PRECIPITATION EVENTS REMOTE MONITORING PILOT PROJECT ON BAF-5 RESOLUTION ISLAND

Prepared by Analytical Services Unit, Queens University Kingston for CIRNAC, 2022

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EXECUTIVE SUMMARY

The Analytical Services Unit, Queens University (ASU), was contracted by Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) to undertake the project entitled "Precipitation Events Remote Monitoring Pilot Project on BAF-5 Resolution Island for 2021/2022". A signed acceptance of the contract was in place, 24th Nov 2021. The work is focused on Phase 2 aspects of an Operations, Maintenance and Surveillance Report (OMS) produced by AECOM for CIRNAC on March 31st, 2021. This work summarizes publicly available weather data that have been modelled to consider the effects of climate change using accepted representative concentration pathways (RCPs) to inform and assist the planning for remote site maintenance operations with the goal of minimizing site visits. Benchmark values have been suggested based on extracted data and datasets as they relate to precipitation, and a methodology postulated for defining deviations from extrapolated normal values. These deviations are broadly classified into three categories: (1) moderately elevated, (2) high, and (3) extreme precipitation events, and correspond to annual precipitation values of (1) 486 mm, (2) 541 mm, and (3) 668 mm, using measurements from the Iqaluit weather station as a proxy for Resolution Island precipitation. Instructions for future calculations are given in Appendices E and F.

ACKNOWLEDGEMENTS

The work was supported by Crown-Indigenous Relations and Northern Affairs Canada through its regional office in Iqaluit, Nunavut. We would like thank Rachel Theoret-Gosselin (Project Manager – Contaminated Sites) and Charlotte Lamontagne (Director – Contaminated Sites) for their support of the project. This report was written by Graham Cairns (Acting Director - Analytical Services Unit, Queens University).

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LIST OF ABBREVIATIONS

AECOM	Architectural, Engineering, Construction, Operations and Management: AECOM Canada Ltd.
AMSRP	Abandoned Military Site Remediation Protocol
ASU	Analytical Services Unit, Queens University
BCCAQv2	Bias Correction with Constructed Analogues and Quantile mapping, Version 2
CEPA	Canadian Environmental Protection Act. Refers to soil concentrations > 50ppm (PCBs)
CIRNAC	Crown-Indigenous Relations and Northern Affairs Canada
DND	Department of National Defense
ECCC	Environment and Climate Change Canada
ECMWF	European Centre for Medium Range Weather Forecasts
ºF, ºC	degrees Fahrenheit, degrees Celsius
FCSAP	Federal Contaminated Sites Action Plan
FMEA	Failure Modes and Effects Analysis
GHG	Green House Gas
IDF	Intense Duration Frequency
IPCC	Intergovernmental Panel on Climate Change
mg/kg, mg/L	milligrams per kilogram, milligrams per liter
MSC	Meteorological Service of Canada
NRCan	Natural Resources Canada
OMS	Operations Maintenance and Surveillance
PCB	Polychlorinated biphenyl
PCIC	Pacific Climate Impacts Consortium
RCP	Representative Concentration Pathway
RSLC	Relative Sea Level Change
TC	Transport Canada
TIER I	Soil containing concentrations of 1-5ppm (PCBs)
TIER II	Soil containing concentrations of 5-50ppm (PCBs)
UCL	Upper Confidence Limit
UPL	Upper Prediction Limit
WMO	World Meteorological Organization

1 INTRODUCTION

The client commissioned ASU at Queens University to conduct a study into the continued effects of precipitation on the stability of several engineered features at a contaminated site. The site is located at a remote island in a sub-arctic region of the Canadian north and the goal of the study was to investigate, compile and collate readily available weather data along with modelled projections of how climate change will affect relevant weather parameters as they relate to these features in the future.

2 SITE BACKGROUND

Resolution Island is an uninhabited island situated at the southeastern tip of Baffin Island at a longitude of 60º40'W and a latitude of 61º35'N. It is the site of an automated North Warning System radar site (constructed 1987) and was previously the site of a Pole Vault communications station (constructed 1954). The main station consists of a short-range radar station (SRR) and several old buildings at the top of a 360 m hill. Other site features include an airstrip and beaching area joined by a 6 km road, several dumps, and debris.[1,2]

Over the period of 1993-1996, environmental work at the site was detailed in a set of reports entitled "Environmental Study of a Military Installation at Resolution Island, BAF-5". These reports fully described items such as site characteristics, history, and previous investigations.[3] Scientific investigations have continued and were reported annually until 2013.[4] Temporary barriers were placed in areas where polychlorinated biphenyls (PCBs) were found to be migrating to the ocean in 1994, which allowed for more time to plan the remediation program. Cleanup of the site started in 1997 with infrastructure improvements and expanded from 1998 onwards to include both remediation activities and training. A three-year plan to complete the work at the site was initiated in 2003 and was essentially completed in 2005.[5] The site was demobilized in 2006 with demolition of the camp, and the removal of the heavy equipment relating to the remediation project, along with the mobile laboratory.

The main contaminant at Resolution Island was PCBs. At the start of the program there were approximately 5000 kg of PCBs in liquids, and this was containerized and shipped off site for disposal. A further 5000 kg was present on the ground, spread over a large area. Nearly all of this was excavated. All soils containing >50 ppm PCBs are referred to in this report as CEPA soils and are subject to regulations arising from the 1999 Canadian Environmental Protection Act (CEPA). CEPA soils were shipped off site for disposal by thermal destruction. Soil with contamination in the range 5–50 ppm PCBs (called Tier II soils in this report) along with metal contaminated soil was placed in a lined landfill. This Tier II facility also contained asbestos and Tier II debris along with all soils containing 1–5 ppm PCBs (Tier I soils), which were used as fill between layers of the Tier II soil and debris. The facility was completed by the addition of a liner and enough clean fill to ensure freeze-back of all the entombed contaminated material. Not all the PCB contaminated soil could be removed because of the nature of the terrain, fractured rock, and safety concerns. Permeable reactive barriers (PRBs) were designed and placed in the drainage pathways through which any residual PCBs might migrate. These PCB barriers were considered experimental, and their setup and operation are unique.

During activities at the site, many structures were demolished and placed in non-hazardous landfills along with debris lying around the site but not all structures or physical debris were cleaned up. The current state of the site, including features that require monitoring, are included in the 2021 Operations Maintenance and Surveillance (OMS) report[2], prepared using information obtained from the last site visit in 2019.

3 RESOLUTION ISLAND SITE VISIT (2019)

The most recent visit to the site was in the summer of 2019. During this visit, AECOM and ASU personnel performed remediation work, which resulted in the production of two reports: (1) Resolution Island 2019 Operation, Maintenance and Surveillance of the PCB Barriers (Analytical Services Unit, Queens University) and (2) An Operations, Maintenance and Surveillance Report (OMS), BAF-5 Resolution Island, Nunavut, 2021 (AECOM). Elements of the 2019 ASU Report and previous ASU reports, especially pertaining to PRBs were included in the AECOM documents.

Residual risks of remaining site features were evaluated using a Failure Modes and Effects Analysis (FMEA) (also provided in Appendix D of the OMS). Several features were identified with risk specified scoring greater than “low”. These features include the following:

Table 1: Features requiring specific monitoring on BAF-5

1	Furniture Dump PRB
2	S1/S4 Beach PRB
3	Airstrip Landfill
4	TIER II Soil Landfill
5	PCB Storage Facility (building – not currently in use)
6	Beach Non-Hazardous Landfill
7	East and West Camp Non-Hazardous Landfill

The approximate locations of these features are shown in Figure 1.

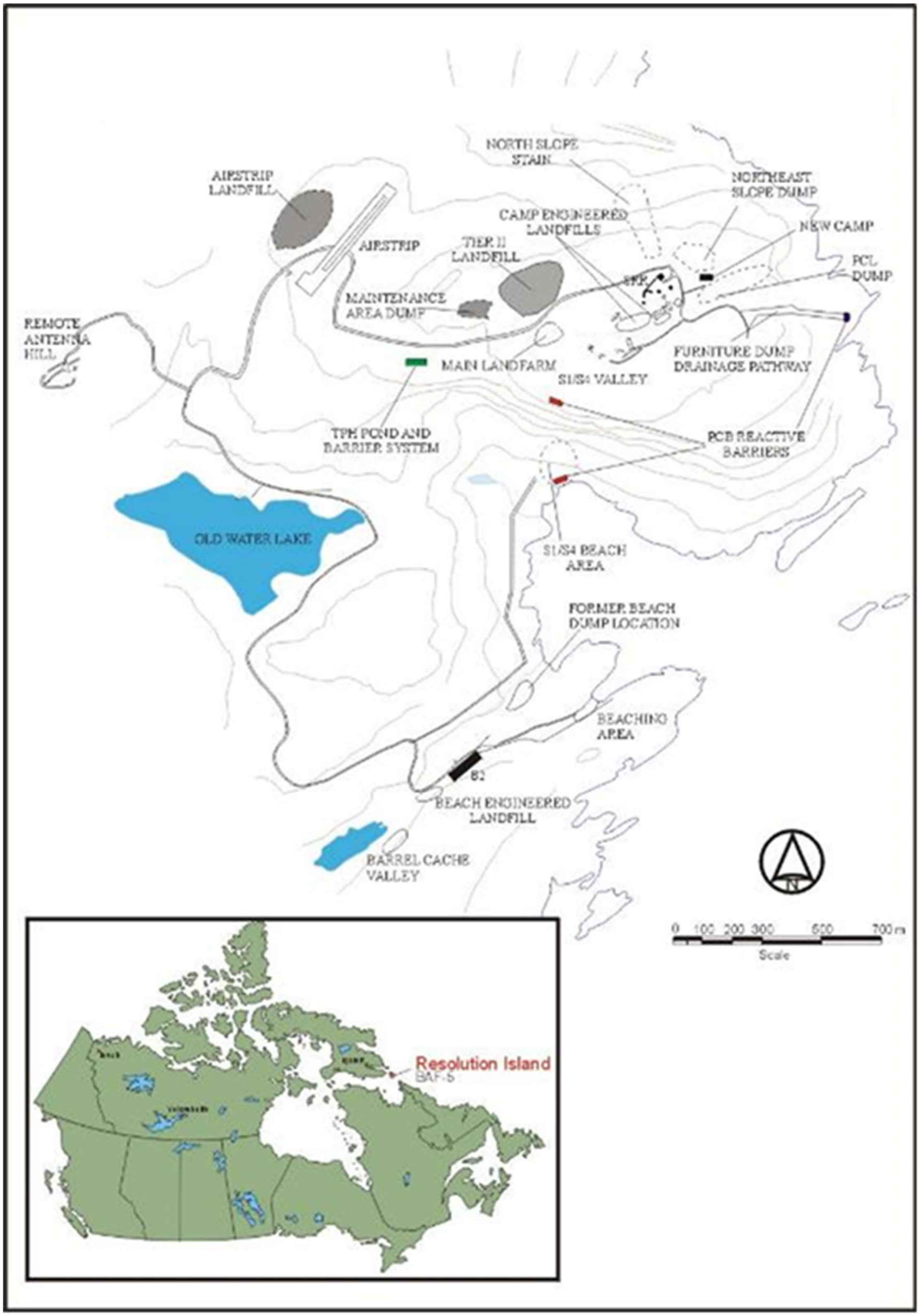

Figure 1: General Layout and Site Features at Resolution Island

4 CLIMATE DATA

4.1 Weather Observations

In Canada, the Meteorological Service of Canada (MSC) is one of the most advanced weather services in the world. Real time weather data is produced using the best technology. Successful forecasting is strongly dependent on the quantity and integrity of the data, which is obtained using radars, weather balloons, fixed weather stations, weather buoys and from space, using dedicated satellites. Environment and Climate Change Canada (ECCC) maintains a national network of over 1700 weather stations although there is a much lower density of these stations in remote areas such as the Canadian Arctic due to logistical difficulties related to staffing and maintenance.[6]

Historically, weather station data is available from seven locations within 200 km of BAF-5. The station located closest to BAF-5 can be identified as Climate ID 2403602, 61º35’00.000N, 64º39’00.000W, 369 m. This is designated below as Resolution Island (0 km), with subsequent stations located progressively further away.

Resolution Island (0 km); Resolution Island (34 km); Loks Land Island (103 km); Killinek AUT (130 km), Killinek (130 km), Cape Kikkiviak (180 km) and Brevoort Island (197 km). These sites (verified by personal communication with ECCC), have operated at different time intervals and recorded different weather parameters. The Resolution Island station (Climate ID: 2403602) was active until 21st July 2018 and the Brevoort Island station (Climate ID:2400565) is still collecting data. Both stations are operated by the Department of National Defence (DND), although the active site at Brevoort Island is not recording precipitation data, and the recently inactive Resolution Island station has not collected precipitation data in decades. The other stations noted above also appear to be inactive or not actively collecting any weather data.

4.2 Data Sources

Climate data is readily available from multiple sources. Worldwide, seven of the top (free) sites are: NASA Earth Observatory, the European Space Agency Climate Change Initiative (CCI), the United Nations Environment Program (UNEP), the United States Government Open Data Initiative, the Food and Agriculture Organization GeoNetwork (FAO-GeoNetwork), NASA’s Socioeconomic Data and Applications Centre (SEDAC) and the Organization for Economic Co-operation and Development (OECD).[7] In Canada, two publicly available national data websites that are frequently utilized, and are supported by the Canadian government, are ClimateData.ca and ClimateAtlas.ca. ClimateData.ca is the result of collaboration between several groups including ECCC, the Computer Research Institute of Montreal (CRIM), Ouranos, the Pacific

Climates Impact Consortium (PCIC), the Prairie Climate Centre (PCC) and Habitat Seven. ClimateData.ca was launched in June 2019. ClimateAtlas.ca also uses data produced from groups such as PCIC and PCC and is another "go-to" resource for Canadians seeking information about climate change and its national, regional, and local impacts. ClimateAtlas.ca was launched in April 2018 and underwent significant changes in July 2019 to produce more robust datasets. Amongst the changes were the inclusion of more climate models.

Both websites are complementary and offer detailed and varied sources of climate data, which is required for more accurate predictions. Higher resolution data and advanced tools are available, which enables sophisticated analyses.

4.3 Model Accuracy and Downscaling

Climate models are often applied to show data on a macro scale. Data presented represent areas in the tens of thousands of square kilometres range. These models are often referred to as General Circulation Models or alternatively as Global Circulation Models (GCMs). These models, however, often fail to consider local topological features, which can lead to systematic bias and significant deviations in data quality at a more localised level (ranges in the low thousands of square kilometres).

To improve the function of GCM projections for these smaller areas, various types of bias-correction and spatial downscaling techniques are employed. These are generally done at the same time and involve a dynamic and statistical component. In this way, course resolution GCM data is converted into higher resolution data in the 30 x 60 km^2 grid range. Even smaller grids can also be generated, but with the caveat that more detail requires more computational power.

Many general descriptions of this bias correction/downscaling process can be readily found in the literature.[8] A widely accepted statistical method used to process data is referred to as Bias Correction with Constructed Analogues and Quantile mapping, Version 2 (BCCAQv2). This has been used in the data presented at ClimateData.ca and in ClimateAtlas.ca. Earlier datasets in ClimateAtlas.ca used a different (simpler) method, which has since been updated with the BCCAQv2 correction.

4.4 Representative Concentration Pathways (RCPs)

RCPs can be considered as climate trajectories linked directly to the concentration of greenhouse gases (GHGs) found in the atmosphere. GHGs can be defined as those capable of absorbing infra-red radiation (emitted from the surface of the earth) and re-radiating it back to the surface. Carbon dioxide, methane and water vapor are important GHGs. In 2014, four RCPs were adopted by the Intergovernmental Panel on Climate Change (IPCC, 2014) and these are RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5, although others are also being considered. The numerical values associated with the RCP designation correspond to an increase in heat (in terms of watts per square meter (W/m^2) on the Earth's surface), which is referred to as a radiative forcing.

Each RCP results from various mitigation measures (or the lack thereof) related to transport, energy generation and new technologies, and each RCP value has consequences related to temperature, sea level and extreme weather increase. The timelines for the various RCPs in most cases are set to the year 2100.[9] In terms of (average) temperature increase in degrees centigrade (ºC), 2ºC is recognised as the threshold at which climate change is considered dangerous.

RCP 2.6 is the most optimistic of these scenarios. It requires CO_2 emissions to start declining by 2020 and to go to zero by 2100. Significant reduction in methane and sulfur dioxide would also be required. This RCP would require a high level of effort to curb emissions. Most energy generation would have to come from renewables; new technology, such as carbon capture would have to be adopted, and most transportation would have to be undertaken using a mix of electric vehicles, bicycles, and public transport. The predicted temperature increase (relative to 1986–2005 as a baseline) is 1ºC. Sea level rise is calculated at 0.4 m and the change in extreme weather events is estimated at a "small increase".

RCP 4.5 is considered an average or intermediate scenario. It requires a decline in CO_2 emissions in the 2040s and for 2100 CO_2 emissions to be half of the 2050 level. Significant reduction in sulfur dioxide and methane are also required, but a lower level of reduction is required relative to RCP 2.6. Moderate efforts would be required to curb emissions. This outcome relies on much power production to come from renewables (as for RCP 2.6). Transportation would have to be undertaken using a mix of electric vehicles, bicycles, and fossil fuel powered cars (with electric cars being utilized at a much higher rate than fossil fuel cars). The predicted temperature increase is 1.8ºC. Sea level rise is calculated at 0.47 m and the change in extreme weather events is estimated at a "moderate increase".

RCP 6.0 is considered a high scenario. It assumes emissions peak later in the century (approximately 2080) and then decline. Power would come from a mix of renewables and fossil fuel power plants. Transportation would have to be undertaken using a mix of electric vehicles, bicycles and fossil fuel powered cars (with electric cars being utilized at a lower rate than fossil fuel cars). The predicted temperature increase is 2.2ºC. Sea level rise is calculated at 0.48 m and the change in extreme weather events is estimated at a "high increase".

RCP 8.5 is considered a maximum scenario with rising emissions through the 21st century. This is now considered as an "unlikely high-risk future". Power generation would utilize fossil fuels including coal-fired power. Transportation including cars and trucks would be mostly fossil fuel powered with minimum adoption of cleaner technology. The predicted temperature increase is 3.7ºC. Sea level rise is calculated at 0.63 m and changes in extreme weather is estimated at a "large increase".

The four RCP pathways summarized above can therefore be categorized as low, average, high and severe, although sometimes different terminology will be used – ClimateData.ca refers to RCP 2.6 as low, RCP 4.5 as moderate and RCP 8.5 as high (emissions), with RCP 6.0 not discussed. PCIC use the terms: very low carbon for RCP 2.6, low carbon for RCP 4.5. and high carbon for RCP 8.5.

4.5 Data Presentation – ClimateData.ca

This website was constructed collaboratively by many leading climate organizations and is supported by the Government of Canada. Information obtained from this website is used to inform and aid climate influenced decision-making by providing up-to-date climate data in a variety of different formats.

ClimateData.ca is supported by the Canadian Centre for Climate Services (CCCS) of Environment and Climate Change Canada as part of its efforts to provide Canadians with easy access to climate related data and to help increase their resilience to climate change.[10] For the purpose of this study, rain, snow, sleet, or hail will all be referred to as precipitation, with standard measurement units of mm.

The website is broken down into several sections, each providing a wide array of data with varying relevance towards the formulation of precipitation benchmarks. These benchmarks will be used to help prompt action where needed, at one or more of the identified FMEA areas on Resolution Island.

Selections relevant to the generation and utilization of weather data for this Resolution Island study will be detailed below along with extracted data.

4.6 ClimateData.ca – Location

In the location tab, data summaries are provided that are related to location-based enquiries. These summaries refer to a 10 km x 6 km grid reference in which the location specified falls. The following general data is given:

Search for a City Town: **Resolution Island**

Results (copied from the website):

“61.508333ºN, 65.008333º W

Resolution Island, NU

For the 1951–1980 period, the annual average temperature was -7.4 ºC; for 1981–2010 it was -7 ºC. Under a high emissions scenario, annual average temperatures are projected to be -5 ºC for the 2021–2050 period, -2.5 ºC for the 2051–2080 period and -1.3 ºC for the last 30 years of this century.

Average annual precipitation for the 1951–1980 period was 386 mm. Under a high emissions scenario, this is projected to be 10% higher for the 2021–2050 period, 19% higher for the 2051–2080 period and 27% higher for the last 30 years of this century.

These values reflect an arbitrary ~10 km x 6 km grid cell (chosen by the website to represent Resolution Island). The actual grid for the BAF-5 site is selectable using the “Variables Tab” and is designated Brewer Bay, NU. This area may more accurately represent the microclimates at the site caused by local topography. It should be noted that considerable local deviations in precipitation quantities may be possible due to these microclimates. Annual values are used in this study, although monthly or seasonal values are available. 30-year averages and 30-year changes are also available. Figure 2 shows a Google Earth aerial view of the site that illustrates the location of Brewer Bay (image from June 2006).

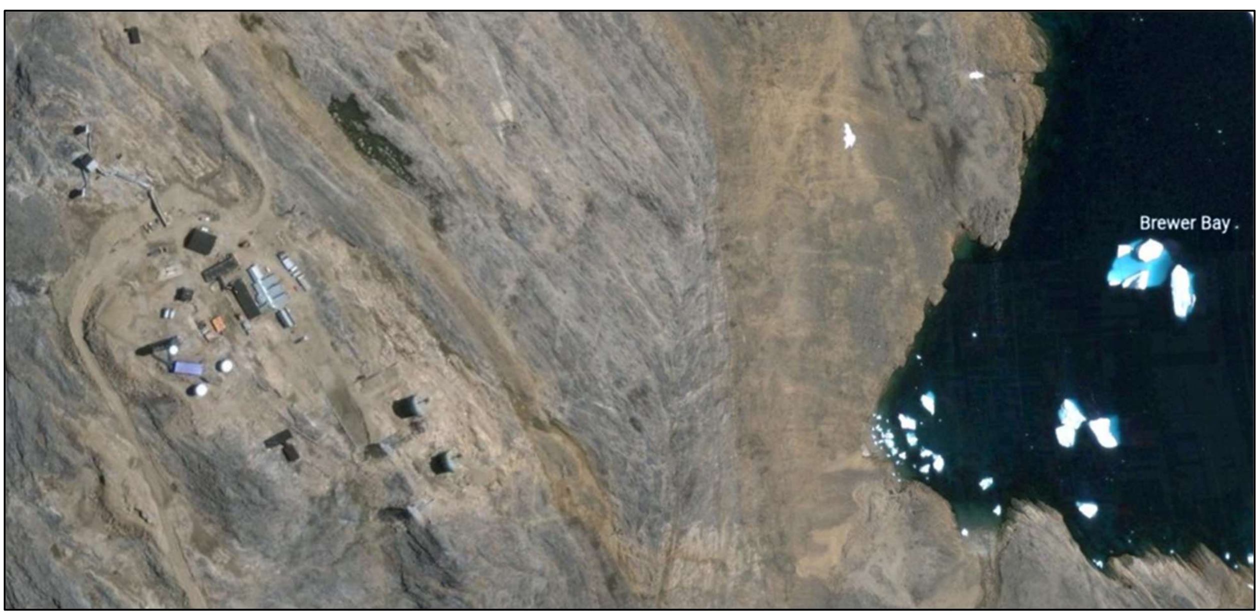

Figure 2: Resolution Island Site and Brewer Bay

4.7 ClimateData.ca – VARIABLES> data export details and presentation

Location data can be broken down into three categories: temperature, precipitation, and other data; within each of these, several more selections (sub-categories) are available. For this report, certain selections are not relevant. One such example is: Temperature > Days with Tmax >37°C, even under the most severe RCP 8.5 scenarios with extended timelines (2100). When a category contains no (or very limited useful data), the category is omitted. For this report, annual data for the category is copied from the website and reproduced here with any relevant descriptions that are useful. Some selections may be omitted for clarity. For future data manipulations and comparisons, raw data will be exported in one of the available download formats (CSV), converted to an XLS file, named, and specified in this report as well as being available to the report sponsor.

The following data has been exported:

1. Annual temperature graph from 1950 to 2100. Brewers Bay, Resolution Island NU for RCP2.6, RCP 4.5, and RCP 8.5 scenarios. PDF Format.
2. Extracted temperature values including median, low range and high range values for each year and RCP scenario. XLS Format.
3. Annual temperature graph from 1950 to 2100. Brewers Bay, Resolution Island NU for RCP2.6, RCP 4.5, and RCP 8.5 scenarios. PNG Format.

Formatting for the file name is demonstrated with the following example: CD Hottest Day MH RCP 2.6 RCP 4.5 RCP 8.5. This represents the data source (i.e. CD = ClimateData.ca), a description of the parameter being measured (i.e. hottest day) and specifics for the data presented (i.e. MH for modelled and historical data and RCP scenarios). A list of the PNG, XLS and PDF files created are presented in Appendix B and a printout of graphs related to precipitation are included in section 4.9.

On the website, there are additional graphics that help explain the data being presented. One such example is shown in Figure 3.

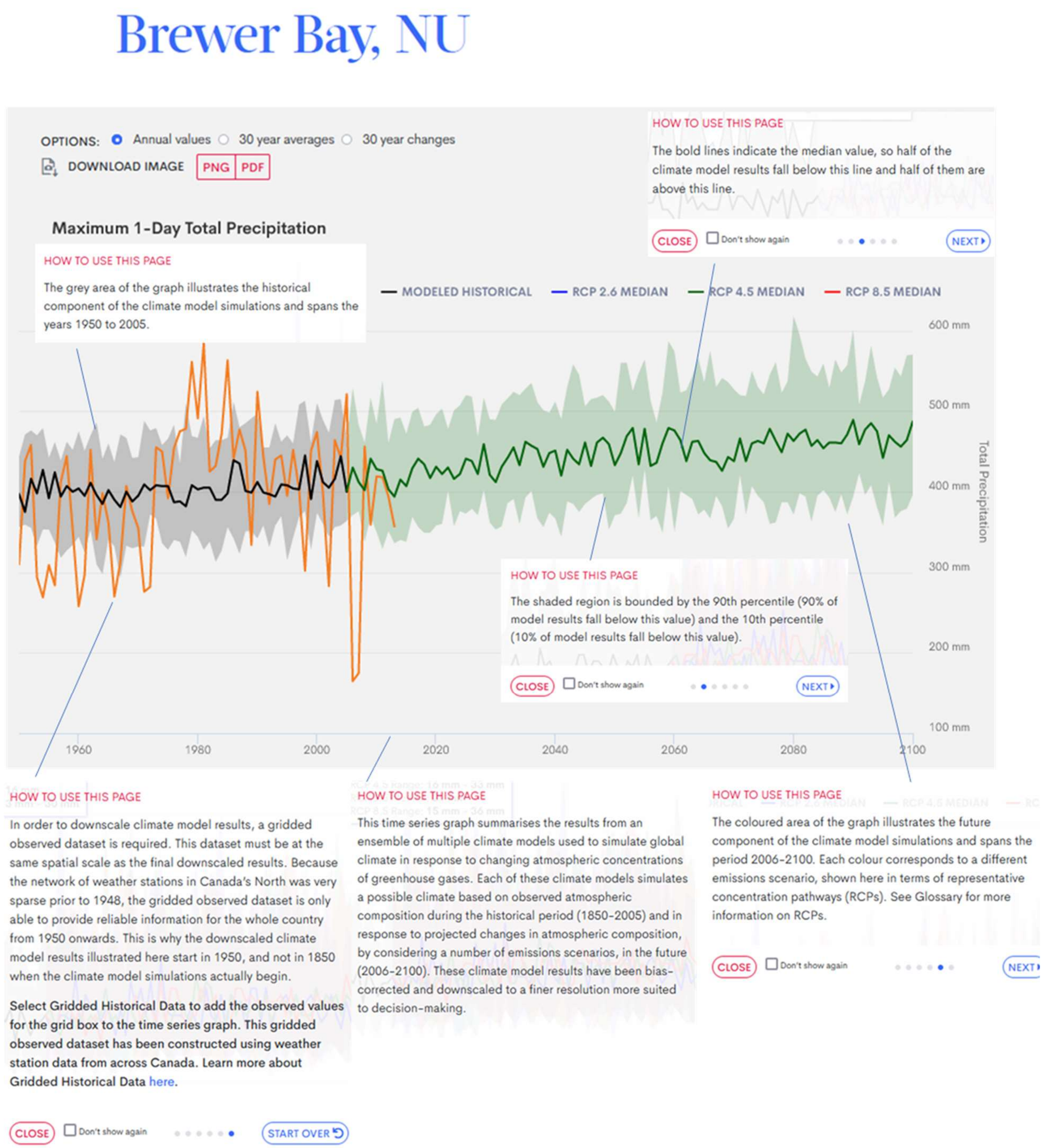

Figure 3: A ClimateData.ca Precipitation Graph

For this report, only definitions for relative precipitation metrics shall be detailed here. Temperature and Other Variables definitions can be found in Appendix C.

