Climate Analysis and Scenario Development for the Canadian Arctic and Subarctic

Project Leader
Ross Brown (Environment Canada, Ouranos)

Collaborators
Carl Barrette, Mickaël Lemay (Centre d’études nordiques); Diane Chaumont, Ramon de Elia, Anne Frigon, Patrick Grenier, Marko Markovic, Maja Rapaic (Ouranos); Trevor Bell, Kathleen Parewick (Memorial University of Newfoundland); Michel Allard (Université Laval); David G. Barber, Ashley Gaden, Brian Horton, Gary A. Stern (University of Manitoba)
Abstract

Analyzing climate variability and trends and constructing climate projection scenarios for the Canadian Arctic and Subarctic regions is more challenging than for southern Canadian regions. This is mostly due to the inconsistent and sparse observational datasets, to the complex regional setting and the interlocked physical processes involved in this environment. The main objective of this project is to supply information on observed and projected changes in key climate variables and indicators in support of the ongoing IRIS (IRIS 1-2-3) and AACA* Baffin-Bay-Davis-Straits activities. This requires 1) the acquisition, evaluation and analysis of in situ and reanalysis datasets in the Canadian Arctic; 2) tracking state-of-the-art developments in coupled cryosphere/atmosphere/ocean models and scenario construction methods; and 3) effective communication of scenarios and their uncertainties to users. The purpose of this project is to provide researchers, stakeholders, decision-makers and communities with robust knowledge of current and anticipated climate changes that can be used to support sustainable development in this complex and rapidly changing environment.

*Adaptation Actions for a Changing Arctic (Arctic Council)

Key Messages

- Ground surface temperature reconstructions and paleoclimatic data indicate that surface and air temperatures in the IRIS-1 region have warmed over the last ~200 years. Analysis of historical climate data show the warming is most marked in the winter period with air temperature increases of ~4°C over the region since 1950. Locally significant warming trends are observed over the entire region in fall, winter and spring. The summer period July, August and September (JAS) has the least amount of warming (~1°C over the region since 1950) and trends are not significant over much of the region. The observed warming is contributing to statistically-significant increases in thaw season duration of 1.2 days/decade since 1950. The period since ~1980 is characterized by more rapid warming that is most pronounced in the fall period. Historical climate data show the observed warming has been accompanied by significant increases in precipitation in all seasons with the largest increases in winter (~10% increase since 1950). The strong multi-decadal variability present in the Arctic climate system means that the spatial pattern, sign and magnitude of climate trends over northern Canada are strongly influenced by the period selected for trend analysis.

- Analysis of in situ daily snow depth observations show that the period of snow on the ground has decreased an average of ~15 days over the IRIS-1 region since 1950 with most of the decrease coming from earlier snow melt. Satellite data confirm this is part of a pan-Arctic trend to earlier snow melt. Trends in snow accumulation show greater spatial variability as these are influenced strongly by terrain, vegetation cover and elevation. Daily snow depth data made in open areas near communities are showing evidence of a thinning snowpack. However, there is evidence of increased snow accumulation in some areas south of the treeline e.g. a ~10 mm/decade increase in annual maximum snow accumulation is seen in snow survey data north of Yellowknife and around Inuvik.

- Ice observations from the Canadian Ice Service Digital Archive show that the summer sea ice cover (all ice types) in the Canadian Arctic Archipelago (CAA) has decreased significantly over the period since 1968 at a rate of ~3% per decade. However, there is considerable variability in trends within the CAA with some regions such as the northern western Parry Channel route to the Northwest Passage showing no trend. The area of multi-year ice (MYI) is also decreasing but at a slower rate due to the continuous import of MYI from the Arctic Ocean. Significant decreases in annual maximum ice thickness of
4-7 cm/decade have been observed at the three communities in the IRIS-1 region with more-or-less continuous measurements since ~1960 (Cambridge Bay, Inuvik and Baker Lake). The duration of the melt season is increasing at a rate of about 7 days/decade since 1979 over the CAA based on passive microwave satellite data.

