TOWARDS A FRAMEWORK FOR DESIGNING SPATIAL AND NON-SPATIAL VISUALIZATIONS FOR COMMUNICATING CLIMATE CHANGE RISKS

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Hazards related to climate change (e.g., intensified storms, coastal flooding associated with sea level rise) are globally pervasive yet geographically-specific problems that demand societal response. Unfortunately, studies have shown that people are often unaware of (or inaccurately perceive) the true risk, thereby limiting their motivation to take steps to lower their vulnerability. Visualization of the anticipated impacts (either spatially or non-spatially) has an important role to play in risk communication, potentially avoiding peoples' cognitive biases, helping to focus their attention, and allowing them to personally evaluate the evidence. In this study, key findings of the risk perception literature are presented and a conceptual framework provided to help guide: (1) the identification of important information requirements (anticipating the influence of psychological effects); (2) the selection and design of visualizations; and (3) the assessment of the effectiveness of visualizations for enhancing perception of risk and inspiring a public willingness to adapt. A case study involving coastal flooding in South-East New Brunswick is referred to throughout.

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Introduction

Between 1970 and 2004, global greenhouse gas (GHG) emissions grew 70% above pre-industrial levels, largely attributable to anthropogenic activities surrounding the access and use of energy supplies, transportation and industry, and forestry and agriculture [*IPCC* 2007]. By altering planetary energy balance, climate change is expected to lead to increased water stress (too much or too little precipitation), increased damages from extreme floods and storms, changes in species distributions, and increased severity of disease and insect outbreaks [*IPCC* 2007]. While a global problem, the trajectory and intensity of specific impacts will vary depending upon geographic location [e.g., *IPCC* 2007].

Since recognition of the importance of anthropogenic climate change in the 1980s, and debate about mitigation strategies, there has been a subsequent recognition that a certain amount of climate change is inevitable [*Grothmann and Patt* 2005]. This realization has shifted much of the discussion towards how to best prepare people for the subsequent impacts, with research focusing on ways to increase people's adaptive capacity.

Visualization is central to exploratory data analysis (EDA) [*Tukey* 1977; *MacEachern et al*. 1992; *Andrienko et al*. 2003; *Keim et al.* 2005], serving to facilitate spatial reasoning and aid in the construction of scientific knowledge [*MacEachern et al*. 2004a]. Given its demonstrated power to inform and augment our ability to think spatially [*MacEachern* 1994; *MacEachern et al*. 2004b], geovisualization has a huge potential role to play in communicating the threats associated with climate change [*Dransch et al*. 2010]. But as the products are largely produced and consumed by domain experts, their effectiveness in the public communication of climate change risk remains to be demonstrated.

Grothmann and Patt [2005] make a persuasive case that the psychological aspects of adaptation—the way in which information affects peoples' perception of risk and encourages (or discourages) a willingness to effect changes to reduce their personal vulnerability—is of vital importance. If there has been little systematic research on risk communication in general [*NRC* 2006], there has been even less on the role of spatial and non-spatial visualization. Given the urgency of the climate change problem, and the gap in our understanding of the effectiveness of "real world" applications of visualization [*MacEachren et al*. 1992; *Slocum et al*. 2001], there is an obvious need for a framework to guide the development and testing of these products in a risk communication context.

Grothmann and Patt [2005] developed a socio-cognitive model of private proactive adaptation to climate change that distinguishes two aspects of the risk adaptation process: 'risk appraisal' and 'adaptation appraisal'. In the case of the former, information (visual and non-visual) informs people about likely outcomes and its associated consequences, e.g., how precipitation patterns may change during the growing season and impact agricultural production. Once individuals perceive that a significant personal threat exists, 'adaptation appraisal' begins, the outcome of which depends on the assessment of their ability to take action and absorb associated costs.

Studies have shown that the public is often unaware of climate-change related risks, or inaccurately perceives the true severity. For example, in a UK study, 41% of people were unaware that they resided within a flood prone area [*Burningham et al*. 2008]. In South-East New Brunswick, current 1-in-10 year extreme storm levels will likely result in sea levels of 8.9m ± 0.1m (CGVD28 datum), with a capacity to overtop 89% of the existing dyke system and flood approximately 20.6% of the Town of Sackville [*Lieske and Bornemann* 2011]. Unfortunately, a preliminary study indicated that only 5% of a randomly selected group of the Sackville public (n=155) indicated awareness of this threat. The importance of deficiencies in basic awareness is underscored by the fact that level of knowledge strongly influences the perception of risk [*Slovic* 1987], which according to *Grothmann and Patt* [2003] is the main determinant of the motivation to adapt. Without understanding the problem of climate change, or being able to visualize its consequences, the general public is unlikely to accurately perceive the extent of the problem. The resulting "awareness deficiency" can be expected to greatly reduce the likelihood of the public taking necessary actions to reduce their personal vulnerability.

When improperly done, risk communication can alarm and polarize the public and entrench them in prejudiced views, leading to what *Grothmann and Patt* [2005] refer to as "avoidant maladaptation": a tendency to deny evidence, reject logical conclusions in favour of wishful thinking, or assume a posture of helpless fatalism. This problem was well illustrated by the furor surrounding the release of a new predictive wetland layer jointly developed by the University of New Brunswick and provincial Department of Environment and Department of Natural Resources in January of 2011 [*Government of New Brunswick* 2011]. The resulting furor over the "top-down" imposition of a map layer with demonstrable imprecision and little public consultation forced the Environment Minister to revoke the mandatory use of the data in March 2011 [*Ball* 2011]. Aside from the issues of data accuracy and precision that surrounded this particular example, a question remains as to whether the intended purpose, limitations, and informativeness of the online tool was ever adequately communicated.

