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An Analysis of the Narrative-Building Features of Interactive Sea Level Rise Viewers

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Abstract

Interactive sea level rise viewers (ISLRVs) are map-based visualization tools that display projections of sea level rise scenarios to communicate their impacts on coastal areas. Information visualization research suggests that as users interact with such tools they construct personalized narratives of their experience. We argue that attention to narrative-building features in ISLRVs can improve communication effectiveness by promoting user engagement and discovery. A content analysis that focuses on the presence and characteristics of narrative-building features in a purposive sample of 20 ISLRVs is conducted. We also identify particular areas where these ISLRVs could be improved as narrative-building tools.

Keywords

sea level rise, interactive visualizations, narrative, visual communication

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Introduction

Communicators use participatory narrative building to connect audiences to information and increase its resonance and salience, for example, to facilitate personal meaning making and local production of knowledge (Daniels & Endfield, 2009), encourage behavioral change (Hinyard & Kreuter, 2007), facilitate organizational change (Llewellyn, 2001), and engage participants in understanding the trade-offs of action alternatives (Vervoort, Kok, van Lammeren, & Veldkamp, 2010). Interactive web-based visualizations are another type of tool for communicating about scientific issues via user-constructed interactive narratives (Vervoort et al., 2010). While traditional narratives use plot, characterization, and point of view to engage audiences, interactive visualizations use visual structuring, scene transitions, user interaction, and annotations to communicate messages (Segel & Heer, 2010). The users' experience of narrative in this context arises as they interact with the visualization, and includes the possible range of user actions and their effects, patterns of user input, and the way the results of actions are interpreted (Harrell & Zhu, 2009).

Interactive visualizations can be described as "narrative builders" that enhance communication effectiveness by guiding users to insights through the process of discovery while lowering their cognitive load (Dove & Jones, 2012). They allow users to explore data sets and construct alternative interpretations of information (Segel & Heer, 2010), thereby participating in the story-building process. Nevertheless, they also incorporate narrative-building features that communicate messages, constrain usage and interpretation, and frame the developing story line (Hullman & Diakopoulos, 2011). An interactive visualization may be more author driven (e.g., linear ordering of information, little interactivity, strong central message) or more reader (user) driven (e.g., free interaction with information, multiple ways of interacting, weaker messaging; Segel & Heer, 2010). Personalized and meaningful interaction with visualization tools can promote a sense of shared agency (Murray, 1998) and space to understand scientific complexity and uncertainty (Vervoort et al., 2010). However, emphasizing user choice may make it difficult to communicate a strong central message (Segel & Heer, 2010).

Interactive sea level rise viewers (ISLRVs) are tools developed to communicate and inform about the results of scientific computer modeling and help users visualize the potential impacts of sea level rise (SLR) in geographic locations of interest to them, therefore extending and intensifying the reach and impact of scientific research. They consist of a base geographic map on which visual representations of potential future SLR impact scenarios can be layered (i.e., displayed), with various options for altering the viewpoint and scenario details. Most existing ISLRVs have presumably been developed with a focus on technical usability (e.g., Davidson & Miglarese, 2003). However, we believe careful design of narrative-building features that guide interpretation may increase communication effectiveness of these visualization tools by enhancing user engagement and promoting insight. Thus, the purpose of the present study's content analysis of a sample of ISLRVs is to examine and characterize the narrative-building features that contribute to this category of visualization tools and to identify areas of potential design improvement.

Communicating About Sea Level Rise Impacts

SLR is a climate change-related process associated with increased flooding, coastal erosion, storm surge damage, and saltwater intrusion (Bilskie, Hagen, Medeiros, & Passeri, 2014). The Intergovernmental Panel on Climate Change (IPCC) predicts an increase in global sea level of between 0.28 and 0.82 meters by 2100, not including possible contributions from the collapse of Antarctic and Greenland ice sheets (IPCC, 2013). When moderate amounts of polar ice sheet melting are included along with thermal expansion of the ocean waters, SLR is projected to range up to 2 meters (Parris et al., 2012). This range of projections, coupled with local conditions that make SLR regionally variable (IPCC, 2013), can make it difficult for laypeople to conceptualize SLR's potential impacts.

The implications of climate change are open to interpretation, have no singular solution, and involve multiple actors who approach them from various political and philosophical perspectives. Public understanding of climate change has strong ties to personal worldviews and political ideologies (Braman, Kahan, Peters, Wittlin, & Slovic, 2012; McCright, Dunlap, & Xiao, 2013), as well as individuals' perceived ability to act effectively to mitigate or adapt to climate change impacts (Milfont, 2012). Additionally, news media coverage of climate change and related processes is driven by a complex set of factors that can influence public perceptions about climate science (Boykoff & Yulsman, 2013; Carvalho, 2007; Doyle, 2011). In the United States, the probable impacts of SLR have been reasonably depicted in news media (Rick, Boykoff, & Pielke, 2011). Many Americans associate climate change with SLR (Bell, 1994), and Americans living near the coast have been shown to perceive higher risks from climate change than those living in inland areas (Brody, Zahran, Vedlitz, & Grover, 2008).

SLR is more amenable to visual representation than some of the other aspects of climate change, such as ocean acidification. One of the strengths of visual communication for SLR is that it allows the demonstration of past and current sea states as well as potential future SLR impacts under alternative scenarios (i.e., situations involving different factors and certain conditions). Scenario-based communication is common among coastal planners and decision makers and also in broader public engagement about SLR (Frazier, Wood, & Yarnal, 2010; Higgason & Brown, 2009; Poulter et al., 2009). Visual communication tools have been used in local planning processes (Shaw et al., 2009) as well as general conversations about SLR and potential future coastal conditions (Nettley, Desilvey, Anderson, Wetherelt, & Caseldine, 2013). Place-based identity can be an important motivator for climate change concern (Devine-Wright, 2013; Safi, Smith, & Liu, 2012), as well as willingness to take mitigation or adaptation measures (Raymond & Robinson, 2013; Shackley & Deanwood, 2002). By extension, tools that help laypeople visualize potential SLR impacts in their own personally significant geographic areas may foster emotional attachments that encourage them to understand SLR better or support efforts to mitigate it. We believe that attention to the narrative-building features in ISLRVs can assist communicators in creating more engaging and effective communication tools.

Based on our review of the data visualization and SLR communication literature, we identified six key features of ISLRVs that may be considered criteria that foster narrative-building: (a) technical and conceptual support, (b) uncertainty and risk, (c) realism, (d) interaction structure, (e), local impacts and/or a global perspective, and (f) features for user self-efficacy. *Technical and conceptual support* help users operate interactive tools and interpret the process and results of their interactions. *Uncertainty and risk* are central components of public understanding about the impacts of SLR, although communicating these scientific concepts may be challenging (Spiegelhalter, Pearson, & Short, 2011). Balancing accuracy, authenticity, and *realism* has been shown to be important in SLR communication efforts (Nettley et al., 2013), as enhanced realism may convey a sense of heightened risk or higher certainty as compared to more abstract visualization methods (J. C. Kostelnick, McDermott, Rowley, & Bunnyfield, 2013). Interactive visualization tools use *interaction structure* such as scenario selection, zooming, and default view specification to create an overall narrative structure in a non–plot-based communication medium (Kosara & Mackinlay, 2013). Features that introduce *local impacts and/or a global perspective* to SLR may motivate users' emotional involvement with the issue and/or help them tie local conditions to a global narrative of SLR. Finally, *features for user self-efficacy* that suggest ways for users to respond to SLR risks (e.g., by locating buildings that are at particular risk) play a role in framing the user's overall narrative interaction and reception to information. Our study involved examining the presence and characteristics of these six features in a purposive sample of 20 ISLRVs

Method

Qualitative content analysis methodology was used to systematically examine and characterize the narrative-building features of ISLRVs. A purposive sample was selected by conducting a Google-based search using the keywords "sea level" plus "viewer," "interactive map," or "visualization." Because results of this initial search were largely focused on North America or were globally oriented, additional searches were conducted using a combination of the words "sea level" plus "interactive map" plus "Europe," "Asia," "Pacific," "Africa," or "Australia." A few additional visualizations were obtained using this expanded set of keywords. Once an initial sample of SLR-related visualizations was acquired, it was filtered to include only web-based interactive map-based SLR viewers, which we define as those that meet the following criteria: (a) show SLR or vulnerable coastal areas; (b) allow users to interact with the visualization tool by scrolling, zooming, and operating other viewing-related features (i.e., not simply an animation that can be stopped and started); (c) use a geographic map as a base layer; and (d) are freely available online (i.e., do not require payment or downloading data or specialized software). This procedure resulted in a total sample of 20 ISLRVs.