- Permafrost temperatures in the IRIS-1 region are estimated to have warmed ~2°C since 1960s and 70s in the outer Mackenzie Delta. However, the rate and timing of warming shows important regional variability with the largest warming observed in the cold tundra environments of the western Arctic. The most important changes in active layer depth and permafrost thickness have occurred south of IRIS-1 in the discontinuous permafrost region.

- Climate change projections for the IRIS-1 region for 2050 show the greatest warming (+5 to +7°C) taking place in the fall October, November and December (OND) period linked to positive feedbacks from later ice formation. Warming is projected to be much lower over the summer (JAS) period (≈2°C). Precipitation is projected to increase 20-30% over the winter period contributing to increased maximum snow accumulations of 3-10 cm despite projected decreases in the length of the snow cover season of 10-30 days. The duration of the period with above-freezing temperature is projected to increase ~2 weeks over the southern mainland area to more than 3 weeks over the northern islands. Permafrost change projections show increases in near surface temperature ranging from 2 to 2.5°C (relative to 1981-2000) and increases in active layer depth ranging from 14 to 30% for 2050. Summer sea ice concentration is projected to decrease 30-50% by 2050 with a 17% reduction in winter ice thickness. The region is unlikely to be ice-free by 2050 but summer ice conditions will be more favorable for commercial shipping.

- Evaluation of eight gridded climate datasets with air temperature and precipitation data over northern Canada showed reasonably good agreement for air temperature but noticeable differences in precipitation, particularly over the Canadian Arctic Archipelago. Evaluation of eight reanalysis datasets over the northern IRIS regions showed they have warm / wet biases in all seasons with the wet bias particularly pronounced over the western Arctic. ERA-interim and CFSR showed the best agreement with observations for air temperature while NARR showed the best agreement for precipitation. The consistency between data products over northern Canada was observed to have declined markedly over the past decade.

- Preliminary evaluation of the CMIP5 model ensemble over northern Canada showed good performance for surface air temperature but large between-model and between observational dataset differences for precipitation and snow accumulation. Between-model spread was highest in the fall and spring transition seasons, and over maritime regions where sea ice extent is projected to undergo the largest changes (e.g. Beaufort Sea, Baffin Bay, Hudson Bay).

Objectives

- To produce climate scenarios for IRIS regions 1-2-3 and updated IRIS-4 scenarios for the second edition of the IRIS-4 report;
- To identify and analyze climate and related data in support of impact and adaptation (I&A) studies and the production of climate scenarios;
- To carry out an evaluation of gridded climate data sets of temperature and precipitation over the IRIS regions;
- To characterize variability and change in the climate and cryosphere of the IRIS regions, and assess the potential of climate models to capture the observed variability and physical processes;
- To track state-of-the-art developments in climate modelling and scenario development for Arctic climate regions.
Introduction

This special project is a continuation of the collaboration initiated in 2008 between Ouranos and ArcticNet to develop climate scenarios for the IRIS-4 region (Integrated Regional Impact Study of the Nunavik and Nunatsiavut region). The main objectives of the project range from supplying climate change (CC) information in support of the ongoing IRIS projects (IRIS 1-2-3) to more fundamental research on variability and change in the Canadian Arctic climate. Achieving a thorough knowledge of recent climate trends in the Arctic is challenging considering the sparse distribution of climate stations and the lack of consistency between available data sets. In this context, it is crucial to characterize the uncertainties in the observations. In addition, building climate scenarios for the Canadian Arctic and Subarctic regions requires special attention due to the complex regional settings and physical processes such as blowing snow that are not included in most climate models.

Activities

Evaluation of gridded climate datasets and estimation of climate trends

• A detailed evaluation was carried out of eight gridded climate datasets (based on surface observations) and seven reanalyses over the IRIS domain to characterize the between-dataset agreement, bias and possible discontinuities. The Environment Canada CANGRD temperature and precipitation dataset incorporating homogenized and corrected climate station data was used as the reference. The dataset evaluation uses Taylor diagrams to provide a concise statistical summary of pattern matching to the CANGRD reference in terms of the spatial pattern correlation, RMS difference, and variance ratio. A journal article is in preparation that summarizes the results of this work conducted by M. Rapaic, M. Markovic, R. Brown, D. Chaumont from Ouranos.