The purpose of this paper is threefold: (1) to present key findings of the risk perception literature (2) to review potentially useful spatial and non-spatial visualizations and offer considerations for their selection and design; and (3) to articulate an evaluation framework for assessing their effectiveness as risk communication tools. Reference will be made throughout to a case example involving the Tantramar area of South-East New Brunswick, Canada (Figure 1).

Risk-Perception Framework

Visualizations intended for public communication of climate-change risk will be most effective when informed by the findings of risk perception research. To be effective in this context means that visualizations should: (1) accurately communicate the spatial extent and severity of climate change risk, and (2) inspire a long-term intention to adapt and lower one's personal risk. To aid in this endeavour a theoretical framework is necessary, one which accurately models the socio-cognitive processes that lead to desirable (proactive adaptation) and undesirable (maladaptation) end states, and which offers suggestions for visualization development that can lead to the former rather than latter. *Smit and Pilifosova* [2003: 881] define "adaptation" as the:

> "adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices and structures to moderate potential changes or to benefit from opportunities associated with climate change.

Clearly, to be effective, visualizations need to contribute to peoples' overall awareness of the climate change problem, thereby altering their perception of associated risks. But it has to do so in a way that doesn't overwhelm the viewer into feeling helpless. *Risbey et al*. [1999] and *Grothmann and Patt* [2005] offer useful (and mutually compatible) socio-cognitive models for thinking about the role of visualizations in influencing risk perception (combined in Figure 2). Their models parallel those from the health belief literature, where variation in individuals' perception of severity, susceptibility and benefits of taking action is weighed relative to the barriers/difficulties to determine their willingness to enact life changes [*Janz and Becker* [1984].

Figure 2 (A) illustrates the risk appraisal processing that occurs when individuals are confronted with climate change information, subject to the influence of three additional variables: cognitive biases, risk experience appraisal, and the degree of reliance on public adaptation [*Grothmann and Patt* 2005]. As indicated in Figure 2, these variables can positively or negatively influence the risk appraisal process that occurs at this stage. With the Tantramar community as a case example, cognitive bias could manifest as rejection of climate change evidence on the basis of uncertainty inherent in the forecasting of climate change models. In this case, an individual would reject forecasted sea-level rise as "unknowable", deterring them from perceiving the estimated probabilities and potential severity of coastal flooding. Previous experience is known to strongly affect risk perception [*Tversky and Kahneman* 1974; *Grothmann and Patt* 2005; *Burningham et al*. 2008], and in the Tantramar case, a dramatic freshwater flood occurred in 1962. Individuals who personally witnessed this event may appraise coastal flood risk differently from individuals who recently immigrated to the region. The third variable, reliance on public adaptation, is relevant for the Tantramar case in that the municipality of Sackville has enjoyed the protection of an extensive dyke system. Some individuals may perceive the dykes as an adequate safeguard, thereby negatively impacting their perception of the true risk.

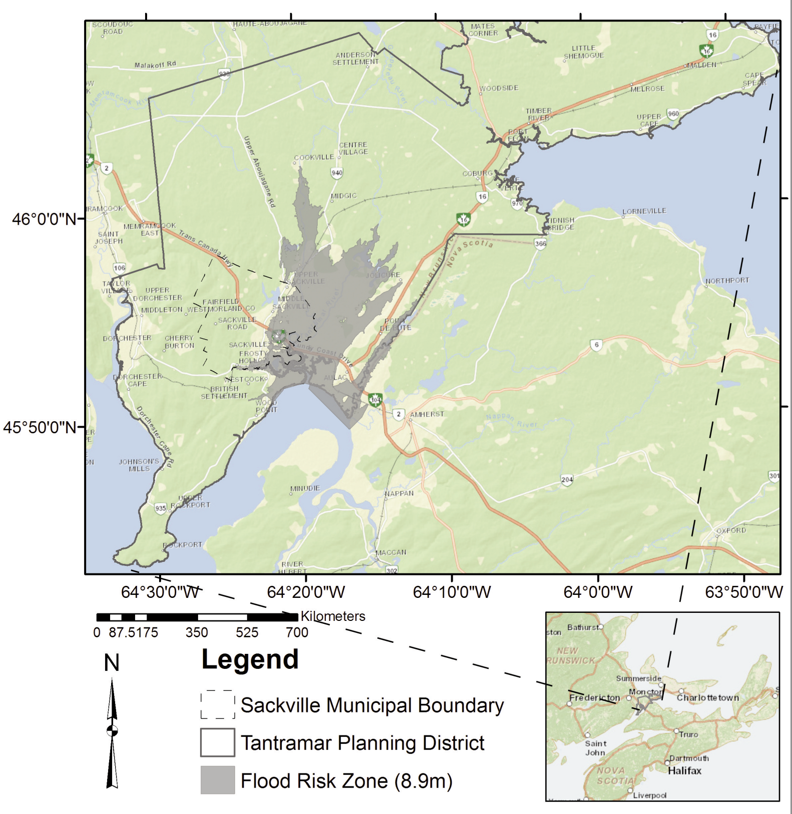

Figure 1: Outline of the Tantramar Planning District Commission within the Province of New Brunswick, which borders the Province of Nova Scotia. Also indicated is the Sackville Municipal boundary, and the flood risk zone at an 8.9m (CGVD28 datum) extreme sea level. The basemap is OpenStreetMap (*http://wiki.openstreetmap.org*).

