September 12, 2018

DRAFT
Supplemental Climate Information for Quttinirpaaq National Park

Prepared by:

Scott Parker, Ph.D.
Office of the Chief Ecosystem Scientist

Parks Canada Parcs Canada

Contents

Preface

This is a supplement to the "Let's Talks about Climate Change: Arctic and Hudson's Plains Region" (Parker, 2017) report and is intended to support climate change discussions at Quttinirpaaq National Park.

Future climate projections are modelled with several greenhouse gas concentration trajectories, called **Representative Concentration Pathways (RCP)** (Vuuren *et al.*, 2011). They describe possible climate futures and are named after respective radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6, +4.5 and +8.5 watts/m^2). **RCP 2.6** assumes we take action and greenhouse gas emissions peak in 2010-2020 and decline thereafter. **RCP 4.5** assumes emissions peak around 2040 and then decline. **RCP 8.5** assumes we take no action and emissions continue to rise "status quo" throughout the 21st century.

This is a site focussed document and to understand the larger climate change context please consult Canada's Changing Climate assessment reports (http://www.nrcan.gc.ca/environment/impacts-adaptation/10029), the Arctic Council reports (e.g., AMAP, 2011; Arctic Council, 2016; CAFF, 2013), and the Intergovernmental Panel on Climate Change assessment reports (e.g., IPCC, 2014). With respect to adaptation and mitigation options, please review Gross *et al.* (2016).

Highlights

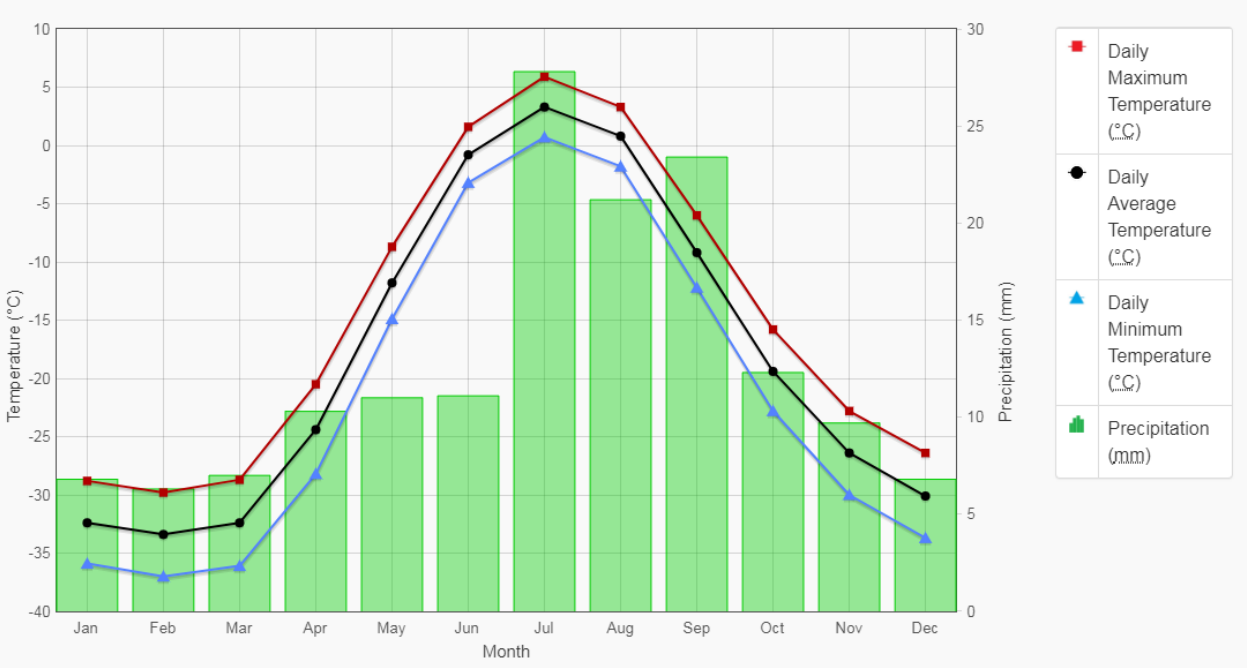
- Mean annual air temperature has increased by ~2˚C since 1950 and is projected to continue to increase 4 to 6.4˚C by 2051-2080 (from 1976-2006 baseline). Winter and autumn are warming faster than the other seasons.
- Total annual precipitation has increased by ~34% since 1950 and is projected to increase 34 to 59% by 2051-2080 (from 1976-2006 baseline). Total amount as rain is increasing, while total amount as snow does not shown a trend. Precipitation in autumn is increasing more than the other seasons.
- Intensity of rainfall events (mm/hr) are projected to increase, e.g., todays' one in 100 year event is expected to become a one in 5 or 10 year event.
- Relative sea level is projected to continue to decrease due glacial isostatic rebound. The coast remains very low to moderately sensitive to climate change.

Disclaimer

Views, statements, findings and conclusions are solely those of the author and do not necessarily reflect the views and policies of Parks Canada. Although the author has made every effort to ensure that the information is accurate, complete and correct, neither Parks Canada nor the author can guarantee its integrity. Readers are encouraged to review original sources.

