the adaptation primers*

PRIMER ONE
CANADA'S CHANGING CLIMATE

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2018

*prim•er (Pronunciation: /ˈprɪmər/; rhymes with "trimmer"):

A small book containing basic facts about a subject, used especially when you are beginning to learn about that subject.
Source: Cambridge Dictionary Online at http://dictionary.cambridge.org/dictionary/english/primer

CITATION

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SUPPORT

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CSLA | AAPC Canadian Society of Landscape Architects Association des architectes paysagistes du Canada

ParCA Partnership for Canada-Caribbean Community Climate Change Adaptation

UNIVERSITY OF WATERLOO

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3 EFFECTS ON ECOSYSTEMS AND SOCIETY

PREFACE

There is scientific certainty that due to global emissions of greenhouse gases our planet is already changing and will continue to change - in some cases dramatically. How global warming will affect the climate and weather patterns across Canada is complicated by the vast landscapes that comprise our nation, and the complex array of direct and indirect effects that are already anticipated. Our uncertain future should compel professionals and decision-makers to be better informed and more capable of making effective and insightful decisions.

Our hope for a stable and sustainable future action requires action be taken today. Whether the goal is to reduce the emissions that are warming the planet, or to prepare society for anticipated changes, efforts towards mitigation and adaptation must begin now. Everyone is responsible, everyone needs to act.

The **PRIMERs** are provided in a four-volume set. PRIMER ONE summarizes the science on climate weather and change. PRIMER TWO provides information on how individuals, communities and organizations can begin now to prepare for anticipated changes. PRIMER THREE presents planning and design tools, existing and emerging, that can help in the creation of resilient and prosperous communities and sustainable ecosystems. PRIMER FOUR summarizes approaches and tools focused on one of the fastest emerging challenges – rising water levels.

The Primers are intended to augment your basic understanding of the science on global warming and climate change, to provide improved access to information on anticipated impacts to Canadian landscapes, and to promote improved understanding of the options available to society through adaptive planning for change. Should you wish to expand your understanding on the topics discussed, access the materials referenced in the *Additional Readings* and *Resources on the Web*, and reach out to do your own search for newer information. Climate adaptation is a rapidly evolving knowledge area.

The Primers rely on two categories of information: reports and papers that have been freely distributed on the internet; and a selection of books and peer-reviewed papers. Many of the reports and books referenced are available from public or university libraries. Should the URLs provided for material available on the internet become inactive, it could mean only that the material has been moved, not that it is outdated or no longer relevant. We encourage you to search by author and/or title to find the document.

Peer reviewed papers are included here because they are an important source of information on climate change science, mitigation and adaptation, and the first access point for new knowledge. Some journal papers are provided freely on the Internet. Unfortunately, digital access to other journals requires paid subscriptions, or individual papers can be purchased on-line. Most university libraries in Canada provide memberships to the public for a nominal annual fee, but not all may include access to online journals. However, in addition to borrowing texts, hard and/or electronic copies of many journals can be viewed at the library. Readers can also become members of local, regional, or national communities of practice, where enrollment and access to many valuable sources of information are freely provided.

PRIMER ONE:
CLIMATE, WEATHER AND CHANGE
Chapters One and Two provide users with a summary of the current science on global warming, and the current and projected future changes in weather and climate throughout Canada. Chapter Three summarizes current thinking on the effects anticipated environmental change will have on ecosystems, on society and on local as well as regional economics.

PRIMER TWO:
PREPARING FOR CHANGE
Chapter Four focusses on managing risk and understanding the role played in decision-making by uncertainty. Chapter Five outlines the need to change what we do, to mitigate and to adapt. Chapter Six provides direction for those seeking a better future, incorporating existing instruments and tools with emerging principles and processes for guiding change.

PRIMER THREE:
CREATING RESILIENT COMMUNITIES
Chapter Seven summarizes opportunities to create resilient communities that integrate with their natural environment and promote well being and sustainability for humans and ecosystems.

PRIMER FOUR:
FACING RISING WATERS
Chapter Eight examines preventative and protective measures to rising water, whether it is fresh water (overland flooding) or the result of rising sea levels and/or storm surges.

1 CLIMATE, WEATHER AND CHANGE

1.1. GLOBAL WARMING – THE BASICS

Warming of the planet's atmosphere has been monitored for over thirty years by scientists and agencies throughout the world. Decades of research have confirmed that changes in the composition of atmospheric gases are increasing average temperatures across the planet. That warming trend is already affecting the climate system (Figure 1-1) through changes in short term weather patterns, seasonal norms, and periods of extreme temperature. The Synthesis Report (SYR) of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC 2014a) confirms that:

"human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The IPCC is now 95 percent certain that humans are the main cause of current global warming. In addition, the SYR finds that the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems, and long-lasting changes in all components of the climate system." (IPCC 2014a Synthesis Report, p v).

The IPCC has developed thousands of pages of information that document the changes already experienced and the changes anticipated as the planet warms. Canadian scientists have contributed to these publications, and continue in their efforts to apply global science to understanding climate change in this country

CLIMATE CHANGE refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and **persistent anthropogenic changes in the composition of the atmosphere or in land use.**

ipcc

INTERGOVERNMENTAL PANEL ON climate change

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. Established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), the IPCC provides the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. The IPCC is an intergovernmental body open to all member countries of the United Nations (UN) and WMO. Currently 195 countries are members of the IPCC. They participate in the review process and the plenary Sessions, where decisions about the work of the IPCC are taken, and reports are accepted, adopted and approved.

The IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct research, nor does it monitor climate related data or parameters. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis.

Because of its combined scientific and intergovernmental structure, the IPCC embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. The work of the organization is policy-relevant and yet policy-neutral, never policy-prescriptive.

Adapted from: https://www.ipcc.ch/organization/organization.shtml

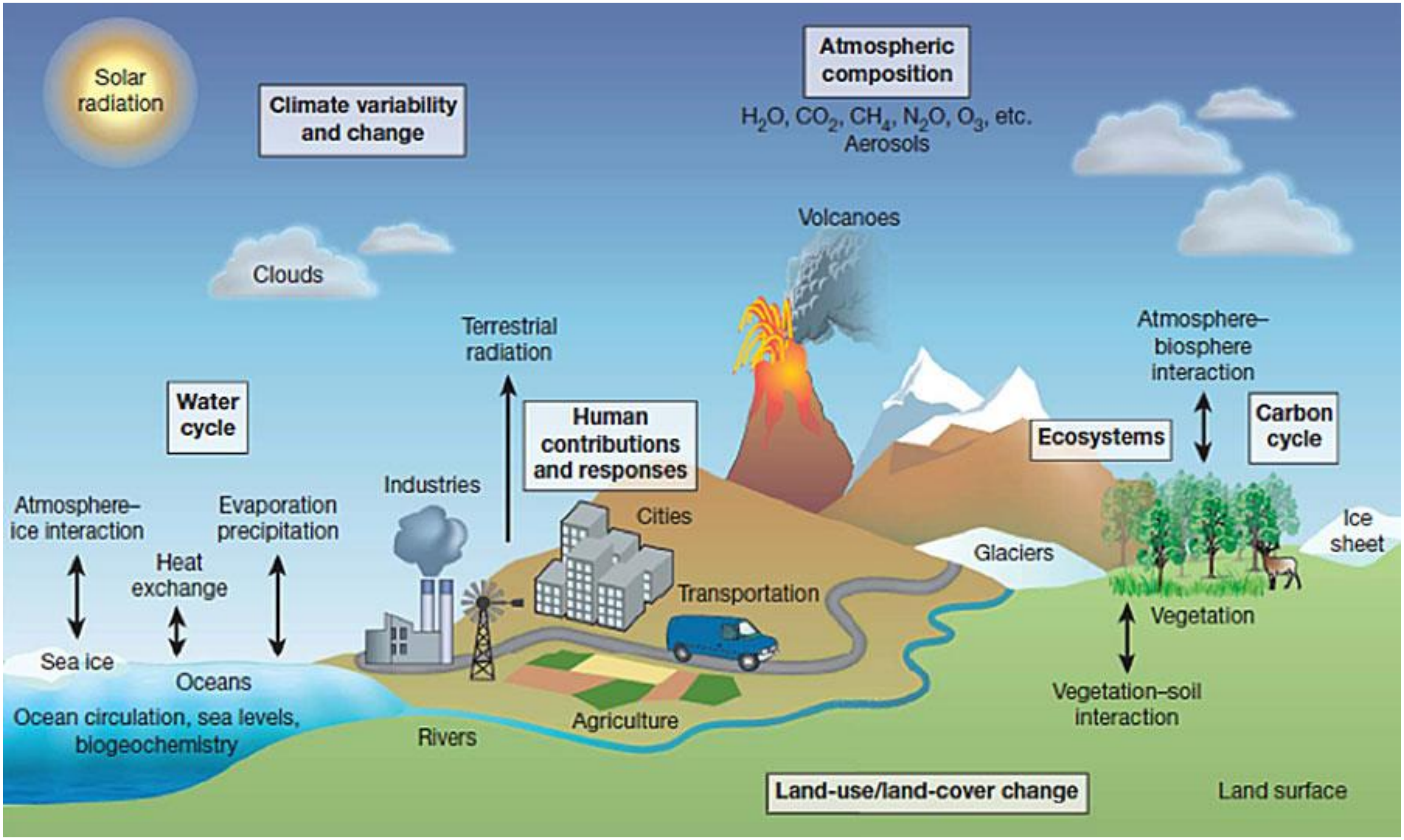

FIGURE 1-1: The major natural and anthropomorphic processes and influences that affect the earth's climate system. Our climate system consists of five interactive components that include: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere *(Image Credit: USA Climate Change Science Program., u*sed with permission. *Available at: https://www.gfdl.noaa.gov/climate-and-ecosystems-comprehensive-earth-system-models/).*

1.1.1 GLOBAL WARMING VISUALIZATION TOOLS

Scientists in Canada and the United States are developing tools that aid understanding of the continuing, and potentially escalating, effects of greenhouse gas emissions on a warming earth. Visualizations convey a great deal of information in a short period of time, and when based on excellent science can be useful tools for communicating the urgency for emission reductions (Figures 1-2 and 1-3).

FIGURE 1-2: The Climate Atlas of Canada is an interactive tool to aid users in understanding climate change in Canada. The Atlas combines climate science, mapping and storytelling to better inform Canadians of the effects of global warming here at home *(Available at: https://climateatlas.ca/about-atlas)*.

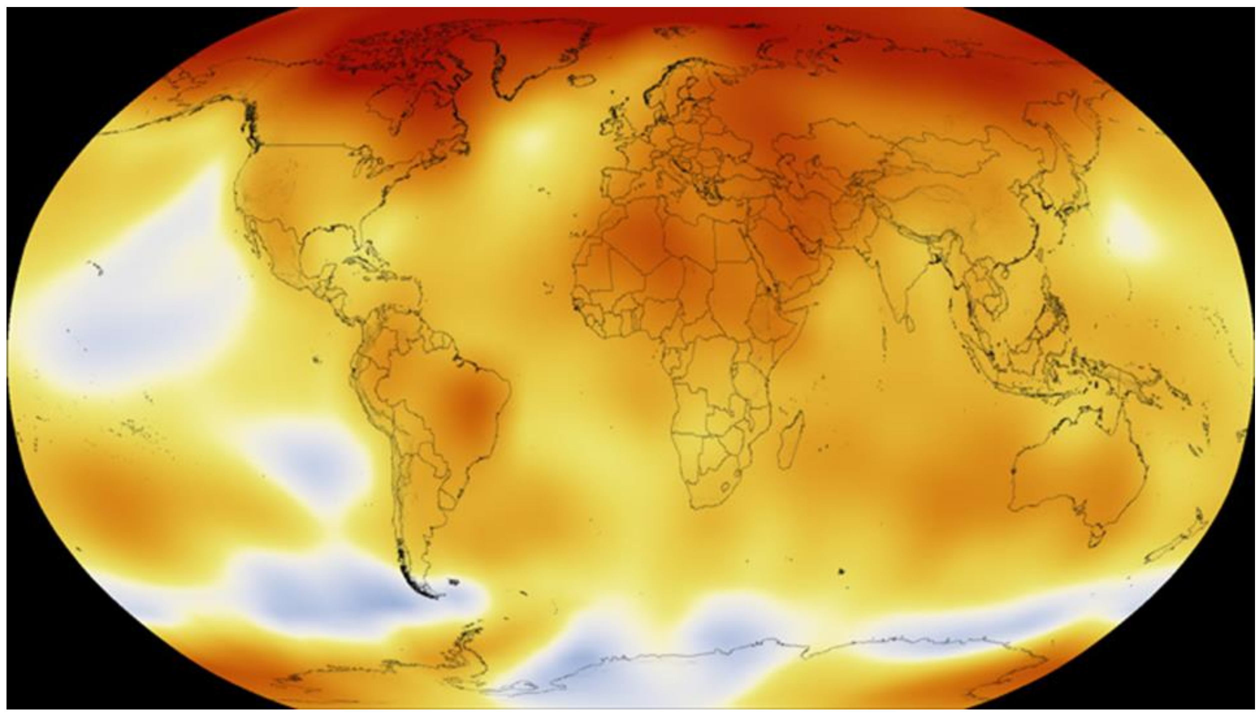

FIGURE 1-3: Progression of changing global surface temperature anomalies from 1880-2015 *(Image Credit: Perkins, USA NASA. Animation available from NASA's Goddard Space Flight Center Science Visualization Studio: https://svs.gsfc.nasa.gov/4252)*.

1.2 GREENHOUSE GASES

Over the past 200 years, the primary source of human contributions of greenhouse gases to the atmosphere has been from the burning of fossil fuels (about 78% in the period 1970-2010) (IPCC 2014a). As atmospheric concentrations of greenhouse gases (GHGs) increase, the surface of the earth becomes warmer – often referred to as the enhanced greenhouse effect (Figure 1-4). After 2035, if emissions of greenhouse gases do not decrease, the mean temperature change is likely to exceed 2 C° by 2100, and to continue increasing thereafter (Figure 1-5) (IPCC 2014a).

IPCC scientists have concluded that, in comparison to mean global temperatures experienced in the period 1986-2005, the average change in global temperature projected for the period 2016 to 2035 is somewhat conservatively in the range of 0.3 to 0.7 °C. Scientists are increasingly concerned that a change of 2 C° in the Earth's mean temperature is the most that could be accommodated if we are to maintain the planet at conditions close to what we have now.

GREENHOUSE GASES (GHGs)

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds. This property causes the greenhouse effect (global warming).

Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

Greenhouse gases also include halocarbons and other chlorine and bromine-containing substances, sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs).

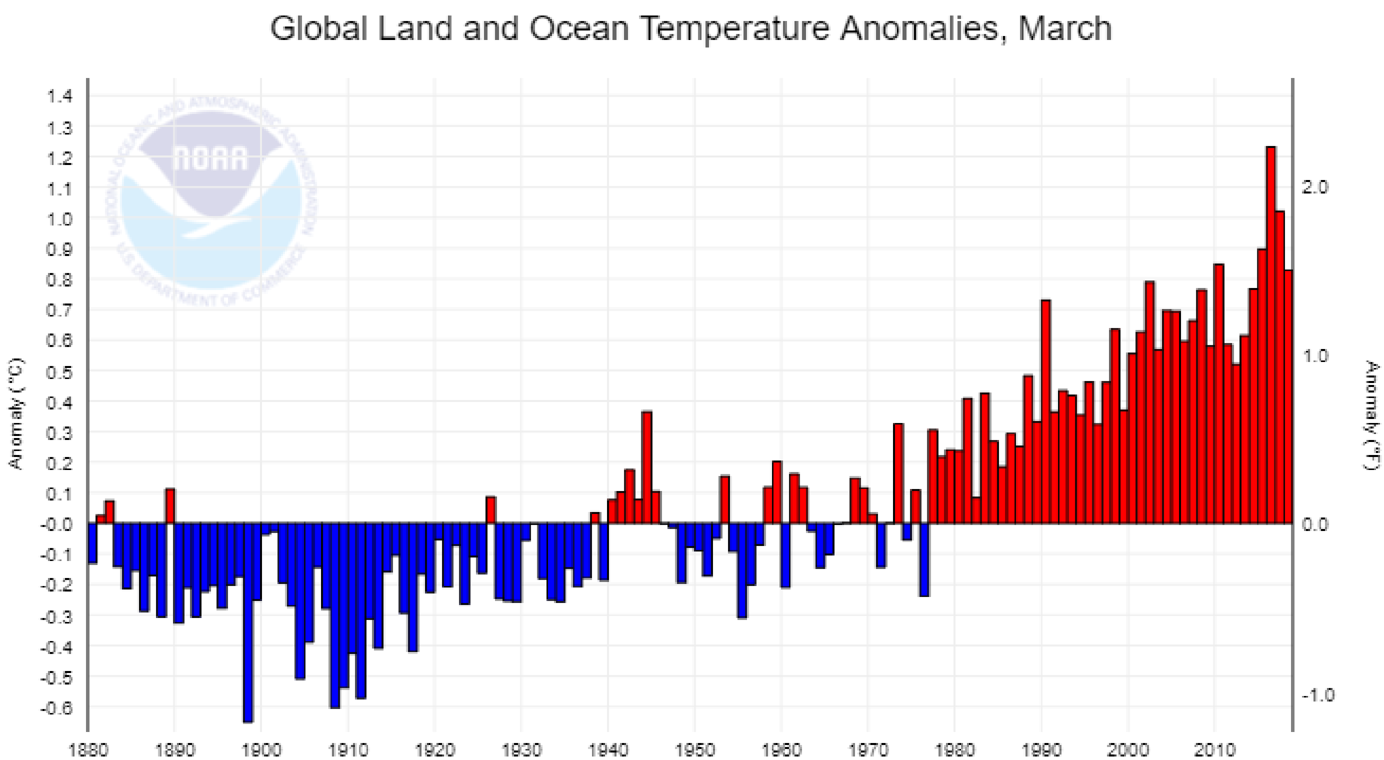

FIGURE 1-4: Global land and ocean temperature anomalies between 1880-2014, relative to the 20th century average. While temperatures were colder between 1880 and 1940, since the late 1970s, temperatures have been warmer, with 2014 the warmest year on record during this period *(Image Credit; USA/NOAA. Available at* https://www.ncdc.noaa.gov/cag/global/time-series *; and as presented in GOV/CAN/ECCC. 2015. Available at:* http://www.ec.gc.ca/sc-cs/Default.asp?lang=En&n=A5F83C26-1 *).*

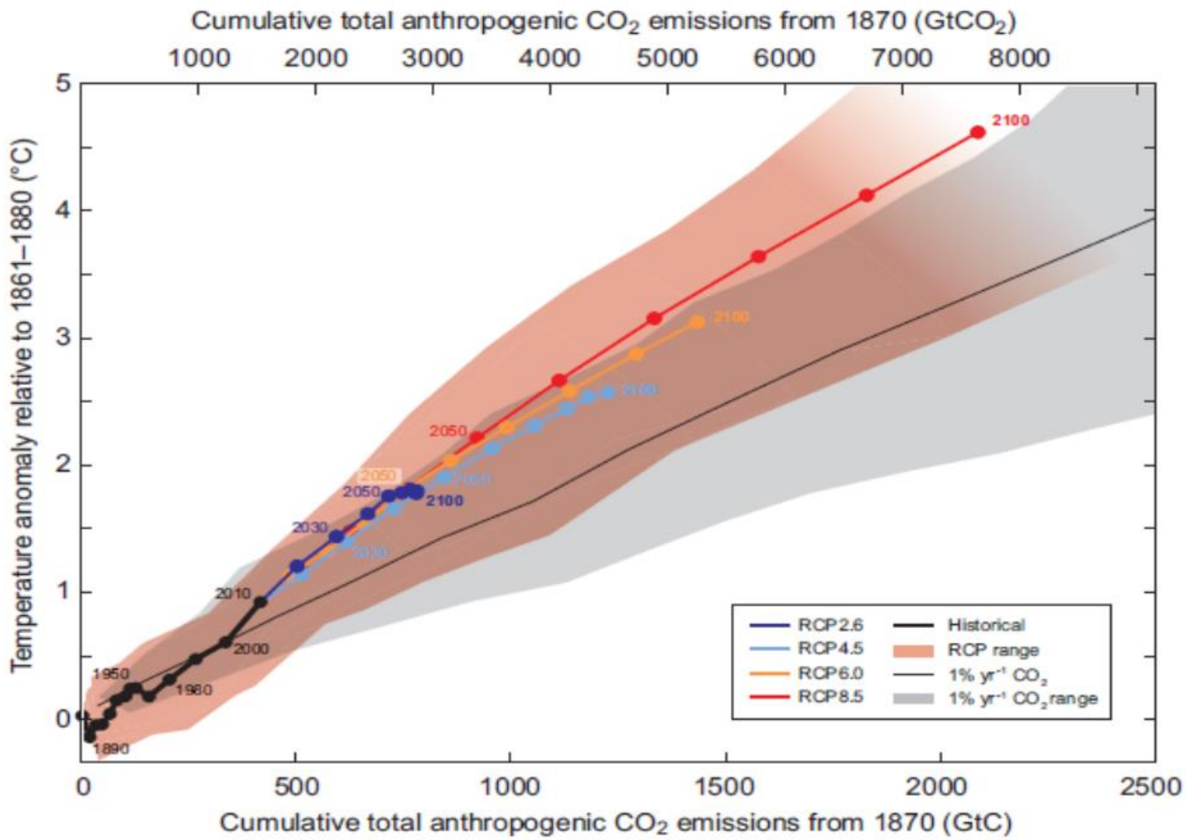

FIGURE 1-5: Global mean surface temperature as a function of cumulative total global emissions of greenhouse gases *(Figure SPM.10, p 26 from IPCC 2013).*

Despite the growing data on how the planet was warming, and the warnings from scientists on the consequences of climate change on ecosystems and on society, emissions of GHGs continued to rise over the period 1970-2010, reaching the highest levels in human history from 2000 to 2010 (IPCC 2014a).

The main drivers for increasing GHG emissions are population growth and economic growth. While population growth continued to rise at roughly the same rate, economic growth has risen sharply. Consequently, and despite efforts by some nations and sectors to reduce emissions, total emissions of greenhouse gases to the atmosphere have also continued to grow.

"Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise." *IPCC 2014a, page10*

"Continued emissions of greenhouse gases will cause further warming and will increase the scope and severity of change in all components of the global climate system" *(IPCC 2014a).*

GREENHOUSE GAS SOURCES:

Human contributions of carbon dioxide are produced largely through the processing and consumption of fossil fuels.

Methane is emitted when vegetation is burned, digested or rotted in the absence of oxygen, or from activities such as cattle and rice farming, solid waste disposal, and in the production of oil and gas

Nitrous oxide is released by chemical fertilizers and in the burning of fossil fuels.

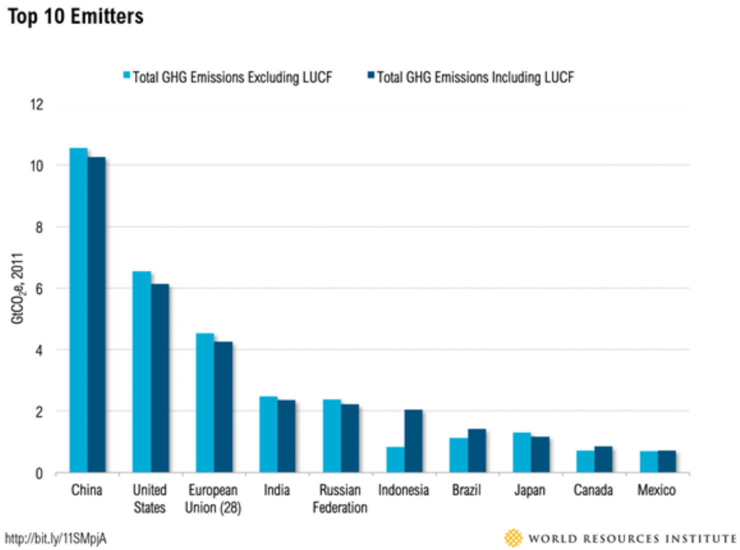

FIGURE 1-6: The top ten nations in annual emissions of greenhouse gases in 2011 *(World Resources Institute 2015).*

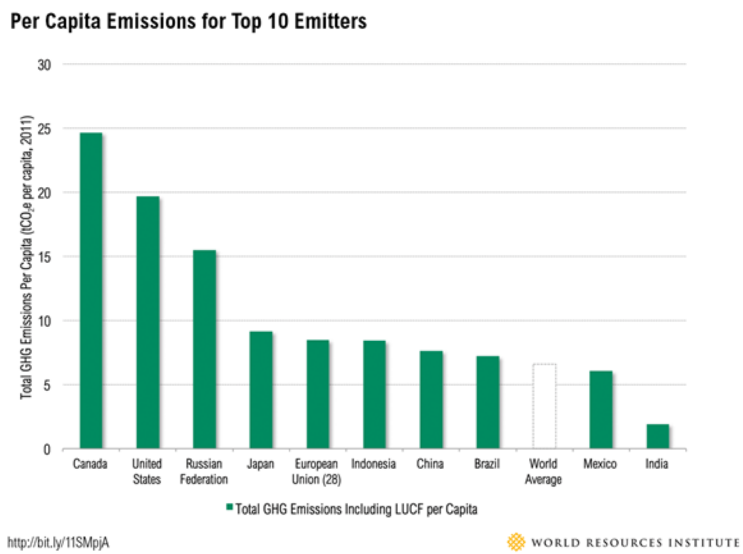

FIGURE 1-7: How the top ten emitters rank in terms of per capita emissions of greenhouse gases *(World Resources Institute 2015).*

As reported by the IPCC (2014b), the largest share of global anthropogenic emissions of greenhouse gases to the atmosphere is contributed by a small number of countries. Canada ranks within the top ten, when LUCF (land use change and forestry) is included in the calculations (Figure 1-6) (World Resources Institute 2015). Based on international data, in 2010 Canada's contribution to carbon dioxide emissions from fuel consumption was only 1.8% of total global emissions. Compared to the total loadings of nations such as China and the United States, Canada's contribution to global emissions is relatively low. However, when Canadian emissions of greenhouse gases are calculated as per capita loadings, we rank #1 in the world, a clear indication on why we should be more concerned over our influence on changing global conditions (Figure 1-7).

