visualizations before	0.7827	4.80179	0.163002	0.870579		NA	NA	NA	NA		-4.56412	30.53852	-0.14945	0.881848	
Encountered them in a training exercise	2.36735	5.104435	0.463783	0.642994		NA	NA	NA	NA		-4.46826	32.52614	-0.13737	0.891334	
Not familiar with the visualizations	-4.00256	4.839694	-0.82703	0.408595		NA	NA	NA	NA		-7.22612	30.65941	-0.23569	0.814719	

Table 16, Part two of the regression models for chapter 3, including expertise and coded responses.

Expertise

	Full cohort					Non-familiar-non-expert					Experts (not including team members)				
Term	estimate	std.error	f-statistic	p.value		estimate	std.error	f-statistic	p.value		estimate	std.error	f-statistic	p.value	
Scientific or academic	5.285526	3.01128	1.755242	0.079798	.	NA	NA	NA	NA		12.31556	7.306636	1.685531	0.098659	.
Planning	8.345334	3.972678	2.100682	0.036142	*	NA	NA	NA	NA		19.97026	10.58632	1.886422	0.06556	.
Emergency Management	-2.37697	3.63015	-0.65479	0.512891		NA	NA	NA	NA		7.615605	8.547955	0.890927	0.377605	
Government / elected	0.812853	3.141819	0.25872	0.795952		NA	NA	NA	NA		-0.75268	9.068313	-0.083	0.934211	
Maritime	-6.93805	7.080059	-0.97994	0.327563		NA	NA	NA	NA		16.08223	31.82956	0.505261	0.615788	
Other relevant expertise	-4.02315	3.906034	-1.02998	0.303489		NA	NA	NA	NA		3.524542	11.27281	0.312659	0.755953	
Non-expert	6.534596	3.010632	2.170507	0.030413	*	NA	NA	NA	NA		NA	NA	NA	NA	
Retired	0.57648	2.843584	0.20273	0.839424		-0.09147	3.570084	-0.02562	0.97958		27.11818	13.15227	2.061862	0.044897	*

Coded responses

	Full cohort					Non-familiar-non-expert					Experts (not including team members)				
Term	estimate	std.error	f-statistic	p.value		estimate	std.error	f-statistic	p.value		estimate	std.error	f-statistic	p.value	
Data and related factors															
Based on data	-3.42156	2.23744	-1.52923	0.126806		-1.57362	3.108427	-0.50624	0.613112		-6.90232	8.519499	-0.81018	0.422009	
Based on computer simulation	5.991237	4.630922	1.293746	0.196319		5.225625	6.917248	0.755449	0.450658		9.296404	18.59356	0.49998	0.619473	
Validation, peer review / Historic storms	0.711103	3.132437	0.227013	0.820502		-3.4216	5.124406	-0.66771	0.504908		1.321886	10.19983	0.129599	0.897449	
Includes probability and or uncertainty	-4.55394	4.479344	-1.01665	0.309784		-8.85694	5.441344	-1.62771	0.104788		-4.65799	17.93367	-0.25973	0.796228	
Objectivity	-1.39238	7.312972	-0.1904	0.84907		-3.67164	13.55215	-0.27093	0.786661		-0.41635	17.61543	-0.02364	0.981246	
Visual cues															
Clarity and ease of understanding	10.16919	4.263583	2.385128	0.017425	*	4.209156	5.696664	0.738881	0.460641		39.56555	21.99417	1.798911	0.078595	.
Quality and aesthetics	4.895131	3.666465	1.335109	0.182416		2.485975	4.580868	0.542686	0.587807		NA	NA	NA	NA	
Visualization style	-3.7372	2.962854	-1.26135	0.207739		-7.26714	4.265528	-1.70369	0.089625	.	1.392018	12.7363	0.109295	0.913444	
Labels legend	0.083298	3.050007	0.027311	0.978222		-5.00148	4.174014	-1.19824	0.231906		-2.10928	12.67657	-0.16639	0.868578	
Accurate geography / recognizable	7.069482	3.306622	2.137977	0.032977	*	5.337823	4.419181	1.207876	0.228184		15.52129	11.40056	1.36145	0.180003	
Use of color scales	3.149539	3.278635	0.960625	0.33718		3.357553	4.08101	0.822726	0.411412		20.62649	17.15381	1.202444	0.235345	
Transparency															
Disclosure of data sources / data	-0.19672	2.304432	-0.08537	0.932002		2.051973	3.394142	0.604563	0.545992		3.25207	9.474832	0.343233	0.732987	
Disclosure of methods	-3.55256	3.333089	-1.06585	0.28698		2.413666	4.836148	0.499088	0.618136		-16.331	10.56207	-1.54619	0.128911	
Provision of background or context	-3.49418	3.012504	-1.15989	0.246617		-8.05261	3.947738	-2.0398	0.042373	*	-12.305	13.29948	-0.92522	0.359679	
Other factors															
Personal Judgement	-0.61254	2.907118	-0.2107	0.833201		2.379372	4.000609	0.594752	0.552522		-1.41031	11.92322	-0.11828	0.906359	
Reputation	7.660167	2.605501	2.939998	0.003426	**	9.936574	3.544134	2.803668	0.00543	**	-7.56206	11.4645	-0.65961	0.512796	**
Don.'t get it	8.952181	13.57543	0.65944	0.509901		-13.5739	18.2267	-0.74472	0.457106		NA	NA	NA	NA	

