COASTAL FLOODING ISSUES

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COASTAL FLOODING ISSUES

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ACASA is a non-profit organization formed to coordinate project management and planning for climate-change adaptation initiatives in Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador. ACASA is supported through the Regional Adaptation Collaborative, a joint undertaking between the Atlantic provinces, Natural Resources Canada, and regional municipalities and other partners.

SACCA est un organisme à but non lucratif formé pour coordonner la gestion de projet et la planification des initiatives d'adaptation au changement climatique en Nouvelle-Écosse, du Nouveau-Brunswick, Île du Prince Édouard et Terre-Neuve et soutenu par la collaboration pour l'adaptation régionale, une entreprise commune entre les provinces de l'Atlantique, Ressources naturelles Canada et municipalités régionales et d'autres partenaires.

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COASTAL FLOODING ISSUES

A paper by R.J. Daigle Enviro

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INTRODUCTION AND BACKGROUND

Overview

The coasts of Atlantic Canada have been shown to have significant sensitivity to sea-level rise and associated storm impacts. Areas with the highest sensitivity include most of the Gulf of St. Lawrence coast of New Brunswick, the north shore of Prince Edward Island, the south coast of Nova Scotia, and the southwest coast and Burin Peninsula regions of Newfoundland and Labrador (see Figure 1 for details). Accelerated sea-level rise under greenhouse warming is expected to aggravate these impacts, increasing the need for adaptation in order to minimize damage and costs. Threats in these areas come primarily from enhanced coastal flooding and erosion. To complicate matters, there has been a modern societal trend to build homes and cottages (usually very expensive), often within tens of metres of coastlines, directly in harm's way of an ever-increasing frequency of damaging storms.

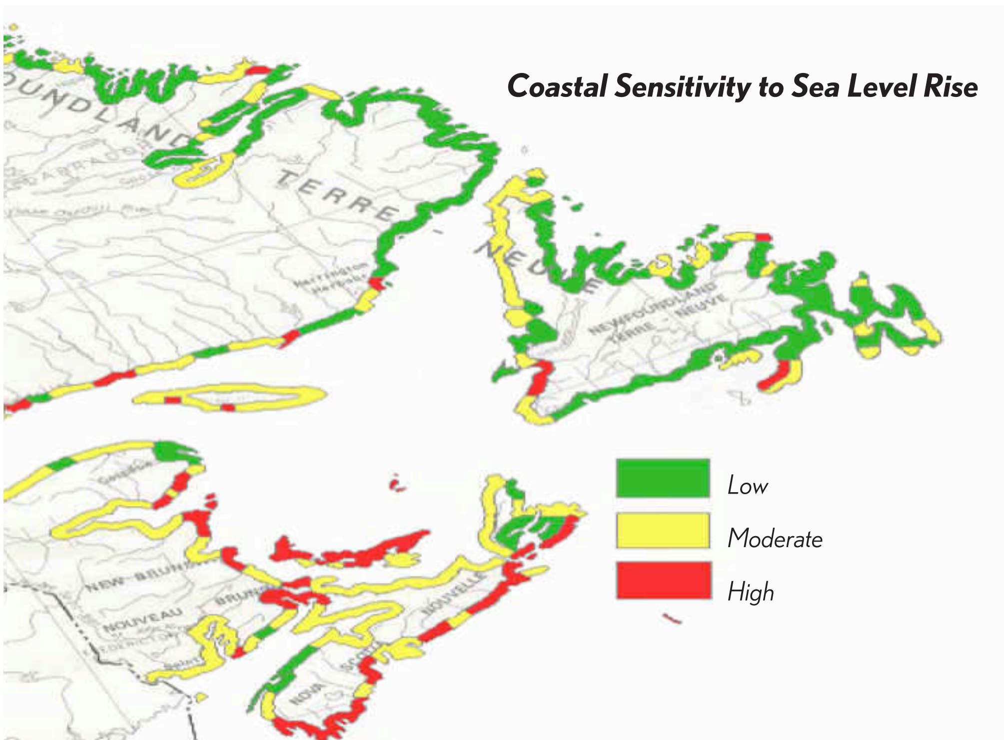

Figure 1.
Coastal sensitivity to sea-level rise, Atlantic Canada. (Map source: John Shaw, Natural Resources Canada)

Coastal flooding normally occurs between late fall and early spring, when fierce storms occur during periods of high tides. At times, the flooding impacts can be catastrophic, as was the case at the height of the record storm surge event of January 21, 2000, and then again ten years later, with the December 21, 2010, storm. Impacts from such storms range from the destruction of natural habitats such as protective sand dunes; of built-up coastal infrastructure such as roadways, fishing wharves, and erosion-protection structures; and in some cases homes and cottages. The objective of this paper is to provide some background information as guidance to help decision makers develop effective and appropriate strategies and actions to address coastal flooding issues. In particular, coastal flooding problems will be considered through the lens of climate change, climate variability, sea-level rise, and storm-surge flooding.

What is a Storm Surge?

At the coast, a storm surge can be defined as the difference between the observed water level and the predicted astronomical tide. Tides result from the rise and fall of sea levels caused by the combined effects of the rotation of the Earth and the gravitational forces exerted by the moon and the sun. In reality, observed tide levels are rarely as predicted because predicted levels are based on standard atmospheric pressure conditions (mean sea-level pressure 101.33 kilopascals, or 1013.3 millibars). Observed tides are higher than predicted at an atmospheric pressure lower than standard and lower than predicted at higher-than-standard atmospheric pressure. Additionally, onshore and offshore winds will respectively increase and diminish the tide level near the coast.

Storm surges can be positive or negative and may therefore raise or lower sea level from its predicted value. Storm surges occur everywhere along our coastlines and can occur anywhere in the tidal cycle, or they may last over several tidal cycles. Large positive storm surges at times of high tide lead to coastal flooding; when they coincide with low tides, flooding problems are averted. Elevated sea levels also enhance wave attack and coastal erosion, and in the presence of sea ice, ice pressure can lead to ice ride-up and pile-up.

The magnitude of a storm surge depends on the nature of the meteorological event responsible for the reduced atmospheric pressure and the strength of the winds associated with a particular event. Atlantic Canada has seen extreme cases of coastal flooding, and the frequency of these events seems to have been increasing over the past ten years. The most common devastating storms are the synoptic-scale (meaning a horizontal scale of the order of 1000 km) events that typically intensify or re-form off the US east coast. The centres of these storms typically cross Nova Scotia and track through the Gulf of Saint Lawrence. The storm of January 21, 2000 (see Figure 2 left), produced a 2.0 m storm surge along the Northumberland Strait coast of New Brunswick caused by a combination of extremely low atmospheric pressure (comparable to a hurricane) and strong onshore winds. On October 29 (Figure 2 right) of the same year, the centre of a storm remained stationary near Cape Breton for approximately 36 hours, resulting in a flooding event and extreme coastal erosion over exposed coastlines throughout the Gulf of St. Lawrence. These two examples represent the types of storms that are responsible for the majority of significant coastal flooding events in the region. When storms remain nearly stationary or become slow moving as is the case in Figure 2 (right), prevailing winds concentrate wave energy inside exposed bays for a long enough period (normally more than six hours) that some additional localized flooding will occur. These types of events have been known to occur in Baie Verte and the Bay of Chaleur in New Brunswick and in White Bay, NL.