Climate change scenario development

• P. Grenier (Ouranos) prepared climate change scenario output for the 2050 period (2041-2070) for the IRIS 1-2-3 regions for air temperature, precipitation and snow cover. A suite of temperature, precipitation and snow cover-related climate change indicators from eight simulations of the Canadian Regional Climate Model Version 4 (CRCM4 - Paquin 2010; de Elia and Côté 2010; Music and Caya 2007; Caya and Laprise 1999) driven by the Canadian CGCM3 and German ECHAM5 global climate models for the SRES A2 emissions scenario were computed at CEN by C. Barrette. The climate change indicator outputs were processed to provide seasonal maps of projected change and a tabular summary of regionally-averaged change for each IRIS region. Reports (“Climate change projection atlases”) containing the scenario construction process methodology and scenario results were provided to the IRIS-1 and -2 teams in May and August of 2013. The IRIS-3 climate scenario atlas will be provided in 2014 following discussions with Brian Horton on the selection of relevant climate indicators.

Contribution to IRIS-1 Report Climate Chapter

• Sections on terrestrial climate, permafrost and climate change projections were contributed to the IRIS-1 Climate Chapter being led by D. Barber and L. Candlish. This included analysis of climate observations, gridded climate data sets, and climate model output (R. Brown, C. Barrette, M. Rapaic, M. Markovic). Key findings from this work are included in the key messages/results section of this report.

Supporting climate analysis and modeling initiatives of specific ArcticNet projects

• An initial evaluation was carried out of the ability of the recent suite of CMIP5 climate model simulations at representing the seasonal cycle
in key climate variables over northern Canada. The evaluation included surface air temperature, precipitation, snow water equivalent (SWE) and sea ice extent. A total of 26 CMIP5 models were included in the analysis. Observational information was obtained from CRU (gridded surface climate observations) and five reanalyses (ERA40, ERA-interim, NCEP2, NARR, and JRA25). The work conducted by M. Markovic was presented at the Halifax 2013 ASM (M. Markovic and R. de Elia).

Results

**Evaluation of gridded climate datasets and estimation of climate trends**

Temperature and precipitation spread among reanalyses was found to be largest in the cold season with contrasting difference patterns between warm and cold seasons. Reanalyses tended to have warm/wet biases in all seasons with the wet bias particularly pronounced over the western Arctic. Over the evaluation region ERA-interim and CFSR showed the best agreement with CANGRD for air temperature while NARR showed best agreement for precipitation. The gridded climate datasets showed good agreement for temperature but noticeable differences in precipitation, particularly over the Canadian Arctic Archipelago. The Climatic Research Unit (CRU) gridded climate dataset was found to agree most closely with CANGRD for temperature and precipitation. The multiple datasets were used to construct trend consensus patterns for temperature and precipitation. The consensus approach was found to be useful for analyzing precipitation trends as these showed strong between-dataset variability. The consistency between data products over northern Canada was observed to have declined markedly over the past decade. Declining surface observing networks, automation of surface observations and the introduction of new satellite products are likely contributing to this situation.

**Climate change scenario development**

Results from the climate change projections for the IRIS-1 region for 2050 show that the strongest warming (+5 to +7°C) is projected to take place in the fall (OND) period (Figure 1). Warming is projected to be much lower over the summer (JAS) period (~+2°C). Precipitation is projected to increase 20-30% (Figure 2) over the winter period contributing to increased maximum snow accumulations of 3-10 cm despite projected decreases in the length of the snow cover season of 10-30 days. The duration of the period with above-freezing temperature is projected to increase ~2
weeks over the southern mainland area to more than 3 weeks over the northern islands.