In interactive texts, the creator and the user cocreate meaning through processes of text design and exploration, respectively (Hayles, 2008). Therefore, our analysis of ISLRVs considered both users and the design choices of creators. We not only focused on design features directly present in ISLRVs but also included text that a user might encounter elsewhere on the website that provided context and thereby could constrain the user's interpretation of the visualization tool itself (e.g., discussions of the ISLRV's purpose or data uncertainty). We identified target audiences (potential users) that were described explicitly in the text accompanying ISLRVs and inferred target audiences in cases where there were no explicit statements. Also documented was whether the visualization tools appeared to be designed for specialists or generalists based on the sophistication and types of data manipulation processes available.

The six key narrative-building features of ISLRVs examined in our analysis are presented in Table 1, along with examples of these features. We assessed the total sample of ISLRVs systematically for these features at four levels or layers of design (data, visual representation, annotation, and interactivity), following Hullman and Diakopoulos (2011). The *data layer* includes the type, source, and timeliness of SLR and other data (e.g., satellite- or

Table 1. Key Narrative-Building Features of ISLRVs Examined in This Study.

Key narrative-building feature	Examples
Technical and conceptual support	• Explanations of ISLRV tool use and/or technical terminology • Explanations of conceptual terminology • Explanations of how SLR scenarios are selected and/or modeled
Representation of uncertainty and risk	• Verbal descriptions/discussions of uncertainty and risk • Visual representations of uncertainty and risk • Numerical representations of uncertainty and risk
Level of realism	• Level of realism in representation of SLR (e.g., outlining flood zones, photos with simulated flooding) • Level of realism in background maps (e.g., political, satellite maps) • Annotations that add realistic representations
Use of interaction structure to encourage narrative building	• Specification of default or preset views or scenarios • Scenario selection options • Map navigation options
Features that introduce local effects and/or global perspective	• Representations of local issues • Representations of local resources at risk • Representations of global issues
Features for self-efficacy	• Ability to download/upload data • Ability to generate quantified risk representations for a specific area • Discussions of mitigation/adaptation options • Tools for social/community discussion or data sharing

Note. ISLRV = interactive sea level rise viewer; SLR = sea level rise.

aircraft-derived elevation data), as well as the type of computer model used to integrate data. The *visual representation layer* includes the choice of base geographic map and how SLR is represented. The *annotation layer* includes text (e.g., technical help), graphics, and social elements (e.g., social media sharing buttons). The *interactivity layer* determines how users can navigate the map, specifies what data can be viewed, and provides large-scale narrative structure (e.g., beginning with a default view). Importantly, design choices are not mutually exclusive and may cross design layers. For example, a creator might choose to utilize a data set that has intrinsic uncertainty (data layer) and to represent that uncertainty by color coding sea level (visual representation layer) or including text annotations about uncertainty (annotation layer). Therefore, these design layers are somewhat permeable.

Results

Table 2 lists the purposive sample of 20 ISLRVs analyzed in this study. Categorized are the type of organization or author who either created the visualization tool or led a team that developed it, based on information available on ISLRV websites. Following are the results of our analysis for each of the six narrative features examined.

Technical and Conceptual Support

Technical and conceptual support features help users operate and interpret interactive visualizations. These features may include explanations of tool use and/or technical terminology, SLR-related concepts and terminology, and how specific scenarios were selected for inclusion and modeled. Technical and conceptual support features in ISLRVs were linked to the intended use and audience of the ISLRV as well as its technical complexity. About one quarter of the total sample of ISLRVs explicitly identified their target audiences. Several other ISLRVs were accompanied by language that stated a specific purpose for use from which the intended audience could be inferred. Other ISLRVs gave implicit clues as to their target audiences through their geographical focus or instructions for downloading specialized data. Table 3 lists the explicit or inferred target audiences for the study's inventory of ISLRVs and the technical and conceptual support that they provided.

Of the total sample, eight ISLRVs provided technical support features. The two primary types of technical support were rollover text that appeared when the user hovered over or clicked on tools or terms, and introductory help that appeared when users began their interaction with the visualization. Both types of technical support occurred at the annotation layer of design. Finally, while text annotations were the most common, three ISLRVs additionally used video or pictorial illustrations to demonstrate tool use and features.

Table 2. Alphabetical List of ISLRVs Analyzed in This Study, Creators' URLs, and Dates of Creation.

Name	Creator(s)	URL	Date created
Chesapeake Bay: The Increasing Effects of Sea-Level Rise and Storm Surge	Chesapeake Sea-Level Rise and Storm Surge Public Awareness and Response (nonprofit partnership)	www.chesapeakeadaptation.org	n.d.
Coastal Resilience 2.0	The Nature Conservancy (nonprofit organization), partners	maps.coastalresilience.org	2013
Digital Coast (beta)	National Oceanic and Atmospheric Administration Coastal Service Center (government organization)	csc.noaa.gov/digitalcoast/tools/slrviewer	2012
Flood Maps	A. Tingle (individual)	flood.firetree.net	2006
Future Coast	K. Akerlof (George Mason University) and the Future Coast research team	www.futurecoast.info	2012
Global Flood Map	Map Large (commercial organization)	globalfloodmap.org	2010
Global Sea Level Rise Map	Geology.com (commercial organization)	geology.com/sea-level-rise	n.d.
Impacts of Sea Level Rise on the California Coast	Pacific Institute (nonprofit organization)	www.pacinst.org/reports/sea_level_rise/gmap.html	2009
Mapping Areas Potentially Affected by Sea Level Rise	J. L. Weiss, Overpeck, and Strauss (University of Arizona)	www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/mapping_slr	2011
New Jersey Flood Mapper	Center for Remote Sensing and Spatial Analysis (Rutgers University), Jacques Cousteau National Estuarine Research Reserve, and National Oceanic and Atmospheric Administration Coastal Services Center	slrviewer.rutgers.edu	2013
Relative Sea Level Trends	Permanent Service for Mean Sea Level (government organization)	www.psmsl.org/products/trends	2013

(continued)

Table 2. (continued)

Name	Creator(s)	URL	Date created
Sarasota Bay Sea Level Rise Map Viewer	Sarasota Bay Estuary Program (nonprofit organization)	sarasotabay.org/slrmap/slrmap_viewer.html	2011
Sea Level Rise Explorer	R. A. Rohde (individual)	www.globalwarmingart.com/wiki/Special:SeaLevel	n.d.
Sea Level Rise Tool For Sandy Recovery	National Oceanic and Atmospheric Administration (government organization), partners	www.globalchange.gov/what-we-do/assessment/coastal-resilience-resources	2013
Sea Level Rise–Threatened Areas Map	California Energy Commission (government organization)	cal-adapt.org/sealevel	2013
Sea Levels Online	National Oceanic and Atmospheric Administration (government organization)	tidesandcurrents.noaa.gov/sltrends	2013
Sea-Level Rise Visualization for Alabama, Mississippi, and Florida	U.S. Geological Survey, National Oceanic and Atmospheric Administration Coastal Service Center (government organization), and Mississippi-Alabama Sea Grant Consortium	gom.usgs.gov/slr/slr.html	2011
SLAMM View (Sea Level Affecting Marshes Model Visualization) 2.0	U.S. Fish and Wildlife Service (government organization), Warren Pinnacle Consulting Inc., Image Matters LLC, The Nature Conservancy, and National Wildlife Federation	www.slammview.org	2012
Surging Seas	Climate Central (nonprofit organization)	sealevel.climatecentral.org/surgingseas	2013
What Could Disappear	Copeland, Keller, and Marsh (in *New York Times*; media organization)	www.nytimes.com/interactive/2012/11/24/opinion/sunday/what-could-disappear.html	2012

Note. ISLRV = interactive sea level rise viewer; SLR = sea level rise.

