



Forecasting a Sea of Change: Lessons from Atlantic Canada



Vol. 2, No. 1
September 2014

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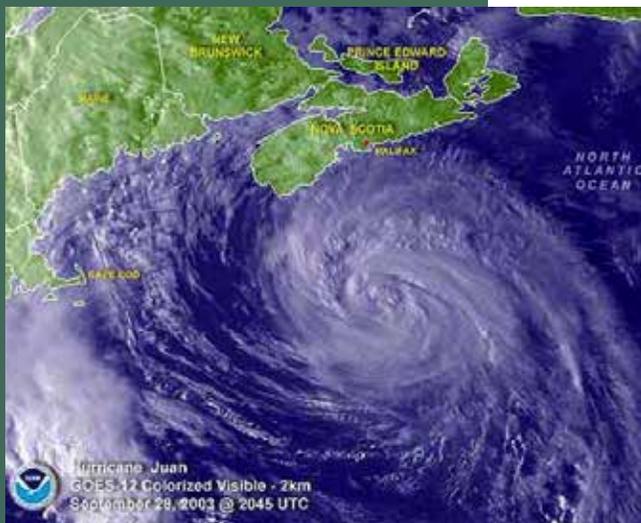


Figure 1: Satellite image of Hurricane Juan approaching Halifax. Credit: NOAA

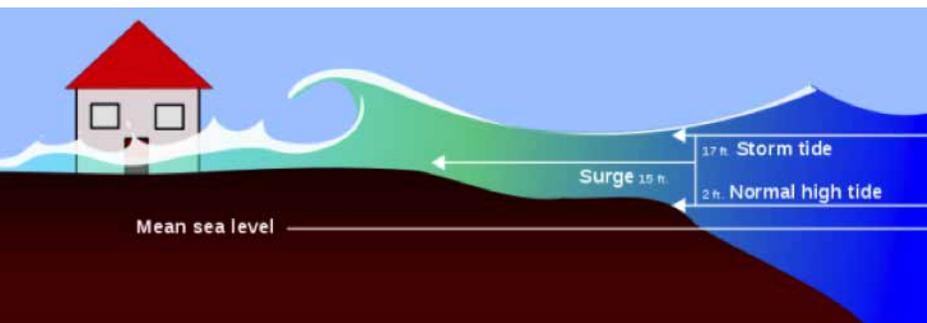
In 2003, Hurricane Juan tore through Atlantic Canada. It made landfall near Halifax, Nova Scotia, causing \$300 million in damage and killing eight people. Hundreds of thousands of Maritimers lost power as the storm hit. Sustained winds of 151 km/h gusted to 176 km/h, sections of forest were flattened, and waves 10 metres high—as tall as a three-storey building—slammed the shoreline. Some waves were even twice that height.¹

THE SURGE OF THE SEA, driven by the storm, caused extensive flooding, and Juan went down in history as one of the most devastating storms ever recorded in Nova Scotia.

As the global climate changes, extreme weather events like these are likely to become stronger. Coastal regions like Atlantic Canada have a unique set of risks. High winds and coastal flooding from storm surges cause death and damage coastal communities, destroying property, infrastructure and disrupting commerce. Water will reach further inland as the sea level rises: in Nova Scotia, for example, sea level is expected to rise between 70 and 140 cm by 2100, posing a severe threat to low-lying areas.² How can we adapt to such threats?

¹ http://www.novaweather.net/Hurricane_Juan_files/Juan_Summary.pdf

² <https://www.novascotia.ca/coast/documents/report/Coastal-Tech-Report-Chapter7.pdf>



One major tool is forecasting and this requires action on two timescales. Forecasting specific flooding events can save lives and minimize damage by allowing for evacuation of coastal communities. But on the time scale of climate change (decades to centuries), adaptation will require projections of how fast and how much sea level will rise in a particular area, how often such storms will happen, as well as greenhouse gas emission scenarios that influence how severe climate change could be. These forecasts of the future can inform building codes and city planning as well as show where an investment in installing infrastructure such as dykes, will be most worthwhile.

