Changing Cold Regions Network (CCRN)

Overview of CCRN Activities in Canada's National Parks

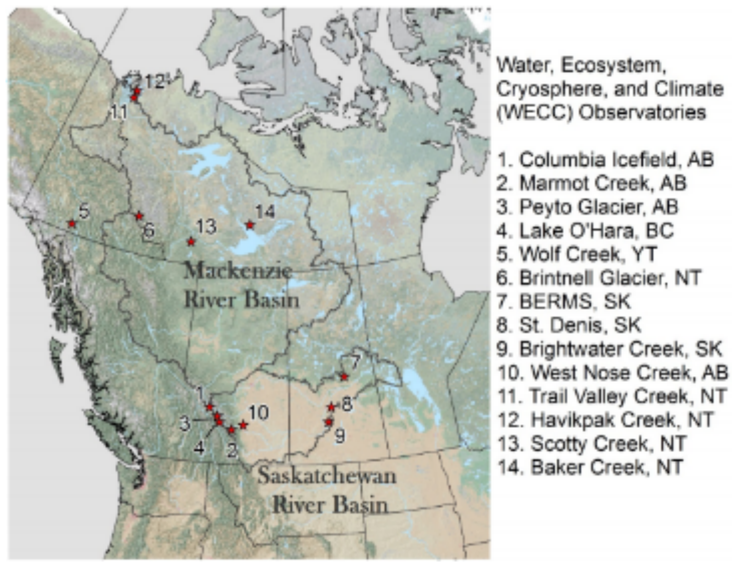
4-10-2017

Contents

Changing Cold Regions Network

Overview

The Changing Cold Regions Network (CCRN) is a collaborative research network that brings together the unique expertise of a team of over 40 Canadian university and government scientists, representing 8 universities and 4 federal government agencies. The network is funded for 5 years (2013-18) through the Climate Change and Atmospheric Research (CCAR) Initiative of the Natural Sciences and Engineering Research Council of Canada (NSERC).



CCRN integrates existing and new experimental data with modelling and remote sensing products to understand, diagnose and predict changing land, water and climate, and their interactions and feedbacks, for this important region. CCRN uses a network of world class Water, Ecosystem, Cryosphere, and Climate (WECC) observatories to study the detailed connections among changing climate, ecosystems and water in the permafrost regions of the Sub-arctic, the Boreal Forest, the Western Cordillera, and the Prairies. CCRN integrates these and other data to understand the changing regional climate and its effects on large-scale Earth system change and the region's major rivers - the Saskatchewan, Mackenzie and Peace-Athabasca.

The programme and its objectives are organized around five inter-related and inter-dependent Themes that address Earth system change and its numerical description and prediction at local, large river basin and regional climate system scales. The themes are as follows:

Theme A: Observed Earth System Change in Cold Regions - Inventory and Statistical Evaluation, documents and evaluates observed change, including hydrological, ecological, cryospheric, and atmospheric components, in the cold regions of interior northwestern Canada over a range of scales.

Theme B: Improved Understanding and Diagnosis of Local-Scale Change, improves our knowledge of local-scale change by developing new and integrative knowledge of Earth system processes, incorporating these processes into a suite of process-based integrative models, and using the models to better understand Earth system change.

Theme C: Upscaling for Improved Atmospheric Modelling and River Basin-Scale Prediction, improves large-scale atmospheric and hydrological models for weather, climate, and river basin-scale modelling and prediction of the changing Earth system and its feedbacks.

Theme D: Analysis and Prediction of Regional and Large-Scale Variability and Change, focusses on the driving factors for the observed trends and variability in large-scale aspects of the Earth system, their representation in current models, and the projections of regional-scale effects of Earth system change on climate, ecology, land, and water resources.

Theme E: Network Outreach and Engagement, engages a community of partners and users, including the public, local stakeholder groups, provincial and federal policy/decision makers, national and international research organizations, and other relevant groups, and disseminates the improved knowledge and tools within this extended community.

Resources

CCRN WECC observatories list and descriptions

Synthesis and information products

CCRN data and data access, including real-time data streaming

List of CCRN publications

Focused Research Projects

Observed Climatic and Environmental Change in Western Canada

As part of Theme A's objectives, the network has focused on summarizing and synthesizing the recent past changes in climate, landcover, terrestrial ecosystems, and water cycling across Western Canada. The synthesis has been published in Hydrology and Earth System Sciences (HESS) and an information brochure was developed to highlight the key aspects of the changes that have been observed, along with some of the recent extreme events that have affected the region.

HESS publication can be found here.

Information brochure can be found here.

2013 Alberta Flood

In late June 2013, intense rain fell for several days over a large area of the southern Canadian Rocky Mountain front ranges and foothills in Alberta, causing widespread flooding with severe and costly damages to many communities, mass evacuations, and loss of life. Shortly after, CCRN set out to examine the chain of events leading to this disaster, focusing on atmospheric conditions and flood meteorology, hydrological and land surface processes associated with the flood, water management and operational decision making aspects, and computer modelling and simulation of various aspects of the flood to improve future prediction of similar events.

The following link provides a summary of CCRN's research efforts in response to this massive flood, including a workshop on "Extreme Weather and Hydrology – Lessons Learned from the Western Canadian Floods of 2013 and Others", publications and media coverage.

Summary of CCRN research on flood

CCRN Flood Workshop overview

2014 Northwest Territories Extreme Fire Year (and other fires)

In 2014, the Northwest Territories (NWT) experienced the worst fire season on record. Hot and dry conditions throughout fall 2013 to summer 2014 led to 385 wildfires burning 3.4 million ha of northern boreal forest. The fires were predominately around the Great Slave Lake region, impacting a majority of the NWT residents. A 2-day workshop was organized to discuss priorities and planning for research in response to the widespread 2014 NWT fires.

Extreme fire years were experienced in subsequent years. A record-breaking fire year occurred in Saskatchewan in 2015 causing thousands to evacuate and a costly fire year occurred at Fort McMurray in AB in 2016 and is one of the costliest natural disasters to affect Western Canada. The frequency of these extreme fire years has prompted researchers to study the impacts and causes of these events as all three fire years had unique characteristics. This information will be available in the coming years, but below are a few resources already published and available.

2014 Northwest Territories Fires Workshop

Presentations

Boreal wildfire (skip to slide 15)

Atmospheric conditions associated with the extreme 2014 wildfire season in the Northwest Territories

Large-scale climatic settings for the 2016 Fort McMurray wildfire

Publication

Kochtubajda, B., R. Stewart and B. Tropea, 2016: Lightning and weather associated with the extreme 2014 wildfire season in Canada's Northwest Territories. 24th Intl. Lightning Detection Conf. and 6th Intl. Lightning Meteor. Conf, San Diego, April 18-19.

Special Observing and Analysis Period (SOAP) – Oct 1, 2014 – Sept 30, 2015

CCRN has conducted a Special Observation and Analysis Period (SOAP) across all of the WECC observatories during the period 1 October, 2014 to 30 September, 2015. This involved coordinated and enhanced field activities, site instrumentation, and observational programmes at all of the sites. The main purpose of this activity was to collect and archive a high-quality and consistent dataset of fine-scale hydrological, ecological, meteorological, and cryospheric process observations for a common period across our study region. The detailed observations will be complemented by regional climate model outputs and full resolution products over the WECC observatories to be archived as part of the SOAP initiative. This will allow for quantification and comparison of energy and water balances for the 2014-2015 hydrological year at WECC observatories and small watersheds across the domain, and will provide a high-quality dataset that can be used for model process algorithm development and testing.