What is a Storm Surge? cont'd

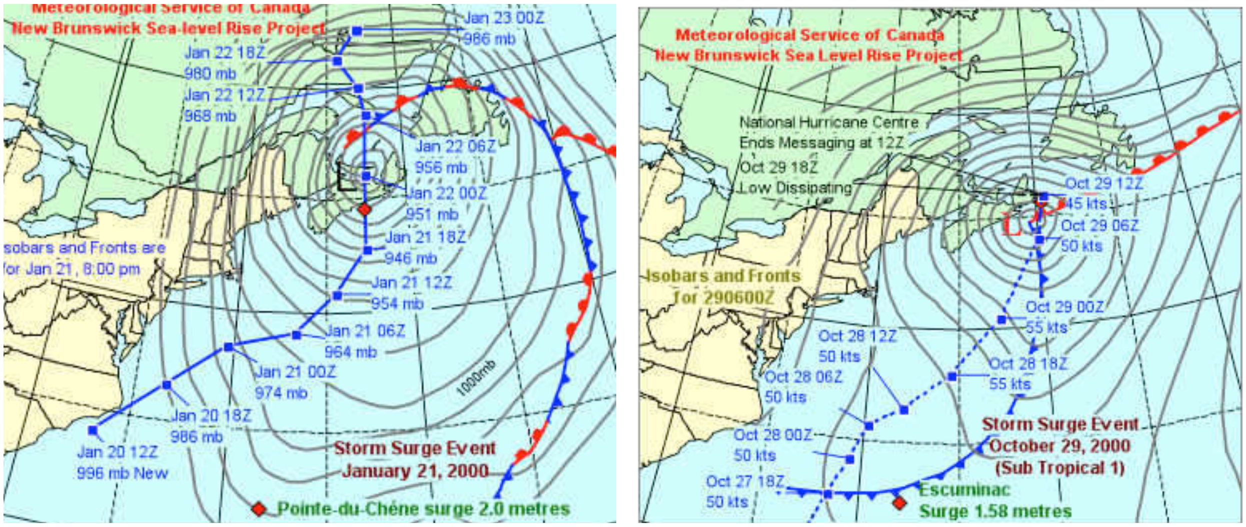

Figure 2. The weather map at left shows a storm system on the evening of January 21, 2000, at 20:00 AST that caused a record storm surge of 2 m in Northumberland Strait. The map at right shows a system on the morning of October 29, 2000, producing a storm surge of the order of 1.6 m along most coasts of the Gulf of St. Lawrence in the onshore flow. (Source: Daigle and Project Research Team 2006)

Another type of extreme flooding is associated with hurricanes, which, compared to synoptic storms, fortunately occur only rarely and in most cases have weakened significantly by the time they reach landfall because of their motion over colder waters surrounding Atlantic Canada. On rare occasions, however, when a hurricane interacts with a frontal system it can re-intensify rather than weaken, thereby causing a significantly higher storm surge than otherwise might be expected.

One notable exception to the normal behaviour of hurricanes was Juan, which hit the coast of Nova Scotia just east of Halifax on September 29, 2003, as one of most powerful and damaging hurricanes ever to affect Canada. Hurricane Juan retained its force because its trajectory over colder water was abnormally short-lived—it moved directly from the south rather than taking the normal hurricane track along the US seaboard.

What is Climate Change?

Climate change is defined as a difference over a period of time with respect to a baseline or reference period; it corresponds to a statistically significant trend of mean climate or its variability, persistent over a long period of time (such as decades or more). Climate change may happen as a result of both natural (internal or external processes of the climate system) and anthropogenic (caused by human activity) causes such as an increase in concentrations of greenhouse gases.

The Earth's climate has changed many times during the planet's history, with events ranging from ice ages, when ice covered significant portions of the Earth, including all of Canada, to long periods of warmth, also referred to as interglacial periods, when ice retreated to the poles or melted entirely.

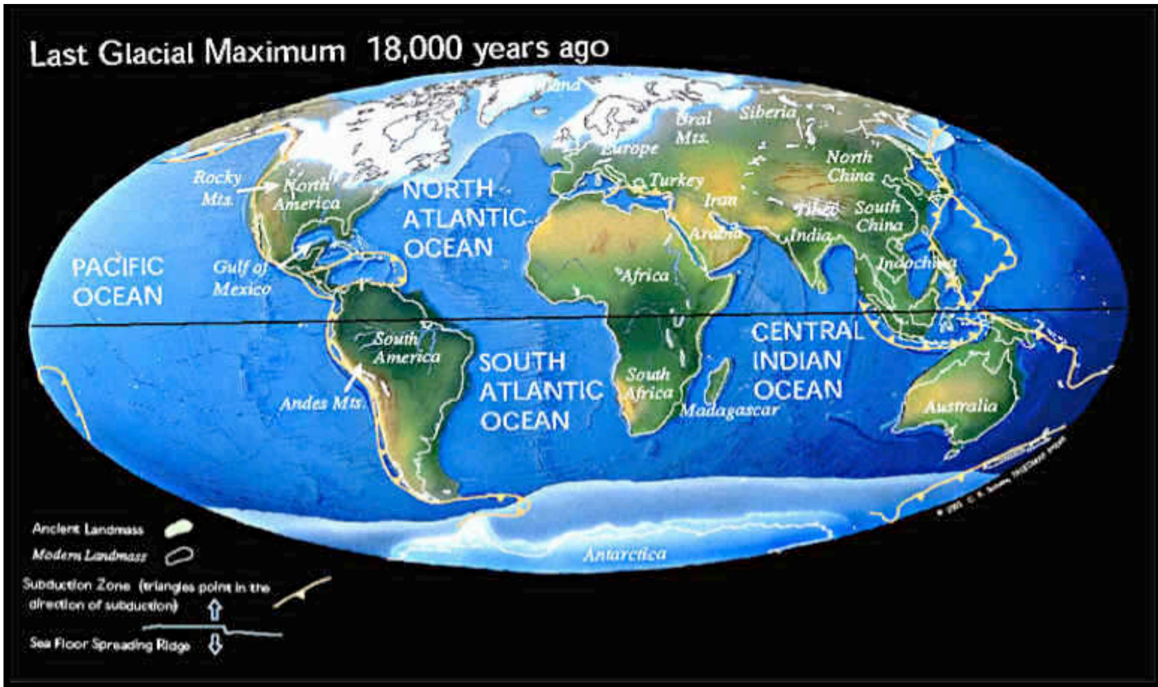

Figure 3. The last Glacial Maximum was 18,000 years ago. Because of a depletion of ocean water–transformed into the extensive continental ice sheets–sea level was then 120 m lower than today. In the northern hemisphere, the remaining Greenland Ice Sheet, if melted entirely, would raise sea levels on a global scale in the order of 7 m. However, because of changes in the gravitational field associated with the changing mass distribution on the Earth, the rise in sea levels would not likely be uniform around the globe. (Source: Scotese 2001)

Figure 3 depicts an estimate of the extent of the ice sheets covering parts of the Earth at the end of the last glaciation maximum, some 18,000 years ago. It is estimated that with the retreat of these ice sheets, global sea levels have risen some 120 metres. Historically, natural factors such as volcanic eruptions, changes in the Earth's orbit, and the amount of energy released from the Sun have affected the Earth's climate. Beginning late in the 18th century, human activity associated with the Industrial Revolution has also changed the composition of the atmosphere and therefore is very likely influencing the Earth's climate.

Climate has changed on all time scales throughout Earth's history. Some aspects of the current climate change are not unusual, but others are. The concentration of carbon dioxide (CO2) in the atmosphere has reached a record high (relative to the past half-million years) and has done so at an exceptionally fast rate. Current global temperatures are warmer than they have ever been during at least the past five centuries, probably even for more than a millennium. If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms. Another unusual aspect of recent climate change is its cause: past climate changes were natural in origin, whereas most of the warming of the past 50 years is attributable to human activities.

What is Climate Variability?

Climate variability is defined as a deviation from the overall trend or from a stationary state. Climate variability can be thought of as a short-term fluctuation superimposed on the long-term climate change or trend. Cycles of high and low values of weather events (drought, floods) are not climate change unless prolonged over many decades. Low-frequency variability refers to phenomena such El Niño or La Niña, which occur in cycles of less than ten years. High-frequency variability refers to significant meteorological events and their annual distribution.