1. Historic Climate

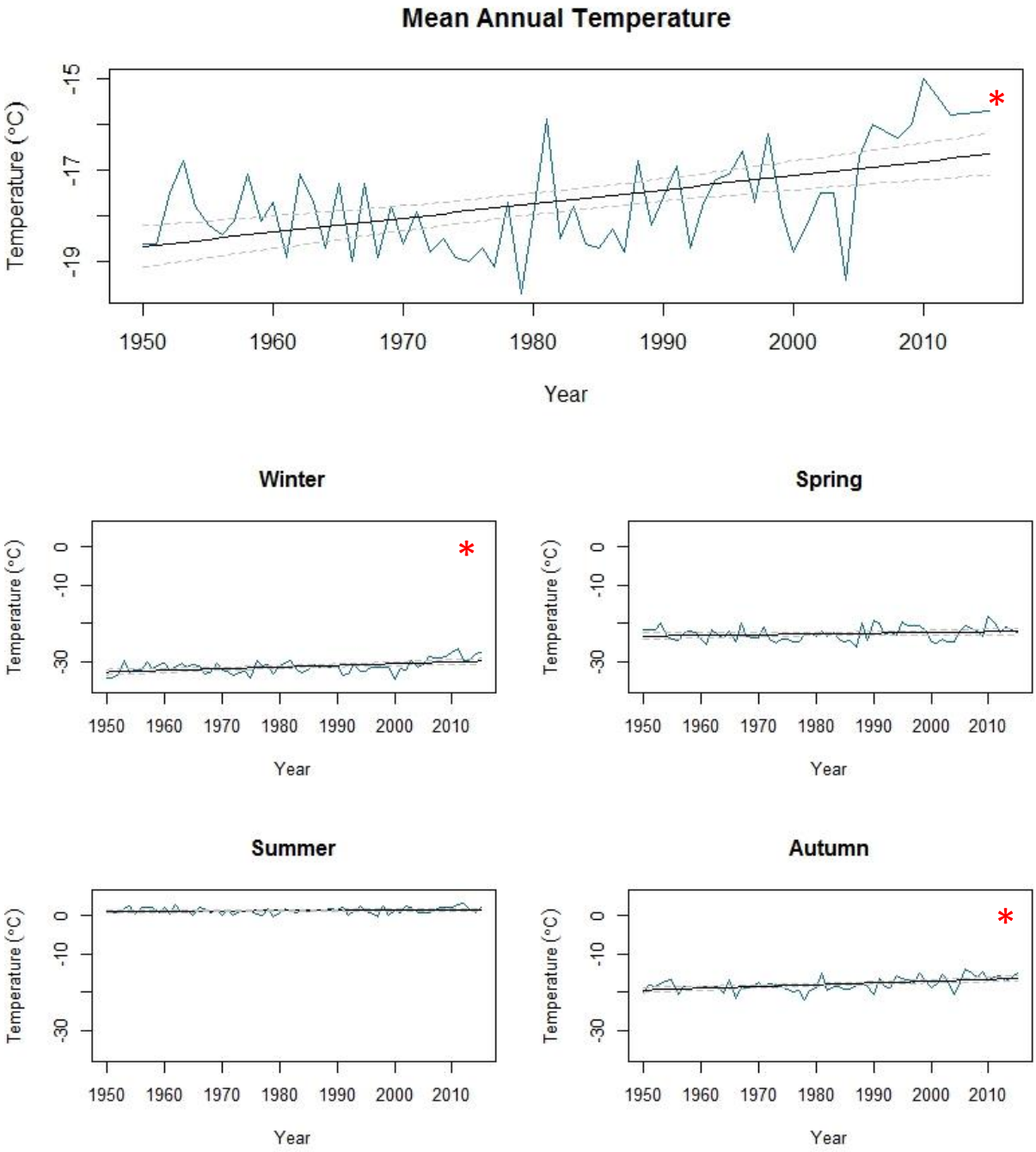
For long-term trend analysis, meteorological data from Environment and Climate Change Canada's (ECCC) Adjusted and Homogenized Canadian Climate Data (AHCCD) database was used in this report (ECCC, 2017). For more detailed analysis, such as hourly trends, please refer to ECCC's Historical Data (http://climate.weather.gc.ca/index_e.html) for Alert, NU (and limited data for Lake Hazen for 1957-1963).



Temperature and precipitation climate "normals" (1971-2000) for Alert, NU. Figure source: Environment and Climate Change Canada (http://climate.weather.gc.ca/).

1.1 Temperature

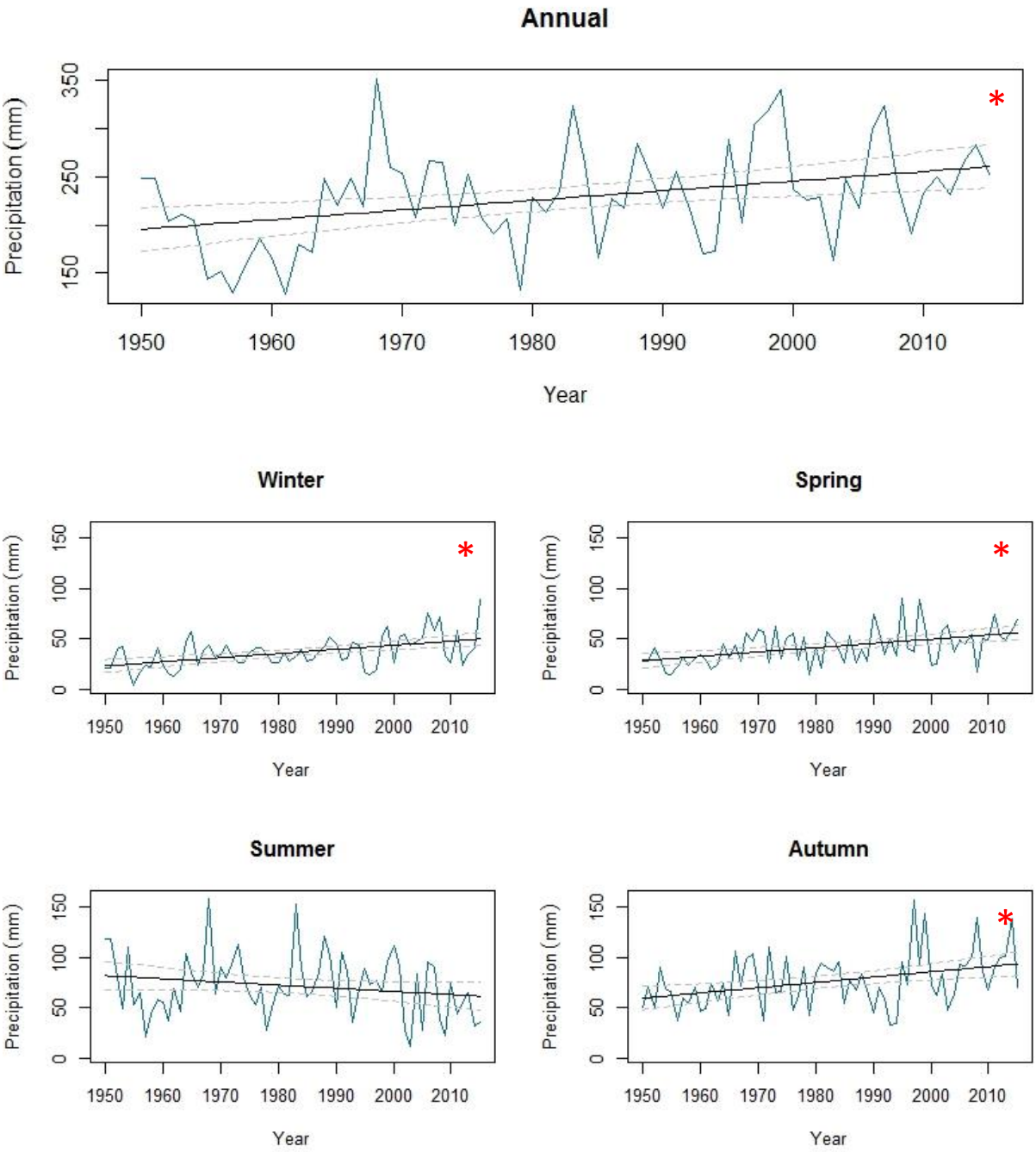
Alert, NU (Stn. ID 2400305) temperature data from AHCCD (ECCC, 2017). Trends from 1950 to 2016 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).



