

# Visualizing flood risk, enabling participation and supporting climate change adaptation using the Geoweb: the case of coastal communities in Nova Scotia, Canada

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**Abstract** Impacts of climate change have been observed in natural systems and are expected to intensify in future decades (IPCC in Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change IPCC, Geneva, 2014). Governments are seeking to establish adaptive measures for minimizing the effects of climate change on vulnerable citizen groups, economic sectors and critical infrastructure (Adger et al. in *Global Environ Change* 15(2):77–86, 2005. doi:10.1016/j.gloenvcha.2004.12.005; Smit and Wandel in *Global Environ Change* 16(3):282–292, 2006. doi:10.1016/j.gloenvcha.2006.03.008). Coastal areas are particularly vulnerable to changing conditions due to rising sea levels and storm event intensification that produce new flood exposures (Richards and Daigle in Government of Prince Edward Island, Halifax, Nova Scotia, 2011 <http://www.gov.pe.ca/photos/original/ccscenarios.pdf>). However, communities oftentimes lack access to locally-relevant climate change information that can support adaptation planning. This research introduces the use of a Geoweb tool for supporting local climate change adaptation efforts in coastal Canadian communities. The Geoweb tool (called “AdaptNS”) is a web-based visualization tool that displays interactive flood exposure maps generated using local climate change

projections of sea level rise and storm surge impacts between the years 2000 and 2100. AdaptNS includes participatory features that allow users to identify and share specific locations to protect against present and future coastal flood events. By soliciting feedback from community members, AdaptNS is shown to support local adaptation through the provision of flood exposure visuals, as a platform for identifying adaptation priorities, and as an avenue to communicate local risks to external entities that could facilitate local adaptation initiatives (e.g. upper levels of government). Future Geoweb research directions include improving the visualization of climate change projection uncertainties, the expansion of informational and participation capabilities, and understanding the potential for long-term adoption of Geoweb tools in adaptation decision-making.

**Keywords** Geoweb · Flooding · Visualization · Adaptation · Community · Participatory

## Introduction

The Intergovernmental Panel on Climate Change (IPCC) indicates that in addition to lowering greenhouse gas emissions to mitigate future climate change, there is a need for climate change adaptation (Noble et al. 2014). This decision is based on evidence that “warming of the climate system is unequivocal” and it

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is challenging societies across the globe (Adger et al. 2005; Van Aalst et al. 2008; IPCC 2014, p. 40). Adaptation to climate change is commonly defined as any “process, action, or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity,” and can occur before, during or after a climate impact or its secondary effects occurs (Smit and Wandel 2006, p. 282). Adaptation to climate change requires that it be integrate with, or mainstreamed into, existing interests and needs of societies, and this requires strengthened communication among researchers, stakeholders and decision makers at all scales (Howden et al. 2007; Noble et al. 2014). Yet, identifying necessary adaptive responses can be problematic since climate change information is often available at coarse scales and is insufficiently detailed to allow an understanding of impacts at the local level (Leblanc and Linkin 2010). In addition, considerations of legitimacy in adaptation at the local level highlight the need to understand what stakeholders value and consider worth protecting (O’Brien and Wolf 2010; Measham et al. 2011). This information gap restricts the identification of valued at-risk assets and infrastructure, as well as developing priorities, actions, policies and decisions that could minimize or better manage imminent climate change impacts.

Climate change geovisualization tools have emerged as promising efforts to fill information gaps and communicate present and future climate change risks through spatial technologies (Sheppard 2012). The purpose of these tools is to connect broad descriptions of climate change impacts with comprehensive visuals to help citizens and governments understand the interactions between climate change, local landscapes and society. In comparison to traditional static maps, geovisualization tools present users with spatially and temporally dynamic 2D and 3D visuals. For example, climate change geovisualization tools have proven effective at communicating information to vulnerable populations, and in integrating climate change risks with socioeconomic factors, such as population density and income differences (Sheppard et al. 2011; Sheppard 2012; Climate Central 2015). In an adaptation context, establishing a relationship between climate change risks with locations that have social value (whether culturally, economically, or other) can serve as a step towards promoting

public discourse, creating a consensus view, and spurring action. Yet, traditionally, geovisualization tools focus on delivering authoritative information (e.g. scientific datasets) and do not integrate local perspectives and opinions that could add a new human dimension for detecting locations that are both exposed to climate change and have value to communities.

This research introduces the use of the Geospatial Web (or “Geoweb”) to support local climate change adaptation. The Geoweb is a collection of Internet-based mapping platforms and applications that enable users to access and/or contribute geographic information (Haklay et al. 2008; Ricker et al. 2013). Geoweb tools offer promising potential to act as climate change information exchange platforms as they offer users the ability to access and share geo-located content and information (e.g. maps, images, comments) via the Web. Geoweb tools have previously been used to display climate change exposure (Taber 2014; Climate Central 2015; NOAA n.d.); yet, thus far, the Geoweb has not been assessed in terms of how it can support the local adaptation process by integrating climate change scenarios and participatory features. This research presents a Geoweb tool (“AdaptNS”) created for a coastal region within the Canadian province of Nova Scotia. AdaptNS displays coastal flood risk during various time periods, allowing users to share specific locations that they perceive as necessary to protect against climate change impacts. Empirical evidence gathered from this case study suggests a role for the Geoweb as a tool supporting local adaptation efforts by making information widely available, communicating local issues to various levels of government, and enabling communities to independently conduct adaptation efforts in the future. This research also presents current limitations of this methodology and suggestions for advancing future Geoweb research in a climate change adaptation context.

