



Climate Change in the GOM 2050

Scenario Paper: Temperature, Sea Level Rise and Storm Projections

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INTRODUCTION

The recent release of collaborative national climate assessments such as the “Canada’s Changing Climate Report (CCCR)” (*Bush and Lemmen, 2019*), the “Climate Science Special Report (CSSR)” (*USGCR, 2017 and 2018*) have provided a scientifically informed national overview of the current state and projected changes to the environment as a result of climate change. This knowledge and information provides the foundation needed for decision makers to consider the possible impacts on ecosystems and people. This scenario paper will outline how changes to temperature, sea level rise and storms are likely to alter the conditions in the Gulf of Maine (GOM) in the intermediate term, by approximately 2050. The results embedded are those of the referenced authors as this is a review to help guide discussions at the Gulf of Maine 2050 International Symposium in November, 2019.

Over the past 3 decades, the Intergovernmental Panel on Climate Change (IPCC), an international body responsible for assessing the science related to climate change, has conducted global-scale scientific assessments of climate change. Projections of future climate change are driven by a range of potential forcing scenarios of greenhouse gas (GHG) and aerosol emissions. These scenarios are based on assumptions about how fossil fuel consumption and land use will change in the coming years. Because future emissions are difficult to predict, it is necessary to use plausible scenarios, ranging from low to high emission scenarios, to project future climate change. The most recent climate change projections, i.e., climate model projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) described in the IPCC Fifth Assessment (*IPCC, 2013 and IPCC, 2014*), are based on a suite of future forcing scenarios called Representative Concentration Pathways (RCPs). The RCPs are identified by a number indicating the change in radiative forcing caused by greenhouse gases and other external drivers. The national climate assessments summarized in the American CSSR and the Canadian CCCR use this standard suite of RCP scenarios in their climate model projections. The information presented in this paper is based primarily on data within the CSSR, the CCCR and multi-model ensemble results from CMIP5 Global Climate Models (GCM) with a focus on the GOM region (100 km resolution). Similar to the CCCR, in this paper we will refer to climate scenarios based on RCP2.6 as “low emission scenarios,” those based on RCP4.5 and RCP6 as “medium emission scenarios,” and those based on RCP8.5 as “high emission scenarios.”



TEMPERATURE PROJECTIONS

Under all emission scenarios, annual average temperatures are projected to rise throughout the next century (Figure 1). All of these scenarios suggest similar projected warming in the near term but show a growing separation between results for the low emission scenario and high emission scenario beginning mid century.

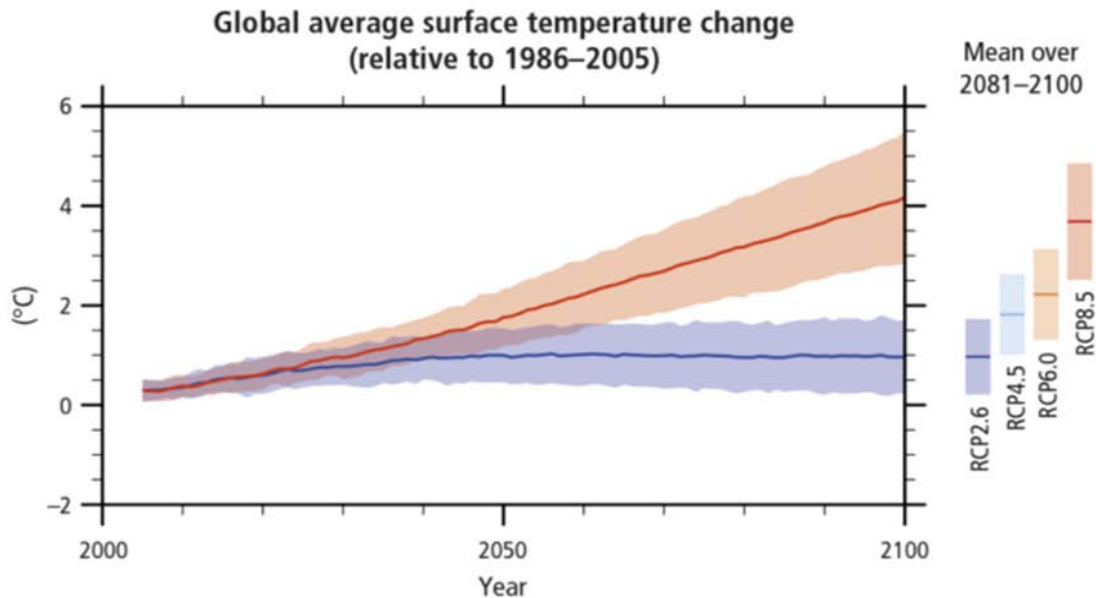


Figure 1. Projected change in global average temperatures. (IPCC 2014)

Due to varying local climate processes and feedbacks the rates of warming are not globally uniform and tend to vary from one region to another. GOM specific output from the CMIP5 multi-model ensemble is given in Table 1 and Figure 2.

Table 1: Projected changes (relative to 1986–2005) in annual precipitation from the CMIP5 multi-model ensemble results for the GOM (100 km resolution) for 2046–2065 for three scenarios (RCP2.6, RCP4.5 and RCP8.5) and for the median (25th, 75th percentiles).