Visualizations, examples of which are discussed in the next section, constitute evidence that will be interpreted by the public during risk appraisal (Figure 2A). If the threat is perceived as meeting or exceeding the threshold of tolerance for that individual, adaptation appraisal (Figure 2B) naturally follows [*Grothmann and Patt* 2005]. During this process, individuals evaluate three things: their perception of the overall possibility for effective adaptation (the perceived adaptation efficacy), their perception that it is possible for them to personally take action (perceived self efficacy) and the perceived costs of adaptation. Quite conceivably, visualizations could also play a role at this stage if it were possible to identify adaptation strategies in advance and present the public with tradeoffs, e.g., expected reductions in long-term financial impact under different flood proofing strategies. The outcome of adaptation appraisal could be either maladaptive or adaptive. As presented by *Grothmann and Patt* [2005], "maladaptation" consists of avoidant reactions: denial, wishful thinking, or fatalism. Maladaptation is most likely when an individual perceives the risk to be high but the possibility for adaptation to be low. Conversely, an intention to adapt is more likely when the motivational energy associated with high-risk perception is paired with belief that adaptation solutions are feasible and personally actionable [*Grothmann and Patt* 2005].

"Feedback" (Figure 2C) constitutes the community learning that occurs following the decision to act or not act. In *Risbey et al's* [1999] study, feedback consisted of monitoring the output from different choices of agricultural production. But it is expected that the intermittent occurrence of major storms or flood events will also trigger a reappraisal of risk and adaptation options. After an event, cognitive biases and reliance on public adaptation strategies will be at their nadir, with personal experience acting to elevate the perception of risk. At such times, communities will inevitably reappraise adaptation strategies and reject those perceived to be ineffective in the wake of recent personal experience. Communities already in possession of viable adaptation plans, and which can provide adaptation incentives (such as tax reductions or land use policy) may witness a wider acceptance of those plans at such times.

Role of Visualization

The communication of potentially emotionally-charged information (e.g., flood risk) can be expected to encounter resistance from many peoples' tendency to reject upsetting facts (the so-called "ostrich effect" of *Burningham et al.* [2008]). *Morss et al.* [2005: 1597] makes the point that "…telling someone with a different perspective (and often limited capacity to change) that they 'should' act differently does not necessarily convince them to do so: in fact, it can induce mental blocking". The problem is compounded by issues of trust and credibility (e.g., bias against outside experts, *Dransch et al.* [2010]). *Burningham et al.* [2008] also point out that people often resent being stigmatized as "vulnerable" because such labels can have negative social and material consequences. However, by rendering facts "visible", visualizations may avoid direct confrontation with peoples' biases, help focus their attention, and provide them with the opportunity to evaluate evidence for themselves [*Eppler* 2004].

Figure 3 presents a matrix of visualization methods, to illustrate the tradeoffs between comprehensibility and model complexity. Four-dimensional data (e.g., 3D models with a time component) are not shown, but could easily be incorporated. While there is an emphasis on numerical information, qualitative visualizations (e.g., photographic or video images) are equally important and may be highly effective communication tools when available.

In the context of coastal flooding, non-spatial visualizations could involve time series records of historical high water levels, storm frequencies, and future sea level projections. This information is likely to be statistical and non-spatial in nature, and falls into the left-most column of Figure 3. Moving from the top to bottom involves the representation of increasingly complicated models, e.g., a density smoothed histogram illustrating a dyke elevation profile (Figure 3, panel b), and a regression model that could depict the relationship between variables like sea level rise and erosion (Figure 3, panel c). While some viewers will be comfortable interpreting

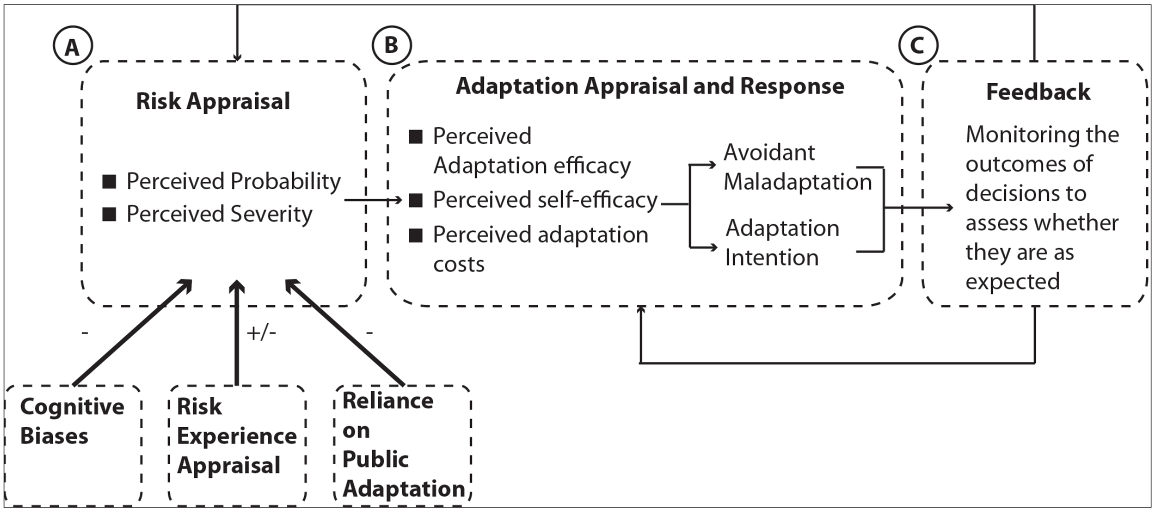

Figure 2: Socio-cognitive framework of climate-change risk appraisal, adapted from *Grothmann and Patt* [2005] and *Risbey et al.* [1999].