Table 3. Explicit or Inferred Audiences and Technical and Conceptual Support for ISLRVs.

SLR viewer	Primary audience(s)	Type(s) of technical support	Type(s) of conceptual support
Chesapeake Bay	Chesapeake Bay area residents (Maryland, United States)	None	Sidebar with explanations of concepts, description of modeling
Coastal Resilience	Coastal decision makers in the United States and the Caribbean	Text explanations and introductory videos explain how to use site	Diagrams explain basic concepts; rollover definitions and explanations of data types
Digital Coast	Coastal residents, resource managers, and scientists in most U.S. states and territories	Rollover definitions; diagrams show how to interpret data layers	Rollover definitions; sidebar with explanations of data types, description of modeling, links to conceptual details
Flood Maps	Worldwide	None	Link to modeling information and conceptual details
Future Coast	Anne Arundel County residents (Maryland, United States)	Introductory text walks through scenario selection; rollover text explains options	Links to modeling information and conceptual details
Global Flood Map	Worldwide	None	Link to modeling information and conceptual details
Global SLR Map	Worldwide	None	None
Impacts of SLR on the CA Coast	Coastal residents and resource managers in California (United States)	None	Sidebar with explanations of concepts
Mapping Areas Potentially Impacted by SLR	Worldwide, focusing on contiguous United States and its Caribbean territories	Pop-up text at start describes features	Link to modeling information and conceptual details
NJ Flood Mapper	Coastal communities and resource managers in New Jersey (United States)	Rollover definitions; diagrams show how to interpret data layers	Rollover definitions; sidebar with explanations of data types, description of modeling, links to conceptual details

(continued)

Table 3. (continued)

SLR viewer	Primary audience(s)	Type(s) of technical support	Type(s) of conceptual support
Relative Sea Level Trends	Researchers (worldwide)	None	Map located on page with modeling information and conceptual details
Sarasota Bay	Sarasota Bay area residents (United States)	None	Links to modeling information and conceptual details
SLR Explorer	Worldwide	None	Map located on page with modeling information and conceptual details
SLR Tool For Sandy Recovery	Coastal communities in New Jersey and New York (United States)	Text explanations of tools	Associated page has modeling information and further details, though no link from map
SLR-Threatened Areas Map	Coastal residents and resource managers in California (United States)	None	Rollover definitions, links to conceptual details
Sea Levels Online	Researchers (worldwide)	None	Map located on page with modeling information and conceptual details
SLR Visualization for AL, MS, & FL	Coastal communities in Alabama, Mississippi, and Florida (United States)	None	None
SLAMM View	Coastal researchers or managers (United States)	Introductory text walks through scenario selection	Links to modeling information and conceptual details
Surging Seas	Coastal residents of the 48 contiguous United States	Rollover text explains tool use	Links to modeling information and conceptual details
What Could Disappear	Residents of various U.S. cities	None	Footnote describes modeling assumptions

Note. ISLRV = interactive sea level rise viewer; SLR = sea level rise.

Conceptual support features were more common, with 18 ISLRVs including at least a minimal level of assistance with conceptual terminology, explanations of included data, or explanations of the process of SLR. Two major data types were included in all but two ISLRVs: a topographic model with land elevation and water depth, and SLR projection(s). However, there was wide variation in how these two types of data were generated, integrated, and explained. Simpler ISLRVs used coarse-scale base maps and a simple "bathtub" model in which SLR was estimated by simply adding the amount of SLR to the existing water level in the topographic model. More complex ISLRVs used fine-scale aerial maps with structure and/or vegetation information and more elaborate modified bathtub models with some level of approximation of erosion, sedimentation, and land use information. Three main types of conceptual support were found: rollover text, short explanations that appeared in sidebars, and longer format linked material that explained concepts in depth.

In general, the ISLRVs that used more complex models and offered more complex scenario selection tools provided more interpretive or conceptual assistance than simpler ISLRVs. For example, *Digital Coast* and *NJ Flood Mapper*, both based on the *Digital Coast* interface, included a sidebar accompanying each map with text giving an overview of the material being presented, describing data sourcing, and providing links to additional information such as how computer models were constructed (Figure 1). Information was also available on demand by clicking on question mark icons located on the menu, which produced a pop-up window that showed how to interpret map features using text and diagrams.

Uncertainty and Risk

The ISLRVs in our sample emphasized different aspects of the primary message of ISLRVs: that the sea level is rising and will affect coastal areas as it does (e.g., the fact of SLR, SLR impacts on the natural environment, or SLR impacts on human infrastructure). Regardless of the specific emphasis, risk and uncertainty are key components of public understanding about SLR. The ISLRVs we examined communicated these components via verbal descriptions or discussions, visual representations, and numerical representations. Numerical representations were the least common, with six ISLRVs providing information such as the number of acres flooded, percentage of population affected, and probability estimates for specific scenarios.

All ISLRVs represented SLR-related risks visually, with flooding being the primary risk communicated (Table 4). Two ISLRVs used arrows whose orientation, size, and color indicated the magnitude and direction of sea level trends, and a third used color-coded dots to depict flooding risk for cities. The

Use the slider bar above to see how various levels of sea level rise will impact this area.

Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth).

Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Figure 1. Screenshot from *NJ Flood Mapper*, showing flooding risks at Cape May, New Jersey, at a 2-foot sea level rise.
Note. Image used with permission. Readers of the print version who see these figures in black and white may go to the relevant URLs given in Table 2 for the full-color visualizations.

remainder used shading or outlines to indicate flood risk. The colors representing flooding varied, with blue shades of increasing saturation most commonly used to indicate deeper flooding. In four cases, only a single hue indicated flooding, and selection of a higher level of SLR simply increased the spatial extent of flooding with no increase in color intensity. Eight ISLRVs also depicted the interaction of flooding with other potential threats, including hurricane storm surge simulations, designation of areas that might experience increased erosion, vegetation types, and regions most at risk due to socioeconomic factors. These layers might be considered alternative ways of communicating SLR impacts that enhance the more predominant message of SLR's contribution to flooding risks. Five ISLRVs also included data layers or other representations (e.g., intensity of shading) that explicitly addressed uncertainty.

Verbal descriptions of risk and/or uncertainty were present in all but 2 ISLRVs, though such explanations were not always prominent features of the visualizations, nor were they always extensive. For example, 12 ISLRVs

Table 4. Representation of SLR Risk in Different ISLRVs.