Projected Annual Temperature Change (°C)		
Median (25th, 75th Percentile)		
RCP2.6	RCP4.5	RCP8.5
1.4 (0.8, 2.1)	1.9 (1.4, 2.6)	2.7 (2.0, 3.4)

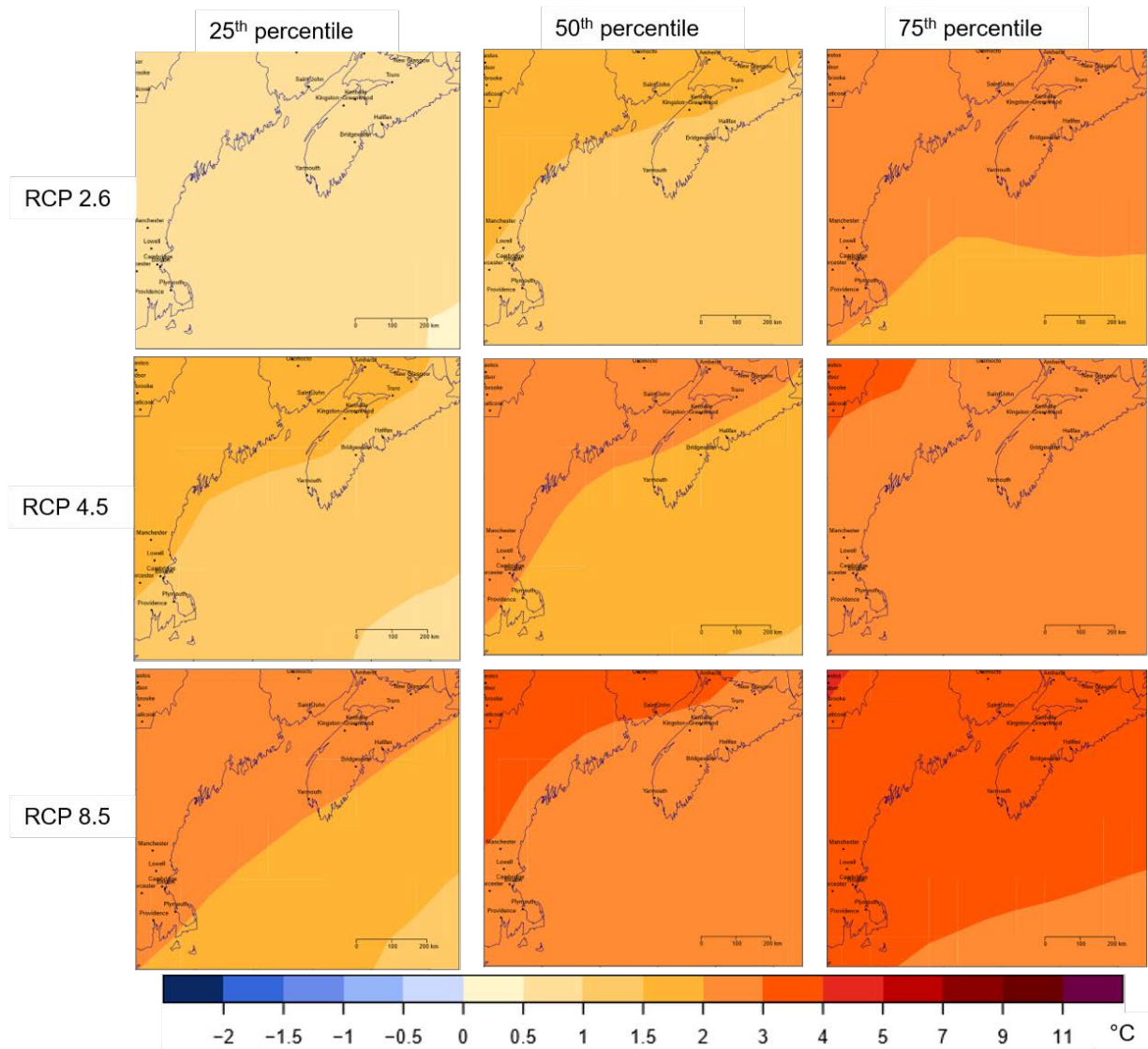


Figure 2: Spatial depiction of projected changes (relative to 1986-2005) in annual mean temperature from CMIP5 multi-model ensemble results for the GOM region (100 km resolution) for 2046-2065 for three scenarios (RCP2.6, RCP4.5 and RCP8.5) and for three percentiles (25th, 50th and 75th).

Table 2 summarizes the projected changes in other temperature indices specific to the GOM region by mid-century. Note that the range of values for each index represents not only the variations within the low to high emission scenarios but also their geographical variation within the GOM region.

Table 2: Summary of projected changes in various temperature indices from recent American climate assessments (relative to 1976-2005) and Canadian climate assessments (relative to 1986-2005) for the GOM region (Zhang et al. 2019, Vose et al. 2017, Kunkel et al. 2013, Dupigny-Giroux et al. 2018).

Index	Projected Change (GOM)
Cooling Degree Days	+50° to +300°C
Heating Degree Days	-400°C to -1300°C
Number of growing season days (warm-season crops)	+18 to +29
Highest Daily Maximum Temperature	+1.9°C to +4.4°C
Lowest Daily Minimum Temperature	+3.8°C to +5.5°C
Annual number of “hot” days **	+2 to +20

** “Hot” days are defined by the CCCR as greater than 30°C

Projected changes to average and extreme temperatures

Based on CIMP5 GCMs, the median of the multi-model ensemble projections show that the annual mean temperature average across the GOM region is expected to rise +1.4°C to +2.7°C by mid-century (Table 1). To put this into perspective, consider that such an increase in the annual mean temperature would be comparable to the hottest year in historical record (2012). Given such a rise in annual temperatures, recent record-setting temperature years could be the norm in the GOM region by mid-century.

