EXECUTIVE SUMMARY: IMPACT OF CLIMATE CHANGE ON NUNAVIK'S MARINE AND COASTAL ENVIRONMENT

Report presented to the Ministère des Transports du Québec

Synopsis

July 2020

IMPACT OF CLIMATE CHANGE ON NUNAVIK'S MARINE AND COASTAL ENVIRONMENT: EXECUTIVE SUMMARY

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INTRODUCTION

The impact of climate change has been very significant in the Arctic, where temperatures have increased by more than double the global average over the last two decades. These effects have been even more significant in the Canadian Arctic, where average annual air temperatures have increased three times faster than the global average. This warming is strongly felt in sub-Arctic regions like Northern Quebec. In this context, and in collaboration with the Kativik Regional Government (KRG), the Government of Quebec wanted to measure the magnitude of the changes with potential future impacts on the marine environment in order to ensure optimal management of marine infrastructure in Nunavik.

This outreach and knowledge transfer tool combines the main findings of the work carried out from 2009 to 2020. This work was coordinated by the Ministère des Transports du Québec (MTQ) under the name "Évaluation de l'impact des changements climatiques sur les infrastructures maritimes du Nunavik et solutions d'adaptation (Evaluation of Climate Change Impacts on Nunavik Marine Infrastructure and Adaptation Solutions)," in the context of the 2006-2012 Climate Change Action Plan (PACC, Plan d'action sur les changements climatiques). It will continue as part of PACC 2013-2020.

Drawing on the more detailed knowledge synthesis, the executive summary is especially aimed at climate change and land-use professionals and municipal managers. This resource will provide these professionals and managers with a decision-support tool for a range of actions, including land occupancy planning and infrastructure and facilities maintenance along the northern coastline. It provides users with information specific to the coasts of Hudson Bay, Hudson Strait and Ungava Bay. In short, this document provides support to decision-making processes in order to preventively reduce the population's vulnerability to the expected effects of climate change on coastal environments, and thus contribute to climate change adaptation solutions for the region.

This short and non-technical executive summary condenses the detailed content in the document "Knowledge Synthesis: Impact of Climate Change on Nunavik's Marine and Coastal Environment." The scientific and technical concepts used for measurements, analysis and the achievement of results are explained in plain language in a second technical document. A flyer and series of presentations are planned for this year, which will further contribute to the non-technical dissemination of the knowledge synthesis.

The first part of the executive summary contextualizes the projects by briefly presenting the geography, demography, economy and future climate of the Nunavik region. Next, the hazards facing the Nunavik coastline are explained. This section also presents a regional map identifying the types of measures used in the projects, as well as their locations and collection periods.

The second part presents the main findings for the various studied hazards. Findings are provided for the recent past and two future periods, for Nunavik as a whole, for the relative water level, for extreme levels associated to storm surges, as well as for storms, waves and ice conditions. A second map shows the locations of the storm surge water level simulation results. Next, specific results are given for Nunavik's three coasts.

The third part gives examples of the ways in which these findings can be integrated to support adaptation-related decision making.

CONTEXT

The Nunavik region is located between the 55th and 62nd parallels. There are 14 coastal communities with a total of 13,000 Inuit and non-Inuit residents[1] on Hudson Bay, Hudson Strait and Ungava Bay. Their populations have grown significantly (four times faster than the Quebec population between 2011 and 2016[2]), and increased land occupancy and sea transport is expected in the context of the various Nunavik socioeconomic development agreements between Inuit communities, Makivik Corporation, the Kativik Regional Government (KRG) and the Government of Québec (Comtois, 2020). This will potentially require expanded marine and coastal infrastructure, or the construction of new infrastructure better adapted to the demographic changes. These remote communities are connected by air and maritime transportation, and there are no roads connecting communities to each other or to the rest of the province. Air transport is used to move people and light cargo, while heavy and non-perishable cargo is transported by sea. Thus, sea access is essential for both traditional activities and economic development. In order to plan safe transport on the pack ice in winter or on ice-free waters, an understanding of climate and hydrological conditions is essential to the population.