APPENDIX 2

REGRESSION MODELS AND SUPPLEMENTAL MATERIALS FOR CHAPTER 4

SUMMARY OF AFFECT WORDS

The word key used to compile one-word responses is included in the project data. A summary of words used five or more times represented in the list is included below in Table *17*. A summary of words used five or more times not present in the list is included in Table *18*.

Table 17, Summary of one-word responses in the affect list that were used 5 or more times.

Word	Frequency	Word	Frequency	Word	Frequency
concerned	252	afraid	16	amazed	6
confused	89	overwhelmed	16	shocked*	7
worried	66	frightened	15	catastrophic	6
informed*	61	scary	14	dangerous	6
nervous	53	frustrated	12	disoriented	6
sad	53	impressed	12	fine	6
scared	47	terrified	12	relieved*	6
curious	35	horrified*	11	uncertain	6
alarmed*	28	resigned*	11	unsure	6
anxious	21	devastating	10	awe	5
vulnerable	21	indifferent	10	cool	5
devastated*	19	apprehensive	9	hopeful	5
aware	18	bad	9	informative	5
neutral	18	cautious	9	realistic	5
safe / safer*	18 (12 / 6)	intrigued*	9	shocking	5
surprised	18	wet	9	unprepared	5
uneasy	18	expected*	7		
interested	17	fearful	7		

Table 18, words used 5 or more times for which there is no near or exact corollary in the ANEW database.

Missing Word	**Frequency**
wow	13
ok	12
ambivalent	10
yikes	10
unsurprised	9
nothing	8

WORDS PLOTTED BY VALENCE, AGITATION AND DOMINANCE

Plotting words according to the three dimensions of Affective content described by ANEW, Valence, Agitation, and Dominance, is revealing of the general sentiments regarding the visualizations. The majority of responses are clustered towards the middle, slightly favoring negative valance, dominance, and agitation. For example:

- The word "informed" has a slightly positive valence, the higher level of dominance indicates feeling in control, and the level of agitation is comparatively low.
- The word "sad" reflects both negative valence and dominance, but similarly has a comparatively low degree of agitation.
- The word "scared" by comparison reflects a combination of negative dominance, positive agitation, and negative valence.
- The word "confused" is not dissimilar from "scared" in its valence, dominance and agitation, but may reflect frustration with the visualization.

The relationship between valence and dominance follows a diagonal pattern, as does the relationship between valence and agitation. The relationship between agitation and dominance is less clear but still present. These three-dimensional relationships are visualized in Figure 38.