El Niño and La Niña episodes have been shown to have a significant impact on climate variability. Figure 4 depicts global annual land-temperature departures from the 1961–90 average annual means over the period 1850–2010. This graph nicely depicts a warming climate through a series of, at times, pronounced deviations (both positive and negative) and provides a visual representation of the accelerating global warming trend since the mid-1970s, largely attributable to human activity.

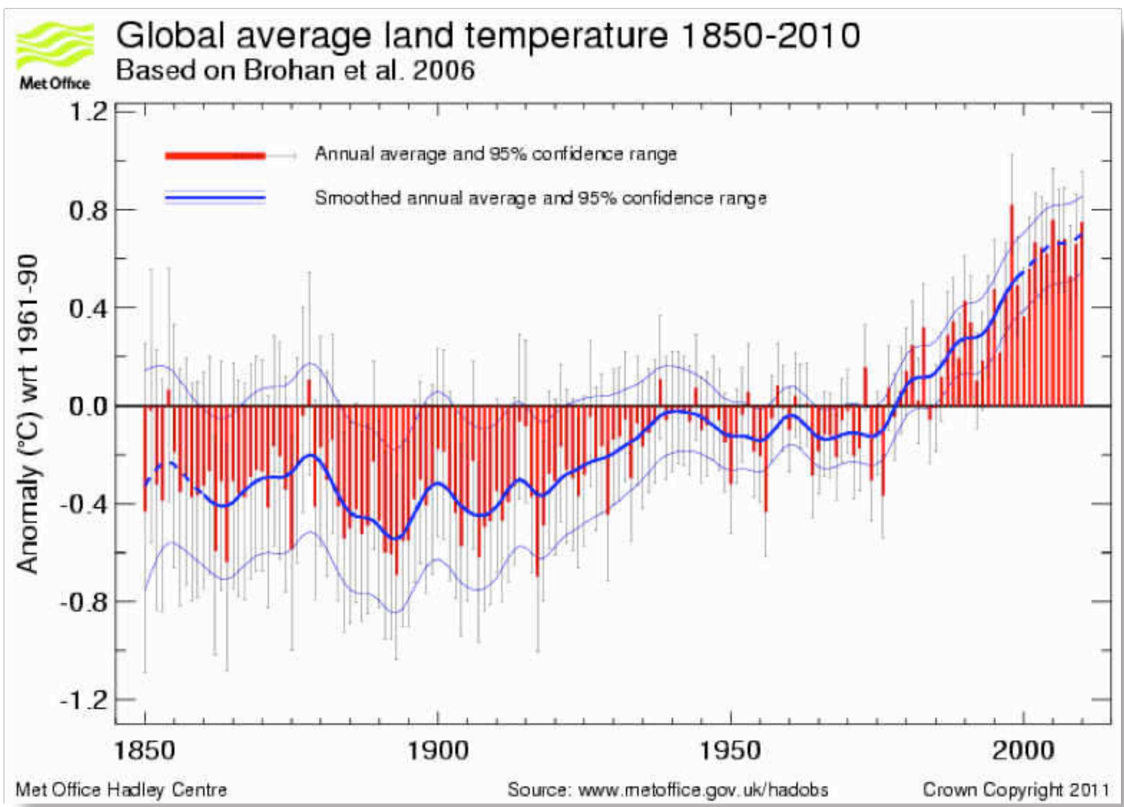

Figure 4. Global annual land temperature departures from the 1961–90 average annual means. Red bars represent the annual global temperature anomaly, and the blue curve represents the smoothed annual average. Pronounced annual maxima (1998) and minima (2000) demonstrate climate variability and have been correlated with, respectively, El Niño and La Niña episodes. (Graph source: Met Office, Hadley Centre for Climate Change)

What is Climate Variability? *cont'd*

According to the US National Oceanic and Atmospheric Administration, the combined global land and ocean surface temperature for 2010 (strong El Niño influence) tied with 2005 as the warmest such period on record, at 0.62°C above the 20th century average of 13.9°C. To date, 1998 is the third-warmest year on record, at 0.60°C above the 20th century average.

The point of this discussion is that one needs to evaluate climate departures from the average in the proper context. By way of example, the average global temperature for the year 2010 has been documented as the warmest on record, with a departure from normal of approximately 4°C. This cannot be categorized as climate change, but as an extreme case of climate variability linked with a strong El Niño cycle. One of the impacts of this event in Atlantic Canada was a contribution to a warming of surrounding ocean waters, including the Gulf of St. Lawrence, resulting in a relatively ice-free gulf during the winters of 2009–10 and 2010–11.
This phenomenon is not expected to occur on a normal basis resulting from climate change until the 2050s. Conversely, the winter of 2010–11 was influenced by a strong La Niña episode that tends to favor the formation of intense "nor'easter" winter storms off the coast of the United States. With the additional energy from a warmer ocean feeding these storms, several of them (notably on December 6 & 21, 2010) resulted in damaging winds and extreme storm-surge episodes over Atlantic Canada. These types of scenarios are expected to become more frequent in the future because of climate change.

What Is the Latest Understanding of Global Sea-Level Rise?

The Intergovernmental Panel on Climate Change (IPCC), a scientific body with participation from more than 130 countries, provides the world with consensus-based policy advice and scientific review of climate-change information in the form of assessment reports, produced every seven years. IPCC is considered to be the authoritative voice for climate-change information at the international level.

The fourth and latest assessment (AR4) by the IPCC, published in 2007, cites updated information on global sea-level rise over the past 50–100 years and provides the latest estimates of potential rise in mean sea level over the coming 100 years. Climate-model projections of global mean sea-level rise (mean for 2090–99 relative to 1980–99) for a suite of scenarios range from 0.18–0.26 m for the B1 scenario (lowest greenhouse gas emissions) to 0.28–0.59 m (central value of 0.43 m) for A1FI ("business as usual").

At the low end, this is equivalent to (or possibly less than) the current rate of rise. At the high end, it is less than that projected in the 2001 IPCC Third Assessment Report (range up to 0.88 m) but still represents more than three times the rise observed during the 20th century. Furthermore, these estimates exclude the effects of any future acceleration in the flow rates of glaciers draining the Greenland and Antarctic ice sheets.

There has been much discussion by the scientific community since the release of AR4 about the effects of potential acceleration in the flow rates of glaciers, particularly those of the Greenland Ice Sheet, which if entirely melted would result in a global sea-level rise of the order of 7 m. However, because of changes in the gravitational field associated with the changing mass distribution on the Earth, rise in sea levels would not be uniform around the globe.

Figure 5.
This image shows the iceberg calving fronts of a glacier into the Greenland Sea, on the central east coast of Greenland. This is but one example of the countless number of calving zones along the entire perimeter of Greenland.
(Map source: Google Earth)

This heightened concern for the additional contribution of meltwater from Greenland relates to the fact that Arctic air temperatures have risen at almost twice the rate of the global average rise over the past few decades. This has resulted in a more rapid loss of ice than projected by computer models from the Greenland Ice Sheet. The faster flow of glaciers to the sea appears to be responsible for much of the increase in mass loss. Figure 5, extracted from Google Earth, shows the iceberg calving fronts of a glacier on the central east coast of Greenland, an excellent visual example of how icebergs are shed to the ocean.