SHORT-TERM FORECASTS

A storm surge is an inundation of unusually high water that is generated at a coast by strong winds and changes in air pressure. Coastal flooding can happen when a storm surge occurs close to high tide, allowing the water to reach far inland in flat-lying areas. Forecasting of coastal flooding therefore requires accurate forecasts of surface winds and air pressure.

Storm surges in Atlantic Canada are forecast today using a computer model called DalCoast.³ This model,⁴ developed at Dalhousie University in cooperation with federal agencies, uses wind and air pressure forecasts from Environment Canada to produce storm surge forecasts in real time, every day. Forecasts can predict conditions up to 10 days in advance.

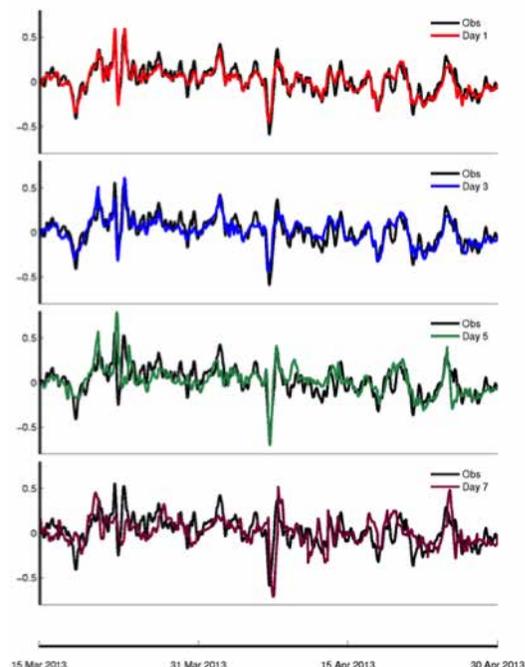
Figure 3 shows DalCoast's storm surge forecasts for Rimouski, Quebec (south shore of the St. Lawrence Estuary). The different panels compare forecasts (colours) with different lead times against actual sea level observations (black). DalCoast is accurate about five days in advance (top three panels). However, accuracy decreases the farther in advance the forecast is made. In the seven-day forecast in

³ DALhousie COASTal Ocean Prediction System

⁴ <http://www.phys.ocean.dal.ca/~dalcoast/Dalcoast1/exper/sealevel.html>

Figure 2 (top left).
Image courtesy of NOAA

Figure 3 (right):
Forecasts of storm surges made 1, 3, 5, and 7 days in advance



FACTS ON CANADA'S COASTS

- **Canada has more than 240,000 kilometres of ocean shoreline**, more than any other country in the world
- **Roughly 7 million Canadians** live in coastal areas
- **Coastal zones are vital to Canada's economy** (e.g., for fisheries, offshore oil and gas, shipping, transport, tourism)
- **Within 40 years**, flood damage to coastal houses due to climate-related sea-level rise and storm surges could cost between \$1 and \$8 billion per year.
- **Commercial fishing contributes over \$2 billion a year** to Canada's economy (GDP) and employs over 70,000 people
- **In 2010, Canada's fish and seafood exports** were valued at \$3.9 billion
- **Shellfish (especially lobster, crab and shrimp) constitute over 50%** of all landed species in Canada and over 60% in the Atlantic region. Shellfish are particularly vulnerable to ocean acidification, which weakens their shells

Sources: Canadian Fishing Industry Overview—Economic Analysis and Statistics, Dept. Fisheries and Oceans, March 2011; Climate Prosperity: Paying the Price—The economic impacts of climate change for Canada, NRTEE 2011; Natural Resources Canada, Climate change impacts and adaptations: A Canadian Perspective, Coastal Zone (archived), <http://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2012pq-eng.htm>

the bottom panel, the amplitude of the large surge event in April 2013 was forecast accurately but there was an error of about one day in the timing.

Forecasts Using Ensembles

Recently, some centres have started to use *ensembles* of wind and air pressure forecasts to decrease uncertainty. This involves combining several forecasts to yield a probabilistic prediction. For example, **Figure 4** was generated on February 11, 2013 using the DalCoast model. It shows the various probabilities (0-100 per cent, on side bar) of a surge exceeding 60 cm for the date February 14, 2013.