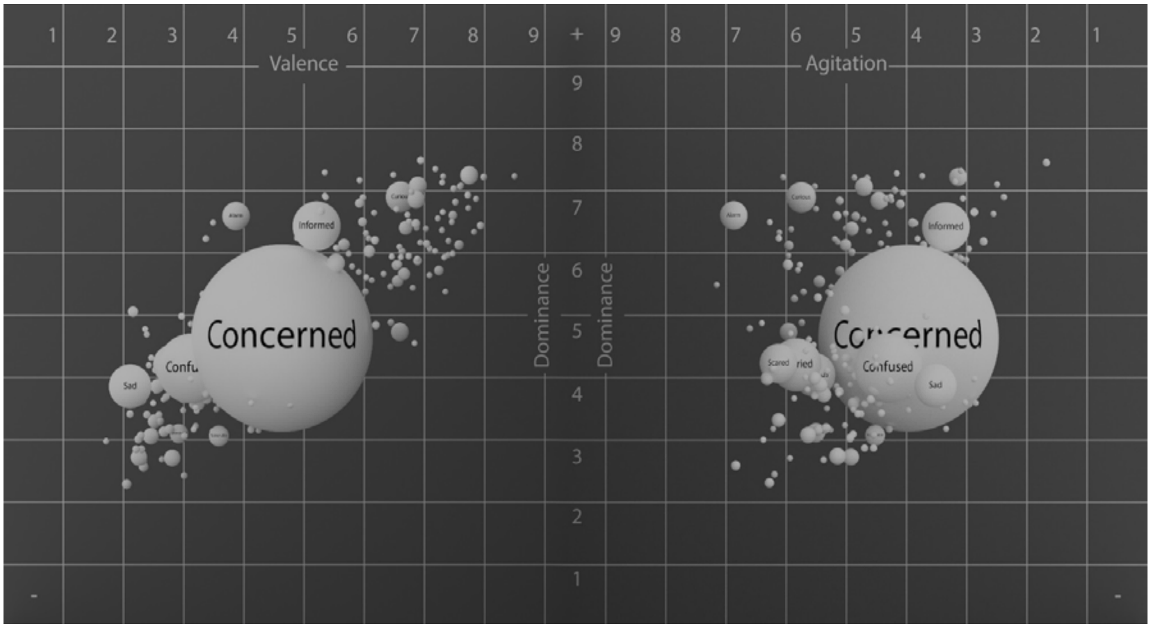


Figure 38, Two views of a three-dimensional plot of valence, agitation (arousal) and dominance using mean values for each word (not accounting for gender). Figure:

ANALYSIS OF STATED POLITICAL LEANING AND CHANGE IN STATED PERCEPTION OF RISK.

In broad political terms, changes in perception of risk after viewing the visualization were reported among both politically liberal and conservative individuals. Correlation coefficients for all political leanings are near zero (Table 19). There are some possible indications of difference among political leanings. For instance, the range of change in stated perception of risk is greatest among extremely liberal persons, while the range of change among stated perception is least among extremely conservative persons. The greatest positive mean change occurred among persons who reported being either slightly liberal or slightly conservative. Ascribing meaning to these differences, however, is speculative without additional information. These observations notwithstanding, politics is only found to be a statistically significant factor in one of the subsequent analyses. This suggests that other factors play a stronger role.

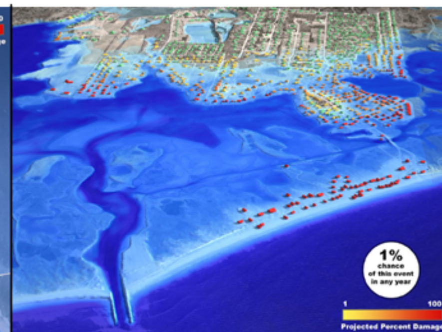
Table 19, summary of change in stated perception of risk after viewing visualization, organized by political leaning A correlation coefficient of 1 indicates strong positive correlation, a correlation coefficient of -1 indicates negative correlation. A coefficient of zero indicates no correlation. All of the coefficients included below are close to zero.

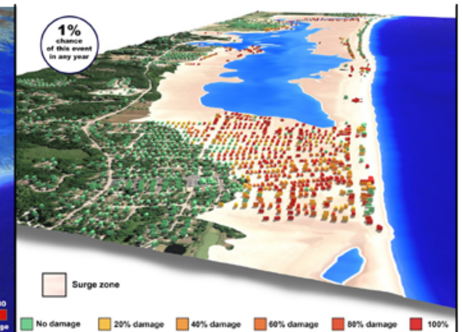
Politics	**Mean change**	**Median change**	**Range of change**	**Correlation coefficient**
Extremely liberal	2.95	1	157	0.05
Moderately liberal	1.02	0	80	-0.02
Slightly liberal	3.13	1	88	0.04
Neither lib. nor conservative	0.70	0	119	-0.02
Slightly conservative	3.76	2	145	0.04
Moderately conservative	-2.61	0	118	-0.07
Extremely conservative	-4.80	-1	24	-0.04

REGRESSION ANALYSES.

Regressions were performed using both the composited risk score (Table 20), and separating evaluations of the severity of an impact and the likelihood of an impact into separate scores (Table *21*, Table *22*, Table *23*). The relative strength of the effects of the Matunuck visualization is reinforced by the relative significance of results among persons who report living in or visiting other coastal communities. These effects are not discussed in the body of the paper, but provide additional evidence as to the overall effectiveness of the visualization.