The contribution of the Antarctic Ice Sheet to global sea-level rise, previously estimated to be negligible, has also been the topic of new research, and there is now widespread concern that the West Antarctic Ice Sheet (WAIS) may collapse entirely as a result of climate change. The contribution to global sea-level rise from a total collapse of WAIS would be approximately five metres, but as in the case of the Greenland Ice Sheet, changes in the gravitational field associated with the changing mass distribution on the earth (referred to as sea-level fingerprinting) would result in sea-level rise not being uniform around the globe. The rise would, in fact, be more pronounced over the northern hemisphere. Conversely, contributions to sea-level rise from the Greenland Ice Sheet would be more pronounced over the southern hemisphere. The net balance from these changes in gravitational fields will depend on the melting rates of the respective glaciers, and noticeable impacts would not likely be evident within the next century.

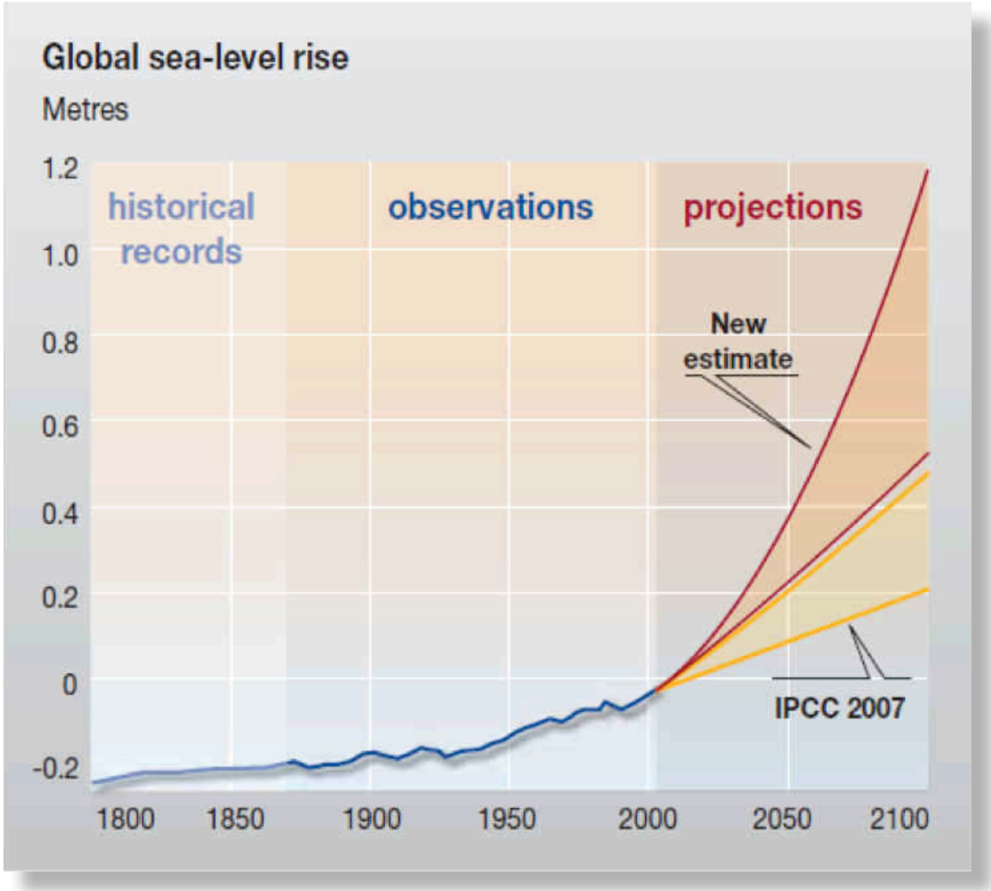

Figure 6.
Future sea-level rise based on the simple relationship between rate of sea-level rise and global average temperature.
(Source: Arctic Climate Feedbacks 2009)

A reputed sea-level rise expert and contributor to the IPCC process, Professor Stefan Rahmstorf (Potsdam University, Germany) has developed a simple correlation between historical globally averaged mean surface air temperature and global sea-level rise trends; applying this correlation to predicted climate change warming over the next century yields new estimates of sea-level rise in the range of approximately 60–120 cm. This approach has been endorsed by other leading experts in the field and was adopted in an August 2009 report by the World Wildlife Fund. Figure 6, reproduced from this report, depicts historical sea-level rise trends and the new global sea-level rise estimates. It is hoped that the next IPCC report (AR5), due in 2014, will bring more clarity to this issue.

What is Regional Crustal Subsidence?

In addition to contributions from thermal expansion of the oceans (from a warming climate), the melting of nonpolar glaciers, and changes in the volume of the Antarctic and Greenland ice sheets, sea levels along most coasts of Atlantic Canada are rising because these coastlines are very slowly sinking (up to a few tenths of metres per century). In response to a depression of the Earth's crust caused by the immense weight of continental ice sheets during the last Ice Age, there is a rebound of the crust (maximum rebound in the Hudson Bay area) and a corresponding subsidence along coastlines (maximum subsidence over Nova Scotia and western Newfoundland). Figure 7 (left) is a schematic drawing of crustal motion during a glacial maximum and after glaciation (the present scenario). Figure 7 (right) shows preliminary results of vertical motion of the Earth's crust in mm/year. These results are in agreement with north-south slopes calculated in *Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick* (Daigle and Project Research Team 2006).

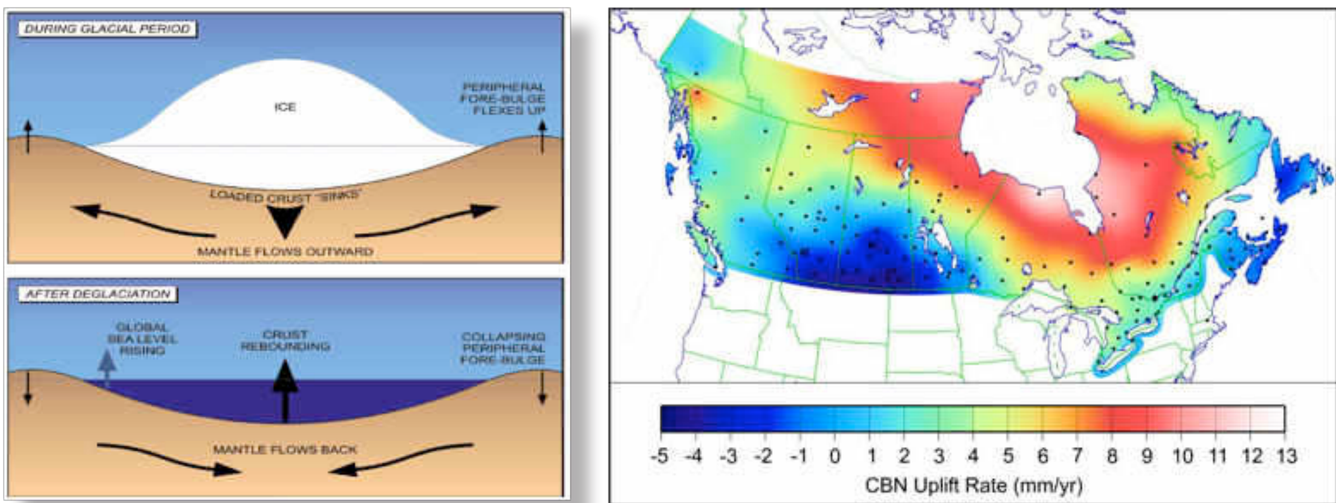

Figure 7. Schematic drawings at left illustrate how the Earth's crust reacts to changes in ice sheet loadings. Map at right depicts preliminary results of vertical motion of the Earth's crust in mm/year obtained from Natural Resources Canada's network of the Canadian Base Network (CBN). The measurements are obtained from a network of approximately 160 high-precision GPS monitors. (Source: Natural Resources Canada)

How Will Climate Change Affect Coastal Flooding?