Figure 3, panel c as a standalone visualization, most members of the public will find it unfamiliar and require more guidance and supporting information to evaluate it.

2D visualizations encompass the full range of traditional cartographic visualization, whether general purpose (Figure 3, panel d) or more highly processed thematic maps (Figure 3, panel e). Figure 3 (panel f) depicts a kriged surface, and represents the output of a complicated geostatistical model. A general audience will not understand the assumptions and limitations inherent in such a figure, and may experience disempowerment and be more likely to counter the evidence with cognitive bias. It seems sensible to predict, *a priori*, that 2D visualizations that closely resemble general-purpose maps, e.g., a road map, will be more familiar and more readily interpreted. *Pousman et al.* [2007] present interesting examples of visualization intended for "casual" users, some of which may have relevance for risk communication.

The development of spatial imagination is an important benefit of interacting with visualizations, potentially allowing people to form an impression of a phenomenon they may not have any direct personal experience with. This is especially important for infrequent events of large magnitude, e.g., catastrophic floods, which for periods of time can appear non-existent and not be perceived as an issue of concern. The "risk experience appraisal" effect (Figure 2A) can strongly influence people's assessments of local risk, causing them to over- or underestimate the likelihood of chance events on the basis of recent personal experience [*Tversky and Kahneman* 1974]; *Grothmann and Patt* 2005; *Burningham et al*. 2008], 3D visualizations (Figure 3, panels g,h,i), with or without animations, may be particularly useful ways to simulate the impacts of climate-change risks by providing more intuitive views of impacted landscapes [*Basic et al*. 2003; *Brandt and Jiang* 2004; *Lai et al*. 2010]. They may also enhance what *Cockburn and McKenzie* [2002] refer to as "spatial memory"—potentially saving someone's life if, for instance, they found themselves in the midst of a natural disaster but remembered that particular streets or highway overpasses were to be avoided. However, development of realistic 3D visualizations can be highly resource intensive [*Lai et al*. 2010] and may constitute overkill.

A comment should be made about animation, which could be applied to all of the visualization types in Figure 3. Dynamic displays can convey unfolding events [*DiBiase et al*. 1992], for instance, rising floodwaters. Used judiciously, they could also focus attention on important changes or trends in non-spatial visualizations (an example of which is discussed in Tantramar Case Study). However, research on change blindness has shown that viewers of even moderately complicated visualizations fail to perceive a significant number of changes [*Simons* 2000; *Fish et al*. 2011]. For this reason it appears unwise to base risk communication solely on animated displays.

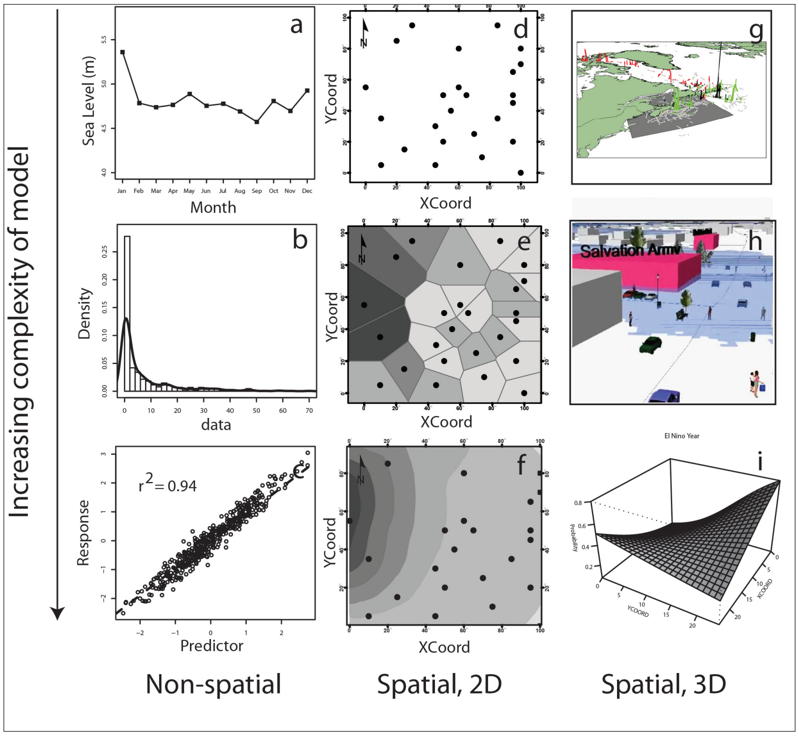

Figure 3: Matrix of non-spatial, 2D and 3D spatial visualizations as a function of the complexity of the underlying data model. See text for further description.

Two problems that need to be discussed in relation to visualization are: scale and uncertainty. In the first case, it can be difficult to decide on the most effective scale for general communication, the choice of which will inevitably introduce tradeoffs, e.g., a regional flood map showing total flood extent but concealing details such as the impact on particular historical buildings. Interactive, dynamic maps have a key role to play here by allowing viewers to pan, zoom and query details from the larger map, thereby alleviating scale limitations.

