The Changing Cold Regions Network:

Observation, Diagnosis, and Prediction of Environmental Change in the Saskatchewan and Mackenzie River Basins

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Global Institute for Water Security & Centre for Hydrology

University of Saskatchewan

Saskatoon, Canada

GEWEX Water Availability Grand Challenge for North America Workshop

Columbia, Maryland, USA

3 May, 2016

CCRN: Changing Cold Regions Network

Funded by the Natural Science and Engineering Research Council, Climate Change and Atmospheric Research initiative
2013-2018

*"This Network aims to **understand, diagnose and predict** interactions amongst the cryospheric, ecological, hydrological, and climatic components of **the changing Earth system** at multiple scales with a geographic focus on **Western Canada's rapidly changing cold interior**."*

Network Development

- CCRN has developed a large, multi-disciplinary team of researchers
  - 42 investigators and 136 students, post-doctoral fellows, and other HQP from 8 Canadian universities and 4 federal government agencies
  - International collaboration includes 18 scientists from Germany, France, the U.S., U.K., and China

- Linked to GEWEX, CLiC, GEO, NCAR, NASA, and more
  - In December 2014, the World Climate Research Programme endorsed CCRN as a GEWEX Regional Hydroclimate Project

List of CCRN Participants

Network Co-Investigators and Collaborators

- Vivek Arora (Env. Can.)
- Jenifer Baltzer (Wilfrid Laurier U.)
- Alan Barr (Env. Can.)
- Paul Bartlett (Env. Can.)
- Aaron Berg (U. Guelph)
- Andy Black (U. British Columbia)
- Barrie Bonsal (Env. Can.)
- **Sean Carey (McMaster U.)**
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- Mike Demuth (Nat. Resources Can.)
- John Diiwu (AB Env. and Sus. Res. Dev.)
- Vincent Fortin (Env. Can.)
- John Hanesiak (U. Manitoba)
- Masaki Hayashi (U. Calgary)
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- **Al Howard (Ag. and Agri-Food Can.)**
- Dave Hudak (Env. Can.)
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- Ed Johnson (U. Calgary)
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- **Phil Marsh (Wilfrid Laurier U.)**
- Sean Marshall (U. Calgary)
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- **William Quinton (Wilfrid Laurier U.)**
- Garry Scrimgeour (Parks Can.)
- Chris Spence (Env. Can.)
- Craig Smith (Env. Can.)
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- Kit Szeto (Env. Can.)
- Julie Thériault (U. Québec à Montréal)
- **Merritt Turetsky (U. Guelph)**
- Garth van der Kamp (Env. Can.)
- **Howard Wheater (U. Sask.; CCRN PI)**
- Daqing Yang (Env. Can.)
- Xuebin Zhang (Env. Can.)

Board of Directors

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- Wayne Dybvig (SK WSA)
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- Donna Kirkwood (Nat. Resources Can.)
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- Denis Petitclerc (Ag. and Agri-Food Can.)

International Advisory Panel

- Don Cline (National Oceanic and Atmospheric Administration)
- Richard Harding (UK Centre Ecology and Hydrology)
- Larry Hinzman (U. Alaska)
- Eric Kasischke (U. Maryland; NASA ABoVE)

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- Graham Strickert (Outreach Co-ordinator)
- Tim Zagozewski (Finance Officer)
- Branko Zdravkovic (Database Manager)