Nunavik's coastline has been exposed to very significant warming, especially during the period from 1987 to 2016 (Table 1). During this period, Nunavik has experienced an increase in winter temperatures of 1.5°C per decade, and an increase in summer temperatures of 0.5°C per decade. Forecasts indicate that this warming will continue. The region could experience annual air temperature increases of 4 to 5.1°C in the period from 2046 to 2064, and 4.1 to 7.5°C increases in the period from 2076 to 2100. However, the warming in winter months is set to be most significant, with increases between 5.5 and 5.8°C, as compared to increases between 2.0 and 2.5°C in the 2046 to 2064 period, according to scenarios RCP4.5 and RCP8.5 (see Inset 1 from the knowledge synthesis).

In Nunavik, the warming is accompanied by an increase in total precipitation (Table 1), which has increased by 3% per decade in the entire region since the 1950s. In the period from 2046 to 2064, average annual precipitation could increase by 20 to 35%. Extreme precipitation could increase in the entire region by 5 mm per day for the 2046-2064 and 10 mm per day for 2076-2100, according to the RCP8.5 scenario. While total precipitation has increased, the warming appears to have contributed to a 13% decline in total solid precipitation (snow, hail, freezing rain) between 1980 and 2014. This decline in solid precipitation is even more pronounced in October and November. The snow cover period is also projected to decrease by one month according to the RCP4.5, and by one to two months according to the RCP8.5, for both studied future periods.

Table 1. Summary of key climate data for Nunavik

Data \ Scenario and Period	RCP4.5		RCP8.5	
	2046-2064	2076-2100	2046-2064	2076-2100
Av. summer air temp. (JJA)	↗ 2.0°C		↗ 2.5°C	
Av. winter air temp. (DJFM)	↗ 5.5°C		↗ 5.8°C	
Av. annual air temp.	↗ 4.0°C	↗ 5.1°C	↗ 4.1°C	↗ 7.5°C
Max. precipitation (mm/day)			↗ 5	↗ 10

[1] Statistics Canada 2016 Census https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/index-eng.cfm

[2] Between 2006 and 2011, the population of the 14 Nunavik communities increased by 11.7%, and between 2011 and 2016, it increased by 12.7% (Statistics Canada 2016 Census). Meanwhile, the population of Quebec increased by 4.9% and 2.8% respectively (Institut de la statistique du Québec, 2019).

Annual av. daily precipitation (mm/day)	↗ 0.33	↗ 0.37	↗ 0.39	↗ 0.69
Av. annual precipitation (%)			↗ 20 à 35	
Snow cover period (days)	↘ 23	↘ 31	↘ 31	↘ 63

Climate change will also modify the hydrological hazards to which Nunavik's coastline is exposed. The hydrological hazards (water levels, waves, extreme winds and ice) could rise in the future and cause increased rates of submersion and erosion. The damage to the natural environment (i.e. disappearance of beaches as a result of submersion, erosion of coastal cliffs) and coastal infrastructure and facilities (i.e. submersion of buildings, washout of protective structure bases) could make access to the region and travel along the coast more difficult.

The hazard studies examined the hazard variations by comparing the impact of the climate situation in the recent past (1982 to 2010) with the effects of the situations projected for the two future periods (2042 to 2069 and 2070 to 2099). The following coastal hazards were studied:

- Storm frequency and intensity
- *Total water levels* and very high/very low *storm surge levels*
- Strong wave frequency
- Longer ice-free season (later ice formation and faster melting of sea and coastal ice) and decreased ice concentration and thickness

The relationships between the various studied hazards are explained in the technical synthesis.

Next, the identification of hazard characteristics (intensity, occurrence probability or frequency, spatial location or range and the potential duration of their impacts) made it possible to better understand their nature and effect on the exposed environment, while also anticipating the needs resulting from their occurrence. In this context, it is important to collect observation series on these disruptive hazards in order to feed the projection models (technical synthesis). Also, starting in 2009, measurement equipment was installed at different sites in Nunavik in order to measure water levels at sea and at the coast, detect the presence of coastal and sea ice, and measure wave height and the meteorological conditions that influence these hazards. A regional synthesis map shows the locations of the Nunavik communities, the current and past data collection sites, the types of collected data, the names of the networks that allow station maintenance as well as data collection and dissemination, and the data collection periods (Figure 1). This figure reveals the numerous efforts deployed over the last decade to improve the understanding of Nunavik's natural environment. The map shows the communities equipped with different kinds of measurement devices that made possible the collection of a large number of datasets over a relatively long period of time (Kuujjuarapik and Quaqtaq) and the communities that are not equipped with measurement facilities (Ungava Bay Marine Region).