Over the northern part of the GOM region in particular, warming over the winter months is expected to be slightly greater than the warming during the summer months (Zhang et al. 2019). This differentiation of annual warming is reflected in other temperature indices, most notably in degree days. Heating degree days (the annual sum of daily mean temperature below 18°C) and cooling degree days (the annual sum of daily mean temperature above 18°C) are indicators of building cooling and heating demand used for energy utility and planning. Degree days are also indicators of the amount of heat available for crop growth. The projected change in the number of heating degree days is considerably greater than the change in cooling degree days, which is a reflection of the higher projected warming trend in winter compared to summer.

Throughout the GOM region, the growing season for warm season crops is expected to lengthen by 2 to 4 weeks by mid-century. A longer growing season and warmer winters provides a longer period for plant growth and productivity of beneficial plants (such as crops and forests), but with it also come challenges including increased weed and pest pressure and an extended period of spring frost risk (Wolfe et al., 2018).

With warmer annual average temperatures and fewer cold extremes, a shorter and less pronounced cold season is expected, along with less early-winter snowfall and earlier snowmelt,

resulting in changes to the seasonal hydrological cycle and stream flows throughout the GOM region (Demaria et al. 2016, Contosa et al. 2017, Notaro et al. 2014).

More frequent and intense heat events are projected throughout the coming decades while the frequency and intensity of cold waves is projected to decrease throughout the GOM region (Thibeault et al., 2014). Extreme warm temperatures are expected to become hotter by mid-century, with a projected rise of 1.9°C to 4.4°C (Table 2). By the 2050s, under a high emissions scenario, once-in-50-year extreme-heat days are projected to occur every three or four years (Zhang et al., 2019).

Implications of Warmer Average Temperatures and Extremes

There are numerous potential implications associated with a local climate that has higher average temperatures with hotter and more frequent extremes. The following short list of potential impacts are summarized and discussed in further detail within the latest Canadian and American national climate change reports (Dupigny-Giroux et al. 2018, Lemmen et al. 2014 Savard et al. 2016, Zhang et al. 2019,).

- More frequent drought conditions due to increased rates of surface evaporation and loss of water from plants caused by higher temperatures.
- Earlier and longer fire seasons due to hotter and drier conditions.
- Increases in associated health-related impacts and costs associated with more frequent and severe heat-related events.
- Increased weed and pest pressure due to a longer growing season and warmer winters.
- An extended period of spring frost risk to vulnerable agricultural sectors, such as fruit crops, due to earlier spring and subsequent cold spells.
- A decline in surface water quality due to more frequent algal blooms in warmer surface waters of large lakes.
- Earlier river ice breakup and freshet flow in spring due to earlier peaks in spring snowmelt.
- Changes to hydrological power production due to changes in timing of spring streamflow.
- Impacts to winter recreation industries due to warmer (and shorter) winter conditions.
- Impacts to rural industries such as logging and maple syrup production due to warmer winter and spring conditions.

SEA LEVEL RISE PROJECTIONS

Global sea-level rise is one of the most significant consequences of increasing global temperatures and is primarily driven by two factors: 1) thermal expansion of a warming ocean, and 2) increased melting of mountain glaciers, icecaps, and the Antarctic and Greenland ice sheets. (IPCC, 2014)

Global mean sea-level change is referenced to the centre of the Earth and is commonly discussed in terms of “absolute” sea level. Recent climate change projections using low to high emission scenarios suggest that the absolute sea level is expected to rise by 15 to 38 cm by 2050 as depicted in Figure 2 (IPCC 2014, Greenan et al. 2018, Sweet et al. 2017a).

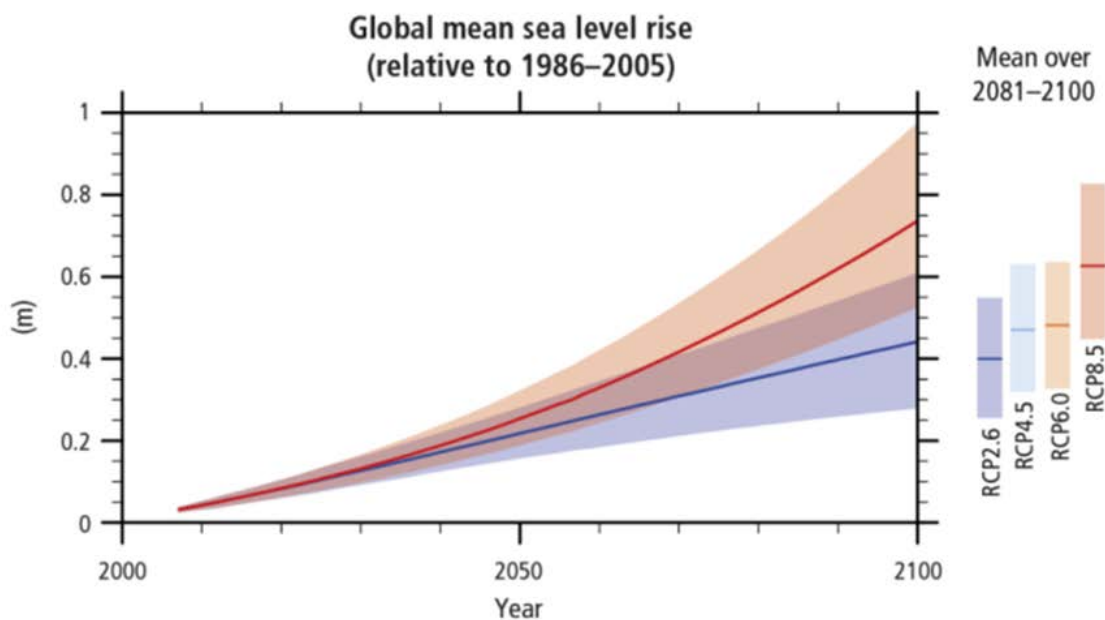


Figure 2. Projected change in global sea levels due to climate change. (IPCC 2014)