Climate change is expected to increase ocean temperatures and accelerate the melting of land glaciers and polar ice sheets (Greenland and Antarctica), resulting in elevated global sea levels of nearly one metre by 2100. Regionally, as ocean temperatures increase, it is expected that the winter sea-ice season in the Gulf of St. Lawrence will continue to shorten and that by the period 2040–50, winter ice will become entirely non-existent. Until then, abnormal relatively ice-free seasons (as occurred in 2010 and 2011) will become more frequent because of climate variability.

With less or no ice to help buffer ocean wave action during intense storms, coastal erosion rates will likely increase, resulting in more-extensive ecosystem damage and coastal infrastructure property damage. Sea-level rise will cause more-frequent coastal flooding because in the future, even weaker storm systems will produce flooding impacts similar to the most extreme storms of the past. For example, given a one-metre sea-level rise scenario, which is expected to occur by 2100, the flooding levels reached with the record event of January 21, 2000, (then close to a 1-in-100-year event) could statistically occur every three to five years.

CHALLENGES, BARRIERS, GAPS, AND NEEDS

Overview

The coastlines of Atlantic Canada, because of their proximity to major tropical and synoptic storm tracks, have been exposed to destructive flooding events over the years. When the timing of the most extreme storms coincides with high astronomical tide cycles, the associated impacts can be catastrophic. Subsequent to the benchmark flooding event of January 21, 2000, in the southern Gulf of St. Lawrence, a multi-disciplinary research project was launched to evaluate its impact at Charlottetown—in the contexts of both the year 2000 and future elevated sea levels. That project and a follow-up larger project focusing on coastal areas of southeastern New Brunswick employed an innovative mapping approach using Light Detection and Ranging (LiDAR), which provides a highly effective visual tool to display flooding extents and to conduct socio-economic impact analyses. (Figure 8 illustrates a LiDAR mapping scenario in the Shediac Bay coastal zone).

Figure 8. LiDAR-derived digital elevation maps showing the January 21, 2000, flooding event given a climate-change-induced sea-level rise scenario of one metre on an orthophoto (geometrically corrected aerial photo) background map. The shaded light-blue area represents the flooding extent that would result if the water level reached at the peak of the January 21, 2000, flooding event (left image) were raised by one metre (right image). (Background map orthophoto, taken in 2000, courtesy of Service New Brunswick)

Flooding Events of Interest

January 21, 2000

On January 21, 2000, a fierce winter storm, during a period of high tides, caused extensive flooding of coastal areas in southeastern New Brunswick, along Northumberland Strait, and in Prince Edward Island. In Charlottetown, this storm brought a new record water level of 4.22 m above Chart Datum (CD), resulting from a 1.37 m storm-surge contribution. On January 17, 2004, another winter storm generated an even higher storm-surge component at Charlottetown (1.53 m), but since this storm coincided with low tides, the maximum observed water level was only 3.31 m above CD, and hence flooding and associated damages were averted; a level of 3.6 m above CD is needed to flood the Charlottetown waterfront. In the case of Shediac Bay, this January 2000 storm resulted in both a record storm surge (2.0 m) and a record water level (3.62 m above CD) at the Pointe-du-Chêne tide-gauge location.

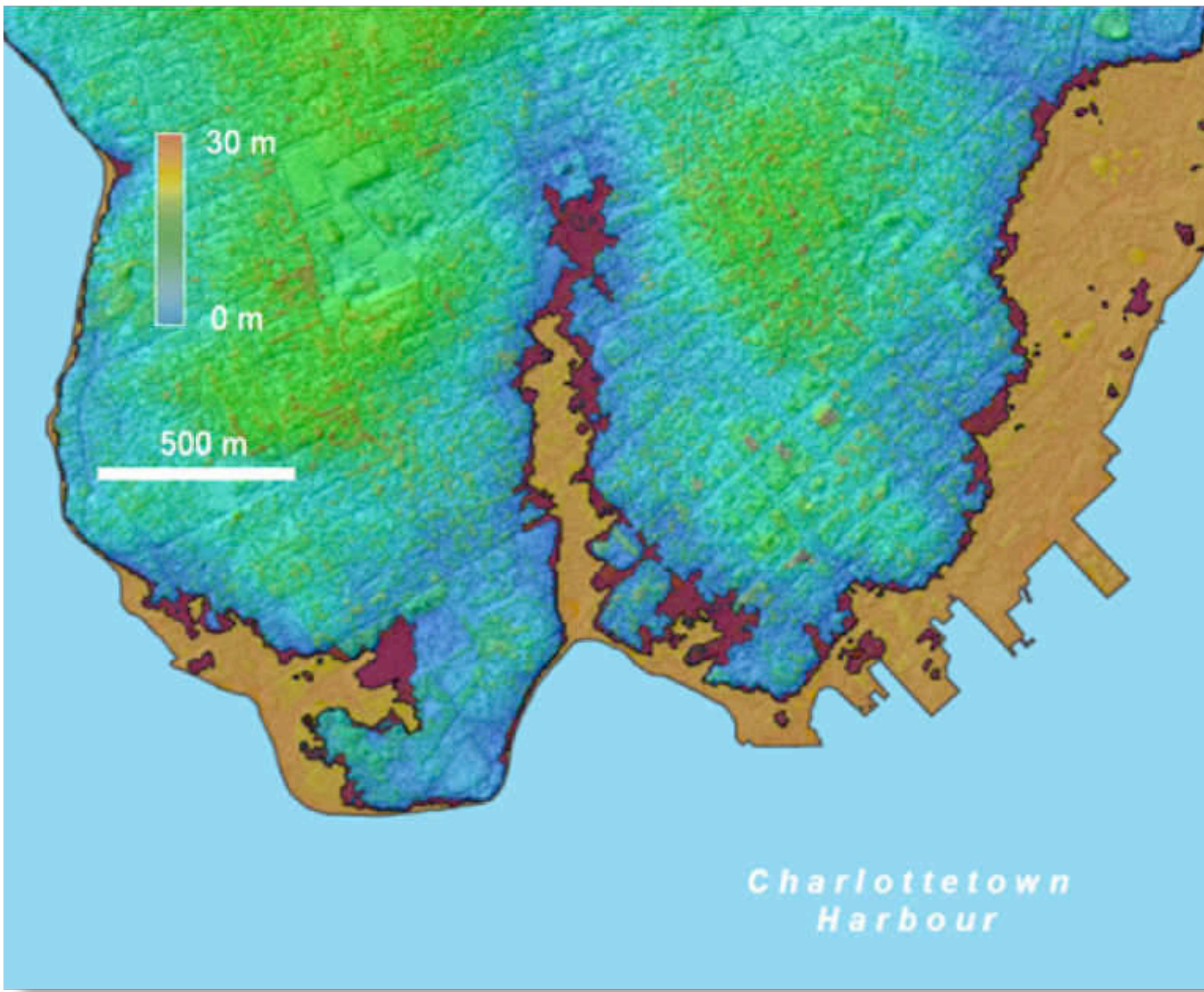

Figure 9. This digital elevation model of Charlottetown shows flooding during the January 2000 storm (brown) and a projection of additional flooding scenario should the same storm occur in 2100 after a 0.7 m sea-level rise (red). Current sea level in light blue shows the usual shoreline and wharves of Charlottetown. (Source: Geological Survey of Canada)

Figure 10. Ice pile-up along the northern shore of Shediac Bay, resulting in the total destruction of the Cap-des-Caissie, NB, fishing wharf. (Photo courtesy of Réal Daigle)

The resulting coastal flooding was particularly severe in eastern New Brunswick and throughout the Northumberland Strait coastlines. The impacts from this storm were felt across the Atlantic region and included wave damage along the Nova Scotia coastlines in the Bay of Fundy and in Cape Breton. The strong winds also brought very large waves and coastal infrastructure damage to the southern coast of Newfoundland. The resulting damage in the Port-aux-Basques area was estimated to be as much as $3 million.