SLR viewer	How SLR is represented
Chesapeake Bay	Effects of Hurricane Isabel storm surge at 1- and 2-m SLR are depicted by shades of blue of increasing intensity. Areas at risk of SLR are depicted by shades of orange of increasing intensity.
Coastal Resilience	SLR of 1-6 ft in 1-ft increments is depicted by shades of blue of increasing intensity. Low-lying areas with no direct connection to ocean are depicted in bright green.
Digital Coast	SLR of 1-6 ft in 1-ft increments is depicted by shades of blue of increasing intensity. Low-lying areas with no direct connection to ocean are depicted in bright green.
Flood Maps	Elevation ranging from 1-60 m is depicted by a single shade of blue.
Future Coast	On same layer: permanent inundation and 100-yr floodplains are depicted in shades of purple; affected neighborhoods in green; individual structures' composite risk exposure is indicated using green, orange, and red.
Global Flood Map	Dots for cities are color-coded shades of blue to green to represent flooding at user-defined number of inches.
Global SLR Map	Elevation ranging from 1-60 m is depicted by a single shade of blue.
Impacts of SLR on the CA Coast	Inundation areas for 100-yr flood events are depicted for current and 1.4-m SLR in aqua and pink.
Mapping Areas Potentially Impacted by SLR	Elevation ranging from 1-6 m is depicted by color ranging from brown through red to yellow.
NJ Flood Mapper	SLR of 1-6 ft in 1-ft increments is depicted by shades of blue of increasing intensity. Low-lying areas with no direct connection to ocean are depicted in bright green.
Relative Sea Level Trends	Orientation of arrows represents direction of change; size and color (blue-red) represent magnitude of change.
Sarasota Bay	SLR of 1-, 3-, and 6-ft increments is depicted by shades of blue of increasing intensity. SLR plus 6 ft of storm surge is depicted in shades of purple of increasing intensity.
SLR Explorer	Elevation from 0-70 m above current sea level is depicted by a red to green gradient; elevations at sea level and below are depicted in shades of purple.
SLR Tool For Sandy Recovery	Inundation areas for 100-yr flood events are depicted in yellow; flood risk at SLR of 0.3-2 ft is depicted in orange, purple, and red shades for 2050; flood risk at SLR of 0.7-6.6 ft is depicted in orange, purple, and red shades for 2100.

(continued)

Table 4. (continued)

SLR viewer	How SLR is represented
SLR-Threatened Areas Map	Inundation areas for 100-yr flood events at current and 55-in. SLR are depicted in blue and yellow; in San Francisco area, aqua and green also depict 19- and 39-in SLR.
Sea Levels Online	Orientation of arrows represents direction of change; size and color (blue-red) represent magnitude of change.
SLR Visualization for AL, MI, & FL	SLR of 1-6 ft is depicted by shades of blue of increasing intensity. This also includes SLR plus effects of Hurricane Isabel storm surge.
SLAMM View	Open water and vegetation types are depicted by a color-coded system at current, 0.4-, 0.7-, 1-, 1.5-, and 2-m SLR.
Surging Seas	SLR of 1-10 ft at 1-ft increments is depicted by the disappearance of a street map overlay from an underlying satellite image.
What Could Disappear	SLR at 5, 12, and 25 ft is depicted by a single shade of blue.

Note. ISLRV = interactive sea level rise viewer; SLR = sea level rise.

incorporated text discussing uncertainty or risk into the ISLRV, while 6 linked to text on another page. The most common aspect of uncertainty addressed was projections of SLR magnitude, followed by discussions of the uncertainty involved in mapping SLR onto the base map. A wide range of SLR magnitudes was found in the visualizations, most within the range of likely scenarios described by the IPCC: about 0.3 to 2 meters. Only 2 ISLRVs visualized SLR under 1 foot, and 5 visualized SLR of over 25 feet (7.6 meters). The ISLRVs that depicted very large SLR were developed by individuals or for a newspaper, while those developed by governmental, academic, or nonprofit organization creators focused on a much narrower (and lower) range of SLR. Only 4 ISLRVs did not contextualize the range of magnitudes shown by mentioning uncertainty or probability, though treatment of this topic was generally limited to a short statement.

For those ISLRVs that integrated text and/or numeric information on risk and uncertainty directly into the ISLRV, it was most common to use a sidebar to include this information. In *Surging Seas*, for example, a sidebar provided text and numeric information, including a list of cities and counties; the number and percentage of population, homes, and land area below the selected SLR level; and a statement of certainty about SLR reaching the selected level by a specific year at a nearby "flood risk indicator site" (Figure 2). The local

List: Cities | Counties

Water level +10ft

Things below +10ft in
San Francisco, California

Population	24,437	3.0%
Homes	13,441	3.6%
Acres	2,812	9.5%

Over 1 in 6 chance sea level rise + storm surge + tide will overtop +10ft by >2100 at nearest flood risk indicator site: San Francisco - San Francisco Bay, 5.6 miles away.

Learn more:
- San Francisco data download
- California map | facts | plans
- Surging Seas report
- Map accuracy | speed tip

Figure 2. Screenshot from *Surging Seas*, showing potential flooding in San Francisco, California, at 10 feet of sea level rise.
Note. Image used with permission.

risk and certainty information updates as the user selects a new SLR scenario, thus integrating these features with the SLR impacts displayed on the map in an intuitive way. As with treatment of conceptual support, the ISLRVs with more complex scenario selection tools discussed risk and uncertainty in more depth than did the simpler ISLRVs.

Realism

We based our analysis of realism in ISLRVs on how closely a given feature resembles the real-world object it represents, following J. C. Kostelnick et al. (2013). We examined the level of realism in three aspects of ISLRVs: representation of SLR, background maps (e.g., political vs. satellite maps), and annotations that added other realistic representations (e.g., photos of locations at risk).

As described in the previous section, visual representation of SLR existed along a scale of realism: For example, an ISLRV representing potential flooding by shading would be considered more realistic than one representing SLR by arrow icons (see Table 4). Two ISLRVs, *Digital Coast* and *NJ Flood Mapper*, enhanced this representation with photos at key locations that simulated flooding at that spot in accompaniment with the level of inundation selected on the map. In another example, *Surging Seas* incorporated a unique design feature in which flood risk was indicated by a gray and white street map "disappearing" to reveal satellite imagery beneath (Figure 2). This created a stark contrast between highly stylized nonflooded areas and the photorealistic areas at risk of flooding.

Background maps in the sample displayed a range of realism. Twelve ISLRVs provided the option of viewing either a political map or a more realistic satellite photo background. One ISLRV gave only the option of viewing the satellite background, five used only political background maps, and one used a highly abstracted representation of vegetation types. The final ISLRV, *Surging Seas*, is described previously. Annotations that added realistic elements appeared in a minority of ISLRVs. These included icons (three ISLRVs) or photos (one ISLRV) of areas or resources at risk and cartoon diagrams illustrating the impacts of SLR (one ISLRV).

Interaction Structuring the Narrative

Interactive operations available to users of ISLRVs included specification of default or preset views or scenarios, scenario selection, and map navigation. Text-based strategies for constructing the initial encounter included reading a disclaimer statement (five ISLRVs), an introduction without disclaimer (seven ISLRVs), and immediately selecting an SLR scenario and location without first encountering the map (one ISLRV). Visual orientation strategies for most ISLRVs included specifying an initial geographic scope and/or beginning with a particular SLR scenario. *Relative Sea Level Trends* and *Sea Levels Online* differed in that they showed existing SLR trends rather than scenarios, and *SLAMM View* required users to select a scenario before viewing the map. In most cases, ISLRVs that oriented users with geographic scope began by zooming out to the farthest extent of the data or by orienting on the United States or Europe. Nine of the total sample of viewers began with an SLR scenario already selected, usually either the lowest SLR value included or a midrange value. Eight ISLRVs started with present-day conditions (i.e., no SLR). In three of the ISLRVs, all data layers were always on, meaning that users could not select specific aspects of the data to focus on.