In October 2016, a workshop was held in Saskatoon to review observations and insights from the SOAP and to plan common network scientific activities and data management/archiving. This led to plans to publish SOAP datasets as a collection of papers in a special issue of the journal Earth System Science Data, and plans to write a synthesis paper describing the hydrometeorological conditions over the year and the regional impacts on different sectors.

CCRN – Special Observing and Analysis Period Presentation

SOAP Workshop: Overview and Presentations

CCRN Research in Canada's National Parks

CCRN conducts research within five National Parks of Canada across the interior of Western Canada, including: Banff, Jasper, Yoho, Nahanni, and Prince Albert National Parks. The location of the WECC observatories in the National Parks provides a unique opportunity for researchers to conduct longer term studies in natural areas protected from development and other landscape-altering activities. Although the research efforts and objectives vary across the WECC observatories, there are some overlapping goals which allow for comparison within a region. For example, the Athabasca Glacier in Jasper National Park and Peyto Glacier in Banff National Park are evaluated against one another to identify similarities and differences in glacial retreat and impacts of climate change on glaciers in the Canadian Rockies.

The following document highlights CCRN's research efforts at the individual WECC observatories within the five National Parks of Canada. The overview includes a brief description and history of the WECC observatories, the research efforts made by CCRN, key researchers and some important resources.

Canadian Rockies Hydrological Observatory (CRHO)

Description

The Canadian Rockies Hydrological Observatory (CRHO) was established in 2012 and includes 35 high elevation snow and weather observations stations and streamflow stations in the headwaters of the Saskatchewan River Basin in Alberta. Three of the CRHO research sites are located within or nearby National Parks:

- Athabasca Glacier (Jasper National Park)
- Peyto Glacier (Banff National Park)
- Marmot Creek Research Basin (near Banff National Park)

These three stations are also part of the CCRN WECC observatories and are described in the document below.

Research Objectives

The CRHO aims to improve the understanding of and capacity to predict the changes in water yield from headwater basins where cold climate processes predominate. It will examine the water supply response to climate variability in a range of mountain headwater ecohydrological site types, incorporating the transient responses of both climate forcing and cryospheric and basin hydrological response. Particular attention will be paid to how snowpacks, glaciers, groundwater, wetlands, forests and frozen soils interact and modulate the response of water supply to variability in climate. An important component will be on downscaling climate model products over complex mountain terrain. The project will support improved water resource modelling and management over larger river basins such as the Saskatchewan River Basin by contributing advanced mountain headwater hydrological modelling capability and future flows under downscaled climate scenarios. It will do so by strengthening the hydrological and glaciological science foundation for estimating water resource impacts from future climate scenarios and by testing and improving hydrological models that can be used for current and future water resource assessments.

Resources

CRHO Website

YouTube video highlighting CRHO research efforts

Parks Canada
2014-15 Progress Re

Primary Researchers

John Pomeroy (hydrologist, University of Saskatchewan) – john.pomeroy@usask.ca

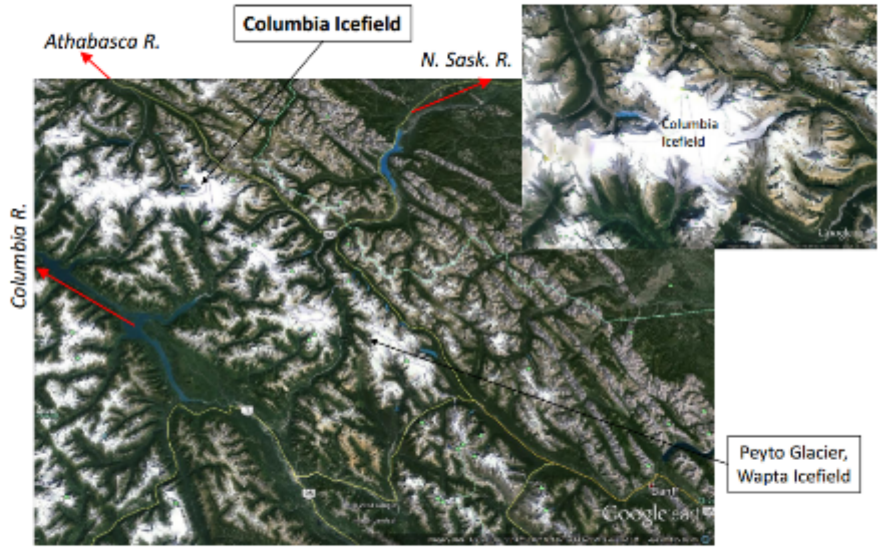
Warren Helgason (hydrologist, University of Saskatchewan) – warren.helgason@uask.ca

Cherie Westbrook (hydrologist, University of Saskatchewan) – cherie.westbrook@usask.ca

Jasper National Park

Columbia Icefield/Athabasca Glacier

Description



The Columbia Icefield is the largest icefield in the Canadian Rockies at over 200 km^2 and is located within the Banff and Jasper National Parks. Straddling the border of Alberta and British Columbia, the Columbia Icefield has numerous large outlet valley glaciers which are the headwater regions for three major river systems in North America which flow into three different oceans: Saskatchewan River (Hudson Bay/Atlantic Ocean), Columbia River (Pacific Ocean) and Mackenzie River (Arctic Ocean). The Columbia Icefield is a source of water for ecosystem functioning, hydro-power production, irrigation, groundwater recharge, and transboundary objectives.

Research Objectives

The research efforts are focused on quantifying the form and flow of the icefield in its outlet glaciers, as well as its past and current geometry. Currently, researchers are working towards developing regional glacier dynamic modelling capabilities and glacier hydrology studies. More recently, on-site meteorological stations were installed at high elevations on the Athabasca Glacier. Key activities include:

- Observation of glacier meteorology with two met stations (on and off the ice, and at different elevations; John Pomeroy)
- Focused micro-meteorology campaign run in 2015 (Warren Helgason & Jono Conway)
- History of glaciology work to examine mass balance and flow characteristics – extension of work from Peyto Glacier to conduct a more regional analysis (Mike Demuth)
- Modelling reconstruction of past and potential futures of Athabasca Glacier (Rituparna Nath & Shawn Marshall)
- Incorporation of glacier dynamics into the Cold Regions Hydrological Model (CRHM; Dhiraj Pradhananga & John Pomeroy)

Primary Researchers

Mike Demuth (glaciologist, Geological Survey of Canada/University of Victoria) – mike.demuth@canada.ca

John Pomeroy (hydrologist, University of Saskatchewan) – john.pomeroy@usask.ca

Warren Helgason (hydrologist, University of Saskatchewan) – warren.helgason@uask.ca

Shawn Marshall (glaciologist, University of Calgary) – shawn.marshall@ucalgary.ca

Key Results

Athabasca Glacier Retreat:

- In ~1824, the Athabasca Glacier terminus was near the location of the Icefield Center. Since then it has retreated ~2 km.
- The glacier can exhibit a horizontal, down-valley surface velocity of 7-25 cm per day, or 25-100 m per year.
- The long-term average in annual length loss is 12 m/year (over 170 years), but has been considerably more in recent years (15-20 m/year).

