Sea-Level Rise Estimates for New Brunswick Municipalities

Saint John
Sackville
Richibucto
Shippagan
Caraquet
Le Goulet

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Context

The coasts of New Brunswick have been shown to have significant sensitivity to sea-level rise and associated storm impacts. Accelerated sea-level rise under greenhouse warming is expected to exacerbate these impacts. Threats in this area come primarily from impacts of coastal flooding and erosion, and damage can occur due to forced sea-ice movement caused by storm surges in winter, as was the case with the benchmark storm of January 21, 2000 and more recently on December 6 and 21, 2010. The objective of this report is to provide estimates of relative sea-level rise, including the storm surge component, over the coming century for the New Brunswick municipalities of Saint John, Sackville, Richibucto, Shippagan, Caraquet and Le Goulet. Specifically, the report is to provide the following:

- For the New Brunswick municipalities of Saint John, Moncton, Sackville, Richibucto, Shippagan, Caraquet and Le Goulet – By combining estimates of global sea level rise and local subsidence provide an estimate of the anticipated change in relative sea level (in cm with error bars) from present values (i.e. 2000) for the years 2025, 2055 and 2085 (i.e. the centre point of the 2020s, 2050s and 2080s periods).

- For the New Brunswick municipalities of Saint John, Sackville, Richibucto, Shippagan, Caraquet and Le Goulet – Using existing literature, provide an estimate of the change of extreme total sea level from present (i.e. 2000) for given levels of risk for the years 2025, 2055 and 2085. Levels of risk will be the 10, 25, 50 and 100 year return periods.

Methodology

Global Sea-Level Rise Trends

The Intergovernmental Panel on Climate Change (IPCC), a scientific intergovernmental body with participation from more than 130 countries, provides the world with a 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. For the global ocean as a whole, the latest literature assessed in AR4 indicates that sea level rose 0.17±0.05 m during the 20th century, an increase over the rate in the 19th century, and slightly less than the mean rate of 1.8±0.5 mm/year observed from 1961 to 2003. Climate

model projections (Table 1) of global mean sea-level rise (mean for 2090-2099 relative to 1980-1999) for a range 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").

Table 1. Sea-level rise projections from AR4. (Source: IPCC, Climate Change 2007: Synthesis Report)

Case	Temperature change (°C at 2090-2099 relative to 1980-1999)		Sea-level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model-based range Excluding future rapid dynamic changes in ice flow
Constant year 2000 concentrations	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 2.9	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI	4.0	2.4 – 6.4	0.26 – 0.59

At the low end, this is equivalent to (or possibly less than) the present rate of rise. At the high end, it is less than projected in the 2001 IPCC Third Assessment (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. For Atlantic Canada, AR4 indicates that the regional sea-level rise related to thermal expansion (the increase due to the warming of the oceans) may be very close to the global mean.

There has been much discussion since the release of AR4, by the scientific community regarding the effects of a potential acceleration in the flow rates of glaciers, particularly with regards to the Greenland Ice Sheet, which if entirely melted, would result in a global