It is also important to note that expectations for declines in the percentage of Canada's contributions to global CO_2, may not be the result only of reductions in Canadian emissions but may be based on Canada achieving a lower percentage of the world's emissions based on anticipated rapid growth in emissions from developing countries such as China and India.

Over the period from 1990 to 2014, total emissions of greenhouse gases in Canada grew by 20% (Figure 1-8) (GOV/CAN/ECCC 2016) (Table 1-1). There was a net growth of 23% in Energy sector emissions, largely attributable to the extraction of bitumen and synthetic crude oil from Canada's oil sands. These increases are consistent with a 91% increase in production of crude oil and natural gas over the period, largely for export

TABLE 1-1: Global warming potentials for carbon dioxide, methane, and nitrous oxide *(adapted from IPCC 2013)*

GREENHOUSE GAS	LIFETIME (YEARS)	GWP (20 YEARS)	GWP (100 YEARS)
CARBON DIOXIDE (CO_2)	COMPLEX	1	1
METHANE (CH_4)	12.4	84	28
NITROUS OXIDE (N_2O)	121.0	265	264

LU^{0}F refers to those changes in atmospheric levels of all greenhouse gases that are attributable to changes in land use and forest cover, including activities such as: decreases or increases in biomass stocks due to forest management, logging, fuelwood collection, etc.; conversion of existing forests and natural grasslands to other land uses; the abandonment of formerly managed lands (e.g. croplands and pastures); and emissions and removals of CO_2 in soil associated with land-use change and management. *(Available by region/country from the World Bank at http://data.worldbank.org/indicator/EN.CLC.GHGR.MT.CE).*

The most impactful greenhouse gases affecting the global climate boil down to three; carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O)(IPCC 2013). Of these three, carbon dioxide gets the most attention in popular literature, but the effects of methane and nitrous oxide cannot be ignored, and the differences between the three gases have important effects in how they influence ongoing warming trends. Carbon dioxide is arguably the most impactful over the long term, due to its complex lifecycle in the atmosphere; CO_2 is absorbed and sequestered by the environment in many varying ways, with the result that 60-80% of carbon dioxide emissions will be sequestered within 200 years, but the remaining 20-40% may remain in the atmosphere for thousands of years more (Archer et al. 2009).

Methane and nitrous oxide both have simpler chemical reabsorption processes, over much shorter time frames, but their contribution to warming while they remain in the atmosphere is significantly higher than that of carbon dioxide over the short term of the next decade or century respectively, for equal proportions of each gas (IPCC 2013). This can be quantified by measures such as the Global Warming Potential (GWP) of each gas, as seen in Table 1-1. This measures the relative warming potential of each greenhouse gas, relatively to carbon dioxide's warming effect, over a given period of time. In terms of current warming trends, the vast majority of warming can be attributed to the effects of these three gases. There are other gases which can also contribute to warming in the same manner, but their emissions rates are low enough that they are not currently major influences. As emissions rates change, however, this may change, and tracking these emissions patterns over time is critical.

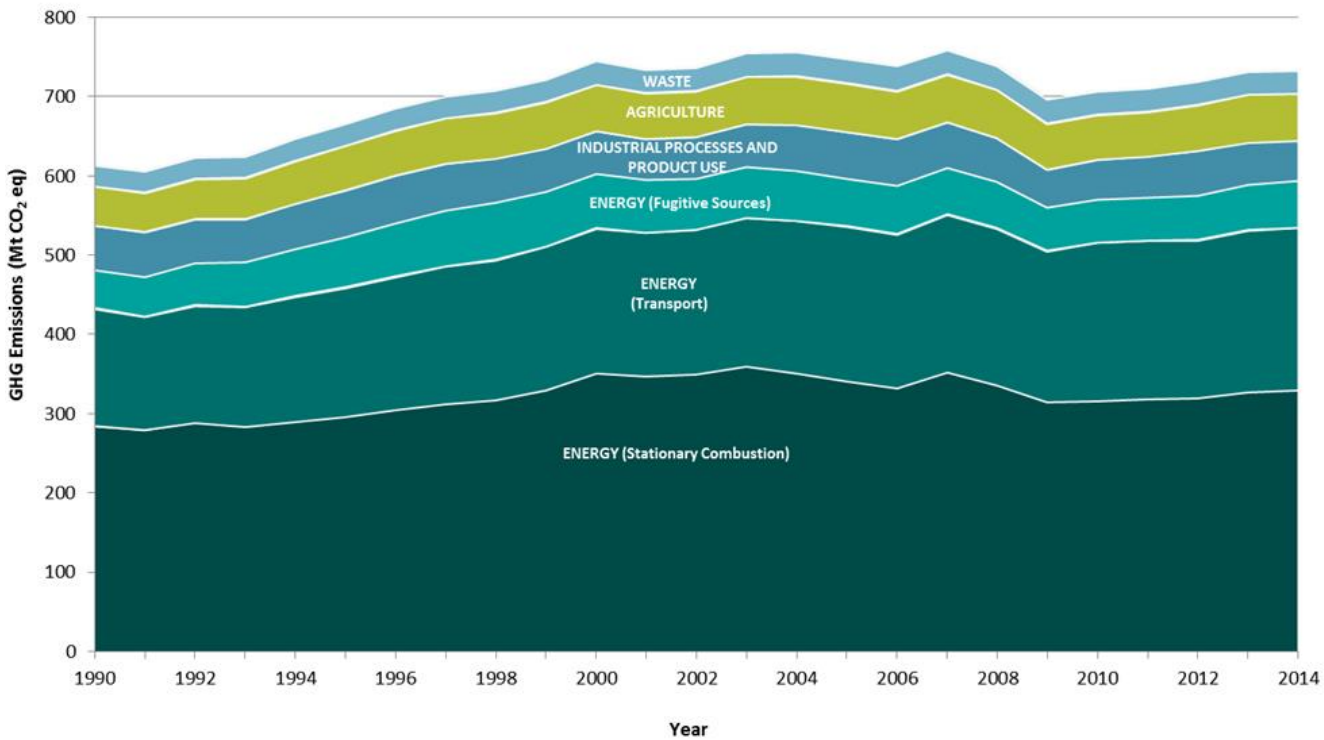

FIGURE 1-8: Trends in Canada's greenhouse gas emissions by IPCC sector *(1990-2014) (GOV/CAN/ECCC*

1.3 THE DIFFERENCE BETWEEN CLIMATE AND WEATHER

The difference between climate and weather is largely a matter of the time over which conditions are recorded. WEATHER records report on conditions in the atmosphere over a relatively short period of time, such as a week, a season or even a decade. Changes in weather patterns across North America can be affected by global events such as seasonal changes in the jet stream, as well as sporadic events such as volcanic eruptions that contribute particulates to the atmosphere, resulting in short-term surface cooling that can last for several years. Natural variations in Pacific oceanic circulation patterns can affect sea temperatures and result in significant regional shifts in air temperature and precipitation patterns (e.g., El Niño, La Niña) (GOV/USA/NAS 2014, 2016). Natural variations in weather patterns often result in some decades being record as 'more stormy', 'drier or wetter', 'warmer or colder' than others, but only the weather, not the climate has changed.

CLIMATE is the average weather for a region based on data collected over a period of 30 or more years. Climate is best understood as the kind of weather that can reasonably be expected in an area at a designated time of the year. By example, winters can be expected to be snowy throughout much of Canada, and summers warmer. Climate is what you expect – a warm summer. Weather is what you get – a hot day with thunder storms. When comparing changes in anticipated weather, such as the frequency and intensity of extreme storm events, scientists require a lengthy data record before they can conclude that a changing climate is now characterized by storms that are more severe or happening more often.

On a global scale, the scientists of the IPCC have in their most recent assessments (IPCC 2014a) become increasingly confident that anomalies in weather systems across the planet are most likely the result of global warming. In Canada and elsewhere climate scientists can yet be reluctant to assign causality for recent extremes in air temperature and severe storm events to human induced changes in climate (Herring et al., 2015). Confidence in the attribution of specific extreme events to anthropogenic climate change is highest for extreme heat and cold events, followed by hydrological drought and heavy precipitation (GOV/USA/NAS 2016).

CLIMATE AND WEATHER

CLIMATE is the pattern of weather measured over decades.

WEATHER is what's happening outside the door right now; today.

CHANGES IN GLOBAL WEATHER EVENTS-

"Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. The frequency or intensity of heavy precipitation events has likely increased in North America and Europe." *IPCC 2013, p5*

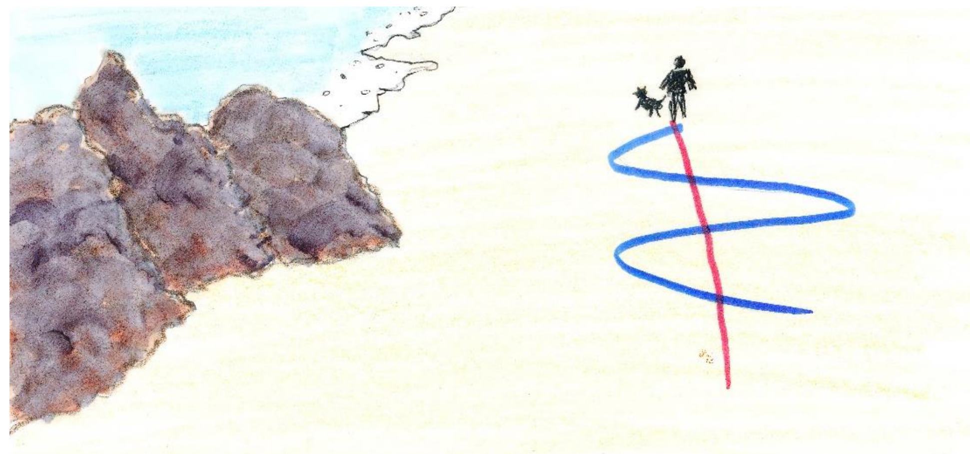

FIGURE 1-9: Neil deGrasse Tyson, scientist and former host of NOVA, breaks down the differences between weather and climate change in a National Geographic Channel podcast (*available at https://www.youtube.com/watch?v=cBdxDFpDp_k*).

1.4 HOW WEATHER MAY CHANGE

The IPCC (2014a) projects that global weather will alter as climate change progresses, anticipating more severe weather events, prolonged periods of precipitation and drought, and more frequent extreme hot and extreme cold days. On any day in any location throughout the world, environmental conditions are complicated by geography, which can make accurate prediction of the scope and pace of changes in weather difficult. As the world warms, expectations for 'normal' weather may become less plausible. The warming climate will contribute to changes in anticipated frequency and expected extremes in temperature, precipitation, and severe weather events. By example, the Government of Canada has projected that the number of extreme hot days (Figure 1-10) (GOV/CAN/Health 2011) and the associated potential for wild fires (Figure 1-11) (Hengeveld et al., 2005) will increase across the country as the atmosphere warms.

HOW DOES GLOBAL WARMING MAKE IT COLDER?

Warming trends are essentially an increase in the amount of energy contributing to weather dynamics around the globe. The result is, broadly speaking, less consistent weather outcomes, resulting in not just a slow and steady average increase in global temperatures, but also greater extremes in terms of both hot *and* cold days. The same holds true of other weather outcomes, such as wind strength and precipitation patterns. While a particular weather pattern may result in unseasonably cold temperatures in one area, global temperatures overall are still warming steadily. In short, steady warming also increases volatility around that rising average.

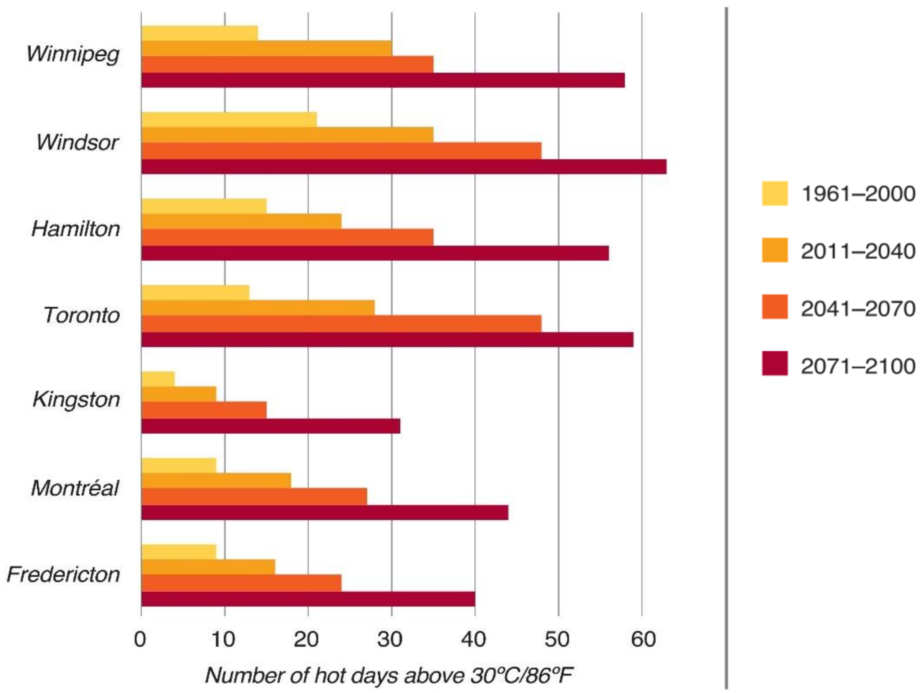

FIGURE 1-10: Number of days with temperatures exceeding 30°C, 2050 vs today (2005) *(adapted from GOV/CAN/Health 2011, p1)*

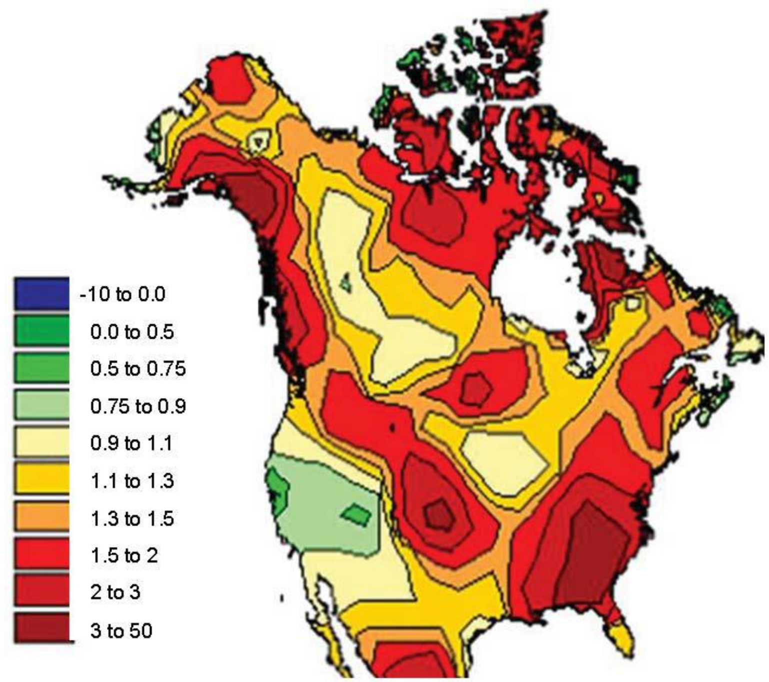

FIGURE 1-11: Projected changes in forest fire risks in 2100 relative to current times. Reported in Hengeveld et al. (2005) and calculated as a ratio of seasonal severity ratings (based on CGCM climate simulations) *(Canadian Forestry Service).*

1.5 HOW WILL GLOBAL WARMING AFFECT NORTH AMERICAN ENVIRONMENTS?

The current situation on atmospheric conditions is unique in history. Scientists are working apace to understand the causative factors and ramifications of the changes that are already upon us, as well as the changes that will come (Table 1-2). However, reliable prediction of the consequences of escalating global warming on the world's environments can be challenging, because human society has never experienced these changes to normal conditions, making the future essentially unknowable.

United Nations
Framework Convention on
Climate Change

Getting the Big Picture: A short video
http://bigpicture.unfccc.int/files/video-1.mp4

TABLE 1-2: IPCC predictions of anticipated environmental changes in North America due to global warming, together with their confidence factors
(adapted from Romero-Lankao et al. 2014, Page 31)

PARAMETER	ANTICIPATED CHANGE	DEGREE OF CONFIDENCE	CONTRIBUTION FROM GLOBAL WARMING
SNOW & ICE, RIVERS AND LAKES, FLOODS AND DROUGHT	Shrinkage of glaciers across western and northern North America	High	Major
	Decreasing amount of water in spring snowpack in western North America	High	Major
	Shift to earlier peak flow in snow dominated rivers in western North America	High	Major
	Increased runoff in the midwestern and northeastern US	High	Major
TERRESTRIAL ECOSYSTEMS	Phenology changes and species distribution shifts upward in elevation and northward across multiple taxa	Medium	Major
	Increased wildfire frequency in subarctic conifer forests and tundra	Medium	Major
	Regional increases in tree mortality and insect infestations in forests	Low	Minor
	Increase in wildfire activity, fire frequency and duration, and burnt area in forests of the western US and boreal forests in Canada, beyond changes due to land use and fire management	Medium	Minor
COASTAL EROSION AND MARINE ECOSYSTEMS	Northward distributional shifts of northwest Atlantic fish species	High	Major
	Changes in mussel beds along the west coast of the US	High	Major
	Changed migration and survival of salmon in northeast Pacific	High	Major
	Increased coastal erosion in Alaska and Canada	Medium	Minor
FOOD PRODUCTION AND LIVELIHOODS	Impacts on livelihoods of indigenous groups in the Canadian Arctic, beyond effects of economic and socio-political changes	Medium	Major

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RESOURCES ON THE WEB

INTERNATIONAL

ARCTIC ADAPTATION EXCHANGE

http://arcticadaptationexchange.com/

An interactive site of the Arctic Council, intended to explore adaptation initiatives and to share knowledge.

AUSTRALIAN NATIONAL CLIMATE CHANGE ADAPTATION RESEARCH FACILITY

https://www.nccarf.edu.au/

The National Climate Change Adaptation Research Facility supports decision-makers throughout Australia who are preparing for climate change and sea level rise. NCCARF has a national focus to build resilience to climate change in governments, NGOs and in the private sector.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

http://www.ipcc.ch

The IPCC Change is the most authoritative source of scientific information on the causes and impacts of climate change, and on the mitigative and adaptive responses being taken throughout the world.

INTERNATIONAL INSTITUTE OF SUSTAINABLE DEVELOPMENT

http://www.iisd.org/publications

Based in Winnipeg, the International Institute of Sustainable Development promotes human development and environmental sustainability through innovative research, communication and partnerships. The IISD library provides access to information on climate change, mitigation and adaptation throughout the world.

UNION OF CONCERNED SCIENTISTS

http://www.climatehotmap.org

This map-based web site of the Union of Concerned Scientists documents the effects of global warming from around the world.

UNITED NATIONS FRAMEWORK ON CLIMATE CHANGE

http://www.unfccc.int

This UNFCC site provides links to recent events on climate change, as well as to reports and other information relating to the United Nations Framework Convention on Climate Change, the Kyoto Protocol and COP21 Paris.

UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM

http://www.globalchange.gov/

The USGCRP is intended to assist the United States and the world in understanding, assessing, predicting and responding to human-induced and natural processes of global change. The site is a clearing house for information on global warming, climate change, and mitigative and adaptive activities

UNITED STATES NASA GLOBAL CLIMATE CHANGE

https://climate.nasa.gov/interactives/climate-time-machine

NASA provides visual simulation of actual changes in global parameters such as sea ice, sea level, carbon dioxide and global temperature.

UNITED STATES NOAA CENTERS FOR ENVIRONMENTAL INFORMATION

http://www.ncdc.noaa.gov/climate-information

NOAA's site provides data and information on climate trends and changes

WORLD METEOROLOGICAL ORGANIZATION

https://public.wmo.int/en/our-mandate

As a specialized agency of the United Nations, WMO is dedicated to international cooperation and coordination on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces, and the resulting distribution of water resources

WORLD RESOURCES INSTITUTE

http://www.wri.org/

The World Resources Institute s a global research organization that spans more than 50 countries. Experts and staff work closely with leaders to turn big ideas into action to sustain natural resources-the foundation of economic opportunity and human well-being. The WRI focuses on six critical issues at the intersection of environment and development: climate, energy, food, forests, water, and cities and transport.

PCC VIDEO: CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS

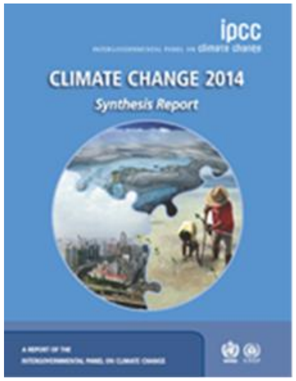
https://www.youtube.com/watch?feature=player_embedded&v=6yiTZm0y1YA

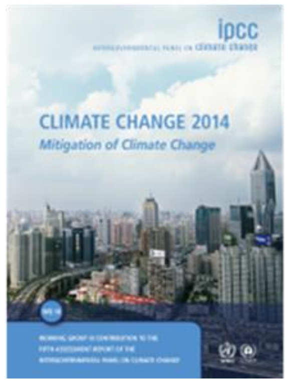
The IPCC has produced a video on its Fifth Assessment Report (AR5). The first part on the Working Group I contribution to AR5 is now available. A wide array of additional videos are available at https://www.youtube.com/c/ipccgeneva

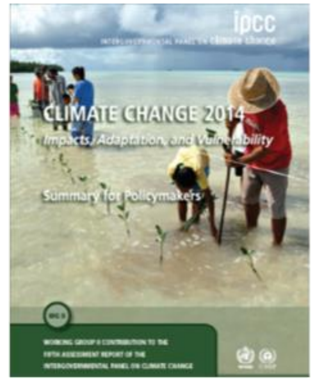
KEY REPORTS

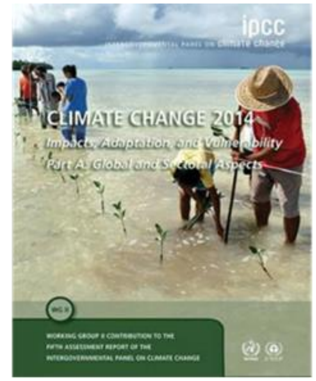
THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE: REPORTS OF THE FIFTH ASSESSMENT

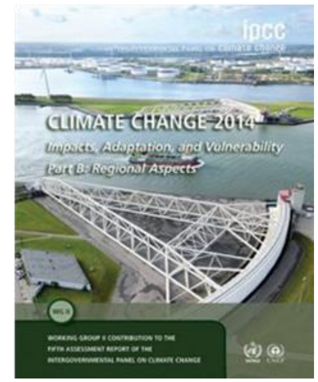
Available at https://www.ipcc.ch/report/ar5/index.shtml











2 CLIMATE CHANGE AND CANADA

2.1 CANADA'S (ALREADY) CHANGING CLIMATE

Climate change is already happening. Across the globe there are more heat waves, seas are rising, and erratic weather is creating havoc. Canada's climate is also changing. For more than sixty years, scientists have observed a general warming trend in air temperatures (Figure 2-1), averaging an increase of 1.5 C° between 1950 and 2010 (Warren and Lemmen 2014) (Figure 2-2). All of Canada is projected to get warmer in the future (Figure 2-3). When compared to warming trends throughout the world, Canadian environments (especially in the North) appear to be warming at a rate that is approximately double the reported global average (Hartmann et al. 2013).