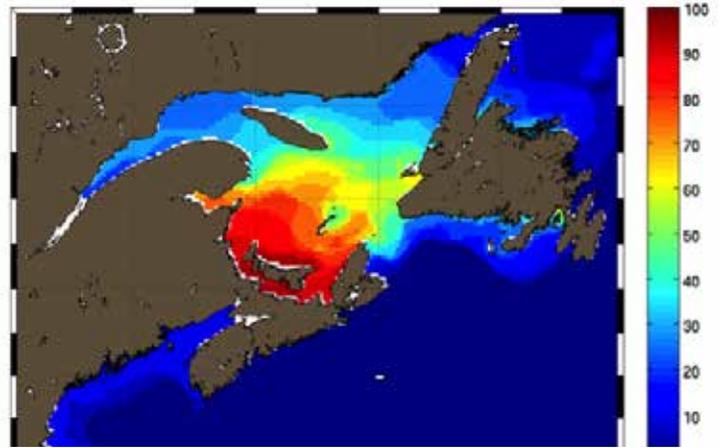


Figure 4: DalCoast ensemble projection



**FORECASTING
SPECIFIC FLOODING
EVENTS CAN
SAVE LIVES AND
MINIMIZE DAMAGE
BY ALLOWING
FOR EVACUATION
OF COASTAL
COMMUNITIES.**

HOW THE PAST CAN HELP: HALIFAX RECORDS

Sea level rise will almost certainly have a negative impact—a conclusion that is supported by historical records. Halifax, Nova Scotia has one of the longest, nearly continuous set of hourly sea level records in Atlantic Canada. This valuable dataset can help make projections more accurate by providing a means to calibrate models by running them backwards. The Halifax record also clearly defines the reality of ongoing sea level rise in Atlantic Canada. **Figure 5** shows the time variation of the average and maximum sea levels for Halifax in each year from 1920 to 2000. The annual mean (red line) has risen almost linearly at a rate of about 30 cm (about 1 foot) per century. About two thirds of this increase is due to global sea level rise; the remaining third is due mostly to sinking of the land. Peaks in the annual maximum record (black line) show when the events that caused coastal flooding happened in the past.

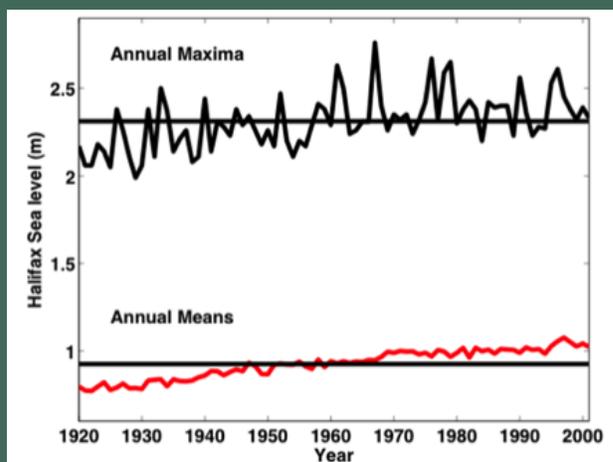


Figure 5: Halifax average and maximum sea levels 1920–2000

OCEANVIEWER

When Hurricane Arthur swept through Atlantic Canada in the summer of 2014, it was an opportunity to bring the power of crowdsourcing to storm surge models. Scientists at Dalhousie University asked members of the public to go out after the storm, stand at the debris line, and record their precise latitude and longitude using a smartphone or GPS. The debris line, where trash and seaweed line the shore, marks the height of the surge at that location. They were then asked to send their location data to OceanViewer.org,¹⁶ a real-time tool that uses ongoing data to produce dynamic forecasts. The forecasts can be used by members of the public, such as divers, boaters and fishermen, as well as scientists.¹⁷

¹⁶ <http://www.cbc.ca/news/canada/nova-scotia/hurricane-crowdsourcing-project-to-track-storm-surge-1.2697087>

¹⁷ <http://oceanviewer.org/atlantic-canada/temperature>

According to the map, there was a greater than 80 per cent chance that the southern Gulf of St. Lawrence would experience such a surge. In fact there was a surge of well over 0.6 m in this region on February 14, 2013, three days after the forecast was generated. Such probabilities can help agencies decide whether to issue early warnings for given regions.