As the storm developed, pack ice in the western Gulf of St. Lawrence was pushed toward the coastlines by the winds. Figure 10 shows an extreme example of infrastructure damage from the combination of elevated water levels, strong onshore winds, and the movement of pack ice onshore.

According to the Atlas of Canada, this storm caused damages totalling $20 million in Atlantic Canada.

September 29, 2003 – Hurricane Juan

Hurricane Juan was a Category 2 hurricane (wind speed range of 154–177 km/h) that made landfall just west of Halifax and tracked across central Nova Scotia and Prince Edward Island, leaving a trail of damage to property, infrastructure, and the environment (cost estimated at $200 million). Juan is believed to be the most widely destructive tropical cyclone to hit Atlantic Canada in over a century, with an estimated loss of 100 million trees in Nova Scotia, 1 million in Halifax alone. The hurricane claimed eight lives: four directly (two inland and two marine) and another four in the aftermath. Power outages in Nova Scotia and Prince Edward Island left over 300,000 people without power for up to two weeks. Nearly all commercial activity ceased in the Halifax area for two to five days, and schools were closed for a week. The landmark public park Point Pleasant Park had 90 per cent of the mature growth destroyed or irreparably damaged. Dozens of marinas around Nova Scotia and PEI were destroyed and dozens of small vessels capsized or sunk. Public reports of a "wall of water" moving into the coast and up Halifax Harbour coincided with the arrival time of the highest surge and waves. The storm surge near and just east of Halifax was estimated at near 2 m, establishing a new record water level at Halifax. Figure 11 provides an example of the force of the storm surge in Halifax Harbour.

Figure 11. Hurricane Juan storm surge washed out train tracks and caused these railcars to slide into Halifax Harbour. (Photo: Roger Percy and Andre Laflamme)

January 16, 2004 – Beaches, Newfoundland & Labrador

The coastlines of White Bay (east of Northern Peninsula), NL, have seen a number of flooding events, particularly on January 16, 2004, and on an earlier occasion, January 5, 1989; both events required evacuations and caused considerable damage to properties and roads. In the more recent event (see Figure 12), news reports stated that waves as high as 10 metres were pounding the coastline and that 40 homes had been evacuated.

The typical meteorological set-up for these flooding events is a winter storm with atmospheric pressures in the 96 to 97 kPa (960 to 970 millibars) range accompanied by strong northeasterly winds converging wave energy inside the bay.

Figure 12. Damages to residential properties and local road in the community of Beaches.
(Photo source: Constable Burridge, Deer Lake RCMP)

January 2-3, 2010

A low-pressure system moved northward toward the Atlantic coast of Nova Scotia during the night of January 2, 2010, and developed into a major winter storm system by the afternoon of that day. The system then started moving westward, crossing the Bay of Fundy overnight, and weakened in the Gulf of Maine on the evening of January 3. The combination of a long period of strong northeast wind gusting in excess of 90 km/h, low atmospheric pressure, and astronomical high tides resulted in storm surges and coastal flooding along several communities of eastern New Brunswick (see Table 1 for summary).

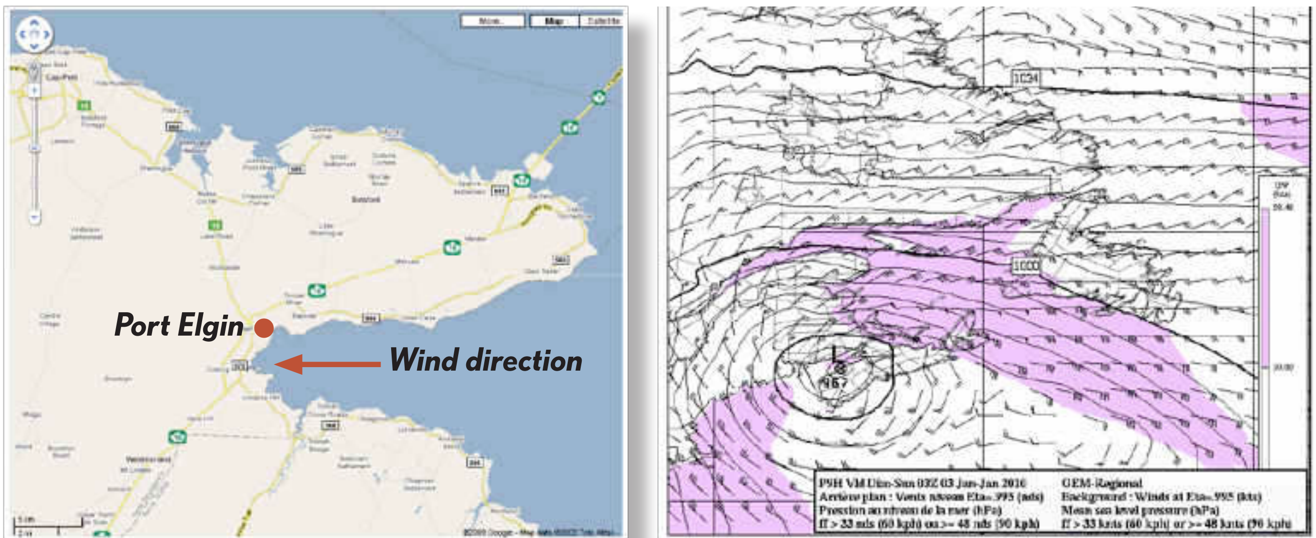

Figure 13. Map at right shows the centre of the storm over the Gulf of Maine and an associated band of strong easterly winds over the Gulf of St. Lawrence and Northumberland Strait (area in purple highlights steady surface winds in the range of 60–90 km/h) Blue arrow on map at left highlights the prevailing wind direction that accentuated the flooding. (Map sources: Google Maps; Environment Canada)

The tide gauge in Shediac recorded a maximum storm surge of 1.7 m near midnight on the evening of the January 2; the tide was going out, hence avoiding a more serious flooding event in that region. In the case of Port Elgin and the Baie Verte region, a similar storm-surge factor coincided with the high tide of that evening, resulting in a catastrophic flooding situation. The flooding was further heightened by the long period of easterly winds pushing additional water into the bay (Baie Verte) and adjoining coastal communities (see Figure 13).

The village of Port Elgin estimated flooding damages of approximately $750,000 (from media reports after the flooding event) to about 50 local homes and businesses. The Province of New Brunswick paid out $200,000 in damage claims to eligible homeowners and businesses in Port Elgin and the surrounding Baie Verte area. Several cottages along the north shore of the bay between Cape Tormentine and Port Elgin were literally moved from their foundations, and retaining walls were demolished (see Figure 14 for examples). In Cape Tormentine, the fishing wharf was damaged and storage sheds were totally demolished.

Figure 14. Example of cottage moved off foundation (left) and demolished retaining wall (right) at Upper Cape. (Photos: Daniel Goguen)

Tide Gauge Site	Max. Water Level (above CD) (m)	Time of Max. Water Level	Surge at Max. Water Level (m)	Max. Surge (m)	Time of Max. Surge
Belledune, NB	3.1	2 Jan / 16:30	0.5	1.3	3 Jan / 00:30
Escuminac, NB	Not available	Not available	Not available	Not available	Not available
Shediac, NB	3.0	2 Jan / 23:45	1.7	1.7	2 Jan / 23:45
Charlottetown, PEI	3.7	2 Jan / 23:30	1.1	0.9	2 Jan / 22:30
North Sydney, NS	1.9	2 Jan / 22:30	0.5	0.6	2 Jan / 19:15
Port aux Basques, NL	2.4	3 Jan / 11:45	0.5	0.6	3 Jan / 03:30

Table 1: Summary of tide-gauge measurements and calculated storm surges as the difference between measured water levels and the predicted astronomical tides for January 2-3, 2010, storm

December 2010

Atlantic Canada saw a succession of three intense storms in 2010, on December 6, 13, and 21, respectively. Each storm was accompanied by extremely strong winds, and to make matters worse, each storm had a different prevailing wind direction, hence extending coastal erosion and infrastructure damage to pretty much all exposed coastlines in a second successive winter of a relatively ice-free Gulf of St. Lawrence.