4.7.1 Wet Days > 1mm; >10mm; >20mm

“Wet Days >1 mm; 10 mm; >20 mm describes the number of days where more than 1 mm; 10 mm or 20 mm respectively, of precipitation (rain and snow combined) falls in the selected time period. This index generally captures every day when there is measurable precipitation.

Adequate precipitation is crucial to water availability, agriculture, electricity generation and wildfire suppression.

Technical description:

The number of days with precipitation > 1.0 mm; 10 mm or 20 mm.”

4.7.2 Max 1 Day Total Precipitation

“Maximum 1-Day Total Precipitation describes the largest amount of precipitation (rain and snow combined) that falls within a single 24-hour day for the selected time period. This index is commonly referred to as the wettest day of the year.

Very high 1-day precipitation totals could be the result of intense, but short-lived precipitation events such as thunderstorms, or may be due to precipitation occurring steadily over the course of the day. Short duration, high intensity precipitation events may lead to flash flooding, particularly in urban areas where storm drains may be overwhelmed. Heavy snowfall events can cause damage to buildings and disrupt transportation services.

Technical description**:**

The largest precipitation total that falls in a single day in the selected time period.”

4.7.3 The Maximum Number of Consecutive Dry Days

“The Maximum Number of Consecutive Dry Days describes the longest spell of days where less than 1mm of precipitation falls daily.

Periods of dry weather can impact agriculture, energy demands and water availability. Drought conditions may result when dry periods are long-lasting.

Technical Description:

The maximum number of consecutive days with precipitation below 1mm/day, within the selected time period.”

4.7.4 Total Precipitation

“Total Precipitation describes the total amount of precipitation (rain and snow combined) that falls within the selected time period.

Precipitation significantly impacts water availability, agricultural practices, electricity generation and wildfire suppression.

Technical description:

The total amount of precipitation (mm) accumulated in the selected time period."

4.7.5 Number of Periods with 5 or More Consecutive Dry Days

"The Number of Periods with 5 or more Consecutive Dry Days describes the number of times when daily precipitation totals are less than 1mm a day for five or more days straight.

Periods of dry weather can impact agriculture, energy demands and water availability. Drought conditions may result when dry periods are long-lasting.

Technical Description:

The number of periods with 5 or more consecutive days with precipitation below 1mm/day, within the selected time period."

4.7.6 Maximum 5 Day Precipitation

"Maximum 5-Day Precipitation describes the largest amount of precipitation (rain and snow combined) to fall over 5 consecutive days.

High precipitation totals can cause flooding in urban areas, damage to crops and roads, and erode topsoil. Heavy snowfall events can cause damage to buildings and disrupt transportation services.

Technical Description:

The maximum total precipitation that falls over a consecutive 5-day period."

4.8 Data Presentation – ClimateAtlas.ca

The ClimateAtlas website is complementary to the ClimateData site. Much of the data on the ClimateAtlas website is presented using different graphics and a "storytelling" narrative to advance awareness of climate change effects to as wide a group as possible.

For Resolution Island, data summaries in a wide array of file formats can be obtained as follows: https://climateatlas.ca/ >select "large grid" and click on Resolution Island. On the display, Region: Resolution Island, a data box with multiple selection options is presented. The data presented is dependent on the values selected on the two sliders at the bottom of the map: Climate Change (more /less), which refers to RCP 8.5 or RCP 4.5; and the time-period (recent past, 2021–2050 or 2051–2080). Five icons under the time-period are also selectable: hot weather, cold weather, temperature, precipitation, and agriculture. For each, a range of sub-headings can be selected. These are broadly like the subcategories available through ClimateData.ca. For an overview, the downloadable file entitled "Climate Data: Resolution Island.pdf" is presented in concise format and included in Table 2 below.

4.9 Exported Data in png format

The following figures demonstrate the available data from ClimateData.ca. For these graphs, gridded historical data plots (1950-2013) have been omitted for simplicity. Only figures relating to precipitation are presented here. Figures relating to temperature and other variables can be found in Appendix D.

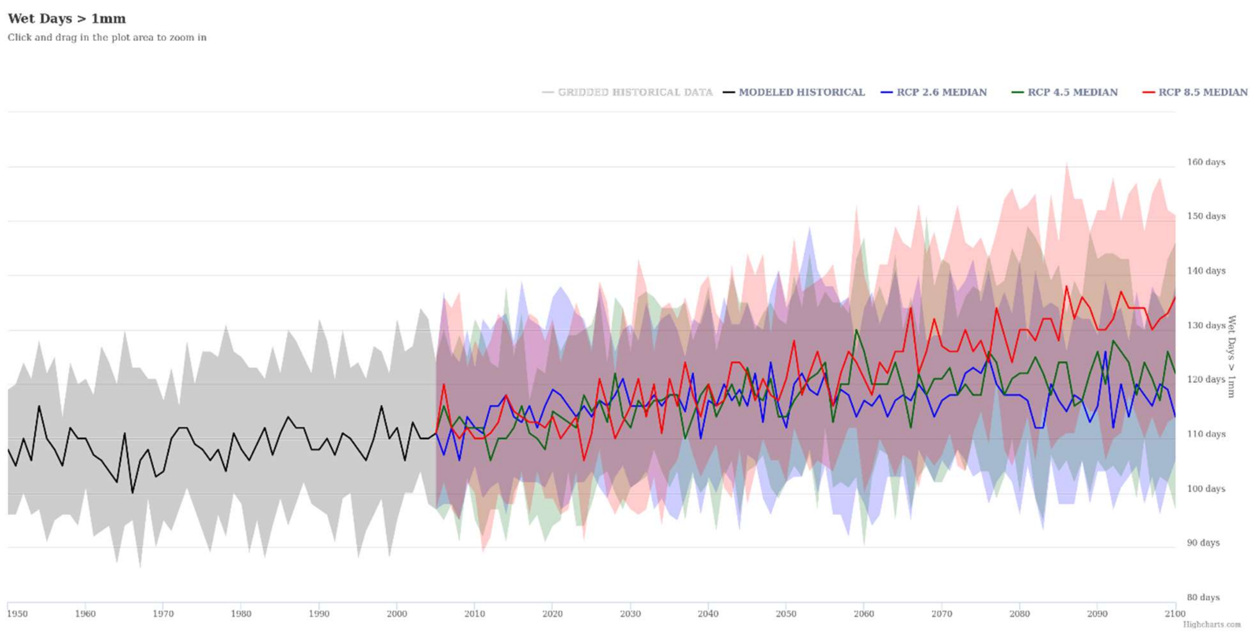

Figure 4: CD Wet days > 1mm MH RCP 2.6 RCP 4.5 RCP 8.5.png

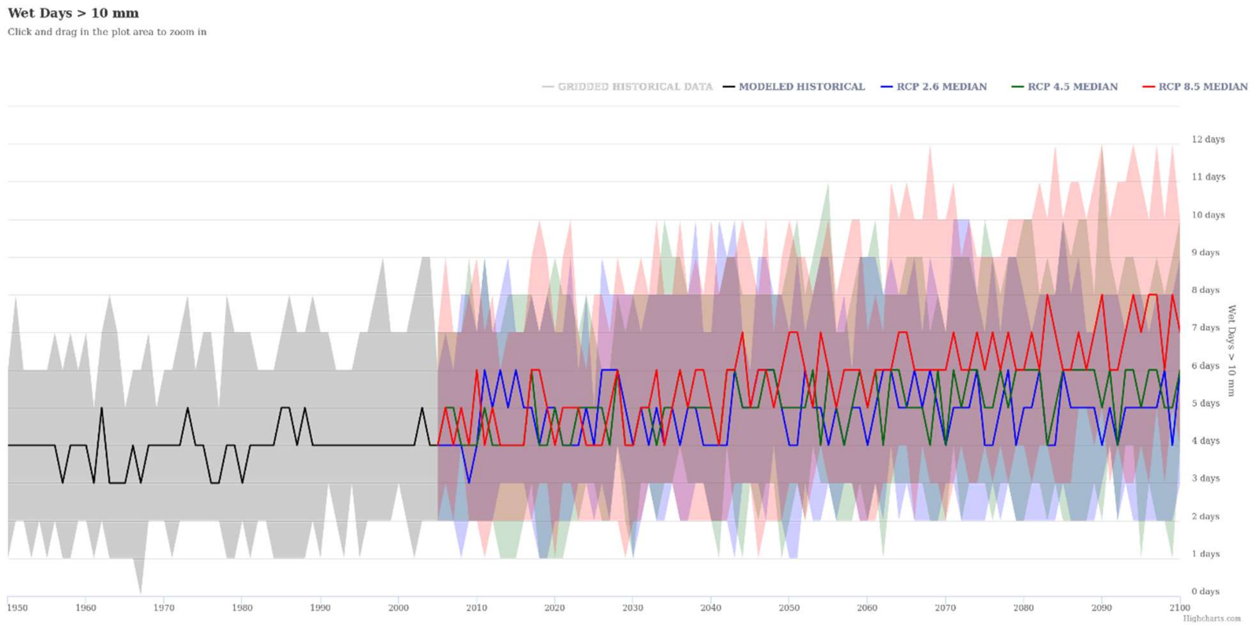

Figure 5: CD Wet days > 10mm MH RCP 2.6 RCP 4.5 RCP 8.5.png

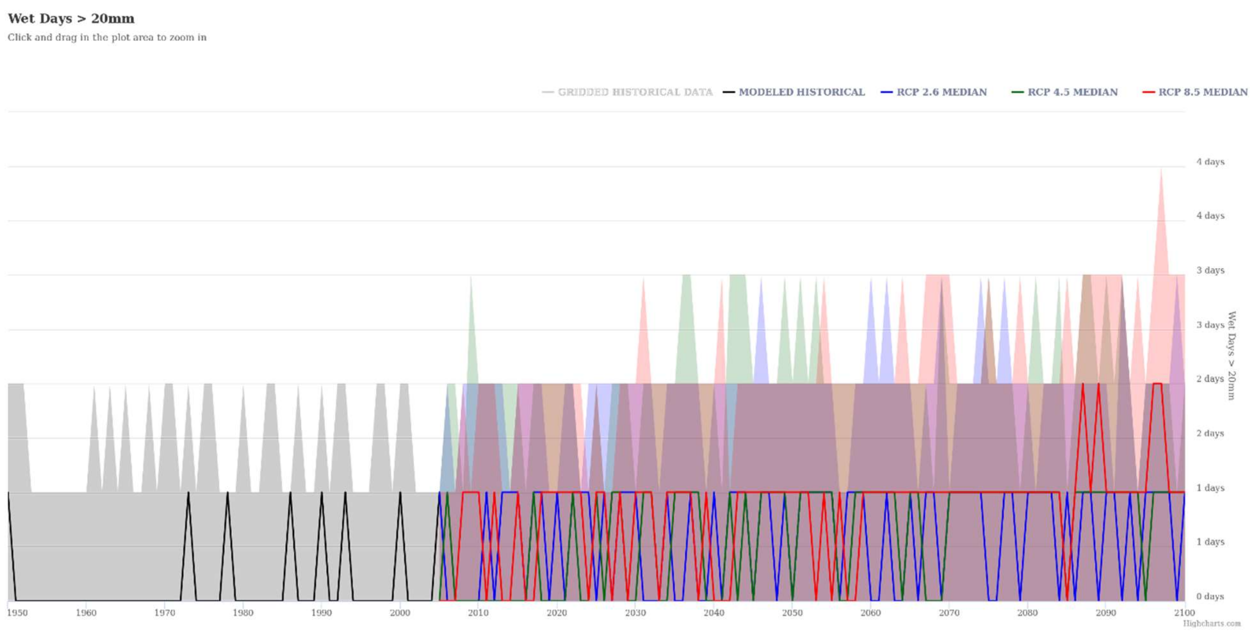

Figure 6: CD Wet days > 20mm MH RCP 2.6 RCP 4.5 RCP 8.5.png

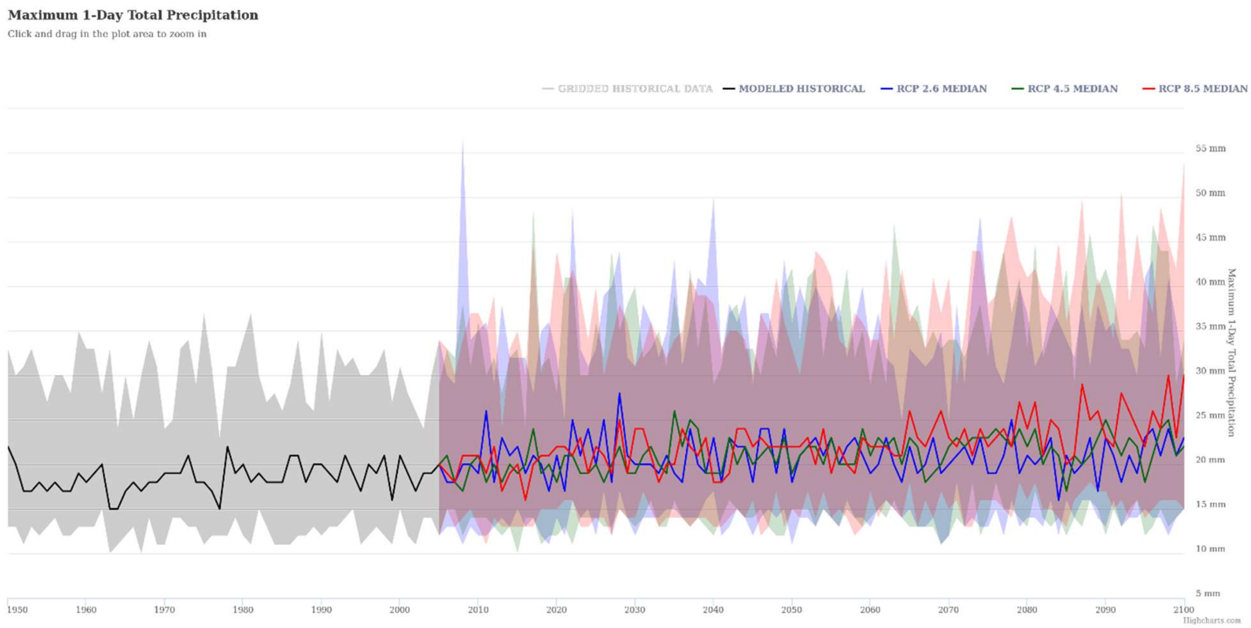

Figure 7: CD 1 Day Total Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5.png

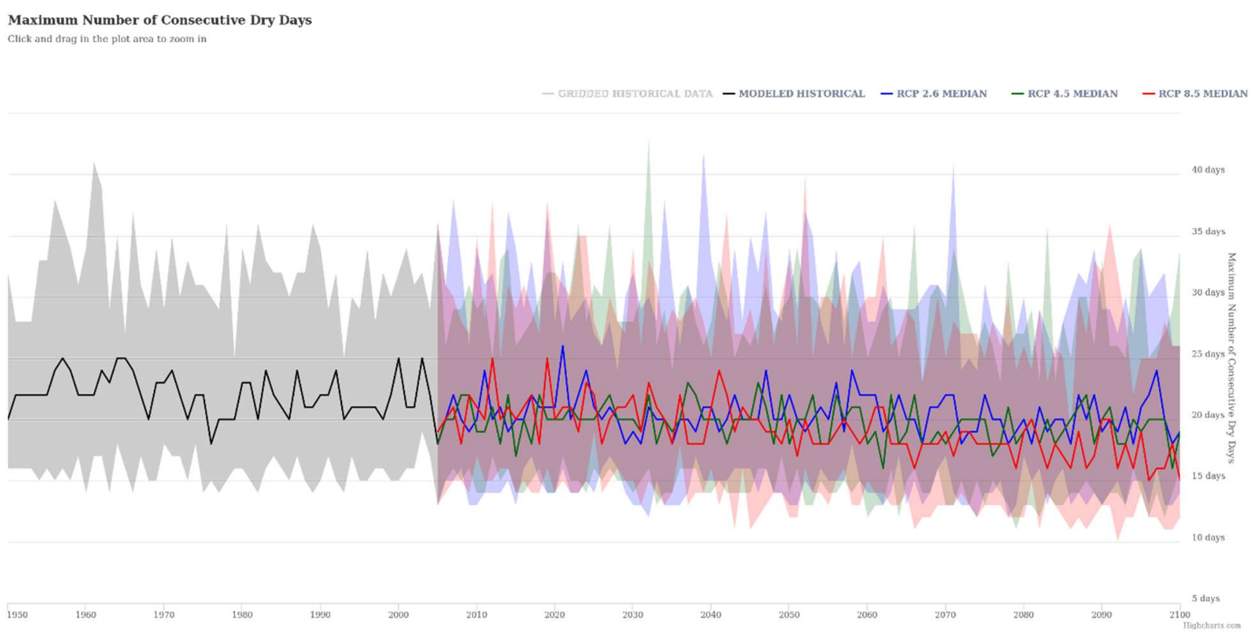

Figure 8: CD Maximum Number of Consecutive Dry Days MH RCP 2.6 RCP 4.5 RCP 8.5.png

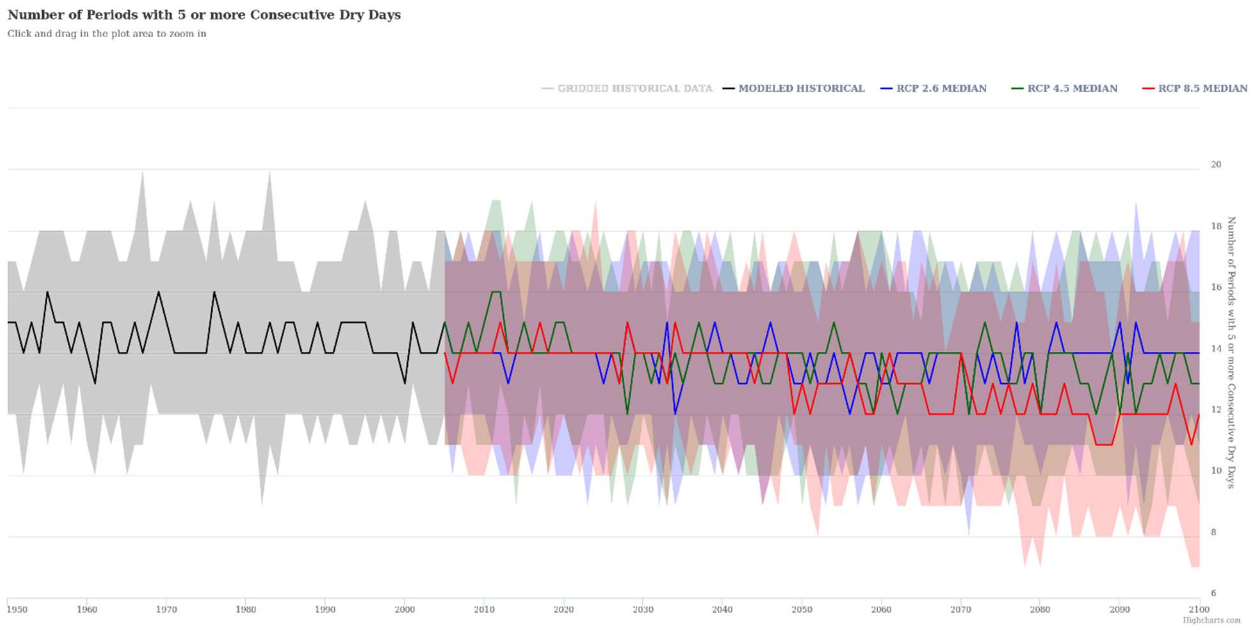

Figure 9: CD Number of Periods with 5 or More Consecutive Dry Days MH RCP 2.6 RCP 4.5 RCP 8.5.png

:

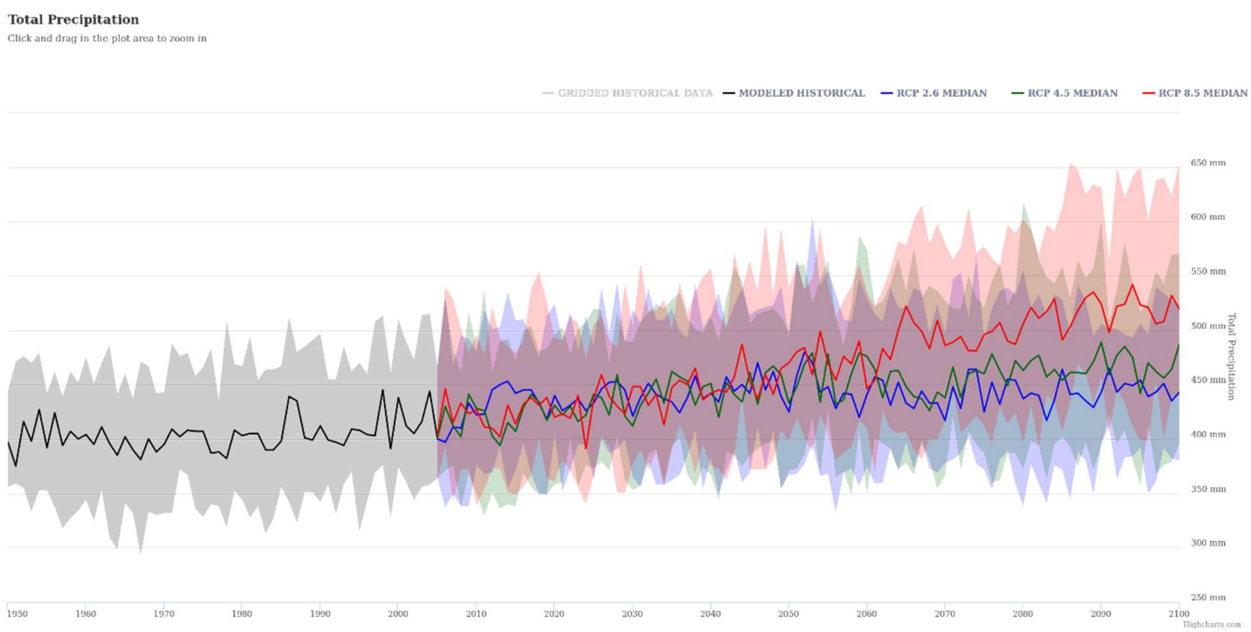

Figure 10: CD Total Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5.png

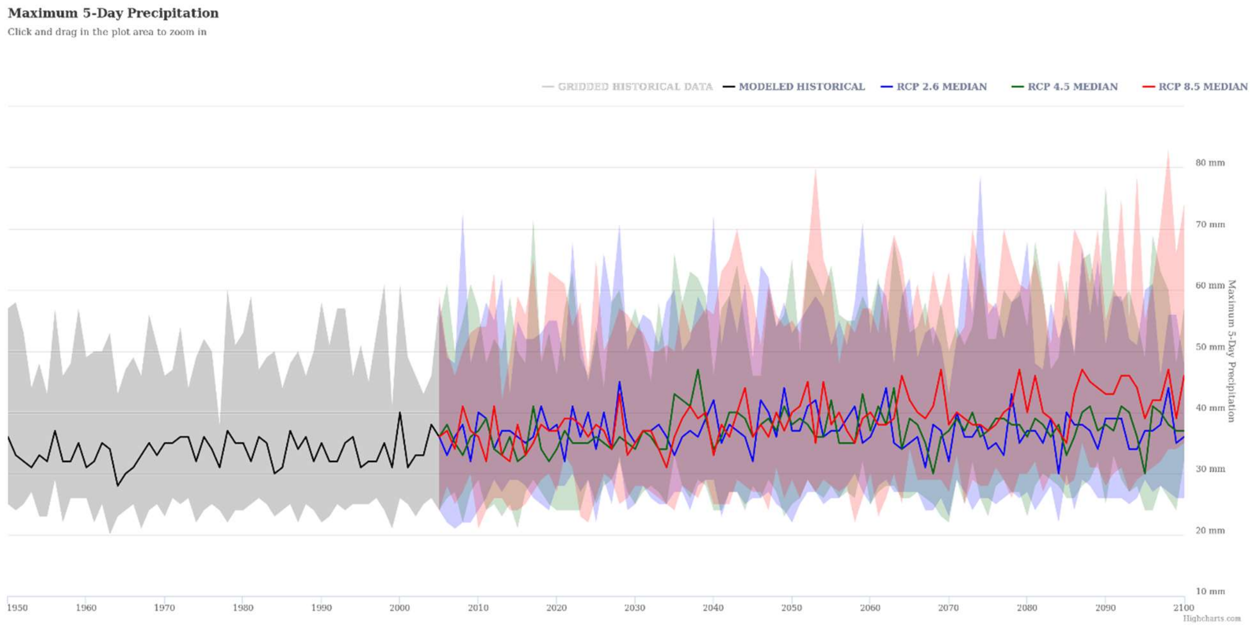

Figure 11: CD Maximum 5-Day Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5.png

5 DERIVATION OF WEATHER-BASED ACTION LEVELS

The effects of precipitation, freeze-thaw cycling, and wind on structures have been extensively studied.[11, 12] These effects are magnified in remote locations where the structures are used on a periodic basis or have been abandoned. In these instances, routine maintenance and basic up-keep is difficult, costly, and problematic. Predictions related to weather-based events now have the added complexity of factoring in climate change, which is affected by a variety of different anthropogenic activities. RCP 4.5[13] is considered a moderate predictor of what a climate altered future might look like and has been used to estimate future weather events for the purpose of this study. ClimateAtlas.ca refers to RCP 4.5 as a "low carbon climate future". The effects of precipitation events are the focus of this study.