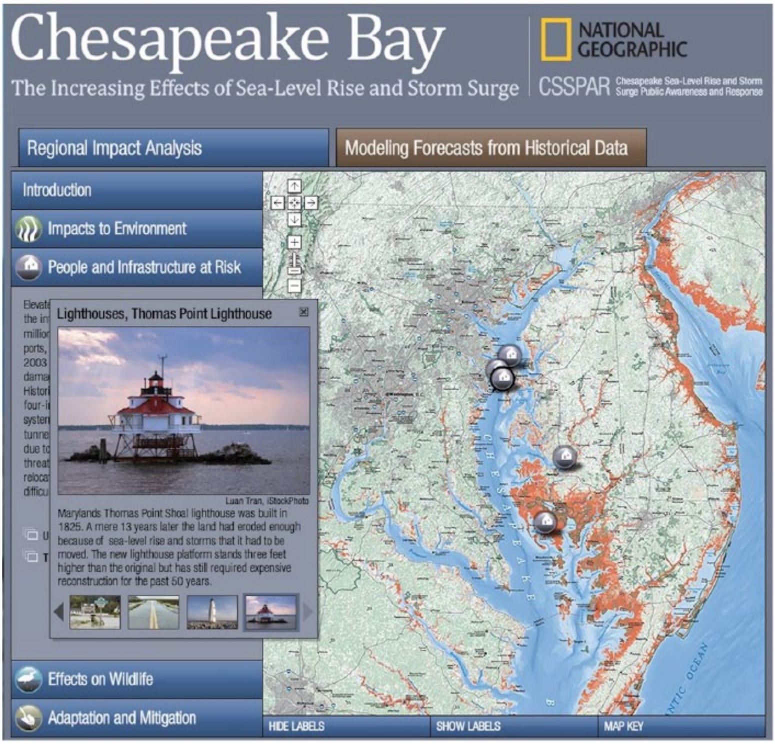
Preset view options helped structure the user's narrative choices by emphasizing certain ISLRV features. Mechanisms for this included focusing on only one information type at a time (e.g., SLR or storm surge), providing links to predetermined spatial views, guiding users through a set of steps to operate the visualization, and providing additional data (e.g., SLR impacts on natural or human-built areas). The primary process through which ISLRVs could be used to create a narrative experience was via map navigation and specification of SLR scenarios. Only a few ISLRVs allowed direct comparisons between locations by presenting two scenarios on the same screen, calculating statistics, or weighting data (e.g., placing more emphasis on shoreline erosion for ranking restoration options).

A variety of smaller scale features also facilitated user interaction. ISLRVs were about evenly split between those that allowed users to search by entering a specific location and those for which movement across the map was confined to panning and zooming. A few ISLRVs had multiple navigation options. It was more common for preprogrammed locations to be within Europe and North America. Several ISLRVs allowed adjustment of the transparency of data, hiding legends or sidebar text, or displaying a larger scale overview map. Another distinction can be made between three different methods of layer selection: selecting a new layer from a list, entering numbers into a box, or selecting a layer by moving a slider. Finally, ISLRVs differed in maximum zoom extent, with most capable of zooming to neighborhood level but others enabling only city-level zooming. With the former, there were some clear examples of being able to zoom in beyond the appropriate resolution of the SLR data.

Local Effects and Global Perspective

Features that introduce local effects and/or a global perspective to SLR may motivate users' emotional involvement with the issue and/or help them tie local conditions to a global narrative of SLR. While ISLRVs in general allow users to zoom in to any area of interest, we considered this a universal attribute of this type of visualization tool and focused on additional local or global features, such as representations of local issues, local resources at risk, or global issues.

Nine ISLRVs had a local or regional focus (e.g., one bay or U.S. state), and 11 had either a national or a global focus. ISLRVs with a limited geographic scope included specific annotations or mechanisms for viewing SLR impacts that emphasized the local area's unique features and challenges. These included numerical summaries relevant to a particular area (e.g., number of people predicted to lose their homes) and brief accounts of local ecology or communities. For example, *Chesapeake Bay* overlaid text and image-based annotations onto a base map of the Chesapeake Bay region that showed potential future flooding. Map icons, when clicked, opened a window with a story and photo representing SLR-related environmental or social



Marylands Thomas Point Shoal lighthouse was built in 1825. A mere 13 years later the land had eroded enough because of sea-level rise and storms that it had to be moved. The new lighthouse platform stands three feet higher than the original but has still required expensive reconstruction for the past 50 years.

Figure 3. Screenshot from *Chesapeake Bay*, showing potential flooding in the Chesapeake Bay area and informational icons with an open storytelling window.
Note. Image used with permission.

problems (Figure 3). This ISLRV used a relatively large amount of text compared to the other ISLRVs in our sample, giving the creators more opportunity to communicate a nuanced message about potential SLR impacts in the area. In another example, two annotations that contributed to *NJ Flood Mapper*'s place-based emphasis were a set of digitally altered photos that simulated the impacts of SLR at specific locations and small icons representing government buildings.

While five of the national or global-scale ISLRVs allowed users to quickly select a more local region of interest (e.g., by clicking on a highlighted city) only three of the local-scale ISLRVs explicitly discussed the global nature of SLR. In general, global discussions of SLR centered on discussing the entirety of the phenomenon, rather than trying to express the global nature of SLR in another way such as by drawing direct parallels between SLR threats to multiple locations. Two examples of the latter were *Flood Maps* and *Global Sea Level Rise Map*, both of which allowed selection from among several default worldwide views.

Tools for User Self-Efficacy

Finally, features of the tools that might contribute to self-efficacy were examined. These included providing the ability to download or upload data, providing the ability to generate quantified risk representations, facilitating discussions of mitigation or adaptation options, and enabling social data sharing. About half of the ISLRVs in the sample were designed for general audiences and half for specialized use that included action-enabling features for data analysis or other purposes (see Table 3), though several of the nonspecialized ISLRVs also contained such features.

Seven ISLRVs enabled users to download data, such as sea level trends and maps that could be imported into geographic analysis programs. One ISLRV, *Coastal Resilience*, offered the opportunity to upload data for community-based planning. These ISLRVs were largely designed for specialized use rather than general communication. Text describing potential adaptation or mitigation responses to SLR risks was found in 4 ISLRVs. More common in the sample (14 ISLRVs) were social media and other links that let users share map views, print their own map or create a URL for a unique map view, and contact creators directly. Two ISLRVs provided users with opportunities to share their own narratives about SLR (*Surging Seas*) or take a survey and compare their responses and opinions with those of others' (*Future Coast*). Finally, *Surging Seas* allowed users to generate quantified risk representations for selected areas.

Discussion

The present study examined narrative-building features of 20 ISLRVs based on six criteria: (a) technical and conceptual support, (b) uncertainty and risk, (c) realism, (d) interaction structure, (e), local impacts and/or a global perspective, and (f) features for user self-efficacy. Overall, the ISLRVs sampled display a spectrum of approaches for communicating with multiple audiences. It is likely that many of the features of ISLRVs are driven by designer decisions pertaining to intended use and target audience. For example, we found that level of technical sophistication, attention to graphic design, and types of annotations were interrelated. Only a few ISLRVs had clearly been

Table 5. Primary Editorial Layers at Which Key Narrative-Building Features Were Found.

Key narrative-building feature	Primary editorial layer
Technical and conceptual support	Annotations
Representation of uncertainty and risk	Visual representations of SLR; annotations
Level of realism	Visual representations of SLR; annotations
Use of interaction structure to encourage narrative building	Interactivity
Features that introduce local effects and/or global perspective	All layers
Features for self-efficacy	Annotations; interactivity

created for multiple audiences (e.g., incorporating both extensive interpretive annotations and multiple tools for data analysis). We note that a strongly narrative-oriented design might be inappropriate for certain ISLRVs (e.g., those designed solely for scientific analysis) but appropriate for others (e.g., those with a public communication or community planning focus). Nevertheless, findings from the present study's analysis indicate several ways in which ISLRVs might be tailored to enhance their communication effectiveness.