Alert, NU mean annual and seasonal temperature. A statistically significant (P<0.05) increase observed in mean annual, winter (Dec, Jan, Feb) and autumn (Sep, Oct, Nov) temperatures. Mean annual temperature has increased by ~2°C and both winter and autumn have increased by ~3°C since 1950.

1.2 Precipitation

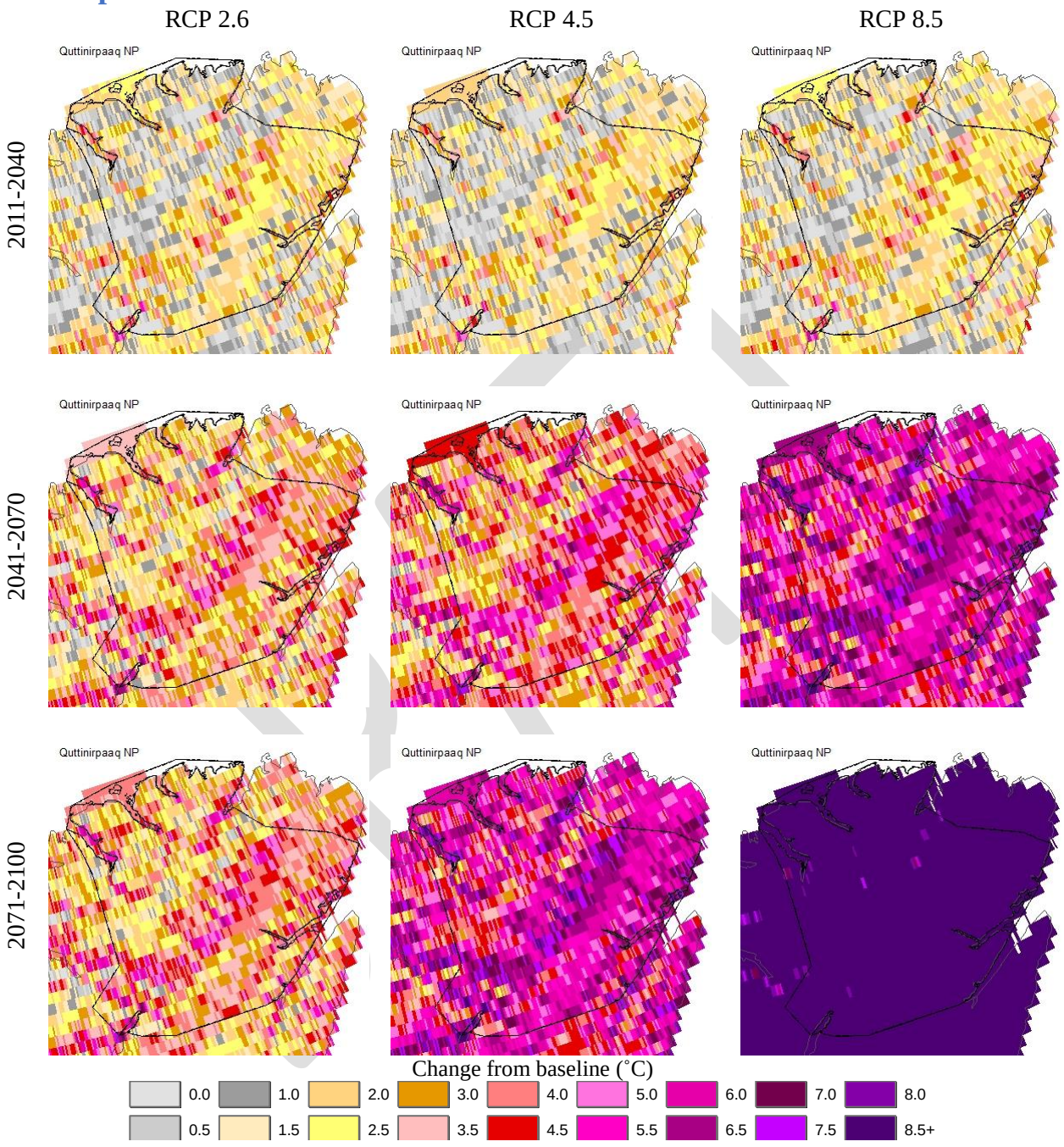
Alert, NU (Stn. ID 2400306) precipitation data from AHCCD (ECCC, 2017). Trends from 1950 to 2016 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).