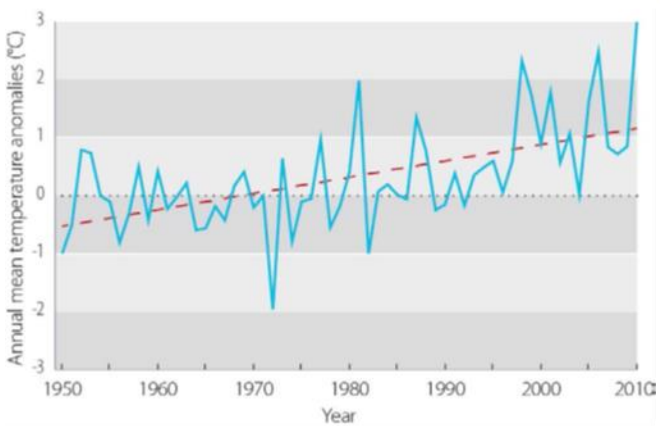


FIGURE 2-1: Warming trends in Canada from 1948-2012 *(GOV/CAN/ECCC 2015).*

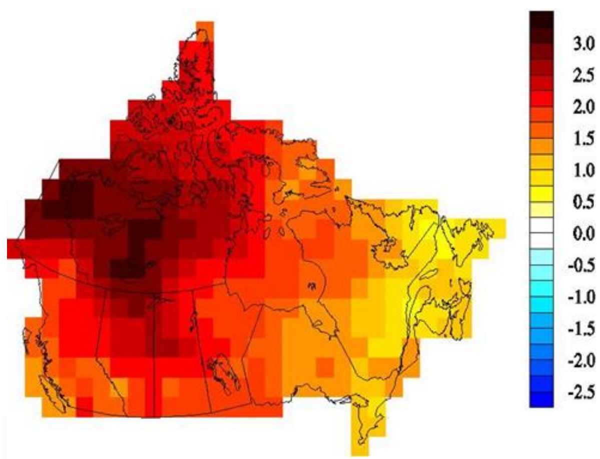


FIGURE 2-2: Annual mean temperature change for Canada (°C), 1950–2010, relative to the 1961–1990 average (represented by zero on the Y-axis) (*Warren and Lemmen 2014).*

CANADA IN A CHANGING CLIMATE: KEY MESSAGES

Warming over the 20th century is indisputable and largely due to human activities.

- Canada's rate of warming is about twice the global rate: a 2ºC increase globally means a 3 to 4ºC increase for Canada.
- Effects will persist for centuries because greenhouse gases (GHGs) are long-lived and the oceans are warming.
- Cumulative CO_2 emissions largely determine ultimate warming. A 2ºC warming target may still be attainable, but we are already 65% of the way to carbon concentrations that would result in a 2ºC shift.
- GHG emissions need to become net zero in order to stabilize climate at any temperature.
- Canada's climate is already changing, with observed changes in air temperature, precipitation, snow and ice cover and other indicators. Further changes in climate are inevitable.
- Changes in climate are increasingly affecting Canada's natural environment, economic sectors and the health of Canadians.
- Extreme weather events are a key concern for Canada and there is growing confidence that some types of extreme events will increase in frequency and/or intensity as the climate continues to warm."

(Extracted from GOV/CAN/ECCC 2015 and Warren and Lemmen et al. 2014).

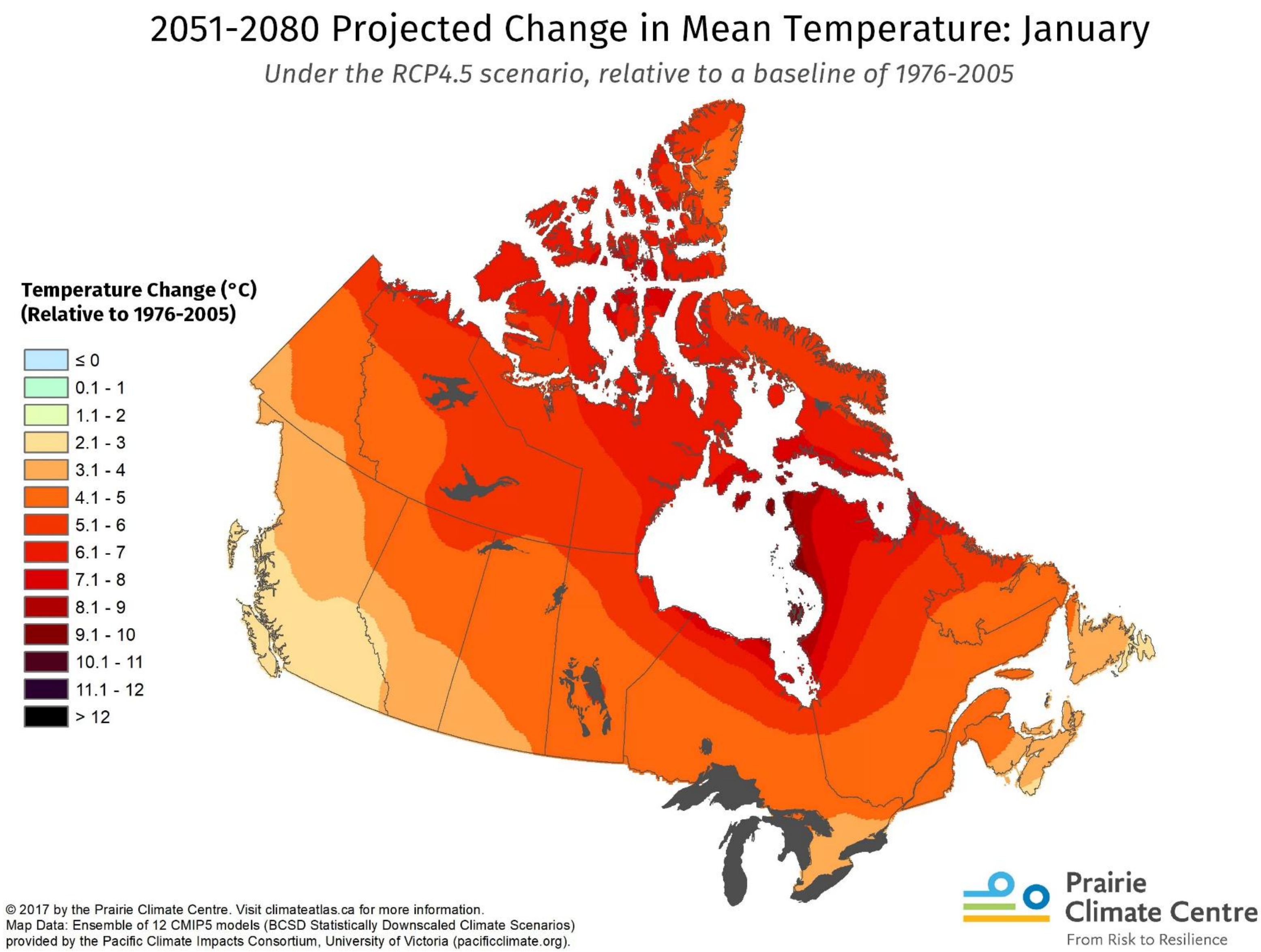


FIGURE 2-3: Projected change in mean January temperatures in Canada *(Source: Prairie Climate Centre. Available at http://prairieclimatecentre.ca/2017/10/new-map-series-highlights-changes-coming-to-canadas-climate /).*

Throughout the Arctic, in both winter and summer, there have been significant declines in sea ice (Figure 2-4). Reductions in the coverage of winter sea ice have also been noted in more southern areas, such as the Gulf of St. Lawrence. Snowfall has decreased in the south, sometimes associated with earlier onset of spring melts, and with shrinkage in the areal extent of glaciers. During this same period (1950-2010), most areas in Canada have generally become wetter (Figures 2-5, 2-6). Annual average precipitation has increased in many areas, but changes in precipitation trends are less consistent across the country than the trends towards increasing temperatures.

New projections from the Prairie Climate Centre demonstrate how precipitation patterns are expected to change across the country during spring and summer (Figure 2-7).

FIGURE 2-4: Trends in Arctic sea ice extent over the period 1979–2012 shown as time series of the percentage difference in ice extent in March and September relative to the mean values for the period 1979–2000. Both trends are statistically significant *(Warren and Lemmen 2014)*.

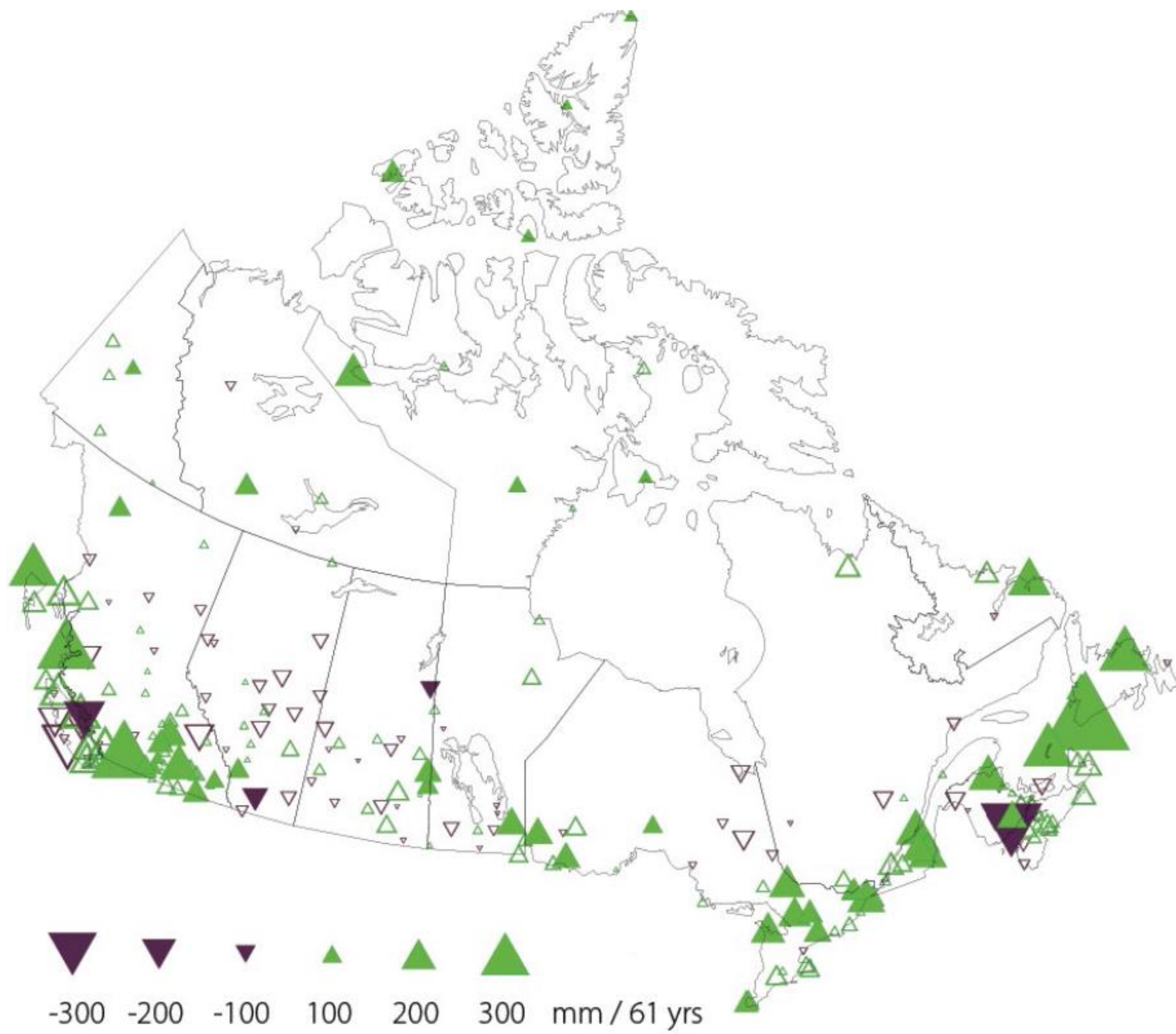
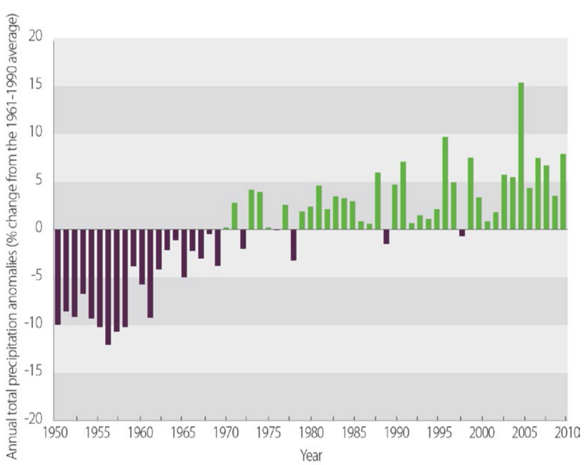
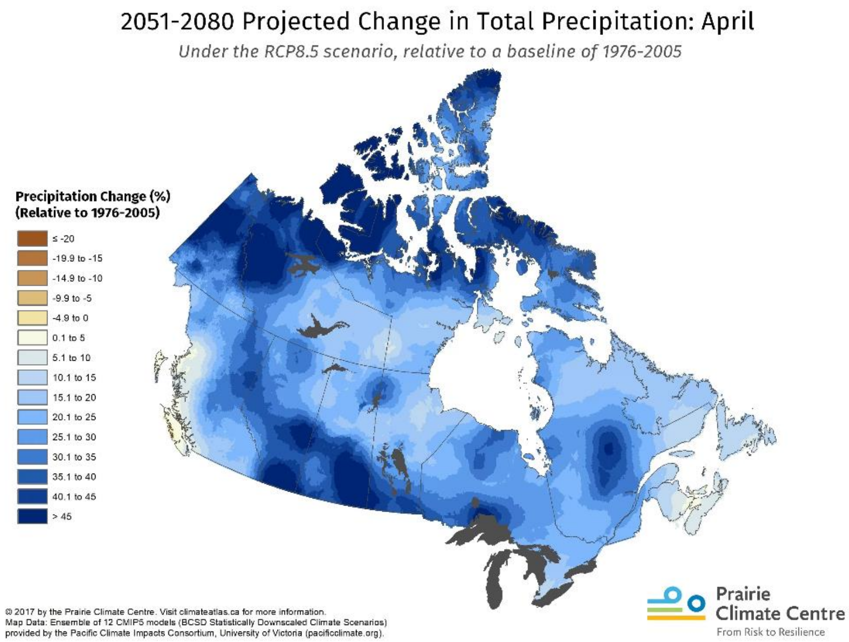


FIGURE 2-5: Patterns of change in annual total precipitation over the period 1950–2010. Upward (green) and downward (purple) pointing triangles indicate positive and negative trends, respectively. Filled triangles correspond to trends significant at the 5% level *(Warren and Lemmen 2014)*.

FIGURE 2-6: Inset: Annual total precipitation anomalies (expressed in % change from the 1961–1990 average) for Canada, 1950–2010 (*Warren and Lemmen 2014)*.





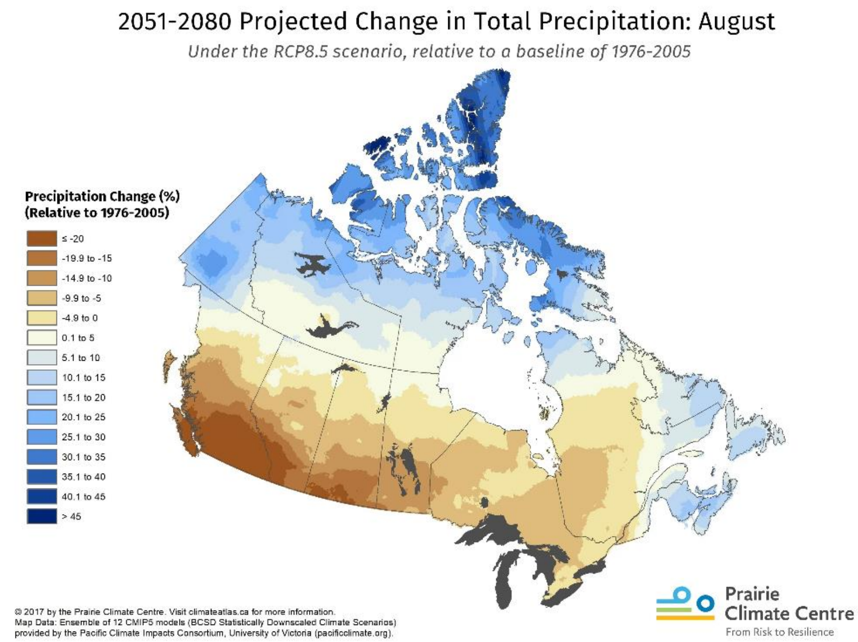


FIGURE 2-7: Projected changes in total precipitation during April and August across Canada *(Source: Prairie Climate Centre. Available at http://prairieclimatecentre.ca/2017/10/new-map-series-highlights-changes-coming-to-canadas-climate/).*

Climate Atlas of Canada

The Climate Atlas of Canada combines climate science, mapping and storytelling to bring the global issue of climate change closer to home for Canadians. It is designed to inspire local, regional, and national action that will let us move from risk to resilience.

In a series of papers and videos, the Climate Atlas provides up to date information on changes in weather and climate already occurring or anticipated to occur throughout Canada. The Atlas is a unique source for information specific to local areas throughout the country.

https://climateatlas.ca

TABLE 2-1: A synopsis of some of the recorded and/or anticipated environmental changes in Canada. The intensity of projected changes will depend on the climate change scenarios chosen but will be greater for those scenarios that have assumed continuing global high emissions of greenhouse gases (*Adapted from information provided in Warren and Lemmen 2014, with material from additional sources).*

PARAMETER	ALREADY OBSERVED CHANGES	PROJECTED CHANGES
TEMPERATURE		
Seasonal temperature	Data since 1948 show predominant warming trends in every season, but these trends are most severe in the winter and spring, and particularly in the northern regions (Hengeveld et al., 2005).	Warming will be greatest in winter, especially in northern Canada. In summer, the largest increases are projected for southern Canada and the central interior.
Extremes in daily temperature	Since 1950 the frequency of hot days (the highest 10% of daily maximum temperatures) in summer has increased and the frequency of cold nights (the lowest 10% of daily minimum temperatures) in winter has decreased nationally since 1950.	Increases in the frequency and magnitude of unusually warm days and nights and decreases for unusually cold days and nights are projected to occur throughout the 21st century.
Long duration hot events	Overall, across Canada, there has been increasing trends of warmer days and nights, combined with declining trends of cooler days and nights, the combination of which amounts to an increasing tendency towards heat waves (Vincent and Mekis 2006).	The length, frequency and/or intensity of warm spells, including heat waves, are projected to increase over most land areas.
Rare hot extremes	In 2014, the Northwest Territories and British Columbia experienced a range of hot extremes during spring and summer, some of which had not been recorded in over 100 years (Blunden and Arndt 2015).	Rare hot extremes are currently projected to become more frequent. For example, by mid-century a one-in-20-year extreme hot day is projected to become about a one-in-5 year event over most of Canada
PRECIPITATION AND HYDROLOGICAL INDICATORS		
Seasonal precipitation	Canada has generally become wetter in recent decades, and some southern regions have observed less snowfall and more rainfall. .	Increases in precipitation are projected for most of Canada in all seasons, with the exception of parts of southern Canada where precipitation in summer and fall is expected to decline,
Heavy precipitation	To date, while precipitation rates have generally been on the rise across Canada, the prevalence of heavy or extreme precipitation events has not followed the same trend, showing only a marginal national increase over the same period (Vincent and Mekis 2006).	Over most of Canada, extreme precipitation events are projected to double in frequency by mid-century.
Streamflow	Much of southern Canada experienced lower maximum and lower minimum river flows over the period 1970-2005. Parts of the North (e.g., western Nunavut, Northwest Territories, Yukon and northern British Columbia) have recorded increases in minimum flows.	Increases in winter streamflow are projected for many parts of southern Canada. Mean annual streamflow is anticipated to decrease in areas of Alberta and Saskatchewan, while projections for other regions vary across different climate scenarios
SNOW COVER		
Snow cover duration	Over the Canadian land mass, there has been a declining trend in the area of snow cover during the spring, with the largest changes reported in northern areas in June.	Widespread decreases in the duration of snow cover are projected across the Northern Hemisphere with the largest changes occurring in maritime mountain regions, such as British Columbia.
Snow depth	In the last 60 years, snow fall has declined throughout most of southern Canada, and increased in the north.	Maximum snow accumulation over high latitudes in the north is projected to increase.
PERMAFROST		
Ground temperature	Permafrost temperatures as measured across the North have increased in the last 20 to 30 years.	Warming of the permafrost is projected to continue at rates surpassing those observed to date, however for much of the colder areas of permafrost in the Arctic it will take decades to centuries to completely thaw (Segal et al. 2016)

PARAMETER	ALREADY OBSERVED CHANGES	PROJECTED CHANGES
SEA LEVEL		
Global sea-level rise	Between 1880 and 2012, average global sea levels rose about 21 cm (averaging 1.6 mm year).	Estimates of future changes in global sea level (by 2100) range from a few tens of centimetres to more than a metre, depending on local conditions. Global sea-level rise after 2100 is expected to continue during the coming centuries and millennia, and may eventually amount to several metres.
Relative sea-level rise in Canada (refer to Chapter 2.5 for more information)	In parts of Canada, land subsidence (e.g., parts of Atlantic Canada) and land rising (e.g. parts of the north) have for hundreds of years contributed to changes in sea levels. Relative sea-level rise of over 3 mm/year has been observed on coastlines of Atlantic Canada and the Beaufort Sea coast, with lower amounts along Pacific coastlines. Relative sea level fall of 10 mm/year has been observed around Hudson Bay where the land is rising rapidly due to post-glacial rebound.	Sea levels along Canadian coastlines will continue to be influenced by land uplift and subsidence as well as by changes in global sea levels. Where the land is rising, it will temper rising sea levels. In some areas where sea levels have been falling, the trend may reverse. Where the land is subsiding, it will contribute to increases in the rate for rising sea levels.
OCEAN CLIMATE		
	Long-term observations have recorded increasing ocean temperatures and acidity in all three of Canada's oceans. Long-term decreases in subsurface dissolved oxygen levels have also been observed in the Atlantic and Pacific oceans off Canada.	Warming trends will continue, particularly with regards to surface waters, although warming trends in deeper waters are also present and will lead to much longer-term consequences. As well, due to changes in the global water cycle, salinity in Canada's three oceans is expected to significantly decrease over the next century, to a greater extent than oceans surrounding most other nations (IPCC 2013).
ICE COVER		
Arctic summer sea ice	End-of-summer minimum ice extent has declined at a rate of 13% per decade over 1979-2012, while maximum winter sea ice extent has declined at a rate of 2.6% per decade. Declines in winter sea ice extent have also been observed in the Labrador-Newfoundland and Gulf of St. Lawrence region. Sea ice in the Arctic has also been shifting from dominated by thicker multi-year ice, to increasing areas of thinner, single year ice.	A nearly ice-free summer is considered a strong possibility for the Arctic Ocean by the middle of the century although summer sea ice may persist longer in the Canadian Arctic Archipelago region.
Lake and River Ice	Since the mid-20th century, trends towards earlier ice-free dates (lakes) and ice break-up dates (rivers) have been observed for most of the country but are particularly evident in Western Canada.	With the continued advance of ice cover break-up dates and delays in ice-cover freeze up, ice cover duration is expected to decrease by up to a month by mid-century.
GLACIERS		
Glacier mass – Yukon, British Columbia, Alberta	Western Cordilleran glaciers are losing mass and shrinking rapidly to the smallest extents in several millennia.	The volume of glacier ice in western Canada is projected to shrink by 70% by 2100, with the greatest loss occurring between 2020-2040. Maritime glaciers in the British Columbia Rockies will survive but in a diminished state (Clarke et al. 2015).
Glacier mass – High Arctic	Arctic glaciers have been losing mass since the early 1960s. Since 2005, the rate of mass loss for glaciers throughout the High Arctic has increased sharply in direct response to warmer regional summer temperatures.	Projections for future glacier volume loss by 2100 estimate that the Canadian Arctic region will be the world leader in this category, seeing greater loss of mass than any other region (Radic et al. 2013).

2.2 CHANGES IN AIR TEMPERATURE AND SEASONALITY

Global temperatures have already increased from pre-industrial records, with 2015 recorded as the warmest year on record. Throughout much of Canada climate change is expected to raise mean annual temperatures, a situation that may be slightly tempered in coastal areas by proximity to the oceans. In addition to changes to both mean and extreme seasonal air temperatures, there is potential for the timing of seasons to alter. Some areas may experience a form of *weather whiplash* arising when there are rapid and extreme shifts in weather from one season to the next.

Changes in the number of expected days per year of extreme heat or cold will challenge existing infrastructure and energy grids and pose risks to human well-being (CPHA 2015; GOV/CAN/Health; GOV/CAN/ON 2016).

Warming air temperatures will also affect water chemistry, resulting in increased acidification and decreased oxygen and knock-on impacts to fecundity, growth, and predator-prey relationships of species in freshwater, terrestrial and marine ecosystems (Figure 2-8). Species that are less able to accommodate to changing conditions, and invading species that are better able to flourish under the new regimes, will compete for habitat, with some species changing in range and in population.

Changes in temperature and seasonality will affect resource sectors such as fisheries, forestry, and agriculture, some negatively, others positively. Tourism in some areas may benefit from longer warmer weather, but winter-based sport and recreation could also suffer. Demands on the energy sector will likely increase, relative to the need for heat and for air conditioning, especially in areas that previously did not need cooling technologies.