***Indicates member of Science Committee**

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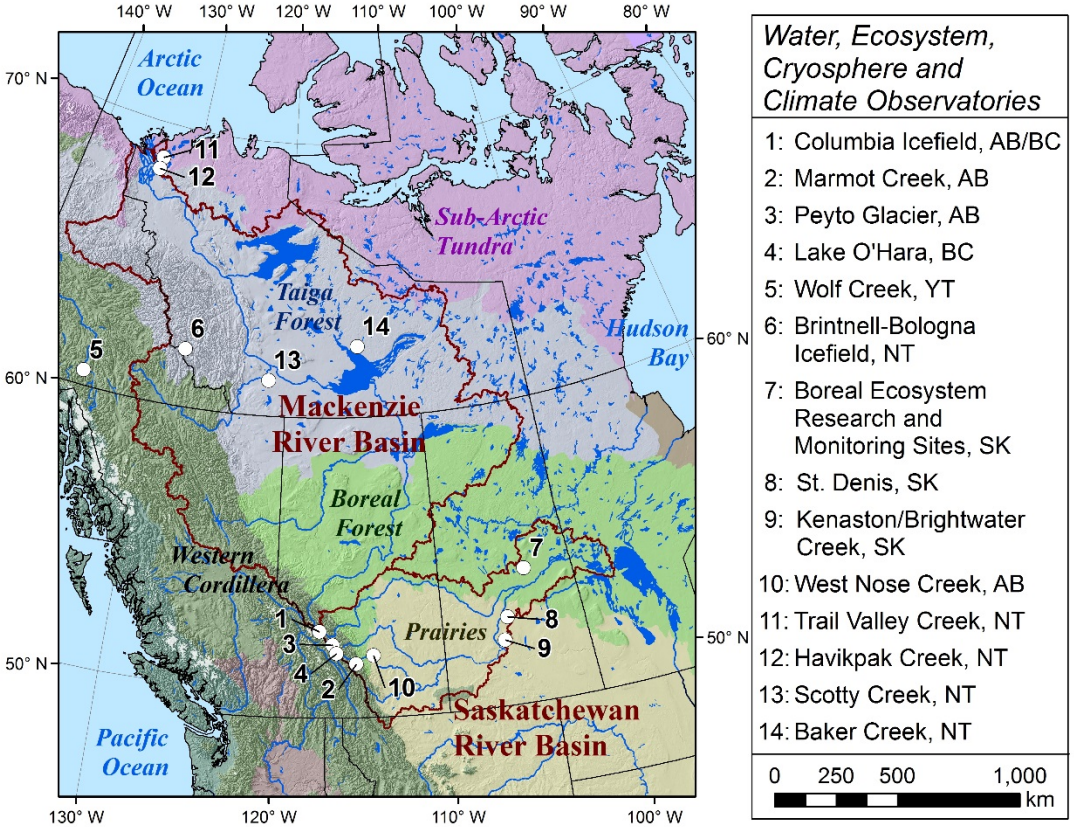
CCRN Research Programme:
Geographic Focus / Water, Ecosystem, Cryosphere and Climate (WECC) Observatories

- A network of WECC Observatories combine meteorological, hydrological, ecosystem, and cryospheric observations with multi-scale coupled models from the surface to the atmosphere.
- Observatories contain long-term legacy data sets, including hydro-meteorological variables, remote sensing observations, LiDAR topography, and soils, geology, and vegetation characterization



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CC ch Program
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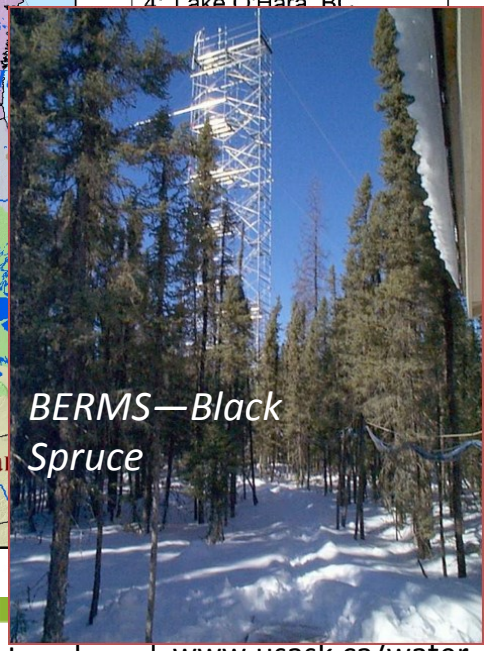
Climate Observations
1: Columbia Icefield, AB/BC
2: Marmot Creek, AB
3: Peyto Glacier, AB
4: Lake O'Hara, BC



CCRN Research Programme:
Thematic Components

The CCRN's research programme and its objectives are organized based on 5 inter-related and inter-dependent Themes:

A. Observed Earth System Change in Cold Regions—Inventory and Statistical Evaluation;

B. Improved Understanding and Diagnosis of Local-Scale Change;

C. Upscaling for Improved Atmospheric Modelling and River Basin-Scale Prediction;

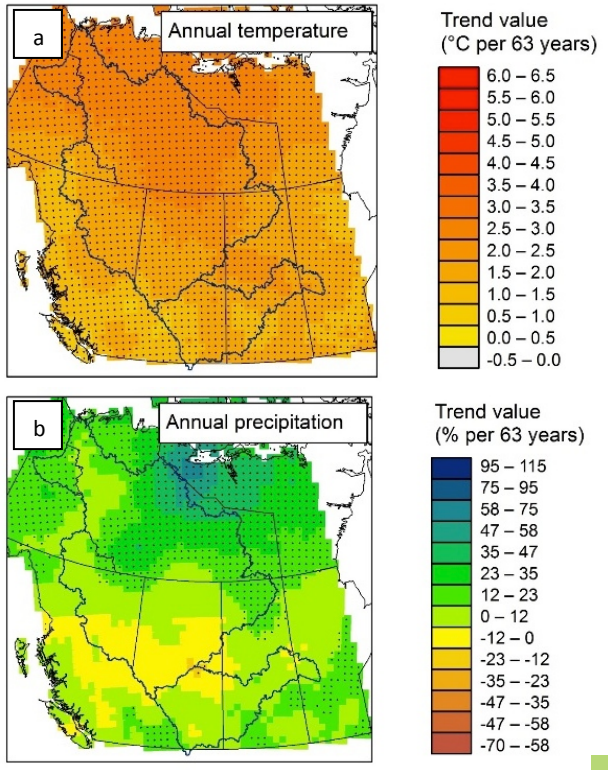
D. Analysis and Prediction of Regional and Large-Scale Variability and Change; and

E. User Community Outreach and Engagement

Progress to Date and Future Directions:
Theme A—Inventory of Observed Change

- The objectives of this early Theme are now nearly complete; targeted products are being developed as deliverables
- Activities have included:
  - Local-scale assessments and inventories of change at WECC sites;
  - Collection of extensive set of dendro-chronological tree core data;
  - Regional-scale synthesis of Earth system change in western Canada;
  - Development of conceptual models of mechanisms and drivers of change for WECC sites and major ecoregions to be diagnosed in Theme B.

Climate trends (1950–2012)

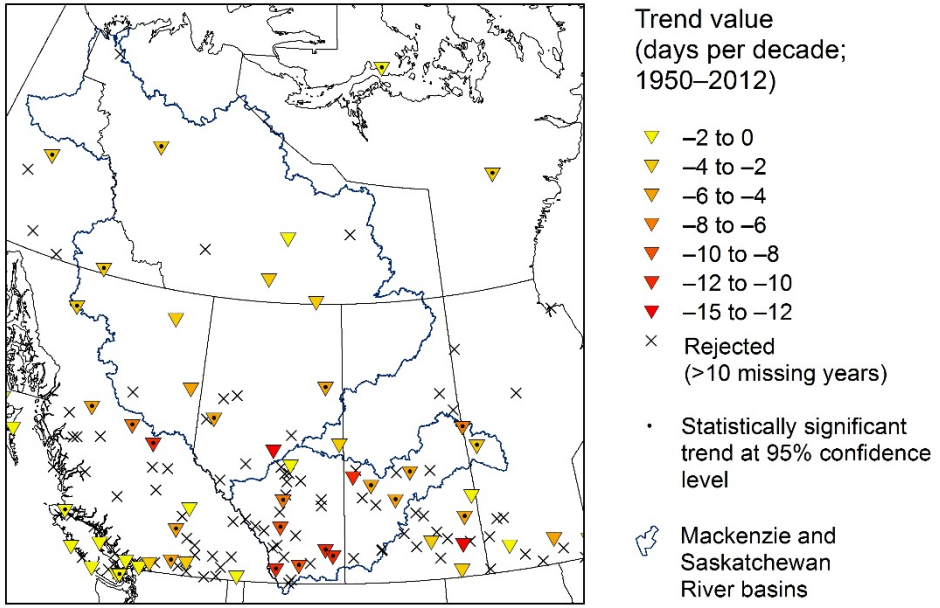


DeBeer, C. M., Wheater, H. S., Carey, S. K., and Chun, K. P.: Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a synthesis and review, Hydrol. Earth Syst. Sci. Discuss., 12, 8615-8674, doi:10.5194/hessd-12-8615-2015, 2015