December 6 Storm

This storm deepened rapidly south of Nova Scotia, crossed the coastline near St. Margarets Bay, and then tracked through the Bay of Fundy to central New Brunswick. The prevailing wind direction was from east to southeast, thereby impacting the southeastern shore of Nova Scotia, the east and north shores of Prince Edward Island, and the east coast of New Brunswick, resulting in coastline erosion. There was no significant flooding other than in the Tantramar area of Nova Scotia, where, according to the New Brunswick Department of Agriculture, nearly 70 per cent of the dykes were over-topped at high tide near midday of December 6 (see Table 2 for tide-gauge measurements).

Tide Gauge Site	Max. Water Level (above CD) (m)	Time of Max. Water Level	Surge at Max. Water Level (m)	Max. Surge (m)	Time of Max. Surge
Belledune, NB	3.3	6 Dec / 15:30	0.7	1.0	6 Dec / 11:30
Escuminac, NB	1.9	6 Dec / 17:00	0.3	1.1	6 Dec / 09:45
Shediac, NB	2.4	6 Dec / 09:45	1.2	1.2	6 Dec / 09:30
Charlottetown, PEI	3.1	6 Dec / 23:00	0.4	0.8	6 Dec / 07:45
Saint John, NB	8.9	6 Dec / 11:45	0.7	0.8	6 Dec / 12:15
Port aux Basques, NL	2.4	6 Dec / 09:36	0.6	0.6	6 Dec / 11:30–15:00

Table 2. Summary of tide-gauge measurements and calculated storm surges as the difference between measured water levels and the predicted astronomical tides for December 6, 2010, storm

December 13 Storm

This storm centre deepened and hovered over northern New England, resulting in a period of approximately 18 hours of strong southeasterly winds over the Maritimes. Because of a favourable astronomical tide cycle, there was no significant flooding, but all coastlines with a southeastern exposure were subject to some degree of erosion.

December 21-24 Storm

This storm deepened south of Cape Breton and remained almost stationary for an extended period. The combination of high astronomical tides (full moon on 21 December) and a period of 36 hours of strong, steady northeasterly winds (range of 50–70 km/h) under reduced atmospheric pressures (less than 100 kPa) resulted in "perfect storm" conditions for coastal flooding and massive erosion (see Table 3 for tide-gauge measurements).

Surveys conducted on December 23 and 24 revealed that the coastal area between Shediac and Richibucto experienced storm surges in the range of 1.6 to 1.7 m., the highest in the region for this storm. The most severe impact from this storm was the alarming erosion component that was experienced along all exposed coastlines as a result of the more-than-36-hour period of pounding waves at elevated water levels (see Figures 15 and 16).Before erosion surveys could be conducted, some unofficial reports suggested that this storm had eaten away as much as six metres of coastline in certain areas, one example being the Baie Verte area of New Brunswick.

Tide Gauge Site	Max. Water Level (above CD) (m)	Time of Max. Water Level	Surge at Max. Water Level (m)	Max. Surge (m)	Time of Max. Surge
Belledune, NB	3.2	21 Dec / 15:30	0.5	0.8	21 Dec / 07:00
Escuminac, NB	2.7	21 Dec / 15:45	1.0	1.2	21 Dec / 09:00
Shediac, NB*	3.3	Not available	1.7	Not available	Not available
Charlottetown, PEI	3.5	21 Dec / 22:00	0.8	1.0	21 Dec / 19:00
North Sydney, NS	2.0	21 Dec / 20:40	0.6	0.8	21 Dec / 12:00
Port aux Basques, NL	2.3	21 Dec / 09:23	0.5	0.6	21 Dec / 19:55
St. John's, NL	2.1	24 Dec / 09:59	0.6	0.6	24 Dec / 18:33
Cap-aux-Meules, QC	2.2	21 Dec / 10:50	1.1	1.1	21 Dec / 10:00–11:00 19:00–21:00

Table 3. Summary of Gulf of St. Lawrence tide-gauge measurements and calculated storm surges as the difference between measured water levels and the predicted astronomical tides for December 21-24, 2010, storm.

*The Shediac tide gauge (located on the Shediac marina wharf) stopped reporting at 10:50 a.m. on Dec 21 (reporting a level of 2.83 m CD), as the wharf was destroyed by wave action. The maximum water level for Shediac was surveyed on December 23, 2010, from flood-debris lines.

Figure 15. Examples of erosion along NB Route 530 in the Caissie Cape area. (Photo credit: Réal Daigle)

Figure 16. Example of sand-dune erosion at West Point, PEI (left).
Pounding waves in action during storm at Cavendish, PEI (right). (Photo credit: Don Jardine)

Storm Surge Modelling Methodology using LiDAR

The research project Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick, (Daigle and Project Research Team 2006) describes an innovative approach of displaying storm-surge flooding scenarios on a LiDAR-derived digital elevation map. This type of visual has proved to be extremely powerful in communicating coastal flooding impacts to audiences ranging from the general public to members of planning organizations.

The LiDAR database, produced as a deliverable from the above-mentioned project, has been used extensively for planning activities by the two planning commissions within the area of coverage: Beaubassin Planning Commission, located in Shediac, NB, and Kent Planning Commission, located in Richibucto, NB. The full database includes large segments of the New Brunswick coastal zone between Kouchibouguac National Park and Cap-Pelé, as well as segments in the Shemogue and Cape Jourimain regions. A complete coastal LiDAR database could become a key tool for the dissemination of storm-surge warning information to emergency measures organizations (EMO) and for land use planning activities.

Figure 17 is an example of how a LiDAR-derived map was used to show the extent of the December 21, 2010, flood in the Shediac area. As part of a climate-change adaptation strategy since the release of the research project mentioned above, the bridge on the main road into Pointe-du-Chêne has now been rebuilt and raised by the New Brunswick Department of Transportation to accommodate future sea-level-rise scenarios.

Figure 17. Flooding zones at the worst of the December 21, 2010, storm in the Shediac area. The light-blue shaded area indicates the maximum water level reached (3.3 m (CD), 2.4 m (CGVD28)). Note that the elevations are as surveyed by LiDAR in May 2003 and that the orthophoto map (courtesy of Service New Brunswick) was taken in 2000. As part of a climate-change adaptation strategy, the bridge on the main road into Pointe-du-Chêne had been rebuilt and raised and was not flooded during this storm, though still being seen as under water on this map. (Map source: R.J. Daigle Enviro)

GAPS AND NEEDS

Monitoring

The Canadian Hydrographic Service of Fisheries and Oceans Canada maintains a tide-gauge monitoring network providing real-time water-level data for 16 sites in Atlantic Canada. While this network was initially established for marine navigation requirements, it has become a source of critical information for storm-surge prediction and flood-monitoring activities. There are several high-frequency flooding zones for which water-level monitoring is currently not available. The following locations are suggested for monitoring sites:

- Acadian Peninsula (Shippagan)
- North Shore Prince Edward Island (North Rustico)
- North Shore Nova Scotia (Pictou)
- Upper Bay of Fundy (Tantramar region)

Mapping

LiDAR mapping has been effectively used for raising awareness of storm-surge flooding and for land use planning. There is a need for a complete LiDAR mapping capability (with appropriate update cycle) for all coastlines subject to coastal flooding, particularly as flooding frequencies are projected to increase with sea-level rise, compounded by an expected increase in the intensity and frequency of storms because of climate change. Such a mapping capability could serve to clearly identify areas at risk for flooding when a storm-surge warning is issued by Environment Canada. Such flood risk maps could be made available to the general public through EMO organizations or other emergency managers' web portals.