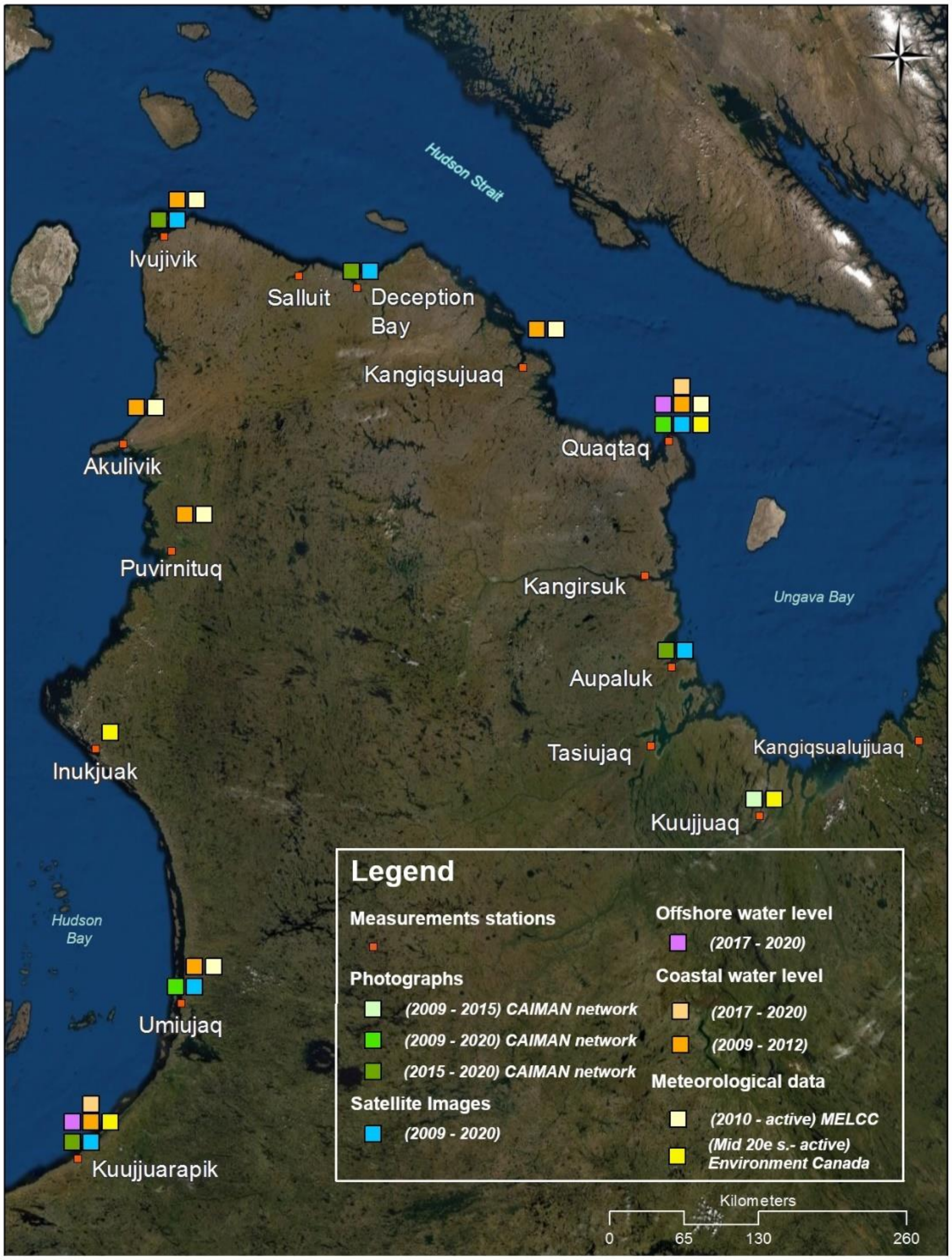

Figure 1: **Data collection locations for the hazards studied in Nunavik, with collection periods and names of maintenance networks.** The data were collected by meteorological stations (temperatures, wind and humidity) tide gauges (water level on the coast), wave gauges (water level at sea), cameras (photos of the sea and the coast) and Landsat and MODIS images (satellite images).