### Climate change visuals and adaptation

There is a widespread recognition in the climate change literature that adaptation planning requires collaboration among multiple levels of governance, but that adaptation is commonly implemented at the local level (Amundsen et al. 2010; Measham et al.

2011). Despite this recognition that “adaptation is local,” priorities are frequently set at the national level, at the expense of place-based values and knowledge (Amundsen et al. 2010; O’Brien and Wolf 2010; Measham et al. 2011). Commonly, relevant climate change impact information is not available or accessible to municipalities, further reinforcing a top-down approach. So-called bottom-up considerations of adaptation are characterized by the engagement of communities in the adaptation process to determine locally-relevant adaptation plans which recognize that community stakeholders hold a range of values and priorities (Measham et al. 2011; Butler et al. 2015). As top-down adaptation often lacks the inclusion of important social factors, community-based approaches are criticized for their overreliance on local knowledge, lack of inclusion of climate science and their isolated nature (Ayers and Huq 2009; Rossing et al. 2012; Dodman and Mitlin 2013). Nevertheless, each approach has its merits that if incorporated “could foster greater adaptive capacity than either may achieve in isolation” (Butler et al. 2015, p. 348). This argument emerges from the understanding that adaptation benefits from cross-sectoral networks and partnerships that facilitate the adaptation process, and the use of platforms for exchanging information related to climate change risks and adaptation (UNFCCC 2007; Rossing et al. 2012; Noble et al. 2014). Fostering the skills, resources and knowledgebase of stakeholders, governments and the public appear promising for supporting adaptation, whether this entails educating communities of their climate change exposure or creating cross-sectoral partnerships for funding adaptation projects that communities value.

Within the existing library of information-sharing platforms, tools for geo-visualizing climate change have emerged in recent years to inform vulnerable communities of their climate change exposure and promote adaptation discourse (Sheppard 2012). Geo-visualization tools are not standardized in design, but as their name implies, they all have significant dependence on geography and spatial information. These tools focus on visualizing climate change science (e.g. sea level rise), adaptation futures (e.g. adaptive infrastructure vs. no adaptation) or community knowledge across geographic landscapes (Sheppard et al. 2011; Fisher 2011; Ricker et al. 2013; Climate Central 2015). For example, a tool that

focuses on sea level rise visualization allows users to increase or decrease water levels interactively and view the vulnerability of low-lying areas to rising waters (Climate Central 2015). Closely related to the use of visualization tools for climate change exposure are tools to support hazard identification more generally, such as flooding risk (Cummings et al. 2012; Richards 2015) or snow avalanche (Kunz and Hurni 2011). In each case, the use of geovisualization tools facilitated the assessment of risk and communication with relevant stakeholders of the location and severity of risk. These tools provide a basis for both education and to direct future action. Despite these generally successful uses, questions of how to best communicate model uncertainty (Kunz et al. 2011) and provide personally-relevant information to stakeholders (Dransch et al. 2010) remain.

Scholars have tested climate change geovisualization tools in workshops and found that in some cases, they can effectively communicate climate change storylines and influence changes in attitude towards adaptation (Sheppard et al. 2011). These tools are a powerful means for visually communicating climate change to vulnerable communities; however, they often lack public accessibility once research is complete and primarily focus on sharing downscaled climate change models and authoritative information (Sheppard et al. 2011; Taber 2014). Similar to top-down adaptation, geovisualization tools have also mostly adopted a “top-down” methodology by focusing on the visualization of downscaled climate change models. Meanwhile the few examples that have incorporated community knowledge have focused only on the participation aspect (Beaudreau et al. 2012; Ricker et al. 2013; Johnson et al. 2015). This gap provides a research opportunity to investigate the benefits and drawbacks of a tool that integrates climate science with local knowledge, experiences and perceptions and how it supports adaptation processes.

The Geoweb presents promising potential to serve as a Web-based platform that supports climate change adaptation where users can access scientific climate change information and also contribute their own values and priorities. Soliciting local insights can highlight local knowledge that is rarely captured in top-down approaches and ensures that adaptation is inclusive, equitable and has the potential to sustain or enhance actions that societies value (Measham et al. 2011; Graham et al. 2013). The integration of climate

change models and community values through a platform can offer a more holistic view of adaptation needs both as a result of imminent risks and community interests. While the online nature of a Geoweb tool can serve to promote adaptation discourse once research is complete and support information exchange. Using a case study approach, a Geoweb tool is developed and evaluated in this paper for its ability to support local adaptation efforts in coastal Canadian communities.