**Contribution to IRIS-1 Report**

Climate chapter results of the analysis of historical climate data for IRIS-1 region show that the air temperature warming is most marked in the winter period with air temperature increases of ~4°C over the region since 1950. Locally significant warming trends are observed over the entire region in fall, winter and spring. The summer period (JAS) has the least amount of warming (~1°C over the region since 1950) and trends are not significant over much of the region (Figure 3). The observed warming is contributing to statistically-significant increases in thaw season duration of 1.2 days/decade since 1950. The period since ~1980 is characterized by more rapid warming that is most pronounced in the fall period.

Historical climate data show that observed warming has been accompanied by significant increases in precipitation in all seasons with the largest increases in winter (~10% increase since 1950) (Figure 4). Moreover, the strong multi-decadal variability observed in the Arctic climate system means that the spatial pattern, sign and magnitude of climate trends over northern Canada are strongly influenced by the period selected for trend analysis. For example, temperature and precipitation trends computed over the recent 1981-2010 period exhibit less statistically significant changes and show quite different regional patterns than those computed over the period from 1950.

Daily snow depth observations show that the period of snow on the ground has decreased an average of ~15 days over the IRIS-1 region since 1950 with most of the decrease coming from earlier snow melt. Satellite data confirm this is part of a pan-Arctic trend to earlier snow melt (Figure 5). Trends in snow accumulation show greater spatial variability as these are influenced strongly by terrain, vegetation cover and elevation. Daily snow depth data made in open areas near communities are showing evidence of a thinning snowpack. However, there is evidence of increased snow accumulation in some areas south of the treeline e.g. a ~10 mm/decade increase in annual maximum snow accumulation is seen in snow survey data north of Yellowknife and around Inuvik.

The decreasing trend in SCDspr is statistically significant at the 0.05 level (the trend in SCDfall is not significant). The average decrease in annual SCD over the 1950-2008 period is 2.5 days/decade (~15 day reduction in SCD over period from 1950).
Figure 3. Regionally-averaged time series of seasonal mean daily air temperature (°C) over 1950-2010 period from the CANGRD dataset. Values are anomalies with respect to a 1961-1990 reference period.

Figure 4. Same as Fig. 3 for regionally-averaged precipitation. Annual anomalies are expressed as percentages of the 1961-1990 mean.
Supporting climate analysis and modeling initiatives of specific ArcticNet projects

The evaluation showed that the CMIP5 model suite is in close agreement with the observed historical evolution of surface air temperature over the 20th century. The seasonal cycle of surface air temperature is also well represented by models with the largest model spread in winter months and a tendency for models to exhibit warm biases in the summer. This contrasts with precipitation and snow water equivalent (SWE) where there is considerable spread between the models and between the observational datasets (i.e. there is greater uncertainty in the observations and the models for precipitation-related variables over the IRIS regions). The evidence suggests that models overestimate precipitation and end of winter SWE over northern Canada. The models all simulated well the observed seasonal cycle of sea ice extent. Compared to the ERA-40 reanalysis (for SWE and air temperature) and the CMAP precipitation analysis, our evaluation identified two models (FIO-ESM for precipitation and GFDL-CM3 for snow water equivalent) that were clear outliers. Scenarios of projected changes in seasonal air temperature and precipitation were generated from the CMIP5 model ensemble (RCP8.5 emission scenario) for the 2050 time period as a check for the CRCM4 scenarios driven with CMIP3 climate models (the two agreed closely). The spread in the CMIP5 model ensemble tended to be highest in the spring and fall seasons over maritime areas where sea ice cover is projected to undergo large changes (e.g. Beaufort Sea, Baffin Bay, and Hudson Bay)(Figure 6).