sea-level rise of the order of seven metres. The rise in sea levels would however not be uniform around the globe due the changes in the gravitational field associated with the changing mass distribution on the earth.
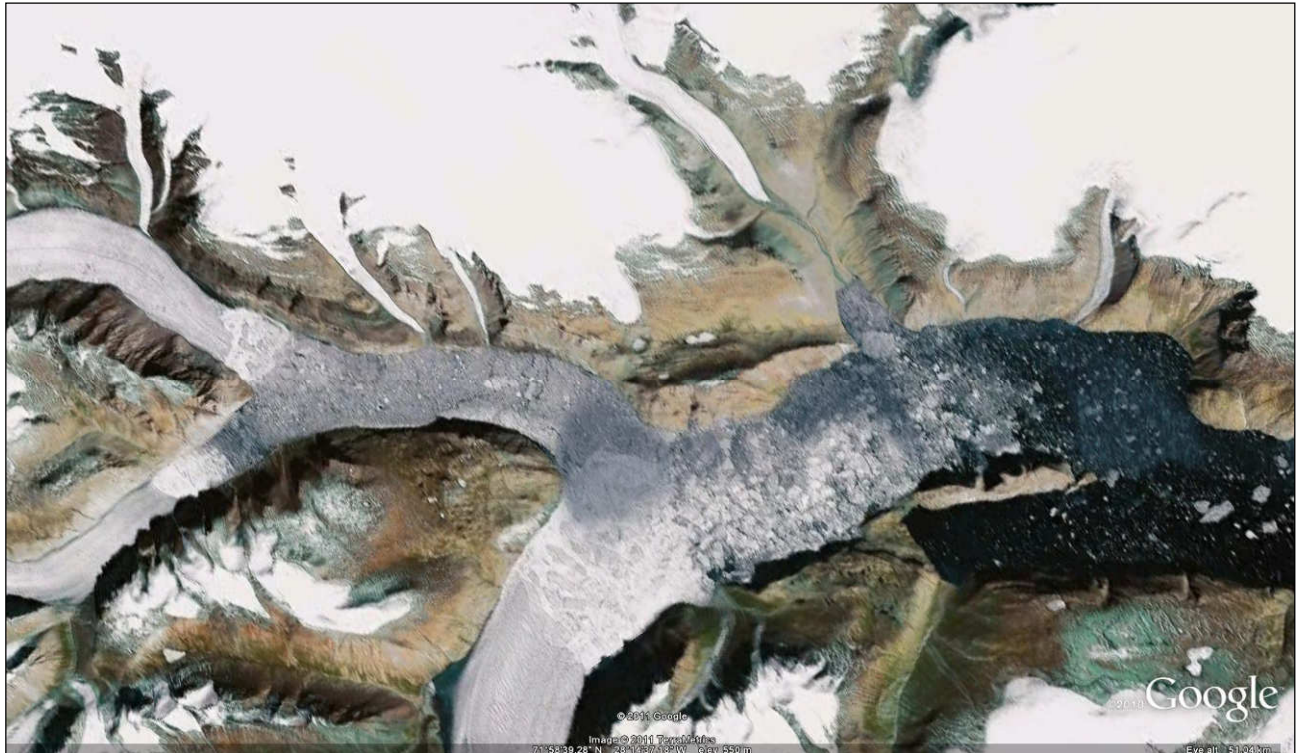
Figure 1. This image shows the iceberg calving fronts of a glacier into the Greenland Sea, on the central east coast of Greenland. This is but one example of the countless number of calving zones along the entire perimeter of Greenland. (Map source: Google Earth)

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 and this trend is predicted to continue. 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 1, 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 Antarctica to global sea-level rise which had been previously estimated to be negligible, has also been the topic of new research and there is now widespread concern that the West Antarctica Ice Sheet (WAIS) may collapse entirely due to climate change (Bamber et al., 2009). The contribution to global sea-level rise from WAIS would be approximately five metres, but the rise in sea levels would however not

be uniform around the globe (Mitrovica et al. 2009) due to changes in the gravitational field associated with the changing mass distribution on the earth (referred to as sea-level fingerprinting), and 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 however depend on the melting rates of the respective glaciers and noticeable impacts would not likely be evident within the next century.

The uncertainty regarding the impact of the flow rates of glaciers is reflected in AR4 in the following text: *"The sea level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. Therefore the upper values of the ranges given are not to be considered upper bounds for sea level rise."* It has been documented that the net loss of ice from the Greenland Ice Sheet has accelerated since the mid-1990s and is now contributing as much as 0.7 millimetres per year to sea-level rise due to both increased melting and accelerated ice flow (The Copenhagen Diagnosis, 2009).

A reputed sea-level rise expert and contributor to the IPCC process, Professor Stefan Rahmstorf (Potsdam University, Germany), has summed up the short-comings of AR4 sea-level rise estimates as follows:

"The main conclusion of this analysis is that sea level uncertainty is not smaller now than it was at the time of the TAR, and that quoting the 18-59 cm range of sea level rise, as many media articles have done, is not telling the full story. 59 cm is unfortunately not the "worst case". It does not include the full ice sheet uncertainty, which could add 20 cm or even more. It does not cover the full "likely" temperature range given in the AR4 (up to 6.4 °C) – correcting for that could again roughly add 15 cm. It does not account for the fact that past sea level rise is underestimated by the models for reasons that are unclear. Considering these issues, a sea level rise exceeding one metre can in my view by no means ruled out. In a completely different analysis, based only on a simple correlation of observed sea level rise and temperature, I came to a similar conclusion. As stated in that paper, my point here is *not* that I predict that sea level rise will be higher than IPCC suggests, or that the IPCC estimates for sea level are wrong in any way. My point is that in terms of a risk assessment, the uncertainty range that one needs to consider is in my view substantially larger than 18-59 cm."