FORECASTING FUTURE COASTAL FLOODS

Flood projections on long time scales need to take into account atmospheric conditions and long-term sea level changes—not in the next ten days, but over the next ten decades. These measurements are more uncertain because they have a greater ‘lead time’—they are made much farther in advance. One source of uncertainty, for example, surrounds how much global sea level is estimated to rise by the year 2100.

Projecting how coastal flooding will change over the next century requires recognizing that changes in that probability will be due to three primary processes:

- vertical movement of the Earth’s crust;
- global sea level rise; and
- changes in storminess.

A Rising Crust

The Earth's crust is slowly rising in many areas of Atlantic Canada. This movement is associated with the retreat of the glaciers at the end of the last Ice Age, and the slow rebound of the land from their weight. In Quebec (and other areas closer to the centre of the continent), the coastline is rising at a rate of about 30 cm. per century, gradually decreasing average relative sea level in this region. However, in areas further from the centre of the continent and that weren't covered by ice, such as Prince Edward Island, land is actually subsiding, much as the edges of a bed sink down when a person laying in the centre gets up. In Atlantic Canada this vertical movement is fairly well understood, and is not expected to change much over the next century.

A Rising Sea

The Intergovernmental Panel on Climate Change (IPCC, 2013) has generated a range of projections for global sea level rise that are linked to the amounts and rates at which greenhouse gases (GHGs) are emitted. They range from 45±15 cm (low end) to 75±20 cm (high end) by 2100. These estimates may be conservative; NASA has said that the projections could be closer to 1 metre if the potential melting of the West Antarctic ice sheet is included.

While melting of huge ice sheets and land-based glaciers is adding water to the oceans, the biggest contributor to sea level rise is actually from *thermal expansion*, the process by which a liquid expands as it warms. As global warming drives up the temperature of the seas, they will expand. Just how much and how fast such expansion raises sea level depends on many other variables, including how the warmed water is distributed through the ocean and how much atmospheric pressure pushes down on the sea.⁵

Changes in Storminess

Changes in storminess over the next century are also uncertain. The resolution of climate models are too coarse to predict individual winter storms and hurricanes. But what modeling can suggest is that changes in storminess will vary significantly from place to place. For the coasts of New Brunswick, Nova Scotia and Newfoundland there is no strong evidence that top annual wind speeds will increase significantly over the next century.

THE FORECASTING CHALLENGE: DEALING WITH UNCERTAINTY

Given this uncertainty, how can we project the probability of coastal flooding over the next century? One way is by keeping yearly records

⁵ <http://www.ipcc.ch/ipccreports/tar/wg1/411.htm>

EXAMPLE: TANTRAMAR

A study of the Tantramar region in southeast New Brunswick⁶ found that in the next century under current climate projections, storm surges and flooding will cost the region an additional \$10 million each year, some 22 per cent above current costs. One scenario explored was a storm surge combined with climate change and the high tides found in the Bay of Fundy, which could create a 8.9 m (29') flood that would inundate 20 per cent of the town of Sackville and could happen once every 10 years. To avoid such a dire occurrence, several strategies were suggested: increasing the height of dykes by 1 m would cost approximately \$40 million, and relocating vulnerable properties would take several decades and cost \$24 million. Both would appear to be cost effective in terms of avoided future damage, and are indicative of the types of steps that jurisdictions in Atlantic Canada need to consider taking now, if they are to adapt to the different future that climate change is bringing to the region.