One important factor and a major source of uncertainty in projections of global sea level, is the stability of the West Antarctic Ice Sheet. The collapse of the West Antarctic Ice could cause global mean sea levels to rise substantially above these projected values. Some estimates suggest that such a collapse could potentially contribute as much as an additional 60-110 cm to global mean sea level change projections during the 21st century (DeConto and Pollard, 2016) Changes to sea level are not uniform globally. Locally, the sea-level change that is experienced relative to land is of most concern to coastal planners and is known as “relative” sea-level change. In addition to the global sea-level change estimates, projected changes to relative sea-level at a coastal site depend on the following:

1) Local vertical motion of the ground.

The primary cause of vertical land motion across North America is glacial isostatic adjustment (GIA), which causes surface uplift or subsidence due to the delayed effects of the last continental glaciation. Within the GOM region, locations along the Canadian coastline to the Canada–US border tend to be sinking while US locations in along the Maine and Massachusetts coasts have very small uplift rates. (*Craymer et al., 2011*)

2) Spatial variations in the redistribution of glacial meltwater in the global oceans

Geographically distinct patterns of sea level change are known as sea level fingerprints and have been discussed in detail by Mitrovica et al. (2011). Simply put, meltwater from glaciers, ice caps and ice exerts a reduced gravitational pull on the surrounding ocean water, causing the nearby ocean surface to fall. The reduced load also causes the land under and adjacent to a shrinking ice sheet to rise relative to the ocean. Close to a source of sea-level rise, sea-level will fall. At greater distances the sea-level rise is smaller than the global average. At even larger distances, sea-level rise is slightly higher than the global average.

3) Regional changes to sea-level due to dynamic oceanographic effects and global circulation patterns.

Changes to atmosphere–ocean dynamic factors such as ocean currents and winds can lead to changes in the sea-surface height and therefore changes in local relative sea level (*Hughes et al. 2009*). For much of the East Coast region, including the GOM, a projected slowing of the Gulf Stream could contribute 10–20 cm to sea-level rise by 2100, due to dynamic oceanographic effects. (*Yin, 2012*)

Table 3 summarizes projected relative sea-level change by 2050 (relative to 1995) for locations within the GOM region. These values are based on projections of sea level change from the IPCC's Fifth Assessment Report (*IPCC, 2014*) for the medium and high emissions scenarios, with the addition of contributions from vertical land motion, variation in meltwater distribution and dynamic oceanographic factors (*James et al., 2014, Zhai et al., 2014*).

Table 3. Summary of relative sea level rise projections for 2050 (relative to 1995) for the GOM Region (James et al., 2014, Zhai et al. 2014).

<i>Tide Gauge Locations</i>	<i>Projections of Relative Sea Level Rise by 2050 (cm)</i>
Halifax, NS	24-32
Yarmouth, NS	
Saint John, NB	19-27
Eastport, ME	
Portland, ME	
Boston, MA	

It should be noted that some recent studies suggest that in a high emissions scenario that considers accelerated Antarctic ice-sheet melt, an additional 50 cm or more would be expected to these relative sea level rise estimates by 2050 (Han et al., 2016 and Sweet et al., 2017b).

Coastal Flooding

Regardless of the uncertainties in the exact magnitude, a rise in sea level in the coming decades is inevitable. Given the rising sea levels, the number of floods each year from tidal forcing alone that cause minor impacts (also called “nuisance floods”) will also increase in depth and frequency, turning it from a rare event into a recurrent and disruptive problem (Sweet et al., 2014, Mofakhari et al., 2015, Ray and Foster, 2016).

The highest high tides of the year, commonly known as King Tides, occur during perigean (moon is closest to Earth) spring tides (moon and sun aligned). Exceptionally high King Tides occur when perigean spring tides optimally coincide with other astronomical occurrences of declination and other orbital positions of the earth, sun and moon. These factors peak simultaneously every 18.03 years in what is termed the Saros Cycle. The most recent Saros cycle peaked in 2016 and caused extensive minor flooding all along the Eastern Seaboard even in the absence of a significant weather system. Such impacts from King Tides are important because they show what average water levels might look like in the future based on sea-level rise projections. Numerous King Tides Projects, in which participants snap and share images of King Tides, have been established locally (Gulf of Maine King Tides Project: <http://gulfofmaine.kingtides.net/>) and worldwide to help citizens understand how sea level rise will impact their local community.