As stated above, Professor Rahmstorf has developed a simple correlation (semi-empirical) between mean globally averaged surface air temperature and global sea-level rise trends; he has then applied this correlation to predicted climate change warming over the next century to come up with new estimates of sea-level rise in the range of

approximately 60-120 cm (Rahmstorf, 2007). This approach has also been endorsed by other leading experts in the field (Rahmstorf et al., 2007) and was adopted in an August 2009 report by the World Wildlife Fund, entitled *Arctic Climate Feedbacks: Global Implications* (Martin Sommerkorn & Susan Joy Hassol, editors, et al., 2009). Figure 2 below, reproduced from this report, depicts historical sea-level rise trends and the new global estimates which have been used as the basis for new sea-level rise estimates presented in this report. It is hoped that the next IPCC report (AR5) due in 2014, will bring more clarity to this issue.
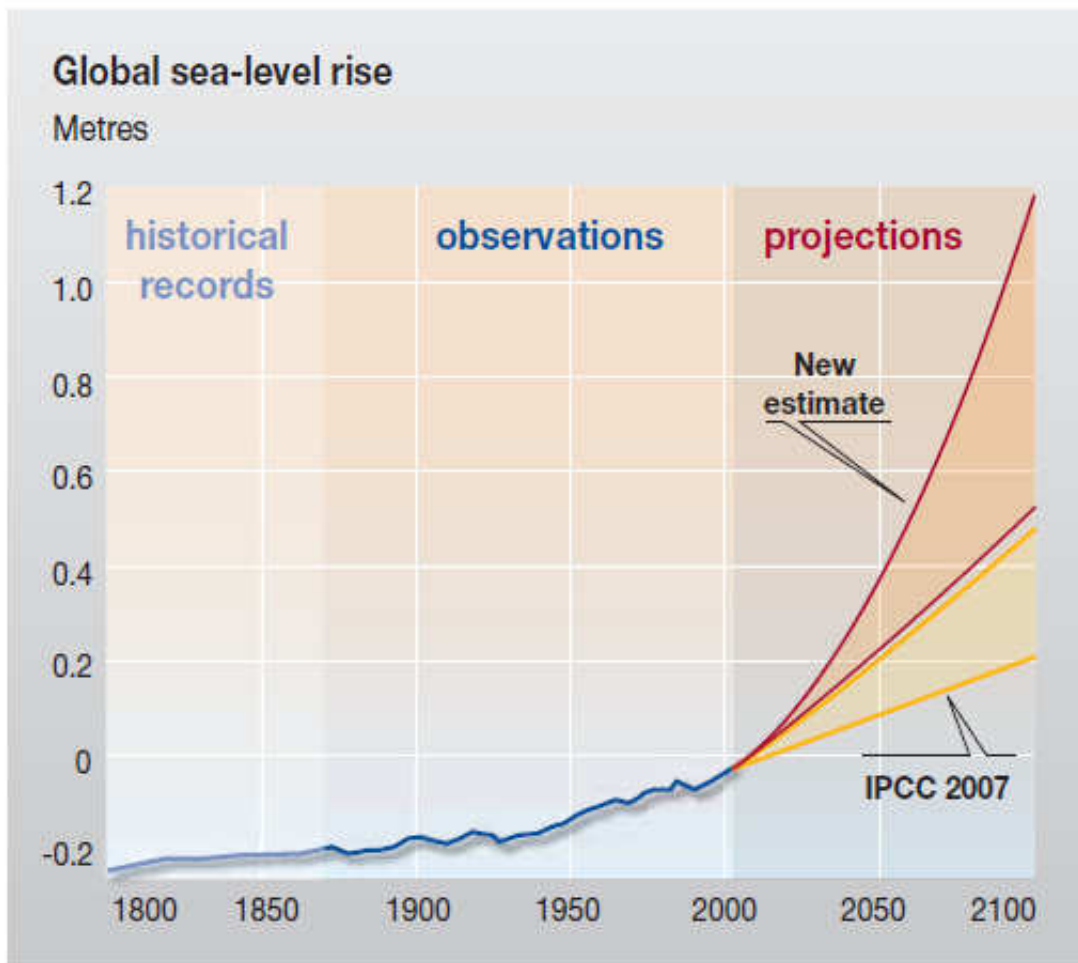