5.1 How to Estimate a Weather Based Action Level for Site Maintenance Visits

The OMS plan summarizes monitoring requirements following from the FMEA (provided in Appendix D of the OMS plan).

For this report, consideration is given to the following precipitation metrics, focusing on annual values. Unless stated otherwise the data relates to Resolution Island.

5.1.1 Wet days > 10 mm MH RCP 4.5 (heavy precipitation days 10 mm –ClimateAtlas.ca)

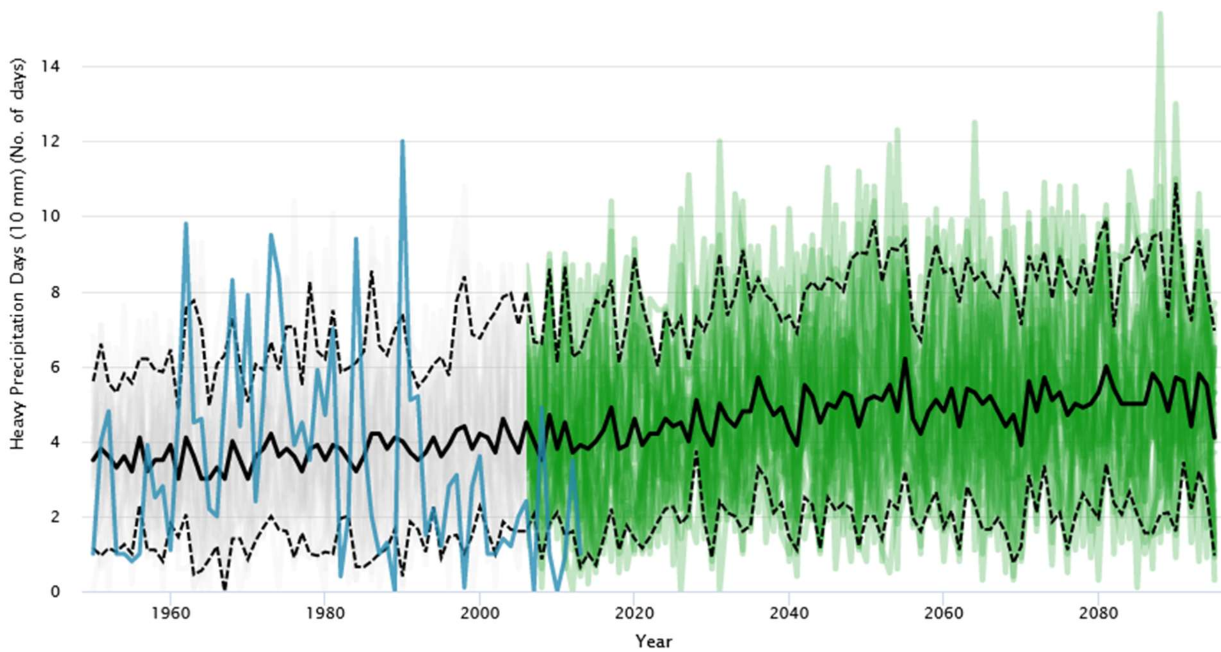

Figure 12: Number of Wet days> 10mm for RCP 4.5

		Low	Mean	High
Projected change in mean 2021-2050	1976-2005	1.3	3.9	6.8
	2021-2050	2.0	4.7	7.7
Projected change in mean: 2051-2080	1976-2005	1.3	3.9	6.8
	2051-2080	2.0	5.0	8.4

This table summarizes the range of values across the 24 climate models for each 30-year period. "Low" and "High" are the mean 10th and 90th percentile values (this means that 10% of the values are higher than "High" and 10% are lower than "Low").

Figure 13: Projected Change in Heavy Precipitation Days (10mm) for RCP 4.5

For RCP 4.5, the baseline value is set at 3.9 days (average) for precipitation events where >10 mm is produced. For 2021–2050, this goes up 21% to 4.7 days and for 2051–2080, an increase of 28% to 5.0 days is observed.

5.1.2 One-Day Total Precipitation MH RCP 4.5 (maximum 1-day total precipitation – ClimateAtlas.ca)

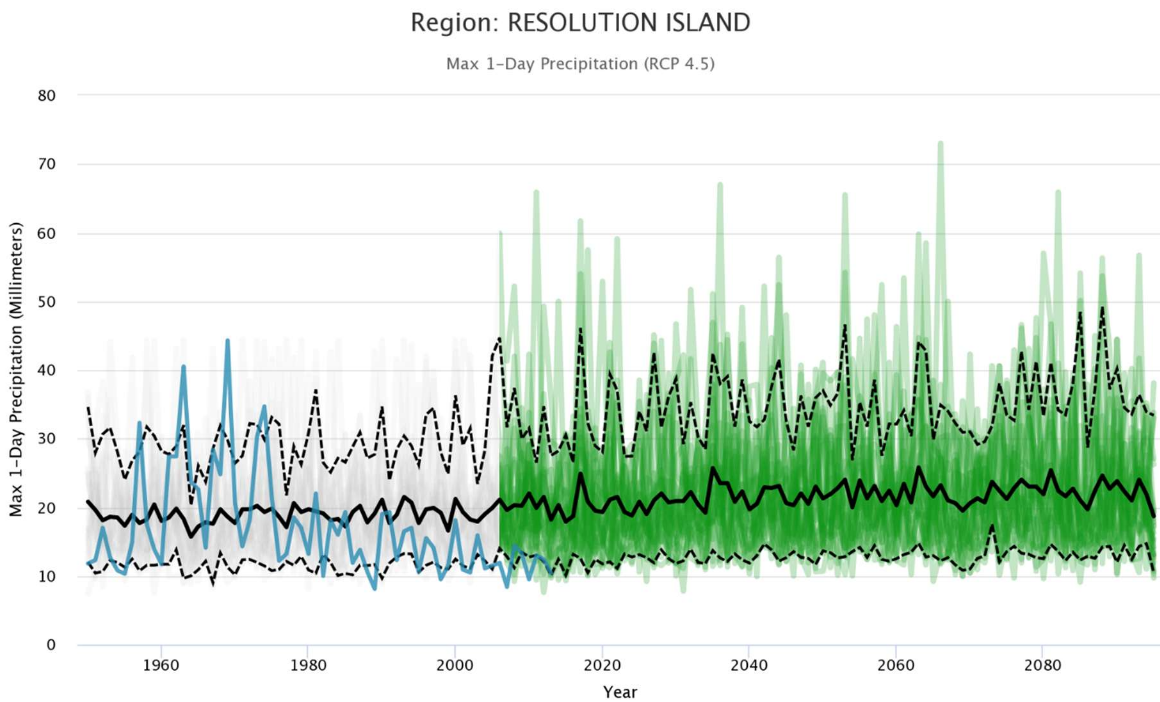

Figure 14: One Day Total Precipitation Maximum (mm) for RCP 4.5

	Period	Low	Mean	High
Projected change in mean: 2021-2050	1976-2005	12	19	29
	2021-2050	13	21	35
Projected change in mean: 2051-2080	1976-2005	12	19	29
	2051-2080	13	22	34

This table summarizes the range of values across the 24 climate models for each 30-year period. "Low" and "High" are the mean 10th and 90th percentile values (this means that 10% of the values are higher than "High" and 10% are lower than "Low").

Figure 15: Projected Change in One-Day Maximum Precipitation (mm) for RCP 4.5

For RCP 4.5, the baseline value is set at 19 mm for maximum 1 day precipitation. For 2021–2050, this goes up 12% to 21 mm and for 2051-2080, it increases by 16% to 22 mm.

5.1.3 Total Annual Precipitation MH RCP 4.5

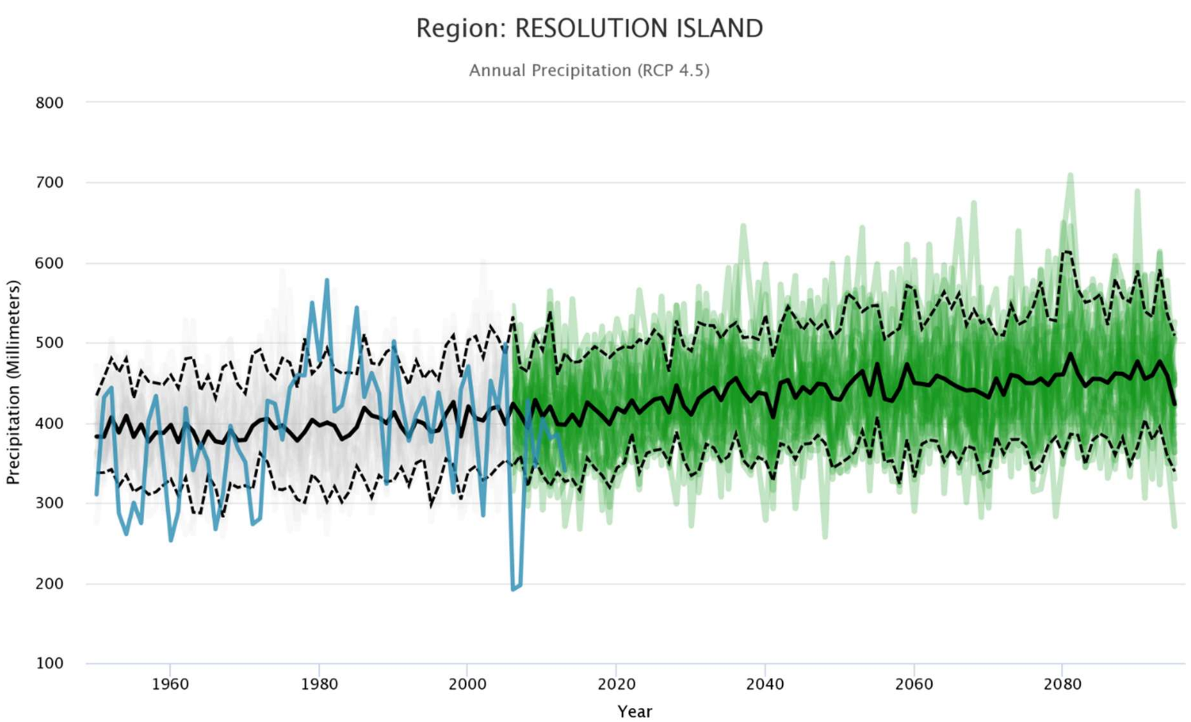

Figure 16:Total Annual Precipitation (mm) for RCP 4.5

		Low	Mean	High
Projected change in mean: 2021-2050	1976-2005	328	400	479
	2021-2050	360	433	512
Projected change in mean: 2051-2080	1976-2005	328	400	479
	2051-2080	363	449	540

This table summarizes the range of values across the 24 climate models for each 30-year period. "Low" and "High" are the mean 10th and 90th percentile values (this means that 10% of the values are higher than "High" and 10% are lower than "Low").

Figure 17: Projected Change in Total Annual Precipitation (mm) for RCP 4.5

The 1976–2005 period is used to set the baseline with a mean (annual) precipitation value of 400 mm, taken from the average (referred to as ensemble) value of the multiple climate models used over this data period.

For 2021–2050, RCP 4.5 mean (annual) rainfall is estimated at 433 mm, which is an 8.3 % on the baseline value. Low and high values are set using the 10 percentile and 90 percentile values of 24 separate climate models. The low value for this range is 360 mm and 512 mm is the high value. Similarly, for 2051–2080, RCP 4.5, the mean (annual) rainfall is estimated at 449 mm, which is an 12.3% increase, with a low of 363 mm and high of 540 mm.

A statistical comparison of means for the years 1950–2013 from the historical data set (387 mm) and the modelled ensemble data (397 mm) suggested no significant difference between the datasets (Student's t test, $p = 0.37$, confidence level of 95%; i.e. since p is greater than 0.05, the means are not statistically different). The year 2095 is used as the cut-off point (for ClimateAtlas.ca), as not all models have data beyond this date.

5.1.4 Maximum 5-Day Precipitation MH RCP 4.5

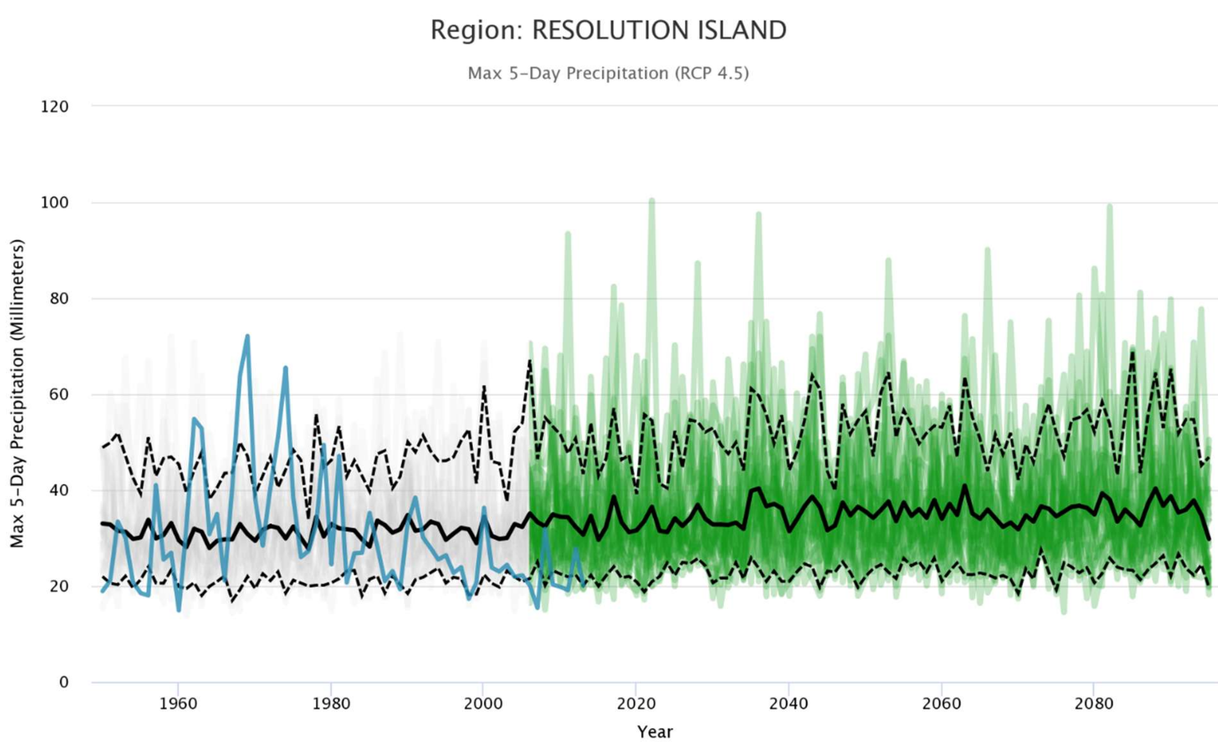

Figure 18: Maximum 5-Day Precipitation (mm) for RCP 4.5

Projected change in mean: 2021-2050		Low	Mean	High
	1976-2005	21	32	47
	2021-2050	23	35	52
Projected change in mean: 2051-2080		Low	Mean	High
	1976-2005	21	32	47
	2051-2080	23	35	53

This table summarizes the range of values across the 24 climate models for each 30-year period. "Low" and "High" are the mean 10th and 90th percentile values (this means that 10% of the values are higher than "High" and 10% are lower than "Low").

Figure 19: Projected Change in Maximum 5-Day Precipitation (mm) for RCP 4.5

For RCP 4.5, the baseline value is set at 32 mm for Maximum 5-day precipitation. For 2021–2050, this goes up 10% to 35 mm and for 2051–2080, an increase of 12% to 35 mm is seen. The change from 10% increase to 12% increase is not observed in the presented data (both values are 35 mm) because of the use of two significant figures.

Certain other precipitation metrics such as Wet days > 20 mm have been omitted from further discussion. Measured occurrences of this metric are low. For example, the 30-year averages for 1951–1980 have a median value = 0, and a range of 0–1, versus a median of 1 (range 1–1) for 2071–2100. Even for the more pessimistic prediction of RCP 8.5, at the maximum extent of the timeline (2100), > 20 mm events are not predicted to increase significantly. Non-precipitation weather events as they relate to temperature or other metrics are beyond the scope of the present report. Frost days, freeze thaw cycles and ice days, however, may well be relevant to degradation pathways in engineered structures and future studies may address these metrics for Resolution Island and/or other sites. [14, 15]. Predictions for freeze thaw cycling at BAF-5 are briefly discussed in section 5.5.2.

A data summary is available (pdf format) in Table 2.

Table 2: Climate Report- Resolution Island

Climate Atlas Report

Region: RESOLUTION ISLAND

RCP 8.5: High Carbon climate future

GHG emissions continue to increase at current rates

Variable	Period	1976-2005 Mean	2021-2050 Low	2021-2050 Mean	2021-2050 High	2051-2080 Low	2051-2080 Mean	2051-2080 High
Precipitation (mm)	annual	400	359	438	528	387	476	566
Precipitation (mm)	spring	64	45	68	93	48	75	104
Precipitation (mm)	summer	136	91	146	208	97	153	218
Precipitation (mm)	fall	124	94	135	178	103	147	196
Precipitation (mm)	winter	76	57	89	122	67	101	140
Mean Temperature (°C)	annual	-6.7	-6	-4.4	-2.4	-3.9	-1.8	0.6
Mean Temperature (°C)	spring	-10.4	-10.6	-8.4	-6	-8.7	-6.1	-2.5
Mean Temperature (°C)	summer	5	4.2	6.2	8.3	5.1	7.8	10.8
Mean Temperature (°C)	fall	-2.7	-2.6	-0.9	0.9	-1.2	0.9	2.9
Mean Temperature (°C)	winter	-19.1	-18.2	-14.7	-10.6	-13.7	-10	-5.8
Tropical Nights	annual	0	0	0	0	0	0	0
Very Hot Days (+30°C)	annual	0	0	0	0	0	0	0
Very Cold Days (-30°C)	annual	14	0	3	9	0	0	1
Date of Last Spring Frost	annual	July 3	June 5	June 20	July 12	May 19	June 9	July 4
Date of First Fall Frost	annual	Sep. 6	Aug. 30	Sep. 19	Oct. 4	Sep. 13	Oct. 1	Oct. 18
Frost-Free Season (days)	annual	62	54	86	111	74	109	142

RCP 4.5: Low Carbon climate future

GHG emissions much reduced

Variable	Period	1976-2005 Mean	2021-2050 Low	2021-2050 Mean	2021-2050 High	2051-2080 Low	2051-2080 Mean	2051-2080 High
Precipitation (mm)	annual	400	360	433	512	363	449	540
Precipitation (mm)	spring	64	44	68	96	46	71	98
Precipitation (mm)	summer	136	95	146	204	93	146	204
Precipitation (mm)	fall	124	93	133	177	99	139	186
Precipitation (mm)	winter	76	57	85	118	60	93	130
Mean Temperature (°C)	annual	-6.7	-6.6	-4.8	-2.9	-5.4	-3.5	-1.3
Mean Temperature (°C)	spring	-10.4	-11.1	-8.8	-6.3	-10	-7.6	-4.5
Mean Temperature (°C)	summer	5	4.1	6.1	8.2	4.6	6.8	9.3
Mean Temperature (°C)	fall	-2.7	-2.9	-1.1	0.5	-2.2	-0.2	1.6
Mean Temperature (°C)	winter	-19.1	-19.1	-15.4	-11.4	-17.1	-13	-8.6
Tropical Nights	annual	0	0	0	0	0	0	0
Very Hot Days (+30°C)	annual	0	0	0	0	0	0	0
Very Cold Days (-30°C)	annual	14	0	4	11	0	1	5
Date of Last Spring Frost	annual	July 3	June 6	June 22	July 14	May 31	June 16	July 9
Date of First Fall Frost	annual	Sep. 6	Aug. 30	Sep. 17	Oct. 3	Sep. 7	Sep. 23	Oct. 10
Frost-Free Season (days)	annual	62	51	83	111	63	95	122

5.2 Generation of Precipitation Data

The ability to produce high quality estimates and measurement for precipitation is essential for accurate climate modelling, and yet quantification remains challenging.

"Most precipitation data sets may be categorized into one of three broad categories: gauge data sets (e.g. CRU TS, GPCC, APHRODITE, PREC/L), satellite-only data sets (e.g., CHOMPS) and merged satellite-gauge products (e.g. GPCP, CMAP, TRMM 3B42)".[16]

Even with thousands of satellites in the sky, most satellites orbit over a region with a relatively low periodicity, leading to the potential for missed precipitation events. For this reason, observations are often made from multiple satellites that carry scientific equipment such as passive microwave and/or infrared instruments. Infrared sensors are used to estimate temperatures, and microwave data are used to calculate a precipitation value from both scattered and emitted radiation. The scattering signal is particularly useful over land because of significant distortion of the emission signal.

Rain gauge-based data sets themselves can be difficult to use, as extrapolating point data to cover a wide geographical area can lead to large uncertainties. Errors in measurement can occur because of wind and/or evaporation effects. In remote locations, weather stations are few and widely spaced. The absence of suitable ground-based measurement can lead to greater errors in weather models and forecasts. When observed climate data cannot be proofed against modelled climate data, errors occur. This is especially prevalent for short, intense duration frequency (IDF) events such as thunderstorms.

5.3 Historic Precipitation Data Used to Set Climate Normals for Resolution Island

Historical weather data can be obtained from a variety of different sources. The type of format used to present the data and ease of extracting this data are often pertinent. In this regard, the Canadian government website https://www.canada.ca/en.html is useful. See: Environment and Natural Resources→weather→climate and hazards→Weather data→research and learning→Historical climate data.

Relevant Resolution Island data can be obtained through the Historical Data tab or the Canadian Climate Normals tab[17,18] and is either transcribed into a new data table or presented as an excerpt from the original data. Results from 1941–1970 are in inches with mm equivalents included below. Data from 1951–1980 are also presented. Updates to climate normals were performed after 10 years (when possible).

Table 3: Total Precipitation 1941–1970, Resolution Island Climate Normals

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Type
Resolution Island - inches	0.68	0.54	0.69	0.56	0.61	1.01	1.39	1.67	1.65	1.20	1.07	1.10	12.12	8
Resolution Island (Cape Warwick) - Inches	0.51	0.41	0.39	0.37	0.42	0.74	3.01	3.43	2.47	1.72	0.88	0.86	15.21	8
Resolution Island - mm	17.3	13.7	17.5	14.2	15.5	25.7	35.3	42.4	41.9	30.5	27.2	27.9	308	-
Resolution Island (Cape Warwick) - mm	13.0	10.4	9.9	9.4	10.7	18.8	76.5	87.1	62.7	43.7	22.4	21.8	386	-

TOTAL PRECIPITATION 1951-80 | Table 3
PRECIPITATIONS TOTALES 1951-80 | Tableau 3

	JAN JAN	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOÛT	SEP SEPT	OCT OCT	NOV NOV	DEC DÉC	YEAR ANNÉE	CODE CODE
NORTHWEST TERRITORIES TERRITOIRES DU NORD-OUEST														
REA POINT	1.4	0.3	1.6	1.1	3.6	4.0	9.1	20.4	6.8	8.4	2.2	2.1	61.0	8
RESOLUTE A	3.3	3.0	3.0	5.9	8.1	12.1	22.5	31.1	18.0	13.8	5.7	4.9	131.4	1
RESOLUTION ISLAND	19.1	13.3	12.5	10.2	21.1	24.7	42.3	39.7	49.2	36.6	24.8	19.8	313.3	8
RESOLUTION ISLAND	12.7	11.7	15.9	10.5	9.0	18.5	83.0	96.5	64.3	38.1	23.4	20.8	404.4	8

Figure 20: Resolution Island Climate Normals 1951–1980

The two different Resolution Island data stations are not specified above but are assumed to be consistent with the 1941–1970 report. In both reports and for the two separate sites, most of the total precipitation comes in the later half of the year (July–December). Cape Warwick is the name of the body of water just outside Brewer Bay, where the BAF-5 site is located, and as such likely refers to weather station ID 2403602, maintained by DND.

Climate normals (averages or means) are terms that are used interchangeably, and they refer to calculations based on observed values for a specific location over a specific time period. “Real time values are often compared to a location’s climate normal to determine how unusual or how great the departure from average, they are”.[19] In general, 30 years of data is preferred when establishing climate normals. Larger datasets help to minimize variability, although for remote northern sites, this was often not possible.

In section 4.9, ClimateData.ca, a precipitation baseline for Resolution Island for annual precipitation was estimated at 386 mm (1951–1980). It may be noted, in some instances, that original data sets are hard to obtain.

As noted earlier, assuming a moderate emissions scenario of RCP 4.5, rainfall on Resolution Island is expected to be 8% higher for the 2021–2050 period, and 12% higher for 2051–2080.

Under a high emissions scenario, this is projected to be 10% higher for the 2021–2050 period, and 19% higher for the 2051–2080 period.

5.4 Establishment of Baseline Values and Use of Precipitation Data towards Meeting OMS (BAF-5) Phase 1 and Phase 2 Monitoring Requirements – Part1

The following sections pertain to the formulation of baseline precipitation information to support exit criteria for the BAF-5 site.

5.4.1 Data Limitations and Mean Precipitation Values for RCP 4.5

With RCP 4.5 selected as an estimate of how greenhouse gas emission may affect our climate, the following precipitation averages for Resolution Island were extracted.

Historical (measured) data are available for download from CanadaAtlas.ca and originates from National Resources Canada (NRCan). Details on the use of “Ensembles” and “Spatial Resolution and Interpolation” can be obtained using the following link: https://climateatlas.ca/important-data-notes-and-limitations. Of note, “the quality of the NRCan data is reduced in parts of Canada where there are i) temporal gaps in the weather station data; ii) large geographic distances between weather stations; iii) mountainous terrain; and/or iv) large contrasts in microclimate in a region. In short, the climate model data used is most prone to interpolation error over mountainous regions, and in areas with few long-term weather stations, such as Northern Canada”.

This is especially true for Resolution Island, where the closest operational weather station actively monitoring precipitation is over 200 km away. With reference to specific climate variables and indices/precipitation, “Precipitation is much more difficult to model than temperature. Consequently, there is lower confidence in point-specific, time-specific precipitation projections. Confidence is increased for the projections, when they are aggregated to produce longer-term averages of monthly, seasonal, and annual precipitation totals. The range of projected precipitation values across models used to create ensemble values is relatively high, compared to the range of values in the temperature projections, which is typical of all climate model studies”.