We believe that applying a storytelling perspective to ISLRV design can support and strengthen communication, especially for ISLRVs not primarily intended for scientific data dissemination. Narrative building has been shown to facilitate personal meaning making (Daniels & Endfield, 2009) and increase engagement with environmental issues that have high levels of complexity and uncertainty (Vervoort et al., 2010), as well as facilitate behavioral change (Hinyard & Kreuter, 2007). Communication about the risks and uncertainty surrounding climate change via place-based and participatory scenarios has been shown to motivate concern and willingness to take mitigative actions (e.g., Raymond & Robinson, 2013; Shackley & Deanwood, 2002).

Table 5 summarizes the design layers in which particular narrative-building features were predominantly found. In all ISLRVs, initial editorial choices of creators (e.g., selection of data sources, computer models, and the method of representing SLR) constrained the overall user experience. For example, substituting elevation for SLR resulted in visualizations in which inland areas unconnected to the ocean "flooded" as sea level increased. The selection of mapping software also played a large role in the types of tools available for interaction and influenced visual design. While some ISLRVs were customized for a specific purpose or audience, others appeared to apply the default features and tools available for creators when working with a particular mapping program. This decision would have limited the opportunities for creators to construct a stronger author-driven narrative structure. Finally, the few ISLRVs that incorporated an author-driven orientation did so by framing SLR effects as it affected certain geographical areas.

The narrative-building features in ISLRVs can support guided discovery (Dove & Jones, 2012) and increase user engagement through a sense of shared agency (Murray, 1998) and emotional involvement (Leiserowitz, 2006). Creating a stronger narrative structure requires a focused consideration of potential audiences, thoughtful framing of the overall narrative, and incorporating tools and techniques that provide an appropriate user experience. Most ISLRVs in our sample were not strongly narrative oriented in that they allowed open-ended data exploration and rarely directed the user in a specific sequence. While this might be appropriate for scientific analysis, communicating with other audiences might require a different structural organization. We recommend that authors make explicit the intended purpose(s) and audience(s) of ISLRVs, if they are not doing do already.

Readers perceive stories as a series of discrete episodes or themes that are connected by a plot (Black & Bower, 1979). In interactive media, a linear plot is replaced by user-driven story built from scenes or themes that they select (e.g., Hayles, 2008; Heiden & Ostovar, 2006). For ISLRVs, the temporal order of interaction creates an overall narrative structure in a non–plot-based communication medium (Kosara & Mackinlay, 2013). Features like a default starting view can frame the overall narrative by suggesting that the specified view includes the most important message or demonstrates the appropriate way to interact with the visualization.

Interaction with a data display also enables exploration at different scales and personally relevant comparisons (C. Kostelnick, 2007), as well as construction of personal storylines within the context of the overall message (Vervoort et al, 2010). We found that the types of features in ISLRVs were highly variable due to different intended uses and audiences for these tools. For more effective public communication, features that support an overall message about SLR while enhancing user interest could involve the ability to search for the user's own home, generate graphs showing the projected rate of SLR on their local coastline or community, or share the results of their interaction with this tool with friends. At a broader level, adopting a modular or "scene"-based structure that directs attention to one aspect of SLR at a time, as seen in *Digital Coast* or *Chesapeake Bay*, might help frame important messages.

Technical and Conceptual Support

Only eight ISLRVs provided technical support, suggesting that most creators relied on assumed audience familiarity with the conventions and tools of interactive maps to ensure usability. Relying on common mapping interfaces will not guarantee that users are able to operate them effectively, particularly for those unfamiliar with interactive maps (Xie & Pearson, 2010). It is important to provide the types of technical and conceptual support that users will need to understand the information in the visualization and construct a narrative by providing help text available on demand (rather than in a single help file) when the user clicks on a tool. Creators should also consider providing tutorials for orientation with the map features and to frame the user's experience of the visualization.

Regarding conceptual support, a few ISLRVs offered extensive text, but links to the text were occasionally difficult to find. Support in the form of definitions and brief statements was much more common. Communication tools that assist individuals' mental models of scientific processes can facilitate understanding of risk and help guide decision making (Fischhoff, 2013). Therefore, our study findings suggest that reinforcing users' understanding of key SLR-related processes, such as risk, measurement or modeling uncertainty, and the level of complexity in how SLR projections are made (e.g., a simple bathtub approach vs. a more dynamic assessment of related processes), would be an appropriate goal of ISLRVs. Communicating risk and uncertainty can be challenging (Spiegelhalter et al., 2011), and discussing these concepts may overshadow the primary intended message (Doyle, 2011). However, ISLRVs allow people to learn as they construct a story through their user experience (Dove & Jones, 2012) and so may be a viable technique to help audiences better understand these concepts while still emphasizing the primary message.

Emotion, Realism, and Features for Self-Efficacy

Another broad finding of our analysis was that emotion-evoking features varied considerably across ISLRVs. Governmental and academic ISLRVs generally included more dispassionate and qualifying language and visuals than independently developed ones. The latter were also more likely to visualize extremely high sea levels and make direct statements about flooding. These results are consistent with a noted tendency for scientists to hedge their language about SLR (Hansen, 2007), while other communicators may use more emotional language (Risbey, 2008). Different audiences will be accustomed to different conventions of visual and verbal representation. However, emotional affect enters into the design of all ISLRVs through language, color, images, and localized narratives. Interactivity itself may be regarded as an aspect of emotional design in that it allows users to construct a personally relevant narrative from the data that are being presented (C. Kostelnick, 2007). For instance, while the minimalist design of *Surging Seas* may be an attempt to emphasize the rationality of the data being presented, the user's ability to shape her or his own narrative can add an emotional connection to the future problems of SLR.

One of the primary ways to evoke emotion in ISLRVs may be through the use of realism in representations of SLR and annotations (J. C. Kostelnick et al., 2013). Balancing accuracy, authenticity, and realism has been deemed important in SLR communication efforts (Nettley et al., 2013), as enhanced realism may convey a sense of heightened risk or higher certainty as compared to more abstract visualization methods (J. C. Kostelnick et al., 2013). Few of the ISLRVs in this study included highly realistic features, with the exception of satellite background options for maps. Our study findings suggest that ISLRV creators should consider how to use realism more prominently to visually convey the risks associated with SLR. This might include incorporating realistic features that support the intended message of the visualization without overstating risks, such as satellite images of coastal marshes or simulations of potential SLR in urban areas.

An emphasis on local impacts of SLR is another key method of creating a stronger central message and motivating emotional involvement with the issue. Affect and values have been shown to be important in climate change–related risk perception (e.g., Leiserowitz, 2006; Raymond & Robinson, 2013; Safi et al., 2012). Place-based photographs, stories, or personal narratives could exemplify how SLR is affecting or is likely to affect people and the environment. While several local-scale ISLRVs did incorporate some of these features, the national or global ISLRVs did not. Conversely, a focus on only locally based SLR may foster the belief that its broader impacts can easily be addressed by local adaptation. We suggest that attention be given to global perspectives, perhaps in the form of text or imagery that emphasizes the global impacts of SLR or by including preset visualization approaches that pertain to multiple locations, such as global river deltas or large coastal cities. This technique might foster a "local" perspective at a global scale.

Finally, providing features for self-efficacy may be a worthwhile strategy for increasing personal salience and utility of ISLRVs. Relationships among self-efficacy and increased knowledge about climate science and climate-related risks suggest that increased self-efficacy motivates engagement with the issues (Pidgeon & Fischhoff, 2011). ISLRVs may enhance communication about SLR by promoting personal empowerment and self-efficacy through discovery (Dörk et al, 2013; Dove & Jones, 2012). While many of the ISLRVs in our sample provided tools for social media sharing, other data analysis features appeared to be designed more for researchers than for the general public. Additionally, few features explicitly discussed what people can do in response to SLR-related risks, which is a key way to increase feelings of self-efficacy and empowerment (Milfont, 2012).