## Methods

### Development process and tool characteristics

AdaptNS is a Geoweb platform that was designed for the use of coastal communities across Shelburne County—a regional, rural municipality in southern Nova Scotia (Fig. 1). By working closely with municipal partners during the development of AdaptNS, it was identified that coastal flood impacts were a primary climate change concern due the proximity of industry-related infrastructure and cultural heritage sites to the shoreline. Yet, at the start of this research, municipal climate change reports were limited to using numerical data of future expected water levels (e.g. 1 m sea level rise by 2100) for describing local climate change impacts (Tipton 2013; Atwood 2013; MCCAP Shelburne 2014). Maps and geographic visuals of coastal flood impacts were unavailable and could not be generated by municipalities due to a lack of technological capacity and expertise. The lack of informational resources restricted municipalities and local residents from becoming aware of how climate change could impact local infrastructure, valuable community amenities as well as their livelihoods and safety; thereby, also limiting their capacity to adapt. This informational gap instigated the need for a Geoweb tool that provides climate change exposure maps to many communities who are seeking to adapt but lack knowledge of local climate change risks.

### Climate change visioning

Coastal flooding scenarios, were created using LiDAR (Light Detection and Ranging) data provided by local municipal governments to provide for precise

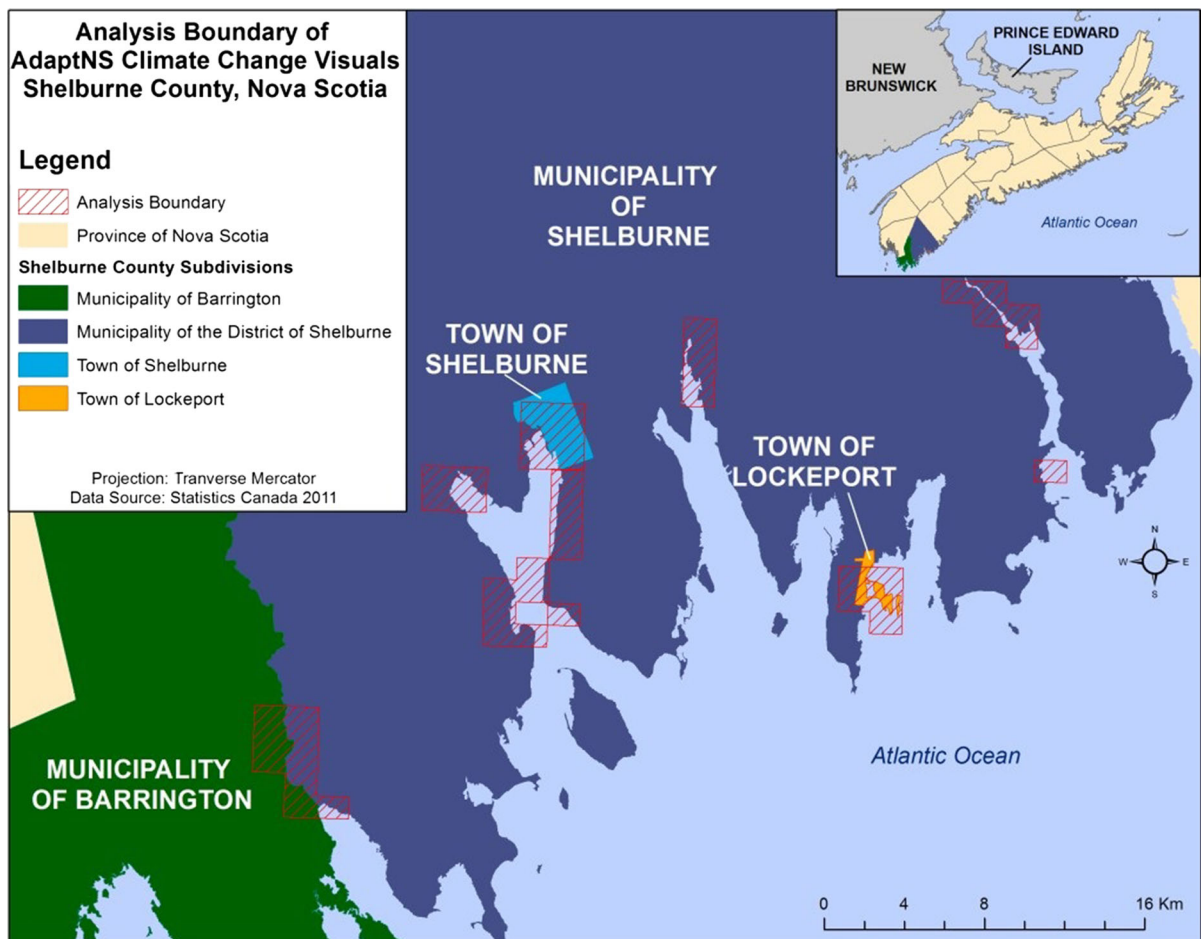
geographic representation of areas that are vulnerable to sea level rise and storm surge impacts (Nicholls et al. 2011; Fisher 2011). Using the LiDAR data and existing projections of local measures of sea level rise and storm surge changes provided by the Province of Nova Scotia, 28 scenarios were created for each of the 9 communities (Figs. 1, 2).