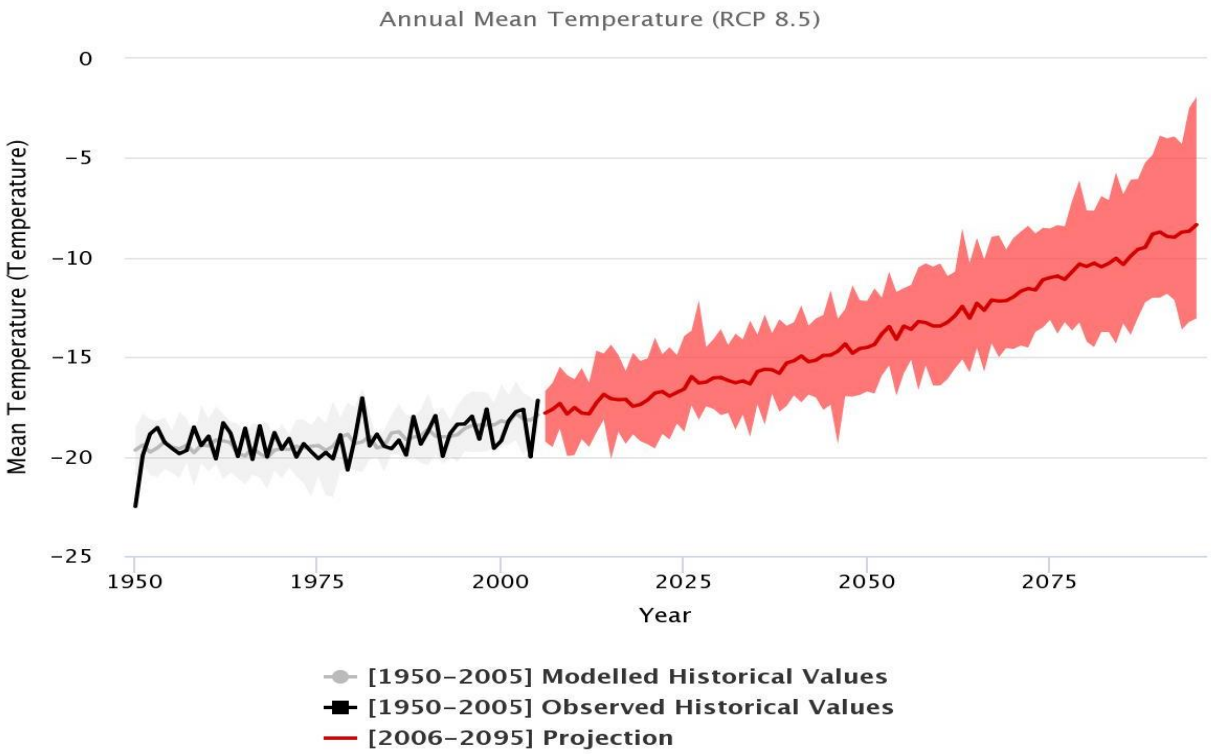
Alert, NU total annual and seasonal precipitation. Total annual precipitation demonstrated a statistically significant increase (P<0.05), ~67 mm (34%) since 1950. All seasons except summer (Jun, Jul, Aug) demonstrated a statistically significant (P<0.05) increase, the greatest being observed for autumn, ~34 mm (58%).

2. Projected Climate

2.1 Temperature

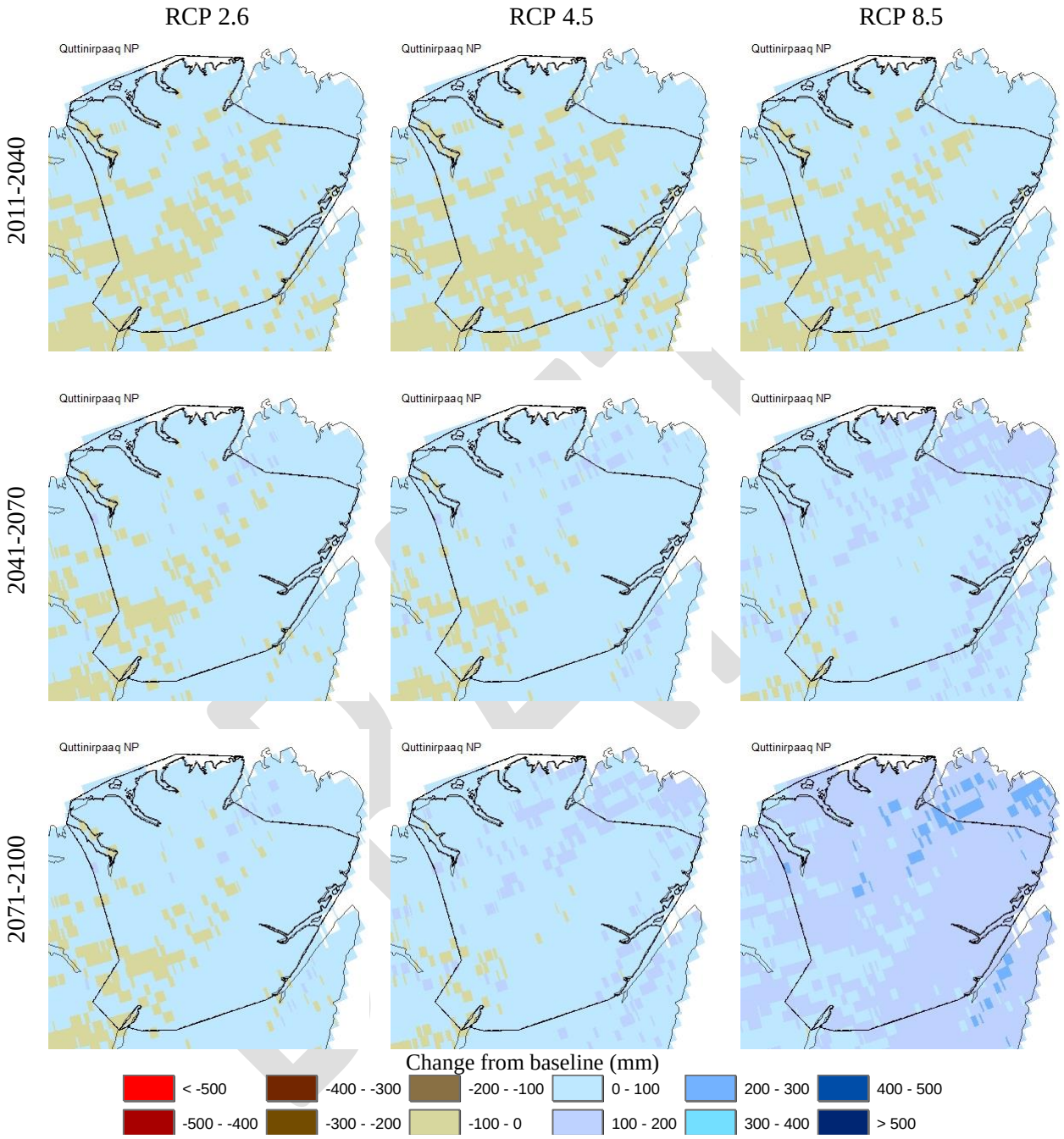


Projected mean annual temperature increase for Quttinirpaaq from a 1980-2010 baseline. Composite projection of CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Depending on scenario, mean annual temperature is projected to increase by 3 to 8.5˚C by 2071-2100. Data source: Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011).