Figure 2. Future sea-level rise based on simple relationship (Rahmstorf, S., 2007) between rate of sea-level rise and global average temperature (Source: Arctic Climate Feedbacks: Global Implications, Martin Sommerkorn & Susan Joy Hassol, editors; published by WWF International Arctic Programme, August 2009)

Local Crustal Subsidence

In addition to contributions relating to thermal expansion of the oceans (due to a warming climate), the melting of nonpolar glaciers and changes in the volume of the ice sheets of

West Antarctica and Greenland, sea levels along most coasts of Atlantic Canada are rising due to the fact that these coastlines are very slowly sinking (up to a few tenths of meters per century). This factor relates to a rebound of the earth's crust (a maximum rebound in the Hudson Bay area) and a corresponding subsidence along coastlines (in eastern Canada, a maximum subsidence over Nova Scotia and western Newfoundland), in response to a depression of the earth's crust caused by the immense weight of continental ice sheets during the last Ice Age. Figure 3 (left) shows a schematic drawing of crustal motion both during a glacial maximum and after glaciations (the present scenario). Figure 3 (right) shows preliminary results of the earth's crust vertical motion in mm/year obtained from Natural Resources Canada's network of the Canadian Base Network (CBN). 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, R. and Project Research Team. 2006).
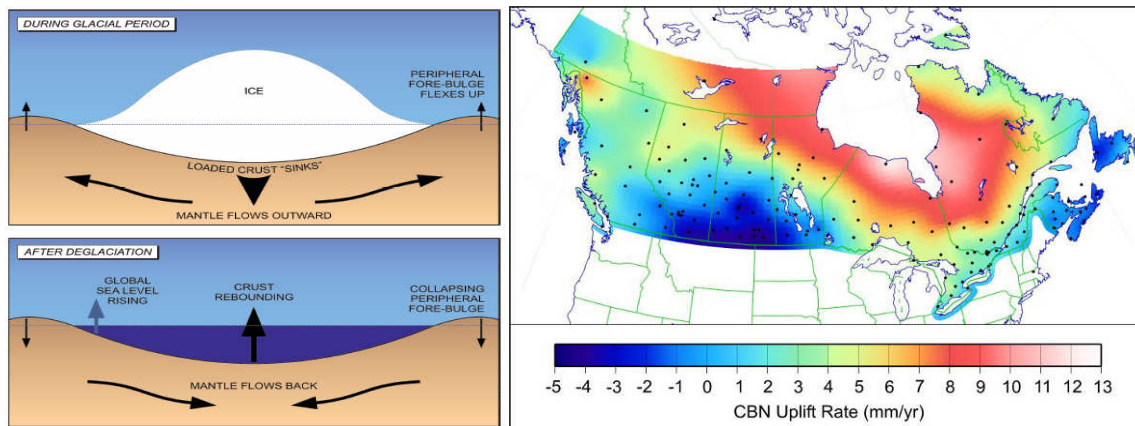
Figure 3.Schematic drawings at left illustrates how the earth's crust reacts to changes in ice sheet loadings. Map at right depicts preliminary results of the earth's crust vertical motion in mm/year obtained from Natural Resources Canada's network of the CBN. The measurements are obtained from a network of approximately 160 high precision GPS monitors. (Source: Natural Resources Canada)

Estimates of vertical motion for the New Brunswick municipalities being considered in this report are detailed in Table 3 below.

Storm Surge Return Periods

Estimates of extreme total sea levels and associated levels of risk were extracted from published results in *Annual and Seasonal Extreme Sea Levels in the Northwest Atlantic: Hindcasts over the Last 40 Years and Projections for the Next Century. Dalhousie University Ph.D (Bernier, N.B. 2005)*, as displayed on the Environment Canada Atmospheric Hazards Web Site – Atlantic at the following link:

http://atlantic.hazards.ca/search/search-e.html?user=H&who=A&class[]=427

Close inspection of the published residual graphs (difference between the observed sea level and the anticipated tides) reveals that a significant number of recorded extreme storm surge events fall within range of the upper 95% confidence limit. This is particularly the case with the Escuminac and Shediac residual graphs. In the case of Shediac, the surveyed record level of 3.62 m (CD) with the January 21, 2000 storm is not included in the statistical analysis because this event was not recorded by the Pointe-du-Chêne tide gauge which had been rendered nonoperational during the storm. For the above-mentioned reasons, the data used to estimate the extreme total sea-level return periods was extracted from the upper boundary of the shaded area on the representative graphs. In the case of the Acadian Peninsula locations of Caraquet, Shippagan and Le Goulet, the mean value was used instead because for these locations, the storm surge contribution is normally less "focused". The procedure used was as follows:

1. Residual sea-level values for the 2, 10 and 100-year return periods, mined from the published semi-logarithmic graphs, were subsequently plotted on a linear graph and fitted to a natural logarithm (LN) regression curve; values were then calculated from the regression equation for the 10, 25, 50 and 100 year return periods. See Figure 4 for Saint John example. Total estimated return-period sea levels for the years 2025, 2055 and 2085 (Tables 4-7) were then calculated as the sum of the relevant incremental values and the current Higher High Water Large Tide (HHWLT) values as published by the Canadian Hydrographic Service (CHS) of Fisheries and Oceans Canada. The incremental value included the anticipated change in relative sea levels (global sea-level rise + local crustal subsidence) as detailed in Table 3.

2. The HHWLT levels at Caraquet, Shippagan, Le Goulet and Richibucto were surveyed using high precision GPS during the summer and fall of 2010 at times when atmospheric conditions were near standard (mean sea level pressure of 1013 mb and light winds) by the New Brunswick Department of Natural Resources (Dominique Bérubé, Marc Desrosiers and Kerr-Ann Jones). This method provided HHWLT values in the geodetic reference frame (CGVD28), for use in the LiDAR-derived water level scenarios. The HHWLT levels for each of the locations of Caraquet, Shippagan and Le Goulet was set at 1.4 m (CGVD28), based on the GPS high precision surveys.

3. The HHWLT level for Sackville was determined from an analysis of the minutely data (8 April 2009 – 31 December 2010) from the New Brunswick Department of Agriculture tide gauge located at Tantramar Dam (TCA highway) with additional input from Water Levels Report, *Tantramar Dykelands Risk and Vulnerability Assessment, Jeff Ollerhead, February 2011*. The HHWLT levels for Sackville was set at 8.0 m (CGVD28).

4. The HHWLT level for Saint John was determined from the long-term Saint John tide gauge database and set at 4.7 m (CGVD28).
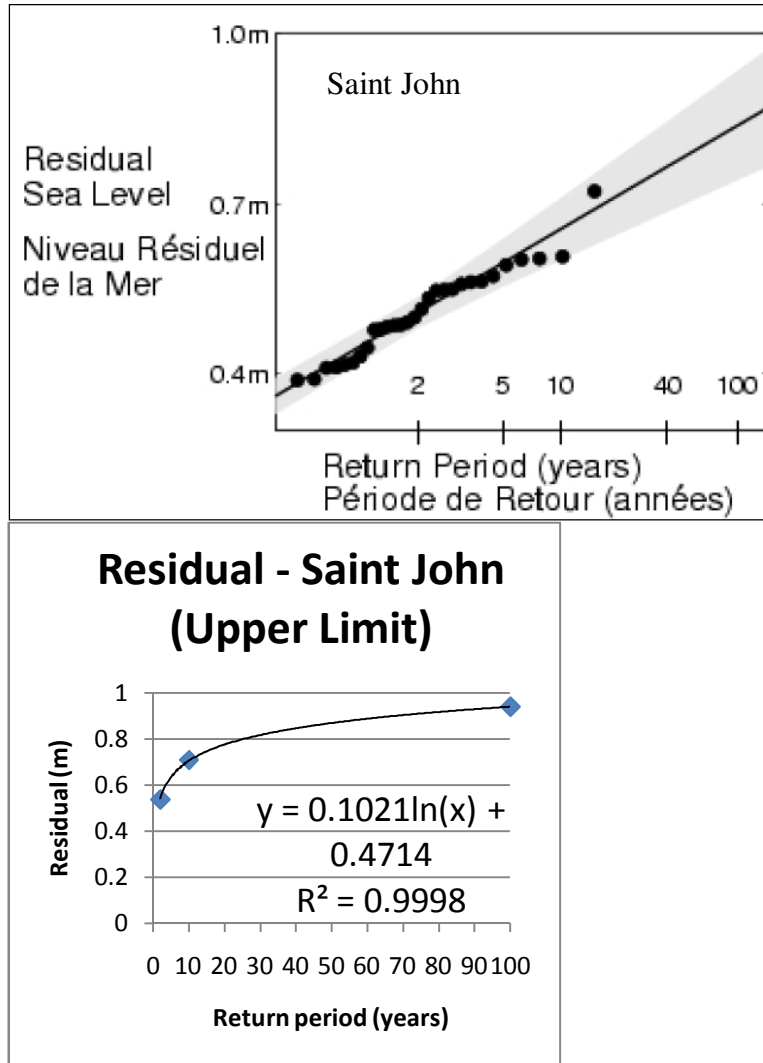