The presentation of uncertainty is another enduring problem, with research showing a discrepancy between the ideal depiction of it (as espoused by the literature) and avoidance of its depiction in practice [*Roth* 2009]. *Roth* [2009] attributes this to a number of factors: (1) fear of undermining credibility; (2) skepticism about the ability of viewers to understand and draw meaningful conclusions; and (3) perception that viewers are averse to knowing this information for fear that it will complicate decision making. These are sensible concerns, and reflect a wider tension in the communication of science. However, when variability has large consequences, e.g., sea level estimates and corresponding flood extents, this uncertainty cannot be ignored. As a notion of uncertainty, the "confidence interval" will only make sense to someone with statistical training (see *Monmonier* [1990] for alternative ways to present this in a non-spatial context), When the consequences of uncertainty are less important, it may be adequate to just show average (expected) values, perhaps with the use of shading to communicate the range of "likely expectation". Clearly this is an area of ongoing research.

In summary, it is recommended that visualization development proceed as outlined in Figure 4. With reference to the socio-cognitive model (Figure 2), each of the elements in the risk appraisal phase (Figure 2A), should be addressed. For instance, information on flood return frequencies may be necessary to counter the cognitive bias that "nothing's really changed". A focus group of domain experts or literature review may also help. Once the list of information requirements has been compiled, the identification of candidate visualizations would benefit from application of Occam's Razor, such that the simplest, adequate representation be explored first. The author suggests (without data to verify) that simple representations (row 1 of Figure 3), judiciously augmented by animation, may be the most generally effective. Once visualizations have been designed and developed, their effectiveness should be assessed using the Evaluation Framework detailed in the next section. Following this assessment, confusing or misleading visualizations can be modified or eliminated, and communication gaps addressed.

Evaluation Framework

In a public communication context, there are many uncertainties about how information will be received, perceived, and processed. If it were possible to identify, *a* priori, the most effective presentation of evidence so as to positively influence risk perception and inspire an adaptation intention there would be no need for an evaluation framework. But negative examples such as the Government of New Brunswick's experience with the presentation of its wetlands predictive map suggest that more information may have been required to place the intended purpose, limitations, and informativeness of the map layer in context. For instance, the credibility of the model was weakened by the decision not to present information about uncertainty in the wetland delineation. The notion of a complete information platform revisits the "atlas touring" idea of *Monmonier* [1990], where maps, statistical diagrams, and textual summaries are presented as part of a "meaningful sequence of relevant views" [*MacEachern et al.* 1992]. Such an information platform stands to prepare viewers for the effective use of fully interactive geovisualization (e.g., a web-based GIS).

Successful application of visualization tools to communicate climate change risks will be most

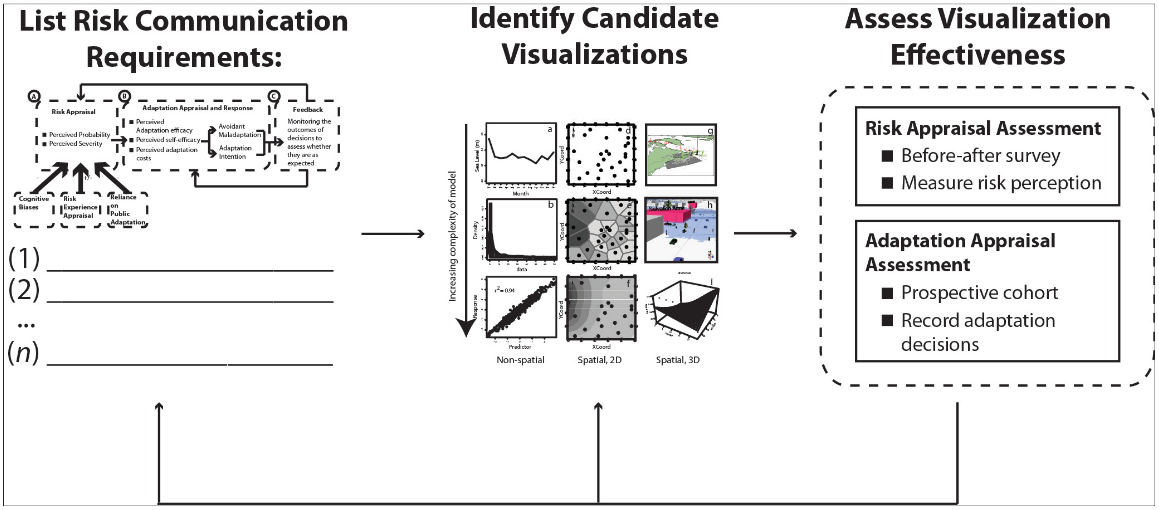

Figure 4: Recommended framework for the development of risk communication visualizations. With reference to the socio-cognitive model (Figure 2) and domain expertise, a list of information requirements should be compiled; candidate visualizations identified using Occam's Razor; and their effectiveness assessed using the framework discussed in the section Evaluation Framework. Following this assessment, confusing or misleading visualizations can be modified or eliminated, and communication gaps addressed.

likely if an effective combination of images can be identified. Will viewers find a flood map most informative, or will an animation illustrating rising water levels work better? In the author's experience, these types of questions are impossible to answer without test deploying them to a sampled public. It is important to note that this is not the same as a "usability study" (in the sense of *Plaisant* [2004]), where the measurements of interest are quantities like time to task completion or reduction in error rates. Rather, this is an assessment of risk-perception and the effect that visualizations have on the risk and adaptation appraisal process. This section, therefore, advances recommendations to achieve this assessment, thereby guiding the development and deployment of visualization tools to a wider audience.