By applying similar methods as those presented by Webster et al. (2011), high-resolution sea level rise and various storm surge scenarios were generated for the years 2000, 2025, 2055, 2085 and 2100. These scenarios used the most up-to-date local estimates of present and future sea level rise and storm surge water levels (Richards and Daigle 2011). This approach was taken to provide municipalities with information that could be used in short-term and long-term adaptation decision making, as well as to communicate and raise awareness to all citizens of local climate change impacts. The output scenarios were made available via AdaptNS for public and municipal use (Fig. 2a). In terms of user interactivity, AdaptNS was built on a Google Maps environment to enable zooming and panning functionalities for browsing the scenarios in many levels of detail.

The coastal flood scenarios were paired with road and public building information (Fig. 2b). By including at-risk roads, the impacts of severe storms, such as the inaccessibility to specific homes and neighborhoods, can be visualized. Public buildings, such as heritage sites, community centers and emergency-response locations, were also included to serve as reference points for Shelburne County residents when engaging with the tool and understanding the implications of climate change impacts in their communities. AdaptNS was designed to be usable in both personal computers and tablets to promote information accessibility and knowledge mobilization.

### Participation features

Public engagement in climate change discussions and raising awareness of climate change risks are consistently emphasized as necessary steps to politically incentivize government response, increasing the public's adaptive capacity, and reducing the probability of maladaptive strategies that are not representative of local needs, interests and culture (Smit and Wandel 2006; Butler et al. 2015). As a result, AdaptNS was designed to collect and aggregate the views of public,



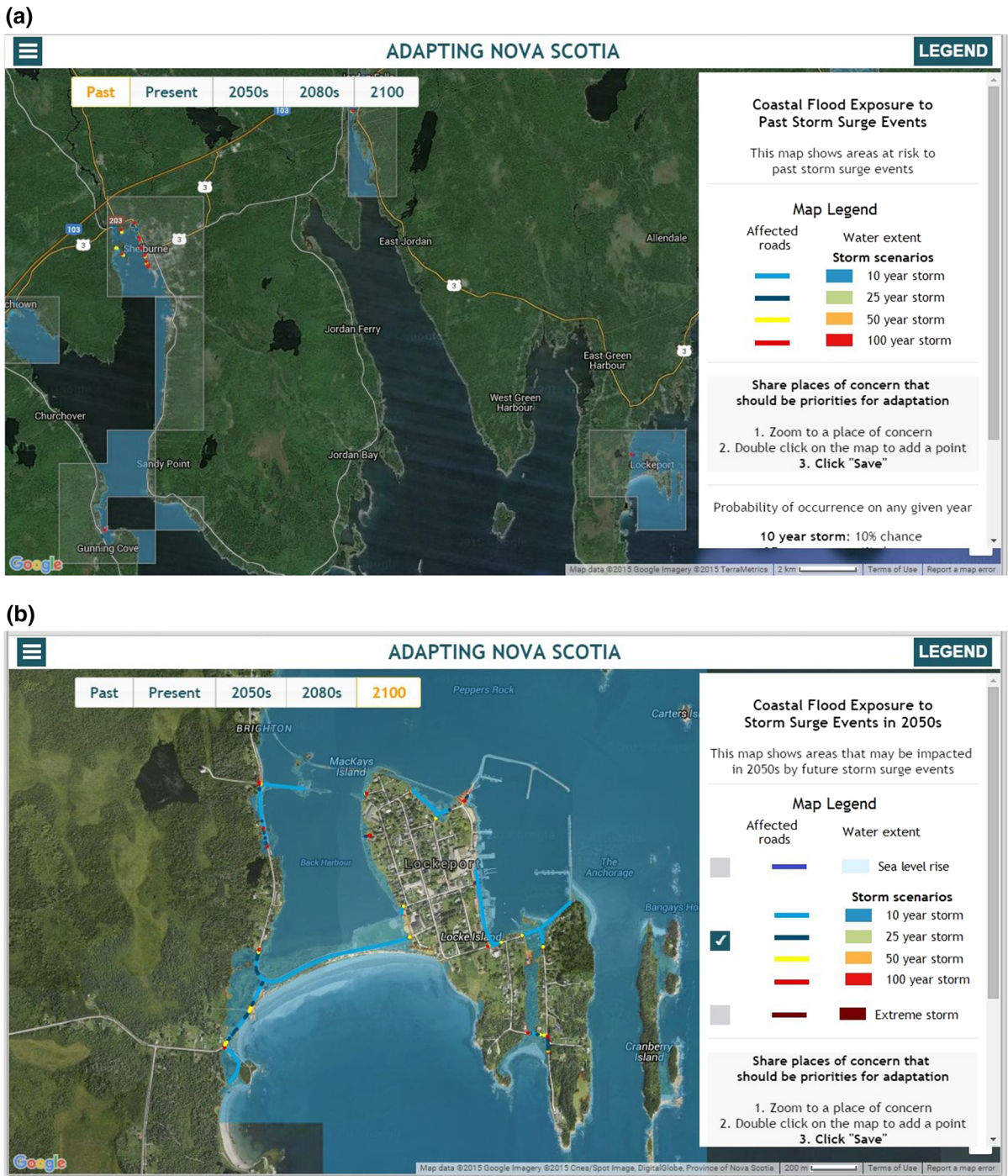
**Fig. 1** Case study analysis boundary

municipal governments and stakeholders in relation to climate change by enabling wide information accessibility and by offering online participation capabilities (Fig. 3). AdaptNS enables individual users to browse scenarios online, and share specific locations that concern them in relation to the coastal flood exposure visuals. This participatory feature aims to provide the individual user with the opportunity to publicly and anonymously share places that, in their opinion, are of concern and should be protected against climate change risks. The overall goal of the “concern-mapping” exercise is to aggregate the perspectives of multiple individuals to identify specific areas that are recognized as valuable community assets by a collection of residents. Through this approach, the integration of user-generated content and coastal flood visuals define geographic zones that are both high risk and have high community value;