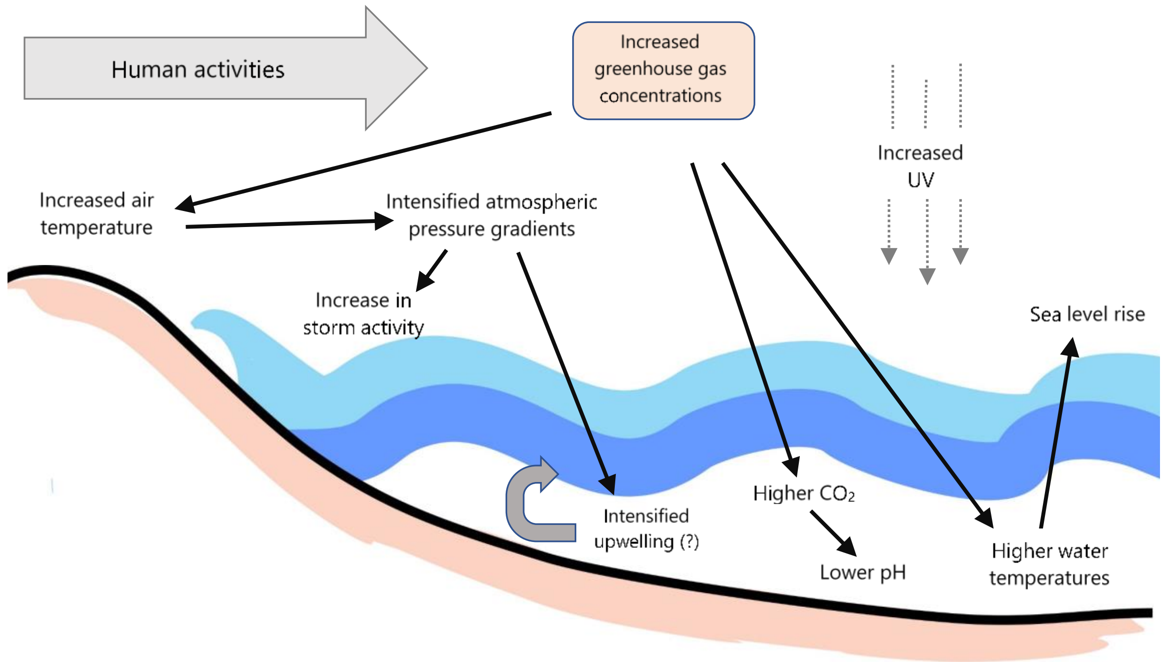


FIGURE 2-8: Human activities such as the burning of fossil fuels, and deforestation lead to increased concentrations of greenhouse gases in the atmosphere. Subsequent global warming results in is a range of physical and chemical changes in the oceans, some of which (e.g., upwelling) are as yet not understood *(Adapted from Harley et al. 2006, p. 230).*

2.3 CHANGES IN ICE COVER

In Canada's North, and on mountain ranges throughout the country, there is a growing concern over the effects of continued warming of planetary and oceanic temperatures on multi-year ice such as sea ice and glaciers. Glaciers will melt, and sea and lake ice cover will be reduced, changing evaporation and run-off patterns, and affecting the timing of spring flushes (Ford et al. 2016; Lemmen et al. 2008). However, across Canada, changes in ice cover on the Great Lakes and St. Lawrence seaway, on near shore coastal waters, and in the thousands of lakes, rivers and wetlands of the nation, will also have physical, chemical, biological and economic consequences.

In the North reduced surface coverage, coupled with the thinning of polar sea ice, is reducing cover and habitats for marine species (e.g., polar bears), and increasing risks to First Nations hunters and fishers as they seek important sources of 'country food'. As ice cover changes in extent and thickness, the breeding, feeding and migration patterns of other species will be affected.

In the North and on more southern mountains, glacial melt has already accelerated, with some glaciers expected to vanish by as early as 2100 (Figure 2-9). Changes in glacial melt quantities and timing will affect downstream conditions in rivers and lakes in British Columbia important to salmon breeding, rearing and migration. Increased water temperatures, coupled with lower volumes pose threats to the continuing viability of these and other aquatic species, and to the communities who are dependent on these resources.

Changes in the extent and thickness of ice cover on lakes, rivers and oceans will have widespread effects on shorelines across the nation. Areas more used to the shore protection offered by winter ice cover will now face increased erosion and sedimentation from storm waves and nearshore currents. In other areas, ice breakup will contribute to erosion of shorelines, especially in Northern areas when loss of ice cover is coupled with thawing permafrost and destabilizing soils.

Along the Great Lakes, winters with more ice cover than normal will reduce evaporation but affect migratory bird patterns and may result in later springs and cooler temperatures. During warmer than usual winters, evaporation from exposed water will contribute to higher rain and snowfall.

SEA ICE AND WARMER WATER

Reduction in sea ice in the North and in the Gulf of St. Lawrence will increase wind and wave erosion on shorelines. Coastal areas in the southern Atlantic region that are already experiencing crustal subsidence will be more severely affected by rising sea levels. Rising sea temperatures and oceanic acidification will affect lifecycles in shellfish and sea corals. Salt marshes, trapped between rising seas and the shoreline, may experience significant loss in area and productivity. Summer tourism could benefit from warming temperatures but could also be negatively affected by increasing storminess.

ICE COVER IN THE GREAT LAKES

In some years, ice will cover the surfaces of some of the Great Lakes, reducing evaporation, but contributing to later springs. In years when temperatures remain higher and the lake surfaces do not freeze, evaporation can lead to heavier snow conditions.

COUNTRY FOOD refers to the traditional food of the Inuit (e.g., arctic char, seal meat, whale, caribou, etc.). Originally consumed for day to day survival, country foods now connect families and community and are best shared. Country food can also be an important food source in remote areas.

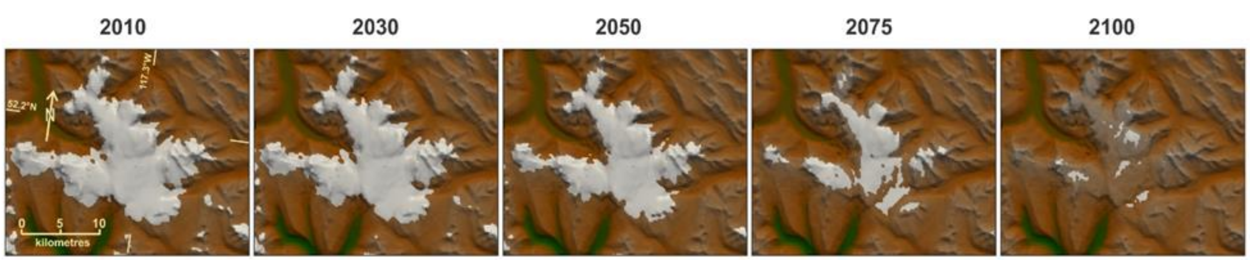


FIGURE 2-9: Projected deglaciation to 2100 in the Columbia Icefield in Western Canada (based on continuing high global emissions of CO_2 *(Clarke et al. 2015, used with permission).*

2.4 CHANGES IN STORM INTENSITY AND IN RETURN PERIODS

For planning and design professionals, as well as other decision-makers, changes in weather patterns become important when they affect minimal standards for construction, and when they alter the anticipated return periods of major precipitation events. Climate scientists in other northern countries such as the United Kingdom (Sanderson 2010) have already anticipated changes to expected conditions that can include increased precipitation, and more heavy precipitation events during winter seasons, and less precipitation, concentrated in intense downpours from storm events. In Canada, studies on changes in return periods for extreme conditions have returned disturbing conclusions. In Quebec, researchers anticipate that climate change may result in "very serious increases in the volume of runoff, maximum discharge and water level", a situation that will become more drastic as longer return periods are considered and may result in increases of 250% in current maximum water discharge, and water levels that are considerably higher than current guidelines for flood events (Roy et al. 2001, p3167). In British Columbia, peak design discharges are estimated to increase by more than 100% by 2050 (Denault et al. 2002).

Researchers with Natural Resources Canada (GOV/CAN/NRCan 2008) concluded that by 2100, storm surges (e.g., 3.6m above mean sea level) in the southern Gulf of St. Lawrence which currently are anticipated to occur once in every 40 years, will occur every year. Rising sea levels would produce higher storm surges (i.e., 4.0m-4.22m) that could occur every 10 to 15 years, even if current conditions for the intensity of storms did not change.

FIGURE 2-10: Storm surge damage to road, Ferryland NL. *(Image Credit: Natural Resources Canada),*

Storms are not necessarily getting stronger, but Canada's aging infrastructure (buildings, stormwater systems, seawalls) are taking more of a beating.

David Phillips, Senior Climatologist, Environment Canada (as reported in The Canadian Press 2015).

2.5 CHANGES ON COASTS AND SHORES

In Canada, and internationally, there have been many long term, principled and sometimes heated debates on what is included when we refer to the 'coast'. Early definitions for the coastal 'zone' drew heavily on the tenets of the international *Law of the Sea,* reinforcing views of a coast defined by its adjacency to a marine shoreline. As a result, early efforts towards a more integrated form of management for coasts relied on landward geospatial boundaries measured as a (relatively short) distance inland from the shoreline (mean sea level). Arbitrary boundaries such as these failed to allow for migratory patterns, for shared ecosystem functions between watersheds and coastal waters, or for the intricate relationships humans and their settlements have with the coast, its cultural assets, and its resources. For Canada, this interpretation also excluded the massive coasts of the Great Lakes, and other large lake and riverine systems. In reality, marine and freshwater coasts share more similarities than they do differences.

Canada's coasts are **diverse landscapes** comprised of a complex array of intertwined components that include:

- **terrestrial, aquatic and marine ecosystems** linked through shared spatial, temporal and functional attributes;
- transition areas or **ecotones** that bridge these ecosystems; and
- co-dependent **human communities** responsible for both the exploitation and protection of coastal resources and ecosystems.

Adapted from Mercer Clarke 2010, p143

To better advance conservation and sustainable management for coastal areas, an increasing number of agencies, including international organizations, have moved away from the notion that coasts are largely focussed on the marine environment. Ecosystem based forms of management, which seek to better understand the linkages among terrestrial, aquatic and marine environments, rely on a broader interpretation of 'coast' to formulate effective management alternatives for deleterious human activities.

Coasts are best considered as landscapes, comprised of nested terrestrial, aquatic, and marine ecosystems and human society. Coastal landscapes include the nearshore water environments, the aquatic systems (lakes, rivers and marshes) that feed into those receiving waters, and terrestrial environments that may stretch inland as far as it is necessary to aid understanding and to enhance effective management. Humans and their communities are clearly a major component of this landscape. Coastal communities are understood to be those settlements that are situated on or near a shoreline, or that have important cultural and/or economic linkages to the shore and to larger freshwater or marine environments. As the climate changes throughout the world, the effects on coasts in Canada will vary greatly across the country. Scientists are working furiously to understand the physical and chemical changes, to anticipate the effects of these on ecosystem structure and function, and to best prepare human society for the world to come.

We need to see our coasts as landscapes,

not as lines in the sand.

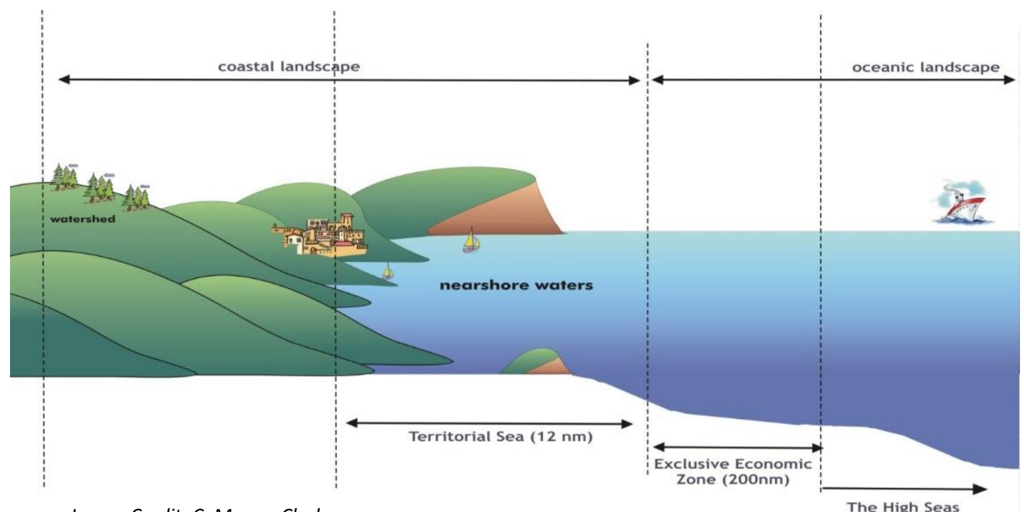


Image Credit: C. Mercer Clarke

FIGURE 2-11: Coastal landscapes *(Mercer Clarke 2010)*

Coasts are diverse, changing environments. Natural processes such as currents, wind and waves, and ice constantly reshape shorelines, depositing accrued sediments in calmer bays, changing sandy beaches to cobble, and collapsing bluffs (Figure 2-12). Glaciers carved bays and deposited entrained materials as drumlin islands. Changing water levels over time stranded some beaches on land and flooded others.

Canadian coastal landscapes have also been shaped by human activities. With the arrival of the first European settlers, large areas of salt marsh throughout what is now Nova Scotia and New Brunswick were dyked and drained for agriculture. Forests were harvested for lumber for ship-building and fuel, and farms sprang up all along the eastern and western shores of the country. For the past four hundred years, coastal landscapes have altered and evolved as first farming, then urbanization spread across large expanses of the country. Shorelines were hardened, beaches mined for sand and rock, harbours deepened, and backshores paved. Causeways and bridges disrupted long shore currents and patterns in erosion and deposition. Port facilities for the transportation of goods and services by sea steadily increased throughout the country, extending into Northern areas as regional settlements expanded and new areas opened to exploitation by the mining and oil and gas sectors. The coasts of Iqaluit NU, and Mahone Bay NS, are not the coasts our ancestors knew, nor will they be the coasts our grandchildren rely on.

Throughout Canada, coastal areas and coastal communities will face the same challenges posed by climate change to inland communities (e.g. extremes of heat and cold, cloud bursts and droughts, and higher and more frequent floods). The most readily observable impacts will be to areas vulnerable to inundation from rising sea levels and higher storm surges. However, even with the dampening effect of the marine environment, there will be more extreme heat and cold days, as well as general warming trends throughout the year. Changes to precipitation patterns may lead to either floods or droughts in some areas, and alterations to seasonal weather will include more severe and more frequent storms. Precipitation changes may also contribute to landslides in some areas, and to lowering of the groundwater table in others. The total area covered by sea ice in the Arctic and the Gulf of St. Lawrence will decline, with spring breakups of the ice coming earlier. Shorelines will change as a result of instability produced by thawing permafrost, and an increased vulnerability to erosion and sedimentation resulting from loss of sea ice, higher energy wave conditions, sea-level rise and storm surges (Figure 2-13). Changes in the volume, quality and periodicity of riverine inputs, especially those dependent on glacial meltwater, will physically affect nearshore marine and estuarine environments, resulting in changes to deltas, marshlands, and to beach and dune complexes.

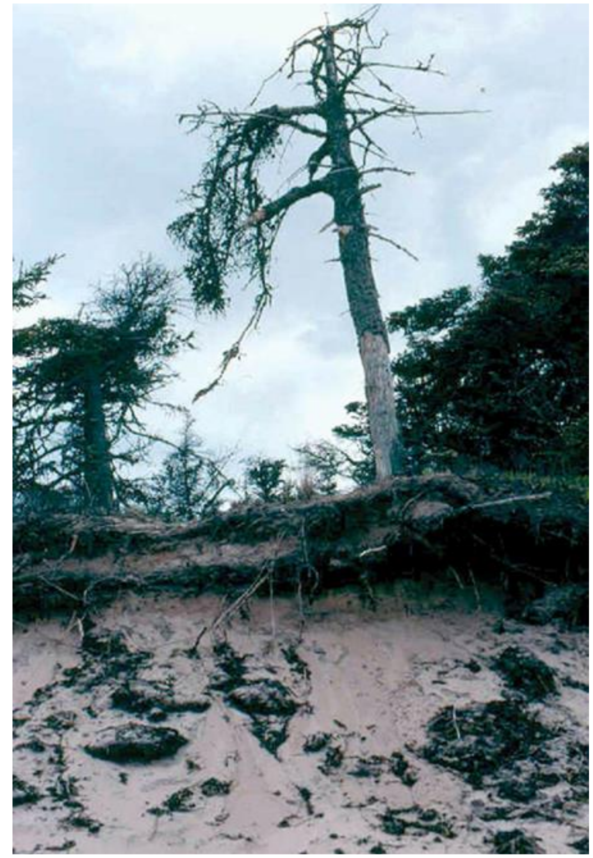


FIGURE 2-12: Wind and erosion of conifers, Red Point PE *(Image Credit: NRCan)*

FIGURE 2-13: Coastal erosion on Pelly Island NWT *(Image Credit: NRCan, Whalen Team)*

2.5.1 CHANGING SEA LEVELS

To better understand how rising sea levels will affect coastal areas in Canada, it is important to differentiate between absolute sea level and relative sea level.

Absolute sea level measures the height of the ocean surface in relation to the centre of the Earth. However, just as the Earth surface is not flat, the surface of the ocean is also not flat. In North America, absolute sea levels have been recorded as higher on the Western coast than on the Eastern coast. When reporting changes in Global Sea-level rise, these changes in absolute sea level refer to an increase that has been observed in the average Global Sea Level Trend. Global Sea Level rise is primarily attributed to changes in the volume of oceanic water caused by melting glaciers, and thermal expansion of water because of warming air temperatures.

Relative sea level, which is the more important parameter for coastal decision-makers, is a local datum derived from combining the accepted mean sea level (MSL), which is the average water level (i.e., the midpoint between a mean low tide and a mean high tide), with local calculations of vertical land motion (i.e., whether the land mass is rising or falling).

Mean sea level is a vertical datum that serves as a standardized geodetic reference point used as a chart datum in bathymetric charts, and in marine and aviation navigation (mean sea level is a standard against which aircraft elevations are measured).

Vertical land motion refers to land uplift and land subsidence. Throughout much of Canada, vertical land motion is largely the result of glacial isostatic adjustment or postglacial rebound, which occurs when the land mass moves in a delayed response to the advance and retreat of the continental ice sheets of the last ice age. Some vertical land motion may also be a response to compaction and dewatering of sediment layers, or from strains accrued in the Earth's crust near active fault lines. As global sea levels rise resulting from climate change, the changes in relative sea level observed at the coast may be offset in areas where the land is also moving upward (e.g., parts of Hudson Bay), or may be exacerbated in areas where the land is sinking (e.g., the Atlantic shore of Nova Scotia) (Figure 2-14).

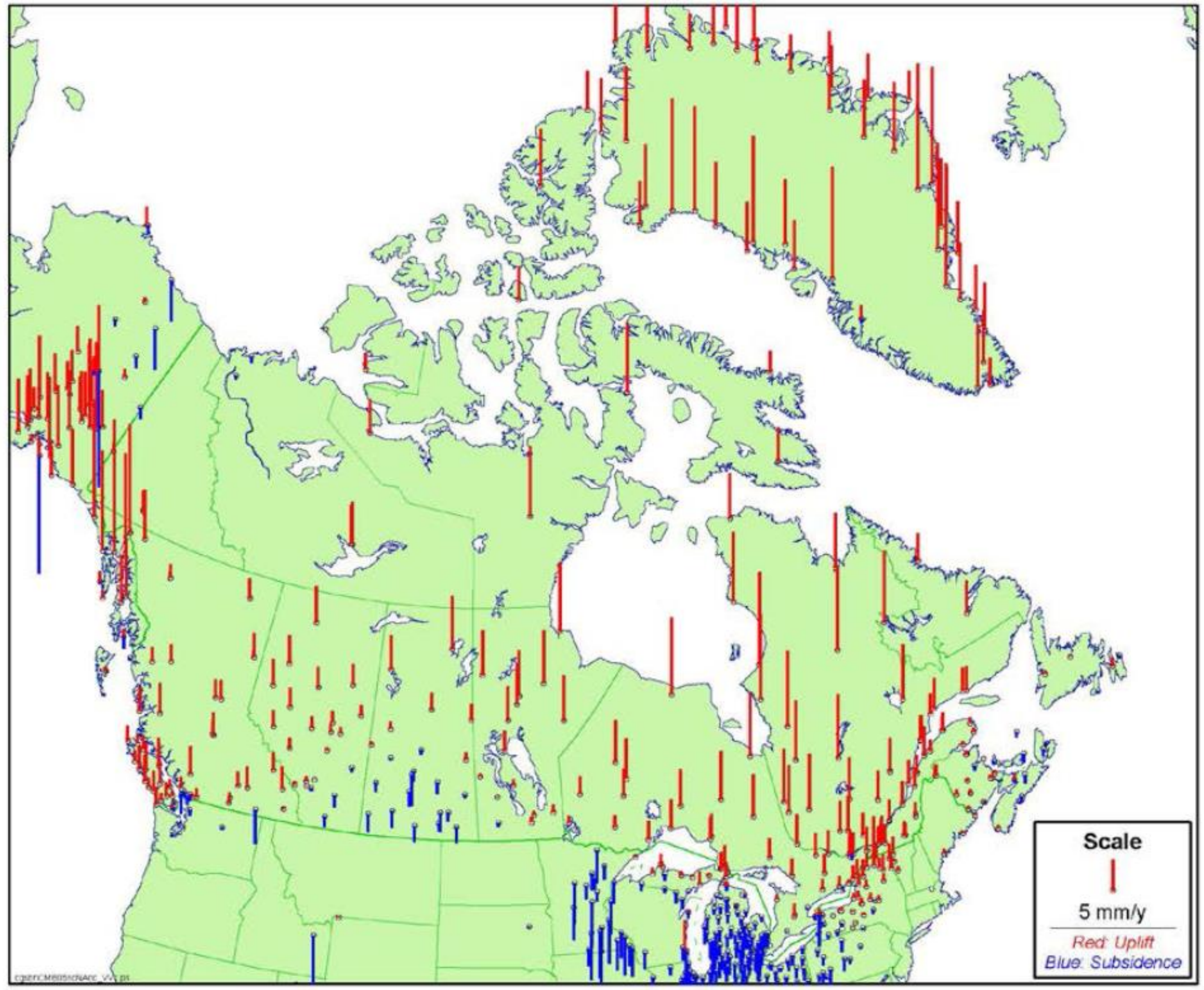


FIGURE 2-14. GPS-derived vertical crustal motion for Canada and surrounding regions *(James et al. 2014).*

Largely because of this experience of vertical land motion, relative sea levels along Canadian shores have been changing for a very long time. In parts of the Arctic, there is visible evidence of earlier shorelines in the lines left by older beaches as the land moved upwards and sea levels dropped (Figure 2-15). On the East coast, where there are remnants of earlier settlements, harbour facilities that were fully operational when constructed nearly 400 years ago, have now lost some functionality as elements (e.g., mooring rings) are now below water during high tide events (Figure 2-16). In areas such as these, where water levels are rising, historic sites and other cultural landscapes are increasingly under threat from inundation, and/or damage from erosion, waves and changes to nearshore currents. In Charlottetown, the capital of Prince Edward Island, historic records of mean sea level demonstrate a steady upward climb of approximately 32 cm per century. Taken over time, this can amount to a significant change in local waterfronts (Figure 2-17).