Future Research Directions

Our study indicates that several areas of future research are especially warranted to help clarify the appropriate use of ISLRVs as communication tools. First, there is a need to investigate how representations of risk and uncertainty are received and interpreted. These concepts are particularly important for ISLRV creators due to legal and ethical concerns related to projecting future coastal flooding. As our analysis shows, there is wide variability in how these concepts are represented in existing ISLRVs. While there are many ways to represent uncertainty and risk (e.g., Spiegelhalter et al., 2011), determining how they are perceived is crucial. Research has found that treating uncertainty as a problem of information quantity may not be effective (e.g., Brashers, 2001; Pidgeon & Fischhoff, 2011). Thus, learning about SLR-related risk and uncertainty via a guided discovery process might be a productive means of conveying the nuances of these concepts.

The context-situated use of ISLRVs should also be examined to better understand how these tools can help construct personalized narratives and effectively communicate the possible impacts of SLR. Our analysis focused on ISLRV design and omitted the crucial narrative-building process that occurs during user interaction. Thus, important research questions remain. For example, to what extent is exploration of ISLRVs influenced by users' technological familiarity, topical knowledge, motivations, and specific interests? While interpretive text that explains uncertainty may be available, how do users employ it in practice? How do users form emotional connections as they interact with ISLRVs? How might the experience of ISLRVs differ between handheld devices and full-size computer monitors? Finally, in what ways does use of a more user-driven ISLRV like *Digital Coast* differ from use of a more modular or scene-based ISLRV like *Chesapeake Bay*? The context-situated study of ISLRVs, messages, and audiences is necessary to develop empirically grounded best practices for constructing visualizations that are better targeted and tailored toward specific audiences.

Several issues of social justice are raised by the present analysis. Our sample was heavily biased toward the United States and to a lesser extent Europe. This likely reflects our sampling methodology and the actual focus of existing visualizations. The absence of highly vulnerable countries in the global

South is striking, and the few globally focused ISLRVs largely used simplified modeling and data display methods. This narrative focus overshadows the potential effects of SLR on other regions. Additionally, most ISLRVs had significant response issues when viewed on low-bandwidth Internet connections. Research suggests that some of the areas most susceptible to coastal flooding are those in which residents are lower income (Chakraborty, Collins, Montgomery, & Grineski, 2014). Therefore, the lack of ISLRVs that emphasize vulnerable populations is tied to broader issues of access to information resources (Chen & Wellman, 2004; Gorski, 2009). Future research in how to effectively communicate SLR-related risk to these communities is particularly important.

Finally, inquiry on how individuals respond to ISLRVs within the broader context of climate change communication would be valuable. As with other climate change–related communication channels, including the mass media, ISLRVs are received and interpreted by users in the context of their worldviews and beliefs (Braman et al., 2012; McCright et al., 2013). Studies that inventory and compare these different channels in terms of structure, process, and reception would be worthwhile. Empirical examination of the relationships and interactions between ISLRVs and users' individual differences (e.g., perceptions, self-efficacy) is another intriguing area of investigation. Research focused on the short- and long-term outcomes of ISLRV use is also needed (e.g., knowledge, attitudes, behavioral intentions regarding SLR impacts). Additionally, future research with ISLRV creators (e.g., in-depth interviews) regarding their purposes, design decisions, and the intended target audiences and outcomes would add an author-centered dimension to this study.

The choices of ISLRV designers can shape user experiences at multiple levels. Based on the six criteria in this study, there are opportunities to strengthen narrative building in future ISLRVs. The variety of features displayed in existing ISLRVs suggests ways that communication about SLR may be enhanced, particularly when tailored to specific audiences and purposes. By carefully fashioning the narrative-building features of ISLRVs, communicators can provide audiences with the ability to individually engage with scientific data in meaningful ways.

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References

Akerlof, K., and the Future Coast research team. (2012). *Future Coast*. Retrieved from http://www.futurecoast.info/

Bell, A. (1994). Media (mis)communication of the science of climate change. *Public Understanding of Science*, *3*, 259-275.

Bilskie, M. V., Hagen, S. C., Medeiros, S. C., & Passeri, D. L. (2014). Dynamics of sea level rise and coastal flooding on a changing landscape. *Geophysical Research Letters*, *41*, 927-934.

Black, J. B., & Bower, G. H. (1979). Episodes as chunks in narrative memory. *Journal of Verbal Learning and Verbal Behavior*, *18*, 309-318.

Braman, D., Kahan, D. M., Peters, E., Wittlin, M., & Slovic, P. (2012). The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, *2*, 732-735.

Brashers, D. E. (2001). Communication and uncertainty management. *Journal of Communication*, *51*, 477-497.

Brody, S. D., Zahran, S., Vedlitz, A., & Grover, H. (2008). Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. *Environment & Behavior*, *40*, 72-95.

Boykoff, M. T., & Yulsman, T. (2013). Political economy, media, and climate change: Sinews of modern life. *WIREs Climate Change*, *4*, 359-371.

California Energy Commission. (2013). *Cal-Adapt sea level rise: Threatened areas map*. Retrieved from http://cal-adapt.org/sealevel/

Carvalho, A. (2007). Ideological cultures and media discourses on scientific knowledge: Re-reading news on climate change. *Public Understanding of Science*, *16*, 223-243.

Center for Remote Sensing and Spatial Analysis, Jacques Cousteau National Estuarine Research Reserve, & NOAA Coastal Services Center. (2013). *NJ flood mapper*. Retrieved from http://slrviewer.rutgers.edu/

Chakraborty, J., Collins, T., Montgomery, M., & Grineski, S. (2014). Social and spatial inequities in exposure to flood risk in Miami, Florida. *Natural Hazards Review*, *15*(3), 04014006.

Chen, W., & Wellman, B. (2004). The global digital divide within and between countries. *IT and Society*, *1*(7), 18-25.

Chesapeake Sea-Level Rise and Storm Surge Public Awareness and Response. (n.d.). *Chesapeake Bay: The increasing effects of sea-level rise and storm surge*. Retrieved from http://www.chesapeakeadaptation.org/

Climate Central. (2013). *Surging seas*. Retrieved from http://sealevel.climatecentral.org/surgingseas/

Copeland, B., Keller, J., & Marsh, B. (2012, November 24). What could disappear. *New York Times*. Retrieved from http://www.nytimes.com/interactive/2012/11/24/opinion/sunday/what-could-disappear.html

Daniels, S., & Endfield, G. H. (2009). Narratives of climate change: Introduction. *Journal of Historical Geography*, *35*, 215-222.

Davidson, M. A., & Miglarese, A. H. (2003). Digital Coast and The National Map: A seamless cooperative. *Photogrammetric Engineering & Remote Sensing*, *69*, 1127-1131.

Devine-Wright, P. (2013). Think global, act local? The relevance of place attachments and place identities in a climate changed world. *Global Environmental Change*, *23*, 61-69.

Dörk, M., Collins, C., Feng, P., & Carpendale, S. (2013, April). *Critical InfoVis: Exploring the politics of visualization*. Paper presented at the ACM SIGCHI Conference on Human Factors in Computing Systems (CHI 2013), Paris, France.

Dove, G., & Jones, S. (2012, July). *Narrative visualization: Sharing insights into complex data*. Paper presented at the Interfaces and Human Computer Interaction (IHCI 2012), Lisbon, Portugal.

Doyle, J. (2011). *Mediating climate change*. Burlington, VT: Ashgate.

Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences*, *110*, 14033-14039.

Frazier, T. G., Wood, N., & Yarnal, B. (2010). Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida. *Applied Geography*, *30*, 506-517.

Geology.com. (n.d.). *Global sea level rise map*. Retrieved from http://geology.com/sea-level-rise/

Gorski, P. C. (2009). Insisting on digital equity: Reframing the dominant discourse on multicultural education and technology. *Urban Education*, *44*, 348-364.

Hansen, J. E. (2007). Scientific reticence and sea level rise. *Environmental Research Letters*, *2*(2), 1-6.