Modelling:

- MSc candidate Rituparna Nath (supervisor: Shawn Marshall) is working on reconstructing the past (back to ~1850) and potential futures of the Athabasca Glacier using modelling techniques. See poster below in publications.
- Glacier dynamics are now being incorporated into models (specifically Cold Regions Hydrological Model; CRHM; John Pomeroy group)

Glacier Response to Climate Change (general analysis for Canadian glaciers):

- Local to regional warming due to changes in albedo, loss of latent energy buffer and loss of cold air flows down glacial valleys
- Rapid disintegration, fragmentation of many glaciers
    - Lower parts of many glaciers will be gone within decades or less (longer probably for larger glaciers)
- Upland icefields may persist longer but in a diminished state
- Increased, then reduced glacial inputs to streamflow (likely already declining in the south during July/Aug; currently increasing in Sept/Oct)
- Meltwater runoff will be flashier as firn/snow decline
- Streamflow will become more pluvial (rainfall) regime (high elevations)
- Reduced buffering capacity for summer streamflow
- Progressively warmer streams

Resources

Real-time Data – Athabasca Glacier Moraine

Real-time access to the meteorological station at the Athabasca Glacier moraine can be found here: http://giws.usask.ca/telemetry/ (Telemetry Sites menu > AB Remote Stations > Athabasca).

Deglaciation Animations

Garry Clarke, Professor Emeritus at UBC, has developed deglaciation animations based on work published in Nature Geoscience in 2015 (see link to publication below). The following is a link to the directory where you can view deglaciation animations for a range of glaciers in the Rocky Mountains under various emission scenarios as well as using different Generalized Circulation Models (GCMs): http://couplet.unbc.ca/data/RGM_archive/RGM_movie_archive/ . A description on how to maneuver the directory is available here:

Deglaciations Animations Director

Publications

Andrius Paznekas & Masaki Hayashi (2016) Groundwater contribution to winter streamflow in the Canadian Rockies, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 41:4, 484-499, DOI: 10.1080/07011784.2015.1060870

Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. Nature Geoscience, 8(5), 372-377, DOI: 10.1038/ngeo2407

Demuth, M.N. et al. (2012) Recent and past-century volume, mass and morphometric changes of the Columbia Icefield, Canada: http://www.usask.ca/hydrology/downloads/Demuth_et_al_2012.pdf

Demuth, M.N. et al. (2012) State and Evolution of Canada's Glaciers: http://www.usask.ca/hydrology/downloads/Demuth_et_al_2012b.pdf

Marshall, S. J., White, E. C., Demuth, M. N., Bolch, T., Wheate, R., Menounos, B., ... & Shea, J. M. (2011). Glacier water resources on the eastern slopes of the Canadian Rocky Mountains. Canadian Water Resources Journal, 36(2), 109-134, DOI: 10.4296/cwrj3602823

Nath, R., Marshall, S., Osborn, G. & Hall-Beyer, M. (2016) Using flow line modelling and GIS to reconstruct glacier volume loss Athabasca Glacier, Canadian Rockies since the Little Ice Age, *poster presentation at CCRN Annual General Meeting Nov 2016*,

Nath_Poster_Athabasca Glacier_UofC.p

Sandford, R.W. (2016) *The Columbia Icefield 3rd Edition*. Victoria, BC: Rocky Mountain Books.

Presentations

- Atmospheric boundary layer dynamics; drivers and implications for surface lapse rates over Athabasca Glacier, Columbia Icefield
- National framework for glacier monitoring & assessment
- Mountain SOAP 2014-2015

- Western Cordillera

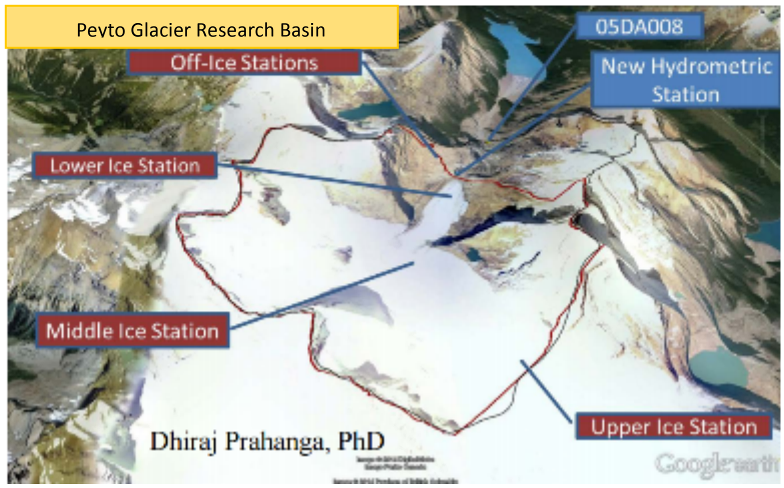
Other

Water Brothers TV Series**:** Dr. John Pomeroy and Robert Sandford were featured in the episode "On Thin Ice" talking about the Athabasca Glacier.

Columbia Icefield
and Athabasca Glaci

Banff National Park

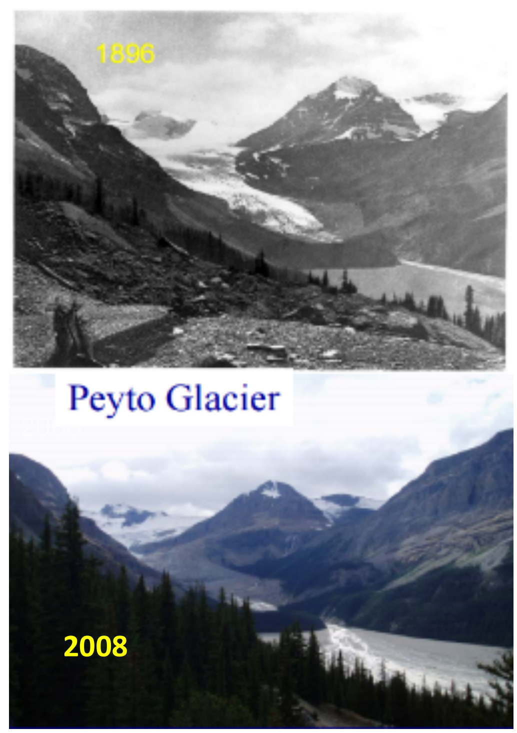
Peyto Glacier (Wapta Icefield)



Description

Peyto Glacier descends from the north-eastern portion of the Wapta Icefield located in the Banff National Park and the meltwater flows in the North Saskatchewan River system. There is a long history of research at this glacier with a mass balance programme being established in 1966 as part of the International Hydrological Decade. Natural Resources Canada has carried out observations of surface mass balance and runoff since then.

The research area is 24 km^2 and has an elevation range for 2100 to 3150 m. Monitoring equipment includes a single meteorological station within the basin adjacent to Peyto Glacier and three stations located on the glacier surface representing different elevation zones. Streamflow records were collected for Peyto Creek, but the gauge was destroyed in July 1983. The Centre for Hydrology, University of Saskatchewan has since resumed these streamflow measurements.