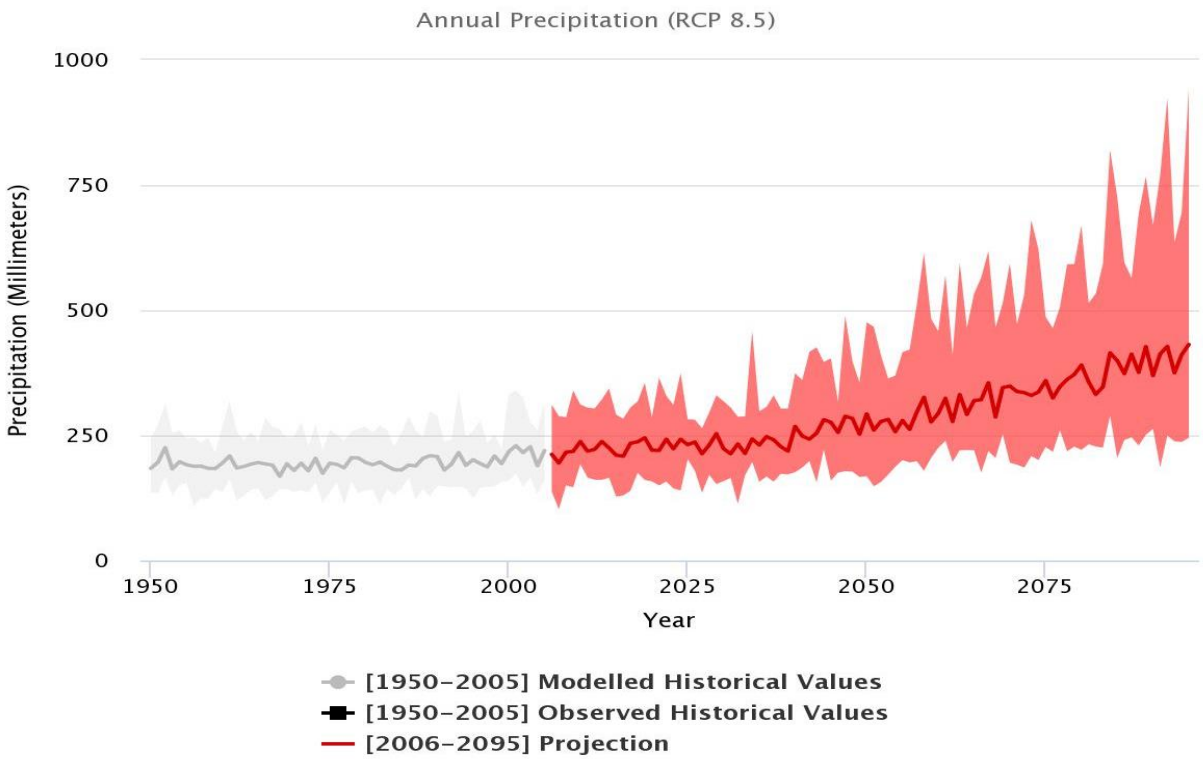


Mean annual temperature projection for Alert, NU area (RCP 8.5). Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