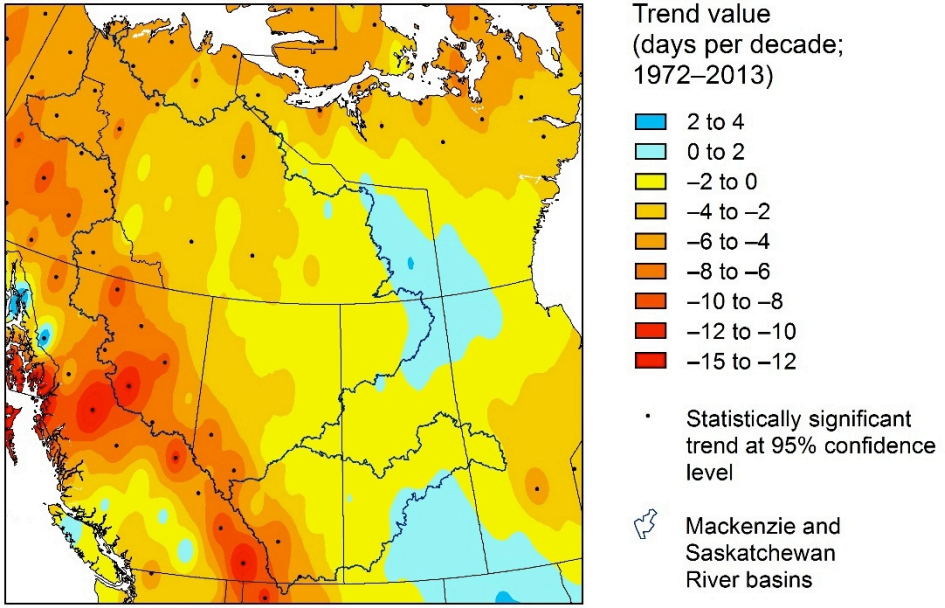
Observed Changes: Snow Cover

- Trends in annual and spring snow cover duration (Results provided by Ross Brown, Environment and Climate Change Canada)

Annual snow cover duration trends, 1950–2012, from surface observations in the Canadian Daily Snow Depth Dataset