Harrell, D. F., & Zhu, J. (2009). Agency play: Dimensions of agency for interactive narrative design. *Proceedings of the 2nd AAAI Spring Symposium on Intelligent Narrative Technologies, Stanford, California, March 23-25, 2009*, 156-162.

Hayles, N. K. (2008). *Electronic literature: New horizons for the literary*. Notre Dame, IN: University of Notre Dame.

Heiden, W., & Ostovar, A. (2006). Structuring hypermedia novels. In S. Göbel, R. Malkewitz, & I. Iurgel (Eds.), *Technologies for interactive digital storytelling and entertainment: Lecture notes in computer science* (Vol. 4326, pp. 98-103). Berlin, Germany: Springer Berlin Heidelberg.

Higgason, K. D., & Brown, M. (2009). Local solutions to manage the effects of global climate change on a marine ecosystem: A process guide for marine resource managers. *ICES Journal of Marine Science*, *66*, 1640-1646.

Hinyard, L. J., & Kreuter, M. W. (2007). Using narrative communication as a tool for health behavior change: A conceptual, theoretical, and empirical overview. *Health Education & Behavior*, *34*, 777-792.

Hullman, J., & Diakopoulos, N. (2011). Visualization rhetoric: Framing effects in narrative visualization. *IEEE Transactions on Visualization and Computer Graphics*, *17*, 2231-2240.

Intergovernmental Panel on Climate Change. (2013). Summary for policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, . . . P. M. Midgley (Eds.), *Climate Change 2013: The physical science basis (Working Group I Contribution to the IPCC Fifth Assessment Report)*. Retrieved from http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

Kosara, R., & Mackinlay, J. (2013). Storytelling: The next step for visualization. *Computer*. *46*(5), 44-50.

Kostelnick, C. (2007). The visual rhetoric of data displays: The conundrum of clarity. *IEEE Transactions on Professional Communication*, *50*, 280-294.

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

Leiserowitz, M. (2006). Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change*, *77*, 45-72.

Llewellyn, N. (2001). The role of storytelling and narrative in a modernisation initiative. *Local Government Studies*, *27*(4), 35-58.

Map Large. (2010). *Global flood map*. Retrieved from http://globalfloodmap.org/

McCright, A. M., Dunlap, R. E., & Xiao, C. (2013). Perceived scientific agreement and support for government action on climate change in the USA. *Climatic Change*, *119*, 511-518.

Milfont, T. L. (2012). The interplay between knowledge, perceived efficacy, and concern about global warming and climate change: A one-year longitudinal study. *Risk Analysis*, *32*, 1003-1020.

Murray, J. H. (1998). *Hamlet on the holodeck: The future of narrative in cyberspace*. Cambridge: MIT Press.

National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, Federal Emergency Management Agency, & U.S. Global Change Research Program. (2013). *Sea level rise tool for Sandy recovery*. Retrieved from http://www.globalchange.gov/what-we-do/assessment/coastal-resilience-resources/

National Oceanic and Atmospheric Administration Coastal Services Center. (2012). *Digital Coast*. Retrieved from http://csc.noaa.gov/digitalcoast/tools/slrviewer/

National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services. (2013). *Sea levels online*. Retrieved from http://tidesandcurrents.noaa.gov/Sltrends/

The Nature Conservancy. (2013). *Coastal resilience 2.0*. Retrieved from http://maps.coastalresilience.org/

Nettley, A., Desilvey, C., Anderson, K., Wetherelt, A., & Caseldine, C. (2013). Visualising sea-level rise at a coastal heritage site: Participatory process and creative communication. *Landscape Research*. Advance online publication. doi: 10.1080/01426397.2013.773965

Pacific Institute. (2009). *Impacts of sea level rise on the California coast*. Retrieved from http://www.pacinst.org/reports/sea_level_rise/gmap.html

Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., . . .Weiss, J. (2012). *Global sea level rise scenarios for the United States National Climate Assessment* (NOAA Technical Memo OAR CPO-1). Retrieved from http://cpo.noaa.gov/Home/AllNews/TabId/315/ArtMID/668/ArticleID/80/Global-Sea-Level-Rise-Scenarios-for-the-United-States-National-Climate-Assessment.aspx

Permanent Service for Mean Sea Level. (2013). *Relative sea level trends*. Retrieved from http://www.psmsl.org/products/trends/

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*, 35-41.

Poulter, B., Feldman, R. L., Brinson, M. M., Horton, B. P., Orbach, M. K., Pearsall, S. H., . . .Whitehead, J. C. (2009). Sea-level rise research and dialogue in North Carolina: Creating windows for policy change. *Ocean & Coastal Management*, *52*, 147-157.

Raymond, C. M., & Robinson, G. M. (2013). Factors affecting rural landholders' adaptation to climate change: Insights from formal institutions and communities of practice. *Global Environmental Change*, *23*, 103-114.

Rick, U. K., Boykoff, M. T., & Pielke, R. A., Jr. (2011). Effective media reporting of sea level rise projections: 1989–2009. *Environmental Research Letters*, *6*. doi:10.1088/1748-9326/6/1/014004

Risbey, J. S. (2008). The new climate discourse: Alarmist or alarming? *Global Environmental Change*, *18*, 26-37.

Rohde, R. A. (n.d.). *Sea level rise explorer*. Retrieved from http://www.globalwarmingart.com/wiki/Special:SeaLevel

Safi, A. H., Smith, W. J., Jr., & Liu, Z. (2012). Rural Nevada and climate change: Vulnerability, beliefs, and risk perception. *Risk Analysis*, *32*, 1041-1095.

Sarasota Bay Estuary Program. (2011). *Sea level rise map viewer*. Retrieved from http://sarasotabay.org/slrmap/slrmap_viewer.html

Segel, E., & Heer, J. (2010). Narrative visualization: Telling stories with data. *IEEE Transactions of Visualization and Computer Graphics*, *16*, 1139-1148.

Shackley, S., & Deanwood, R. (2002). Stakeholder perceptions of climate change impacts at the regional scale: Implications for the effectiveness of regional and local responses. *Journal of Environmental Planning and Management*, *45*, 381-402.

Shaw, A., Sheppard, S., Burch, S., Flanders, D., Wiek, A., Carmichael, J., . . .Cohen, S. (2009). Making local futures tangible—Synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. *Global Environmental Change*, *19*, 447-463.

Spiegelhalter, D., Pearson, M., & Short, I. (2011). Visualizing uncertainty about the future. *Science*, *333*, 1393-1400.

Tingle, A. (2006). *Flood maps*. Retrieved from http://flood.firetree.net/

U.S. Fish and Wildlife Service, Warren Pinnacle Consulting Inc., Image Matters LLC, The Nature Conservancy, & National Wildlife Federation. (2012). *Sea Level Affecting Marshes Visualization (SLAMM View)*. Retrieved from http://www.slammview.org/

U.S. Geological Survey, NOAA-CSC, & Mississippi-Alabama Sea Grant Consortium. (2011). *Sea-level rise visualization for Alabama, Mississippi, and Florida*. Retrieved from http://gom.usgs.gov/slr/slr.html

Vervoort, J. M., Kok, K, van Lammeren, R., & Veldkamp, T. (2010). Stepping into futures: Exploring the potential of interactive media for participatory scenarios on social-ecological systems. *Futures*, *42*, 604-616.

Xie, B., & Pearson, G. (2010). Usability testing by older Americans of a prototype Google Map web site to select nursing homes. In *HICSS '10 Proceedings of the 2010 43rd Hawaii International Conference on System Sciences* (pp. 1-10). Washington, DC: IEEE Computer Society.

Weiss, J. L., Overpeck, J. T., & Strauss, B. (2011). *Mapping areas potentially impacted by sea level rise*. Retrieved from http://www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/mapping_slr/

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