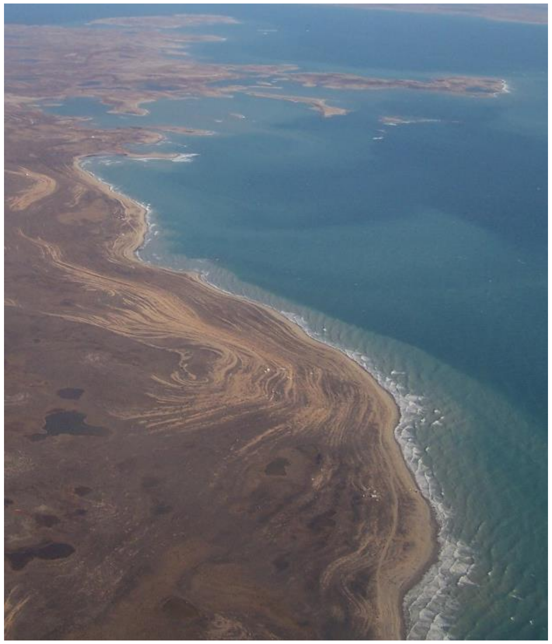


FIGURE 2-15: Raised beaches in the Arctic formed as the land moves upward from earlier positions during the last Ice Age *(Image Credit: Gavin Manson, NRCan, used with permission).*

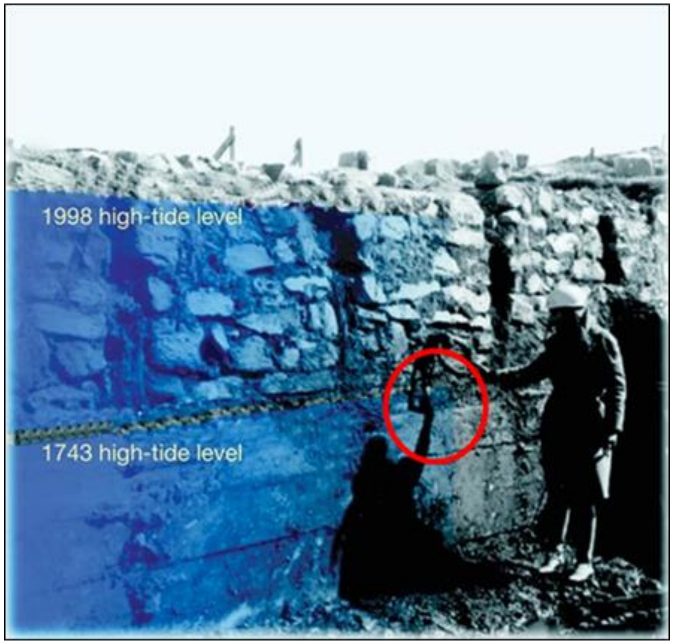


FIGURE 2-16: Field evidence of sea level changes due to land subsidence at the Fortress of Louisbourg NS. Note the position of the historic mooring ring (red circle) as compared to the 1998 high tide level *(Image Credit: Taylor et al. 2000).*

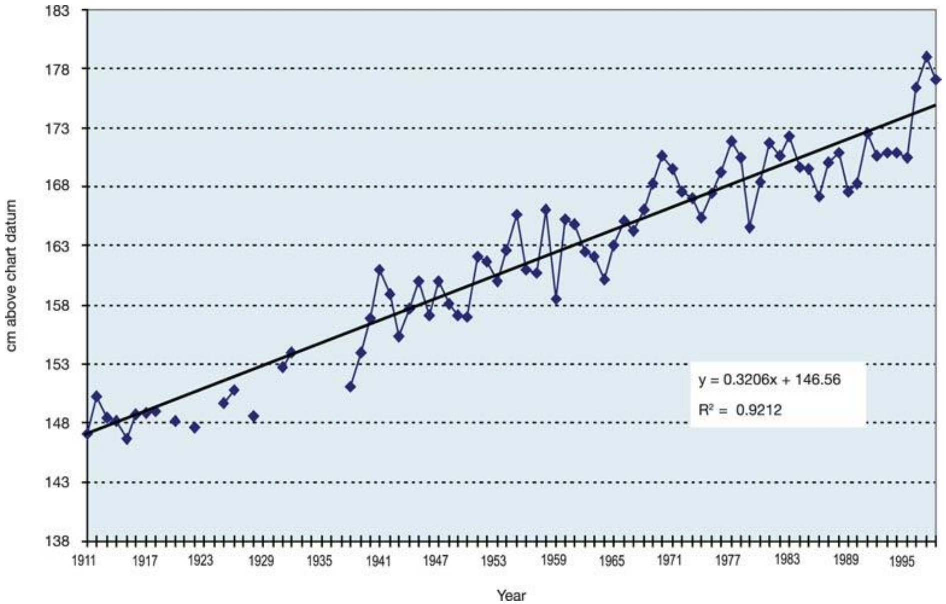


FIGURE 2-17: Annual mean water levels (1911-1998) recorded at Charlottetown, PE in centimetres above chart datum. The linear regression through the data indicates a sea-level rise of approximately 32 cm/century. Similar rates of sea-level rise have been reported for Halifax, NS, New Brunswick's southeastern coast, St. John's, NL, and Channel-Port aux Basques, NL (*Accessible from NRCan at http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2008/10261).*

For coastal areas, sea-level rise is perhaps the most significant anticipated impact of a changing global climate. Expectations to date are that throughout the globe sea levels will rise by at least several centimetres, and in some areas potentially by more than a metre. Changes to sea level will have a range of effects on coastal ecosystems and coastal communities. As nearshore waters deepen over the next century, coastlines become more vulnerable to damage from heightened storm surges and more intense wave action. Deepening waters will inundate salt marshes, contribute to the loss of seagrass beds, erode beaches and dunes, and alter nearshore marine ecosystems.

Global sea-level rise has already begun and is projected to continue over the next century and beyond. In the most recent models, mean sea levels throughout the globe could increase from several centimetres to over a metre. The IPCC and other research agencies are estimating the scale of sea-level rise based on a number of factors, the chief driver being the concentration of greenhouse gases in the atmosphere. Scenarios based on the more recent Representative Concentration Pathways (RCPs) (See Text Box) provide estimates of global change derived primarily from land use change and continuing green house gas emissions. In Canada, because of the range in contributing factors such as vertical land motion that our coasts face, sea levels will rise in some areas, and remain stable, or continue to fall in others. Anticipating the effects on the Canadian coastline is a complex endeavour derived from the IPCC global scenarios, current data on changing local parameters, and models that consider local, regional and global factors such as (Figure 2-18; Table 2-2):

- accurate delineation of mean sea level at local scales;
- the spatial extent and the rate of vertical land motion;
- regional oceanographic effects;
- land water storage;
- thermal expansion of warming sea water; and the
- late/distribution of meltwaters from glaciers, ice caps and ice sheets.

The most current science on anticipated changes in relative sea level at coastal locations across Canada has been summarized by Natural Resources Canada (Figure 2-19). The James et al. (2014) study was based on the recent IPCC RCP scenarios for global warming, and contains detailed information on the factors appropriate to Canadian coasts

REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs) (IPCC 2014).

RCPs are scenarios adopted by the IPCC in its Fifth Assessment Report (AR5) to model time series of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases as well as anticipated changes in land use and land cover. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models, and cover a period of time extending up to 2100. Of the four RCPs developed for the AR5, the RCP8.5 scenario, used by James et al. 2014 to estimate sea level rise in Canada, assumes high levels of greenhouse gas emissions, that continue to increase after 2100.

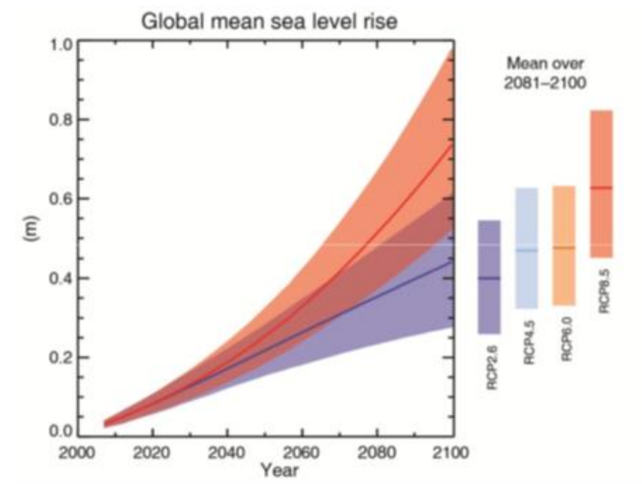


FIGURE 2-18: Projected global sea level rise over the 21st century relative to 1986-2005 for RCP2.6 and RCP8.5. Projected mean sea level rise for 2081-2100 is provided on the right for all four IPCC RCP scenarios. *(James et al. 2014).*

TABLE 2-2: Factors that contribute to sea-level rise *(adapted from Horton et al. 2015)*

RELATIVE SEA-LEVEL RISE COMPONENTS	SCALE	DESCRIPTION
Global thermal expansion	Global	Ocean water expands in volume as it warms
Loss of ice from Greenland and Antarctic ice sheets	Global	Addition of freshwater to the oceans
Loss of ice from glaciers and ice caps	Global	Addition of freshwater to the ocean
Gravitational, rotational and elastic 'fingerprints' of ice loss	Local	Regional sea-level changes due to ice mass change are modified by gravitational, rotational, and fast (elastic) isostatic responses
Vertical land movements/glacioisostatic adjustments	Local	Local land subsidence or rebound is an ongoing slow response to the last deglaciation
Land-water storage	Global	Addition or subtraction of freshwater stored in reservoirs or in groundwater.

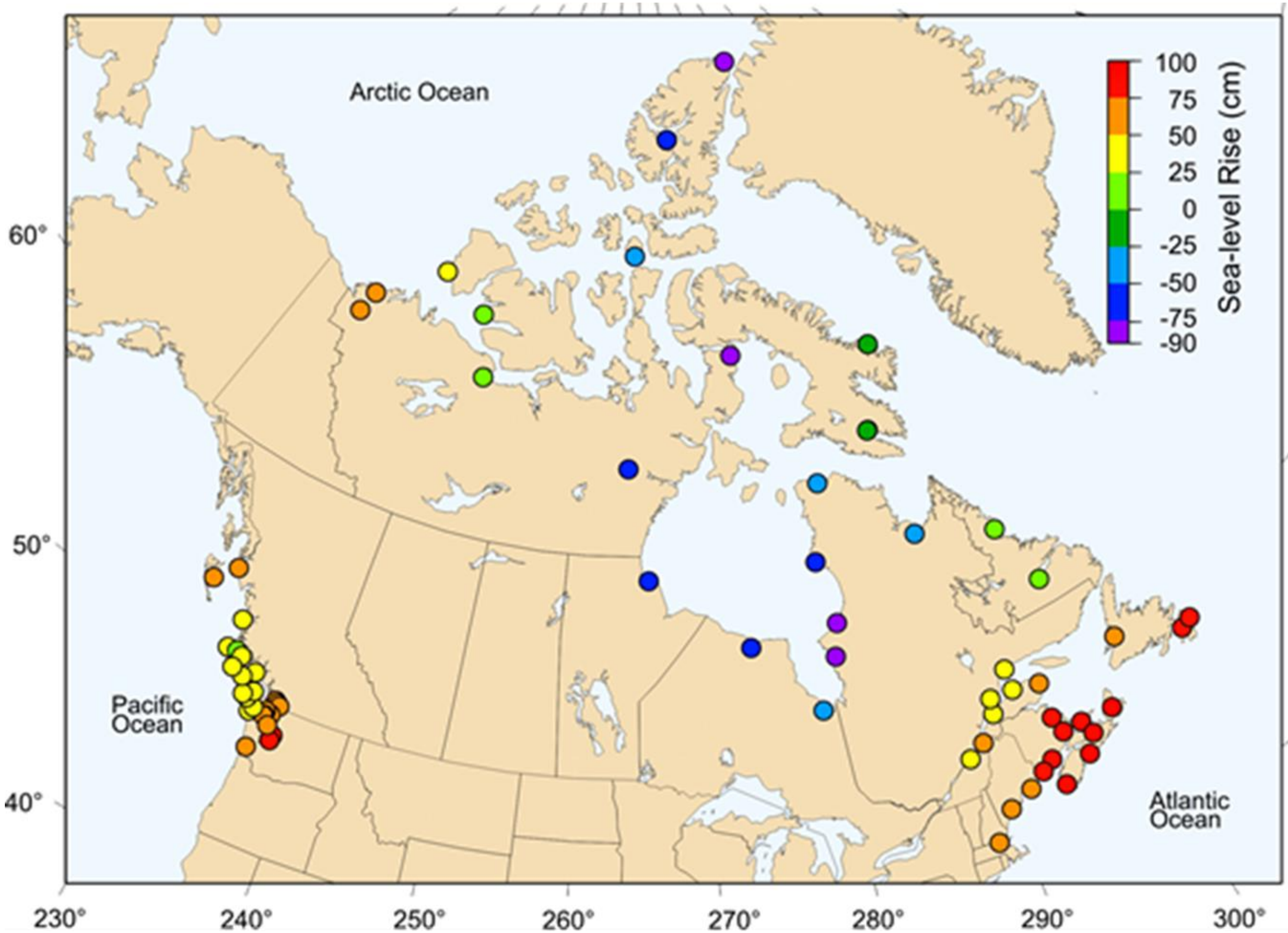


FIGURE 2-19. Projected relative sea level changes at Canadian sites by 2100, based on IPCC Scenario RCP8.5. Values range from -84 to 93 cm and are relative to 1986-2005. *(Atkinson et al. 2016, James et al. 2014).*

To better understand the implications of sea-level rise and to assist in efforts in adaptation planning, anticipated changes in sea levels must be combined with other data on the exposure and sensitivity of shorelines and coastal areas (e.g., coastal topography, exposure, wave heights, historic storm surge, coastal geology and landforms). Shaw et al. (1998) was one the first reviews of Canadian coastal sensitivity to sea-level rise and contributed to the development of sensitivity mapping (Figure 2-20). A range of relatively recent studies (SEE: ADDITIONAL READING: Sea-level Rise) have provided more detailed information on sea-level changes across the country (Figure 2-21). Currently, the Geological Survey of Canada is developing a new sensitivity tool, that will provide more detailed information at local scales (Box 2-1).

WEBINAR ON SEA LEVEL RISE IN BRITISH COLUMBIA

A webinar on the New Sea Level Rise Projections in British Columbia is available at http://www.retooling.ca/cgi/page.cgi/New_Sea_Level_Rise_Projections_in_British_Columbia_-r309?_id=105

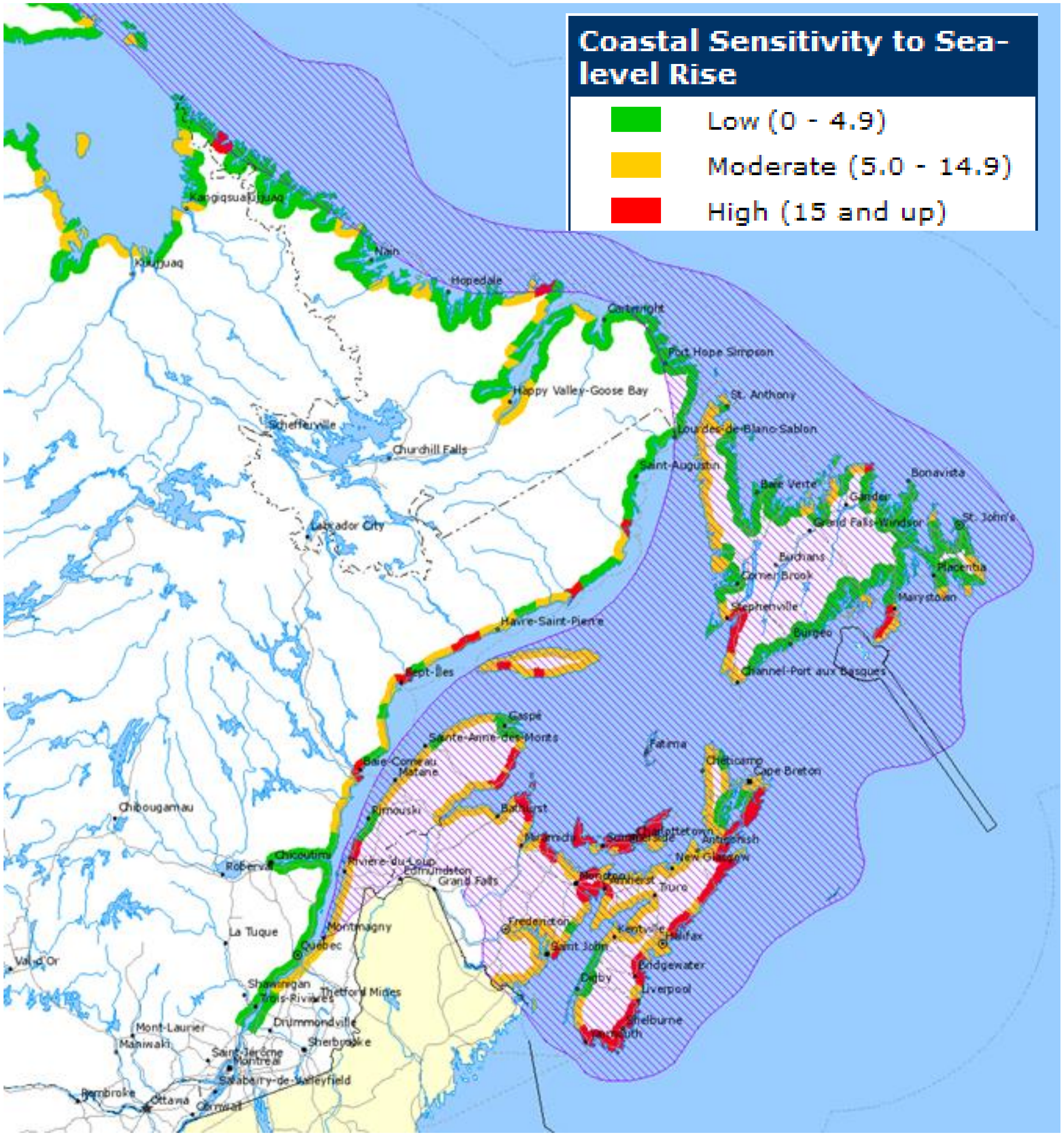


FIGURE 2-20: Atlantic region coastal sensitivity to sea level rise, Atlantic Canada *(Shaw et al.,1998.) Accessible at* http://blog.scienceborealis.ca/working-with-sea-level-rise-not-against-it/

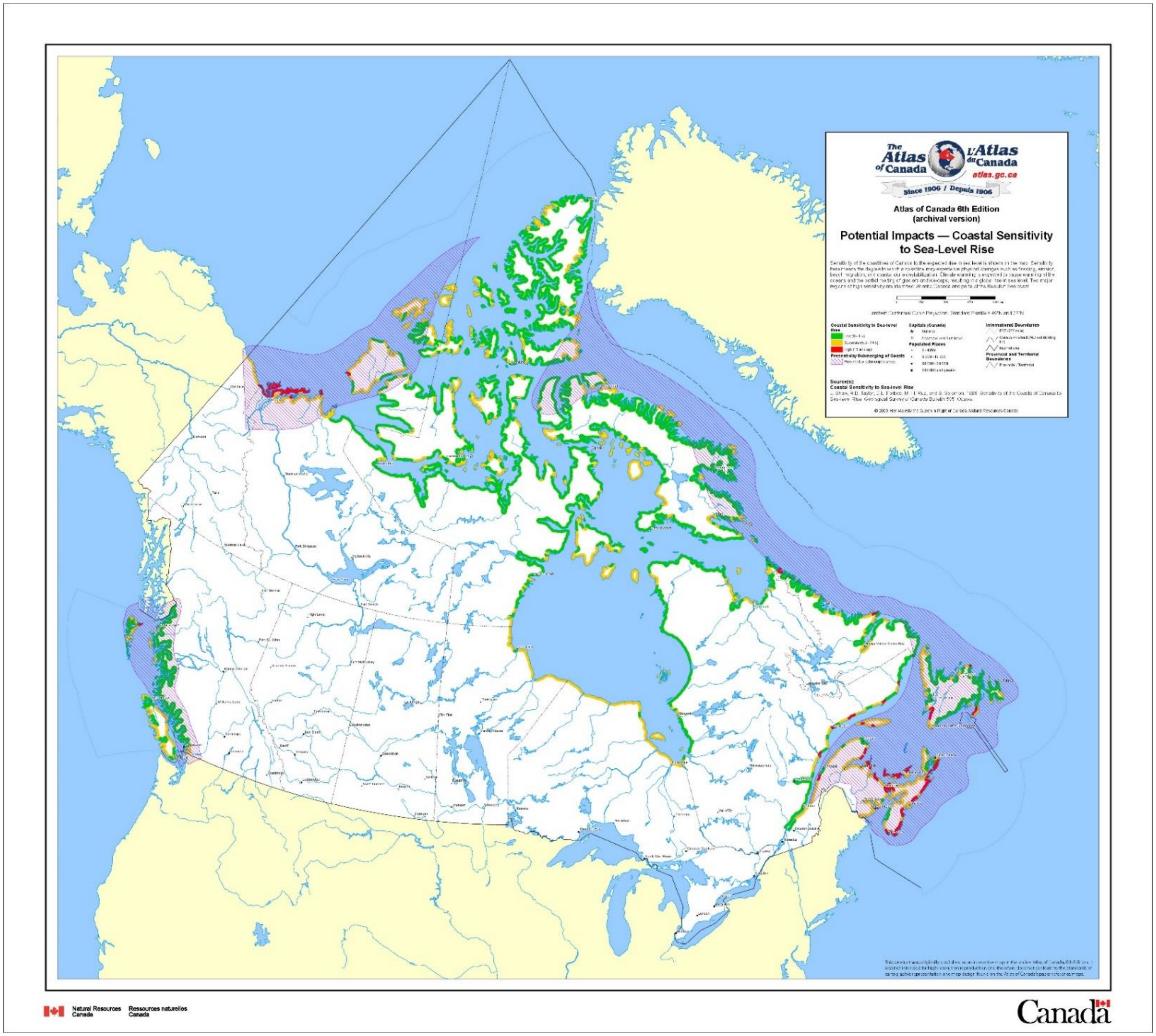


FIGURE 2-21: Full version of the potential impacts and anticipated coastal sensitivity to sea level rise graphic *(GOV/CAN/NRCan 2010)*

CANCOAST: ASSESSING COASTAL SENSITIVITY TO SEA-LEVEL RISE

CanCoast is a new tool being developed to assist in the adaptation of coastal areas to anticipated intensified physical stresses associated with climate change. An initiative of the Geological Survey of Canada (Natural Resources Canada), CanCoast is an ArcGIS-based geospatial database that enables coastal data to be collated, archived, and analysed. Current estimates of the sensitivity of sea-level rise on Canadian coasts, while providing indications of the level of threat, are insufficient for adaptation efforts at the local level.

CanCoast is developed using a geodatabase derived from publicly available data. The platform consists of a high-resolution marine shoreline vector developed from CanVec9 that groups coastal attribute layers of physical features, materials and processes (e.g., geomorphology, topography, sea level). CanCoast will facilitate analysis of coastal sensitivity to climate change impacts (e.g., sea-level rise, storm surge) at varying spatial and temporal scales.

To date, a number of datasets (e.g., landforms, tidal range, wave height) from the Shaw et al. (1998) study of coastal sensitivity to sea-level change have been mapped onto the CanCoast shoreline. Additional layers are now being added. Topographic relief is based on the Canadian Digital Elevation Data which is a raster representation of elevation values over all of Canada at 1 km spatial resolution. Sea-level rise is based on projections of regional sea-level rise for 2050 for representative concentration pathway RCP8.5 from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Ground ice conditions for coastal permafrost regions are based on the Canadian permafrost map (Using the CanCoast layers, a new index of sensitivity to climate change, incorporating both inundation and erosion has been developed (Figure 2-22).

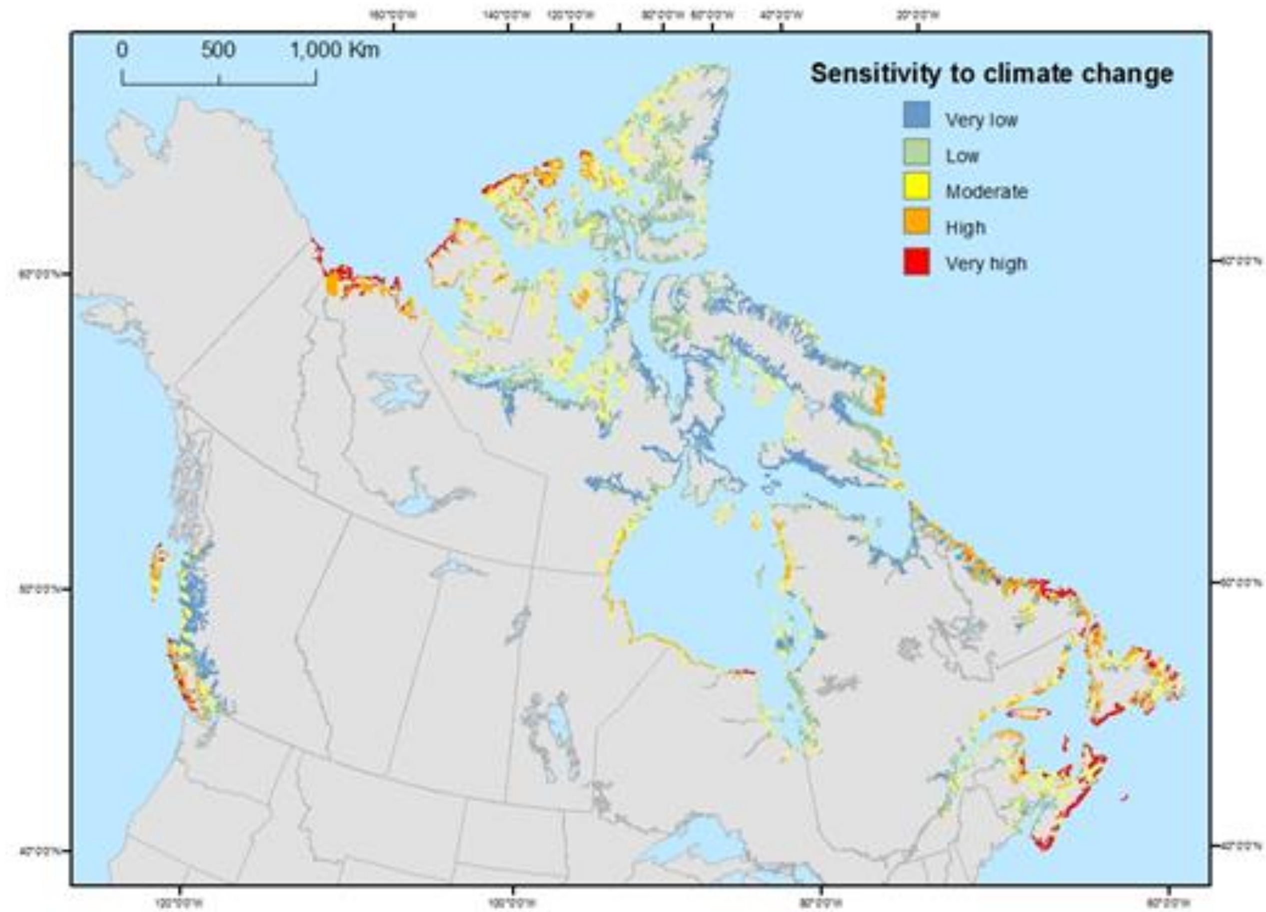


FIGURE 2-22: Preliminary map of coastal sensitivity to climate change in Canada developed using the CanCoast database. Sensitivity is based on present-day coastal materials, landforms, relief, ground ice, wave height, and tidal range, as well as recent trends in total sea-ice concentration and projected changes in sea level to 2050 *(Atkinson et al. 2016). Note that some quite sensitive areas of local or regional importance (e.g. the Fraser Delta) are not clearly visible at the resolution shown here.*

It is planned for CanCOAST to assist in the assessment of heightened erosion and sedimentation, the development of hazard mapping, and in planning for waterfront development.