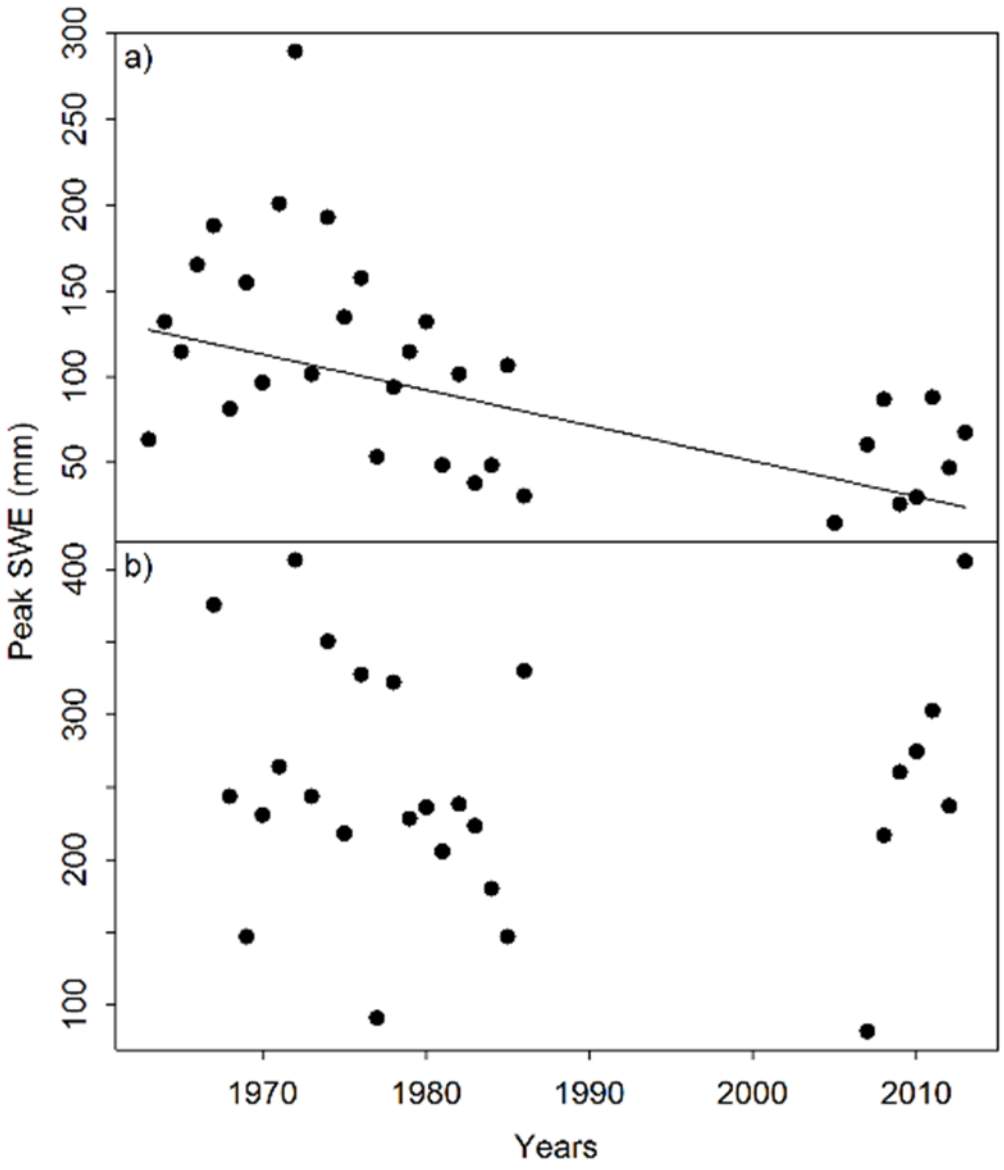


Spring season snow cover duration trends, 1972–2013, from NOAA weekly snow cover product