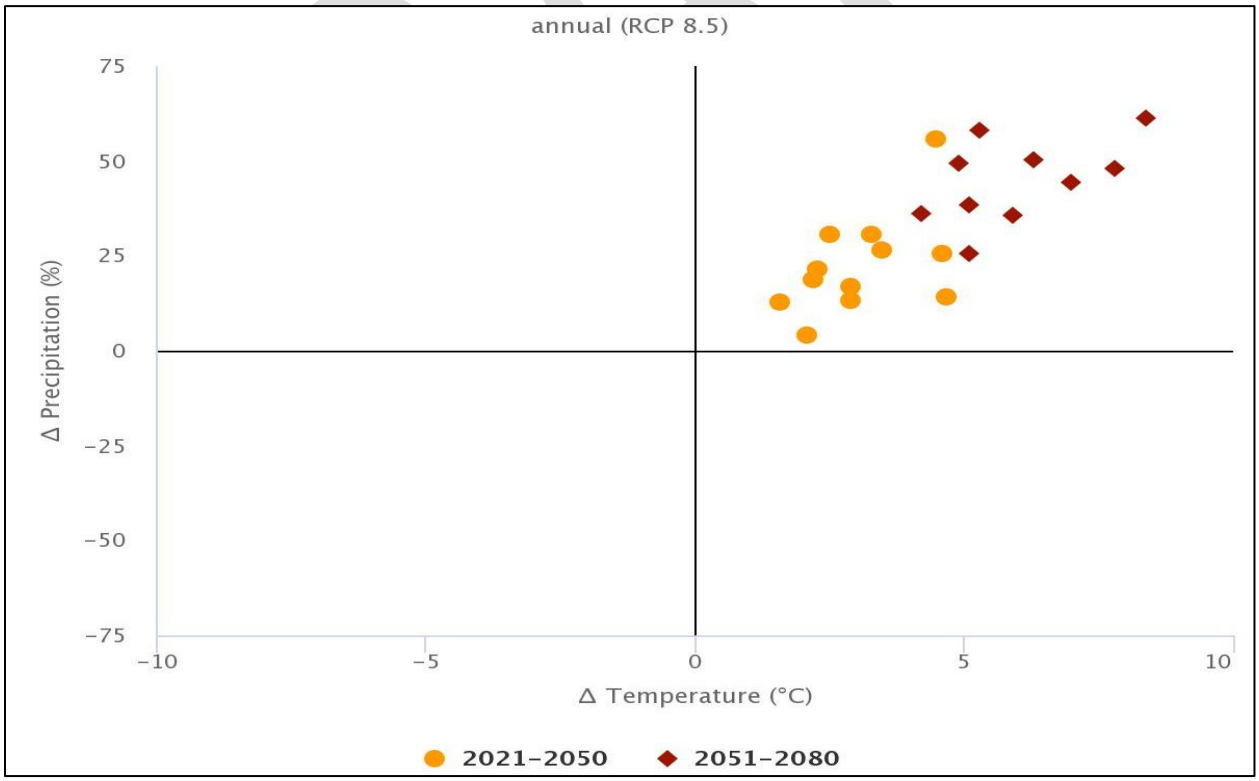
2.2 Precipitation



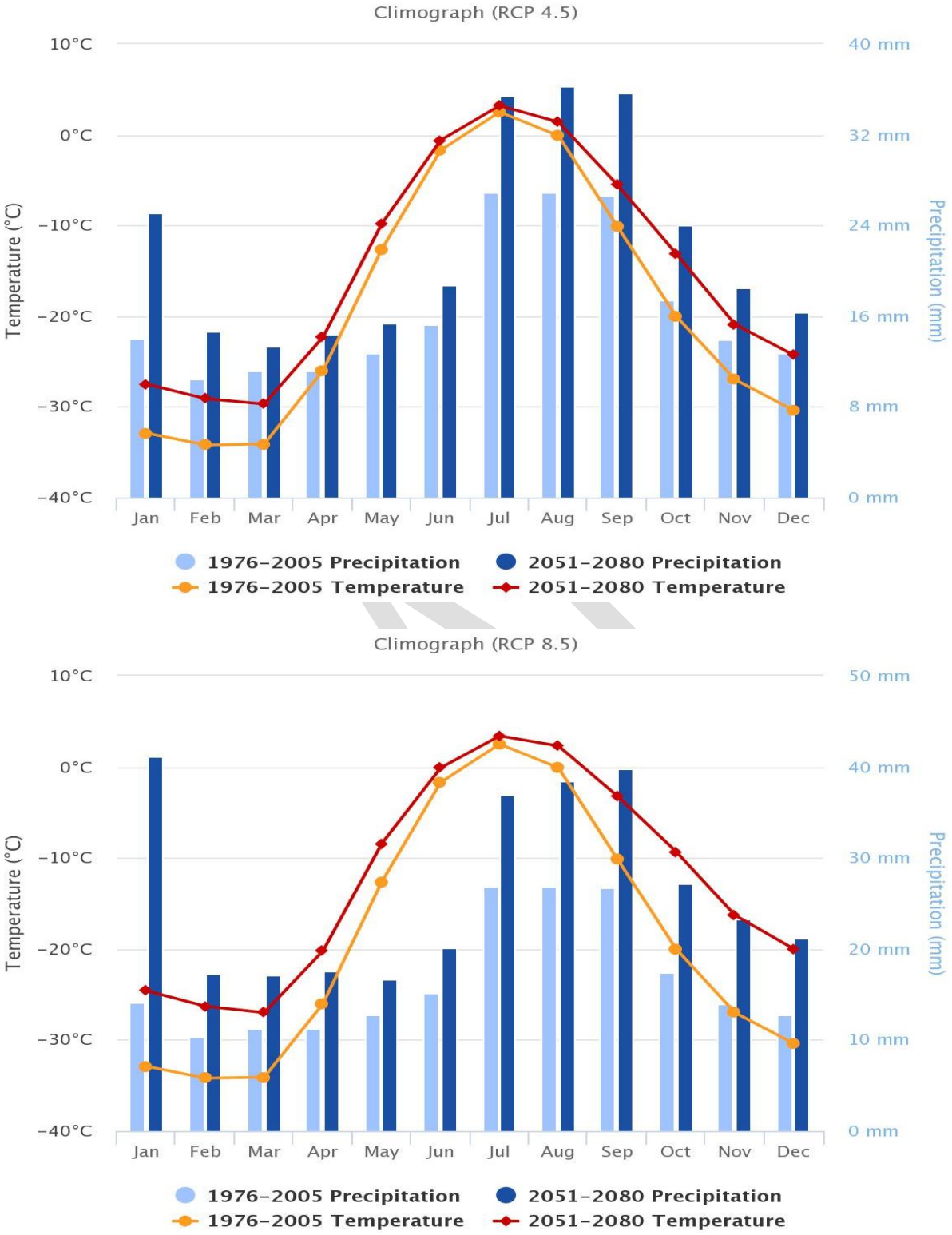
Projected total annual precipitation change for Quttinirpaaq from a 1980-2010 baseline. Composite projection of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Although drier conditions may be possible in some locations, in general, total annual precipitation is projected to increase by 25-150mm depending on the RCP scenario. Data source Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011).



Total annual precipitation projection for Alert, NU area (RCP 8.5). Figure source: Climate Atlas of Canada (https://climateatlas.ca/).



Scatterplot of projected change in temperature and precipitation for Alert, NU area. Each point represents a single model output (RCP 8.5) from 12 CMIP5 global climate models (PCIC, 2014). All models project warmer and wetter conditions. Figure source: Climate Atlas of Canada (https://climateatlas.ca/).



Climographs for Alert, NU area. Climographs for both RCP scenarios project warmer and wetter conditions for all months. Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

Rainfall Intensity, Duration and Frequency (IDF)

These rainfall IDF values are calculated with IDF_CC Tool 3.0 (http://www.idf-cc-uwo.ca) using Generalized Extreme Values (Simonovic *et al.*, 2017)

Baseline (1962-2012) total precipitation amounts (mm) for Alert, NU.

T (years)	2	5	10	25	50	100
5 min	0.62	0.86	1.05	1.33	1.57	1.85
10 min	0.82	1.15	1.37	1.64	1.84	2.04
15 min	1.06	1.50	1.78	2.13	2.38	2.62
30 min	1.74	2.43	2.79	3.17	3.41	3.61
1 h	2.65	3.80	4.46	5.19	5.67	6.10
2 h	4.20	6.31	7.58	9.06	10.06	10.98
6 h	7.81	12.93	16.15	20.04	22.79	25.43
12 h	9.91	18.09	24.15	32.63	39.58	47.10
24 h	12.80	23.15	30.30	39.67	46.88	54.26

Projected (2050-2100) precipitation (mm) for Alert, NU using an ensemble of models and **RCP 4.5**.

T (years)	2	5	10	25	50	100
5 min	1.02	1.75	2.34	3.22	3.95	4.70
10 min	1.35	2.35	3.07	3.98	4.64	5.18
15 min	1.74	3.06	3.99	5.16	5.98	6.65
30 min	2.85	4.95	6.26	7.70	8.58	9.16
1 h	4.35	7.75	9.98	12.58	14.27	15.49
2 h	6.88	12.88	16.99	21.96	25.31	27.89
6 h	12.81	26.39	36.17	48.58	57.36	64.59
12 h	16.25	36.91	54.08	79.12	99.61	119.64
24 h	21.00	47.26	67.85	96.19	117.97	137.83

Projected (2050-2100) precipitation (mm) for Alert, NU using an ensemble of models and **RCP 8.5**.