⁶ http://greenanalytics.ca/docs/tantramar_final.pdf
<http://atlanticadaptation.ca/sites/discovery.upei.ca.acasa/files/NB-Sea%20Level%20Rise-Coastal%20Sections-Daigle-2012.pdf>

of sea level, both average and the maximum levels such as those during Hurricane Juan. This lets us plot trends, and predict how often a surge with a given height is likely to happen as we move further into the twenty-first century.

For example, what about a surge of 1.9 metres (6 feet), which currently occurs about once every 300 years or so? We know that by 2100, sea levels in Atlantic Canada are expected to be between 30 cm and 1 m above today's levels. Projections using land subsidence and increased storm intensity show that by 2100, a 1.9 m surge would happen every ten years. However, if sea level rises even more, for example by 1 m, then the 1.9 m surge may become a yearly event. When all the uncertainties are factored in, the return period for a surge of 1.9 m then becomes about five years.

Despite uncertainties inherent in estimating return period probabilities, extreme flooding events will occur. Coastal planners and infrastructure designers must not ignore extreme sea level rise scenarios just because uncertainty exists and the probability of a major event is low. A 1.9 m surge that has a return period of about 300 years at Halifax today would have a major impact, as shown in **Figure 6**.



Figure 6: Halifax waterfront with a 1.9 m surge. Flooded areas are in blue.

OCEAN ACIDIFICATION



Image Credit: FWC Fish and Wildlife Research Institute (flickr)

Storm surges aren't the only threat Atlantic Canada faces from climate. Oceans absorb about one third of man-made emissions in their surface water, to create carbonic acid, which lowers the pH¹² and is thus a major problem for ocean ecosystems. Lower pH dissolves the calcium carbonate skeletons of many ocean creatures, from coral to tiny plankton to shellfish. Data from over 100 studies combined to show that a pH reduction of just 0.5 units—within the estimates for 2100 under current IPCC projections—reduces shellfish survival and calcification by about 27 per cent. This was most severe in corals and mollusks, with up to 39 per cent reduced calcification.¹³ In Atlantic Canada, there is much at risk. In 2006, Nova Scotia's landed catch was worth \$657 million; 80 per cent of which is shellfish. Including processing and aquaculture, the industry brings about \$1.1 billion to the province.¹⁴ Over the last 70 years the pH levels of water in the

Lower St. Lawrence Estuary has decreased by about 0.2 to 0.3, evidence that the effects are already here. How bad could it get? In some areas along Vancouver Island, pH has dropped from 8.1 or 8.2 to 7.3, and over 10 million farmed scallops off Vancouver Island have been killed since 2009, wiping out three years of harvests and forcing layoffs and facility closures.¹⁵

¹² <http://www.dfo-mpo.gc.ca/science/oceanography-oceanographie/impacts/acidification-eng.html>

¹³ <http://onlinelibrary.wiley.com/doi/10.1111/gcb.12179/full>

¹⁴ <http://coinatlantic.ca/docs/ocean-acidification.pdf>

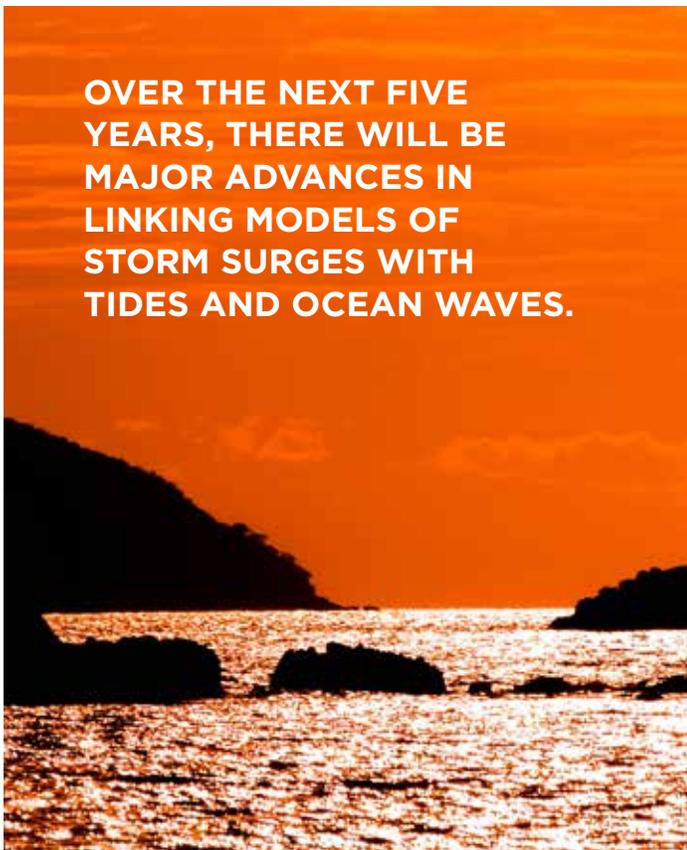
¹⁵ <http://www.pqbnews.com/news/247092381.html>