1 to 2 month decline in snowcover period over most of the CCRN domain

Marmot Creek Observed Peak SWE

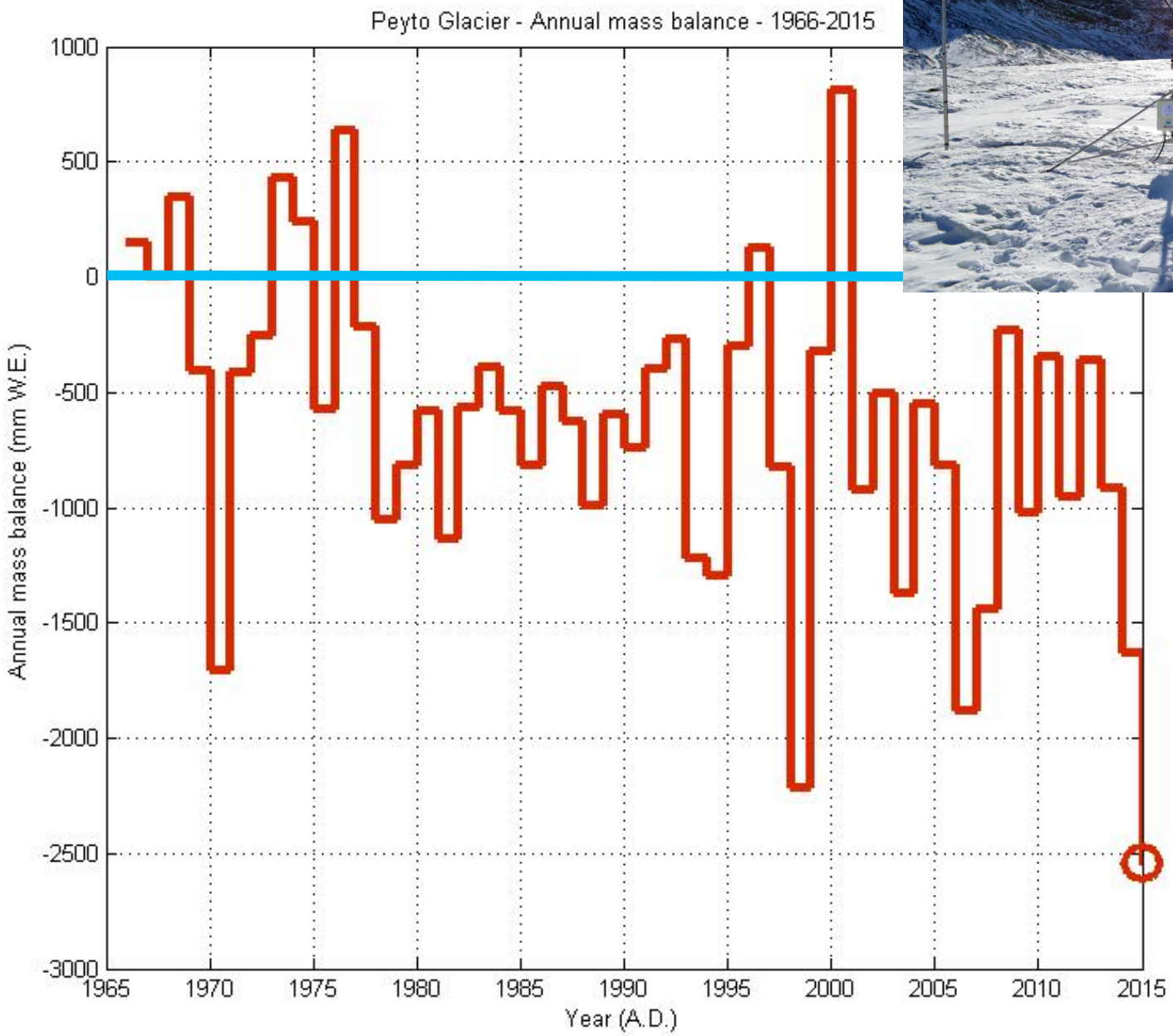


Low elevation forest ~1450 m

Elevational component to changing SWE

Alpine elevation ~2100 m