therefore, serving as an outline of priorities that municipalities can focus on in the short-term and long-term adaptation process. The participatory feature of AdaptNS allows users to share a location of concern on the map, rank their level of concern (low to critical), share the community value associated to that location and provide a reason for their concern.

#### Community workshop

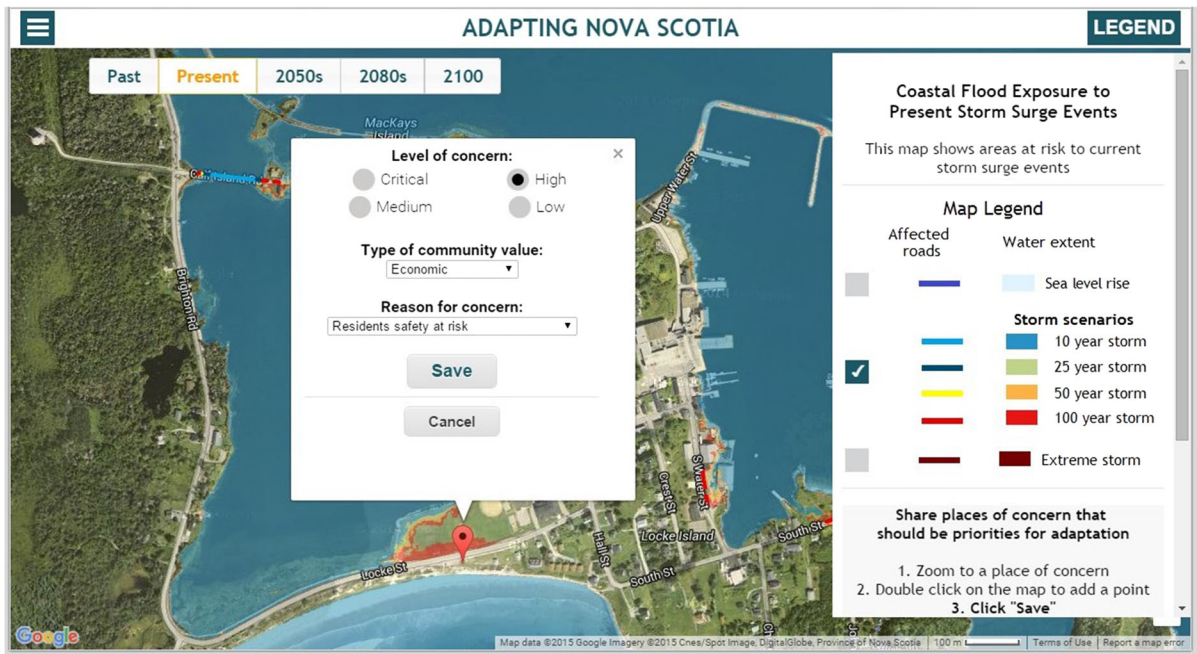
AdaptNS was subjected to evaluation during an in-person workshop with residents of the Town of Lockeport—a coastal town located on a particularly vulnerable island in Shelburne County (see Fig. 2b; Statistics Canada 2011). Lockeport residents were chosen to evaluate the Geoweb tool since the town has historically been affected by extreme weather events and residents have recently experienced higher-



**Fig. 2** AdaptNS visualization capabilities. **a** Boundary of climate change visuals as seen on AdaptNS. **b** Coastal flood exposure in Town of Lockeport by 2100

intensity storms (Atwood 2013). Researchers encouraged any resident of the town to attend the workshop, including municipal employees, stakeholders and

citizens at large. In total, 11 adult residents of the town attended the 2-h workshop. This workshop group consisted of elected officials, business owners,



**Fig. 3** Concern-mapping features as seen on AdaptNS

teachers, and retirees. Given the nature of recruitment for this workshop, this sample should not be considered representative, as it notably excluded the key stakeholder group of fisheries workers (Majeed 2015).