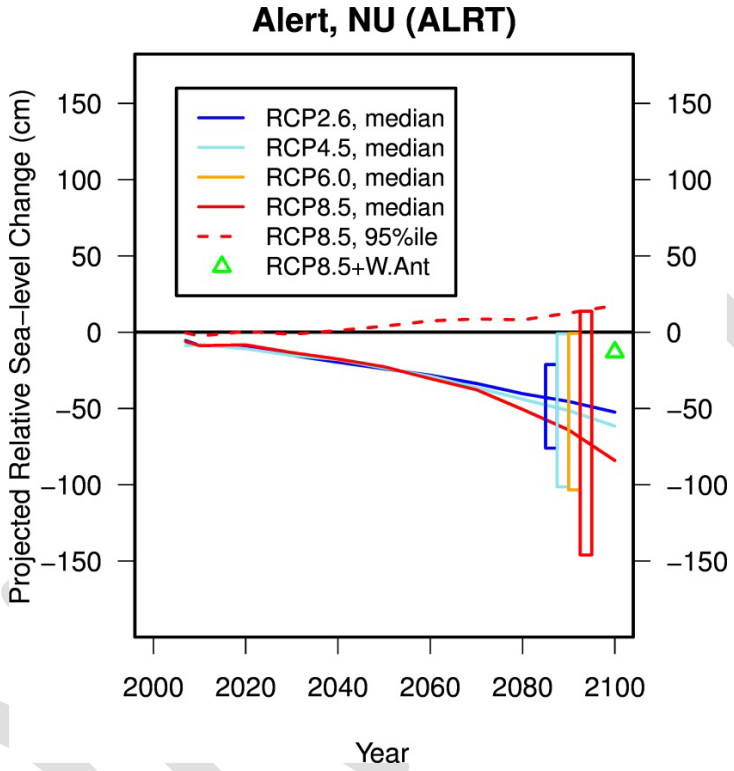
T (years)	2	5	10	25	50	100
5 min	1.55	2.69	3.44	4.30	5.20	6.33
10 min	2.06	3.61	4.50	5.32	6.10	6.99
15 min	2.66	4.70	5.86	6.90	7.87	8.96
30 min	4.34	7.61	9.18	10.29	11.28	12.35
1 h	6.63	11.90	14.65	16.83	18.77	20.89
2 h	10.49	19.78	24.93	29.37	33.30	37.61
6 h	19.52	40.51	53.08	64.97	75.45	87.11
12 h	24.76	56.68	79.37	105.82	131.04	161.34
24 h	32.01	72.55	99.58	128.65	155.20	185.87

Alert, NU Ungauged IDF modelled data. Note that today's "one in 100 year" rainfall event (i.e., 6.10 mm/hr) is projected to be closer to a "one in 5 or 10 year" event by 2050-2100 and the future "one in 100 year" rainfall event is projected to increase in intensity (i.e., 15.49 – 20.89 mm/hr).

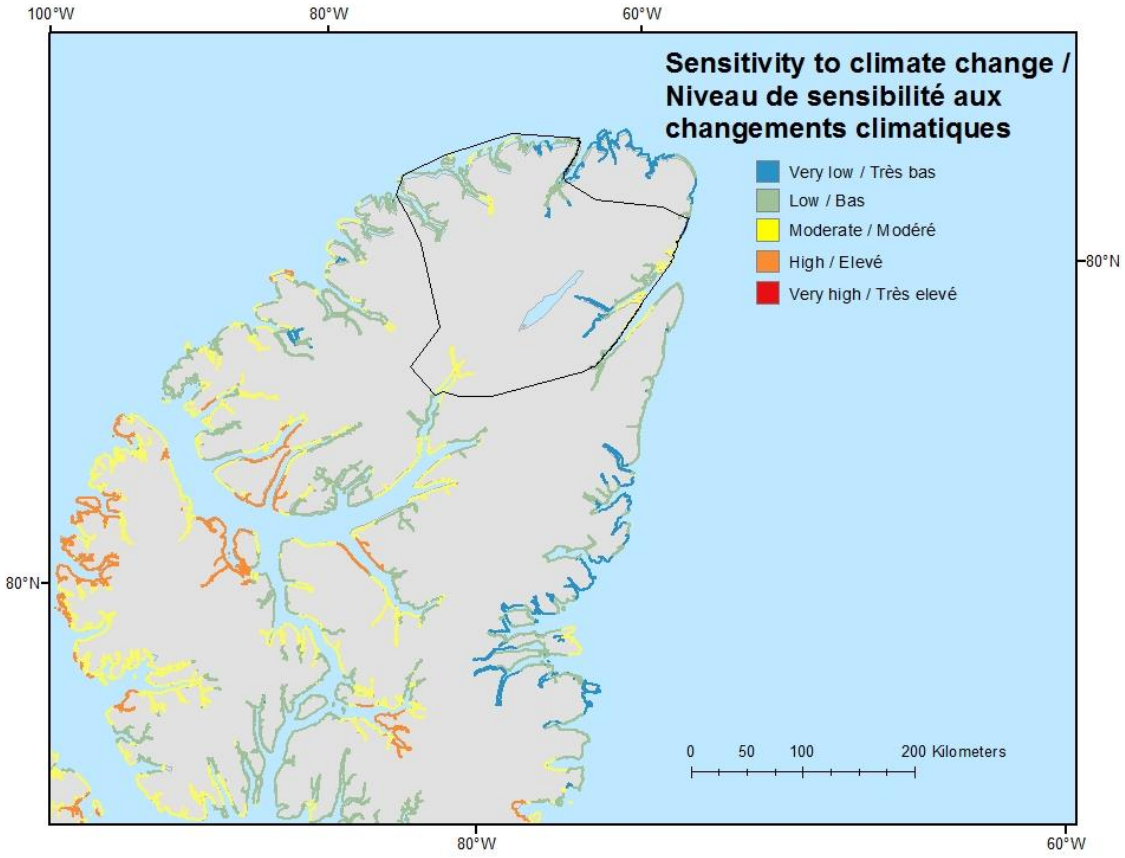
3. Climate Change Impacts

3.1 Sea Level Change

Sea level is influenced by ocean temperature (thermal expansion) and salinity, circulation patterns, glacier and ice-sheet melt water, and glacial isostatic adjustments (vertical land motion). The large crustal rebound in the region due to glacial isostatic adjustments are projected to be sufficiently large as to offset global sea level rise. As a result relative sea level fall is projected for the area.



Sea level change projection for Alert, NU. Figure source: James *et al.* (2015)



Map of coastal sensitivity to climate change in the Quttinirpaaq NP region. Sensitivity is based on coastal materials, landforms, relief, ground ice, wave height, tidal range, recent trends in sea ice concentration, and projected sea level rise to 2050. Data provided by Natural Resources Canada (Couture and Manson, 2016).

3.2 Ice Loss

- White and Copland (2018) report that regional ice coverage in Northern Ellesmere Island has decreased by ~5.9% between 1999 and 2015 and they predict continued losses in the future.
- Lake Hazen and other lakes in the High Arctic are experiencing ice regime changes with earlier summer ice minimum and water-clear-of-ice dates (e.g., Paquette *et al.*, 2015; Surdu *et al.*, 2016).