The availability of LiDAR mapping capabilities in conjunction with appropriate return-period flooding statistics could provide a tool to better manage land use planning for existing and future developments.

WHAT ARE WE DOING ABOUT COASTAL FLOODING?

The milestone storm surge event of January 21, 2000, was instrumental in raising serious concern about the impacts of coastal flooding in Atlantic Canada, both in present times and, more importantly, in the context of rising sea levels and the more-frequent flooding events expected with climate change. Later in 2000, Environment Canada introduced a storm-surge prediction program in Atlantic Canada and subsequently led sea-level-rise studies in Prince Edward Island and southeastern New Brunswick. These actions, coupled with a genuine interest in storm-surge flooding events by the news media, contributed to the development of flooding response strategies.

The community of Pointe-du-Chêne was the first in southern New Brunswick to implement a flooding response plan in light of its particular flooding problem whereby even a minor storm-surge flooding event inundates the low-lying section of the community and also cuts off the community from emergency response services (see Figure 17). An emergency response centre was established at the local community centre and is activated before predicted flooding events. As part of a climate-change adaptation strategy, the bridge on the main road into Pointe-du-Chêne has now been rebuilt and raised by the New Brunswick Department of Transportation, thereby resolving the isolation problem. Following is a brief up-to-date summary of selected applied projects, university or other research, government legislation, policies, and plans or commitments—either underway or imminent—dealing with flooding response strategies.

Atlantic Climate Adaptation Solutions Association (ACASA)

The currently most extensive ongoing applied project in climate change adaptation is linked with the Atlantic Climate Adaptation Solutions, with collaborative initiatives in all four Atlantic provinces. Full details of the project can be viewed at the partner website:

http://www.gnb.ca/0009/0373/0007/index-e.asp

New Brunswick Mi'gmag First Nations Climate Change Adaptation

This project, led by the North Shore MicMac District Council Inc., being run in parallel with the New Brunswick component of ACASA, has as a main focus an evaluation of climate change and storm-surge flooding impacts on New Brunswick Mi'gmag First Nations reserves for a planning window through the end of the current century. The work involves the development of a LiDAR geodatabase and flooding scenarios from which adaptation strategies and emergency response plans will be derived. An interactive secure web mapping interface (third party) will provide communication to the communities.

Communauté Rurale Beaubassin-Est Rural Community

The Council of the Communauté Rurale Beaubassin-est Rural Community has adopted a bylaw to better regulate construction along coastal areas. The municipality is the first in New Brunswick to adopt such a bylaw to be integrated in the Rural Plan. The modifications to the existing bylaw include the addition of a new zone regarding the elevation of the sea (4.3 m CGVD28), which is identified in the zoning map, and a bylaw that specifies guidelines for new construction in the regions.

http://www.beaubassinest.ca/index_en.cfm

New Brunswick Coastal Areas Protection Regulation

The Province of New Brunswick is continuing development toward a regulated approach for wetland and coastal area protection that will clearly define and enforce the requirements of the existing Coastal Areas Protection Policy and the Wetlands Conservation Policy. The new regulation will improve local planning and development in areas that are frequently impacted by weather events and will reduce climate-change-related risks to people and wetland ecosystems.

Planning for Sea-level Rise in Halifax Harbour

In August 2006, the Halifax Regional Municipality Council adopted the Regional Municipal Planning Strategy, an integrated land use planning guide for future development. To inform development of an area-specific land use plan for Halifax Harbour, the strategy explicitly includes policies to address climate change impacts and recognizes the need to gather scientific data on sea-level rise, storm surges, and vulnerability.

http://adaptation.nrcan.gc.ca/mun/halifax_e.php

Prince Edward Island Report on Land Use and Local Governance

The Prince Edward Island Commission on the Land and Local Governance is currently engaged in efforts to revamp land use planning policies and will be identifying climate change in the process.

http://www.gov.pe.ca/photos/original/ReportEng.pdf

Le Goulet's Climate Change Adaptation Plan

Le Goulet is a small fishing community (population 950) located on the Acadian Peninsula in northeast New Brunswick. The village is low-lying and relatively flat, features that make it particularly vulnerable to the impacts of a changing climate and rising sea levels. In Le Goulet, policy makers were able to rely on nearby researchers from the Université de Moncton to provide impartial impacts and adaptation information, to facilitate a discussion process, and to draft a plan based on the outcomes from the discussions. This example demonstrates the importance of collaboration between local residents and climate-change specialists when producing a climate change adaptation plan for a small community.

http://adaptation.nrcan.gc.ca/mun/legoulet_e.php

LINKAGES AND KEY RESOURCES

Following is a listing of links to organizations involved in adaptation work.

The Intergovernmental Panel on Climate Change (IPCC) is the leading body for the assessment of climate change, established by the United Nations Environment Programme and the World Meteorological Organization to provide the world with a clear, scientific view on the state of climate change and its potential environmental and socio-economic consequences.

http://www.ipcc.ch

The Climate Change Impacts and Adaptation Division of Natural Resources Canada (NRCan) facilitates the generation and sharing of knowledge, tools, and mechanisms to integrate adaptation into policy, plans, and projects.

http://www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/climate-change-impacts-adaptation-division/283

Canadian Climate Change Scenarios Network (CCCSN) is Environment Canada's vehicle for distributing climate change scenarios and adaptation research from national and regional perspectives.

http://www.cccsn.ca

Ouranos is a Quebec-based consortium on regional climatology and adaptation to climate change. Ouranos develops and adapts the necessary tools to provide decision makers with detailed climate-change scenarios on a regional scale. It also performs evaluations of expected sectoral impacts to optimize adaptation strategies. The Climate Simulations team at Ouranos develops and uses the Canadian Regional Climate Model (CRCM) to provide regional climate data.

http://www.ouranos.ca

The Climate Change Geoscience Program of Natural Resources Canada, provides planners, decision makers, and the general public with access to a source of credible scientific information on the risks and opportunities faced by Canadian communities and industries as a result of a changing climate.

http://www.nrcan.gc.ca/earth-sciences/climate-change/landscape-ecosystem/2539

Prince Edward Island Department of Environment, Labour and Justice, Climate Change

http://www.gov.pe.ca/environment/climatechange

Nova Scotia Department of the Environment, Adaptation to Climate Change

http://climatechange.gov.ns.ca/content/home

New Brunswick Department of Environment, Climate Change

http://www.gnb.ca/0009/0369/0015/0002-e.asp

Newfoundland and Labrador Department of Environment and Conservation, Climate Change

http://www.env.gov.nl.ca/env/climate_change/index.html

Climate Change and Health is Health Canada's resource for researchers and decision makers to better understand how a changing climate will affect human health and to determine the best ways to prepare for these changes.

http://www.hc-sc.gc.ca/ewh-semt/climat/index_e.html

Linkages and Key Resources *cont'd*

Canada's Action on Climate Change is the Government of Canada's website on action on climate change across domestic, continental, and international fronts.

http://www.climatechange.gc.ca

Planning for Climate Change is a website maintained by the Canadian Institute of Planners for disseminating urban planning–related climate change information to its members and the public.

http://www.planningforclimatechange.ca

The National Roundtable on the Environment and the Economy works to enhance the understanding and adoption of sustainable ways of life: "Relying on our unique convening role, we develop and promote viable policy recommendations for all sectors of our society and for all regions of Canada."

http://www.nrtee-trnee.com/

The Nature Conservancy ClimateWizard enables technical and non-technical audiences alike to access leading climate-change information and visualize the impacts anywhere on Earth.

http://www.climatewizard.org/

Fisheries and Oceans Canada / Canadian Hydrographic Service

http://www.lau.chs-shc.gc.ca/english/Canada.shtml

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