Workshop participants interacted with AdaptNS in three general phases: introduction to the study and tool; using the tool on a tablet, computer, or projected screen; and feedback to researchers. First, participants were given an overview of key terminology definitions (e.g. adaptation), a description of current municipal climate change initiatives and an overview of geovisualization tools. This was followed by an overview of the capabilities of AdaptNS, including its context, available scenarios and concern-mapping capabilities. Participants were then asked to browse the coastal flood scenarios and contribute their concerns by using AdaptNS. Though participants had been discussing with each other while engaging with the tool, time was allocated for a formal group feedback discussion which was then followed by a written feedback form completed by individual participants. This feedback form focused on how AdaptNS could be used to support climate change understanding, its utility for adaptation planning, and the overall user experience of the tool. Participants were asked to use a ranking system for each question between 1 and 5 where 5

generally represented positive feedback. Given the low number of participants in the workshop, this quantitative data proved less useful compared to the extensive written comments. The following results and discussion section focuses on these qualitative comments and the participant’s evaluation of AdaptNS as both a piece of software and as tool to support understanding climate change and adaptation planning.

### Results and discussion

The workshop participants provided insight on how AdaptNS can support local climate change adaptation. AdaptNS was found to assist in risk identification, prompting adaptation discussions and as a platform for sharing climate change-related knowledge. Workshop participants also provided feedback on the tool’s current limitations and drawbacks.

#### Identification of climate change-induced risk

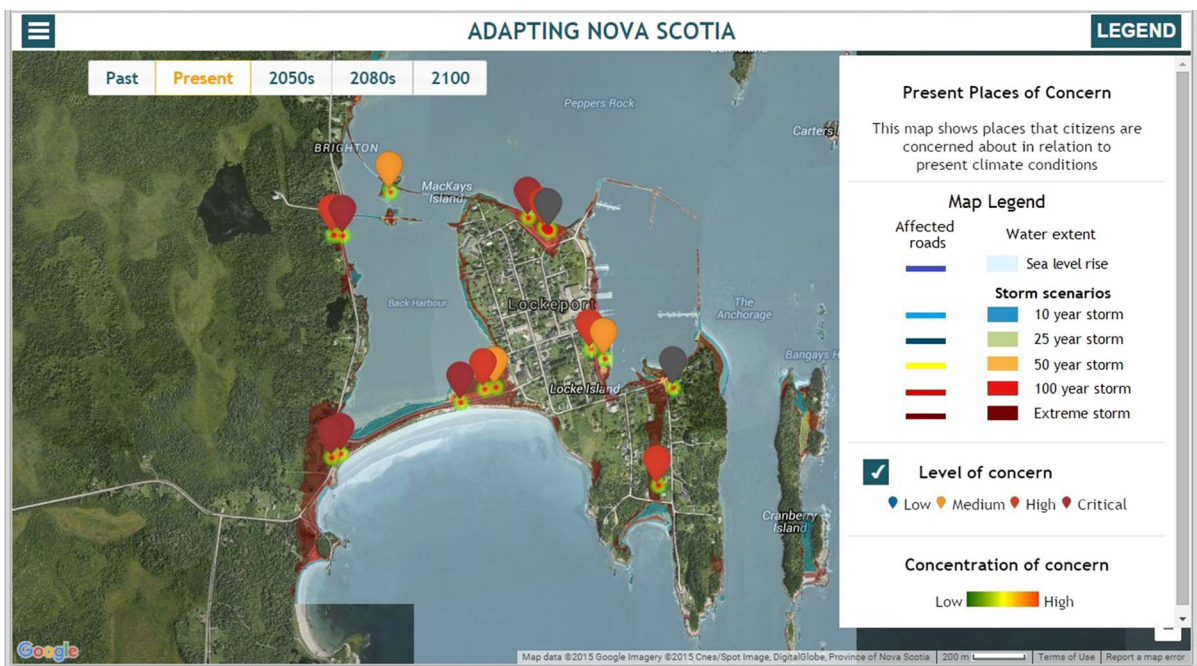
Throughout the workshop, participants interacted with AdaptNS and contributed a total of 23 locations that concerned them due to their exposure to past, present

and future coastal floods. Most of the locations that concerned participants were in regards to estimates of present (however new) flood exposures that, in some cases, have affected the town for the first time as early as 2013. Participants also identified locations that concerned them in relation to the 2080s and 2100 scenarios (Fig. 4).

Two main hot spots of concern were identified by Lockeport residents using AdaptNS: the complete obstruction of the town's causeway during a severe storm, as well as complete loss of power due to flooding of the only electrical substation located on the north end of the island. In the event of a severe storm, partial or complete loss of causeway access can critically impact the safety of all Lockeport residents. The island community has a single road access that is surrounded by sand dunes to protect it from waves; however, a mixture of wind, high tides and waves can lead to severe damages to the causeway resulting in the complete inaccessibility from the town to the mainland. This particular scenario can prevent emergency vehicles (e.g. ambulances, helicopters) from accessing the town. Post-storm obstruction of the causeway can also lead to health implications for residents who rely on daily deliveries of their prescription medication

(Atwood 2013). Similarly, flood exposure to the town's electrical substation was also highlighted as a critical concern to residents since it is the town's only power source. Having exposure to storms during the summer and winter months, losing power indefinitely can lead to significant public safety issues due to a lack of heating and cooling systems, particularly since many Lockeport residents are seniors (Government of Nova Scotia 2014). Though these two potential cases have been previously mentioned in a municipal report (Atwood 2013), participants reported that by using AdaptNS they became "more aware of vulnerable areas" in their town, the "sheer instability of it all", and that "did not anticipate how quickly a major problem [could] develop". AdaptNS was found to support the understanding that current low-probability flood events are likely to become more frequent overtime and that there is a present and urgent need for improving emergency preparedness to extreme storm events.