All the collected data (Figure 1) were processed and used to validate the hydro-climatic models behind the simulations produced for the recent past (1989-2009 period), near future (2040-2069 period) and distant future (2070-2099) (see technical synthesis). The ice concentration simulation results are available in the ice condition atlas produced by Senneville in 2018, where ice conditions are catalogued on a monthly basis for future periods. The wave and storm simulations are still being studied and cannot be represented on a map. Part of the results obtained for storm surges are presented in Figure 2.

Finally, since the consequence (or impact) of a given hazard on the coast is also influenced by the vulnerability of the environment, the following vulnerability factors for the natural environment were considered:

- The geomorphology of the coast and the presence of islands off the coast
- The soil type (sandy clay or rocky)

However, vulnerabilities also result from a third category encompassing social, economic and environmental factors (Morin, 2008b). In order to be comprehensive, a vulnerability study should also include infrastructure and population characteristics in addition to the hazard characteristics studied in this document.

To summarize, coastal risks exist where potential hazards coincide with the presence of populations or infrastructure. In Nunavik, the population of the 14 Inuit communities and the infrastructure associated with both these communities and Deception Bay are located on the coastline, around the mouths of rivers or estuaries, or around fords or bays. They are thus always potentially at risk. A risk study could be carried out in order to evaluate the risk levels for these communities.

While still partial, the first results from the study simulations carried out by the MTQ were made possible by the data collected over the last ten years. In the next section, the results are presented by hazard for all of Nunavik, and then in more detail for the three coasts (Hudson Bay, Hudson Strait and Ungava Bay).

In the context of the impact of climate change on hazards, it is not always possible to provide conclusions that are as reliable or uncertainties that are as well quantified as those associated with temperatures, since these hazards have not been studied as deeply. These questions will be addressed more particularly in several sections of this document (See Chapter 1 – Section 6 to learn more and Chapter 3 – Section 4 for possible solutions). The concerns associated with the extreme water level data has not been quantified, and the results should be used with caution.

RESULTS OF THE STUDIES CONDUCTED FOR THE MTQ[3]

Results obtained for Nunavik as a whole

RELATIVE SEA LEVEL
Nunavik could see its relative sea level fall by 40 to 90 cm, depending on the community and considered scenario.

At the end of the century, in the 2070-2100 period, the effects of isostatic uplift will outweigh the impact of higher global sea levels for a large part of Nunavik.

- The maximum height and frequency of extremely high water levels will decrease.
- The anticipated damages will result mainly from extremely low water levels, which could be even lower and more frequent than in the recent past.

By the mid-century, in the 2040-2070 period, the effects of isostatic uplift will not be great enough to compensate for the impact of storm surges.

[3] The key results are shown in the coloured insets.

STORM SURGES : NEGATIVE STORM SURGES AND POSITIVE STORM SURGES

Extreme water levels could increase or decrease by up to ±1 m. Their frequency could increase by the middle of the 21st century. The period when extreme water levels are more frequent could take up a larger portion of the year.

More frequent very high water levels could lead to more frequent erosion and submersion. Meanwhile, the recession of water and very low water levels could lead to the formation of beaches. Table 2 and Figure 2 summarize the main results from the storm surge simulations.

Table 2: Extreme storm surge levels (negative and positive): Nunavik average, frequency and seasonality.