Grothmann and Patt's [2005] socio-cognitive model identifies 'risk' and 'adaptation' appraisal as separate processes. As risk appraisal is a "signal detection" exercise [*Risbey et al*. 1999], communication should be designed to accurately convey the likely probability and severity of risk. Assessment should measure how effectively the visualizations impacted the quality of people's understanding (Figure 2A), and would be best evaluated using a "before-after" survey design [*Golding et al*. 1992] involving questionnaires, survey responses, and comments from interviews [*Koua and Kraak* 2004]. The use of a focus group methodology allows for the solicitation of open-ended comments [*Morgan* 1998; *Roth* 2009], and permits the identification of incidences of maladaptation, e.g., statements such as "the situation is hopeless; there's nothing we can do". Participant-volunteered rankings of the relative risk facing different locations would constitute a useful metric. If visualizations offer insights beyond, for example, mere verbal descriptions of the problem, risk rankings will be demonstrably more accurate. When administered across multiple sessions as a type of controlled experiment [*Plaisant* 2004], this framework permits the assessment of different combinations of "treatments". On account of the impact of such factors as income, education and home ownership on risk perception [*NRC* 2006] such demographic information should be routinely gathered.

Adaptation appraisal, which is expected to occur over a longer time frame, would be most appropriately assessed using a prospective "cohort" approach. Viewers of the spatial and non-spatial information could be contacted at a future date, and their adaptation decision-making evaluated. *Shneiderman and Plaisant* [2006] discuss just such an approach in the context of human-computer interaction research.

Tantramar Case Study

The Tantramar region of South-East New Brunswick (Figure 1) is a coastal zone subject to strong tidal forces from the upper Bay of Fundy, and relies on a dyke system to protect the Town of Sackville (population approx. 5500), an interprovincial railway and highway, and surrounding agricultural lands. Current 1-in-10 year extreme storm levels are estimated at 8.9m ± 0.1m (CGVD28 datum, *R.J. Daigle Enviro* [2011]), which has the capacity to overtop 89% of the existing dyke system (average height = 8.6m) and flood approximately 20.6% of the town (Figure 1, *Lieske and Bornemann* [2011]). This region provides a useful example illustrating the types of risk communication requirements that could be met using visualization tools:

1. Counter to claims that sea level changes are "unknowable" (cognitive bias),
2. Presentation of flood probabilities,
3. Presentation of flood severity.

Cognitive biases are often strongly entrenched with regards to statistical evidence or model predictions. Traditional approaches to communicate uncertainty (e.g., a 95% confidence interval) may not be properly interpreted. Line charts, which will be familiar to many people from climate or stock market time series plots, are a convenient starting point for communication. In the Tantramar case, an historical time series of maximum monthly sea levels could illustrate a general tendency for higher sea levels. But even well established statistical techniques (such as trend lines) may not be interpretable to non-scientific audiences. In the author's personal experience, the notion of a regression line can be unfamiliar to even Ph.D.-educated mathematicians. Animation, through the selective focusing of attention, could improve the interpretability of the changes. As an exploratory prototype, a longer time series of maximum sea levels was augmented using Adobe Flash Builder (*Adobe* [2011], Figure 5). To emphasize the changing frequency and amplitude of unusual sea levels, a moving ball was animated to trace the time series. At points crossing the 95th percentile, a boldly-coloured expanding sphere appeared to draw attention to the event. By the end of the animation the tendency for more frequent anomalies of greater amplitude in the most recent decades of the time series is apparent without the need for further explanation.

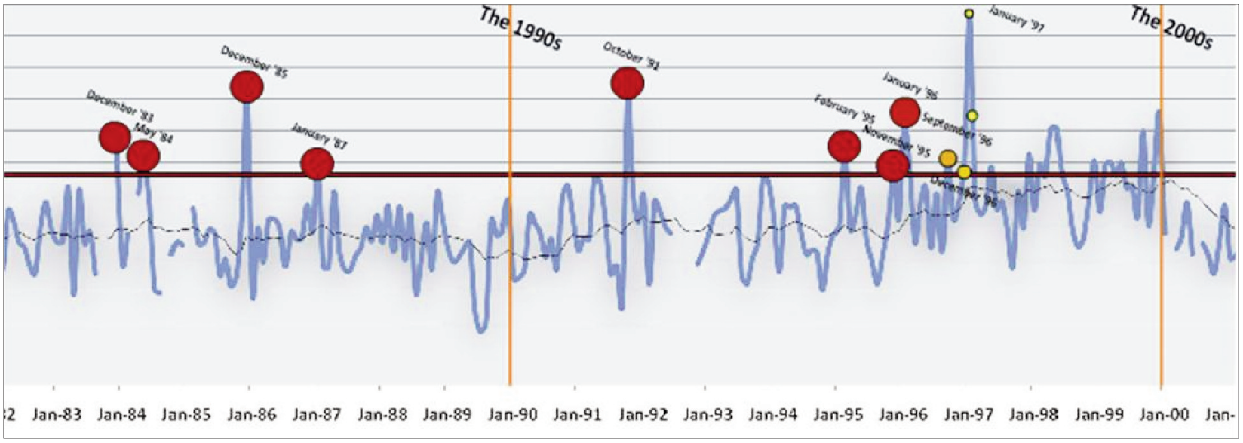

Figure 5: Adobe Flash-enabled viewer for displaying a time series of the tide gauge records for the City of Saint John, New Brunswick. Data consisted of the monthly maximum of the average daily tide gauge readings, from January, 1939 - July, 2010. Also indicated is the 95th percentile (solid black line), and animated icons signaling when an anomalous tide level was recorded. The increasing frequency and magnitude of anomalies are clearly visible in the latter third of the time series.