For long-term problem areas and issues, AdaptNS was successful at raising awareness to residents of changes to coastal flood exposure and supported the identification of future challenges. In relation to the 2080s and 2100 scenarios, residents expressed concern



**Fig. 4** Places of concern identified by workshop participants. Concern hot spots are highlighted within white boxes



about the inaccessibility to eastern part of town during a storm, the increased exposure of utility lines and water and sewer systems that are currently built to cross from the mainland, and salt water intrusion to groundwater reservoirs. During the workshop, one participant came to the realization that “Lockeport is not going to be underwater in 100 years. We have to prepare for future generations, their economics and safety”. While another mentioned that the “visual tool is [very] powerful and showed areas of vulnerability that I did not think of before”. All workshop participants stated that AdaptNS “enhanced my learning greatly” when asked to rank the tool’s ability to educate on local climate change impacts and adaptation. This was found to be one of the key strengths of AdaptNS since the tool provided residents with scientific information that complemented existing local knowledge, theories and opinions of climate change vulnerabilities. Participants did not find AdaptNS difficult to use, rather they saw its capacity to visually explain complex issues through the integration of scientifically-based scenarios and recognizable local landscapes.

#### Support in adaptation and knowledge sharing

In addition to supporting the identification of problem areas, AdaptNS also inspired a series of adaptation discussions among participants. These discussions revolved around methods to address coastal flood risks now and in the future and the need for public education and engagement. Participants also provided insight on how AdaptNS can support future adaptation efforts.

Participants in particular focused on strategies to ensure accessibility on and off the island during severe weather events to minimize public safety risks. Participants expressed that the tool was “extraordinarily valuable” for visualizing risk and “that there are immediate things to be done/put in place...such as a second access off the island should be planned now” to offset that risk. Having a second access route off the island was discussed as one viable option during the workshop; while municipal reports have stated that elevating the causeway could be another option (Atwood 2013). Yet, these adaptation discussions also prompted residents to recognize the town’s lack of capacity to address the accessibility issues of the causeway, such as a lack of financial resources and governance limitations, both of which are commonly

cited barriers to local-level adaptation (Amundsen et al. 2010; Measham et al. 2011). Workshop participants indicated that the town can use AdaptNS to engage with external entities for realizing adaptation projects since the tool can be “great...when trying to access funding for projects from [upper levels of] governments” and that it can promote “planning for individuals at all levels of government/business”. Participants determined the role of AdaptNS in communicating local risks to upper levels of government and businesses that can both provide resources, expertise and governance support that are needed to establish tangible adaptation action.

As a means to ease the adaptation process, participants saw AdaptNS as an engagement tool for facilitating public education of local climate change vulnerabilities. Climate change adaptation literature emphasizes the need for engaging community members in the adaptation process to encourage adaptive behavior by the individual and communities at-large, and for lessening the possibility of maladaptation through transparent and inclusive discussions with diverse residents (Hill 2012). This finding in the literature was echoed by several workshop participants who suggested that AdaptNS can “educate [the] general population of Lockeport and area for the need for adaptation and change” since “many people can access [the tool] and have [the] opportunity to respond”. For example, one participant indicated that AdaptNS can be used for “preparing for evacuation that people may not have understood before”. Workshop participants stated that AdaptNS can help residents of the town and the region at-large to become informed of their own climate change vulnerabilities and in “understanding the [climate change] issue and the need for planning”. Due to its online nature, all participants recognized the advantages of a Geoweb tool over paper maps for widely disseminating information to residents across the region who did not attend the workshop. Based on workshop results, AdaptNS has potential to educate residents of Shelburne County about climate change and increase their willingness to accept necessary changes that aim to minimize climate change vulnerabilities.

During the workshop, participants expressed a positive outlook towards greater use of AdaptNS in future adaptation efforts. Specifically, Lockeport residents suggested the use of AdaptNS in “future

workshops and planning activities” to promote ongoing discussions about climate change vulnerabilities and adaptation. Participants’ approval of the tool was high, as 90% of participants found the tool “very easy to use” and expressed their interest in accessing the tool in the future. Some of the beneficial aspects of the inclusion of Geoweb tools in climate change initiatives are its capabilities to provide readily available climate change information that can be used in a variety of settings (e.g. individual access online, workshops). In addition to its acceptance in future adaptation efforts, participants also demonstrated an interest in improving AdaptNS with new information sources and technical capabilities. Participants were mostly interested in including more commenting capabilities to the tool and enhancing present scenario modelling efforts with “wind direction/type of storm e.g. nor’easter” and “wave action damage”.

#### Present Geoweb limitations

In addition to the beneficial aspects of using Geoweb tools in climate change-related initiatives, this research also identified several limitations to this methodology: audience access limitations, issues with representing uncertainty, challenges for long-term maintenance and the potential to steer adaptation discussions to prioritize physical protection of infrastructure.