Figure 4. Graph on top showing residual sea levels and associated return periods for Saint John, with x-axis values on logarithmic scale (Source: Bernier, N.B 2005). Graph on bottom showing same data as at left but with x-axis values on a linear scale and associated regression equation used to calculate residual values for 10, 25, 50 and 100-year return periods.

5. Residual values for Saint John were calculated directly from the Saint John tide gauge database.
6. Residual values for Caraquet, Shippagan and Le Goulet were calculated as the "mean" average of the Rivière-au-Renard and Escuminac residual values. Figure 5 shows the 100-year mean return level for the entire domain. This relationship was verified with the 6 Dec 2010 storm surge event.

7. Residual values for Richibucto were calculated as the average of the Escuminac and Shediac residual values.

8. Residual values for the Sackville area (Chignecto Bay/Cumberland Basin) were initially estimated from visual examination of the various color-coded storm surge return period maps as being approximately 20% higher than the Saint John data. This relationship was confirmed with a significant storm surge event on 6 Dec 2010 (Maximum surge at Saint John 0.76 m; maximum surge at Tantramar 0.92 m).

9. Specific details about the representative CHS tide prediction sites for each municipality are listed in Table 2 below.

10. This report is purposely excluding storm surge return period scenarios for the Greater Moncton area, because this area is too far removed from the direct impacts of Bay of Fundy storm surge events. Instead, only sea-level rise estimates are produced in Table 3, reflecting estimates of sea-level rise at the mouth of the Petitcodiac River at the Bay of Fundy.

Table 2. Details and coordinates of representative tide prediction sites as documented in the CHS website.

http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/list-liste-eng.asp?user=isdm-gdsi&region=ATL&tst=1

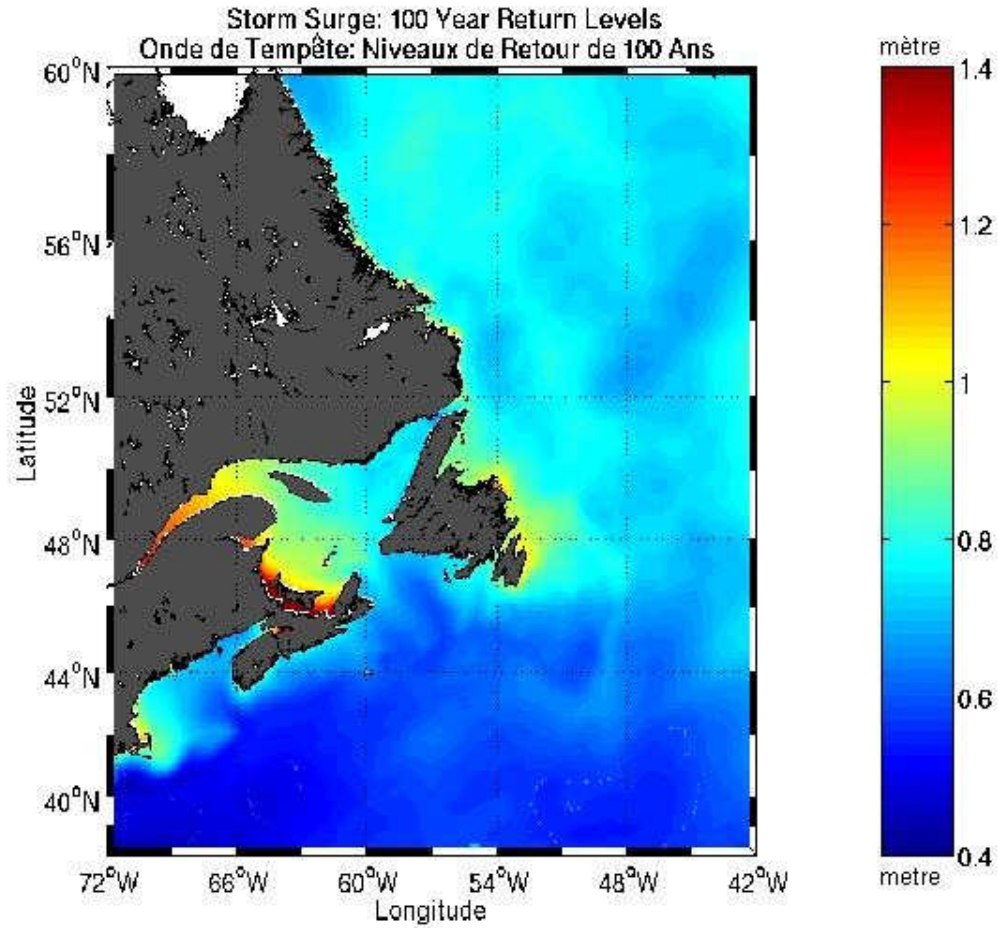| Municipality	Representitive site	Station number
Saint John	Saint John	65
Sackville	Pecks Point	190
Richibucto	Richibucto Wharf	1827
Le Goulet	Shippegan Gully	2070
Shippagan	Shippagan	2071
Caraquet	Caraquet	2110