Many small businesses and infrastructure close to the water's edge would be heavily flooded by such a high sea level, and the increased likelihood of such events occurring more frequently in the future paints an unwelcome prospect for which we must prepare.

CONCLUSION

Over the next five years, in addition to 'ensemble-based' techniques, there will be major advances in linking models of storm surges with tides and ocean waves. Models are also becoming more finely resolved (over distances less than 1 km). This will allow application of more accurate models to more precise locations, including small scale features such as roads or important buildings.

The major uncertainty in projections of coastal flooding probabilities over the next century is rooted in estimates of the expected rise of global sea level. The impact of Hurricane Juan on Atlantic Canada and the city of Halifax specifically, highlights the stakes involved and the importance of considering large, if unlikely, scenarios of sea level rise. Forecasting changing seas holds practical implications for coastal communities and industries, as well as for the planners and engineers responsible for ensuring that coastal infrastructures will survive well into this century.



OVER THE NEXT FIVE YEARS, THERE WILL BE MAJOR ADVANCES IN LINKING MODELS OF STORM SURGES WITH TIDES AND OCEAN WAVES.

CLIVE

A new tool called CLIVE (short for Coastal Impact Visualization Environment), developed with

the University of Prince Edward Island and Simon Fraser University, combines 3-D game technology with geographical and climate data to show coastal erosion and sea level rise in PEI. To make the tool, Natural Resources Canada (NRCan) and the PEI government used airborne lidar⁷ to map PEI's elevation digitally, and combined with high-resolution aerial photographs, to model the island in 3-D. This data was combined with IPCC climate projections of 1 m sea level rise by 2100, and measurements of PEI's coastal erosion rates for the last several decades. Users can toggle settings to see future changes, such as how far a surge could reach in 2050 or 2080. CLIVE can then help them plan adaptation and mitigation efforts to address coastal erosion. In PEI, erosion rates range from 0.5 m per year to 1.5 m per year on the north and west coasts where storm exposure is greater, including huge swaths of PEI's iconic red sand beaches.⁸ Erosion will accelerate as the climate changes. The impact on tourism could be devastating. Tourism accounts for approximately \$380 million or seven per cent of PEI's GDP, the highest percentage of any province.^{9,10} Developer Adam Fenech says that among other things, CLIVE can show people why they shouldn't build so close to the shore. "In many cases [buildings] will just have to be moved in ten years," he said.¹¹ CLIVE is currently a finalist in the MIT CoLab Communicating Coastal Risk and Resilience competition.



Image Credit: Simon Fraser University Public Affairs and Media Relations

⁷ Light Detection and Ranging—a remote sensing method used to examine the surface of the Earth.