2.5.2 THE COMBINED EFFECTS OF STORM SURGES AND SEA LEVEL RISE

A storm surge on a marine coastline occurs when water pushed ahead of strong winds piles up in much the same matter as when blowing on a shallow bowl of soup to cool it can cause the soup to overflow at the opposite rim of the bowl. Storm surges of sufficient height can top existing shoreline features, seawalls and dykes and drive water further inland, flooding considerably larger areas than would happen during normal sea-level conditions. Storm surges that occur during low tide periods can go relatively un-noticed, but when storm surges occur during higher tide events (storm tide), water levels will exceed expected conditions (e.g., a 5-metre storm surge on top of a high tide that is 1.5 metres above mean sea level will produce a 6.5 metre storm tide). In addition to damage to marine infrastructure and waterfront property, storm surges can push water up river channels, flooding into areas normally at distance from the shore (Figures 2-23, 2-24). As storm surges reach land, water in the nearshore areas deepen, allowing more intense waves to reach previously protected coastlines and increasing the threat of erosion and other damage.

As the climate warms and sea levels in some areas rise, additional stresses are placed on the nearshore. Extreme highwater levels are calculated as:

Sea Level +Tide Level + Storm Surge = High Water Levels

Throughout Canada there are considerable assets as well as sensitive ecosystems that exist within anticipated changes to sea level and are especially vulnerable to storm surges that occur during highest tide events.

FIGURE 2-23: 2010 storm surge flooding in Shediac Bay NB *(Richards and Daigle. 2011, used with permission).*

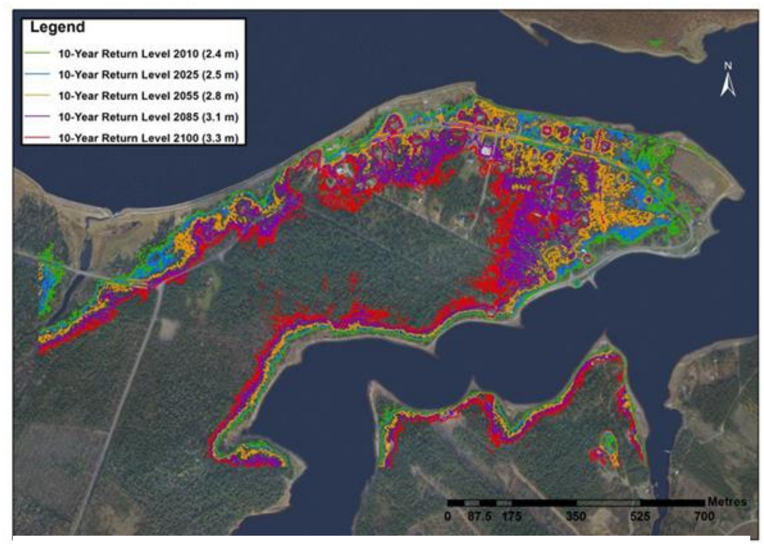


FIGURE 2-24: Projected 10-year return flooding based on projected sea level rise to 2100, Indian Island NB (*Richards and Daigle 2011, used with permission).*

STORM SURGE is the abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

STORM TIDE is the water level rise during a storm due to the combination of storm surge and the astronomical tide

(USA NOAA http://www.nws.noaa.gov/om/hurricane/resources/surge_intro.pdf).

FIGURE 2-25: Charlottetown downtown area before and after anticipated high water event at 4.93m above chart datum (current mean sea level) (Hope Parnham, former City of Charlottetown) (*Image Credit: Hope Parnham, used with permission).*

2.5.3 SEA LEVEL RISE AND PLANNING FOR THE FUTURE

In the past few years, across North America and Europe there have been events of coastal and overland flooding that have resulted in significantly higher damage to environments, settlements, infrastructure and human well-being. Cities such as Calgary and New York have found new commonalities as they seek to recover from catastrophic weather events.

Working internally, and through university-community partnerships, the City of Charlottetown, Prince Edward Island has been considering the effects of sea-level rise on its downtown areas. In the past decade Charlottetown has experienced unusually high storm surges (e.g., 4.23 m above Chart Datum- 21 January 2000). When projected sea-level rise is considered together with storm surges arising from events already experienced, flooding in the downtown area and along some of the rivers will reach new heights. Relative sea-level change and storm surges based on current storm intensities were used to calculate anticipated flood levels, now set at 4.93m above mean tide (Chart Datum) (McCulloch et al 2002; Forbes et al. 2012). When storm surges are combined with high precipitation events (situations that are not uncommon in this part of Canada), the potential for overland flooding from the combination of higher sea levels and increased stormwater runoff increases (Figure 2-25).

As a consequence of these changing conditions, the City has included new guidelines for anticipated highwater levels along its waterfront and adapted its Town Plan. Continuing planning efforts work to inform local landowners of increasing risk, and to adapt to the changing future.

> "When the climate changes, almost everything else about the environment changes with it."
>
> *John Holdren, Assistant to the President (USA) for Science and Technology*

2.6 THE SPECIAL CASE FOR CANADA'S NORTH

The Canadian North is unique in so many ways that discussion of the effects of climate change takes on whole new dimensions. It is likely that north of 60 in Canada is where the impacts of the changing environment will be first felt, hardest felt, and will pose the most difficult challenges to an adapting society (AMAP 2017; Arctic Council 2016); Streiker 2016).

The truth of the matter is we can only speculate on the scope and range of direct and indirect impacts of warming temperatures and melting ice in the Arctic. Ford et al. (2015) have attempted to summarize the biophysical aspects of change in the Arctic (Table 2-3). The authors, in their review of the literature on adaptation to the changing environment conclude that:

"The challenge of adaptation in the Arctic is formidable, but the reviewed studies indicate that many of these challenges can be overcome, avoided or reduced by individual or collective effort, creative management, changed ways of thinking, political will, institutional change and financial support. Indeed, northerners are already active agents in responding to climate change at multiple levels, and adaptations are already taking place at household and community scales. Although these local responses represent important developments, adapting to future change will require broader-level action to address both generic and specific capacities to adapt in the context of ongoing social, economic, political, demographic and environmental change. There is evidence of this happening in some locations, although a coherent vision and framework for approaching adaptation is largely absent (Ford et al. 2015, p1051).

This Primer does not presume to discuss Arctic climate change in any degree of depth or sensitivity. Readers are advised to find more expert sources for information from the material provided and their own research.

TABLE 2-3: Impacts and challenges of biophysical changes in climate in the Arctic *(Adapted from Ford et al. 2015)*

IMPACTS	QUANTIFIED CONSEQUENCES	CHALLENGES
Decreased sea ice extent	~37.9% reduction in summer ice minimum since 1979	Changes in ice extent, thickness and melt and freeze-up timing present new opportunities and challenges for accessing the Arctic
Decreased sea ice thickness	~1.8 m reduction in thickness since 1980	
Changing melt and freeze-up timing of sea ice	~18.8 more melt days since 1979	
Changing melt and freeze-up timing of river and lake ice	Poorly quantified, but widely observed	
Decreased snow cover extent	~7.2% reduction in Northern Hemisphere spring coverage since 1967; 52.7% reduction in summer coverage	Heightened land-use hazards and challenges associated with animal harvesting
Accelerated permafrost thaw	Permafrost has warmed up to ~3 °C since the 1980s, increasing permafrost degradation	Degraded Arctic transportation infrastructure (e.g., ice roads), with implications for the mobility of residents and industry
Sea-level rise	~3.2 mm yr increase since 1993 — global average	Threats to continuing viability of low-lying coastal communities, prompting forced migration/relocation
Increased coastal erosion	Poorly quantified, but widely observed	
Increased weather intensity and variability	Poorly quantified, but widely observed	Increased risks associated with travel in the Arctic
Changes in terrestrial, marine and freshwater flora and fauna distribution, abundance and health	For example: reduced sea ice extent affecting ice-dependent species, shifts in biomass production disrupting food webs, rising surface-water temperatures and changing discharge regimes altering the structure and function of aquatic ecosystems	Changes in Arctic ecology alter the abundance of, access to and quality of country foods

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RESOURCES ON THE WEB

INTERNATIONAL

CLIMATE CENTRAL SURGING SEAS

http://sealevel.climatecentral.org/surgingseas/

EUROPEAN CLIMATE ADAPTATION PLATFORM: (CLIMATE-ADAPT)

http://climate-adapt.eea.europa.eu/

The EU program is a partnership between the European Commission (DG CLIMA, DG Joint Research Centre and other DGs) and the European Environment Agency. CLIMATE-ADAPT aims to support Europe in adapting to climate change. It is an initiative of the European Commission and helps users to access and share data and information on: expected climate change in Europe; current and future vulnerability of regions and sectors; EU, national and transnational adaptation strategies and actions; adaptation case studies and potential adaptation options; and tools that support adaptation planning.

INTERNATIONAL JOINT COMMISSION

http://www.ijc.org/en_/

The work of the joint commission between the USA and Canada to manage trans-boundary waters and to protect them

USA ENVIRONMENTAL PROTECTION AGENCY CLIMATE READY ESTUARIES

http://www.epa.gov/cre

The Climate Ready Estuaries program works to assess vulnerabilities, develop and implement adaptation strategies, and engage and educate stakeholders

USA NATIONAL CLIMATE ASSESSMENT: CLIMATE CHANGE IMPACTS IN THE UNITED STATES:

http://nca2014.globalchange.gov/report

USA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA) STATE OF THE CLIMATE:

http://www.ncdc.noaa.gov/sotc/global/201413

COASTAL AND WATERFRONT SMARTGROWTH:

http://coastalsmartgrowth.noaa.gov/welcome.html

INTRODUCTION TO STORM SURGES:

http://www.nws.noaa.gov/om/hurricane/resources/surge_intro.pdf

SAFFIR SIMPSON HURRICANE WIND SCALE:

http://www.nhc.noaa.gov/aboutsshws.php

NATIONAL AND REGIONAL

CLIMATE ATLAS OF CANADA

https://climateatlas.ca/

The Climate Atlas website combines climate science, mapping and storytelling to bring the global issue of climate change closer to home for Canadians. It is designed to inspire local, regional, and national action that will let us move from risk to resilience.

CLIMATE CHANGE ADAPTATION COMMUNITY OF PRACTICE (CCACoP)

https://www.ccadaptation.ca/en/landing

http://www.climateontario.ca/p_ccac.php

The CCACoP is an interactive online community that provides a space where researchers, experts, policy-makers and practitioners from across Canada can come together to ask questions, generate ideas, share knowledge and communicate with others who are also working in the field of climate change adaptation. Membership is free and includes regular emails that provides links to useful new publications and webcasts.

GOVERNMENT OF CANADA

http://www.climatechange.gc.ca/default.asp?lang=En&n=E18C8F2D-1

The Government of Canada's official climate change web site provides limited information on the science of climate change, impacts on Canada, and Canadian responses.

NATURAL RESOURCES CANADA

http://www.nrcan.gc.ca/earth-sciences/geography/atlas-canada

http://www.nrcan.gc.ca/environment/resources/maps/11019

The Atlas of Canada provides hundreds of online maps about Canada's environment, society, economy and history, including mapping climate changes across the country

http://www.nrcan.gc.ca/environment

This NRCan site on the environment provides access to recent reports on Canada in a changing climate, as well as to work being completed on adaptation throughout the county. The site also provides links to research initiatives and to a wide range of climate change publications, data and interactive mapping.

NATURAL RESOURCES CANADA CLIMATE CHANGE DIRECTORATE

https://www.nrcan.gc.ca/environment/impacts-adaptation10761

Impacts and Adaptation page of the Climate Change Directorate at Natural Resources Canada

ENVIRONMENT AND CLIMATE CHANGE CANADA

http://www.ec.gc.ca/cc/Default.asp?lang=En&n=9853BFC5-1

Environment Canada's climate change site provides fact sheets on climate change science and research, greenhouse gas emission reporting, and other key topics.

ENVIRONMENT AND CLIMATE CHANGE CANADA:
CANADIAN CENTRE FOR CLIMATE MODELLING AND ANALYSIS

https://www.canada.ca/en/environment-climate-change/services/climate-change/centre-modelling-analysis.html

ENVIRONMENT AND CLIMATE CHANGE CANADA: CANADIAN HURRICANE CENTER

http://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=En&n=DA74FE64-1

ENVIRONMENT AND CLIMATE CHANGE CANADA: CANADIAN CLMATE DATA AND SCENARIOS

http://climate-scenarios.canada.ca/index.php?page=main

The Canadian Climate Data and Scenarios site at Environment Canada provides the science behind climate projections, as well as information on observed and projected changes.

PACIFIC CLIMATE IMPACTS CONSORTIUM:

https://www.pacificclimate.org/

OCIC is a regional climate service centre at the University of Victoria that provides practical information on the physical impacts of climate variability and change in the Pacific and Yukon Region of Canada.

PRAIRIE CLIMATE CENTRE

http://prairieclimatecentre.ca/

ONTARIO CENTRE FOR CLIMATE IMPACTS AND ADAPTATION RESOURCES

http://www.climateontario.ca/

PROVINCIAL AND TERRITORIAL GOVERNEMENT RESOURCES

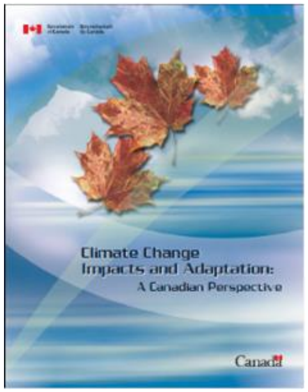
The web pages on climate science and climate change response for the provincial and territorial governments of Canada:

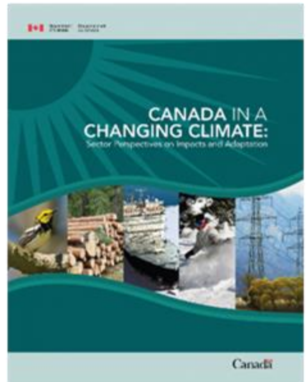
BRITISH COLUMBIA.	http://www2.gov.bc.ca/gov/content/environment/climate-change
YUKON.	http://www.env.gov.yk.ca/air-water-waste/ccactionplan.php
ALBERTA.	https://www.alberta.ca/climate-leadership-plan.aspx
NORTHWEST TERRITORIES.	http://www.nwtclimatechange.ca/
SASKATCHEWAN.	http://www.saskatchewan.ca/business/environmental-protection-and-sustainability/climate-change-policy
MANITOBA.	https://www.gov.mb.ca/climateandgreenplan/climatechange.html
ONTARIO.	http://www.ontario.ca/environment-and-energy/climate-change
QUÉBEC.	http://www.mddelcc.gouv.qc.ca/changementsclimatiques/index-en.htm
NUNAVUT.	http://climatechangenunavut.ca/
NEW BRUNSWICK:	http://climatechangenunavut.ca/
PRINCE EDWARD ISLAND.	http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/climate_change.html
NOVA SCOTIA.	https://www.princeedwardisland.ca/en/information/communities-land-and-environment/our-changing-climate
BRITISH COLUMBIA.	https://climatechange.novascotia.ca/
NEWFOUNDLAND AND LABRADOR.	http://www.exec.gov.nl.ca/exec/occ/
	http://www.turnbackthetide.ca/

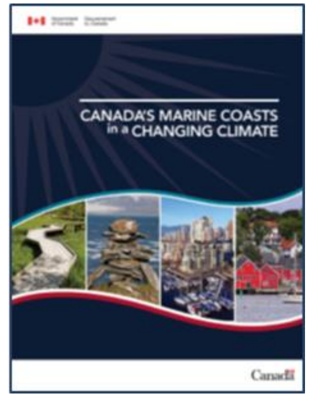
KEY REPORTS

NATURAL RESOURCE CANADA ASSESSMENT REPORTS ON CLIMATE CHANGE

All NRCan publications are available in digital format, free of charge at: http://www.nrcan.gc.ca/environment/resources/publications/10766







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available at http://publications.gc.ca/collections/collection_2016/rncan-nrcan/M183-2-7737-eng.pdf

3 EFFECTS ON ECOSYSTEMS AND SOCIETY

3.1 A CHANGING CLIMATE AFFECTS US ALL


Image Credit: C. Mercer Clarke

Too often the iconic image of how climate change is affecting the Canadian environment is a beleaguered polar bear on a diminishing ice floe. While Canadian polar bears, which are top predators in Northern ecosystems, will be affected by a warming climate, they are not the only species or ecosystem that will be changed. Climate change will influence all the landscapes of Canada, with the impacts more severely felt in some areas than in others.

Terrestrial, freshwater and marine ecosystems are physically, chemically and biologically linked in complex, supportive relationships. What happens on the hilltop can and does change what happens in the bay. As the climate changes, and weather and seasons are affected, short- and long-term shifts in environmental parameters (e.g., air and water temperature, precipitation, wind speed, snow and ice cover, erosion and sedimentation) will directly and indirectly affect other factors such as river water levels, ground water stability, soil chemistry and structure, and ocean acidification.

"While 'global warming' is a general description of the potential effects, scientists believe that the biggest effects from climate change will be changes in rainfall patterns, ocean currents, growing seasons and everything else that depends on climate.

The impacts of climate change differ between one region and the next, with some regions likely to experience more frequent droughts, whilst others experience an increase in rainfall and potentially flooding. This could affect the availability and affordability of food and water, significantly impact poverty levels, health, mortality rates, and ultimately drive sizeable population displacement with all its associated implications." *CitiGroup GPS 2015*

3.2 EFFECTS ON ECOSYSTEMS AND ECOSYSTEM SERVICES

Changes to ecosystem structure and function may arise as a result of local, seasonal, or migrational sensitivities to changes in physiological functions, to disturbances in the structure and functioning of habitat, and to interference with existing interspecies relationships whether they be predator-prey, shelter, or competition.

Much of the recent focus on climate change has been on extreme weather events and the flooding resulting from cloudbursts and storm surge. However, changes in the climate and impacts from storms will have much broader effects on the structure and functioning of ecosystems and on the ecosystem services upon which human society depends.

SOILS

Rising temperatures, heat and cold extremes and changes in precipitation will affect soil chemistry and structure, degrading soil conditions, and increasing the potential for landslides and erosion. Changes in precipitation patterns and rising seas may challenge the availability of potable water and water for irrigation. Severe weather events that erode shorelines, alter stream channels and contribute high volumes of water to nearshore areas will destroy shallow water habitat, change shoreline configurations, and damage or destroy nearshore human settlement.

HABITATS AND SPECIES

As conditions change, growing seasons will be affected, and habitats may become less hospitable for native species and more welcoming to invasive species. Plants and animals will either adapt to these changes in climate, or they may migrate over time to areas that better meet their requirements (e.g., higher altitudes, deeper water, more northern areas). In British Columbia, it has been estimated that even a shift of 1 C° may result in shifting the range of existing forest ecosystems by as much as 150 km northward or 300 metres higher in elevation (GOV/CAN/BC 2010). In some situations, plant and animal species may not be able to accomplish needed migrations quickly enough to outpace changing conditions, resulting in deterioration in local populations and the potential for loss of species in affected area ecosystems.

In addition to changes to growing seasons, extreme periods of heat or cold will alter the viability of some species while increasing the potential for invasion by new organisms. Drought and high temperatures may have other affects as well. In some regions in Canada, changing conditions have already contributed to increases in the frequency, intensity and coverage of forest fires, destroying valuable habitat and resources, and wreaking havoc on human communities.

FIGURE 3-1: Ashcroft Reserve wildfire burning at Loon Lake British Columbia. *(Image Credit: Shawn Cahill Wikipedia CC By-SA 4.0).*

LANDSCAPE: a cluster of interacting and nested ecosystems that is characterized by the structures, functions and developmental trends of the natural and social environment that make it distinctly different from adjacent landscapes. Landscapes are an integral part of ecological organization, falling below biomes and regions, and above ecosystems.

ECOSYSTEM: a community of living organisms that function in conjunction with the nonliving components of their environment (e.g., air, water and soil), interacting through nutrient cycles and energy flows. Ecosystems can be any size but usually encompass specific, limited spaces.

HABITAT: the natural home of a plant or animal species, which may include feeding, breeding, and/or migrating habitats. Habitats are characterized by physical, chemical and biological factors.

FRESHWATER AND MARINE SYSTEMS

In the ocean, rising temperatures will affect water chemistry, altering parameters such as oxygen concentration and acidity. Chemistry changes such as these, especially when coupled with the impacts from human activities at or near the shore, or on the water, will have knock-on effects on the range and abundance of some species, on the viability of shelled species (e.g. clams, mussels) and on the productivity of important habitats such as salt marshes.

RESOURCES

As environments, ecosystems and species are changed, human access to potable water, food, and shelter may be affected. In resource-based economies, some industries dependent on forest or fish resources may suffer badly. Recreation based tourism may be either negatively or positively affected, depending on local conditions, and opportunities may open in other sectors such as agriculture.

In the ocean, rising temperatures will affect water chemistry, altering parameters such as oxygen concentration and acidity. Chemistry changes such as these, especially when coupled with the impacts from human activities at or near the shore, or on the water, will have knock-on effects on the range and abundance of some species, on the viability of shelled species (e.g. clams, mussels) and on the productivity of important habitats such as salt marshes.

GLACIERS AND FRESHWATER AND MARINE ECOSYSTEMS

Along the western coasts of Canada, late summer glacial meltwater has important implications to aquatic ecosystems, agriculture, forestry, tourism, water quality and resources development (Clarke et al. 2015). As glaciers diminish or are eliminated, reduced meltwater in British Columbian rivers may have deleterious effects on the viability of cold water fish species such as salmon and trout. Nearshore commercial fish stocks may migrate to more northern waters, displacing local fisheries. The changing climate may reduce resilience in species already pressured by other stressors such as the effect of pine beetles on forests.

IMPACTS ON ECOSYSTEMS IN CANADA

- Climate shifts will affect the productivity and range of species and alter the functioning of ecosystems
- Higher water temperatures will affect fecundity, productivity and food chain relationships in aquatic and marine species. Cold water species such as trout and salmon will be challenged to survive in warmer waters.
- Acidification of seawater will threaten the growth and survival of shellfish species and may interfere with the performance of species such as the pink salmon.
- Rising levels of nutrients in water systems will stimulate phytoplankton blooms leading to depleted oxygen in some areas and creating dead zones.
- Rising sea levels, floods and droughts and loss of ice cover will result in changes in erosion and sedimentation patterns, and alter lake shores, river channels and shoreline topography. Historic dykes may be overwhelmed and features such as eel grass beds and wetlands lost to coastal squeeze.
- In the North, terrestrial ecosystems will be affected by changes in seasonality, loss of snow and ice and thawing permafrost, all of which will impact traditional hunter-gathering services to aboriginal populations *(Mercer Clarke et al. 2016):*

Image Credit: C. Mercer Clarke

3.2.1 THE CARBON CYCLE

Throughout Canada, shifts in climatic normals will affect the growth and productivity of plant species, a situation important to the provision of food services, but also critical to the sustainability of air quality, the reduction of urban heat islands, and the capture of carbon from the atmosphere. The forests of Canada play a critical role in the earth's carbon cycle

The "carbon cycle" refers to the constant movement of carbon from the land and water through the atmosphere and living organisms (Figure 3-2). While the oceans contain 85% of the active carbon on earth, Canada's forests also play an important role as both carbon sinks and carbon sources. Carbon sinks absorb more carbon from the atmosphere than they release. Carbon sources release more carbon than they absorb. Historically, forests in Canada have been carbon sinks, but in the past 100 years the situation has reversed, probably as the result of deforestation practices, wildfires, and insect damage. Improving forests, even urban forest canopies, will improve our capacity to reduce greenhouse gas contributions, and contribute overall to better air quality.

Trees and forests are susceptible to damage from wind, extremes of temperature, drought and excessive precipitation or flooding, and from shifts in growing season conditions. As temperatures warm, while the ranges of some forest tree species will expand in altitude and in latitude, there are increasing concerns for the sustainability of forest biomes throughout the country. Within urban centres, maintenance of the tree canopy that provides a range of physical and aesthetic services, faces additional challenges as some species become less viable.

The **CARBON CYCLE** is the constant circulation of carbon atoms throughout the biosphere. Plants on the land, and in freshwater and marine ecosystems absorb carbon dioxide from the atmosphere, processing it during photosynthesis to create complex organic compounds which can be consumer by other organisms. Carbon returns to the atmosphere through respiration by plants and animals, through decay and through the burning of fossil fuels.