Coastal flooding is often intensified if a King Tide coincides with a storm (Wood, 1986). Mid-latitude and tropical storms often cause an abnormal rise in water level above the predicted tide (referred to as a storm surge) due primarily to changes in atmospheric pressure and the effect of

winds pushing water onshore. A storm surge coinciding with a King Tide often results in unusually high water levels, which can extend further inland and lead to more extensive flooding. Several major coastal flooding events of the past in the GOM region have resulted from mid-latitude storms striking the area close to a King Tide (i.e. the Saxby Gale [Desplanque and Mossman, 1999], the Ash Wednesday Storm of 1962 [Cooperman and Rosendal, 1962], the Northeastern US Blizzard of 1978 [USACE, 1979], Winter Storm Grayson 2018 [LeComte, 2019]). It is of particular interest that future Saros cycles, producing exceptionally high King Tides, will peak again in the mid 2030s and again in the early 2050s.

Implications of Sea Level Rise for the GOM

The potential impacts associated with sea level rise are numerous and can be specific to a local community or municipality. The following is a short set of some of the more significant challenges that sea level rise will bring to coastal regions, the GOM in particular (Atkinson *et al.* 2016, Savard *et al.*, 2016, Greenan *et al.* 2018, Bush *et al.*, 2014, Sweet *et al.*, 2017a):

- Accelerated erosion and more frequent and severe flooding will impact:
 - coastal farmland, housing or recreation areas.
 - coastal infrastructure used for fisheries, such as ports, wharves, piers and fish plants.
 - tourism infrastructure (e.g., wharves and coastal properties) and cultural resources.
 - existing and proposed coastal export terminals.
- Flooding of wetlands and ecosystem changes that will affect the flora and fauna, causing the loss of habitat for fish, birds, plants and many other species.
- Flooding of highways causing isolation of coastal communities
- Loss of areas providing physical protection
- Increased permanent inundation due to higher average water levels
- Increased saltwater intrusion within coastal rivers and aquifers

STORM PROJECTIONS

As mentioned above, air temperatures are projected to continue to rise into 2050. These increasing temperatures have implications on many aspects of storms including their development. Changes in the frequencies and intensities of these storms by 2050 are difficult to predict due to the nature of these events, the varying results within the scientific literature and the uncertainties associated with characterizing them for the initial stages of climate modelling (*Greenan et al., 2018*). One of the largest factors when considering storm track projections begins with the global atmospheric circulation pattern. For example, the North Atlantic Oscillation (NAO), which represents the pressure pattern between the Subtropical (Azores) High and the Subpolar (Arctic) Low, significantly influences the path and intensity of storms that would affect the GOM region. However, while the NAO and other large scale atmospheric patterns such as the El Niño–Southern Oscillation (ENSO) have significant effects on climate variability, they are not captured to the accuracy needed in order to resolve regional level questions such as storm projections with high confidence (*Shepherd, 2014*). One trend of storms that has been consistently projected, although still with low confidence, is the continued northward push of storm tracks (*Collins et al., 2013*). This change to storm tracks has consequential effects on weather elements of the storm such as a shift in the precipitation and wind patterns for a given location.

Although the level of detail and confidence for storm projections is limited and more analysis is needed (*Colle et al., 2015*), a general overview of the information found in the scientific literature pertaining to high-impact storms, such as winter storms and tropical storms, is given below.

Winter Storms

Projections of Atlantic Extratropical Cyclones based on a method whereby the seven best members of the 15 within phase 5 of the Coupled Model Intercomparison Project (CMIP5) were used to evaluate storm behavior in the western Atlantic during the “cool season” (November – March) (*Colle et al., 2013*). The results for the 2039-2068 period show fewer storms over the east coast including the area off Cape Hatteras, NC where east coast winter storm tracks often originate. However, projections of cyclone deepening rates indicate a peak at year 2050 in more quickly deepening storms (< 980 mb) along the inland area of the northeast US seaboard. These results depict the differences between storm traits along inland and offshore areas of the coast within the GOM domain. These more quickly deepening storms could result in coastal infrastructure being less useable due to increased wave action as well as produce more damage from the wind-driven waves and storm surge possibly severe enough to cut-off access to coastal communities (*Savard et al., 2016*). Increase in storm-driven winds and wave action would also result in a proportional increase in demand for environmental response and search and rescue services (*Shackell et al., 2013*).

When considering changes to precipitation phase, increasing temperatures imply that more wintertime precipitation will fall as rain than snow. The projected higher temperatures combined

with the northward shift of storm tracks and associated rain-snow boundary to higher latitudes further suggests a changing proportion of liquid to solid phase precipitation for snow-dominated areas. Statistically downscaled output from the CMIP5 for a high emission scenario shows this evolution of liquid dominated precipitation by the end of the 21st century for the eastern US (Ning *et al*, 2015), including areas within the GOM. Similar uncertainties exist with model initialization as stated above, as there have been changes in monitoring procedures and locations over time making the observations of snowfall amounts in particular subject to variability. Also, climate model computations of precipitation has an inherent level of uncertainty due to the nature of these events, especially for snow (Easterling *et al.*, 2017). However, with the potential for less snow occurrence and a shorter snow season there are possible implications on water resources, ecosystems and the economy (Ning *et al*, 2015). Further to that, with more precipitation during the winter season falling as rain, there will be an increase of rain-on-snow events which can cause damage to roadways including extensive washouts (Rapaport *et. al*, 2017). An earlier spring snowmelt can also result in major inland flooding, as has been the case for rivers within the GOM (Kunkel *et al.*, 2013).