Research Objectives

Peyto Glacier has undergone considerable negative mass balance, downwasting and terminal retreat over the previous 50+ years. The site remains a focal point for wide range of glaciological and hydrological research, including:

- Measurement and observation of glacier meteorology (stations on and off the ice, at different elevations)
- Measurement and observation of streamflow of Peyto Creek
- Development of glacier dynamics in the Cold Regions Hydrological Model (CRHM)
- Mass balance observation carried out by Geological Survey of Canada

- Nearby sites (i.e. Helen Creek) examine groundwater flow paths and dynamics (information included in presentations below)

Primary Researchers

John Pomeroy (hydrologist, University of Saskatchewan) – john.pomeroy@usask.ca

Mike Demuth (glaciologist, Geological Survey of Canada/University of Victoria) – mike.demuth@canada.ca

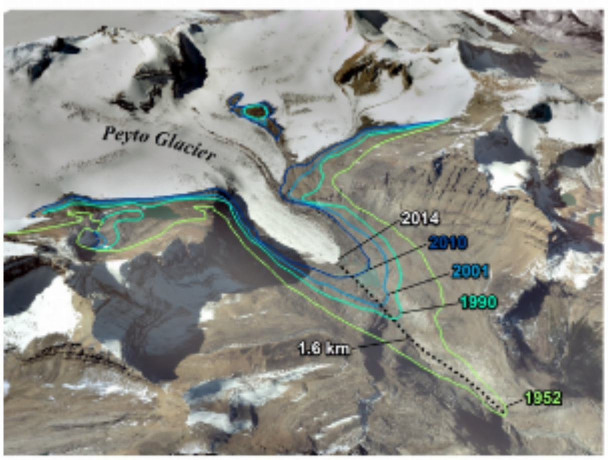
Key Results

Peyto Glacier Retreat:

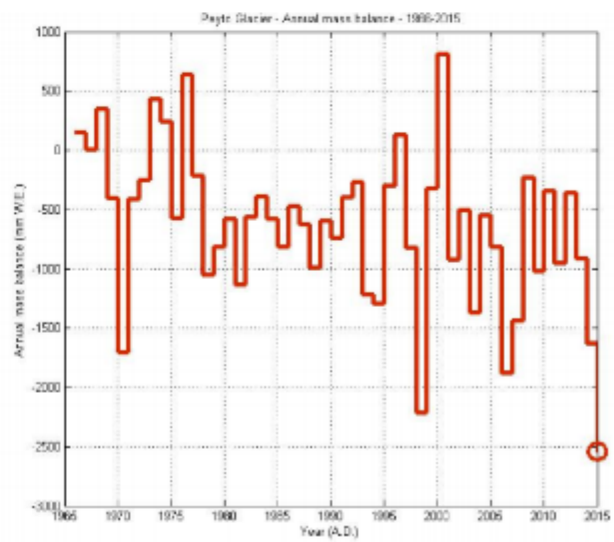
- Between 1952 and 2014, Peyto Glacier retreated 1.6 km.

Peyto Glacier Response to 2015 Drought:

- Precipitation was -150 mm below normal and 1.5 C warmer than normal in icefields, leading to a record negative glacier mass balance at Peyto Glacier (-2500 mm) and early summer glacier streamflow discharge was almost double the long term average.



L: Peyto Glacier retreated 1.6 km from 1952 to 2014.



R: In 2015, a record was made for loss of glacial mass in a single year.

Resources

Real-time Data – Banff National Park (Peyto Moraine, Bow Hut, Helen Creek)

Real-time access to the meteorological stations in Banff National Park can be found here: http://giws.usask.ca/telemetry/ (Telemetry Sites menu > AB Remote Stations > Peyto Moraine OR Bow Hut OR Helen Creek).

Publications

Bash, E. A., & Marshall, S. J. (2014). Estimation of glacial melt contributions to the Bow River, Alberta, Canada, using a radiation–temperature melt model. *Annals of Glaciology*, 55(66), 138-152. DOI: 10.3189/2014AoG66A226

Demuth, M.N. et al. (2012) State and Evolution of Canada's Glaciers: http://www.usask.ca/hydrology/downloads/Demuth_et_al_2012b.pdf

Marshall, S. J., White, E. C., Demuth, M. N., Bolch, T., Wheate, R., Menounos, B., ... & Shea, J. M. (2011). Glacier water resources on the eastern slopes of the Canadian Rocky Mountains. Canadian Water Resources Journal, 36(2), 109-134, DOI: 10.4296/cwrj3602823

Paznekas, A. & Hayashi, M. (2016) Groundwater contribution to winter streamflow in the Canadian Rockies, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 41:4, 484-499, DOI: 10.1080/07011784.2015.1060870

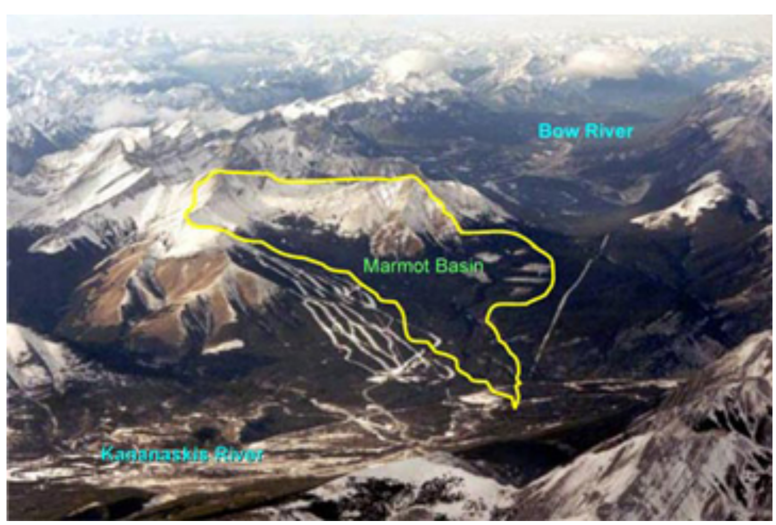
Presentations

- Marmot Creek, Peyto Glacier and the Canadian Rockies Hydrological Observatory
- Groundwater process studies in alpine and prairie watersheds
- A glacier snow and ice hydrological model for CCRN
- CRHM-glacier for CCRN Peyto Glacier Research Basin
- CRHM-glacier for CCRN Peyto Glacier Research Basin – Glacier Change
- Mountain SOAP 2014-2015
- Cold regions processes, multiscale modelling and change diagnosis
- Western Cordillera
- (of interest) Energy and mass balance of Haig glacier, Canadian Rockies

Marmot Creek Research Basin (near Banff National Park)

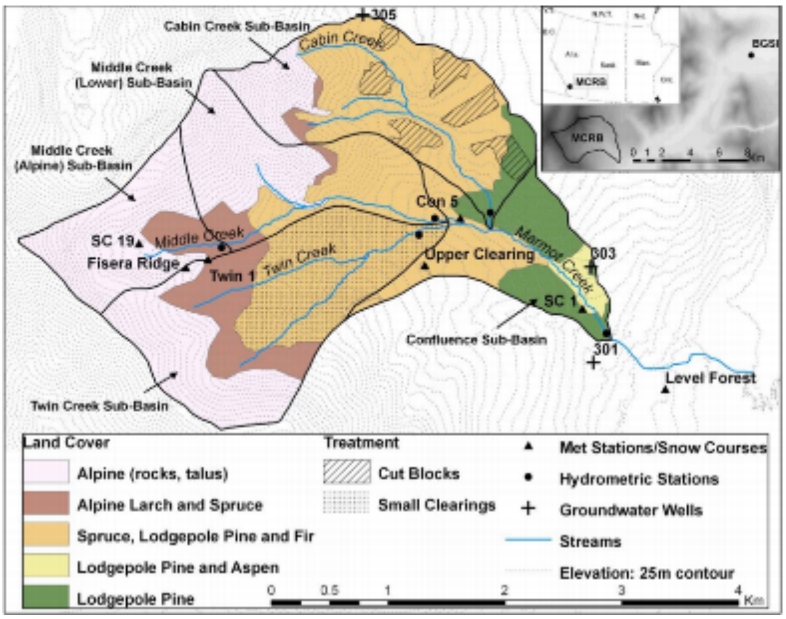
Description

Marmot Creek Research Basin (MCRB) is located in the Kananaskis Valley is a tributary to the Bow River. Although this research site is not within one of Canada's National Parks, the close proximity of the research site can still provide insights into the past, current and future changes the Canadian Rockies are experiencing. It was established in 1962 as a part of the



International Hydrological Decade to study the hydrological effects of forest management. The program ended in 1986 for the development of the Nakiska Ski resort, but subsequent monitoring program was re-established in 2005 by the Centre for Hydrology, University of Saskatchewan.