Table 20, Summary of linear regression using risk-score as response variable. Note the prevalence of more significant responses in the Matunuck visualization, which most clearly depicted consequences using a conventional color scheme.





	Matunuck, Rhode Island, USA					Charlestown, Rhode Island, USA					Misquamicut, Rhode Island, USA				
term	est.	std. error	t value	p value	sig.	est.	std. error	t value	p value	sig.	est.	std. error	t value	p value	sig.
(Intercept)	6.334	1.028	6.161	1.76E-09	***	4.813	1.014	4.745	2.85E-06	***	6.638	1.012	6.557	1.58E-10	***
Visit or live in the community depicted	0.889	0.362	2.459	0.014	*	0.314	0.388	0.810	0.418		0.200	0.461	0.434	0.665	
Recognize the community depicted	0.782	0.333	2.346	0.019	*	0.970	0.315	3.078	0.002	**	0.707	0.321	2.204	0.028	*
Visit or live in another coastal community	1.001	0.281	3.555	4.24E-04	***	0.546	0.272	2.011	0.045	*	0.339	0.274	1.238	0.216	
Distance to the community depicted	-6.641E-05	1.135E-04	-0.585	0.559		-4.586E-05	1.143E-04	-0.401	0.688	.	-2.189E-04	1.143E-04	-1.915	0.056	.
Valence	-0.417	0.112	-3.704	2.42E-04	***	-0.189	0.110	-1.707	0.089		-0.171	0.111	-1.539	0.125	
Agitation	0.007	0.125	0.054	0.957		0.155	0.113	1.371	0.171		0.027	0.118	0.228	0.820	
Dominance	-0.002	0.147	-0.011	0.991		-0.073	0.136	-0.533	0.594		-0.172	0.144	-1.192	0.234	
Scientist or academic	0.934	0.463	2.017	0.044	*	0.960	0.472	2.033	0.043	*	1.050	0.450	2.333	0.020	*
Planner	1.012	0.629	1.608	0.109		0.673	0.600	1.121	0.263		0.593	0.624	0.951	0.342	
Emergency Manager	-0.119	0.559	-0.214	0.831		0.827	0.578	1.432	0.153		0.747	0.547	1.366	0.173	
Government or elected official	0.130	0.499	0.261	0.794		-0.132	0.460	-0.288	0.774		0.158	0.465	0.339	0.735	
Non-expert	0.952	0.417	2.287	0.023	*	1.241	0.425	2.922	0.004	**	0.907	0.411	2.207	0.028	*
Female	0.448	0.272	1.649	0.100	.	0.609	0.265	2.296	0.022	*	0.616	0.273	2.255	0.025	*
Age (under 30)	-0.409	0.380	-1.076	0.282		-0.642	0.357	-1.798	0.073	.	-0.573	0.370	-1.548	0.122	
Income (below median)	0.089	0.311	0.288	0.774		0.323	0.297	1.089	0.277		0.108	0.304	0.356	0.722	
Politics (liberal)	0.308	0.288	1.070	0.285		0.501	0.283	1.773	0.077	.	0.544	0.292	1.864	0.063	.
Non-white	1.075	0.485	2.214	0.027	*	0.728	0.495	1.472	0.142		0.778	0.487	1.596	0.111	
Unfamiliar with the visualizations presented	-0.566	0.360	-1.573	0.117		-0.064	0.356	-0.179	0.858		-0.465	0.364	-1.277	0.202	

Table 21, Comparison of likelihood and severity regression results for Matunuck, RI, USA. Note the greater significance of valence related to perceived severity of impacts.