Tropical Storms (Hurricanes)

Tropical cyclones (hurricanes) are a crucial component when considering the likelihood of more extreme weather events in the coming decades as they are a source of extreme precipitation and can cause significant damage especially to coastal sectors such as the GOM. As mentioned with other model projections, there is a high degree of uncertainty in modelling tropical cyclones as historical characterization of the storms has varied and changed over time. The observational data has changed, as mentioned for other weather parameters considered, but also, how weather agencies define maximum wind speed, and therefore hurricane category, has not been consistent, making reanalysis of tropical storms difficult and leading to increased model errors. However, with increasing sea surface temperatures (SSTs) as a result of increasing air temperatures (Loder and Wang., 2015), and these SSTs being a key parameter for the strength of tropical cyclones, models are in general agreement that there will be an increase in the intensity of these storms. It is also suggested that there will be more tropical cyclones in the Atlantic basin within the very intense category (Knutson *et al.*, 2013), defined by the Saffir-Simpson Hurricane wind scale as category 4 (sustained winds of 114-135 knots) and category 5 (sustained winds > 135 knots). This possibility is notable from an impact perspective because while hurricanes of these categories do not occur as often, they cause a disproportionate amount of damage as has been shown by historical analyses of U.S. hurricane damage with category 4 and 5 hurricanes accounting for approximately half of the damage (Pielke *et al.*, 2008). This in turn leads to effects on the tourism and insurance sectors (Kovacs and Thistlethwaite, 2014) as well as significant implications on human health and well-being (Berry, *et al.*, 2014). Storm-related disruptions, in general, can also cause a loss of productivity to the transportation sector with a consequential economical impact.

Precipitation

Changing precipitation patterns are important to consider when thinking about implications for the future as they can have many consequential impacts. A projection of storm tracks northward would result in a general shift of precipitation patterns. Regional level precipitation patterns are more difficult to project than temperature because they are affected by the global circulation pattern as well as temperature, which dictates how much moisture the atmosphere can hold (Shepherd, 2014). However, with increasing water vapor (Santer et al, 2006) and higher temperatures, there is confidence in trends toward increases in extreme precipitation events, but it is unclear if this is the main driver for the increase and more research is needed to clearly link the two (Kunkel et al, 2013). Extreme precipitation events can cause flooding, erosion and damage to infrastructure such as roads and buildings.

Projected changes in annual precipitation for the GOM for the mid-century period (2046-2065) relative to 1986-2005 as given by the CMIP5 multi-model ensemble results are shown in Table 4. The results are for three scenarios (RCP2.6, RCP4.5 and RCP8.5) and for three percentiles (25th, 50th and 75th) showing the range of uncertainties. The median values spanning the low (RCP2.6) to high (RCP8.5) emission scenarios, suggest a 2.2 – 4.6% increase in annual precipitation for the area.

Table 4: Projected changes (relative to 1986-2005) in annual precipitation from the CMIP5 multi-model ensemble results for the GOM (100 km resolution) for 2046-2065 for three scenarios (RCP2.6, RCP4.5 and RCP8.5) and for the median (25th, 75th percentiles).

<i>Projected Annual Precipitation Change (%)</i>		
<i>Median (25th, 75th Percentile)</i>		
RCP2.6	RCP4.5	RCP8.5
2.2 (-5.2, 10.4)	4.1 (-3.6, 12.2)	4.6 (-3.2, 13.2)

Seasonal Projections

Table 5 gives the projected seasonal changes (relative to 1986-2005) in temperature and precipitation from the CMIP5 multi-model ensemble results for the GOM region (100 km resolution) for 2046-2065. There is no notable seasonal difference in temperatures for the GOM depicted in these results. All three emissions scenarios show similar ranges of temperature changes with median ensemble values of 1.3 - 2.8°C from the low emission (RCP2.6) scenario to the high (RCP8.5). The change in precipitation appears to be larger for the winter months, with median values of 3.0% (RCP2.6) to 6.8% (RCP8.5). However, it should be noted that there is less confidence in seasonal precipitation projections than annual projections (Zhang, 2019).

Table 5: Projected changes (relative to 1986-2005) in seasonal temperature (top) and precipitation (bottom) based on CMIP5 multi-model ensemble results for the GOM (100 km resolution) for 2046-2065 for three scenarios (RCP2.6, RCP4.5 and RCP8.5) and for the median (25th, 75th percentiles).

Projected Temperature Change (°C)					
Median (25th, 75th Percentile)					
Winter (December - February)			Spring (March - May)		
RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
1.4 (0.3, 2.5)	2.1 (1.1, 3.0)	2.7 (1.7, 3.7)	1.3 (0.5, 2.3)	1.7 (0.9, 2.7)	2.4 (1.5, 3.4)
Summer (June - August)			Fall (September - November)		
RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
1.4 (0.7, 2.2)	1.9 (1.2, 2.7)	2.7 (2.0, 3.5)	1.5 (0.8, 2.3)	2.0 (1.3, 2.7)	2.8 (2.0, 3.6)
Projected Precipitation Change (%)					
Median (25th, 75th Percentile)					
Winter (December - February)			Spring (March - May)		
RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
3.0 (-10.5, 17.9)	5.0 (-8.2, 19.4)	6.8 (-6.6, 22.1)	2.8 (-11.1, 18.0)	4.4 (-9.8, 20.2)	5.4 (-9.6, 21.6)
Summer (June - August)			Fall (September - November)		
RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
0.3 (-14.2, 17.1)	2.3 (-13.7, 19.9)	1.1 (-15.0, 19.6)	-1.1 (-15.3, 15.1)	1.6 (-12.6, 17.2)	0.9 (-14.5, 17.0)

Implications of Storms for the GOM

There are many possible consequential impacts as a result of changing storm patterns. The list below is a selection of the possibilities for various sectors within the GOM (*Savard et al., 2016, Forbes et al., 2004, Shackell et al., 2013, Rapaport, et al., 2017*).