MCRB is ~9.4 km2 in size and covers various topographic descriptions, including alpine, subalpine, montane, clear-cut and meadow areas. The average annual precipitation is +600 mm with 70% being snowfall and ~50% runs off and contributes to streamflow. The MCRB has 3 sub-basins of roughly equal area (Twin, Middle, and Cabin Creeks) and is heavily instrumented with ten meteorological stations (range of elevation: 1450-2500 m, cover various surface cover types and orientations), groundwater wells, snow pillows and seasonal pressure transducers on each tributary and gauge/weir at the outlet (operated by Water Survey of Canada). There are also two 30 m instrumented towers (forest and clearing) with profile measurements and weighed hanging tree and half a dozen groundwater wells in and adjacent to the basin (operated by Alberta Government).



For more information, visit the Centre for Hydrology webpage on MCRB at: http://www.usask.ca/hydrology/MarmotBasin.php

Research Objectives

MCRB is an outdoor research laboratory used to investigate the principles of mountain hydrology and the influences of forest management on streamflow generation. With its long-term records of high altitude streamflow, precipitation, snowpack, groundwater, vegetation and mountain meteorology observations, it continues to provide a unique asset to support the improved understanding of environmental change in the Canadian Rockies. Research currently focus on mountain snow processes, hydrochemistry, hydrological and hydrogeological modelling (including analysis of hydro-climatic trends and sensitivity to climate change), and the hydrological impacts of changes in forest cover.

Primary Researcher

John Pomeroy (hydrologist, University of Saskatchewan) – john.pomeroy@usask.ca

Resources

Real-time Data

Real-time access to the five meteorological stations in Marmot Creek Research Basin can be found here: http://giws.usask.ca/telemetry/ (Telemetry Sites menu > AB Marmot Creek). These sites vary in altitude (1437m to 2325 m) as well as topographic cover.

Analysis of 2013 Alberta Flood

CCRN conducted an in-depth analysis of the 2013 June flood that affected large areas in Alberta. Although the MCRB was heavily impacted by the rain event which washed away hydrometric stations and caused a shift in the morphology of channels, the meteorological stations captured the event in its entirety. The following summarizes CCRN's publications, workshop presentations and media coverage in response to this event: http://www.ccrnetwork.ca/science/2013-Alberta-flood/index.php

Publications

For key resources, information and publications: http://www.usask.ca/hydrology/ListMarmotPubs.php

Fang, X., & Pomeroy, J. W. (2016). Impact of antecedent conditions on simulations of a flood in a mountain headwater basin. *Hydrological Processes*, *30*(16), 2754-2772, doi: 10.1002/hyp.10910

Harder, P., Pomeroy, J. W., & Westbrook, C. J. (2015). Hydrological resilience of a Canadian Rockies headwaters basin subject to changing climate, extreme weather, and forest management. *Hydrological Processes*, 29(18), 3905-3924. DOI: 10.1002/hyp.10596

Pomeroy, J. W., Fang, X., & Rasouli, K. (2015) Sensitivity of snow processes to warming in the Canadian Rockies, *72nd Eastern Snow Conference*

Rothwell, R., Hillman, G., & Pomeroy, J. W. (2016). Marmot Creek Experimental Watershed Study. *The Forestry Chronicle*, 92(1), 32-36, doi: 10.5558/tfc2016-010

Siemens, E. (2016) Effects of climate variability on hydrological processes in a Canadian Rockies headwater catchment, MSc Thesis, University of Saskatchewan.

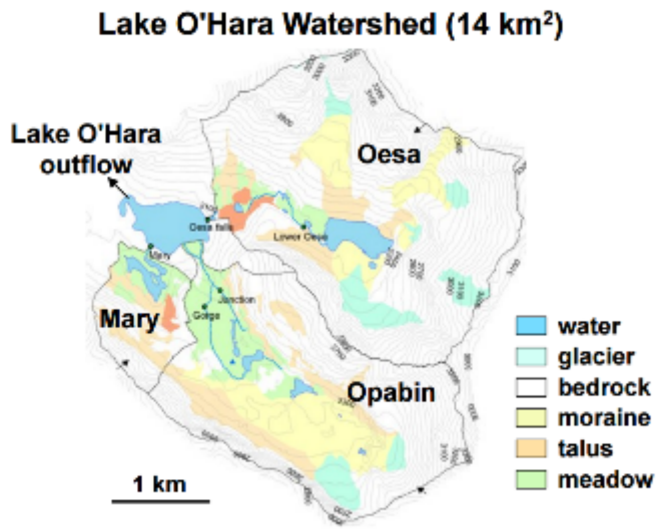
Presentations

- Mountain hydrology modelling at Marmot Creek Research Basin
- Vegetation change and antecedent conditions
- Marmot Creek, Peyto Glacier and the Canadian Rockies Hydrological Observatory
- Snow and glacier change
- Fine-scale sensitivity analysis of mountain hydrology to transient climate, vegetation, and soil changes
- Mountain SOAP 2014-2015
- Comparing and contrasting regional hydrological change in the CCRN domain
- Canadian Rockies and Alberta flood of June 2013
- Western Cordillera
- Baseline runs of the Canadian Land Surface Scheme at CCRN WECC observatories

Yoho National Park

Lake O'Hara

Description



Lake O'Hara is a small watershed (14 km^2) located in Yoho National Park and is representative of alpine headwater catchments in the Canadian Rockies. Approximately 20% of the watershed is sub-alpine coniferous forest and 80% is alpine (exposed bedrock, talus slopes, glacial moraine material and a very small amount of glacier ice cover – Opabin Glacier). The research basin was established in 2004 by the University of Calgary with the permission and assistance from Parks Canada.

The research site is heavily instrumented and includes: two weather stations, five stream gauging stations, and two lake water level stations. Annual snow surveys are conducted at maximum accumulation since 2006 and include 1200-1500 depth points and 200-300 density measurements. There has also been an intensive characterization of subsurface materials and structure by geophysical imaging.

Research Objectives

Research at the Lake O'Hara site focuses on snow hydrology, groundwater hydrology, stream-groundwater interaction, alpine permafrost and glacier mass and energy balance. Dr. Hayashi is continuing with the long-term monitoring of hydrometeorological fluxes in the key locations. There are also efforts being made to examine whether the process understanding from Lake O'Hara is transferrable to other watersheds having different geological and topographic characteristics (Helen Creek in Banff National Park and Bonsai Lake in Kananaskis).