3.3 Species and Ecosystems

- McLennan *et al.* (2012) provides a review of recent climate related impacts to territorial biodiversity in Quttinirpaaq and other Arctic national parks.
- Lehnheer *et al.* (2018) report on a significant decline in Arctic Char from Lake Hazen due a warming climate and concomitant biogeochemical and limnological changes.
- Timing of flowering and fruiting are advancing as temperatures warms (e.g., Panchen and Gorelick, 2015; Panchen and Gorelick, 2017).
- Vegetation cover is changing (Broll *et al.*, 2003).

4. Additional Information

4.1 Greenhouse Gas Monitoring at Alert, NU

The Alert World Meteorological Organisation Global Atmosphere Watch Observatory is the most northerly site in the global network. Greenhouse gas (GHG) monitoring began in Alert in 1975 and currently includes hourly measurements of methane, carbon monoxide and carbon dioxide and weekly measurements of other GHGs. Data and quick plots are available from the World Data Centre for Greenhouse Gases (http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/catalogue.cgi).

5. References

AMAP. (2011). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. http://www.amap.no/documents/doc/snow-water-ice-and-permafrost-in-the-arctic-swipa-climate-change-and-the-cryosphere/743.

Arctic Council. (2016). *Arctic Resilience Report*. M. Carson and G. Peterson (eds). Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm. https://oaarchive.arctic-council.org/handle/11374/1838.

Broll, G., Tarnocai, C., and Gould, J. (2003). *Long-term high Arctic ecosystem monitoring in Quttinirpaaq National Park, Ellesmere Island, Canada*. Leiden: A. A. Balkema Publishers

CAFF. (2013). *Arctic Biodiversity Assessment 2013: Status and Trends in Arctic Biodiversity*. Conservation of Arctic Flora and Fauna (CAFF), Arctic Council. https://www.arcticbiodiversity.is/.

Couture, N. J. and Manson, G. K. (2016). *CanCoast: a tool for helping to assess climate vulnerability*. Natural Resources Canada. Geological Survey of Canada

ECCC. (2017). *Adjusted and Homogenized Canadian Climate Data (AHCCD)*. Environment and Climate Change Canada. https://www.ec.gc.ca/dccha-ahccd/.

Gross, J. E., Woodley, S., Welling, L. A., and Watson, J. E. M. (Eds.). (2016). *Adapting to Climate Change. Guidance for protected area managers and planners.* (Vol. No. 24). Gland, Switzerland: IUCN. https://portals.iucn.org/library/node/46685.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change (IPCC). Geneva, Switzerland. http://www.ipcc.ch/report/ar5/.

James, T. S., Henton, J. A., Leonard, L. J., Darlington, A., Forbes, D. L., and Craymer, M. (2015). *Tabulated Values of Relative Sea-level Projections in Canada and the Adjacent Mainland United States*. Geological Survey of Canada, Ottawa. http://ftp.maps.canada.ca/pub/nrcan_rncan/publications/ess_sst/297/297048/of_7942.pdf.

Lehnherr, I., St. Louis, V. L., Sharp, M., Gardner, A. S., Smol, J. P., Schiff, S. L., Muir, D. C. G., Mortimer, C. A., Michelutti, N., Tarnocai, C., St. Pierre, K. A., Emmerton, C. A., Wiklund, J. A., Köck, G., Lamoureux, S. F., and Talbot, C. H. (2018). The world's largest High Arctic lake responds rapidly to climate warming. *Nature Communications, 9*(1), 1290. doi:10.1038/s41467-018-03685-z.

McLennan, D. S., Bell, T., Berteaux, D., Chen, W., Copland, L., Fraser, R., Gallant, D., Gauthier, G., Hik, D., Krebs, C. J., Myers-Smith, I. H., Olthof, I., Reid, D., Sladen, W., Tarnocai, C., Vincent, W. F., and Zhang, Y. (2012). Recent climate-related terrestrial biodiversity research in Canada's Arctic national parks: review, summary, and management implications. *Biodiversity, 13(3-4)*, 157-173. doi:10.1080/14888386.2012.720818.

Panchen, Z. A. and Gorelick, R. (2015). Flowering and fruiting responses to climate change of two Arctic plant species, purple saxifrage (Saxifraga oppositifolia) and mountain avens (Dryas integrifolia). *Arctic Science, 1*(2), 45-58. doi:10.1139/as-2015-0016.

Panchen, Z. A. and Gorelick, R. (2017). Prediction of Arctic plant phenological sensitivity to climate change from historical records. *Ecology and Evolution, 7*(5), 1325-1338. doi:10.1002/ece3.2702.

Paquette, M., Fortier, D., Mueller, D. R., Sarrazin, D., and Vincent, W. F. (2015). Rapid disappearance of perennial ice on Canada's most northern lake. *Geophysical Research Letters, 42*(5), 1433-1440. doi:10.1002/2014GL062960.

Parker, S. (2017). *Let's Talk about Climate Change: Arctic and Hudson Plains Region*. Parks Canada, Office of the Chief Ecosystem Scientist

PCIC. (2014). *Statistically Downscaled Climate Scenarios*. Pacific Climate Impacts Consortium, University of Victoria. https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios.

Price, D. T., McKenney, D. W., Joyce, L. A., Siltanen, R. M., Papadopol, P., and Lawrence, K. (2011). *High-Resolution Interpolation of Climate Scenarios for Canada Derived from General Circulation Model Simulations*. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. http://cfs.nrcan.gc.ca/publications?id=32971.

R Core Team. (2017). R: A Language and Environment for Statistical Computing (ver. 3.4.3). http://www.R-project.org

Simonovic, S. P., Schardong, A., and Sandink, D. (2017). Mapping Extreme Rainfall Statistics for Canada under Climate Change Using Updated Intensity-Duration-Frequency Curves. *Journal of Water Resources Planning and Management, 143*(3), 12. doi:10.1061/(asce)wr.1943-5452.0000725.

Surdu, C. M., Duguay, C. R., and Prieto, D. F. (2016). Evidence of recent changes in the ice regime of lakes in the Canadian High Arctic from spaceborne satellite observations. *Cryosphere, 10*(3), 941-960. doi:10.5194/tc-10-941-2016.

Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S., and Rose, S. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1-2), 5-31. doi:10.1007/s10584-011-0148-z.

White, A. and Copland, L. (2018). Area change of glaciers across Northern Ellesmere Island, Nunavut, between similar to 1999 and similar to 2015. *Journal of Glaciology, 64*(246), 609-623. doi:10.1017/jog.2018.49.