	Likelihood					Severity				
term	est.	std. error	t value	p value	sig.	est.	std. error	t value	p value	sig.
(Intercept)	65.991	9.539	6.918	1.81E-11	***	93.245	7.380	12.636	3.88E-31	***
Visit or live in the community depicted	2.035	4.939	0.412	0.681		-0.111	3.957	-0.028	0.978	
Visit or live in another coastal community	6.668	2.629	2.536	1.16E-02	*	7.962	2.052	3.880	0.000	***
Recognize the community depicted	9.559	3.710	2.576	0.010	*	7.927	2.918	2.716	0.007	**
Did not recognize a community visited or lived in	7.709	6.488	1.188	0.235		8.957	5.106	1.754	0.080	.
Distance to the community depicted	-2.828E-04	1.063E-03	-0.266	0.790		-4.716E-04	8.383E-04	-0.563	0.574	
ANEW: valence	-2.398	1.039	-2.307	2.15E-02	*	-4.049	0.818	-4.948	0.000	***
ANEW: agitation	0.181	1.161	0.156	0.876		-0.654	0.912	-0.717	0.474	
ANEW: dominance	0.626	1.365	0.458	0.647		-0.514	1.063	-0.483	0.629	
Female	4.169	2.516	1.657	0.098	.	1.837	1.973	0.931	0.352	
Age (under 30)	-2.416	3.512	-0.688	0.492		-1.311	2.792	-0.469	0.639	
Income (below median)	2.450	2.879	0.851	0.395		-2.357	2.262	-1.042	0.298	
Politics (liberal)	2.350	2.654	0.885	0.377		1.224	2.090	0.586	0.558	
Non-white	6.494	4.575	1.419	0.157		5.536	3.611	1.533	0.126	
Scientist or academic	8.850	4.337	2.041	0.042	*	4.442	3.384	1.312	0.190	
Planner	9.878	5.860	1.686	0.093	.	7.518	4.600	1.634	0.103	
Emergency Manager	-2.990	5.215	-0.573	0.567		-4.787	4.040	-1.185	0.237	
Government or elected official	-0.235	4.663	-0.050	0.960		0.561	3.622	0.155	0.877	
Maritime industry	20.978	15.291	1.372	0.171		20.667	12.059	1.714	0.087	.
Non-expert	9.522	3.955	2.408	0.017	*	4.279	3.082	1.388	0.166	
Unfamiliar with the visualizations presented	-3.652	3.339	-1.094	0.275		-4.076	2.607	-1.564	0.119	

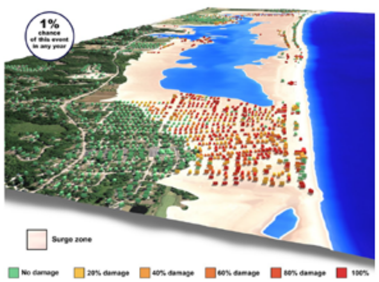
Matunuck, Rhode Island, USA

Table 22, Comparison of likelihood and severity regression results for Charlestown, RI, USA. Note the significance of ANEW variables related to perceived severity of impacts, and their lack of significance related to perceived likelihood of impacts.

	Likelihood					Severity				
term	est.	std. error	t value	p value	sig.	est.	std. error	t value	p value	sig.
(Intercept)	56.841	9.737	5.837	1.05E-08	***	79.670	5.204	15.308	1.07E-42	***
Visit or live in the community depicted	0.031	4.402	0.007	0.994		-0.843	2.384	-0.354	0.724	
Visit or live in another coastal community	4.596	2.597	1.770	7.75E-02	.	1.682	1.400	1.201	0.230	
Recognize the community depicted	10.678	3.252	3.283	0.001	**	3.496	1.750	1.998	0.046	*
Did not recognize a community visited or lived in	10.973	7.963	1.378	0.169		4.011	4.241	0.946	0.345	
Distance to the community depicted	-3.934E-04	1.093E-03	-0.360	0.719		-1.355E-04	5.927E-04	-0.229	0.819	
ANEW: valence	-1.340	1.053	-1.272	2.04E-01		-1.226	0.571	-2.149	0.032	*
ANEW: agitation	0.959	1.076	0.891	0.373		1.529	0.576	2.652	0.008	**
ANEW: dominance	-0.583	1.297	-0.449	0.654		-0.102	0.707	-0.144	0.885	
Female	5.782	2.523	2.292	0.022	*	1.448	1.355	1.068	0.286	
Age (under 30)	-6.802	3.397	-2.002	0.046	*	0.529	1.848	0.286	0.775	
Income (below median)	3.794	2.822	1.344	0.180		-0.249	1.527	-0.163	0.871	
Politics (liberal)	5.173	2.711	1.908	0.057	.	1.129	1.463	0.772	0.441	
Non-white	8.866	4.773	1.857	0.064	.	-1.986	2.537	-0.783	0.434	
Scientist or academic	8.963	4.549	1.970	0.049	*	1.554	2.450	0.634	0.526	
Planner	6.689	5.723	1.169	0.243		3.314	3.079	1.076	0.282	
Emergency Manager	6.742	5.523	1.221	0.223		2.603	2.972	0.876	0.382	
Government or elected official	-1.309	4.407	-0.297	0.767		-0.094	2.385	-0.039	0.969	
Maritime industry	12.928	15.511	0.833	0.405		4.858	8.452	0.575	0.566	
Non-expert	11.124	4.146	2.683	0.008	**	4.672	2.231	2.094	0.037	*
Unfamiliar with the visualizations presented	-0.779	3.392	-0.230	0.818		-0.801	1.817	-0.441	0.659	

Charlestown, Rhode Island, USA

Table 23, Comparison of likelihood and severity regression results for Misquamicut, RI, USA. Notice the significance of not recognizing a place the respondent reported visiting or living in.