The research conducted at this site has been done in close collaboration with Parks Canada, who have helped facilitate access, provide logistical support, and allow this research to be conducted in this pristine environment.

Primary Researcher

Masaki Hayashi (hydrologist, University of Calgary) – hayashi@ucalgary.ca

Resources

Publications

Hood, J. (2013) Quantifying snowmelt inputs in an alpine watershed for the purpose of investigating the role of groundwater storage, MSc Thesis, University of Calgary.

Hood, J. L., & Hayashi, M. (2015). Characterization of snowmelt flux and groundwater storage in an alpine headwater basin. Journal of Hydrology, 521, 482-497. DOI: 10.1016/j.jhydrol.2014.12.041

Langston, G., Hayashi, M., & Roy, J. W. (2013). Quantifying groundwater-surface water interactions in a proglacial moraine using heat and solute tracers. *Water Resources Research*, 49(9), 5411-5426. DOI: 10.1002/wrcr.20372

Paznekas, A. & Hayashi, M. (2016) Groundwater contribution to winter streamflow in the Canadian Rockies, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 41:4, 484-499, DOI: 10.1080/07011784.2015.1060870

Presentations

- Lake O'Hara during SOAP year (2014-2015)
- Lake O'Hara Research Basin: Groundwater (skip to slide 11)
- Potential Roles of Groundwater in Mitigating or Exacerbating the Impacts of Floods
- Opabin Glacier and moraine
- Lake O'Hara Research Basin

Other

Andrius Paznekas research was featured in CCRN's May 2016 Newsletter (pg 8)

Nahanni National Park

Brintnell-Bologna Icefield

Description

The Brintnell-Bologna Icefield is located approximately 350 km west of Fort Simpson, NWT and covers ~ 30 km^2. The geographic location in the high peaks of the Ragged Range acts to intercept moisture from the Pacific and results in high snowfalls and cold year-round temperatures which maintains the icefield and two outlet glaciers. The Brintnell-Bologna Icefield drains into the South Nahanni and Flat Rivers which feeds into the Liard River and ultimately the Mackenzie River. The mean annual temperature is estimated to be -11 ˚C on the icefield plateau region.

Two meteorological stations were recently installed at the Bologna Glacier in August 2014: the Ice Station (University of Victoria) the Nunatak Station (University of Saskatchewan).

Research Objectives

The impact of climate change on glacier hydrology in Canada's continental North is unknown. Given glaciers in the region have significant influence on the timing and magnitude of streamflow and local ecosystems rely on glaciers, it is important to further our understanding of the state and fate of Canada's glaciers.

Research efforts at the Brintnell-Bologna Icefield include:

- Comparison of glacier change with hydrometric and climatic variations;
- Document and characterize hydrological regime shifts in relation to glacier decline (South Nahanni and Flat Rivers);
- Modelling to identify the changes in multi-decadal streamflow contributions;
- Improve the understanding of synoptic and local controls on glacier accumulation and ablation processes.

Key Researchers

Mike Demuth (glaciologist, Geological Survey of Canada/University of Victoria) – mike.demuth@canada.ca

John Pomeroy (hydrologist, University of Saskatchewan) – john.pomeroy@usask.ca

Key Results

Based on Emily Anderson's MSc research at the University of Saskatchewan (supervisors John Pomeroy & Mike Demuth) – upcoming defense at end of April 2017.

Climate change (1979-2015):

- 5% Increase in rainfall ratio of annual precipitation (25% to 30%)
- Average daily maximum temperature increased 0.5 ˚C
- Decline in spring (March, April, May) precipitation of 24 mm

Bologna Glacier Change (1984 to 2014):

- 14% decline in glacier area (18.7 km^2 to 16 km^2)
- Decline in firn area (82% to 47%)
    - Decrease in accumulation area, increase in ablation area
    - During the 2015 field season, it was observed that the firn was entirely gone
- 150% increase in exposed ice area (5.2 km^2)
- 42 m decline in surface elevation (on average)

Glacier Hydrology (1980-2015):

Based on model results using the Cold Regions Hydrological Model (CRHM)

- Total discharge and ice melt have increased
- Glacier wastage contributes 35-53% to discharge (wastage is any glacier melt beyond zero mass balance)
- Overall glacial loss between 9 m to 20.3 m water equivalent (from 1980 to 2015)
    - Range in glacial loss is due to various model runs using different configurations

Regional Impact:

The Bologna Glacier feeds into the South Nahanni River at Virginia Falls. It has been estimated that the Bologna Glacier contributes 4.1% to 7.0% to total streamflow. It should be noted that this is likely an overestimation as it is quite high when compared to glaciers of similar size in the literature.

Resources

Publications

Demuth, M.N, Wilson, P., Haggarty, D. (2014) Glaciers of the Ragged Range, Nahanni National Park Reserve, Northwest Territories, Canada,

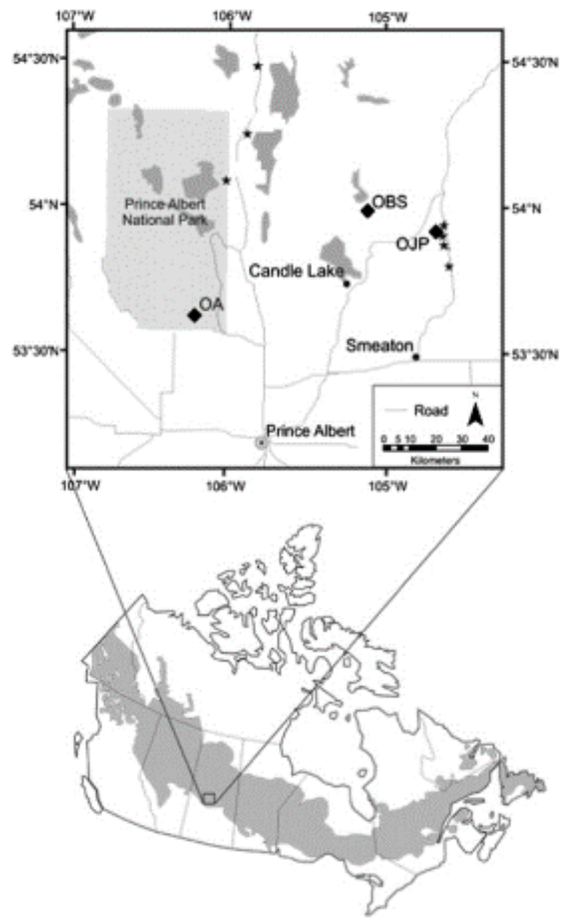
Presentations

- Modelling changes in multi-decadal streamflow contributions – Bologna Glacier, Selwyn Mountains, NWT (skip to slide 17)
- Brintnell-Bologna Icefield (skip to slide 13)

Prince Albert National Park

Boreal Ecosystem Research and Monitoring Sites (BERMS)

Description



The Boreal Ecosystem Research Monitoring Sites (BERMS) study area is located near the southern edge of the boreal forest in the Boreal Plains Ecozone, just to the north of Prince Albert, Saskatchewan. It is a joint initiative of Environment Canada, NRCan, Parks Canada, University of Saskatcheawn, University of British Columbia and Queens University. BERMS project began in 1996 and was to initially study the carbon, water, and energy cycles of the Boreal Forest and later included the role of forest disturbance.