The consequence of the points noted above is that precipitation data metrics for Resolution Island are limited, highly variable and difficult to obtain. Historic modelled data for time periods relevant to this study (circa 2005 onwards) in a format that allows for ready data manipulation and straightforward graphical comparisons was a challenge. One company that offers (paid) access to modelled data for Resolution Island is Meteoblue (https://www.meteoblue.com). Data obtained from this site are based on the following grid location (61º33'3.6 N, 64º58'51.5994 W, 305 m), which is within 20 km of BAF-5 (61º35'47'N 64º 38'21W, 355 m). Access to climate modelling through the History+ feature is available for 1 year for one location at a cost of 100 Euros. Location data from Meteoblue for Resolution Island is displayed in Decimal Degrees instead of Degrees, Minutes and Seconds. However, interconversion is straightforward and online tools can readily be used as required. Modelled precipitation data for 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013 were obtained. Precipitation values were also collected for the period 2011–2019 to see if a correlation exists between the amount of precipitation and the quantity of soil transported by runoff into two of the relevant monitored features at the site: 1) the Furniture Dump PCB Barrier and 2) the Beach S1/S4 Barrier. Data from Meteoblue were further processed using a re-analysis model (ERA5). Re-analysis is a term used where modern-day technology is used to re-analyze climate data from the past and by doing so can produce more accurate information for making decisions moving forward, and the Meteoblue website provides a calculator for this procedure.

A concise explanation of ERA5 is reproduced below from the AWS Public Sector Blog.[20]

"ERA5 is the latest generation of ECMWF atmospheric reanalysis of the global climate, and the first reanalysis produced as an operational service. The dataset is produced using ECMWF's Integrated Forecast System (IFS) numerical model, the same model used to produce their global weather forecast.

Reanalysis datasets are important because they assimilate vast amounts of observational data with computer models to create a detailed and consistent overview of weather and climate conditions. This is valuable in areas where observational data is either sparse or non-existent, such as the oceans and polar regions. ERA5 is particularly exciting because of its improved model accuracy and higher geographical and temporal resolution than its predecessors".

The Meteoblue (Data Download and ERA5 Download) values are compared against gridded historical values, which were available up to and including 2013. The source of this daily historical data used in the atlas is Natural Resources Canada (NRCan; McKenney et al., 2011[21]). This dataset is comprised of daily maximum and minimum air temperature and daily precipitation totals for the same 10 km by 10 km grid used in the downscaled GCM datasets produced by PCIC. More explanation is given at the following link: https://climateatlas.ca/data-sources-and-methods#toc-0 → data sources and methods→about this data→observed values. In the following paragraphs, the two datasets (Meteoblue Data Download and ERA5 Download) are further compared with ensemble (averaged data) obtained from ClimateAtlas.ca.

5.4.2 Meteoblue Data: Resolution Island

5.4.2.1. Meteoblue Simulated Historic Climate and Weather Data – 30 Years

The minimum and maximum temperatures (for an average day) as well as precipitation amounts for each month are displayed below. The dotted lines show the average hottest day and coldest day for each month. These averages have been compiled for the last 30 years (circa 1991–2021). This simulated historical climate data has a spatial resolution of approximately 30 km. The average annual precipitation (1991–2021) is 553 mm and is broken down as follows: Jan (30 mm); Feb (27 mm); Mar (32 mm); Apr (36 mm); May (46 mm); June (51 mm); July (56 mm); Aug (64 mm); Sep (68 mm); Oct (54 mm); Nov (54 mm); Dec (35 mm). Seasonal values are spring (114 mm), summer (171 mm), fall (176 mm), and winter (92 mm). Note that this total annual precipitation amount of 553 mm is substantially elevated over the measured climate normal value of 386 mm (1951–1980) reported by ClimateData.ca.

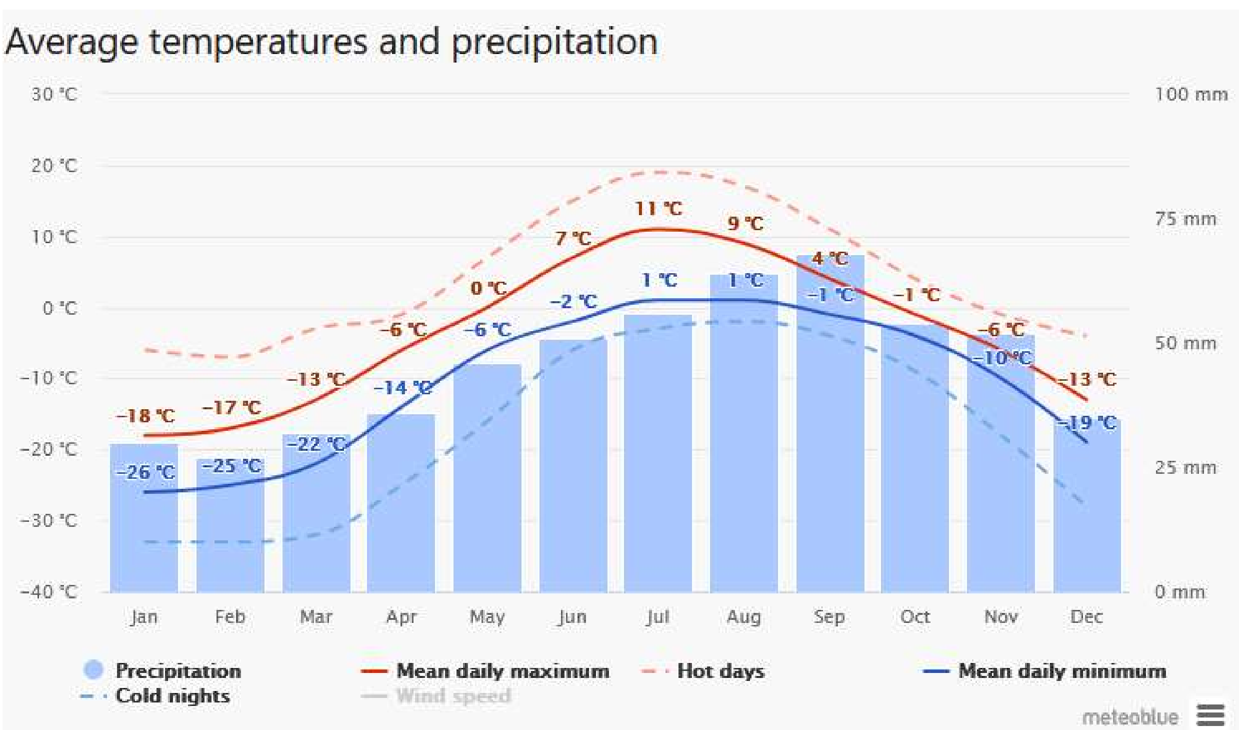

Figure 21: Meteoblue Average Precipitation and Temperature (1991–2021)

5.4.2.2. Meteoblue Precipitation and Temperature Data 2006 – 2019. Data Download

The figures that follow (Figures 22 to 35) show the precipitation and temperature data obtained as unaltered downloaded data from Meteoblue for the years of interest.

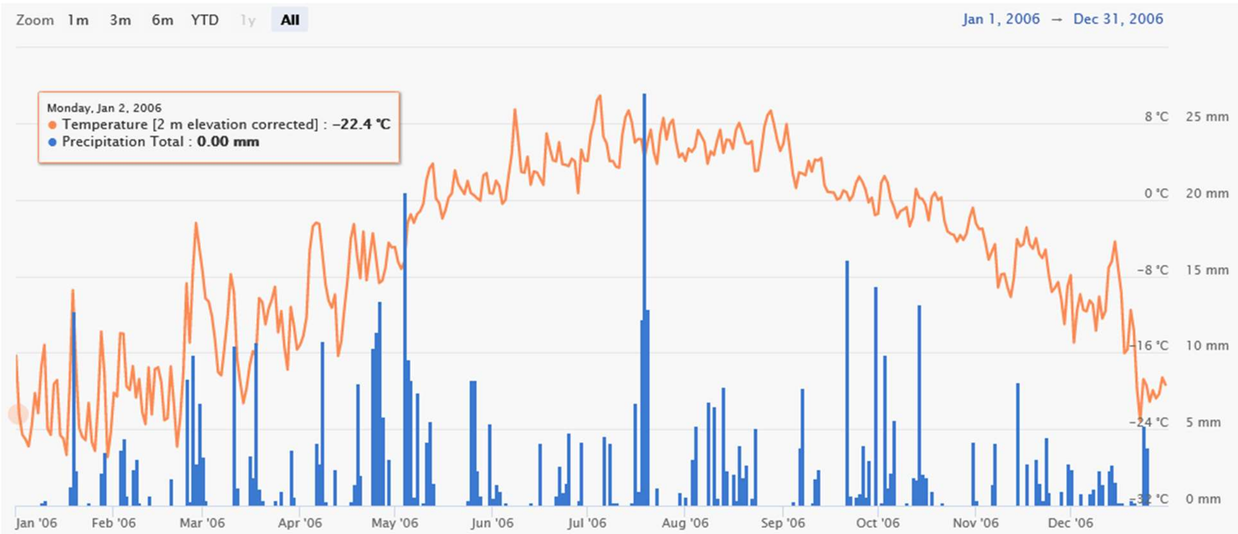

Figure 22: Meteoblue -Precipitation and Temperature 2006 Data Download

Temperature: orange, 2m elevation corrected (ºC); precipitation: blue (mm) – valid for 2006-2019