Figure 6: "Walking man" animation illustrating the potential consequence of a 1-in-10 year flood event of 8.9m (CGVD28 datum, *R.J. Daigle Enviro* [2011]) in downtown Sackville, New Brunswick. In this context, 3D visualization facilitates an awareness of flood depth and severity (e.g., where cars are fully vs. only partially submerged) in a familiar setting, and may be more emotionally compelling.

Communicating flood probabilities to a lay audience can be problematic. Conventional definitions of expected flood return rates (e.g., 1 in 10 years) can be confusing, and may even appear nonsensical. To some people, the fact that the last major flood in the Tantramar occurred in 1962 (fifty years ago) renders a "1 in 10 year" scenario an unreasonable proposition. But such a belief disregards the fact that: (1) the risks are changing under the influence of climate change, and (2) purely by chance, 36% of decades "drawn" randomly from a Poisson distribution will not experience major flood events. Unfortunately, 20% of "randomly selected" decades can also be expected to experience two such events. Visualizations could also play a role here, either by depicting sequences of years experiencing random flood events, or by referring to useful analogies from games of chance.

The presentation of flood severity is another challenge for risk communication. In a meeting (unrelated to this study) of municipal emergency measures officials, planners, and regional experts, it was suggested that conventional (2D) maps may be limited in their ability to communicate flood impacts. This sparked the question of whether the public needs access to 3D model buildings and people in order to confidently grasp the consequences of hypothetical flood risks. Given the "invisible threat" posed by infrequent, large magnitude climate change events, 3D models and animations may have a special role to play in rendering projected disasters "real". At the very least, they have the potential to render the information more vivid and emotionally interesting [*Dransch et al.* 2010]. While still at the prototype stage, ArcScene 10.0 [*ESRI* 2010] was used to develop a "walking man" animation featuring a flooded 3D street scene in the core of the town of Sackville, New Brunswick (Figure 6). In this context, 3D visualization could facilitate a greater awareness of flood depth and severity (e.g., where cars are fully vs. only partially submerged) in a familiar setting, and may be more emotionally compelling.

Conclusions and Recommendations

Information about climate change risks needs to be readily comprehensible, and objectively presented. Visualizations have a potentially significant role to play in this regard, by helping to avoid direct confrontation with peoples' tendency to deny uncomfortable information, improving the understanding of complicated concepts, and stimulating spatial imagination. Arguably, visualizations for climate-change communication potentially serve both exploratory and explanatory/communicative functions (falling in the mid- to lower-slope of the "swoopy" diagram of *DiBiase* [1990: 3], cited in *Roth* [2011]). Assessment of the effectiveness of any given visualization should be based on its ability to raise risk awareness (i.e., demonstrably facilitate knowledge transfer) and inspire adaptation intention, while at the same time not drive people towards maladaptive positions (e.g., denial, wishful thinking). Communities already in possession of viable adaptation plans and incentives at the time of wide-scale communication initiatives (e.g., tax reductions or land use policies) may experience the widest adoption of adaptation strategies. Therefore, it is recommended that public risk communication be paired with the presentation of adaptation plans whenever possible.

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References

Adobe. 2011. Adobe Flash Builder 4.5 Premium. Adobe Systems Incorporated, San Jose, California.

Andrienko, N., G. Andrienko and P. Gatalsky. 2003. Exploratory spatio-temporal visualiation: an analytical review. *Journal of Visual Languages and Computing*, 14, 503-541.

Ball, M. 2011. New Brunswick drops their wetlands mapping tool amid controversy. Spatial Sustain, URL: *http://www.vector1media.com/spatialsustain/wetlands-mapping-tool-dropped.html*.

Basic, F., W. Cartwright and J. Handmer. 2003. Geographic visualization tools for communicating the risk of floods. *Proceedings of the 21st International Cartographic Conference*, pp. 2033-2044.

Brandt, S.A. and B. Jiang. 2004. 3D geovisualization as a communication and analysis tool in fluvial geomorphology. *Geoinformatics*, 2004, pp. 339-346.

Burningham, K., J. Fielding and D. Thrush. 2008. 'It'll never happen to me': understanding public awareness of local flood risk. *Disasters*, 32, pp.216-238.

Cockburn, A. and B. McKenzie. 2002. Evaluating the effectiveness of spatial memory in 2D and 3D physical and virtual environments. *Proceedings of CHI 2002*, 2002, pp. 203-210.

DiBiase, D. 1990. Visualization in the earth sciences. *Bulletin of the College of Earth and Mineral Sciences*, 59, pp. 13-18.

DiBiase, D., A.M. MacEachren, B. Krygier and C. Reeves. 1992. Animation and the role of map design in scientific visualization. *Cartography and Geographic Information Systems*, 19, pp. 201-214.

Dransch, D., H. Rotzoll and K. Poser. 2010. The contribution of maps to the challenges of risk communication to the public. *International Journal of Digital Earth*, 3, pp. 292-311.

ESRI. 2010. ArcScene version 10.0. Environmental Systems Research Insititute, Redlands, California.

Eppler, M.J. 2004. Facilitating knowledge communication through joint interactive visualization. *Journal of Universal Computer Science*, 10, pp. 683-690.

Fish, C., K.P. Goldsberry and S. Battersby. 2011. Change blindness in animated choropleth maps: an empirical study. *Cartography and Geographic Information Sciences*, 38, pp. 350-362.