BERMS consists of four main sites: Old Jack Pine (OJP), Old Aspen (OA), Old Black Spruce (OBS), and Fen. Each site includes scaffold flux towers to measure various meteorological parameters and fluxes. In addition, ground and surface water are monitored through stream gauging, continuous lake level measurements as well as piezometers. A data catalogue can be found here.

Research Objectives

BERMS primary science goal is to understand the carbon and water balance of the Canadian Boreal Forest. Specific investigations include:

- Characterization of ecosystem resilience of southern boreal forests in relation to variation in climate averages and extremes, with particular emphasis on the effects of hydrology and soil properties;
- Analysis of the climatic, hydrologic and biophysical processes that govern water, energy and carbon balances at the stand level;
- Synthesis, integration and upscaling of stand scale processes to watershed scales by developing improved hydrological models for application to the Boreal Plains ecozone and within the wider Saskatchewan River Basin;
- Simulation of ecosystem responses of upland forest stands to environmental stressors such as climate change and air pollution using a dynamic coupled biogeochemical-vegetation model.

Watch a YouTube video highlight the research efforts at the BERMS site: https://www.youtube.com/watch?v=0I9TX97GBsg&t=69s

Primary Researchers

Alan Barr (Climate Processes Section, Environment and Climate Change Canada) – alan.barr@canada.ca

Andrew Ireson (hydrologist, University of Saskatchewan) – andrew.ireson@usask.ca

Jill Johnstone (ecologist, University of Saskatchewan) – jill.johnstone@usask.ca

Andy Black (biometeorologist, University of British Columbia) – andrew.black@ubc.ca

Resources

Publications

Barr, A. V., Van der Kamp, G., Black, T. A., McCaughey, J. H., & Nesic, Z. (2012). Energy balance closure at the BERMS flux towers in relation to the water balance of the White Gull Creek watershed 1999–2009. *Agricultural and forest meteorology*, 153, 3-13, doi: 10.1016/j.agrformet.2011.05.017

Chen, L., Li, Y., Chen, F., Barr, A., Barlage, M., & Wan, B. (2016). The incorporation of an organic soil layer in the Noah-MP land surface model and its evaluation over a boreal aspen forest. Atmospheric Chemistry and Physics, 16(13), 8375-8387. doi: 10.5194/acp-16-8375-2016

Gaumont-Guay, D., Black, T. A., Barr, A. G., Griffis, T. J., Jassal, R. S., Krishnan, P., ... & Nesic, Z. (2014). Eight years of forest-floor CO 2 exchange in a boreal black spruce forest: Spatial integration and long-term temporal trends. Agricultural and Forest Meteorology, 184, 25-35. DOI: 10.1016/j.agrformet.2013.08.010

Hogg, E. H., Barr, A. G., & Black, T. A. (2013). A simple soil moisture index for representing multi-year drought impacts on aspen productivity in the western Canadian interior. *Agricultural and forest meteorology*, 178, 173-182. DOI: 10.1016/j.agrformet.2013.04.025

Ireson, A. M., Barr, A. G., Johnstone, J. F., Mamet, S. D., van der Kamp, G., Whitfield, C. J., ... & Chun, K. P. (2015). The changing water cycle: the Boreal Plains ecozone of Western Canada. *Wiley Interdisciplinary Reviews: Water*, 2(5), 505-521. DOI: 10.1002/wat2.1098

Mamet, S. D., Chun, K. P., Metsaranta, J. M., Barr, A. G., & Johnstone, J. F. (2015). Tree rings provide early warning signals of jack pine mortality across a moisture gradient in the southern boreal forest. *Environmental Research Letters*, 10(8), 084021. DOI: 10.1088/1748-9326/10/8/084021

Presentations

- Boreal Ecosystem Research & Monitoring Sites current and future process observations
- Vegetation Dynamics in the Western Boreal Forest
- BERMS results during SOAP (Oct 1, 2014- Sept 30, 2015)
- BERMS Research Group - Climate Sensitivity in the Southern Boreal Forest
- BERMS Observatory in the Southern Boreal Forest
- Update on modelling studies in the Prairies and Boreal Forest

- Land-surface modelling of observations from BERMS sites and its application to regional climate modelling
- Baseline runs of the Canadian Land Surface Scheme at CCRN WECC observatories
- Accounting for the hysteretic affect in canopy conductance modelling
- Water vapour and CO_2 flux research at BERMS Old Aspen and Old Black Spruce
- 2015 Ecology Theme Update
- Ecology Theme Update (2016)
- Seasonal and annual ET at the BERMS sites & the “C connection”

Atmospheric and Large-scale Hydrological Modelling over CCRN Domain

Primarily under Themes C and D, CCRN is aiming to address Earth system change at large river basins and regional climate system scales. The key science questions include:

- How can our large-scale predictive models be improved to better account for the changing Earth system and atmospheric feedbacks?
- What governs the observed trends and variability in large-scale aspects of the Earth system and how well are these factors and effects represented in current models?
- What are the projected regional scale effects of Earth system change on climate, land and water resources?

Substantial progress has been made with answering these questions and a majority of the deliverables will be available leading up to the end of the program in March 2018. The following provides a brief overview of the large-scale modelling efforts being made by CCRN over the Saskatchewan River Basin (SRB) and Mackenzie River Basin (MRB).

High Resolution Climate Modelling

Overview

Several studies have indicated that one of the expected results of climate change will be an intensification of the water cycle due to the enhanced moisture available in a warmer climate. The on-going science suggests that these warming trends are resulting to substantial recent observed changes in the hydro-climatic regimes of major river basins in western Canada. Changes in the timing and magnitude of river discharge, shifts in extreme temperature and precipitation regimes, and changes in snow and ice regimes are anticipated.

Most climate predictions have a low resolution (>100 km) and lack the representation of topographic and convective precipitation resulting in considerable uncertainty regarding the magnitude of the intensification and its seasonal dependence. Ground-based measurements are limited especially over the Rocky Mountains, and suffer from gross inaccuracies associated with cold climate processes.

Leading research from Dr. Yanping Li has advanced our understanding of future climate conditions at high resolutions using the Pseudo-Global Warming (PGW) method and dynamically downscaling the data using the Weather Research and Forecasting (WRF) Model at 4 km grid spacing. This methodology provides researchers and users with water, weather and climate information needed to make informed decisions at local and regional scales.

Research Objectives

The major science objectives within this overarching goal are:

1) To assess the ability of a convection-permitting simulation at 4-km to reproduce orographic and convective precipitation over western Canada;

2) To assess future changes in seasonal precipitation, temperature, and snowpack and associated surface hydrological cycles along with their regional variability across the different eco-regions in response to the CMIP5 projected 2071–2100 climate warming; and
3) To inform earth system model development over this region by providing more reliable fine-scale inputs for model performance evaluation. These new tools will help in diagnosing and predicting change over western Canada.

Summarily, this work should contribute towards our fundamental understanding of the full water cycle, including ground and surface water processes, water resource, and snowpack changes, and the impacts of climate change over western Canada.

This work is expected to be published later in 2017 and an information brochure will be available May 2017.