		Storm surges	
	Period	**Negative**	**Positive**
Average of 100-year return period extreme levels in all of Nunavik	**1980-2010**	between -1 m and -50 cm	between +68 cm and +1.5 m
	2040-2069	↘ 1.5 cm	↗ 10 cm
	2070-2099	↘ 6 cm	↗ 10 cm
Return period of extreme levels with current 100-year return period	**2040-2069**	50 years	50 years
	2070-2099	100 years	100 years
Seasonality (seasonal frequency)	**2040-2069**	↗ July to August ↗ December to January ↘ February to March	↗ August to February
	2070-2099	↗↗ July to August ↘↘ December to January	↗ October to February Appearing in March and summer months

Figure 2 is composed of two maps presenting the regional synthesis of the extreme water level simulations for storm surges: (a) negative storm surges – water levels below the tide or zero level and (b) positive storm surges – water levels above the tide. Water levels are said to be extreme when they reach very rare maximum heights occurring once every 100 years. On these maps, the water levels are indicated in centimetres (cm). The negative and positive storm surge levels from 1980 to 2009 are indicated by a circular symbol, with levels closest to zero cm indicated in blue and the most extreme levels indicated in red. For the future periods, the variations in the extreme levels (i.e. the extreme level for the considered future period minus the extreme level from the recent past) are indicated by an arrow. A positive value indicates an increase, represented by a rising arrow, while a negative value indicates a decrease, represented by a descending arrow. If the variation is small (0 to 5 cm), the arrow is blue. If the variation is moderate (5 to 10 cm), the arrow is green. If the variation is large (10 to 15 cm), the arrow is orange. Finally, if the variation is very large (15 to 20 cm), the arrow is red.