Average temperature: -5.4 ºC; Total Annual Precipitation: 568 mm

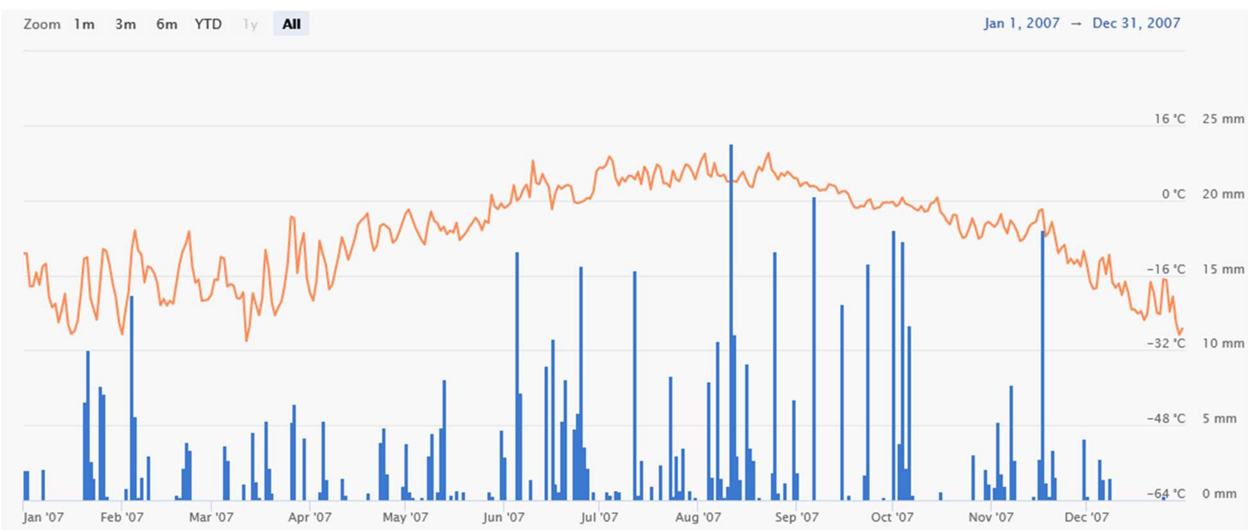

Figure 23: Meteoblue -Precipitation and Temperature 2007 Data Download

Average temperature: - 7.0ºC; Total Annual Precipitation: 582 mm

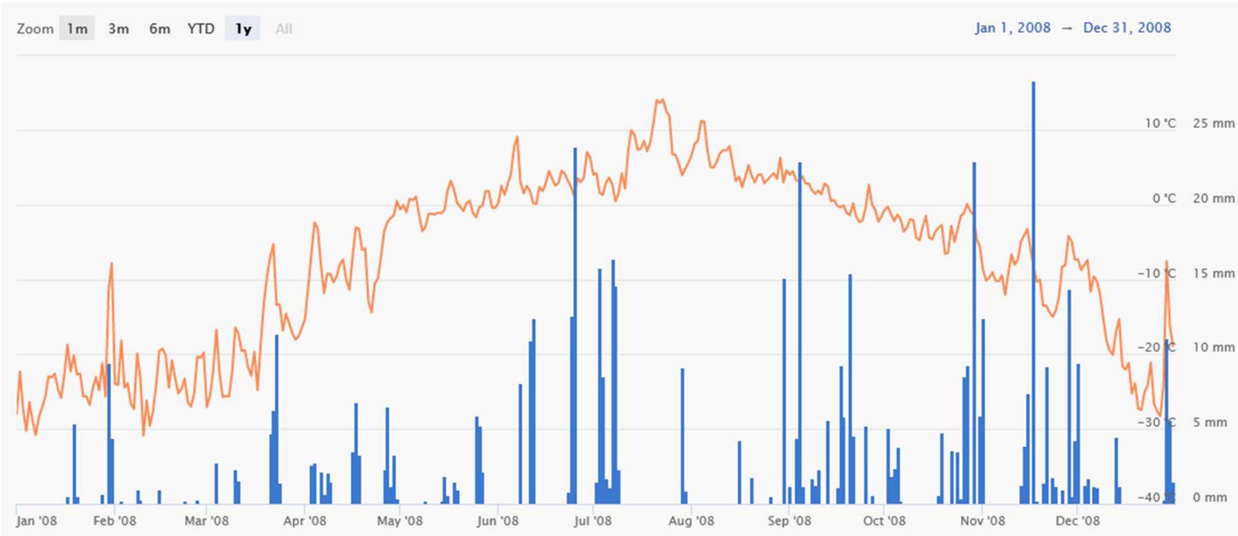

Figure 24: Meteoblue -Precipitation and Temperature 2008 Data Download

Average temperature: - 7.3ºC; Total Annual Precipitation: 556 mm

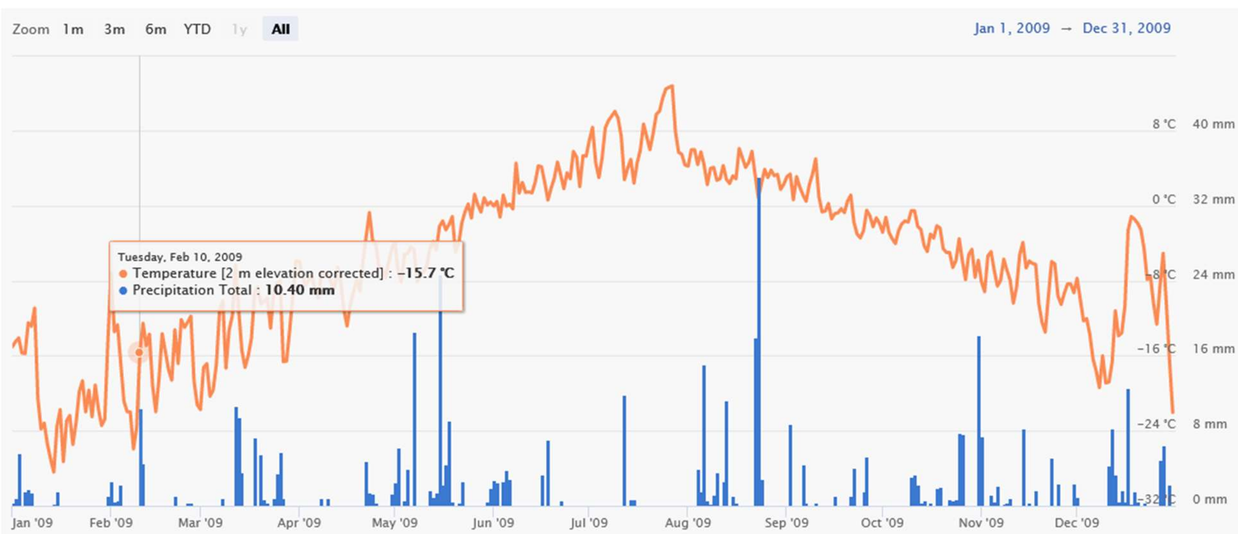

Figure 25: Meteoblue -Precipitation and Temperature 2009 Data Download

Average temperature: - 5.8ºC; Total Annual Precipitation: 475 mm

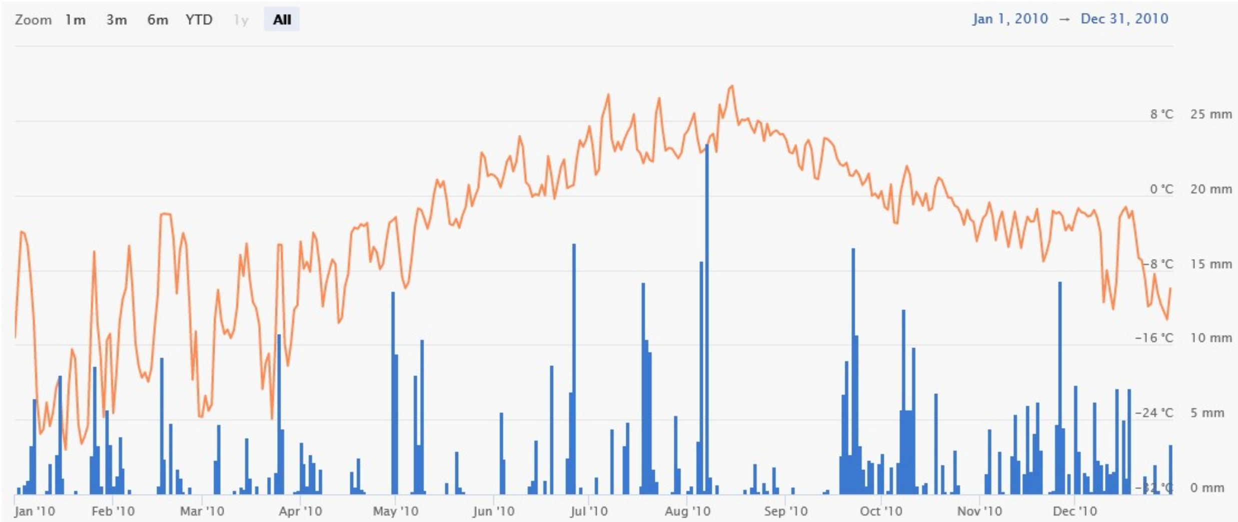

Figure 26: Meteoblue -Precipitation and Temperature 2010 Data Download

Average temperature: - 3.6ºC; Total Annual Precipitation: 587 mm

Figure 27: Meteoblue -Precipitation and Temperature 2011 Data Download

Average temperature: - 6.8ºC; Total Annual Precipitation: 418 mm

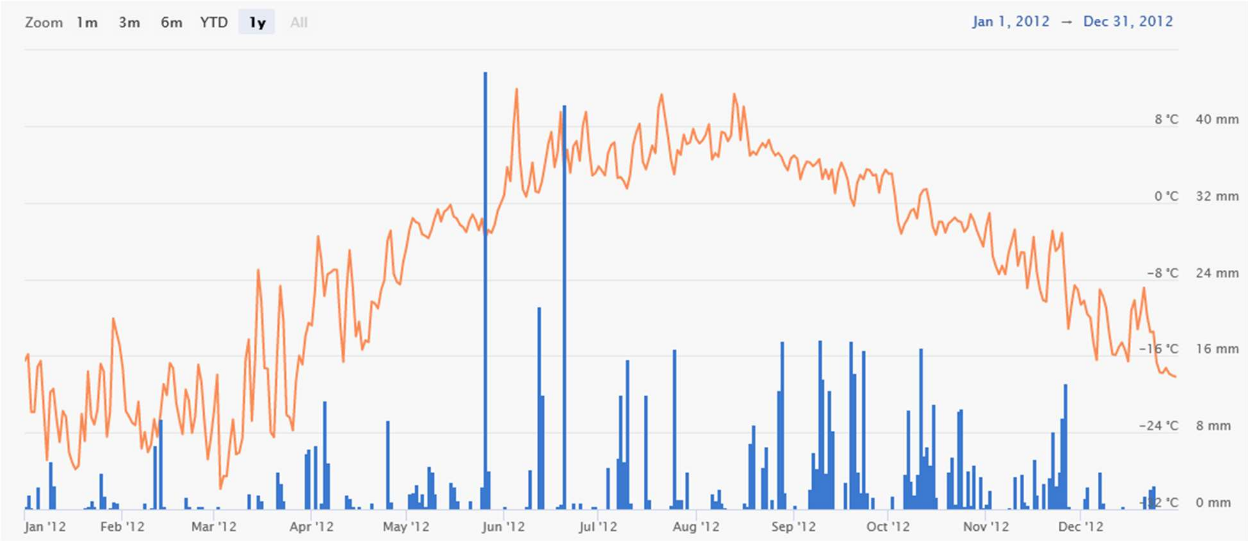

Figure 28: Meteoblue -Precipitation and Temperature 2012 Data Download

Average temperature: -6.3ºC; Total Annual Precipitation: 730 mm

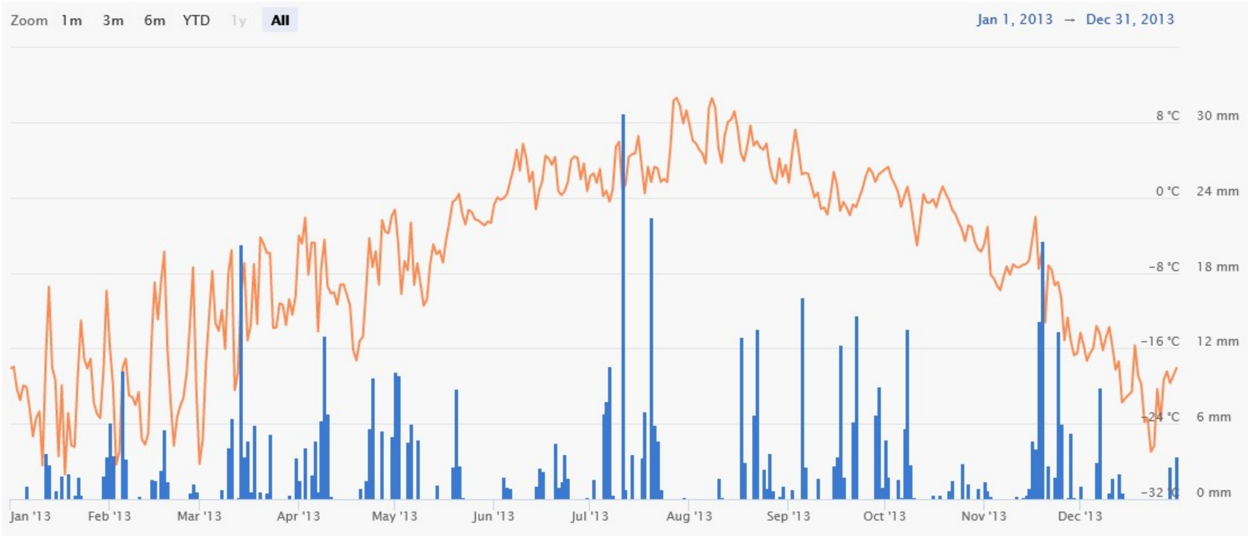

Figure 29: Meteoblue -Precipitation and Temperature 2013 Data Download

Average temperature: -6.7ºC; Total Annual Precipitation: 630 mm

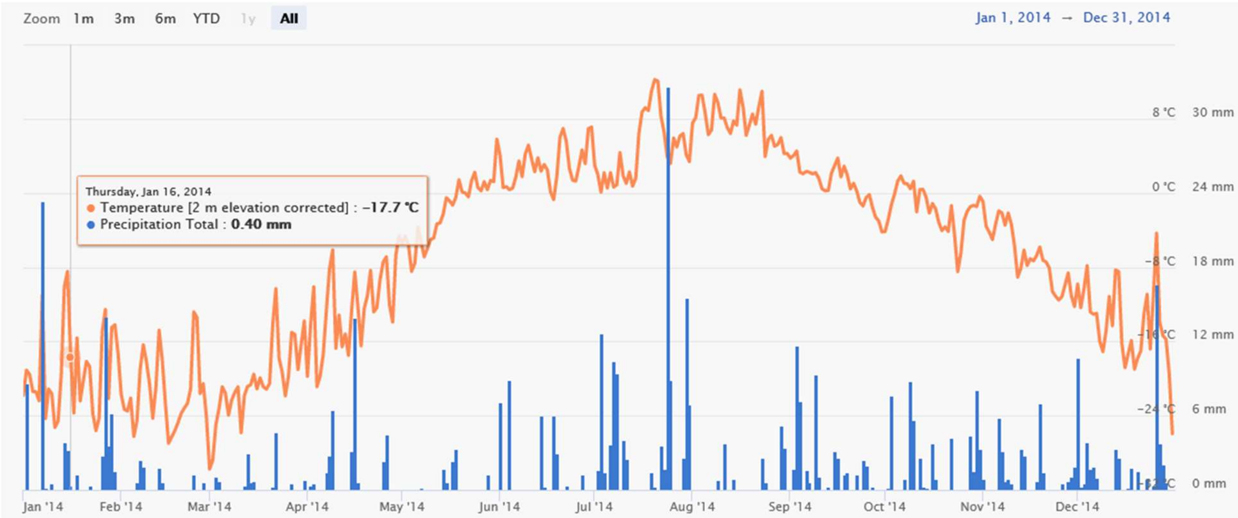

Figure 30: Meteoblue -Precipitation and Temperature 2014 Data Download

Average temperature: -6.8ºC; Total Annual Precipitation: 494 mm

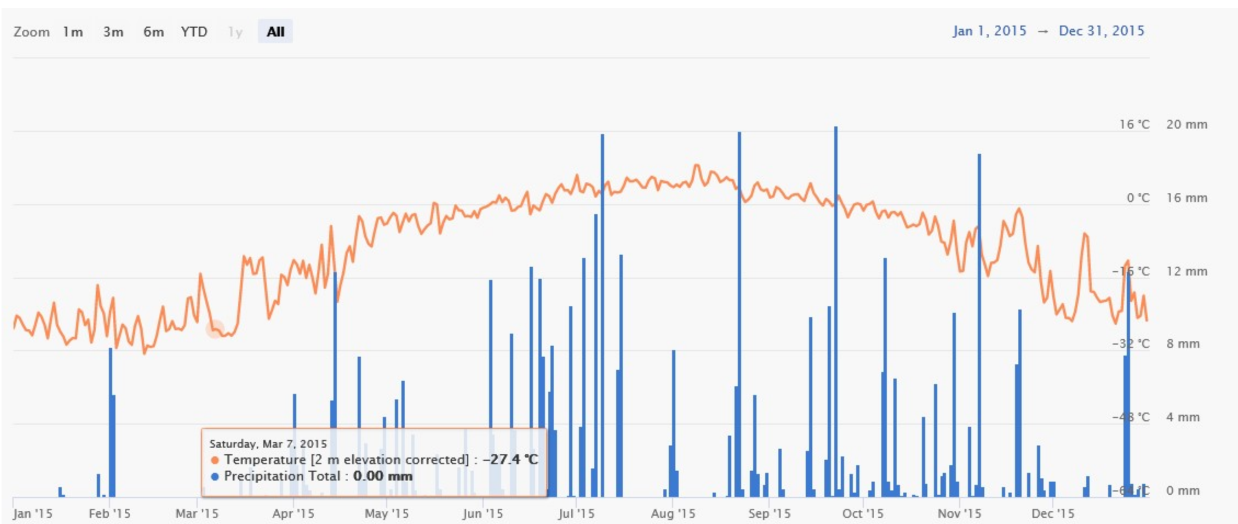

Figure 31: Meteoblue -Precipitation and Temperature 2015 Data Download

Average temperature: -9.3ºC; Total Annual Precipitation: 513 mm

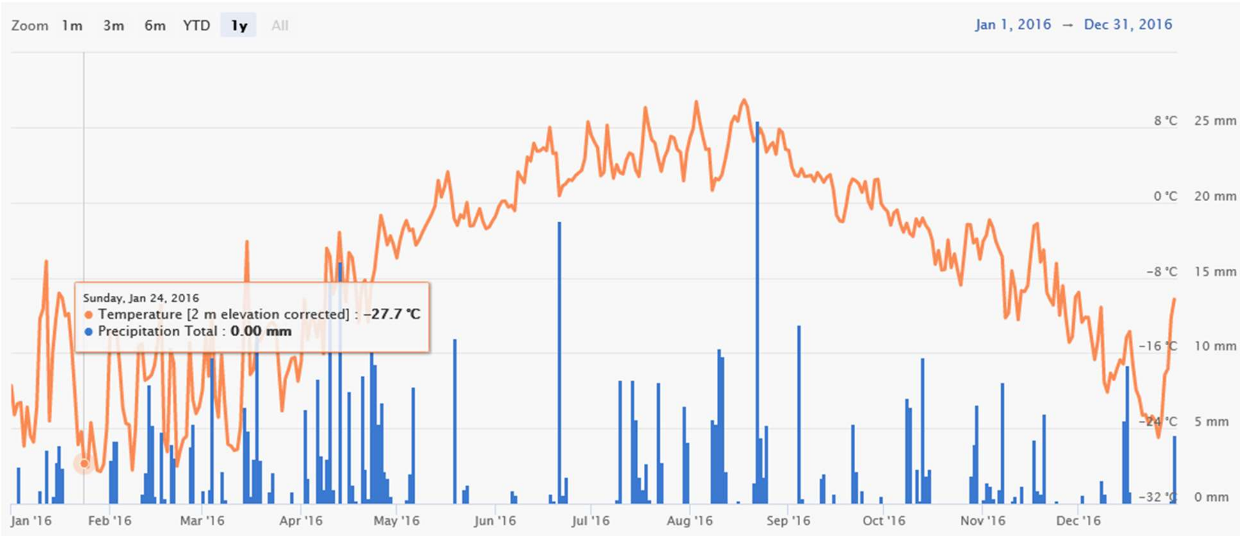

Figure 32: Meteoblue -Precipitation and Temperature 2016 Data Download

Average temperature: -6.7ºC; Total Annual Precipitation: 511 mm

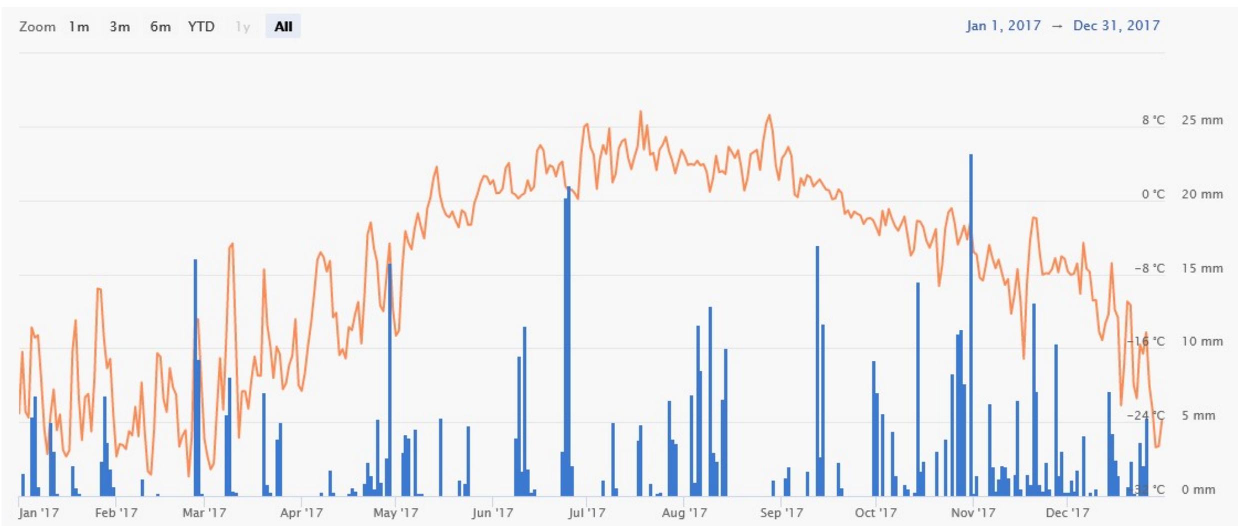

Figure 33: Meteoblue -Precipitation and Temperature 2017 Data Download

Average temperature: -7.2ºC; Total Annual Precipitation: 593mm

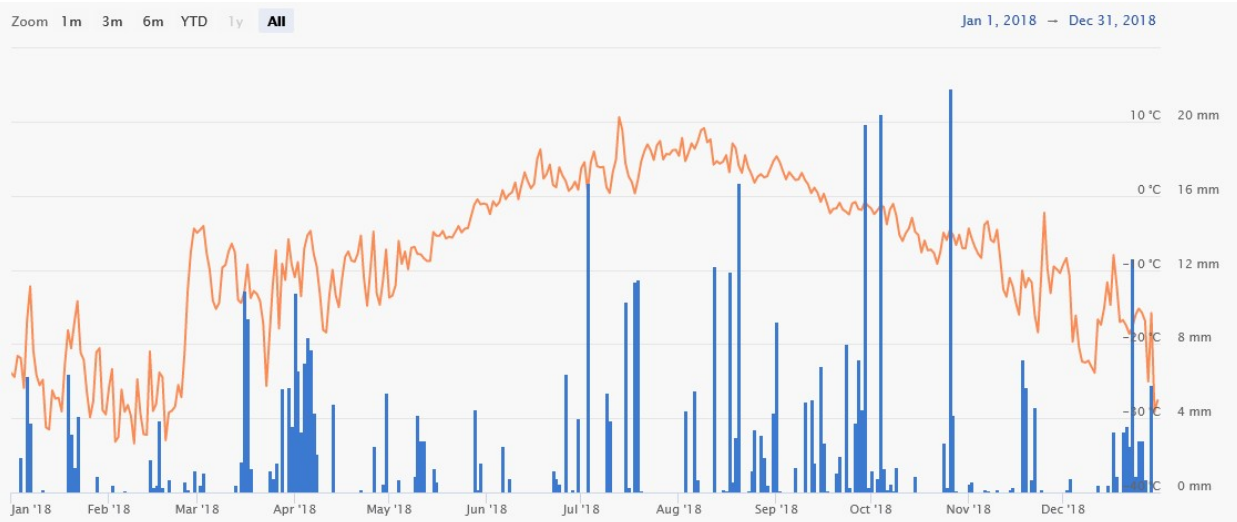

Figure 34: Meteoblue -Precipitation and Temperature 2018 Data Download

Average temperature: -8.1ºC; Total Annual Precipitation: 507 mm

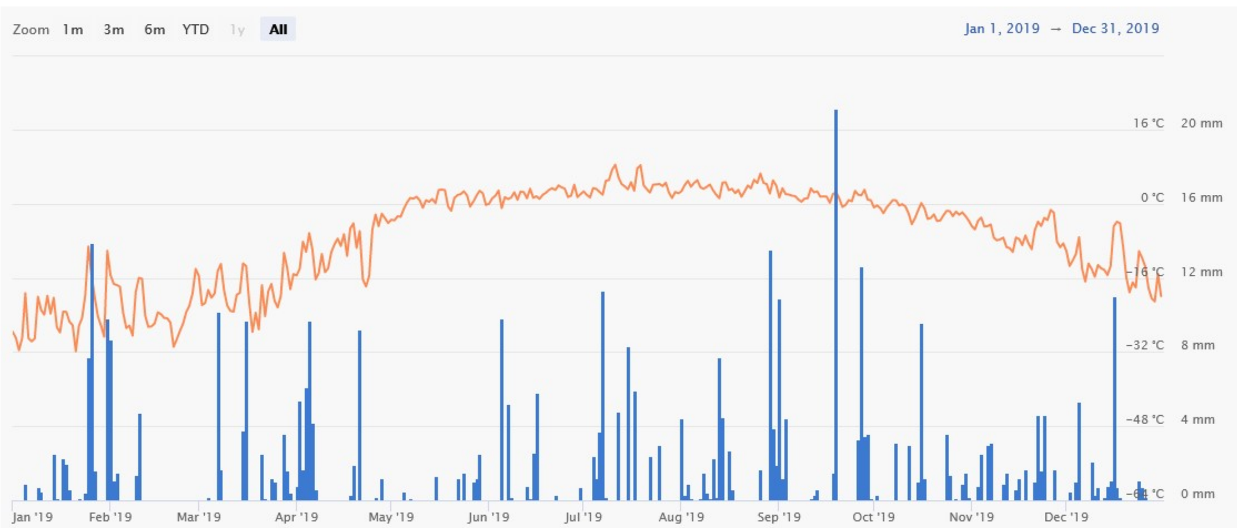

Figure 35: Meteoblue -Precipitation and Temperature 2019 Data Download

Average temperature: -7.1ºC; Total Annual Precipitation: 406 mm

5.4.3 Meteoblue Precipitation and Temperature Data 2006 – 2019. ERA5 Download

The figure for the first "ERA5 Download" (Figure 36) allows a direct visual comparison with the equivalent "Data Download" image (Figure 22). For the subsequent years 2007 to 2019 inclusive, only the ERA5 recalculated average temperature and total annual precipitation are presented in the following list. The images and xls data for these years are available on request.

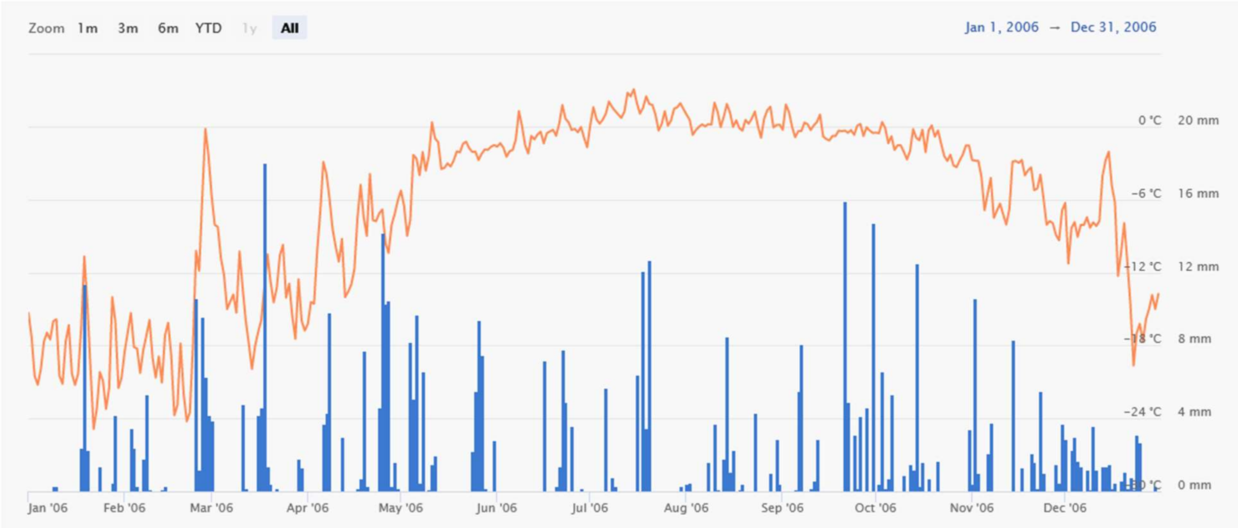

Figure 36: Meteoblue -Precipitation and Temperature 2006 -ERA5 Processed

Average temperature: -6.4°C; Total Annual Precipitation: 515 mm

Meteoblue -Precipitation and Temperature 2007 ERA5 Processed

Average temperature: -7.5°C; Total Annual Precipitation: 510 mm

Meteoblue -Precipitation and Temperature 2008 ERA5 Processed

Average temperature: -8.1°C; Total Annual Precipitation: 508 mm

Meteoblue -Precipitation and Temperature 2009 ERA5 Processed

Average temperature: -7.7°C; Total Annual Precipitation: 416 mm

Meteoblue -Precipitation and Temperature 2010 ERA5 Processed

Average temperature: -4.8°C; Total Annual Precipitation: 528 mm

Meteoblue -Precipitation and Temperature 2011 ERA5 Processed

Average temperature: -6.5°C; Total Annual Precipitation: 493 mm

Meteoblue -Precipitation and Temperature 2012 ERA5 Processed

Average temperature: -6.7°C; Total Annual Precipitation: 659 mm

Meteoblue -Precipitation and Temperature 2013 ERA5 Processed

Average temperature: -7.4°C; Total Annual Precipitation: 577 mm

Meteoblue -Precipitation and Temperature 2014 ERA5 Processed

Average temperature: -7.6ºC; Total Annual Precipitation: 425 mm

Meteoblue -Precipitation and Temperature 2015 ERA5 Processed

Average temperature: -9.1ºC; Total Annual Precipitation: 461 mm

Meteoblue -Precipitation and Temperature 2016 ERA5 Processed

Average temperature: -7.5ºC; Total Annual Precipitation: 462 mm

Meteoblue -Precipitation and Temperature 2017 ERA5 Processed

Average temperature: -7.5ºC; Total Annual Precipitation: 517 mm

Meteoblue -Precipitation and Temperature 2018 ERA5 Processed

Average temperature: -7.9ºC; Total Annual Precipitation: 480 mm

Meteoblue -Precipitation and Temperature 2019 ERA5 Processed

Average temperature: -6.7ºC; Total Annual Precipitation: 420 mm

5.4.4 Iqaluit Weather Station as a Proxy for Missing Resolution Island Data

Iqaluit is the capital city in Nunavut with a population of 7710 (2016 Census) and as such, is Nunavut's most populated city. The weather station is readily maintained and missing only occasional data sets. Climate normals may approximate (to those found at Resolution Island) and are available from 1941–2010 (inclusive). As a comparison:

Resolution Island, Climate Normal 1941–1970. Annual precipitation = 386 mm

Iqaluit, Climate Normal 1941–1970. Annual precipitation = 415 mm

Resolution Island, Climate Normal 1951–1980. Annual precipitation = 404 mm

Iqaluit, Climate Normal 1951–1980. Annual precipitation = 433 mm

It should be noted that the Iqaluit weather station is located approximately 310 km from the Resolution Island site.

Data pertaining to climate normals for Iqaluit are displayed in Figure 37.

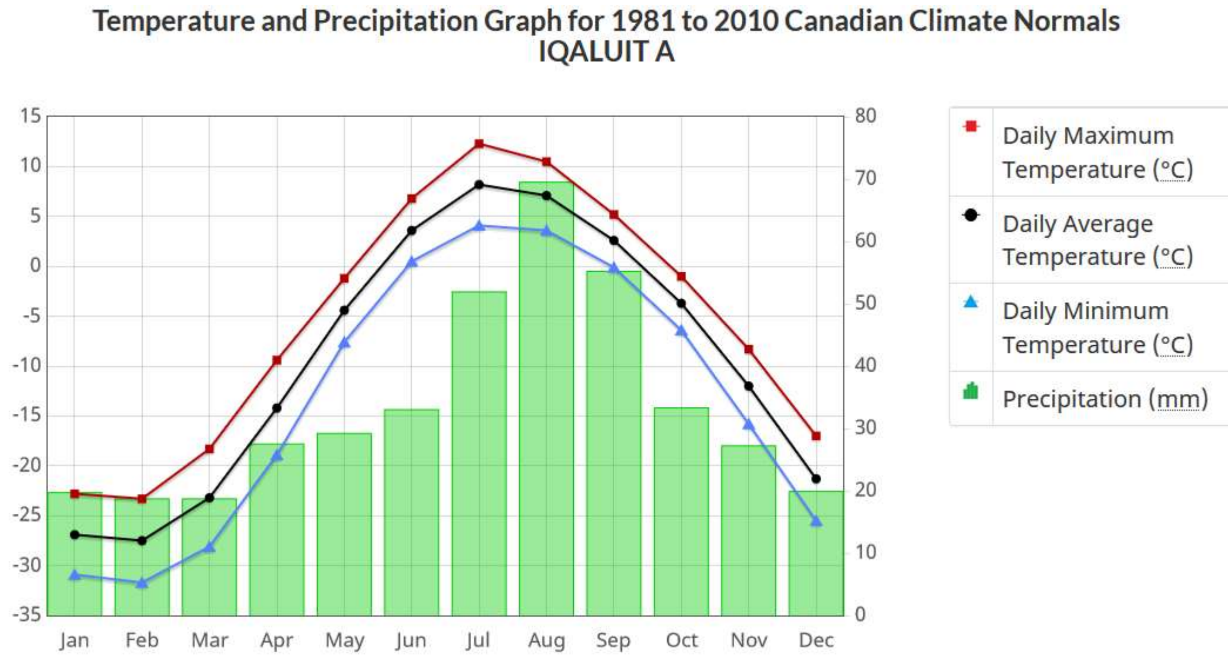

Figure 37: Iqaluit Climate Normal 1981–2010

The average annual precipitation (1981–2010) is 404 mm and is broken down as follows: Jan (19.7 mm); Feb (18.7 mm); Mar (18.7 mm); Apr (27.5 mm); May (29.2 mm); June (33.0 mm); July (51.9 mm); Aug (69.5 mm); Sep (55.2 mm); Oct (33.3 mm); Nov (27.2 mm); Dec (19.9 mm). Seasonal values are spring (75.4 mm), summer (154.4 mm), fall (115.7 mm), and winter (58.3 mm).

Other useful precipitation data is also accessible, including Extreme Daily Precipitation (mm), which is organized by month in a tabulated format.

Gridded historical data is not available for Resolution Island (or any other sites) after 2013. For the duration of the study period relevant for the present work, 2006–2019, the Iqaluit annual precipitation measurements were downloaded (from the Iqaluit Climate weather station) and results are presented in Table 4. Gridded Historical Data (2006–2013), Ensemble Mean Data, Meteoblue (data download) and Meteoblue (ERA5) are also compared. These annual precipitation datasets are compared to soil (movement) metrics, recorded in previous ASU reports. This was carried out to see if a correlation exists between the amount of precipitation received and the quantity of soil transported by runoff. Two monitored features at the site: 1) the Furniture Dump PRB and 2) the Beach S1/S4 PRB were of particular interest.

Table 4: Annual Precipitation Using Gridded Historical (GH), Ensemble Mean (EM), Iqaluit Weather Station (IS), Meteoblue data (MB) and Meteoblue ERA5 (MB-ERA) data

	Annual Precipitation (mm)				
Year	GH Gridded Historical (NRCan) - Observed	EM Ensemble (Mean-24 Climate Models)	IS Weather Station Data (Iqaluit)	MB Meteoblue (Data Download)	MB ERA5 (Meteoblue ERA5 Download)
2006	192	423	268	568	515
2007	197	410	341	582	510
2008	428	393	340	556	508
2009	345	428	208	475	416
2010	405	407	382	587	528
2011	380	420	257	418	493
2012	386	398	350	730	659
2013	340	397	327	630	577
2014	-	410	619	494	425
2015	-	396	301	513	461
2016	-	425	487	511	462
2017	-	417	359	593	517
2018	-	408	324	507	480
2019	-	398	254	406	420
Average	334	410	344	568	526
STDEV	91	13	104	94	70

GH, EM, MB and MB ERA5 data are from Resolution Island; IS data are from Iqaluit

Table 5: RI Precipitation Data Set Comparison of Means

Annual Precipitation (mm)					
	GH Gridded Historical (NRCan) - Observed	EM Ensemble (Mean-24 Climate Models)	IS Weather Station Data (Iqaluit)	MB Meteoblue (Data Download)	MB ERA5 Meteoblue (ERA5 Download)
TTEST	TTEST	EM vs MB	0.00010		
TTEST	TTEST	GH vs EM	**0.065**		
TTEST	TTEST	GH vs MB	0.0015		
TTEST	TTEST	EM vs MB ERA5	0.00039		
TTEST	TTEST	MB vs MB ERA5	0.0018		
TTEST	TTEST	GH vs MB ERA5	0.0014		
TTEST	TTEST	GH vs IS	**0.49**		
TTEST	TTEST **	EM vs IS	0.037		
TTEST	TTEST	MB vs IS	0.0001		
TTEST	TTEST	MB ERA5 vs IS	0.0005		

** This is comparing the RI EM (not the Iqaluit EM) with the IS data. Comparison with Iqaluit EM data (1950-2013) with the IS data has a P value of 0.13.

P values less than 0.05 are obtained for eight of the ten comparisons in Table 5. For a significance level of 0.05, the sample data for these sets is therefore influenced by a (non-random) source. GH data is not available from 2013 onwards and therefore cannot be used to compare EM values for years after 2013. However, there is no significant difference between the data sets for GH Resolution Island (2006–2013) and the EM Resolution Island data (2006–2013) and it may be inferred that this would continue for 2014–2019. This lack of significant difference also implies that the use of Iqaluit Station data 2014–2019 as a proxy for missing GH Resolution Island data (2014-2019) may be valid.

The use of either MB Data download or MB ERA5 data, while readily available/organized, does not show a good correlation with any of the other data sets.

5.4.5 Resolution Island Historic Precipitation Maximums

The maximum annual rainfall observed at Resolution Island (from historical records-gridded) over the course of a single year was 578 mm (ClimateAtlas.ca) in 1981 and 584 mm (ClimateData.ca) in 1981. This was the maximum recorded value over the period 1950-2013. For the same time, for EM data, 2009 had a maximum value of 428 mm. MB and MB ERA5 values were not used. For Resolution Island, weather station precipitation data came from two sources located approximately 30 km apart. Precipitation measurements for these stations were not continuous with many gaps in the collected data and only for 1941–1970 and 1951–1980. This information is presented in a scanned pdf format (copied into Table 3 and Figure 20 in the present report), in which precipitation is ordered by the cumulative average for each month over the entire 30-year period as well as the total average yearly precipitation for this period. For the first station (exact location unspecified), an average of 308 mm was observed with the second station (identified as Resolution Island Cape Warwick) having an average of 386 mm in 1941–1970 (this average was also reported by ClimateData.ca for Resolution Island for 1951–1980; the source of this number and similarity to earlier data is unexplained on the website). For 1951–1980 precipitation normals of 313 and 404 mm were observed. For the 1951–1980 data, there was no differentiation between the names of the stations, being presented as "Resolution Island" data. However, based on the precipitation differences between these stations and the order in the table they were presented, it can be inferred that the second value belongs to the Cape Warwick site. The DND weather station on the island (active until 2018) is also located near Cape Warwick. Climate normal data for 1961–1990, 1971–2000 and 1981–2010 were not available for Resolution Island. The normals data produced for Canadian weather stations for these time periods became progressively better organised and easier to access with time. Data from the latest climate normal period 1981–2010 for the closest major station, Iqaluit, includes important metrics related to periodicity of data collection and completeness of data intervals as well as precipitation maximums.

On investigation of the discontinuous precipitation data for the Resolution Island stations outside the climate normal periods, the maximum recorded value for 1921–1961 was in 1946 (574 mm) and for 1972–1975 was in 1973 (529 mm). No precipitation data were observed to have been collected after July 1975, although the station with the climate ID 2403602 was used to collect (other) data periodically until 22 July 2018.

Resolution Island climate normals (1941–1970) of 386 mm, (1951–1980) of 404 mm and obtained from ClimateAtlas.ca (1975–2005) of 400 mm closely resemble the most recent values found for Iqaluit (1981–2010) of 403 mm. It is reasonable, therefore, given the inherent uncertainty in precipitation values, to use Iqaluit as a proxy for future measurements related to precipitation events at Resolution Island.

In terms of setting an average precipitation value against which action levels can be calculated, although there are advantages and disadvantages to the way the data is presented for both ClimateData.ca and ClimateAtlas.ca, the ClimateAtlas.ca website overall has a simpler interface.

Using a ClimateData.ca defined RCP value of 4.5 (low carbon) approach, for calculation related to site action, the mean ensemble value (24 climate models) should be a reasonable way to base a given year's expected or predicted average precipitation value.

As an example, for 2025, an expected average precipitation value of 429 mm can be assumed; for 2026, 431 mm; for 2027, 413 mm and so on.

In terms of setting action levels, hard data measured at the site itself is very limited and many unknown variables exist as to the quality of the data and measurement uncertainties. A much larger data set with several accurate and well-maintained weather stations would ideally be required to provide high quality historic data sufficiently accurate to take site topographical variation into account.

5.4.6 Soil Movement at Resolution Island 2006-2019

Three PCB barriers were designed and constructed on Resolution Island between 2003 and 2006, by Queens University, Analytical Services Unit. The design, operation, maintenance, and construction of these barriers were part of Dr. Indra Kalinovich's doctoral thesis.

Two of these structures are currently still in operation and are used to prevent PCB-contaminated soil from being transported into the marine environment. The operation and efficiency of the barriers has varied from year to year. The main factor affecting the barriers is the amount of sediment migrating into the funnel and the resulting amount of sediment to be removed from the trap each season. The arrangement of the filters and their composition was also optimized over the years.

5.4.7 Resolution Island Furniture Dump Barrier

The Furniture Dump Barrier was created in 2006. Field book measurements were used to create the following map from which the capacity was estimated at 8 m^3. The barrier was constructed to intercept contaminated soil from the drainage pathway. Since its construction, only low volumes of soil have been recorded in front of the barrier gates.

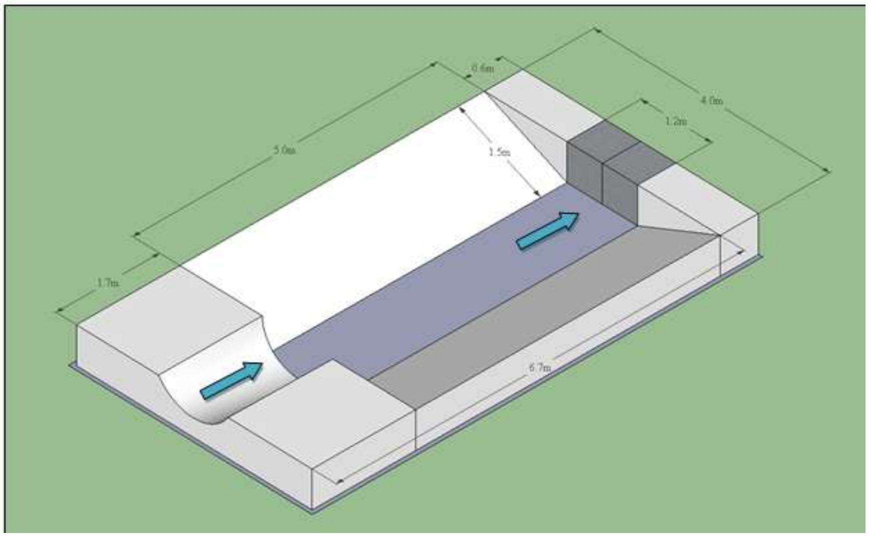

Figure 38: Schematic of the Furniture Dump Barrier

Estimates were made for soil quantities excavated from the Furniture Dump Barrier on several different occasions. These quantities were compared with yearly precipitation values. For years where estimates were not made and the soil left untouched, volumes were estimated based on the aggregated total, divided by the number of years passed to give a soil quantity per year estimate.