Figure 5. Storm surge 100-year mean return period map. (Source: Bernier, N.B 2005)

Results

Estimate of anticipated change in total sea level for the years 2025, 2055, 2085 and 2100

Table 3. Anticipated change in relative sea level

Anticipated Change in Relative Sea Level (centimetres)						
Municipality	Global Sea-Level Rise (2100) (Note 1)	Vertical Motion (2100)	Total Change (2100)	Total Change (2025) (Note2)	Total Change (2055) (Note 3)	Total Change (2085) (Note 4)
Saint John	85 ± 33	10 ± 5	95 ± 38	12 ± 3	40 ± 12	76 ± 28
Moncton	85 ± 33	15 ± 5	100 ± 38	13 ± 3	42 ± 12	80 ± 28
Sackville	85 ± 33	15 ± 5	100 ± 38	13 ± 3	42 ± 12	80 ± 28
Richibucto	85 ± 33	8 ± 5	93 ± 38	11 ± 3	38 ± 12	74 ± 28
Le Goulet	85 ± 33	5 ± 5	90 ± 38	10 ± 3	37 ± 12	71 ± 28
Shippagan	85 ± 33	5 ± 5	90 ± 38	10 ± 3	37 ± 12	71 ± 28
Caraquet	85 ± 33	5 ± 5	90 ± 38	10 ± 3	37 ± 12	71 ± 28

Note 1. The value of 85 cm is the central value for the Rahmstorf year 2100 estimates (Figure 2) and the ±33 cm error bar represents the associated range.
Note 2. Total includes linear increase of vertical motion (25%) + prorated non-linear increase of 100-year global sea-level rise
Note 3. Total includes linear increase of vertical motion (55%) + prorated non-linear increase of 100-year global sea-level rise
Note 4. Total includes linear increase of vertical motion (85%) + prorated non-linear increase of 100-year global sea-level rise

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Estimated Extreme Total Sea Levels (HHWLT + Sea-Level-Rise + Storm Surge) for Return Periods of 10, 25, 50 and 100 years for Years 2000, 2025, 2050, 2085 and 2100

Table 4. Saint John, HHWLT, 4.7 m (CGVD28)

Extreme Total Sea Level (metres CGVD28) – Saint John					
Return Period	**Residual**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
10-Year	0.7 ± 0.1	5.4 ± 0.1	5.5 ± 0.1	5.8 ± 0.2	6.2 ± 0.4	6.4 ± 0.5
25-Year	0.8 ± 0.1	5.5 ± 0.1	5.6 ± 0.1	5.9 ± 0.2	6.3 ± 0.4	6.5 ± 0.5
50-Year	0.9 ± 0.1	5.6 ± 0.1	5.7 ± 0.1	6.0 ± 0.2	6.3 ± 0.4	6.5 ± 0.5
100-Year	0.9 ± 0.1	5.6 ± 0.1	5.8 ± 0.1	6.0 ± 0.2	6.4 ± 0.4	6.6 ± 0.5