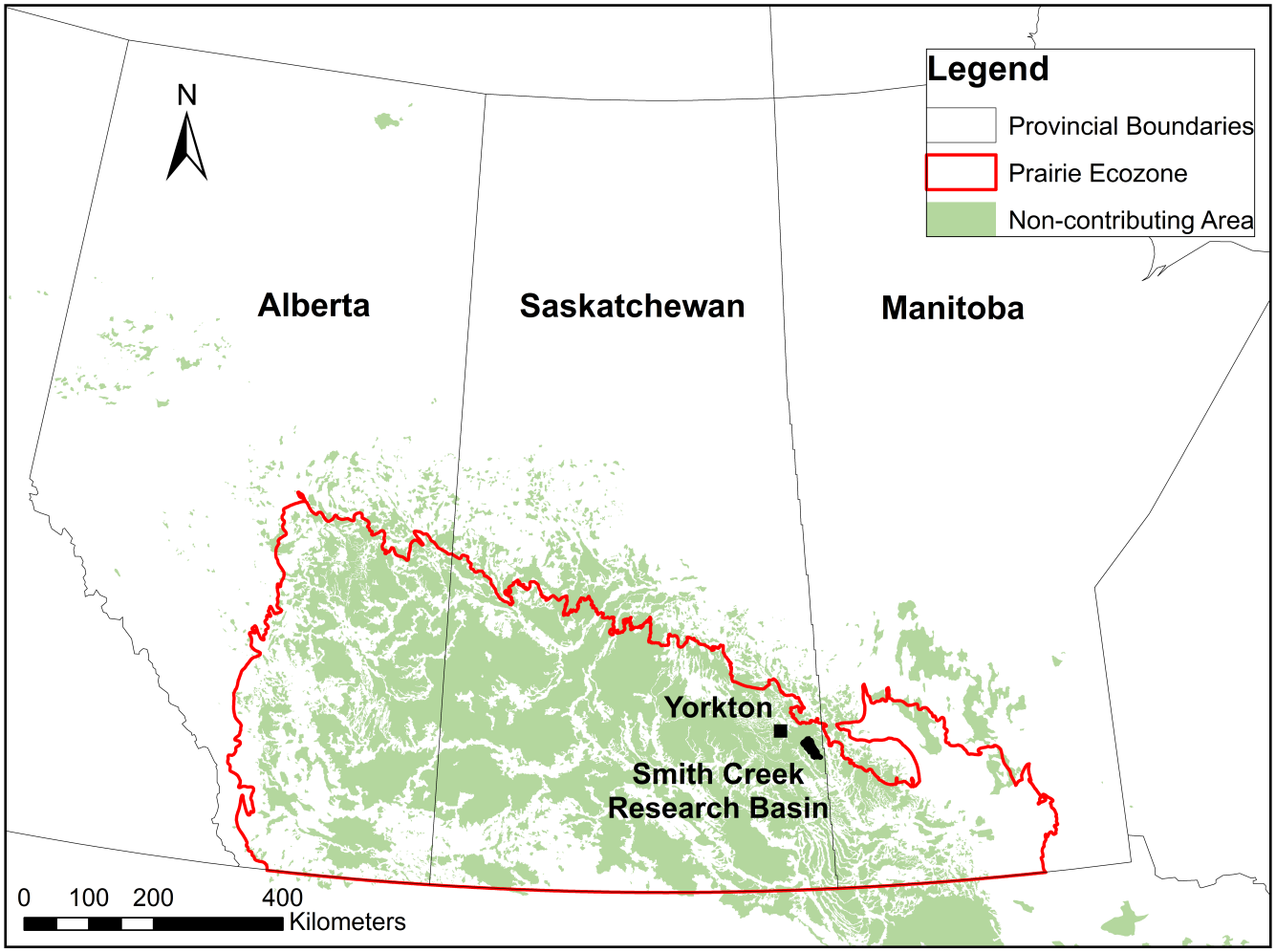
Glacier Mass Balance



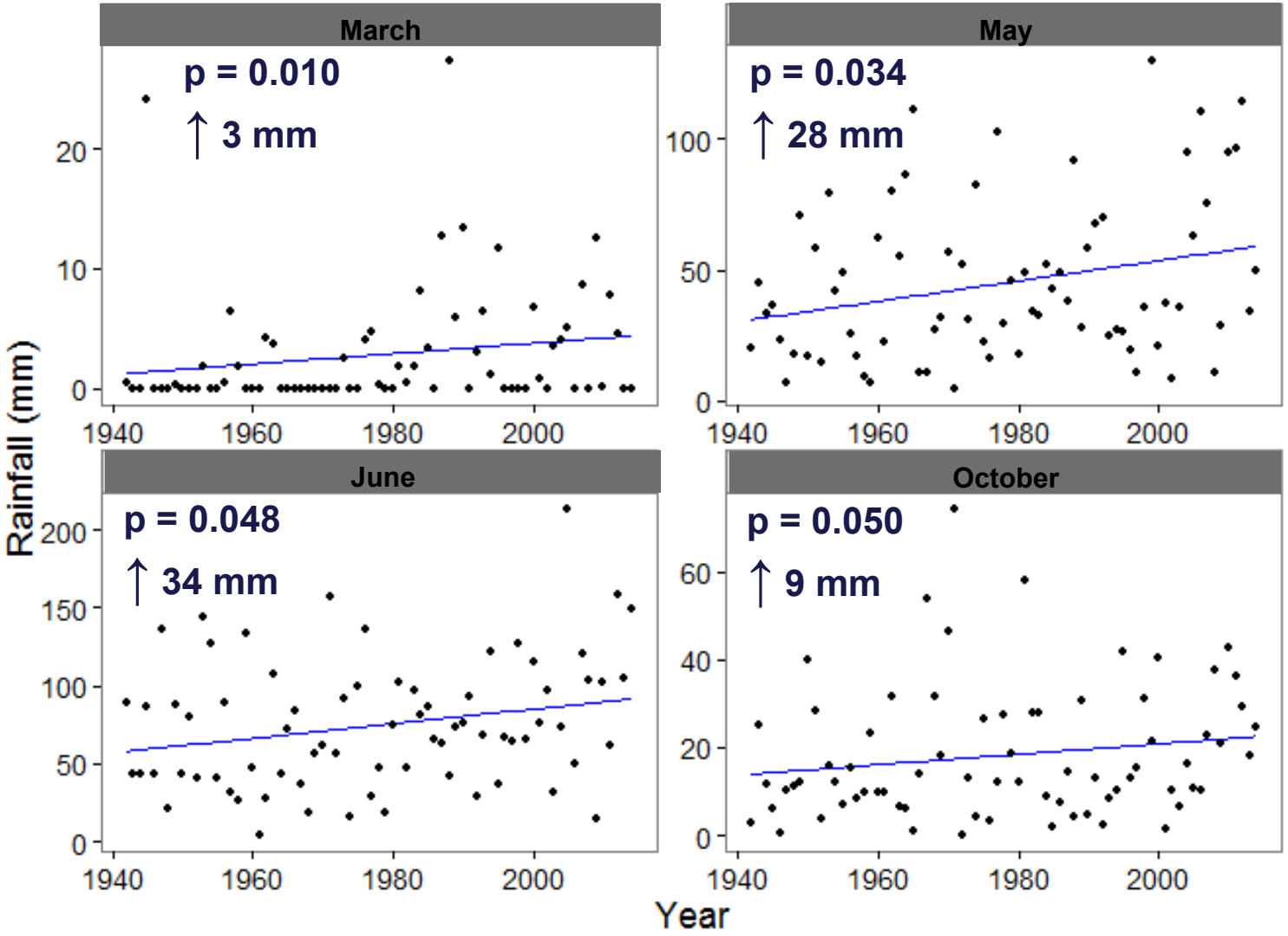
Example of observed change

Smith Creek Research Basin (SCRB), Saskatchewan

- Small, agriculturally dominated basin (393 km^2)