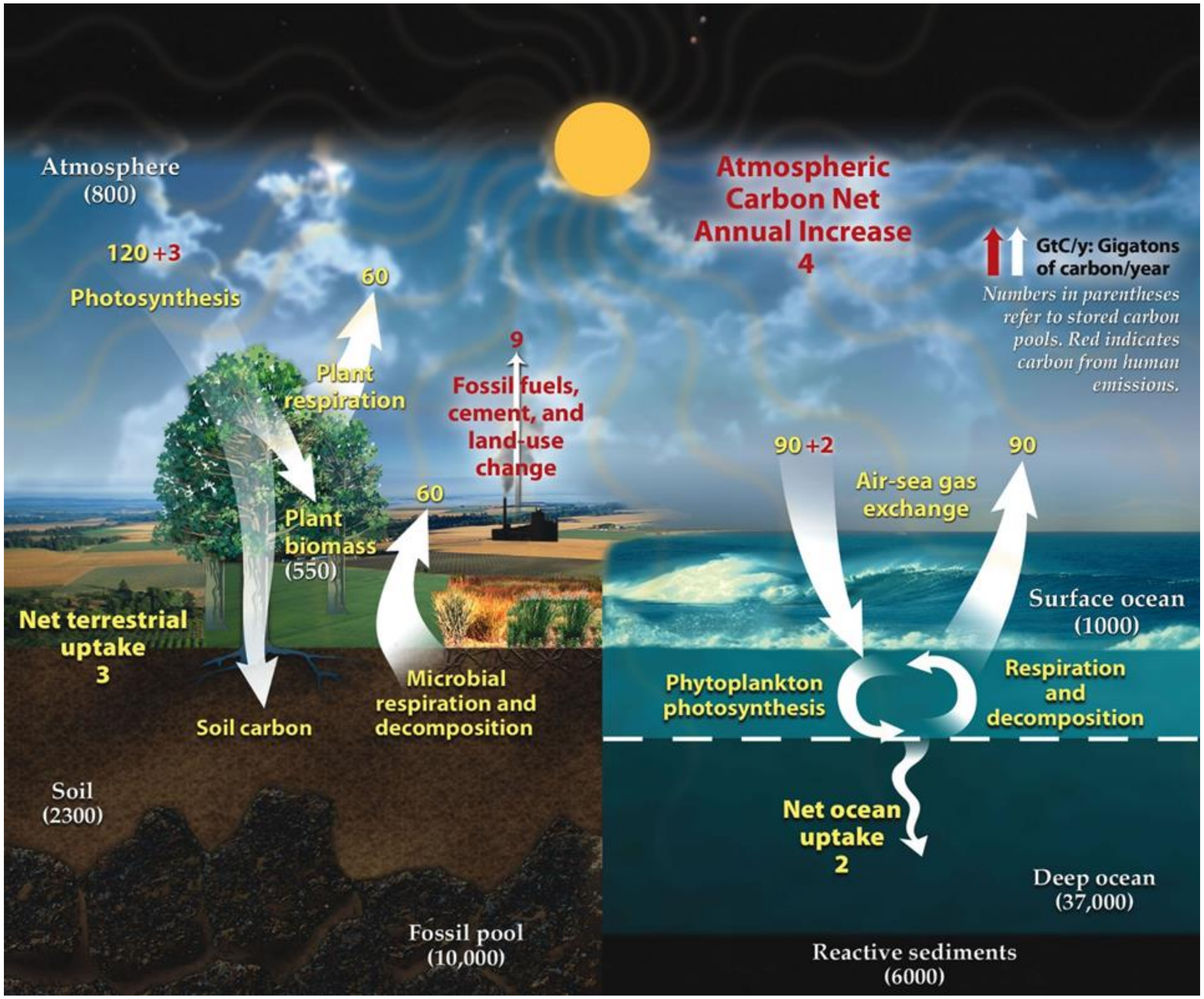

FIGURE 3-2: Graphic representation of the carbon cycle *(Image Credit: USA Department of Energy, Oak Ridge National Laboratory, Wikipedia Public Domain. Available at: https://commons.wikimedia.org/wiki/File:Diagram_showing_a_simplified_representation_of_the_Earth%27s_annual_carbon_cycle_(US_DOE).png).*

3.2.2 OCEAN ACIDIFICATION

Acidification of the ocean happens when carbon dioxide (CO_2) molecules in the air are absorbed by sea water, react with other compounds, and form carbonic acid (Figure 3-3). Increasing amounts of carbon dioxide in the ocean leads to higher carbonic acid concentration in surface waters, increasing acidity, decreasing concentrations of available carbonate ions, and reducing the levels of other biologically important calcium carbonate minerals. Calcium is an important building block for the skeletons and shells of many marine organisms. As carbon dioxide levels rise in surface waters, the ability of some organisms (e.g., mussels, lobster, corals) to produce and to maintain their shells is impeded.

Ocean acidification will have an array of impacts on marine and coastal species. Some species of phytoplankton and seagrasses may benefit from more substantial concentrations of carbon dioxide. Other organisms, such as shellfish, corals and calcareous plankton, will face challenges in an acidifying environment. In some areas of the United States and Canada, lower pH in nearshore waters may be one of the causative factors for current failures in shellfish aquaculture and fisheries.

As concentrations of atmospheric carbon dioxide increases, and the climate warms, surface water concentrations will also increase, resulting in pH levels that the oceans have not experienced in more than 20 million years.

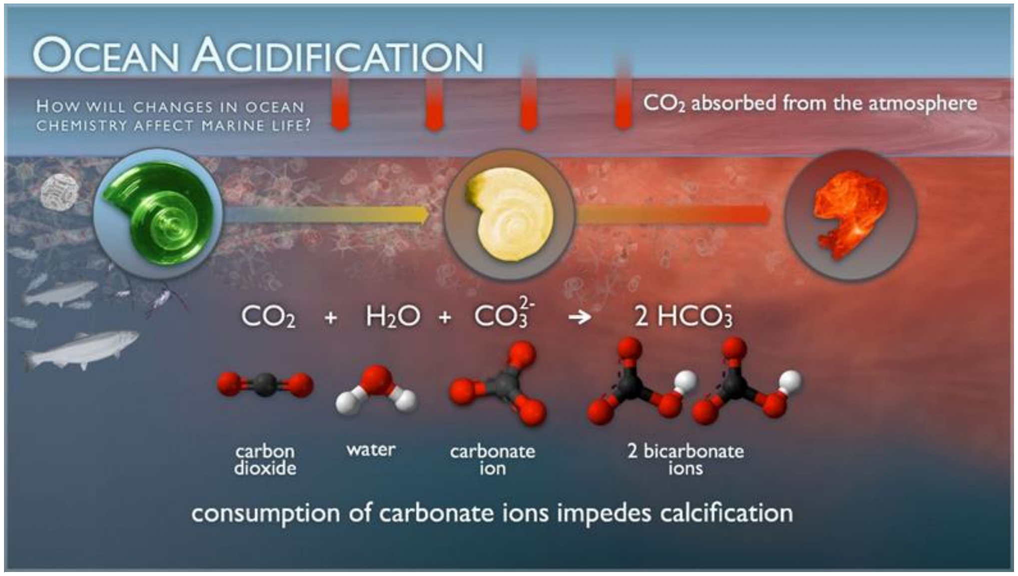

FIGURE 3-3: Graphic representation of ocean acidification *(Image Credit: GOV/USA/NOAA 2016, used with permission).*

OCEAN ACIDIFICATION is the ongoing decrease in the pH of the world's oceans, caused by the uptake of carbon dioxide (CO_2) from the atmosphere. An estimated 30-40% of the carbon dioxide derived from human activities and released into the atmosphere finds its way into oceans, rivers and lakes. When carbon dioxide is absorbed by seawater, chemical reactions occur that reduce the pH of the seawater (increasing acidity).

A **pH UNIT** is a measure of acidity that ranges from 0-14. The lower the value, the more acidic the water. Since the beginning of the industrial revolution, acidity in the world's surface oceans has increased by 0.01 pH units. Since pH is a logarithmic scale, this decrease in pH represents a 30 per cent increase in acidity.

(Adapted from GOV/USA/NOAA 2016 PMEL Carbon Program and others)

A CLIMATE CALAMITY IN THE GULF OF MAINE
PART 2: ACID IN THE GULF

A short video produced with support from Maine Sea Grant, Dalhousie University, MEOPAR (Marine Environmental Observation Prediction and Response Network), NERACOOS (The Northeastern Regional Association of Coastal Ocean Observing Systems) and NECAN (Northeast Coastal Acidification Network and accessible at:

https://www.youtube.com/watch?v=ZimEBFw1Q7c

3.2.3 COASTAL SQUEEZE

The shorelines of many freshwater and marine environments often are home to ecotone habitats such as beaches, dunes, and marshes, which occupy the complex transition areas between the land and the water. As the climate changes, and water levels rise, shifts in physical, chemical and biological conditions may no longer support these habitats. While these shifts are common throughout coastal ecosystems, the timing of change may be accelerated beyond that needed for natural migration of habitats and species.

Marsh plants have a quite narrow range of tolerance for water depths. In some cases, variations in water depths of only a few centimetres will determine which species of plant lives where in a marsh. Changes in water depths can cause major changes in marsh composition and may even impact the capacity of a marsh to survive in that location. When marshes and dunes are pinched between rising water levels (e.g., changes in precipitation patterns, sea level rise, storm surge) and unfriendly nearshore topography (e.g., cliffs, rocky shores), and/or built environments (e.g., sea walls, roadways, land development), they may be unable to migrate to more optimum conditions. When marshes and dunes are unable to move inland, they can be caught in a *coastal squeeze* that can result in reductions in area, loss of productivity or even permanent loss of these unique ecosystems.

Species that rely on marsh and dune ecosystems, for even a portion of their life-cycle, will also be affected when habitats are lost due to coastal squeeze. Even when un-impacted in other areas of their range, coastal squeeze can also affect the feeding, breeding and/or rearing patterns of migratory species. When native species are adversely impacted, new species that can better adapt to changing conditions may move into new areas, affecting biodiversity, altering predator-prey relationships, and in some cases detrimentally affecting ecosystem structure and function. Ecosystems, habitats and species already impacted by human activities (e.g., nitrification, contamination, siltation, urbanization) may be unable to cope with the additional stresses associated with changing conditions.

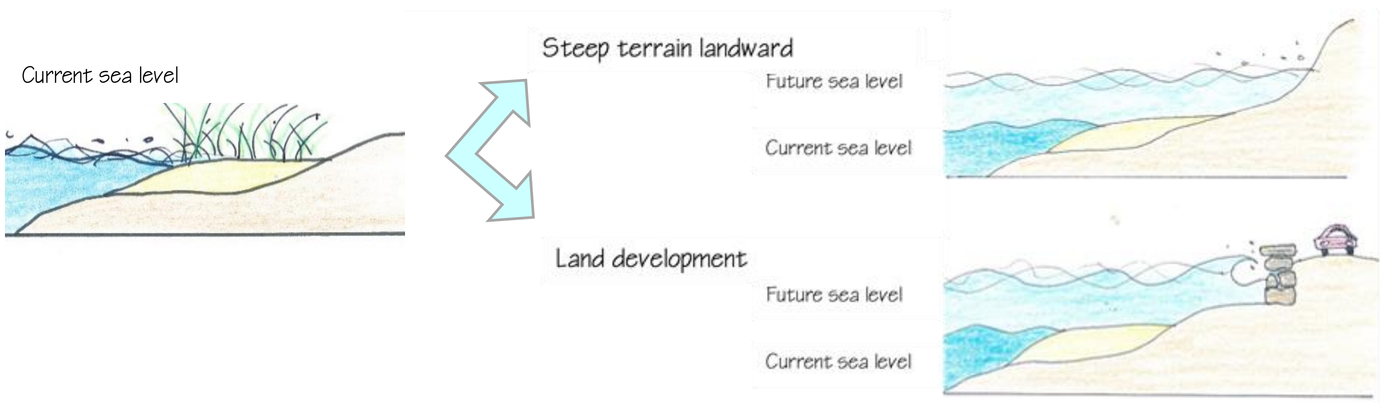

FIGURE 3-4: Graphic illustration of the natural and man-made barriers that prevent marsh migration and create coastal squeeze.

3.2.4 ECOSYSTEM SERVICES

When environmental change occurs in conjunction with human-induced stresses, the resilience of natural environments may be further compromised, further reducing the capacity to absorb the effects of significant climate shifts (e.g., long-term droughts) and/or extreme events (e.g., storms, wildfires, and floods. Direct and indirect, or trickle down, effects will result in increasingly widespread ramifications on human society.

Canada is home to over 70,000 species of animals, plants and fungi, many of which feed us, clothe us, provide resources for our shelter, filter our water, pollinate our crops and ensure we have air to breathe. Harvesting and processing of biological resources employ millions of Canadians, and in 2012 contributed over $24.8 Billion to the GDP (Sustainable Canada Dialogues 2015). The services provided by the marine, aquatic, and terrestrial ecosystems of the country have to date been too often taken for granted, resulting in a general decline in biodiversity, that has placed more than 700 species at risk of extinction.

Throughout the diverse landscapes of Canada, many communities directly rely on local environmental resources for services that support their economic and cultural well-being. Ecosystem services can include provisioning services (e.g., food and drinking water supplies, energy, wood products); supporting services (e.g., land for settlement, transportation, water for energy generation and irrigation); regulating services (e.g., purifying water, waste reception and treatment, tempering weather) and cultural services (e.g., aesthetics, recreation, education) (Figure 3-5). Nearshore habitats (e.g., wetlands, coastal forests, dunes) can also provide valuable support that shelters vulnerable shorelines and assets from extreme weather. As human populations in Canada have shifted from being primarily rural to being primarily urban, society has developed often complex infrastructure and systems to deliver food, clean drinking water and dependable energy to consumers. While efficient in their use of resources, these systems have created environments where the consumer is increasingly disconnected from the natural environment that services their community, at a time when a shifting climate and severe weather events may alter or eliminate the provision of those services.

FIGURE 3-5: Ecosystem services as categorized in the Millennium Ecosystem Assessment *(Image Credit: MetroVancouver.org, used with permission).*

The effects of a changing climate on ecosystems and ecosystem services are wide-ranging, with some changes anticipated for the entire country, and others being locally significant only (Table 3-1). Extreme weather may disrupt or destroy ecosystem structure and function. Food supply can be affected through the diminished fish stocks, destruction of farms and crops, and impacts to food distribution networks.

Impacts to water resources can include contamination of surface water drinking supplies, and disruption of wastewater treatment systems (which in turn can contribute to contamination of other water resources). Flood waters may become contaminated with chemicals and nutrients (St.-Hilaire et al. 2016). Reductions in freshwater discharges to coastal waters may affect local and migratory fish species, more so where flows have already been reduced by human use of water (e.g., potable water supply, irrigation, dams and diversions, energy generation). Further reductions as a result of diminished precipitation (i.e., rain and snow), reduced glacial melt water, and higher temperatures increase seasonal stresses on some nearshore marine waters, increasing salinity and nutrient and contaminant loading and reducing oxygen levels. Nutrification of nearshore waters increases the potential for harmful algal blooms, and can impact coastal tourism, aquaculture and the quality of life for nearshore residents. There are increasing concerns that changes in freshwater discharge regimes will affect recruitment, predator prey relationships and ecosystem functions of important habitats such as wetlands and seagrass beds.

As the climate changes, some of the associated alterations to ecosystem services may be less dramatic and more insidious. Higher air and water temperatures will alter the range of some agricultural and forestry crops, and interfere with the productivity of local area fisheries. As ecosystem services to communities deteriorate, society may become more vulnerable to stress and to disease.

In some areas of the country, changes to ecosystems could open new opportunities for humans. However, it will take time and resources for most societies to make the transition from established practices to the kind of evolving and strategic planning needed to capitalize on new species, increased production, or shifting opportunities in agriculture, forestry or tourism.

TABLE 3-1: Implications of climate change on ecosystems and ecosystem services.

PARAMETER	EFFECTS ON LANDSCAPES	EFFECTS ON ECOSYSTEM SERVICES
TEMPERATURE		
Seasonal temperature	Changes in growing seasons, predator-prey relationships, ecosystem functioning, habitat conditions and species range. Changes in biodiversity and ecosystem structure and composition. Altered metabolism and growth rates. Local extinctions. Increased harmful algal blooms. Droughts and wildfires. Increased potential for higher forest productivity.	Increased yields in colder environments. Decreased yields in warmer environments. Opportunities for new crops. Stress on urban trees. Expanding ranges for invasive species. Increased potential for insect outbreaks. Increased emergence of vector borne diseases. Changes in the supply in waters dependent on snow melt. Reduced demand for heating in winter, but increased demand for cooling. Reduced snow and ice conditions improves travel options. Impacts to winter and summer tourism, some positive, some negative.
Daily Extremes and Heat Waves /Cold Snaps	Heat and cold stress on flora and fauna. Water quality issues related to high temperatures, low oxygen conditions, and increases in algal blooms.	Increased demand for energy and water for heating and cooling, Pressures on vulnerable populations (e.g., seniors, infants, infirm, disabled). Reduction of quality of life in impacted areas without sufficient heating or cooling options, especially in socially disadvantaged communities. Reduced yields in some crops. Increased danger of wildfires. Increased demands on water supplies. Increased potential for energy disruptions.
PRECIPITATION		
Seasonal precipitation	Changes to habitat and range conditions.	Reductions or improvements in crop conditions and in the range of suitable species for cultivation. Impacts to local tourism operations and to environmental and resource based industries.
Heavy precipitation	Riverine and coastal erosion, flooding, landslides. Altered flushing and residence times. Increased loading of non-point and point source nutrients and contaminants.	Damage to crops. Soil loss to erosion. Stress on stormwater and wastewater systems, contamination of potable water resources, damage to infrastructure, especially to stormwater and wastewater systems and electrical transmission lines. Deteriorating surface water, groundwater and nearshore water quality. Relief in high water demand locations. Increased risk of death, injury, and disease in human populations. Disruptions to commerce, transportation, and settlements. Loss of property. Loss of insurability in areas deemed at high risk of damage.
Drought	Land degradation and/or subsidence. Loss of vegetation and wildlife. Increased algal growth in freshwater and nearshore areas. Concentration of contaminants.	Water shortages and imposed restrictions on water use. Lower crop yield and damage to livestock. Food shortages. Increased risk of wildfires, blow downs, and other impacts to forest resources. Reduced hydroelectric power generation. Increased famine and risk of water and food borne disease.
Streamflow	Reduced stream flows leading to higher temperatures, lowered oxygen and increased potential for contamination and algal blooms. Increased flows resulting in bank erosion, and bottom scour. Alterations to stable horizontal and vertical profiles and riffle-run sequences. Impacts on spawning and recruitment of fish species. Changes in delta erosion and sedimentation patterns. Changes in seasonal water contributions to nearshore waters and estuarine productivity.	Reduced recruitment in year class of important fish species (e.g., salmon). Impacts to local food fisheries, aboriginal fisheries and tourism. Erosion and damage to roads and bridges. Property damage. Increased risk of injury and death. Drought conditions resulting in altered approvals for extraction of water for irrigation and deteriorating water quality.
WIND		
Severe storm events	Damage to forests from wind throw (uprooting). Increased wave intensity.	Power outages, and related disruption of water supply. Increased risk of injury or death, and in water and food borne disease and post-traumatic stress disorders. Temporary or permanent population displacement/migration. Loss of property. Loss of insurability in areas deemed at high risk of damage.

PARAMETER	EFFECTS ON LANDSCAPES	EFFECTS ON ECOSYSTEM SERVICES
SNOW COVER		
Snow cover duration	Longer winters stress wildlife populations. Later thaws impact predator-prey relationships.	Longer snow cover impacts construction and other industries. Shorter snow season impacts winter tourism. Delays or earlier spring planting season.
Snow depth	Stress on wildlife populations. Implications for spring melt and run-off.	Heavy, wet snow pack can impact roof structures and destabilize buildings. Loss of snow cover will alter river and lake levels in watersheds.
PERMAFROST		
Ground temperature	Thawing of local permafrost leads to destabilization of shorelines, erosion and shoreline retreat.	Structural instability in buildings and infrastructure. Impacts to aboriginal hunting and fishing patterns.
SEA LEVEL		
Relative sea-level rise	Coastal flooding and erosion. Loss of land. Deposition of sediments. Sea water intrusion into surface and groundwater, and contamination of soils. Loss of coastal wetlands. Loss of beaches, dunes, mudflats, and seagrass beds.	Inundation of low-lying structures, flooded utilities and impaired access to services, salt water contamination of surface and ground water resources. Increased risk of injury or death. Burden of cost for protection measures, loss of access, and/or movement of populations and infrastructure. Stress related to human displacement/migration.
Storm surge	Higher inland flooding, wind damage, coastal erosion,	Damage to buildings/ infrastructure including docks, altered coastal assets (e.g., beaches).
Wave intensity	Larger waves reach shorelines, increased ice-rafting, bottom scouring, erosion and deposition along shorelines, loss of land.	Damage to buildings / infrastructure including docks, altered assets (e.g., beaches).
OCEAN CLIMATE		
Sea Temperature	Heat stress on species can result in lowered fecundity, changes in species range, disease, and algal blooms and contribute to acidification and impacts on shellfish and molluscs.	Temperature changes can reduce or improve the suitability of nearshore environments for aquaculture, and may also increase the potential for vector borne diseases. Higher temperatures contribute to algal blooms which may contaminate seafood.
Acidification	Increases affect life stages of marine species, impacting food chain and reducing productivity.	Reduced yields for aquaculture and fisheries dependent on shellfish species.
ICE COVER		
Sea ice	Reduced sea ice cover and earlier breakup increase access of storm surges and waves to erodible shorelines. Loss of sea ice affects birthing in seals, and hunting patterns in top predators.	Loss of sea ice can result in shoreline retreat and increased vulnerabilities in buildings and infrastructures. Loss of sea ice in Arctic opens new opportunities in shipping and resource extraction. Loss of sea ice affects aboriginal hunting and fishing patterns.
Lake and River Ice	Changes in riverine and lake ice cover affects timing in summer breakup and in lake water turnover, affecting predator-prey relationships in freshwater and nearshore environments.	In large systems less ice can improve transportation conditions, but can also reduce access if ice highway seasons are shortened, or determined to be unsafe.
Glaciers	Reduced seasonal water supply to rivers and nearshore areas. Reduced water quality and impacts to fish recruitment.	Impacts to fish populations, water supply for potable use and for irrigation.

3.3 EFFECTS ON SOCIETY

The impacts of a changing climate and intensifying weather patterns on human health and well-being have only recently come under scrutiny. Traditional expectations have been that communities and individuals will be resilient to normal changes and variations in weather patterns, but this is being challenged by emerging understandings of the complex relationships between society and its connection with the natural environment, and an acknowledgement of the failings of current building practice and management.

As the climate changes, human health and well-being will be impacted both directly and indirectly, through increased stress on individual well-being, on local economics and population dynamics, and on cultures (Figure 3-6) (Table 3-2).

Increasing temperatures in these and other areas can also foster increased transmission of waterborne and insect-borne diseases and may foster the entrance or expansion of invasive species, some of which may pose threats to human populations or activity. Changes in agricultural growing cycles, resulting from changes in mean and extreme temperature profiles and changes in precipitation, will challenge food security and food costs in some areas. Traditional crops may also become more difficult to grow as conditions in these regions move beyond that crop's capacity to adapt. In some areas of the country, especially in the North, remote communities will require additional resources to move goods and services over long distances, as existing transportation routes and methods are increasingly challenged by changing conditions

"WELL-BEING is about promoting a better way of life and equality for citizens. Well being in its simplest definition is: Being Well. It is where the basic human requirements are met, whilst being afforded the opportunity to have optimistic aspirations enveloped in an environment where the endeavour of 'Being Well' can be achieved, therefore, attaining a satisfactory quality and standard of life and happiness." *(Institute of Wellbeing 2015)*

VULNERABILITY: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. *(IPCC 2014, p5)*.

Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity (Parry et al. 2007, p883).

Vulnerable segments of society can include identifiable populations such as the aged or young, the disabled, or the economically or politically disadvantaged.

FIGURE 3-6: Factors that affect a person's vulnerability to extreme heat at an Individual and community scale (*GOV/CAN/Health 2011)*.

Many elements of society in Canada rely on linkages that bridge between marine, aquatic and terrestrial systems. Transportation networks in most communities rely on some combination of airline, road, rail, and subway systems, and coastal communities additionally link to local, national and international waterborne traffic. Changes in the environment will result in damage to and delays in most of these systems. Without proactive measures to protect against these impacts, communities will suffer as these needed connections are severed, even if only for a matter of days. Urban infrastructure such as stormwater management and distribution and treatment systems for water and wastewater also traverse multiple environments, and in many cases, are structured so that disposal outfalls are in close proximity to marine and freshwater environments. These systems are vulnerable to increased precipitation events, and flooding created by rising waters (including sea levels) and intensified storm surges. Stormwater systems and wastewater disposal systems can be doubly challenged as heightened flood levels meet rising seas, increasing the potential for back flooding in the community and compounding the impacts accordingly. These rising costs and risks, whether for repairing damage, increased insurance burdens, or relocation efforts, all act to elevate stress overall throughout the community in general, both to individuals and with organizations that must cope with these issues. This is further exacerbated because often, those most at risk in these instances are also those with the least capacity to adapt to these changes.