Primary Researchers

Yanping Li (University of Saskatchewan) – yanping.li@usask.ca

Ronald Stewart (University of Manitoba) – ronald.stewart@umanitoba.ca

Julie Thèriault (Universitè du Quèbec à Montrèal) - theriault.julie@uqam.ca

Changes in Temperature and Precipitation

The following figures show the changes in temperature and precipitation between two climatic periods: 1976-2005 (HIST) and 2071-2100 (PGW). The future climate conditions were obtained by using the highest radiative forcing scenario (RCP8.5) from Assessment Report 5 of the Intergovernmental Panel on Climate Change (IPCC).

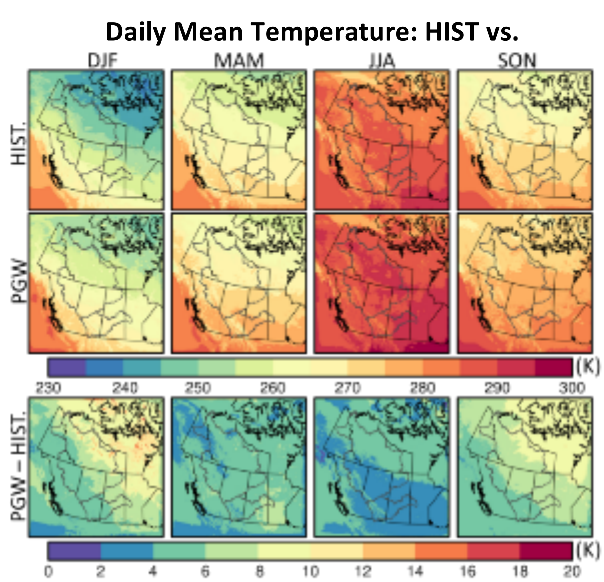


Figure: Spatial evolution of seasonal mean temperatures between historical and future climate

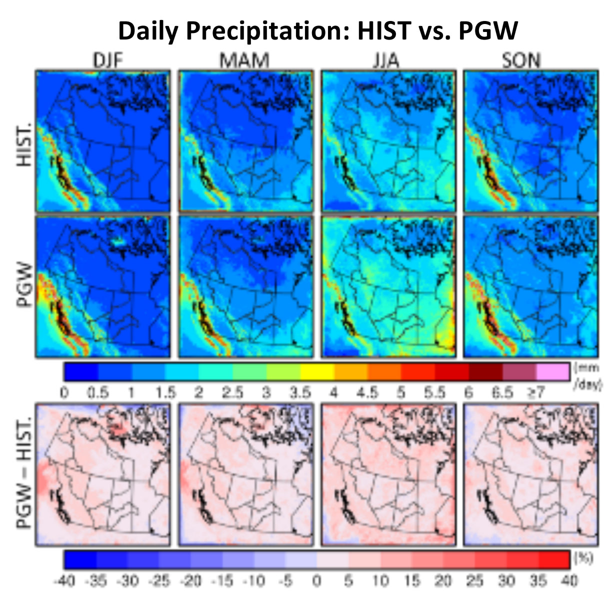


Figure: Spatial pattern of seasonal precipitation between historical and future climate scenarios.

Results from this experiment indicate that mean precipitation will likely increase over Western Canada alongside an increase in mean temperature. Also, both precipitation and temperature extremes are projected to intensify with enhanced radiative forcing (data not shown here –poster below).

See attached poster for more information.

PGW_WRF_Asong_2017.pdf

Other Climate Modelling Initiatives

There are numerous other climate modelling initiatives undertaken by CCRN researchers, including:

- Feedback of land-use change to regional climate over the Canadian Prairies
- Analysis of biased-corrected precipitation gauge observations across the US-Canada border
- Convection initiation mechanisms over the Canadian Prairie in summertime (impacts of severe thunderstorms and possibility of flooding)
- How the ensemble behaviours of the convection over tropical Pacific "remotely control" the hydrological cycle over the Canadian Prairies
- Examine factors leading to precipitation and related extremes across the region as well as their trends and future occurrence
    - Extreme precipitation across the region (including forest fires, flooding, drought)
    - The 'climate' of near 0 C precipitation
    - Precipitation in the lee of the mountains

Resources

Publications

Chen, L., Li, Y., Chen, F., Barr, A., Barlage, M., & Wan, B. (2016). The incorporation of an organic soil layer in the Noah-MP land surface model and its evaluation over a boreal aspen forest. *Atmospheric Chemistry and Physics*, 16(13), 8375-8387. doi: 10.5194/acp-16-8375-2016

Liu, A., Mooney, C., Szeto, K., Thériault, J. M., Kochtubajda, B., Stewart, R. E., Boodoo, S., Goodson, R., Li, Y., & Pomeroy, J. (2016). The June 2013 Alberta Catastrophic Flooding Event: Part 1–Climatological aspects and hydrometeorological features. *Hydrological Processes*.

Kochtubajda, B., Stewart, R. E., Boodoo, S., Thériault, J. M., Li, Y., Liu, A., ... & Szeto, K. (2016). The June 2013 Alberta Catastrophic Flooding Event–Part 2: Fine-scale precipitation and associated features. *Hydrological Processes*. DOI: 10.1002/hyp.10855.

Kotchtubajda, B., Mooney, C., Stewart, R. (2017) Characteristics, atmospheric drivers and occurrence patterns of freezing precipitation and ice pellets over the Prairie Provinces and Arctic Territories of Canada: 1964-2005. *Atmospheric Research*, 191 (2017), 115-127, doi: 10.1016/j.atmosres.2017.03.005

Pomeroy, J. W., Stewart, R. E., & Whitfield, P. H. (2016). The 2013 flood event in the South Saskatchewan and Elk River basins: Causes, assessment and damages. *Canadian Water Resources Journal/Revue canadienne des ressources hydriques*, *41*(1-2), 105-117.

Scaff, L., Yang, D., Li, Y., & Mekis, E. (2015). Inconsistency in precipitation measurements across the Alaska–Yukon border. *The Cryosphere*, 9(6), 2417-2428. DOI: 10.5194/tc-9-2417-2015

Presentations

See Theme D Workshop Presentations

- Convection-permitting WRF historical and pseudo-global warming simulations over CCRN region
- Annual update – Yanping Li

Large-Scale Hydrological Modelling: Saskatchewan and Mackenzie River Basins

Overview

Accurate simulation of river streamflow is essential for water resources management and climate change impact studies. CCRN researchers are improving the simulations within the Saskatchewan River Basin (SRB) and Mackenzie River Basin (MRB) using the Modèlisation Environmentale Communautaire Surface and Hydrology (MESH) model. There are numerous National Parks within the headwater region of the SRB as well as throughout the MRB.

Research Objectives

Significant progress has been made in setting up large-scale models of the SRB and MRB and improving simulation performance, as a precursor to running scenarios of change and evaluating land-atmosphere feedbacks. CCRN recently held a Scenarios of Change Workshop in which included defining plausible alternative future scenarios of landscape change to incorporate into our models to examine outcomes, responses, and feedbacks. Deliverables from this research initiative will be available in 2018.

Primary Researchers

Howard Wheater (University of Saskatchewan) – howard.wheater@usask.ca

Resources

Presentations

See 2016 Modelling Workshop & Scenarios of Change Workshop Presentations

- Modelling the hydrology and streamflow of the Mackenzie River Basin (MRB)
- Saskatchewan River Basin Hydrological Modelling – CCRN Modelling Workshop

SRB_MESH_2014.pdf

MRB_MESHmodelling_2016.pdf