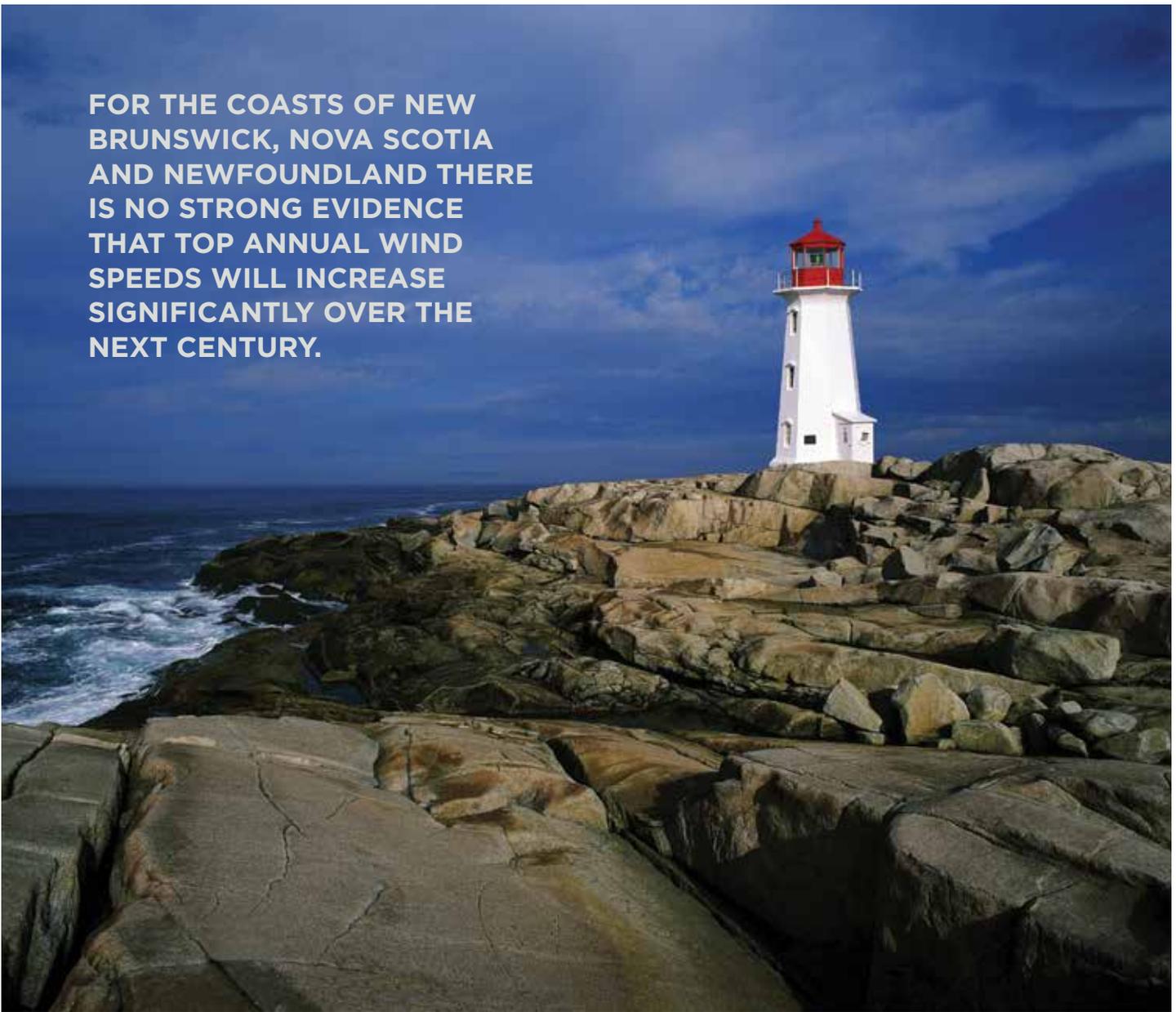
⁸ <http://www.gov.pe.ca/environment/shoreline-erosion>

⁹ <http://www.gov.pe.ca/tourism/index.php3?number=news&newsnumber=9798&dept=&lang=E>

¹⁰ <http://climatecolab.org/web/guest/plans/-/plans/contestId/1300801/planId/1309316>

¹¹ Adam Fenech Interview.

**FOR THE COASTS OF NEW
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AND NEWFOUNDLAND THERE
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The Canadian Climate Forum is a non-governmental agency dedicated to improving understanding of weather and climate in the Earth System. It collaborates with partner agencies and individuals to accelerate the uptake and use of weather and climate knowledge to serve the needs of society and the economy.



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