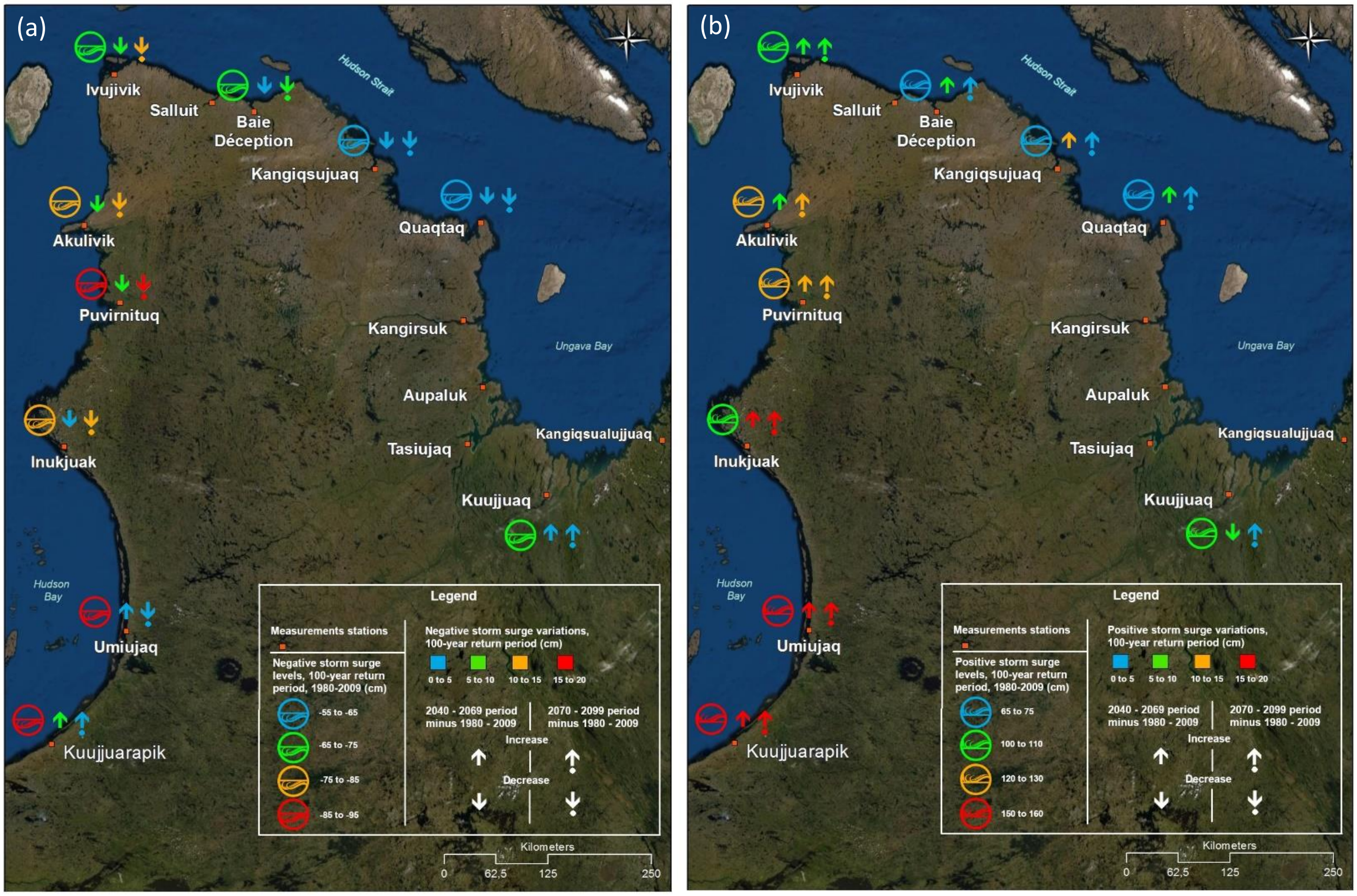

Figure 1: Extreme storm surge levels, with a 100-year recurrence, from the recent past (1980-2009) and (a) negative surge and (b) positive surge variations for the 2049-2069 and 2070-2099 periods.

STORMS

Future storm trends in Hudson Bay are not clear from our current level of knowledge.

Since the changes in storm patterns in Hudson Bay are still poorly understood, we recommend studying them with the new, more powerful climate models developed for the region (see technical synthesis). The current understanding of storms in northern marine environments focuses mainly on the Arctic Ocean and was developed through the *CORDEX ARCTIC* ensemble simulations. While Hudson Bay and the Arctic Ocean are distinct environments, the occurrence of storms during the coastal ice formation period, when the ice is unstable and mobile, has drastic consequences on coastal environments in both cases. For example:

- The ice displacement caused by strong winds blowing towards the coast could further reduce ice stability on the coast.
- Even with no significant change in storm patterns, the reduced stable sea ice contributes to:
  - Higher water levels and higher and stronger waves, increasing the risk of submersion and erosion during storms.

- A longer ice-free period (with no sea ice) that increases the potential for cumulative damage resulting from the repetitive stresses associated with the successive storms in this period.

ICE CONDITIONS

In the future, the ice could form later in the fall and melt earlier in the spring, leading to a partial ice cover period that is six weeks longer by the 2040-2070 period, and two months longer by 2070-2100. The increased mobility of the ice could lead to a higher probability of ice-related erosion.

By 2040-2070, the ice is expected to be 15 cm thinner in November and 80 cm thinner in June. The thinner ice cover could break if strong winds and higher water levels occur simultaneously.

- In winter, the complete stable sea ice cover diminishes the fetch (the space available for wind acceleration) and protects the coast against erosion.
- In spring and fall, the partial unstable (or mobile) sea ice cover increases the risk of erosion when wind pushes the ice towards the shore.
- In December, ice concentrations could decrease to 40 to 60% on the coasts from Ivujivik to Kangiqsualujjuaq and could be nearly gone between Ivujivik and Inukjuak in the 2040-2070 period.

Table 3. Nunavik ice coverage and duration risks in future periods, in winter, spring and fall

<table>
<tr><th></th><th>Ice stability</th></tr>
<tr><td>Winter</td><td>Stable ice
Shorter complete cover, Coastal erosion protection</td></tr>
<tr><td>Spring</td><td rowspan="2">Mobile ice
Longer partial cover, Increased erosion risk</td></tr>
<tr><td>Fall</td></tr>
</table>

WAVES

The longer open-water period and higher average sea level contribute to the formation of higher and stronger waves during storms. As a result, in Nunavik, the shortening of the sea ice season by around 40 days will increase the total energy of waves created by storms that reach the shore. Additionally, in the near future (2040-2070), the probability of high wave occurrence could increase. However, as a result of the decreased relative sea level, the role played by these higher waves in the context of submersion risks will gradually diminish over the course of the century.

The wave modeling for Nunavik (which covers wave frequency and strength, as well as wind direction and coastal orientation) is still underway, with results expected in 2021. It will make it possible to determine coastal exposure to waves.

Results specific to maritime regions

The following grey inset summarizes the main results for Nunavik's maritime regions.