#### Audience access limitations

When providing feedback on AdaptNS, participants warned that some members of the community did not have Internet access or are not particularly comfortable using computer technology. At the provincial level, Internet infrastructure is available to 99% of Nova Scotians (MacDonald 2014); however, members of the general public may not purchase this service in their homes or access information using web technologies. Oftentimes it is citizens who may not use the Internet (e.g. those with financial limitations) that could be disproportionately more vulnerable to climate change than others, and who would benefit from learning about climate change impacts and strategies to minimize their vulnerability (Adger et al. 2004; Forsyth 2013). Based on participant feedback at this time, Geoweb tools are argued to be supportive

informational resources that can be used in conjunction with other communication platforms, such as community meetings and traditional media for raising climate change awareness.

#### Representing uncertainty

Both maps and Geoweb tools have limitations in how to represent uncertainty. For example, changes in sea level are represented with numerical values that have a margin of error (e.g.  $3 \pm 0.5$  m; Richards and Daigle 2011). This margin of error is often challenging to display on an online map; as a result, Geoweb tools display future sea level rise with a distinct boundary dividing vulnerable areas and non-vulnerable areas (Tingle 2006; CalAdapt 2015). These types of maps can provide a false sense of certainty to viewers if they are not aware of how these maps are created, including assumptions when modelling future scenarios (Shepard and Cizek 2009). This problem is further emphasized in Geoweb tools since users who are exposed to these maps are not all experts in climate change science or have understanding of the assumptions used in climate change modelling. To provide a clear climate change narrative, AdaptNS can be tailored to mimic recent efforts in mapping climate change futures to show dual scenario visualization (e.g. high vs. low. emission scenarios during the same time frame; Climate Central 2015).

#### Challenges for long-term maintenance

As seen in this research, rural communities can have limited funds, technology and expertise that restrict them from generating their own climate change scenarios or visualization tools. Geoweb tools, such as AdaptNS, require maintenance whether it is in updating the visuals to represent the latest climate change projections, purchasing web server space to host the tool online or monitoring online contributions from users. There is also the need for the tool to be marketed, in some capacity, to promote its use by vulnerable municipalities and citizens. Based on this research, it is suggested that a provincial or state government work with small rural communities, supplying them with relevant information, such as sea level rise estimates, that can then be used to assist local adaptation initiatives.

## Potential to steer adaptation discussions toward protection

AdaptNS is primarily focused on physical impacts associated with sea level rise. While providing locally-scaled impact information is key to overcoming the common barrier of lack of relevant information at this level, it also has the potential for stakeholders to focus primarily on their own properties. This in turn can contribute to an emphasis on physical protection, particularly so as the visualization tool does not include a mechanism for identifying tradeoffs in the allocation of scarce financial resources. The use of AdaptNS on its own does not guarantee that potential adaptations are not maladaptive, as it provides no mechanism for balancing opportunity costs or preventing path dependency (both of which are considered maladaptive by Barnett and O'Neill 2010). Consequently, the bottom-up data collection capacities of AdaptNS on their own serve as an input to multi-level adaptation planning, but do not on their own ensure effective adaptation.

## Conclusions

Climate change challenges societies in complex and uncertain ways. Geovisualization tools, including the Geoweb, are successful means for communicating the complexities of climate change to audiences in ways that are understandable and that trigger discussion. This alone is a benefit of these tools, but this study also showed that Geoweb tools can complement existing geovisualization and adaptation efforts. Geoweb tools provide communities with participatory features for sharing their concerns in relation to best-available climate change information. By integrating climate science and social perspectives, Geoweb tools help enrich adaptation discussions with climate science and support communities in determining adaptation needs and priorities. This promotes a positive exchange of information that can benefit communities with low resources to improve their understanding of climate change and support them in sharing their concerns with external entities that could provide resources to establish local adaptation projects.

Though Geoweb tools were shown to support adaptation efforts in this case study, it is necessary to address that the results presented here were gathered

in a monitored workshop environment. Researchers were present at the workshop to provide context on the tool and engage with participants. Thus, there continue to be questions about the types of participation and quality of contributions when Geoweb tools are released online for public use. For example, users may provide poor quality information upon its online release or governments may be hesitant of using anonymously-contributed concerns that may have emerged from users outside of a government's legislative boundary. This poses the question of how to best provide this service, whether it is in asking users for explicit permission to share their location prior to using the Geoweb tool or only allowing participants to share their comments and concerns during workshops. Similarly, understanding "who" should provide this service is also important as they would need to encourage the long-term use of Geoweb tools, as well as for referencing online participation exercises in adaptation planning and decision-making processes (Sieber et al. 2016). Though these are all small technicalities in the face of climate risk, they provide a basis for improving tools that have, at this point, been shown to be beneficial for fostering knowledge and local opinions that support climate change adaptation.

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## Compliance with ethical standards

**Conflict of interest** Funding for this research has been provided by the Social Sciences and Humanities Research Council of Canada (SSHRC). This research involved human participants, and research was conducted according to the rules and regulations governing research with human subjects at the home institution of the research team. Ethical clearance was obtained for this research, which included an assessment of informed consent, participant recruitment, study protocols, and data storage and confidentiality. Evidence of this ethical review can be provided upon request.

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