Discussion

The large interannual variability of the Arctic climate system, the different response times of the climate system components, and the lack of climate observations make it a real challenge to document just how fast the climatic environment of northern Canada is changing. The available evidence suggests the climate has changed significantly over the period of historical observations from ~1950. However, the
magnitude and statistical significance of the changes varies considerably between different components of the climate system, by region and by the time period analyzed. The largest changes are observed in winter minimum temperatures which have warmed ~6°C over the IRIS-1 region since 1950. Significant changes have also been observed in snow cover (shorter season, earlier melt). Other variables such as snowfall, permafrost temperature, active layer depth and ice freeze-up/break-up dates also show evidence of changes consistent with local knowledge and pan-Arctic climate responses to warming (e.g. ACIA, 2005; AMAP 2011). However, the signals are less clear and show greater regional variability than air temperature or spring snow cover.

Evaluating climate models in this environment is also a challenge when the differences between observational datasets can be as large or larger than the differences between climate models as seen with the evaluation of Arctic precipitation datasets. Another somewhat disturbing finding from the dataset evaluation was that the degree of consistency between products over northern Canada has decreased markedly over the last decade. These challenges require the analysis of multiple observational and model-based information together with local knowledge to provide state-of-the-art information on current and anticipated climate changes. Another aspect that has emerged from the preliminary analysis of the CMIP5 model ensemble is that projected climate changes over northern Canada are closely linked to projected changes in sea ice extent. Previous studies (e.g. Stroeve et al. 2011; Wang and Overland 2012) have shown large between-model differences in the projected magnitude and timing of Arctic sea ice changes. This is an important source of between-model variability in climate change scenarios that will be looked at in more detail in 2014-15.

Conclusion

A major component of the work carried out in 2013 involved the discovery, downloading, processing and analysis of multi-dataset observational data from various sources (e.g. station data, gridded climate data, reanalyses, satellite-derived datasets) and climate model output from the recent CMIP5 and CORDEX experiments. Results of analysing these data were used to provide key contributions to the IRIS-1 climate chapter, to investigate the uncertainty in climate observations over northern Canada (Rapaic et al. 2014) and to carry out a preliminary evaluation of the CMIP5 climate model ensemble (Markovic et al. 2014). The project is now well positioned to provide input to the IRIS-2 and -3 climate chapters in 2014 and to provide a final overview and synthesis publication on observed and projected climate change over northern Canada planned as a final deliverable for the project.

Acknowledgements

We thank the following institutions for supplying data sets: Observed data for estimating biases were distributed by the Climate Research Unit of University of East Anglia. Data from the CRCM were supplied by the Ouranos Climate Simulation and Analysis Group. Global Climate model data used in comparing deltas and biases were distributed by the Coupled Model Intercomparison Project phase 5 (CMIP5) of the World Climate Research Program (WCRP).

References


Markovic et al 2014: “Seasonal cycle evaluation of the CMIP5 models over the Canadian Arctic”, Atmosphere-Ocean (in prep).


Publications

(All ArcticNet refereed publications are available on the ASTIS website (http://www.aina.ucalgary.ca/arcticnet/).

Barrette, C., Grenier, P. and Chaumont D., 2013, Climate change projections for the Canadian Arctic IRIS regions, Poster presentation, ArctNet ASM, 1

Barrette, C., Grenier, P., Brown, R. and Chaumont, D., 2013, Initial climate change projections for the Western and Central Canadian Arctic, IRIS 1 region, ArcticNet Internal document, 28

Barrette, C., Grenier, P., Chaumont, D. and Brown R., 2013, Climate scenarios in support of ArcticNet IRISs, Oral presentation, ArcticNet ASM, 1

Brown, R., Barrette, C., Rapaic, M. and Markovic, M., 2013, Characterizing variability and change in the terrestrial climate of the IRIS-1 Region, Oral presentation, ArcticNet ASM, 1

Brown, R., Derksen, C. and Wang, L., 2013, Variability and Change in Arctic Snow Cover, Oral presentation, ArcticNet ASM, 1


Rapiac, M., Brown, R., Markovic, M. and Chaumont, C., 2013, Evaluation of data-sets for climate analysis and climate model evaluation over the Canadian Arctic, Poster presentation, ArctNet ASM, 1