Misquamicut, Rhode Island, USA

	Likelihood					Severity				
term	est.	std. error	t value	p value	sig.	est.	std. error	t value	p value	sig.
(Intercept)	74.541	9.547	7.808	4.49E-14	***	88.443	5.472	16.164	1.90E-46	***
Visit or live in the community depicted	3.500	5.212	0.672	0.502		3.800	3.017	1.260	0.208	
Visit or live in another coastal community	2.373	2.591	0.916	3.60E-01		2.975	1.487	2.001	0.046	*
Recognize the community depicted	6.663	3.158	2.110	0.035	*	1.523	1.810	0.841	0.401	
Did not recognize a community visited or lived in	-0.193	9.038	-0.021	0.983		-13.240	5.246	-2.524	0.012	*
Distance to the community depicted	-2.202E-03	1.081E-03	-2.037	0.042	*	-8.939E-04	6.219E-04	-1.437	0.151	
ANEW: valence	-1.805	1.042	-1.733	8.38E-02	.	0.070	0.603	0.117	0.907	
ANEW: agitation	-0.335	1.108	-0.302	0.763		0.217	0.634	0.342	0.732	
ANEW: dominance	-1.123	1.353	-0.830	0.407		-1.133	0.780	-1.452	0.147	
Female	6.422	2.556	2.513	0.012	*	2.573	1.473	1.747	0.081	.
Age (under 30)	-6.594	3.483	-1.893	0.059	.	1.903	2.007	0.948	0.344	
Income (below median)	2.123	2.856	0.743	0.458		-0.544	1.643	-0.331	0.741	
Politics (liberal)	4.751	2.743	1.732	0.084	.	0.808	1.581	0.511	0.610	
Non-white	8.538	4.645	1.838	0.067	.	-1.642	2.661	-0.617	0.537	
Scientist or academic	9.343	4.270	2.188	0.029	*	2.267	2.453	0.924	0.356	
Planner	4.804	5.859	0.820	0.413		1.757	3.399	0.517	0.605	
Emergency Manager	6.274	5.162	1.215	0.225		2.362	2.989	0.790	0.430	
Government or elected official	1.511	4.395	0.344	0.731		0.330	2.542	0.130	0.897	
Maritime industry	13.681	15.591	0.877	0.381		2.399	9.048	0.265	0.791	
Non-expert	8.879	3.959	2.242	0.025	*	1.060	2.294	0.462	0.644	
Unfamiliar with the visualizations presented	-2.971	3.391	-0.876	0.381		-2.812	1.947	-1.444	0.149	

Before using the risk score in regression analyses, it was validated by examining the distribution and correlation of the stated severity and likelihood. It became immediately apparent that there were differences in the scores among the different visualizations. There was a closer correlation between likelihood and severity in the Matunuck visualization, while severity of damage was rated as higher in both the Misquamicut and Charlestown visualizations. The lowest severity rating of the Charlestown visualizations was 19, whereas Matunuck and Misquamicut had low ratings of 0 and 1 respectively.

Table 24, Comparison of risk scores for the three communities visualized.

Community	**Correlation Coefficient**	**Mean severity**	**Median severity**	**Mean likelihood**	**Median likelihood**
Matunuck, RI, USA	.475	78.2	82	75.2	80
Charlestown, RI, USA	.357	87.8	90	74.8	81
Misquamicut, (South Kingstown), RI, USA	.390	87.3	91	74.6	81

While the overall distribution of all scores is towards the higher end of the scales, there is clearly a wider and more even distribution among the scores for the Matunuck visualization as shown in Figure 39, resulting in a distinct trendline. Given the modest correlation and distribution observed, neither likelihood nor severity alone predict the risk score.

Figure 39, graph plotting the relationship between likelihood and severity evaluations for all three visualizations. Note the greater distribution of scores and distinct trendline for the Matunuck visualization, which most clearly depicted impacts (e.g., individual impacts discernable.