Table 6: Furniture Dump Soil Quantity vs Precipitation Model-Year by Year

	Measured	Soil (m^3)	IS (mm)	EM (mm)	GH (mm)
2006	Y (0.30)	0.30	268	423	192
2007	Y (0.25)	0.25	341	410	197
2008	Y (0.60)	0.60	340	393	428
2009	N	0.24	208	428	345
2010	Y (0.48)	0.24	382	407	405
2011	N	0.22	257	420	380
2012	N	0.22	350	398	386
2013	N	0.22	327	397	340
2014	N	0.22	619	410	NA
2015	N	0.22	301	396	NA
2016	N	0.22	487	425	NA
2017	N	0.22	359	417	NA
2018	N	0.22	324	408	NA
2019	Y (2.0)	0.22	254	398	NA

IS: Iqaluit Station Data; EM: Ensemble Mean Data (Resolution Island), GH: Gridded Historical Data (Resolution Island). NA: Not Available.

Table 7: Furniture Dump Soil Quantity m^3/mm Annual Precipitation Estimate

	IS	EM	GH
Total Soil m^3	3.61	3.61	2.3 *
Total Precipitation (mm)	4817	5730	2673 *
Average Precipitation/Year	344	409	334 *
Mean m^3/mm	0.00075	0.00063	0.00086

* Soil quantities, total precipitation (sum), average precipitation and mean soil movement values (m^3/mm) are based on the 2006-2013 study period only

The estimates given above (Tables 6 and 7) relate ONLY to the Furniture Dump Barrier.

The Furniture Dump Barrier has an estimated maximum capacity of 8.0 m^3 and would expect to lose efficiency at 4.0 m^3. Based on IS average precipitation values, assuming no physical degradation, it would take 16 years for the barrier to fill half-way. Any maintenance in or around the barrier pathway, alteration of the watercourse or significant deviations from current (modelled) RCP4.5 climate projections could shorten this time estimate significantly.

5.4.8 Resolution Island S1/S4 Beach Barrier

The S1/S4 Beach Barrier was created in 2006. Field book measurements were used to create the following map from which the capacity was estimated at 13 m^3. The barrier was constructed in 2005 to intercept contaminated soil from the S1/S4 valley drainage pathway, which empties over the cliff. This water runs down the steep slope above the beach barrier and is funnelled through the barrier. The original location of the barrier was chosen to maximise the use of natural contouring and was optimized using a judicial quantity of gabions. A large amount of disturbed soil lies above the barrier and although natural revegetation is helping to stabilize the slope, this barrier receives much higher quantities of soil than the Furniture Dump Barrier. Planting of vegetation on the upper slope as a remedial activity would significantly assist with soil stabilization in the long term.

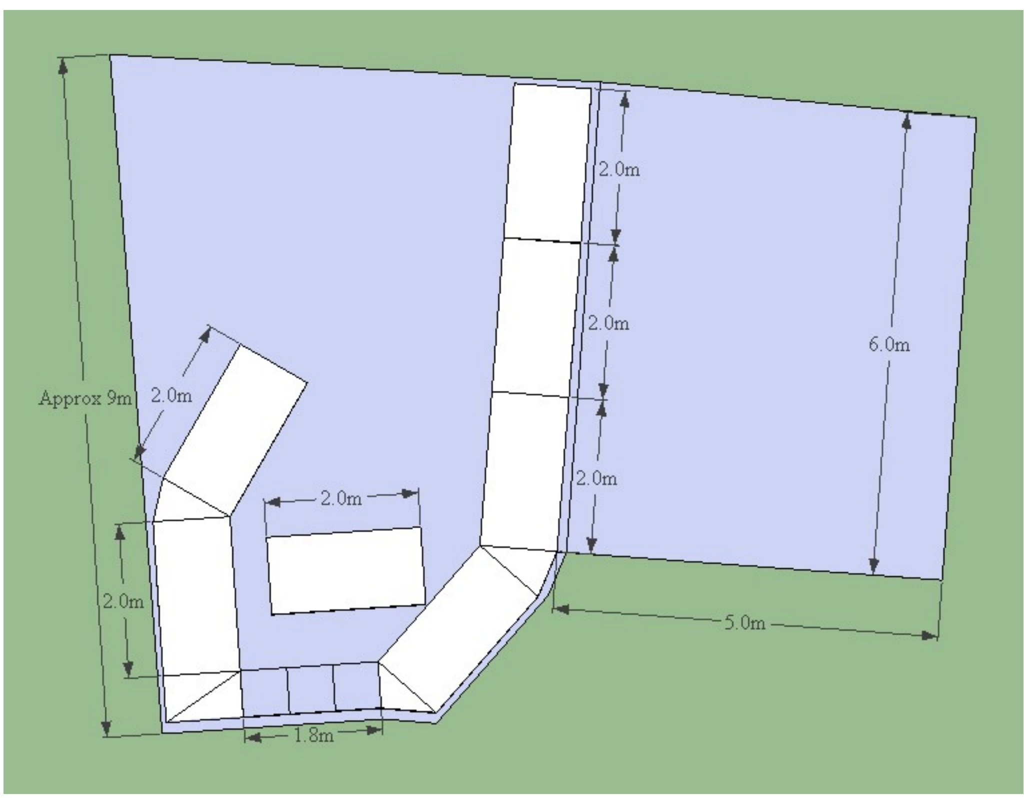

Figure 39: Schematic of the S1/S4 Beach Valley Barrier

Table 8: S1/S4 Beach Barrier Soil Quantity vs Precipitation Model-Year Per Year

	Measured	Soil (m^3)	IS	EM	GH
2006	Y (2.0)	2.0	268	423	192
2007	Y (1.2)	1.2	341	410	197
2008	Y (5.3)	5.3	340	393	428
2009	N	1.15*	208	428	345
2010	Y (2.3)*	1.15*	382	407	405
2011	N	2.0	257	420	380
2012	N	2.0	350	398	386
2013	Y (6.0)**	2.0	327	397	340
2014	N	1.17	619	410	NA
2015	N	1.17	301	396	NA
2016	N	1.17	487	425	NA
2017	N	1.17	359	417	NA
2018	N	1.17	324	408	NA
2019	Y (13)**	1.17	254	398	NA

IS: Iqaluit Station Data; EM: Ensemble Mean Data (Resolution Island), GH: Gridded Historical Data (Resolution Island). NA: Not Available. * 2010 measured volume assumed to be cumulative since 2008 (soil quantity not measured in 2009), so volumes estimated for 2009 and 2010 are half of 2010 cumulative volume. ** 2013 volume not excavated and thus estimated; 2019 quantity assumed to be cumulative since 2010, and 2014 to 2019 volumes are (13-6) m^3/6 years = 1.17 m^3 for each year.

Table 9: S1/S4 Beach Barrier Soil Quantity m^3/mm Annual Precipitation Estimate

	IS	EM	GH
Total Soil m^3	23.8	23.8	18.8 *
Total Precipitation (mm)	4817	5730	2673 *
Average Precipitation/Year	344	409	334 *
Mean m^3/mm	0.00452	0.0038	0.0063

* Soil quantities, total precipitation (sum), average precipitation and mean soil movement values (m^3/mm) are based on the 2006–2013 study period only

The estimates given above (Tables 8 and 9) relate ONLY to the S1/S4 Beach Barrier.

The S1/S4 Beach Barrier has an estimated maximum capacity of 13 m^3 and would expect to lose efficiency at approximately 6.5 m^3. Based on IS average precipitation values, assuming no physical degradation, it would take 4.2 years for the barrier to fill half-way. Any maintenance in or around the barrier pathway, alteration of the watercourse or significant deviations from current (modelled) RCP4.5 climate projections could decrease this estimate significantly.

5.4.9 Furniture Dump and S1/S4 Beach Barrier Capacity Summary

The Furniture Dump and S1/S4 Beach Barrier soil volume capacities (estimated) and number of years to reach a 50% level are presented in Table 10.

Table 10: Furniture Dump and S1/S4 Beach Barrier Capacity Summary

	Capacity (m^3)	Years to Reach 50%
Furniture Dump Barrier	8.0	16
S1/S4 Beach Barrier	13	4.2

5.4.10 Trends in Barrier Soil Volumes

Figure 40 from ASU report: “Resolution Island Five Year Monitoring Report 2006–2010” shows the general downwards trend with time, from 2006–2010, for the Beach and Furniture Dump Barriers. The S1/S4 Valley Barrier was decommissioned in 2019 but is included here for comparison. There is a general downwards trend, apart from 2008, which showed a substantial increase for all barriers. This year was not associated with any excavation or construction work at the site with activities focused on monitoring, so this increase is likely to be from environmental factors.

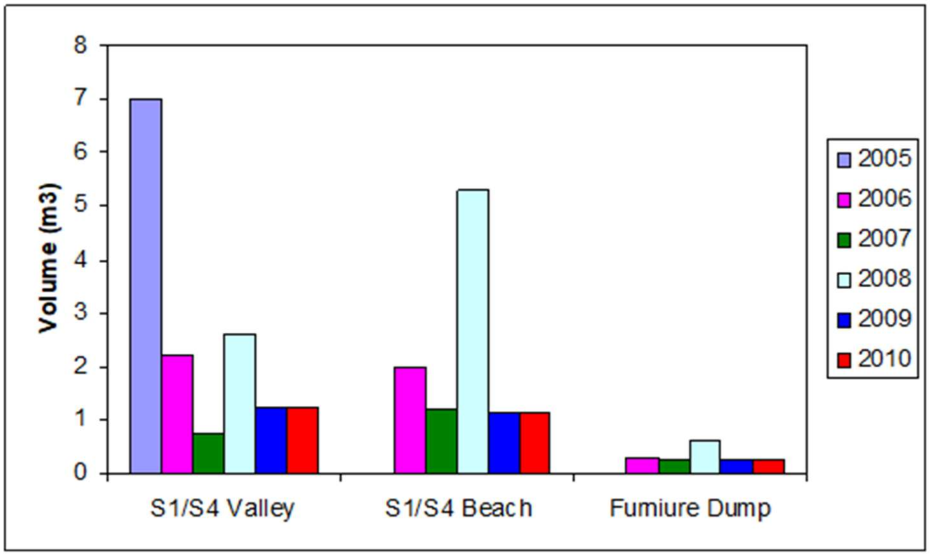

Figure 40: Change in Volume of Sediment in RI Barriers (2005-2010)

IS and EM precipitation data (2006–2019) and GH data (2006–2013) were investigated to consider potential links to weather phenomenon. GH data showed a peak value in 2008 of 428 mm annual precipitation (with a dataset mean of 334 mm). The EM value of 393 (dataset mean of 398) was not elevated in 2008, nor was the IS measurement of 340 mm (vs a mean of 343 mm).

The ClimateAtlas.ca GH dataset was reviewed for Resolution Island with a focus on the data range 2006–2013 and 2008, for the following additional precipitation metrics: Days with precipitation > 10 mm (heavy precipitation), Maximum 1-day precipitation (mm) and Maximum 5-day precipitation (mm).

For Days with precipitation > 10mm (heavy precipitation), the data ranged from 0.0 to 4.9 days per year with an average of 1.7 days. For 2008, the GH value was 4.9 days, which is a 286% elevation from the mean (n=9).

For Maximum 1-day precipitation (mm), the data range was 8.4 – 14.4 mm with an average value of 11.7 mm. In 2008, the GH value was 14.4 mm. This is a 23% elevation from the mean (n=9).

For Maximum 5-day precipitation (mm), the data range was 15.4–31.9 mm with an average value of 22 mm. In 2008, the GH value was 31.9 mm. This is a 46% elevation from the mean (n=9).

Despite the higher soil volumes observed in 2008, the decreasing trend in recent years suggests that the estimated fill times for the barriers may be overly conservative and, fill times may be much longer than predicted in the previous sections.

5.5 Establishment of Baseline Values and Use of Precipitation Data towards Meeting OMS (BAF-5) Phase 1 and Phase 2 Monitoring Requirements – Part 2

Some limited evidence exists to suggest a correlation between soil volumes in the two active barriers at Resolution Island and precipitation (GH) data. In the absence of GH data from 2013 onwards, an easily accessible and reliable way to obtain precipitation data for Resolution Island is required. Various climate models exist that can be used to predict long term trends, with the calculation of ensemble means (EM). EMs are based on the average of several different climate models, use a combination of computational power, mathematics, and historical weather data to predict weather patterns in the future. ClimateAtlas.ca and ClimateData.ca are Canadian focused entities tasked with providing EM data for a wide variety of environmental parameters. This type of data is relevant for various types of planning, but just like weather forecasts, there remains a level of uncertainty about any type of prediction, and when applying model data to specific areas, proofing using direct reading instrumentation is essential. Ground-based weather stations as well as dedicated satellites with appropriate instrumentation are required, and the data must be made readily available within suitable timescales to be useful. Data from direct readings are continuously being fed into climate models and used to generate "best estimates" for areas where no or less data exist, using interpolation. This interpolation procedure is used to provide information in fixed geographical grids, and thereby suffers from greater uncertainty as data density decreases in remote areas such as Resolution Island and elsewhere in Nunavut.

As previously mentioned, there are currently no weather stations on Resolution Island with the ability to measure precipitation, and from approximately 1975, any ground-based precipitation measurements were either sporadic or non-existent. In this investigation, one of the next closest weather stations for which continuous precipitation data exists and will exist going forward is in Iqaluit (310 km distant). This available data can be accessed using Government of Canada resources, although the data is not as organised as for climate focussed sites (ClimateAtlas.ca and ClimateData.ca).

A comparison of means for the available data indicates no significant statistical difference between annual precipitation values (mm) for GH data for Resolution Island (from ClimateAtlas.ca) and Iqaluit measured data (Student's t-test, n=64). In the absence of any other ways to measure precipitation directly, the Iqaluit weather station may be used with caution as a proxy for Resolution Island, as shown previously as well. In this case, in terms of predicting baseline (future) values against which to adjust precipitation action levels, it may be preferable to use ensemble mean (EM) values originating from the Iqaluit RCP 4.5 climate model (ClimateData.ca) rather than the Resolution Island equivalent model. No significant statistical difference was observed between annual precipitation values (mm) for GH data for Iqaluit (from ClimateAtlas.ca) and the Iqaluit EM, RCP4.5 (from ClimateAtlas.ca) (Student's t-test, n=64).

5.5.1 Setting Action Levels Using EM Iqaluit for a RCP 4.5 Baseline

Given the variability in measurable data and the requirement to use Iqaluit weather station as a proxy for Resolution Island precipitation data, the data used to develop moderate, high, and extreme action levels are somewhat arbitrary. The following is one possible mechanism to set an appropriate response.

Upper prediction levels (UPLs) were calculated using ProUCL5.1 (freeware for statistical computations from USEPA). Confidence levels were selected to represent moderate (90%), high (95%) and extreme (99%) action levels for EM and GH data separately. These levels are displayed in Table 11 using data from 1950 to 2013 (when GH data reporting stopped).

Table 11: Action Levels (Upper Prediction Level, UPL)

Effect Level	GH Iqaluit UPL (mm) 1950–2013	EM Iqaluit UPL (mm) 1950–2013
Moderate	539	474
High	570	481
Extreme	628	495

The effect levels established for EM Iqaluit data to 2013 do not account for the trend towards higher precipitation levels as predicted for RCP 4.5. Data for 1950–2013 follow a normal distribution, but not data from 1950–2100. The EM values as calculated in Table 11 therefore may be overly conservative (i.e., they do not allow for enough variance) and the use of a moving average, with an example given for a time-period relevant for the next 8 years, may be more appropriate (Table 12).

Table 12: Action Levels (Upper Prediction Level, UPL) – EM Moving Average (2006-2030)

Effect Level	EM Iqaluit UPL (mm) 2006–2030
Moderate	498
High	504
Extreme	518

An example of the use of the GH action levels could be to flag annual precipitation levels in real time (yearly), leading to an immediate or next year visit to the site to see if significant degradation of one or more of the currently monitored features has taken place. However, as GH results only exist up to 2013, calculated GH Iqaluit UPL action levels (Table 11), cannot be updated to account for future variability as predicted by RCP models and may be of limited use for future predictions. On the other hand, EM Iqaluit UPL action levels may still be useful as modelled data exists up to 2095 and a moving average can be used to account for RCP changes (Table 12).

An example of the use of the EM values in Table 12 (using a moving average, which should be re-calculated using updated modeled data for future years, as time passes) may be able to establish the approximate frequency for which elevated precipitation years may reasonably be expected and to determine or refine the periodicity of site visits. For example, based o ClimateAtlas.ca projections, for the next 5-year period (2022-2027), it is likely that there will be one year where a precipitation level meets the High action level value (Table 12). Caution must be used, however, with EM action levels as the data set has low variability compared to the GH data set.

In 2030, EM action levels may be recalculated. The recalculation frequency is somewhat arbitrary, but a recalculation rate of every 8-10 years may be appropriate. An example for future action levels, for 2030-2038 (based on 2014-2038 data) is given in Appendix E-1.

The ability to predict whether a site visit is required in the near term (1-2 years), to deal with potential weather-related damage and to prevent further structural degradation, must be based only on measured data. Here, action levels are based on total annual precipitation data from the Iqaluit weather station (Table 13).

The Iqaluit Climate weather station operated by ECCC-MSC, Latitude: 63°44'50.000" N, Longitude: 68°32'40.000" W, Elevation 33.5 m, can be used to provide suitable data. To be manageable, this should be downloaded using daily intervals that will provide per month data for download in several formats. Additional weather station data include a Climate Identifier (CI) Number: 2402592, a World Meteorological Organization Identifier (WMO) number: 71321 and a Transport Canada (TC) identifier: XFB.

Table 13: Action Levels (Upper Prediction Level, UPL) – Iqaluit Station*

Effect Level	Iqaluit Station UPL (mm) 2006-2019
Moderate	486
High	541
Extreme	668

* Levels calculated using IS (Iqaluit Station) data 2006-2019 seen in Table 8

The Iqaluit data are not normally distributed. They appear to show a gamma distribution and the UPL values were calculated accordingly. The smaller data set resulted in a much larger range of action levels, which may or may not be applicable for use. The action levels presented in Table 13 can also be updated as required to account for future variability as predicted by RCP models. This may be timed to coincide with EM recalculations in 2030. Iqaluit weather station data from 2020-2030 can be compiled and added to the 2006-2019 data as it becomes available, and Iqaluit station action limits updated in 2030. Details of how precipitation data for can be obtained from the Iqaluit Climate weather station are given in Appendix F.

5.5.2 Predictions for Freeze Thaw Cycling at BAF-5

Increases in freeze thaw cycling are directly related to damage both at the surface level as well as the interior of concrete structures [22]. From ClimateAtlas.ca data, for RCP 4.5, there is an expected reduction in freeze thaw cycles at Resolution Island, from 48.5 days (1976-2005) to 46.0 (2021-2050) and 46.3 days (2051-2080). These correspond to a 5.2% reduction and 4.6% reduction respectively, which presumably is beneficial for structures. For shallow concrete structures placed on bedrock, such as the Furniture Dump PRB concrete pad, the predicted values may indicate that climate change will not result in increased damage through freeze thaw cycling. Counterintuitively, however, predictions for RCP 8.5, show a reduction of only 1.9% (2021-2050) and 0.5% (2051-2080). For structures sitting atop concrete pads on compacted soil, increased temperatures (leading to a growth of the soil active layer) and/or precipitation are therefore predicted to be the dominant factors in structural degradation induced by climate change, rather than freeze thaw cycling (at Resolution Island). Further discussion of factors other than precipitation are outside the scope of this work.

6 SUMMARY AND RECOMMENDATIONS

Investigation of publicly available climate data with a focus on annual precipitation was undertaken to ascertain if action levels could be set for the monitoring of contamination barriers at Resolution Island. Various sources were reviewed in detail, including historical data from ClimateData.ca and ClimateAtlas.ca, and modeled data from these two websites, as well as modeled data from Meteoblue. Of these sources, the ClimateAtlas.ca website gave data that was in the main, easiest to use. It was determined that Iqaluit, having a major weather station that still collects precipitation data (and is expected to into the future), rather than the station at Resolution Island, which does not appear to collect any data at present, is a suitable proxy for monitoring weather/precipitation events at Resolution Island.

An examination of soil volumes removed from barrier installations at Resolution Island revealed that little data is available and yearly amounts had to be interpolated, with probable high uncertainty. The soil volumes appear to be generally trending towards lower amounts appearing in the barrier installations, with a high year in 2008. This year could not be easily explained by comparisons to weather data, although one metric (GH Resolution Island) indicated high precipitation that year, but other metrics – modeled and Iqaluit data – did not.

Action levels were proposed that are based on upper prediction limits of data from 1950 to 2013, and 2006 to 2019 from different sources, reflecting moderate (90% confidence), high (95% confidence) and extreme (99% confidence) limits.

Soil movement and volumes should continue to be monitored at Resolution Island to continue to gather data and assess a correlation between climatic data and soil movement. From the data collated and presented, the action levels (upper prediction limit, UPL) calculated using an EM Iqaluit moving average for 2006-2030, and presented in Table 12, can be used to estimate the general frequency of weather events occurring. These calculations should be updated every 8-10 years to refine the UPL with additional data from model recalculations (Appendix E). However, site visits (outside scheduled norms) in the near term (1-2 years), to deal with potential weather-related damage and to prevent further structural degradation, are recommended to be based only on measured data from the Iqaluit weather station. These action levels should be updated every 8-10 years to ensure relevant and current values are used (Appendix F). Current action levels are presented in Table 13, based on total annual precipitation data from the Iqaluit weather station. These values have been estimated at 486 mm (Moderate), 541 mm (High) and 668 mm (Extreme) and are considered valid until 2030.

If no correlation between precipitation and soil volumes can be established with coming observations, alternative variables may be investigated for future studies.

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APPENDIX A: PROPOSAL

RE: Application to undertake a study regarding the project entitled "Precipitation events remote monitoring Pilot Project on BAF-5 Resolution Island" for 2021/2022

Crown-Indigenous Relations and Northern Affairs Canada | Relations Couronne-Autochtones et Affaires du Nord Canada

STATEMENT OF WORK

Project Title: Precipitation events remote monitoring Pilot Project on BAF-5 Resolution Island

Background:

As part of the remediation of contaminated sites, Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC) has an obligation to conduct Long Term Monitoring (LTM) of the sites where infrastructure was left to ensure the stability of the remediation work and the overall risks at the site remain closed. The LTM Plan developed in 2005 for BAF-5 Resolution Island, a former military site which was part of the Pole Vault system, was based on the monitoring requirements outlined in the CIRNAC Abandoned Military Site Remediation Protocol (AMSRP). Between 2005 and 2012, post-monitoring site visits were conducted until a Maintenance Assessment was required due to the identification of potential remedial deficiencies. Additional remedial maintenance work was deemed necessary and the work was completed in 2019. An updated monitoring strategy was developed in accordance with the latest work done on site and is included in the 2020 BAF-5 Resolution Island Operation, Maintenance and Surveillance Plan (OMS). The surveillance plan is established in two subsequent Phases to account for the disparity in the stability of the different features on site. Phase 1 consists of regular monitoring visits of the site to assess the status of the seven remaining features that pose greater risks. Once all of the features have met the general stability exit criteria, the site can be moved into Phase 2 of the surveillance plan. Phase 2 of the surveillance plan is to implement an atypical weather-event based approach. The primary failure pathway for all of the monitored features is via water flow, either causing erosion or mobilizing contaminants, and at a much greater flow rate or volume than experienced at the site under climatic conditions to date. It is, therefore, recommended that monitoring be completed in response to precipitation events. CIRNAC requires support from experts to develop the precipitation benchmarks to prepare for the second Phase of monitoring of BAF-5 Resolution Island. The development of the method for this atypical weather-event based monitoring for this site in Nunavut will serve as a pilot project to test its applicability to other remote contaminated sites monitored by CIRNAC.

Objective:

This call up is to complete tasks involved with the development of specific benchmark values and the methodology for weather-based monitoring efforts at BAF-5 Resolution Island. Activities include: obtaining and reviewing historical climate data, evaluating modelled future climate data for Resolution Island, analyzing past and future data to determine levels of precipitation adequate for monitoring purposes, and developing a testing protocol for the benchmarks during the current Phase 1 monitoring.

Requirements:

The Contractor shall perform the following tasks to the satisfaction of the Departmental Representative, which includes at a minimum:

Task 1: Preparation

- Host a kick-off meeting via teleconference between Project Manager, key project staff (if applicable), and CIRNAC department representative(s).
- Review existing documentation.
- Produce a list of additional documentation required if applicable.

Task 2: Prepare benchmarks values

- Obtain detailed historical climate data as wells as modelled future climate data for Resolution Island and/or Iqaluit from publicly available sources (such as climatedata.ca).
- Review historical precipitation data to evaluate worst-case precipitation event that has occurred at the site to date. Complete statistical analysis of past and future precipitation dataset to identify three levels of precipitation event that would be considered sufficiently above average or extreme: a "moderate" event (sufficiently above historical climate normal to warrant concern of failure); a "high" event that would be well above historical normal; and an "extreme" event that would be very likely to cause failure of one of the barriers or a landfill/dump.
- In consultation with hydrologist and geotechnical engineer, develop the specific precipitation benchmark values for use as Phase 2 exit criteria for each of the monitored features (see OMS Plan).

Task 3: Prepare method to implement weather-based monitoring

- Prepare a draft Weather-Based Monitoring Pilot Report that completes the current OMS Plan and plan for the implementation of the Phase 2 monitoring. The Report should outline a strategy to test the identified benchmark values during the current Phase 1 monitoring to refine the remote monitoring plan when exit criteria are met. Consideration should be included for potential of developing similar monitoring program for other northern remediated contaminated sites.

Task 4: Other

- Participate in telephone calls and correspond via emails as required.

Deliverables:

The Contractor shall:

1. Submit one (1) electronic copy (Microsoft Word) of a Draft #1 Weather-Based Monitoring Pilot Report to the Departmental Contact on or before **September 28th, 2021**.
2. Receive the review of Draft #1 Weather-Based Monitoring Pilot Report with comments included by the Departmental Representative on or before **October 12th, 2021**.
3. Submit one (1) electronic copy (Adobe Acrobat) of a Draft #2 Weather-Based Monitoring Pilot Report incorporating comments received to the Departmental Contact on or before **November 2nd, 2021**.
4. Receive the review of Draft #2 Weather-Based Monitoring Pilot Report with comments included by the Departmental Representative on or before **November 16th, 2021**.
5. Submit one (1) electronic copy (Adobe Acrobat) of a Final Weather-Based Monitoring Pilot Report incorporating comments received to the Departmental Contact on or before **November 30th, 2021**.
6. Submit one (1) electronic copy (Microsoft Word and/or Excel) of raw data and figures produced in the Final Report to the Departmental Contact on or before **November 30th, 2021**.