- Coastal infrastructure may become less usable due to increased wave action.
- Increased damage to coastal infrastructure due to storm surge and waves including the potential for coastal communities to become inaccessible.
- Increase in storm-driven winds and wave action would result in a proportional increase in demand for environmental response and search and rescue services.
- Potential for less snow occurrence and a shorter snow season leads to possible effects on water resources, ecosystems and the economy.
- More winter season rain could increase rain-on-snow events which can cause damage to roadways including extensive washouts.
- Earlier spring snowmelt could result in major inland flooding and overflowing rivers.
- Potential for more intense tropical cyclones producing more severe regional-scale impacts such as those from higher storm surge and wind-driven damage and having effects on the tourism and insurance sectors as well as human health.
- Storm-related disruptions can cause a loss of productivity to the transportation sector with a consequential economical impact.
- Extreme precipitation events can cause flooding, erosion and damage to infrastructure such as roads and buildings.
- Average storms that re-occur in the same area can result in destabilization of the coast within small dunes.

SUMMARY OF CLIMATE CHANGE IMPACTS FOR THE GOM

The GOM may be vulnerable to the conditions that will result from climate change as outlined in the previous sections of this scenario paper. Table 6 summarizes those potential impacts by element.

Table 6: Summary of climate change impact by element for the GOM

Climate Element		Impact
Air Temperature	Higher average temperatures	More frequent drought conditions due to increased rates of surface evaporation and loss of water from plants caused by higher temperatures.
		Earlier and longer fire seasons due to hotter and drier conditions.
		Increased weed and pest pressure due to a longer growing season and warmer winters.
		Decline in surface water quality due to more frequent algal blooms in warmer surface waters of large lakes.
		Earlier river ice breakup and freshet flow in spring due to earlier peaks in spring snowmelt.
		Changes to hydrological power production due to changes in timing of spring streamflow.
		Impacts to winter recreation industries due to warmer (and shorter) winter conditions.
		Impacts to rural industries such as logging and maple syrup production due to warmer winter conditions.
	Possible changed patterns of infectious and vector-borne diseases due to warmer conditions.	
More frequent and severe heat events	Increases in associated health-related impacts and costs associated with more frequent and severe heat-related events.	
Sea level Rise	Higher average water levels	More frequent and severe flooding events.
		Loss of areas providing physical protection at the coastline.
		Increased permanent inundation due to higher average water levels.
		Increased saltwater intrusion within coastal rivers and aquifers.
	More frequent and severe coastal flooding	Flooding of wetlands and ecosystem changes that will affect the flora and fauna, causing the loss of habitat for fish, birds, plants and many other species.
		Flooding of highways causing isolation of coastal communities
		Accelerated erosion of coastal farmland, housing or recreation areas.
		Damage to coastal infrastructure used for fisheries, such as ports, wharves, piers and fish plants.
		Damage to tourism infrastructure (e.g., wharves and coastal properties) and cultural resources.
Impacts to existing and proposed coastal export terminals.		
Storms	Increase wave action and storm surge	Coastal infrastructure becoming less usable due to increased wave action.
		Increased damage to coastal infrastructure including the potential for coastal communities to become inaccessible.
		Increased demand for emergency response and search and rescue services due to increase in storm-driven winds and wave action
		Potential for increased severe storm surge and wind-driven damage due to more intense tropical cyclones and winter storms.
		Impacts on the tourism and insurance sectors as well as human health due to more intense tropical cyclones.
		Loss of productivity to the transportation sector with a consequential economical impact due to storm-related disruptions
		Destabilization of the coast within small dunes.
	Precipitation	Extreme precipitation events can cause flooding, erosion and damage to infrastructure such as roads and buildings.
		Potential for less snow occurrence and a shorter snow season leads to possible effects on water resources, ecosystems and the economy.
	More winter season rain could increase rain-on-snow events which can cause damage to roadways including extensive washouts.	

RECENT INITIATIVES WITH A FOCUS ON ADDRESSING CLIMATE CHANGE RESILIENCE, ADAPTATION AND EDUCATION WITHIN THE GOM

With the increased concern regarding the potential impacts associated with rising sea levels and intensifying weather events caused by climate change, federal governments have begun supporting provincial/state level projects in coastal regions that focus on reducing the impact of natural disasters, such as coastal flooding:

- Earlier this year, the province of Nova Scotia and the Canadian Federal government (through the Disaster Mitigation and Adaptation Fund) announced funding for two projects in Nova Scotia to reduce the impact of coastal flooding along the Bay of Fundy and Minas Basin. In the face of rising tides and storm surge events, these projects will mitigate damage to the region's ecosystems and municipal infrastructure and provide flood protection for residents and businesses, historical and world heritage sites, Indigenous communities and thousands of hectares of farmland.
- The Canadian Department of Fisheries and Oceans (DFO) developed the **Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT)**. This information is intended to provide advice to DFO Small Craft Harbours (SCH) sectors but can also be utilized more broadly by coastal planners. Projections of sea level allowances, or vertical change to infrastructure necessary to accommodate for changing sea levels due to climate change, are calculated (*Zhai et al., 2014*). The output is given in 10-year intervals (including 2050) over the 21st century period and available through an online interface (CAN-EWLAT) for tide gauge sites along the east coast of Canada and parts of the northeast US (<http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php>).
- In the Northeastern United States, the federal government (through the Federal Highway Administrations "Green Infrastructure Techniques for Coastal Highway Resilience" project) funded a pilot project in which the Maine and New Hampshire Departments of Transportation partnered to study future sea-level rise and storm surge impacts on portions of state coastal highways and to develop nature-based solutions that address vulnerabilities. The final report is available at https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/northeastern/.
- The **New Hampshire Coastal Risk and Hazards Commission** (<https://www.nhcrhc.org/>) was established in 2013 to assist the state and coastal municipalities prepare for climate change and the associated coastal flooding risks. The

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commission is comprised primarily of representatives from all three levels of government and includes science and technical advisory panel members. An extensive report overseen by the Commission (*NH Coastal Risk and Hazards Commission, 2016*) provide guidance and recommendations that will help New Hampshire enhance coastal community and watershed resilience to the effects of storm surge, sea-level rise, and extreme precipitation.

- At the international level, the **International Joint Commission (IJC)** was formed between Canada and the US under the 1909 Boundary Water Treaty to prevent and resolve disputes along boundary or transboundary waters. The Climate Adaptation Working Group (CAWG) within the IJC developed a Climate Change Guidance Framework Pilot Project in 2017 to recommend an approach to addressing climate change for the boards within the IJC (*Bernstein et al. 2017*). The St. Croix River, which forms the boundary water between New Brunswick and Maine, was used in the pilot. An analysis was conducted to estimate how climate change may alter the flows and levels within the watershed, and particularly how these changes may affect compliance with IJC Orders of Approval for structures (i.e. dams) along the river. The results showed a generally warmer and wetter climate for the 2036-2065 period with the possibility of the river flows and levels exceeding the tolerances of the current parameters. With these projections, the St. Croix River Watershed Board has recognized the need to develop and implement a plan in response to climate change. This is an example of science informed decision-making, resulting in action.

There are also many other initiatives at the municipal and provincial/state levels that have a common goal to investigate local sea level rise impacts and to educate and engage the public on adaptation and mitigation efforts. Although such climate change adaptation initiatives in a few of the larger metropolitan areas discussed above have received funding and are well advanced, for much of the GOM region such initiatives remain at the grass-roots level and tend to be underfunded or in their infancy stage.

The following is a sampling of some of the municipal and provincial/state level initiatives currently taking place throughout the GOM region:

- In the larger metropolitan areas within the GOM, climate change resilience studies and programs can be well funded and are well advanced. For example, **Climate Ready Boston** (<https://www.boston.gov/departments/environment/climate-ready-boston>) is an initiative, led by the City of Boston, to work with the community and other partners with the goal of helping Boston and its metro region plan for the impacts of climate change and build a resilient future. This well funded and leading-edge initiative features four components including updated climate projections, vulnerability assessments, focus areas and climate resilience initiatives. As Boston moves towards developing a city adaptation plan, the city worked with the Boston Research Advisory Group (BRAG)

team, overseen by the University of Massachusetts-Boston, to produce a Climate Projections Consensus Report (*Douglas et al. 2016*). City-wide and neighborhood-scale vulnerability assessments have also been conducted and various neighborhood resilience plans have been put in place, all of which are publicly available.

- The provincial governments of Newfoundland and Labrador, Nova Scotia, Prince Edward Island, and New Brunswick, along with regional stakeholders including nonprofits, tribal governments, and industry are working together to address regional climate change impacts through the **Atlantic Climate Adaptation Solutions (ACASA) Project**. The ASCASA website (<https://atlanticadaptation.ca/>) provides information and access to projects, publications, toolkits and other research outputs that aim to help Atlantic Canadians better prepare for, and adapt to, climate change.
- The **Ecology Action Centre (EAC)** is a member-based environmental charity in Nova Scotia which takes leadership on critical environmental issues from biodiversity protection to climate change to environmental justice. The EAC and their Coastal Adaptations branch have been working alongside government in support of legislation for coastal protection. In addition, EAC has an Educating Coastal Communities About Sea-level Rise (ECoAS) Project which is designed to make useful climate change information available to coastal communities in Atlantic Canada and to provide education on the need for planning for future sea-level rise impacts. As part of this initiative, EAC has teamed up with Fisheries and Oceans Canada to create an informative website – www.sealevelrise.ca - with sea-level rise resources for coastal residents, fishers, and municipalities that are specific to Atlantic Canada and British Columbia.
- Relative sea-level rise projections for Atlantic Canada are expected to be higher than the global average (*Greenan et al., 2018*). The Halifax Regional Municipality within Nova Scotia, being the largest urban centre within Atlantic Canada, has formed a group “**HalifACT 2050 – Acting on Climate Together**” to develop a plan to reduce emissions and adapt to climate change. The group aims to engage the public as well as stakeholders to raise awareness about climate change and help develop and support climate actions to reduce emissions and to ensure communities and individuals are more resilient to the impacts of climate change. Community involvement to date includes an interactive map where locals can highlight changes they have observed due to climate change, for example changes and damages due to coastal erosion, storm surge, wind and flooding (<https://www.shapeyourcityhalifax.ca/haliFACT2050/maps/map-hazards-in-your-community>).

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