Hudson Bay

The increase in temperatures and total winter precipitation could be more significant in Hudson Bay.

The amount of ice in Hudson Bay already decreased by 10.5% between 1968 and 2010.

Extreme positive storm surges with a 100-year return period could reach levels 10 to 20 cm higher than in the 1989-2009 period.

Extreme negative storm surges could lead to minimum water levels 70 cm to 1 m lower in the 2049-2069 period and 80 cm to 1.1 m lower in the 2070-2099 period. Winter negative surges could occur more frequently in early winter and in March.

Hudson Strait and Ungava Bay

Storm surges (positive and negative) are forecasted to be strictly less than 1 m.

The longer open-water (ice-free) period restricts the mobility of Inuit in the region and the use of snowmobiles and other transportation methods on the pack ice. What is more, the mobile ice alone can irreversibly damage the coastal infrastructure and facilities. However, the Ungava Bay coast is relatively protected from erosion as a result of the many islands that diminish the fetch in the large estuaries.

The eastern coast of Hudson Bay and certain parts of Ungava Bay are mainly composed of sedimentary soil. These areas are currently advancing towards the sea as a result of progradation and are not particularly susceptible to erosion.

That being said, the coast of Hudson Bay has a low *tidal* range, making it susceptible to flooding through submersion. The occurrence of an extreme surge will always lead to flooding, whether the surge coincides with the spring tide or not. The extreme surge level (1 m) is very close to the tidal range for several communities. On the coasts of Hudson Strait and Ungava Bay, the tidal range is greater (between 2 and 6 m), which is much larger than the extreme surge projection (1 m). These coasts will only be vulnerable to submersion when extreme surges coincide with *high spring tides*.

Knowledge integration for the implementation of adaptation measures

The impacts of climate change, which are likely to have significant consequences on the coasts of Nunavik by the end of the 21st century, are linked to the submersion and erosion processes that could occur mainly in fall and winter.

One way to decrease the serious repercussions of these impacts is to reduce the vulnerability of the natural environment, infrastructure and communities. This will involve the improvement of stakeholder skills, as well as the power or capacity of stakeholders to take concrete action aimed at reducing vulnerabilities. This is why the decision-support and planning tools are based on up-to-date scientific knowledge and aim to integrate as much information as possible. For example, a vulnerability analysis could incorporate external hazards and the environment's intrinsic particularities in the form of a sensitivity analysis, allowing a qualitative coastal sensitivity scale to be established (i.e. low, moderate or high sensitivity to climate change). Once the vulnerabilities are known, a spatial analysis of the at-risk areas can be carried out by overlapping different layers of information, including the results of the previously cited studies. Carrying out such analyses at various regional or community levels makes it possible to identify and prioritize the necessary land occupancy actions to reduce the existing vulnerabilities and risks.

Several Arctic communities are already adapting through concrete actions that minimize the risks caused by climate hazards in marine and coastal environments. For example, the application of construction standards specific to the realities of Nunavik (BNQ 2501-500 for building foundations in permafrost) or the protocol on the vulnerability of public infrastructure engineering (https://pievc.ca) makes it possible to improve site location planning and estimate both the climate change adaptative capacity of infrastructure components and the required investments. Summary works produced by Arctinet, RNCan and Ouranos also contribute to this reflection, planning and decision-making process with respect to climate change adaptation.

Conclusion

The Arctic is warming two times faster than the rest of the planet. We must therefore expect the impacts predicted in the North, and in Nunavik especially, to occur sooner. In this dynamic climate context, the decision-making processes must be flexible in order to continually produce and include new knowledge on climate and non-climate related variables, on seasonal hazard variations and on the impact of these factors on the natural environment. The presented results already provide some answers that allow for better-informed planning decisions.

The information in this non-exhaustive summary can be supplemented by consulting the knowledge synthesis, the technical synthesis, and the flyer and presentations aimed at communicating in plain language the main highlights of the studies carried out by the Ministère des Transports.

While decision-makers are advised to make decisions with up-to-date scientific knowledge, it must also be recognized that our understanding is incomplete and decisions must still be made to protect coasts and people in spite of this fact. There are several promising research avenues for improving the scientific understanding of climate risks and making the adaptation process more efficient and robust.