Departmental Support:

The Departmental Contact shall:

1. Provide all reports, documentation, or other information related to this assignment, if deemed necessary to its successful completion;
2. Provide timely review/responses on any interim material provided for comments and/or direction; and
3. Be available for consultations and discussion with the contractor to discuss issues that may arise during the work.

Contract Dates:

Commencement Date: July 13th, 2021 Completion Date: December 31st, 2021

Contact Information:

Departmental Representative	**Departmental Contact**
Charlotte Lamontagne	Rachel Theoret-Gosselin
Director, Contaminated Sites	Project Manager
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APPENDIX B: EXPORTED DATA XLS, PNG AND PDF

File names as follows:

CD Hottest Day MH RCP 2.6 RCP 4.5 RCP 8.5

CD Mean Temperature MH RCP 2.6 RCP 4.5 RCP 8.5

CD Minimum Temperature MH RCP 2.6 RCP 4.5 RCP 8.5

CD Maximum Temperature MH RCP 2.6 RCP 4.5 RCP 8.5

CD Days with Tmin < -15ºC MH RCP 2.6 RCP 4.5 RCP 8.5

CD Days with Tmin < -25ºC MH RCP 2.6 RCP 4.5 RCP 8.5

CD Days with Tmax > 25ºC MH RCP 2.6 RCP 4.5 RCP 8.5

CD Coldest Day MH RCP 2.6 RCP 4.5 RCP 8.5

CD Last Spring Frost MH RCP 2.6 RCP 4.5 RCP 8.5

CD First Fall Frost MH RCP 2.6 RCP 4.5 RCP 8.5

CD Frost Free Season MH RCP 2.6 RCP 4.5 RCP 8.5

CD Wet days > 1mm MH RCP 2.6 RCP 4.5 RCP 8.5

CD Wet days > 10mm MH RCP 2.6 RCP 4.5 RCP 8.5

CD Wet days > 20mm MH RCP 2.6 RCP 4.5 RCP 8.5

CD 1 Day Total Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5

CD Maximum Number of Consecutive Dry Days MH RCP 2.6 RCP 4.5 RCP 8.5

CD Number of Periods with 5 or More Consecutive Dry Days MH RCP 2.6 RCP 4.5 RCP 8.5

CD Total Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5

CD Maximum 5-Day Precipitation MH RCP 2.6 RCP 4.5 RCP 8.5

CD Relative Sea Level Change MH RCP 2.6 RCP 4.5 RCP 8.5

CD Frost Days MH RCP 2.6 RCP 4.5 RCP 8.5

CD Freeze Thaw Cycles MH RCP 2.6 RCP 4.5 RCP 8.5

CD Ice Days MH RCP 2.6 RCP 4.5 RCP 8.5

APPENDIX C: TEMPERATURE AND OTHER VARIABLE DEFINITIONS

Hottest Day

"The Hottest Day describes the warmest daytime temperature in the selected time period. In general, the hottest day of the year occurs during the summer months.

High temperatures are important. They determine if plants and animals can thrive, they limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use. However, when temperatures are very hot, people – especially the elderly – are much more likely to suffer from heat exhaustion and heat stroke. Many outdoor activities become dangerous or impossible in very high temperatures.

Technical Description:

The highest maximum temperature (Tmax) in the selected time-period. Annual values are used for this report."

Mean Temperature

"Mean temperature describes the average temperature for the 24-hour day.

The average temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, and more.

Technical description:

The average of the daily maximum temperature (T_{max}) and the daily minimum temperature (T_{min})."

Minimum Temperature

"Minimum temperature describes the coldest temperature of the 24-hour day. Typically, but not always, the minimum temperature occurs at night and so this variable is commonly referred to as the nighttime low.

The average lowest temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, and more.

Technical description:

The daily minimum temperature (Tmin)."

Maximum Temperature

"Maximum temperature describes the warmest temperature of the 24-hour day. Typically, but not always, the maximum temperatures occur during the day and so this variable is commonly referred to as the daytime high.

The average highest temperature is an environmental indicator with many applications in agriculture, engineering, health, energy management, recreation, and more.

Technical description:

The daily maximum temperature (Tmax)."

Days with Tmin < -15ºC; <-25ºC

"Days with Tmin <-15°C ; <-25ºC describes the number of days where the lowest temperature of the day is colder than -15°C or -25ºC. This index gives an indication of the number of very cold days in the selected time period.

Cold weather is an important aspect of life in Canada, and many places in Canada are well adapted to very cold winters. Cold temperatures affect our health and safety, determine what plants and animals can live in the area, limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use.

Technical description:

The number of days with a minimum temperature (T_{min}) less than -15°C; -25ºC."

Days with Tmax >25ºC; >27ºC

"Days with Tmax > 25°C; >27ºC describes the number of days where the daytime high temperature is warmer than 25° or 27ºC respectively. This index gives an indication of number of summer days in the selected time period.

High temperatures are important. They determine if plants and animals can thrive, they limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use. However, when temperatures are very hot, people – especially the elderly – are much more likely to suffer from heat exhaustion and heat stroke. Many outdoor activities become dangerous or impossible in very high temperatures.

Technical description:

The number of days with a maximum temperature (Tmax) greater than 25°; 27ºC."

Days with Tmax>29ºC; 30ºC;>32ºC and >37ºC

These data sets were omitted from this report, with the exception for RCP 8.5 (2100) for Tmax>29ºC. No temperatures higher than 29ºC are predicted. Only one day is predicted for RCP 8.5.

Coldest Day

"The Coldest Day describes the lowest nighttime temperature in the selected time period. In general, the coldest day of the year occurs during the winter months.

Cold weather is an important aspect of life in Canada, and many places in Canada are well adapted to very cold winters. Cold temperatures affect our health and safety, determine what plants and animals can live in the area, limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use.

Technical Description:

The lowest minimum temperature (T_{min}) in the selected time period."

Last Spring Frost

"The Last Spring Frost marks the approximate beginning of the growing season for frost-sensitive crops and plants. When the lowest temperature of the day remains above 0°C for one consecutive day (before July 15th) the date of the last spring frost is established.

Technical description:

The spring date after which there are no daily minimum temperatures during the growing season less than 0°C ($T_{min} > 0$°C). Because this variable is largely used to assess the beginning of the growing season in southern Canada, the latest possible date for a spring frost was set as July 15."

First Fall Frost

"The First Fall Frost marks the approximate end of the growing season for frost-sensitive crops and plants. When the lowest temperature of the day is colder than 0°C for one consecutive day (after July 15th) the date of the first fall frost is established.

Technical description:

The first date in the fall (or late summer) on which the daily minimum temperature is less than 0°C ($T_{min} < 0$°C). Because this variable is largely used to assess the end of the growing season in southern Canada, the earliest possible date for a fall frost was set as July 15."

Frost Free Season

"The Frost Free Season is the approximate length of the growing season during which there are no freezing temperatures to kill or damage frost-sensitive plants. This index describes the number of days between the Last Spring Frost and the First Fall Frost.

Technical description:

The number of days between the date of the last spring frost and the date of the first fall frost, equivalent to the number of consecutive days during the 'summer' without any daily minimum temperatures below 0°C."

Relative Sea Level change

"Relative Sea Level Change is the change in ocean level relative to land. Whereas global sea-level change can be attributed to thermal expansion of water and meltwater from glaciers, ice caps, and ice sheets, relative sea-level change is the combination of the effects from global sea-level change and the vertical motion of the land.

Projected relative sea level change data is available for 2006 and for every decade from 2010-2100, relative to 1986-2005 conditions."

More details as they relate to the models, and calculations used to predict the effect of RCPs on relative sea level change, can be found on the ClimateData.ca website at https://ClimateData.ca/variable→Relative Sea Level Change (RSLC)→read more. Resolution Island is expected to be strongly impacted, with a RSLC predicted to be in the 100–150 cm range for RCP 8.5, by 2100.

Frost Days

"Frost Days describes the number of days where the coldest temperature of the day is lower than 0°C.

The number of frost days is an indicator of the length and severity of the winter season. A location with many frost days is also likely to have a short growing season since frost is harmful to many plants.

Technical description:

A day when the daily minimum temperature (Tmin) is below 0°C."

Freeze-Thaw Cycles

"This is a simple count of the days when the air temperature fluctuates between freezing and non-freezing temperatures on the same day. Freeze-thaw cycles can have major impacts on infrastructure. Water expands when it freezes, so the freezing, melting and re-freezing of water can, over time, cause significant damage to roads, sidewalks, and other outdoor structures.

Technical description

A freeze-thaw cycle occurs when the daily maximum temperature (Tmax) is higher than 0°C and the daily minimum temperature (Tmin) is less than or equal to -1°C."

Ice Days

"Ice Days describe the number of days where the warmest temperature of the day is not above 0°C.

In other words, this index indicates the number of days when temperatures have remained below freezing for the entire 24-hour period. This index is an indicator of the length and severity of the winter season.

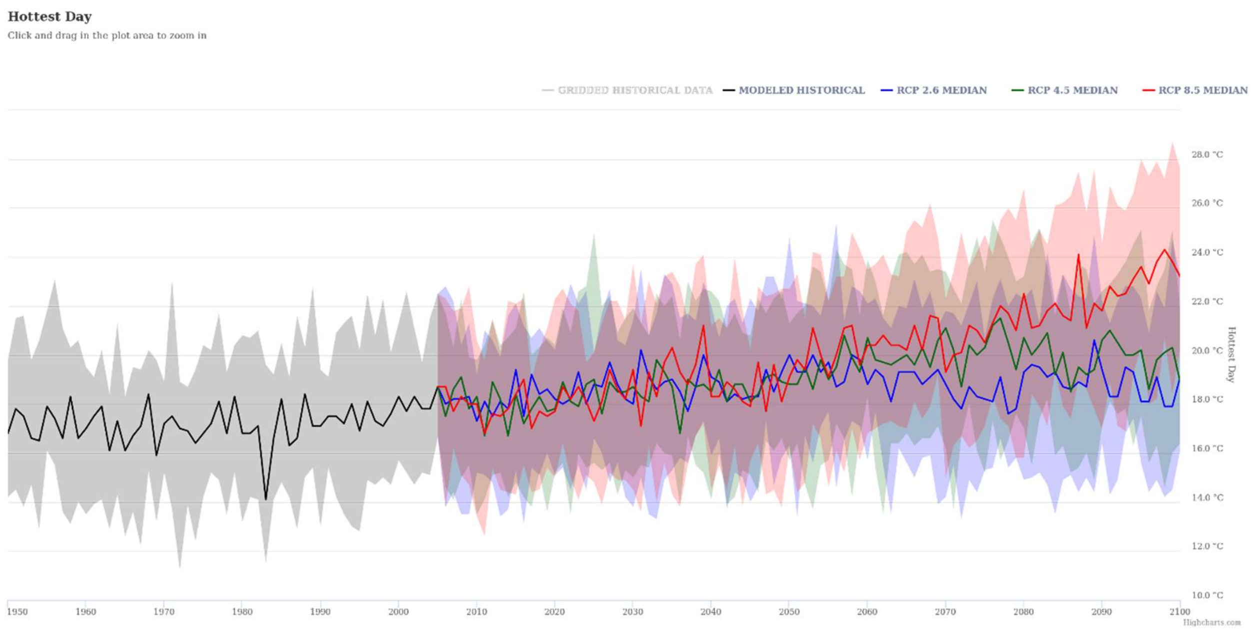
Technical description:

A day when the daily maximum temperature (Tmax) is less than 0°C."

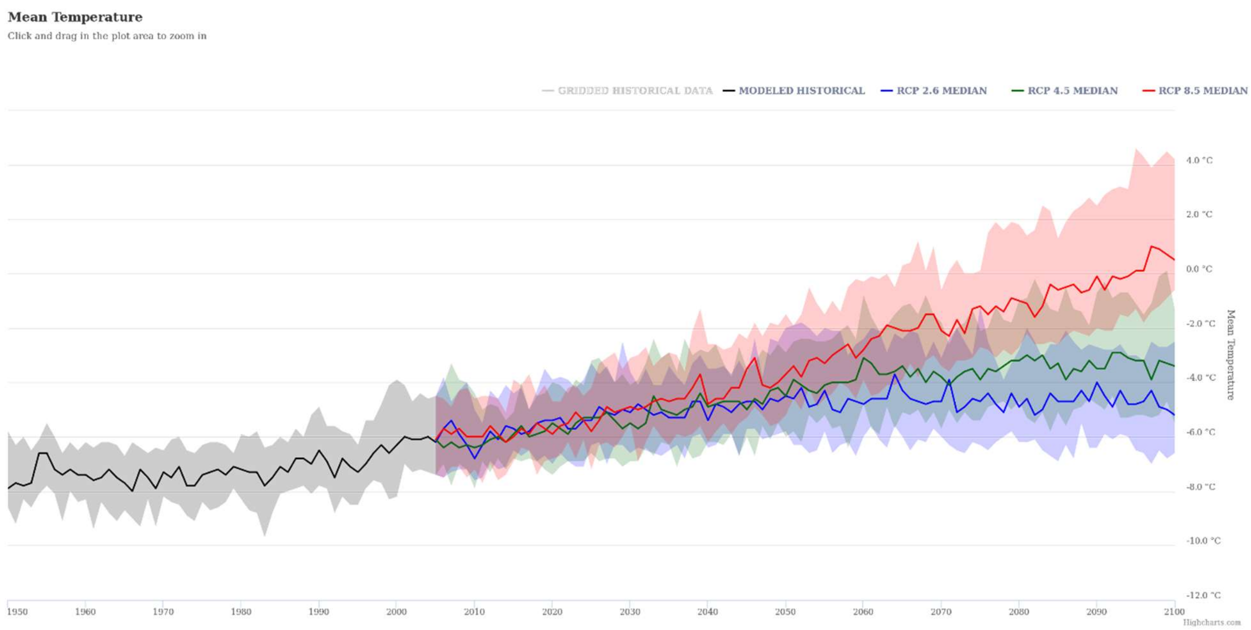
The following categories of weather data were not included in this study: standardized precipitation evapotranspiration index; cooling degree days; tropical nights (Tmin>18ºC, 20ºC of 22ºC); growing degree days (5ºC or 10ºC); cumulative degree days above 0ºC; heating degree days; intense duration frequency (IDF) curves; and climate normals.

In the case of Resolution Island, categories that relate to tropical weather classifications or to agricultural growing season norms are not relevant. Other categories such as IDF curves or climate normal for select periods were omitted because of the absence of appropriate weather stations (station data).

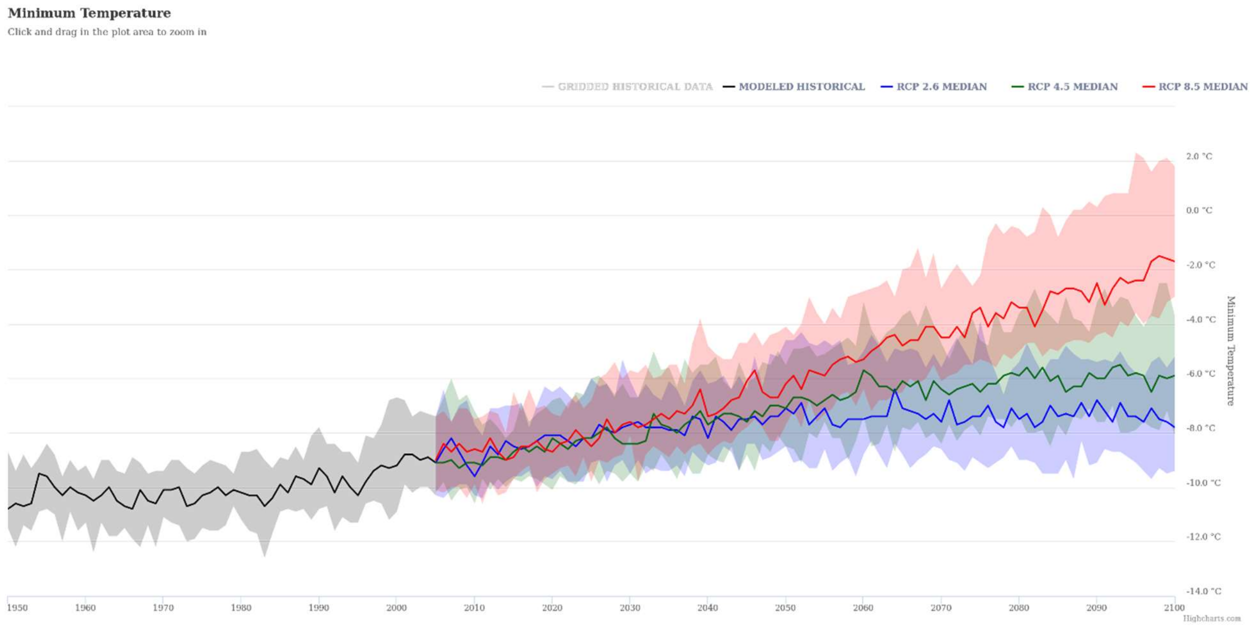
APPENDIX D: TEMPERATURE AND OTHER VARIABLES - FIGURES



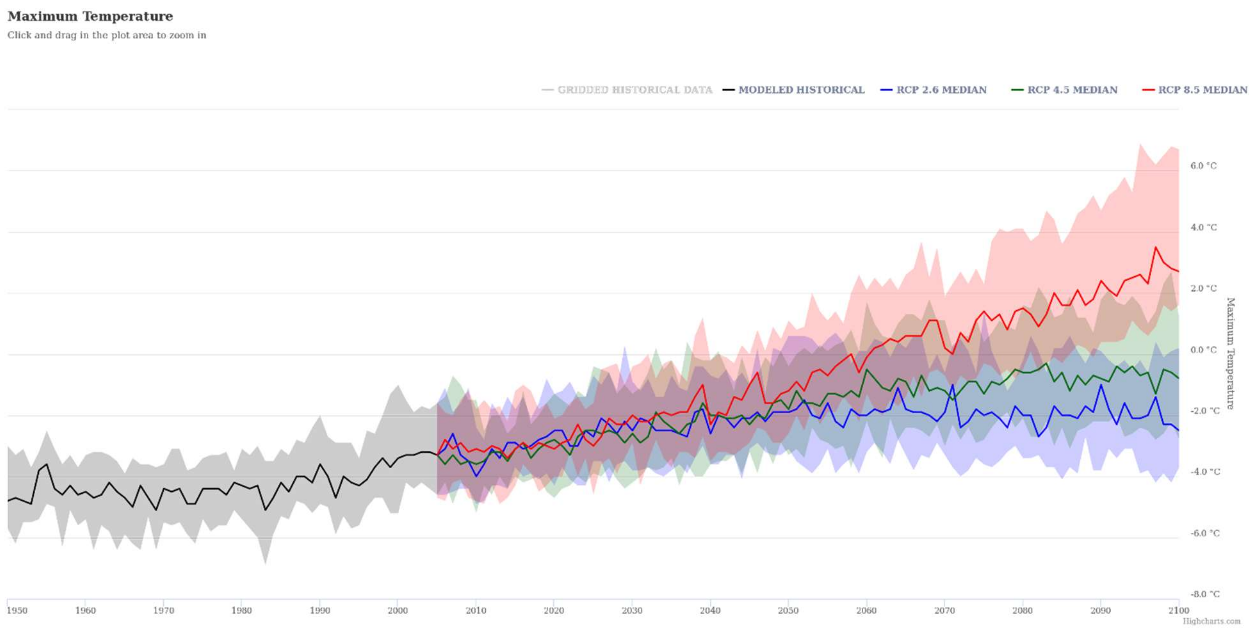
CD Hottest Day MH RCP 2.6 RCP 4.5 RCP 8.5.png



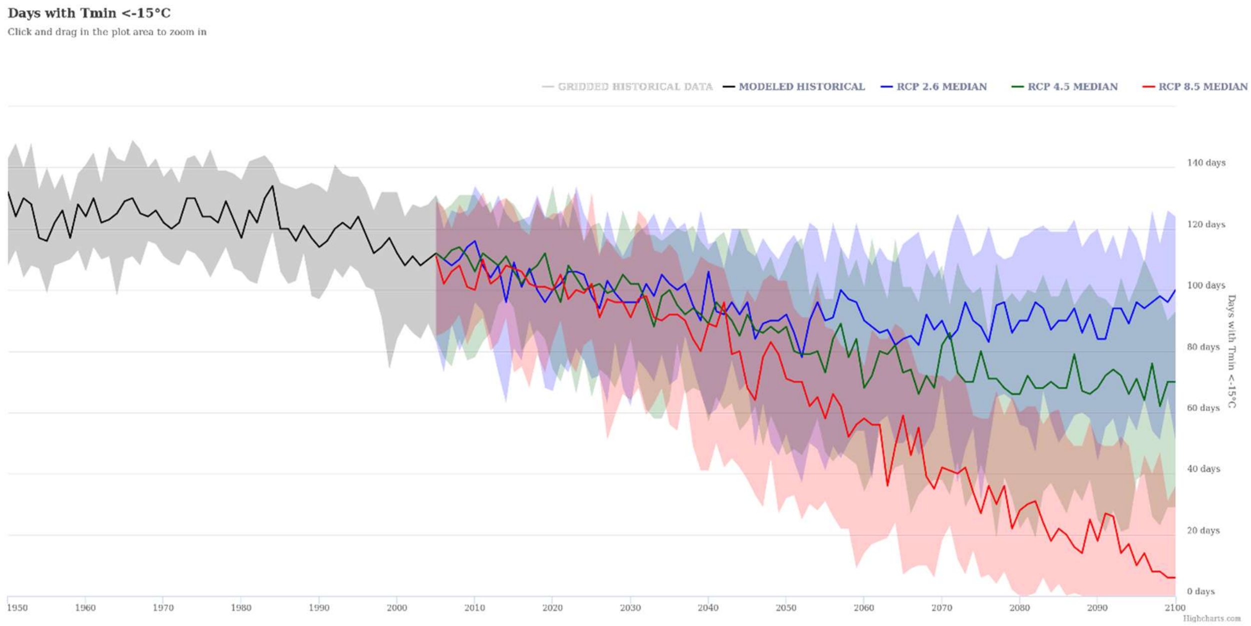
CD Mean Temperature MH RCP 2.6 RCP 4.5 RCP 8.5.png



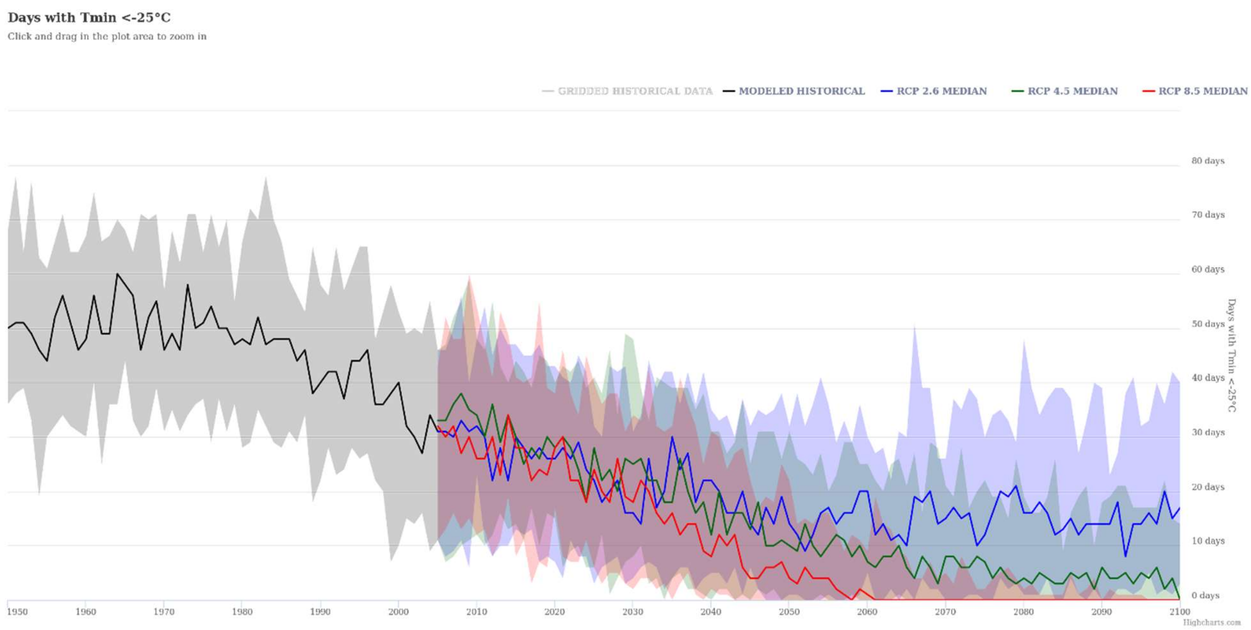
CD Minimum Temperature MH RCP 2.6 RCP 4.5 RCP 8.5.png



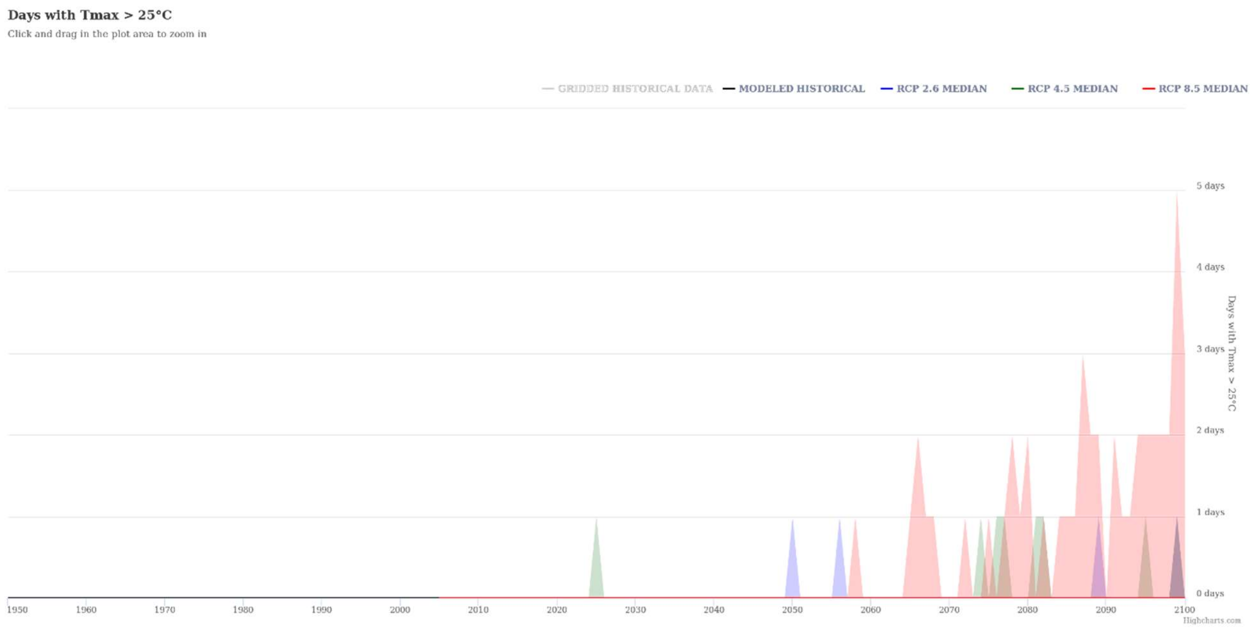
CD Maximum Temperature MH RCP 2.6 RCP 4.5 RCP 8.5.png