Table 5. Sackville, HHWLT, 8.0 m (CGVD28)

Extreme Total Sea Level (metres CGVD28) – Sackville					
Return Period	**Residual**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
10-Year	0.9 ± 0.1	8.9 ± 0.1	9.0 ± 0.1	9.3 ± 0.2	9.7 ± 0.4	9.9 ± 0.5
25-Year	1.0 ± 0.1	9.0 ± 0.1	9.1 ± 0.1	9.4 ± 0.2	9.8 ± 0.4	10.0 ± 0.5
50-Year	1.0 ± 0.1	9.0 ± 0.1	9.2 ± 0.1	9.5 ± 0.2	9.8 ± 0.4	10.0 ± 0.5
100-Year	1.1 ± 0.1	9.1 ± 0.1	9.3 ± 0.1	9.6 ± 0.2	9.9 ± 0.4	10.1 ± 0.5

Table 6. Richibucto, HHWLT, 0.9 m (CGVD28)

Extreme Total Sea Level (metres CGVD28) – Richibucto					
Return Period	**Residual**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
10-Year	1.4 ± 0.1	2.3 ± 0.1	2.4 ± 0.1	2.6 ± 0.2	3.0 ± 0.4	3.2 ± 0.5
25-Year	1.6 ± 0.1	2.5 ± 0.1	2.6 ± 0.1	2.9 ± 0.2	3.2 ± 0.4	3.4 ± 0.5
50-Year	1.8 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	3.0 ± 0.2	3.4 ± 0.4	3.6 ± 0.5
100-Year	1.9 ± 0.1	2.8 ± 0.1	2.9 ± 0.1	3.2 ± 0.2	3.6 ± 0.4	3.8 ± 0.5

Table 7. Caraquet, Shippagan, Le Goulet, HHWLT, 1.4 m (CGVD28)

Extreme Total Sea Level (metres CGVD28) – Caraquet, Shippagan, LeGoulet					
Return Period	**Residual**	**Level 2000**	**Level 2025**	**Level 2055**	**Level 2085**	**Level 2100**
10-Year	1.0 ± 0.1	2.4 ± 0.1	2.5 ± 0.1	2.8 ± 0.2	3.1 ± 0.4	3.3 ± 0.5
25-Year	1.1 ± 0.1	2.5 ± 0.1	2.6 ± 0.1	2.9 ± 0.2	3.2 ± 0.4	3.4 ± 0.5
50-Year	1.2 ± 0.1	2.6 ± 0.1	2.7 ± 0.1	3.0 ± 0.2	3.3 ± 0.4	3.5 ± 0.5
100-Year	1.3 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	3.1 ± 0.2	3.5 ± 0.4	3.6 ± 0.5

NOTE: **It should be noted that the Residual values listed in Tables 4-7 exclude the incremental value of any wave run-up that could potentially accompany a storm surge event.**

Summary

The scientific community has concluded that global sea-level rise estimates presented in the IPCC AR4 report were too low because the impact of the melting of the Greenland and Antarctic ice sheets were purposely excluded from the calculations.

This report is based on the higher estimates of global sea-level rise using a new approach based on a simple correlation (semi-empirical) between mean globally averaged surface air temperature and global sea-level rise trends. The correlation is then applied to predicted climate change warming scenarios over the next century to come up with new global estimates of sea-level rise in the range of approximately 60-120 cm (Rahmstorf, S., 2007).

The new estimates of global sea-level rise were used, in conjunction with the best estimates of local vertical motion (crustal subsidence) to come up with total sea-level rise estimates over the next century for the New Brunswick municipalities of Saint John, Moncton, Sackville, Richibucto, Caraquet, Shippagan and Le Goulet.

It should be noted that with a 1-metre sea level rise scenario, the flooding levels reached at the height of the January 21, 2000 record storm-surge event (then near a 100-year return period event) could statistically occur every 3 to 5 years.

It is recommended that the median value of the new sea-level rise estimates (Tables 4-7) be used as a tool for sea-level rise adaptation planning and that contingencies be planned to account for the potential impact of the upper limits (up to 1.4 m), a sea-level scenario that would potentially result should greenhouse gas emissions continue to increase at the present rate. Planners should also keep in mind that sea levels will continue to increase past the year 2100.

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