Golding, D., S. Krimsky and A. Plough. 1992. Evaluating risk communication: narrative vs. technical presentations of information about radon. *Risk Analysis*, 12, pp. 27-35.

Government of New Brunswick. 2011. Wetland map data on GeoNB map viewer. News Release, January 13, 2011.

Grothmann, T. and A. Patt. 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Global Environmental Change*, 15, pp. 199-213.

IPCC. 2007. Climate change 2007: synthesis report, URL: *http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf*.

Janz, N.K. and M.H. Becker. 1984. The health belief model: a decade later. *Health Education Quarterly*, 11, pp. 1-47.

Keim, D.A., C. Panse and M. Sips. 2005. Information visualization: scope, techniques and opportunities for geovisualization. In M.-J. Kraak (ed.), *Exploring Geovisualization*, Elsevier, Amsterdam, pp. 23-52.

Koua, E.L. and M-J. Kraak. 2004. A usability framework for the design and evaluation of an exploratory geovisualization environment. *Proceedings of the Eighth International Conference on Information Visualization,* IV'04, IEEE Computer Society Press.
Lai, P.C., K-H. Kwong and A.S.H. Mak. 2010. Assessing the applicability and effectiveness of 3D visualization in environmental impact assessment. *Environment and Planning B: Planning and Design*, 37, pp. 221-233.
Lieske, D.J. and J. Bornemann. 2011. Coastal dykelands in the Tantramar area: impacts of climate change on dyke erosion and flood risk, URL: *http://www.mta.ca/~dlieske/GML/docs/CoastalDykelandsinTantramar-ImpactsofClimateChange.pdf*.
MacEachren, A.M. 1994. Visualization in modern cartography: setting the agenda. In A.M. MacEachren and D.R.F. Taylor (eds.), *Visualization in modern cartography*. Pergamon, Oxford, UK, pp. 1-12.
MacEachren, A.M., B.P. Buttenfield, J.B. Campbell, D.W. DiBiase and M. Monmonier. 1992. Visualization. In R. Abler, M. Marcus and J. Olson (eds.), *Geography's inner worlds: pervasive themes in American geography*, Rutgers University Press, New Brunswick, New Jersey, pp. 99-137.
MacEachren, A.M., M. Gahegan and W. Pike. 2004a. Visualization for constructing and sharing geo-scientific concepts. *Proceedings of the National Academy of Sciences*, 101 (Suppl. 1), pp. 5279-5286.
MacEachren, A.M., M. Gahegan, W. Pike, I. Brewer, G. Cai and E. Lengerich. 2004b. Geovisualization for knowledge construction and decision support. *IEEE Computer Graphics and Applications*, 24, pp. 13-17.
Monmonier, M. 1990. Strategies for the visualization of geographic time-series data. *Cartographica*, 27, pp. 40-45.
Morgan, D.L. 1998. *The focus group guidebook, focus group kit 1*. Sage Publications, New York.
Morss, R.E., O.V. Wilhelmi, M.W. Downton and E. Gruntfest. 2005. Flood risk, uncertainty, and scientific information for decision making: lessons from an interdisciplinary project. *Bulletin of the American Meteorological Society*, 86, pp. 1593-1601.
NRC. 2006. *Facing hazards and disasters: understanding human dimensions*. The National Academies Press, Washington, D.C. 394 pages.
Plaisant, C. 2004. The challenge of information visualization evaluation. *Proceedings of the Conference on Advanced Visual Interfaces*, New York, pp. 109-116.
Pousman, Z., Stasko, J. and M. Mateas. 2007. Casual information visualization: depictions of everyday life. *IEEE Transactions in Visualization and Computer Graphics*, 13, pp. 1145-1153.
Risbey, J., Kandlikar, M., Dowlatabadi, H. and D. Graetz. 1999. Scale, context and decision-making in agricultural adaptation to climate variability and change. *Mitigation and Adaptation Strategies for Global Change*, 4, pp. 137-165.
R.J. Daigle Enviro. 2011. Sea-level rise estimates for New Brunswick municipalities: Saint John, Sackville, Richibucto, Shippagan, Caraquet, Le Goulet. Report for the Atlantic Climate Adaptation Solutions Association.
Roth, R.E. 2009. A qualitative approach to understanding the role of geographic information uncertainty during decision making. *Cartography and Geographic Information Science*, 36, pp. 315-330.
Roth, R.E. 2011. *Interacting with maps: the science and practice of cartographic interaction*. Doctoral dissertation, Pennsylvania State University.
Shneiderman, B. and C. Plaisant. 2006. Strategies for evaluating information visualization tools: multi-dimensional in-depth long-term case studies In *Proceedings of beyond time and errors: novel evaluation methods for information visualization*, Workshop of the Advanced Visual Interfaces Conference (2006).
Simons, D.J. 2000. Current approaches to change blindness. *Visual Cognition*, 7, pp. 1-15.
Slocum, T.A., C. Blok, B. Jian, A. Koussoulakou, D.R. Montello, S. Fuhrmann and N.R. Hedley. 2001. Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28, pp. 61-75.
Slovic, P. 1987. Perception of risk. *Science*, 236, pp. 280-285.
Smit, B. and O. Pilifosova. 2001. Adaptation to climate change in the context of sustainable development and equity. In *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, WMO/UNEP, 877-912.
Tukey, J.W. 1977. *Exploratory data analysis*. Addison-Wesley, Ontario. 503 pages.
Tversky, A. and D. Kahneman. 1974. Judgment under uncertainty: heuristics and biases. *Science*, 211, pp. 1124-1131.

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