CD Days with Tmin < -15ºC MH RCP 2.6 RCP 4.5 RCP 8.5.png

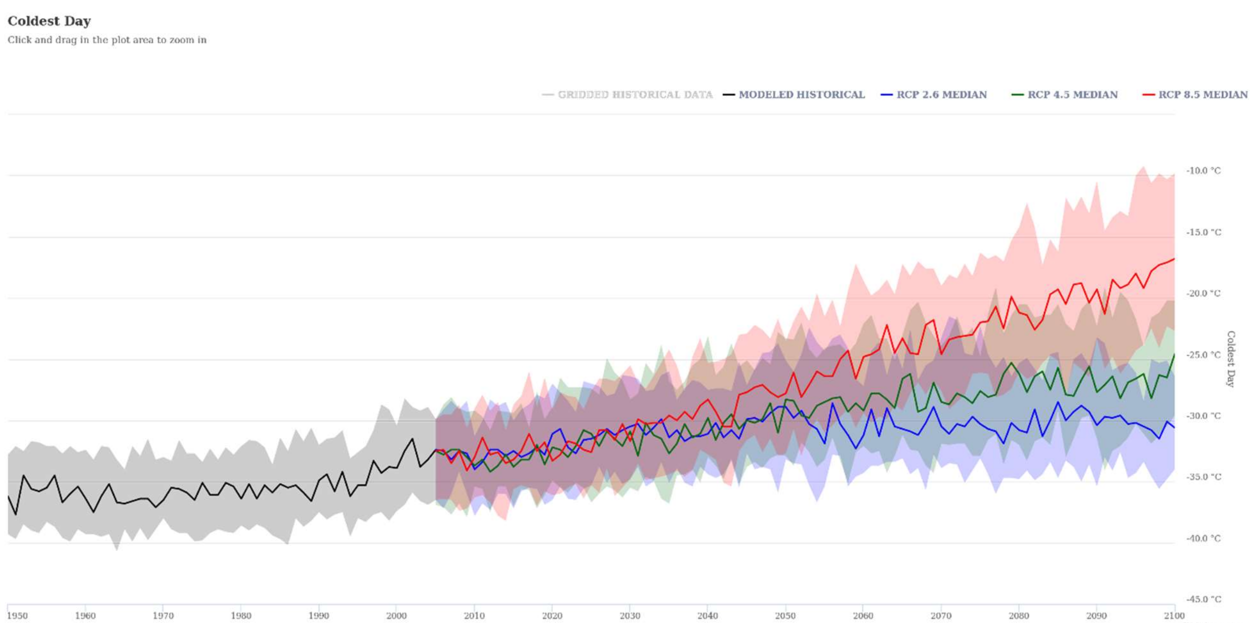


CD Days with Tmin < -25ºC MH RCP 2.6 RCP 4.5 RCP 8.5.png

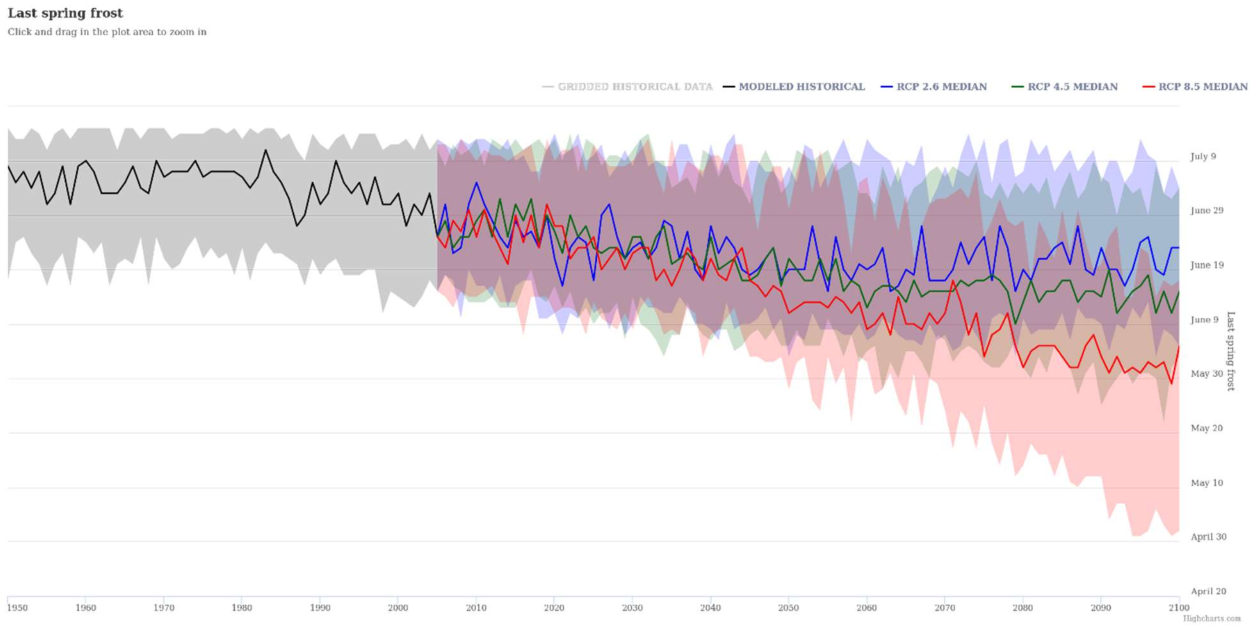


CD Days with Tmax > 25ºC MH RCP 2.6 RCP 4.5 RCP 8.5.png

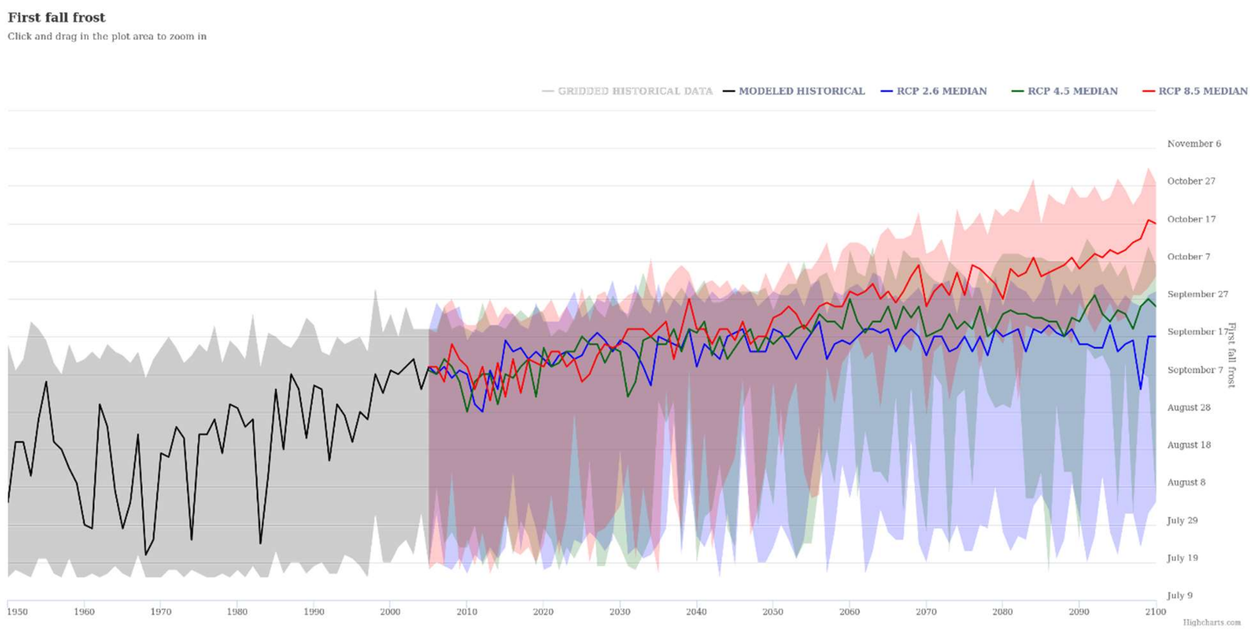
Note: Data was not presented in figure format for “Days with Tmax > 27ºC” as there were no possibilities of years with a single day >27ºC for the RCP 2.6 and 4.5 scenarios. From RCP 8.5, there were 8 possibilities of a single day >27ºC (all after 2080) and one possibility (2100), with two days >27ºC.



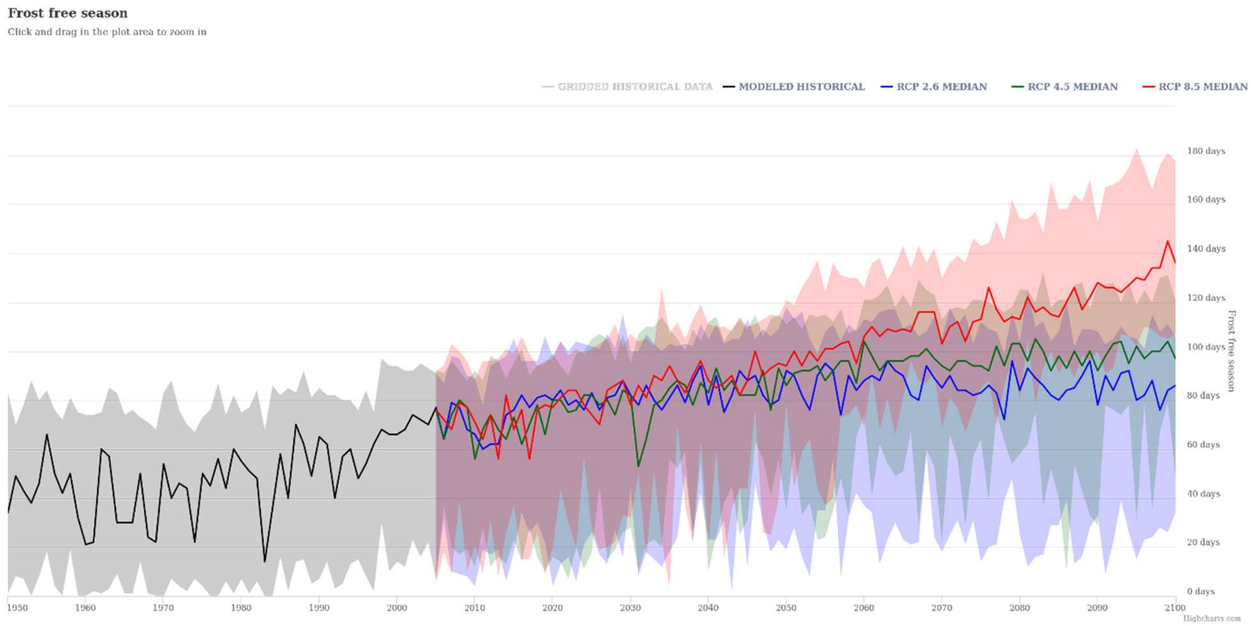
CD Coldest Day MH RCP 2.6 RCP 4.5 RCP 8.5.png



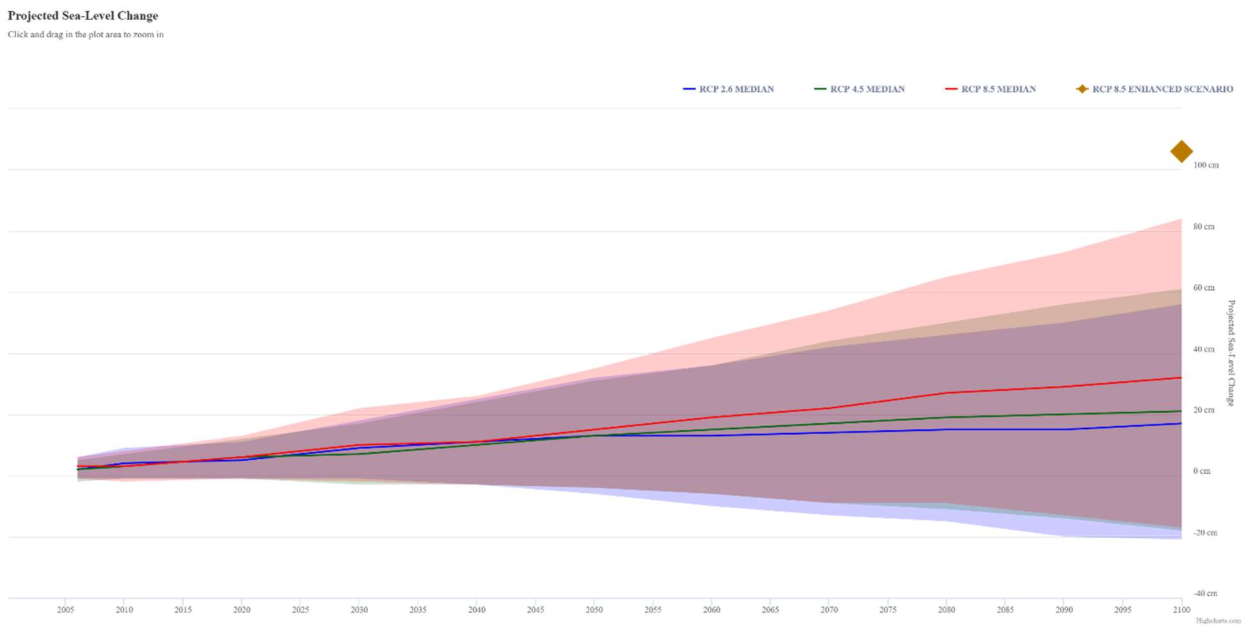
CD Last Spring Frost MH RCP 2.6 RCP 4.5 RCP 8.5.png



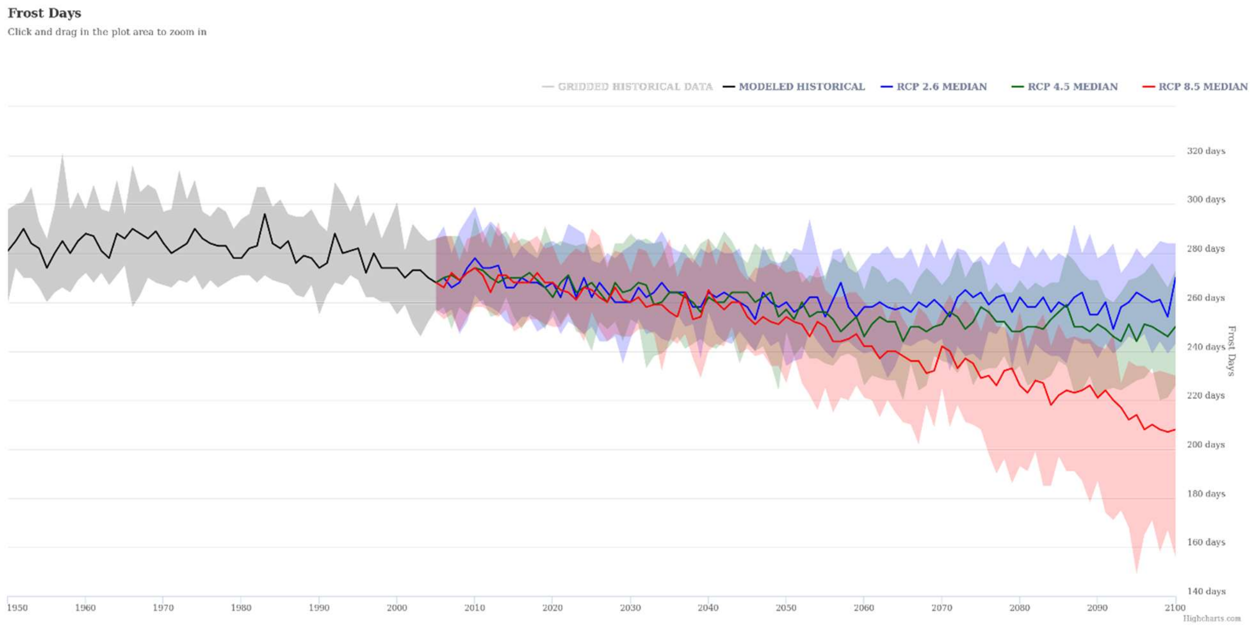
CD First Fall Frost MH RCP 2.6 RCP 4.5 RCP 8.5.png



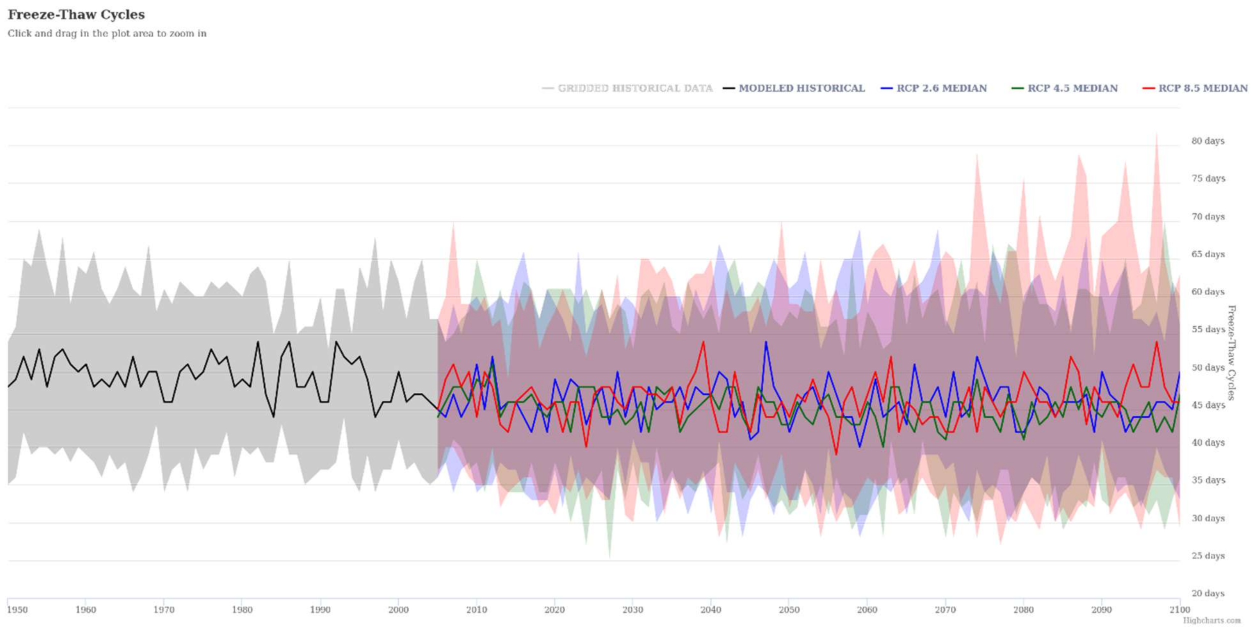
CD Frost Free Season MH RCP 2.6 RCP 4.5 RCP 8.5.png



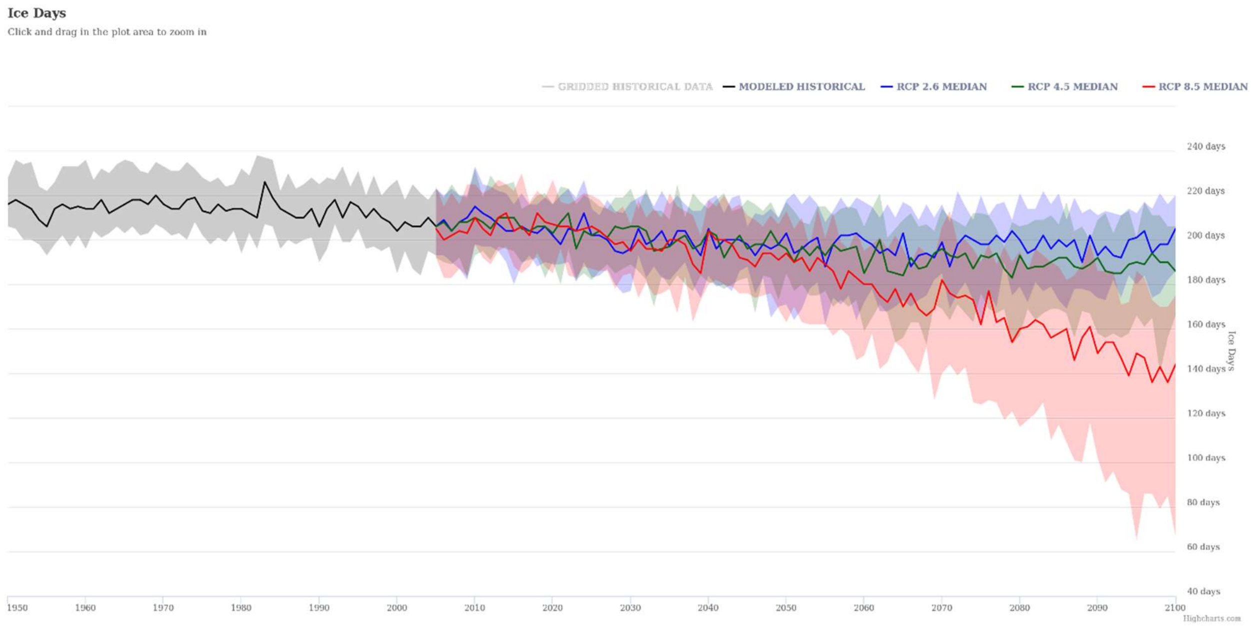
CD Relative Sea Level Change MH RCP 2.6 RCP 4.5 RCP 8.5.png



CD Frost Days MH RCP 2.6 RCP 4.5 RCP 8.5.png



CD Freeze Thaw Cycles MH RCP 2.6 RCP 4.5 RCP 8.5.png



CD Ice Days MH RCP 2.6 RCP 4.5 RCP 8.5.png

APPENDIX E: SAMPLE CALCULATION TO DETERMINE ACTION LEVEL PRECIPITATION VALUES (EM MOVING AVERAGES)

Action Levels (Upper Prediction Level, UPL) – EM Moving Average, For use in 2030-2038 (data from 2014-2038)

Action Levels (Upper Prediction Level, UPL) – EM Moving Average (2014-2038)

Effect Level	EM Iqaluit UPL (mm) 2014-2038
Moderate	512
High	519
Extreme	535

For details illustrating how these action levels were calculated, refer to the excel file: Iqaluit Gridded Historic Vs Ensemble Mean with UCL Stats.xlsx, under the tab: EM Sample Calc 2014-2038. Raw data, a list of instructions and ProUCL 5.1 outputs are included. Instructions have also been included below.

Instructions for Action Level Calculation:

STEPS	Description
1	To calculate Moderate (90% Action level). In ProUCL: File, NEW.
2	Select any column header e.g., column 4, right click and select header name. Use an appropriate header name e.g., 2014-2038 Iqaluit EM.
3	Copy the relevant data range from exported xls data file obtained from ClimateAtlas.ca.
4	Go to ClimateAtlas.ca, scroll down to TOTAL ANNUAL PRECIPITATION and select.
5	Zoom in on the map and click the grid with Iqaluit in it.
6	Scroll down in right tab and select Explore Detailed Climate Data
7	Change scenario to LOW CARBON RCP 4.5
8	Click on Location: Find a Municipality: Type Iqaluit and GO

9	Chart data will be presented for YEAR, HISTORICAL, ENSEMBLE etc.
10	This data can be copied and pasted to a suitable excel file or exported as CHART DATA. csv format
11	Select the relevant EM data range years e.g., 2014-2038.
12	Paste this data under the header in ProUCL 5.1 (use the edit/paste heading in ProUCL 5.1)
13	Select Upper Limits/BTVs, then all.
14	For Available Variables, select and move to Selected Variables, click OK.
15	Select Confidence Interval, Type 0.90; Coverage 0.90. This will be repeated for 0.95 and 0.99 to set 3 different action level values). For 0.95 confidence interval, select 0.95 coverage; For 0.99 confidence interval, select 0.99 coverage). Different or future K operations and number of bootstrap operation values should be left at the default setting.
16	The ProUCL 5.1 output data can be copied into a suitable excel file
17	If the data presented appears normal: go to Background Statistics Assuming Normal Distribution, then select the value associated with 90% UPL (t) or 95 and 99 as appropriate.
18	Alternatively, choose the value associated with gamma or nonparametric.

ProUCL 5.1. can be downloaded from the USUPA website using the following link - https://www.epa.gov/land-research/proucl-software

APPENDIX F: PROCEDURE FOR RECALCULATION OF ACTION LEVEL PRECIPITATION VALUES (IS STATION DATA)

Details for Extracting Precipitation Data from The Iqaluit Climate weather station

Weather station data can be obtained through the following link:

https://climate.weather.gc.ca/historical_data/search_historic_data_e.html

The ability to predict whether a site visit is required in the near term (1-2 years), to deal with potential weather-related damage and to prevent further structural degradation, must be based only on measured data. Current action levels were based on total annual precipitation data from the Iqaluit weather station (Table 13).

UPL action levels were last calculated from IS 2006-2019 data and are to be used till 2029. To keep the data set range comparable, early in 2030 data from 2016-2029 should be used to calculate a new set of action levels for use in the 2030 field season.

Instructions for Extracting Weather Station Precipitation Data:

STEPS	Description
1	Under search by station name, type Iqaluit.
2	Select Iqaluit Climate Station, Daily Interval, the appropriate year (e.g., 2020) and the month (e.g., Jan): a daily data report (including precipitation) will be displayed.
3	Scroll up to the Download Data box, Daily Data (e.g., 2020), select csv and click download data. This will download data for the entire year.
4	Open the file with excel and find the Total Precipitation (mm) column
5	Select the daily totals for the year and sum the data to find the annual precipitation (mm) total for that year. Save and edit as appropriate. Repeat for all relevant years.
6	Once the annual precipitation data has been collated eg for 2006-2019, select these values.
7	Paste this data under the header in ProUCL 5.1 (use the edit/paste heading in ProUCL 5.1)
8	Select Upper Limits/BTVs, then all.

9	For Available Variables, select and move to Selected Variables, click OK.
10	Select Confidence Interval, Type 0.90; Coverage 0.90. This will be repeated for 0.95 and 0.99 to set 3 different action level values). For 0.95 confidence interval, select 0.95 coverage; For 0.99 confidence interval, select 0.99 coverage). Different or future K operations and number of bootstrap operation values should be left at the default setting.
11	The ProUCL 5.1 output data can be copied into a suitable excel file
12	If the data presented appears normal: go to Background Statistics Assuming Normal Distribution, then select the value associated with 90% UPL (t) or 95 and 99 as appropriate.
13	Alternatively, choose the value associated with gamma or nonparametric.

If data is missing for more than 10 days for any month (missing data is denoted with a M), it may be preferable to substitute climate normal data for that appropriate month. Average precipitation data for 1981-2010 is available for Iqaluit (Figure 37).