Adaptation planning must proactively address issues of social justice to ensure that significant harm does not befall vulnerable populations. It will also be important to ensure adaptation efforts are fully integrated into local, regional and national cultures. As a driver of human behaviour, cultural perspectives and cultural responses can be resistant to change but can alter when faced with pressing needs. In adapting to the challenges presented by climate change, a cultural shift in the protection and management of existing assets and in the development of new regions may be required, and in some communities, is arguably already under way. In some communities in Canada, broad changes are already taking place, fueled by the conviction that a prosperous and sustainable future, one that addresses immediate and long-term effects from a changing environment, must entail consideration of all needs and aspects of society from individual actions to the greater public good. To be completely successful, integration of sustainability must go further than town policies and urban planning and must support incorporating these needed changes into local culture. It must delve into specific local threats, propose changes relevant and attractive to local populations, and ensure that there is sufficient local capacity to effect such changes.


Image Credit: C. Mercer Clarke

TABLE 3-2: Examples of social consequences arising from specific environmental impacts

ENVIRONMENTAL CHANGE	CONSEQUENCES TO SOCIETY
Sea-level rise	Rising seas can affect real estate values in waterfront areas, contaminate ground and surface waters with salt
	Damage to infrastructure in coastal cities and altered use of assets by coastal residents, threats to human heath and safety
	Changes in biodiversity and productivity can alter fisheries in dependent coastal communities
	Populations on low-lying islands will be at risk of losing their communities and/or livelihoods
	Cultural assets in low-lying areas may be lost to rising seas
Increased storm activity	Intensified storm surges could overtop existing coastal defences leading to unpredictable impacts on coastal cities, including damage from higher intensity waves reaching further inland
	Damage from high winds could result in damage to harbours, housing and businesses, as well as shifts in existing designated hazard zones (e.g., hurricane vulnerable areas)
	Power outages and shut-down of commercial activities, as well as disruptions to services such as transportation, health, education
	Stresses produced by more intense storms can affect residents well-being and impair investment in the community
Changes in precipitation	Increased precipitation could challenge existing stormwater management infrastructure, leading to an increase in overland flooding
	Reduced rainfall could result in drought conditions in some areas challenging drinking water supplies as well as irrigation
	Changes in local topography could result from landslides produced by saturated soils, and/or from subsidence as groundwater levels fall
	Falling or rising water levels could negatively impact residential land value in nearshore areas of freshwater as well as marine shorelines
	Snow and ice loads threaten the integrity of roofs and other structures
Agricultural climate shifts	Drought conditions could render previously fertile regions arid, making agriculture unprofitable if not impossible
	New opportunities for commercial agriculture could open in areas previously too cold
Increased atmospheric temperatures	Increased prevalence of contagious diseases, particularly insect borne and waterborne diseases
	Risk of new diseases emerging into newly-hospitable regions
	Harm to vulnerable populations such as the young and the elderly, due to heat island effects in urban centers
	Thawing permafrost will result in significant change for Arctic peoples and for their traditional lifestyle
	Warming trends can positively and negatively affect industries (e.g., tourism) and commercial operations
Atmospheric changes	The potential for accumulation of smog and other air pollution could directly affect health in urban areas as well as those living downwind
Changes in biodiversity	Loss of existing species/habitat (e.g., urban tree canopy) can contribute to a change in the cultural setting in which people have settled.
	Introduction of new species can introduce new challenges or dangers, such as venomous animals, which locals are unfamiliar

3.3.1 EFFECTS ON HUMAN HEALTH AND WELL-BEING

The primary effects of climate change on human health are (GOV/USA/USGCRP 2016):

- changes in the severity or frequency of existing health issues that are already sensitive to climate and/or weather factors; and by
- unprecedented or unanticipated health problems or threats to well-being in places, or at times, where such issues have not previously occurred.

Table 3-3 outlines how changes in climate and weather patterns can have effects on human health and well-being, now and in the future. These impacts can be felt at the national, regional or local scale, and will change in geographic distribution and in timing as climate change advances.

In Canada, where wastewater treatment facilities are often located in areas that could be vulnerable to both overland flooding and sea-level rise, the potential exists for these systems to fail during extreme weather events, especially where this infrastructure is already aging. Additionally, measures currently in place to determine safe levels of contaminants in discharged water (including industrial effluents) may require adjustment, as water levels change, temperatures increase, and circulation patterns are altered, all of which change the baseline those discharge standards are set to work with.

TABLE 3-3: Examples of the effects of climate change and severe weather on human health and well-being *(adapted from GOV/USA/USGCRP 2016).*

	CLIMATE EFFECT	EXPOSURE	HEALTH OUTCOME	IMPACT
EXTREME HEAT	More frequent, severe, and prolonged heat events	Elevated temperatures	Heat-related death and illness	Rising temperatures lead to an increase in heat related deaths and illnesses
OUTDOOR AIR QUALITY	Increasing temperatures and changing precipitation patters	Worsening air quality (ozone, particulates, pollen)	Premature death, acute and chronic cardiovascular and respiratory disease	Rising temperatures and wildfires coupled with decreasing precipitations lead to poor air quality increasing respiratory illness and deaths
FLOODING	Rising sea level and more frequent or intense extreme precipitation, storms and storm surges	Contaminated water, debris, and disruptions to essential services	Drowning, injuries, mental health issues, gastrointestinal and other illnesses	Coastal and inland flooding increases exposure of populations to a wide range of negative health impacts, before, during and after events
VECTOR-BORNE INFECTION	Changes in temperature extremes and seasonal weather patterns	Earlier and geographically expanded tick and mosquito activity	Lyme disease, West Nile Virus	Insects show earlier activity, and northward expansions to range, increasing risk of exposure to human populations
WATER-RELATED INFECTION	Rising sea surface temperature, changes in precipitation and runoff	Recreational water and/or shellfish/seafood contamination with bacteria and viruses	Gastrointestinal illnesses, wound and blood stream infections	Higher water temperatures alter timing and location of infectious organisms increasing risk of exposure to water borne illnesses
FOOD-RELATED INFECTION	Increases in temperature, humidity and changes to growing seasons	Increased range and contact with pathogens, seasonal shifts in the prevalence of some diseases	Gastrointestinal illnesses	Rising temperatures increase prevalence of pathogens in food, longer season and warming winters increase risk of exposure and infection
MENTAL HEALTH AND WELL-BEING	All climate changes especially severe weather	Increased exposure to traumatic events or the fear of traumatic events	Distress, grief, behavioural health disorders, social impacts, loss of resilience	Changes in exposure to climate or weather related disasters cause or exacerbate stress and mental health issues with greater risks for vulnerable populations

3.3.2 FORCED MIGRATION AND RESETTLEMENT

FIGURE 3-7: Floods along the Ottawa River 2017. *(Image Credit: C. Mercer Clarke).*

FIGURE 3-8: Male, the capital city of the Maldives, an island nation threatened by sea level rise *(Image Credit: Shahee Ilyas, Wikipedia, CC BY SA 3.0).*

"The **speed, severity, and complexity** of known and unknown changes in climate and ecosystems will challenge the ability of society to generate fitting responses." *(Adger et al. 2011, p758)*

In Canada, and throughout the world many communities will be, and in some cases already are, affected by migration away from areas of threat and by migration toward areas offering more secure resources, greater safety and more opportunity (GOV/CAN 2013). The most immediate threats will be to those nations which are already challenged by increases in flooding events, whether through sea level rise, or as the result of some combination of low-elevation development patterns, subsiding landscapes, increased precipitation, snow melt, erosion of shorelines (Figures 3-7, 3-8).

While the risks of flooding can be obvious, issues such as desertification and inland flooding can pose both encroaching or sudden impacts to landlocked communities as well. Canadians will also need to consider how climate change can be a trigger for conflict in areas in which resources are under stress. Even before the Middle East refugee crisis of 2015, the International Monetary Fund had accepted that massive migrations would 'warrant serious and current attention' (IMF 2008, p. 4).

Situations being experienced in the Middle East, and in other conflict areas of the world, could be the harbinger of future challenges as changing sea levels render regions of the world inhospitable or unsafe for human populations. Drought and flood exacerbate civil instability and enhance conditions for strife and war. This is particularly evident in poorer nations, which can lack the resources to relocate displaced citizens, driving them to seek refugee status in neighbouring nations or elsewhere in the global community. The needed resettlement of substantial numbers of climate refugees will place stresses upon communities and individuals in Canada as well as other nations, as the world struggles to ensure that everyone has a safe home and access to basic needs and comforts.

3.4 EFFECTS ON THE ECONOMY

The financial sector has recently awakened to the risks imposed by a changing climate on assets and on investment. Estimated losses worldwide leading up to 2100 have been valued at US$ 4.3 trillion, a figure equivalent to the total worth of all the world's oil and gas companies, or to the GDP of Japan (The Economist 2015). Climate change is now understood to be inevitable and permanent, but the magnitude of the change is not yet set in stone. Should the globe warm by at least 5 C°, economic losses could climb to US$7 trillion, or to US$13.8 trillion if temperatures increases soar to 6 C° (The Economist 2015). The costs of adaptation and mitigation need to be measured against these risked losses, even if focusing exclusively on the fiscally responsible choice to make for investors over the next several decades.

The World Economic Forum (2016) has identified the failure of climate change mitigation and adaptation measures as the top most impactful global risk, ranking above the risks associated with weapons of mass destruction or crises in water supply. Failures to address climate change, the potential for extreme weather events, and large-scale involuntary migration were the top three risks in terms of likelihood to occur. As nations struggle with water availability and food security, failures to address the changing climate will only exacerbate these circumstances, leading to forced displacement, civil strife and to both voluntary and involuntary migration. The economic costs will be daunting both to the nations affected by these impacts directly, and to those nations receiving these refugees.

The changing environment will have both positive and negative effects on national and regional economies, but to capitalize on the former and minimize the latter, proactive decision-making is required (Figure 3-9). The degree of financial impact on institutions and individuals will largely relate to how resilient they are, to their capacity and willingness to change where needed, and most especially, to the early onset of planning and action to reduce greenhouse gas emissions to the atmosphere and to prepare society for the coming changes in environmental conditions. As documentation on climate changes accrues, scientists are increasingly concerned over projections of future weather and climate over the next 80 years, which show a clear escalation in trends over that time frame, if emissions of greenhouse gases are not significantly curbed and reduced from 2005 levels. The highest estimates for future damages, and indeed for failures to capture potential opportunities, will result from a refusal to acknowledge and to adjust to these projected outcomes proactively, with one eye always towards the future (GOV/CAN/NRTEE 2010).

A **GLOBAL RISK** is an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years. (WEF 2016)

DIRECT IMPACTS are economic impacts that occur at the source of where climate-related extreme event influences the economy. The source may be an economic sector, or an asset class (e.g., buildings). The economic impact can result from damages to fixed assets, and losses due to business interruptions. (IBC 2015)

SECONDARY IMPACTS result from the ripple effect of direct impacts on the broader economy, as subsequent spending takes place. Spending from a direct impact does not result in a net gain for society. Spending related to construction and remediation might benefit the construction sector, but there will be a transfer of resources and activity to industries responding to an event and away from those that suffered damage because of the event. *(IBC 2015)*

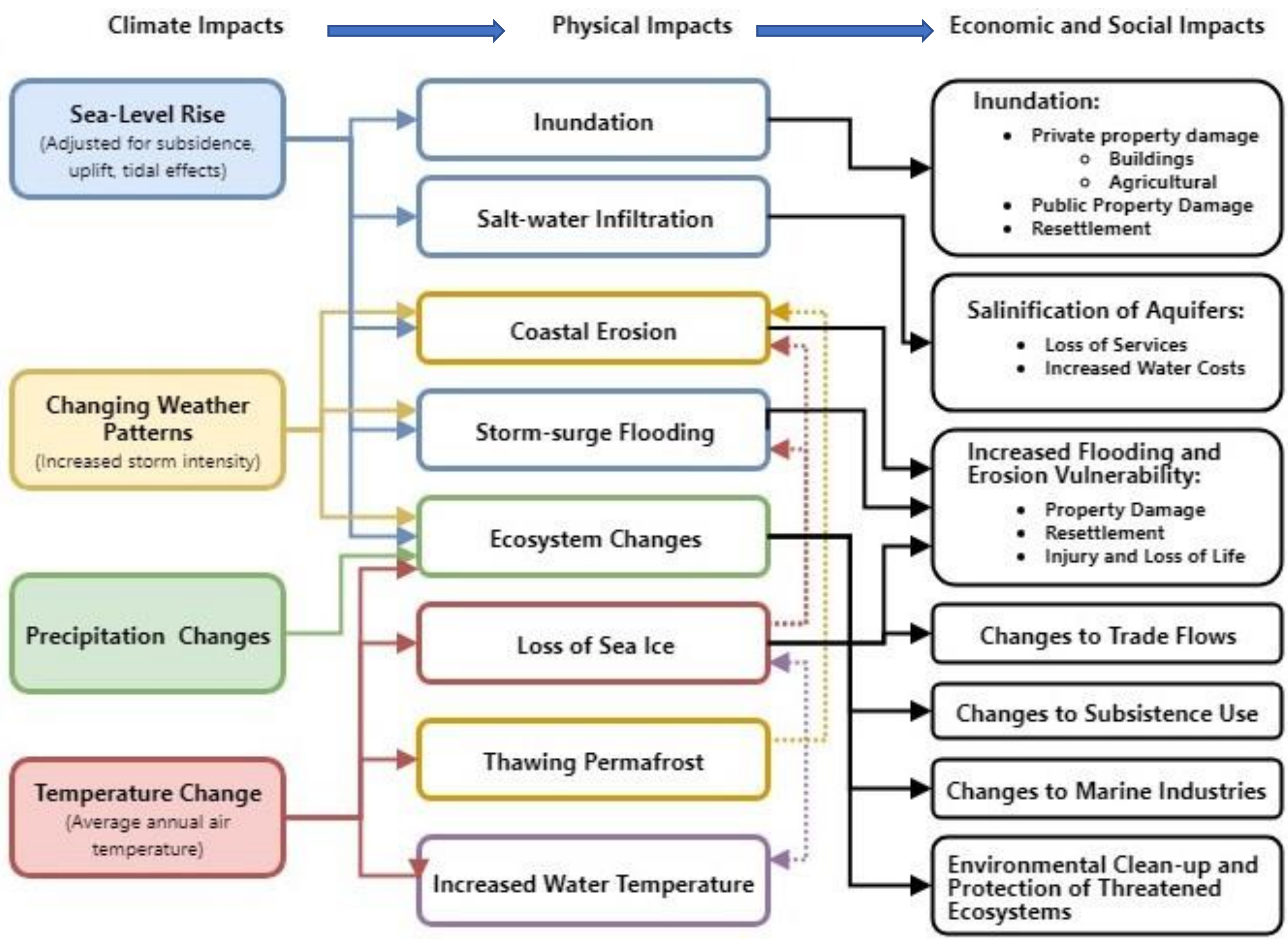

FIGURE 3-9: Economic and social impacts associated with climate change (*Adapted from GOV/CAN/NRTEE 2010*).

In North America and in Europe, it has been determined that considerable costs could be avoided, and significant gains could be achieved through early reductions in greenhouse gas emissions (GOV/USA/EPA 2015). In Canada, the effects of extreme weather are already setting new records, whether it is in merchantable timber lost to wildfires, crops damaged by drought and/or flooding, migrating fish stocks, losses related to transportation delays, or in direct damage to buildings, roads and services. Sales derived from ecosystem services in Canada totalled US$3.9 billion in 2010, in which sales of goods contributed US$ 2.2 billion (UNEP 2014). The economic value of the other contributions made by Canada's natural environments has not been calculated but the list includes services such as provisions of safe drinking water, removal of contaminants, acceptance and purification of wastes, and, of course, clean air and a protective atmosphere

Throughout Canada, public infrastructure is aging, and in its weakened state may be more vulnerable to damage (Table 3-5). Early attention paid to needed upgrades, to address projected future conditions, could require additional funds to be expended in the coming years. However, this short-term expenditure will lead to significant savings in the long run, as proactive upgrades are typically less costly than repairing and rebuilding after structural damage has occurred. This early attention to wise economic planning could save billions in damages and retrofit costs. Current estimates anticipate that the long term financial impacts of natural catastrophes (Table 3-4) in Canada could reach $5 Billion per year by 2020 and $21-43 billion per year by 2050 (Alexander and McDonald 2014). Stanton et al. (2010) estimated that the damages to Canada's economy could reach as high as $1.1 trillion by 2100. In recent work on case studies conducted in Halifax (NS) and Mississauga (ON), the IBC (2015) projected that direct damages from anticipated storm surges alone in the Halifax Regional Municipality could cost as much as $9 million annually by 2040.

The Insurance Bureau of Canada (IBC) has reported that prior to 2011, insurance claims for damages due to severe weather were not notable. Since that time, damage claims resulting from weather events are on average $1 billion annually, and in 2013 reached a high of $3.6 billion (Table 3-4). Private insurance in Canada has generally not covered damage from overland flooding (although some insurers are changing this policy), and there is as yet no federally supported relief program such as the National Flood Insurance Program in the United States. As forest fires rage across large areas and water levels rise, whether from inland flooding or from sea-level rise and storm surges, the liabilities will continue to increase for insurance companies, and the expectation is that the cost for home and property insurance will increase as a result. By example, to keep pace with damage claims, insurance premiums in Newfoundland and Labrador have increased 493% in the past 20 years, largely attributable to severe weather events (The Canadian Press 2015).

TABLE 3-4: Top 10 largest natural catastrophes in Canada since 2000 (as determined by damage to infrastructure) *(adapted from Alexander and McDonald 2014, Canadian Disaster Database, Insurance Bureau of Canada).*

YEAR	LOCATION	TYPE OF CATASTROPHE	INFRASTRUCTURE DAMAGE ($ Millions)
2013	Southern Alberta	Flooding	$ 1,743
2013	Toronto Ontario	Flooding	$ 944
2011	Slave Lake Alberta	Wild fire	$ 742
2005	Southern Ontario	Wind, rainstorm	$ 625
2010	Southern Alberta	Wind, thunder storm	$ 530
2012	Alberta	Flooding, hail, winds	$ 530
2009	Ontario	Heavy rain	$ 376
2005	Alberta	Flooding	$ 300
2009	Ontario and Quebec	Heavy rain	$ 228
2003	British Columbia	Wild fire	$ 200

TABLE 3-5: Potential consequences of environmental change on infrastructure economics *(Adapted from Boyle et al. 2013)*.

ENVIRONMENTAL CHANGE	CONSEQUENCES TO ECONOMICS
Sea-level rise, higher storm surges	Damage to shoreline features, waterfront real estate and to recreation and tourism assets
	Retrofit costs to increase capacity of existing stormwater system, damage to roads and bridges, relocation of infrastructure/buildings/uses
	Damage from flooding, erosion, sedimentation, wave energy
	Higher insurance costs
	Salt intrusion into local water supplies
Thawing permafrost, increased frequency of freeze-thaw cycles in winter	Soil instability leads to increased costs to move or retrofit buildings
	Damage to land transportation systems and to water systems (e.g., potable, storm, wastewater)
	Containment structures and other physical infrastructure may exhibit reduced reliability/strength
	Deterioration of drinking water resources
Increased precipitation	Accelerated deterioration in the built environment
	Damage from flooding
Hotter, drier summers	Increased demand for drinking water and water for irrigation
	Damage to road surfaces (e.g., softening of pavements), shortened life expectancy for land transportation infrastructure, reduction in maximum loads/changes in seasonal load restrictions
	Increased urban heat island effects leading to heightened demand for energy for cooling systems
	Changes in soil profiles resulting in foundation damage or failure, land subsidence
	Drought affected crops in some areas, new opportunities in others
	Loss of forest and real estate to wildfires
	New opportunities for tourism, including a longer summer season
Milder winters	Shortened ice road season, lessened frost damage on southern roads,
	Decreased damage to structures from freeze-thaw cycles
	Longer construction season in much of the country
	Impacts to winter tourism
Severe weather (hurricanes, tornadoes, hail, wind, ice)	Damage to property
	Retrofit for existing structures to meet new requirements
	Damage to infrastructure,

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RESOURCES ON THE WEB

CLIMATE CENTRAL SURGING SEAS

http://sealevel.climatecentral.org/surgingseas/

COASTAL AND WATERFRONT SMARTGROWTH

http://coastalsmartgrowth.noaa.gov/welcome.html

GOVERNMENT OF CANADA: COMMUNITY INFORMATION DATABASE

http://www.cid-bdc.ca/welcome-bienvenue

The site offers internet-based access to consistent and reliable socio-economic and demographic data and information for all communities across Canada.

GOVERNMENT OF CANADA: FISHERIES AND OCEANS CANADA

Risk-based assessment of climate change impacts and risks on the biological systems and infrastructure within Fisheries and Oceans Canada's mandate

Pacific Large Aquatic Basin.

http://waves-vagues.dfo-mpo.gc.ca/Library/349895.pdf

http://waves-vagues.dfo-mpo.gc.ca/Library/349980.pdf

Arctic Large Aquatic Basin

http://waves-vagues.dfo-mpo.gc.ca/Library/348878.pdf

http://waves-vagues.dfo-mpo.gc.ca/Library/348880.pdf

Atlantic Large Aquatic Basin.

http://waves-vagues.dfo-mpo.gc.ca/Library/348874.pdf

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Freshwater Large Aquatic Basin.

http://waves-vagues.dfo-mpo.gc.ca/Library/349668.pdf

http://waves-vagues.dfo-mpo.gc.ca/Library/349976.pdf

EUROPEAN CLIMATE ADAPTATION PLATFORM: (CLIMATE-ADAPT)

http://climate-adapt.eea.europa.eu/

The EU program is a partnership between the European Commission (DG CLIMA, DG Joint Research Centre and other DGs) and the European Environment Agency. CLIMATE-ADAPT aims to support Europe in adapting to climate change. It is an initiative of the European Commission and helps users to access and share data and information on: expected climate change in Europe; current and future vulnerability of regions and sectors; EU, national and transnational adaptation strategies and actions; adaptation case studies and potential adaptation options; and tools that support adaptation planning.

GOVERNMENT OF BRITISH COLUMBIA: PLANTING OUR FUTURE TOOLKIT

http://www.toolkit.bc.ca/resource/planting-our-future

GOVERNMENT OF BRITISH COLUMBIA: STEWARDSHIP CENTRE

http://stewardshipcentrebc.ca/

The Stewardship Centre is committed to promote advancement of stewardship education and to champion science-based best stewardship practices for land and water in BC.

GULF OF MAINE CLIMATE NETWORK

http://www.gulfofmaine.org/2/climate-network-homepage/

The Climate Network brings together planners and scientists from around the Gulf of Maine to raise awareness about climate impacts and inspire effective action in local communities — where residents experience first-hand the effects of changing conditions

HEALTH CANADA

http://www.hc-sc.gc.ca/ewh-semt/climat/eval/index-eng.php

Assessing the health effects of climate change in Canada.

INTERNATIONAL JOINT COMMISSION FOR THE GREAT LAKES

http://www.ijc.org/en_/

INSTITUTE OF WELLBEING

http://theinstituteofwellbeing.com/

The Institute is a national and specialist organization promoting total wellbeing and healthy living through a range of Personal Development Programmes, Private Therapies, Multimedia and Creative Arts for all people at all stages of life.

NATURESERVE: CONSERVATION TOOLS AND SERVICES

http://www.natureserve.org/conservation-tools/ecosystem-based-management-tools-network/coastal-adaptation-sea-level-rise-tool-coast.html

NatureServe is a non-profit organization that provides high-quality scientific expertise for conservation. Their data, tools and resources are intended to guide conservation action where it is needed most. Included on their website are a number of reports for identifying climate impacts on ecosystems.

GOVERNMENT OF THE USA

USAEPA CLIMATE CHANGE SCIENCE

https://19january2017snapshot.epa.gov/climatechange_.html

on changing climate and the effects on ecosystems in the USA.

USA EPA CLIMATE READY ESTUARIES

http://www.epa.gov/cre

The Climate Ready Estuaries program works to assess vulnerabilities, develop and implement adaptation strategies, and engage and educate stakeholders

GLOBAL CHANGE RESEARCH PROJECT

http://www.globalchange.gov

The USGCRP was established to assist the US and the wold to assess, predict and respond to human-induced and natural processes of global change.

USA NOAA STATE OF THE CLIMATE

http://www.ncdc.noaa.gov/sotc/global/201413

USA NATIONAL CLIMATE ASSESSMENT; CLIMATE CHANGE IMPACTS IN THE UNITED STATES:

http://nca2014.globalchange.gov/report

THANK YOU OCEAN PODCAST ON WHAT IS OCEAN ACIDIFICATION 2016

http://thankyouocean.org/what-is-ocean-acidification/

KEY REPORTS

NATURAL RESOURCE CANADA ASSESSMENT REPORTS ON CLIMATE CHANGE

All NRCAN publications are available in digital format, free of charge at: http://www.nrcan.gc.ca/environment/resources/publications/10766