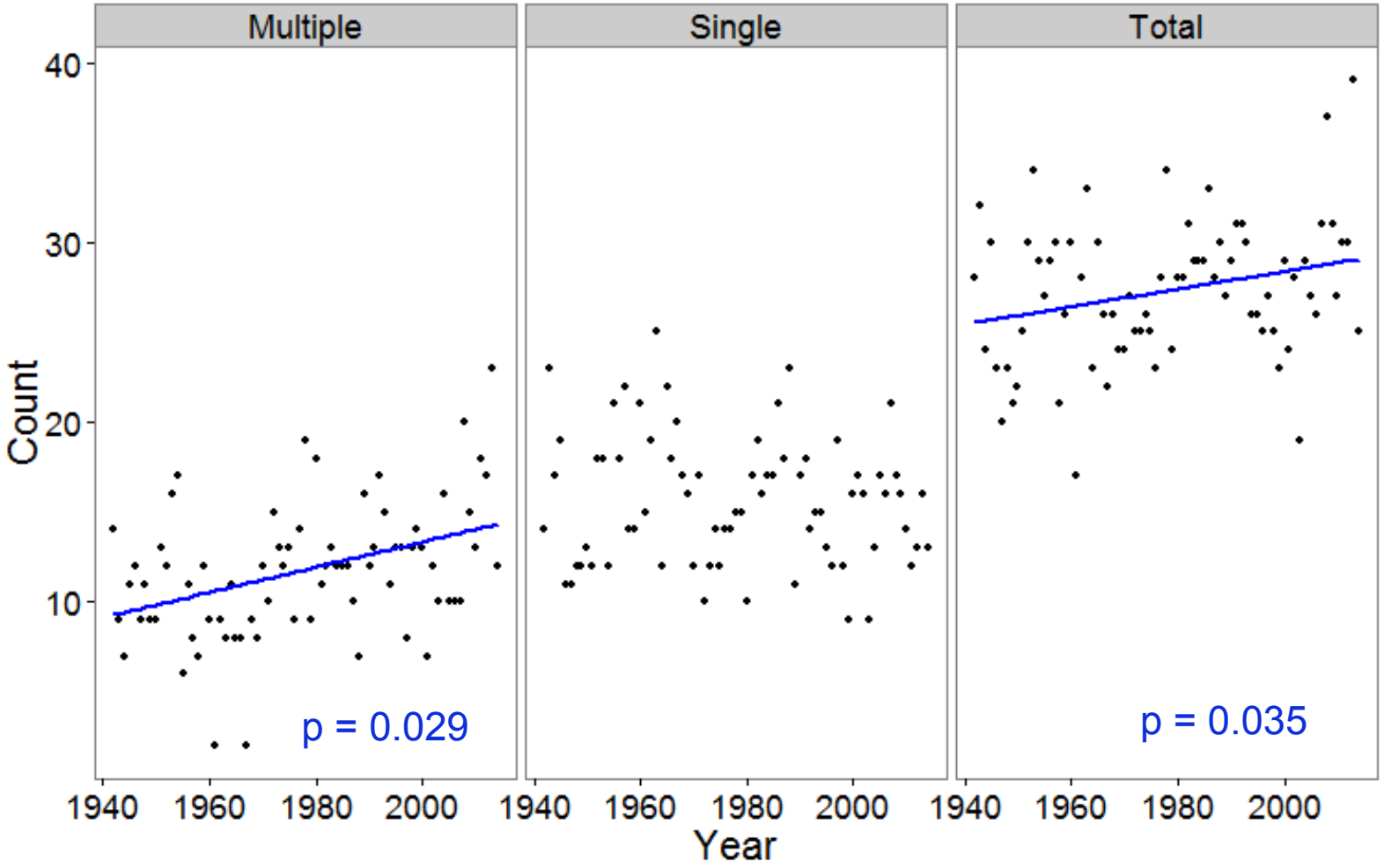


Monthly Rainfall – no change in annual precipitation



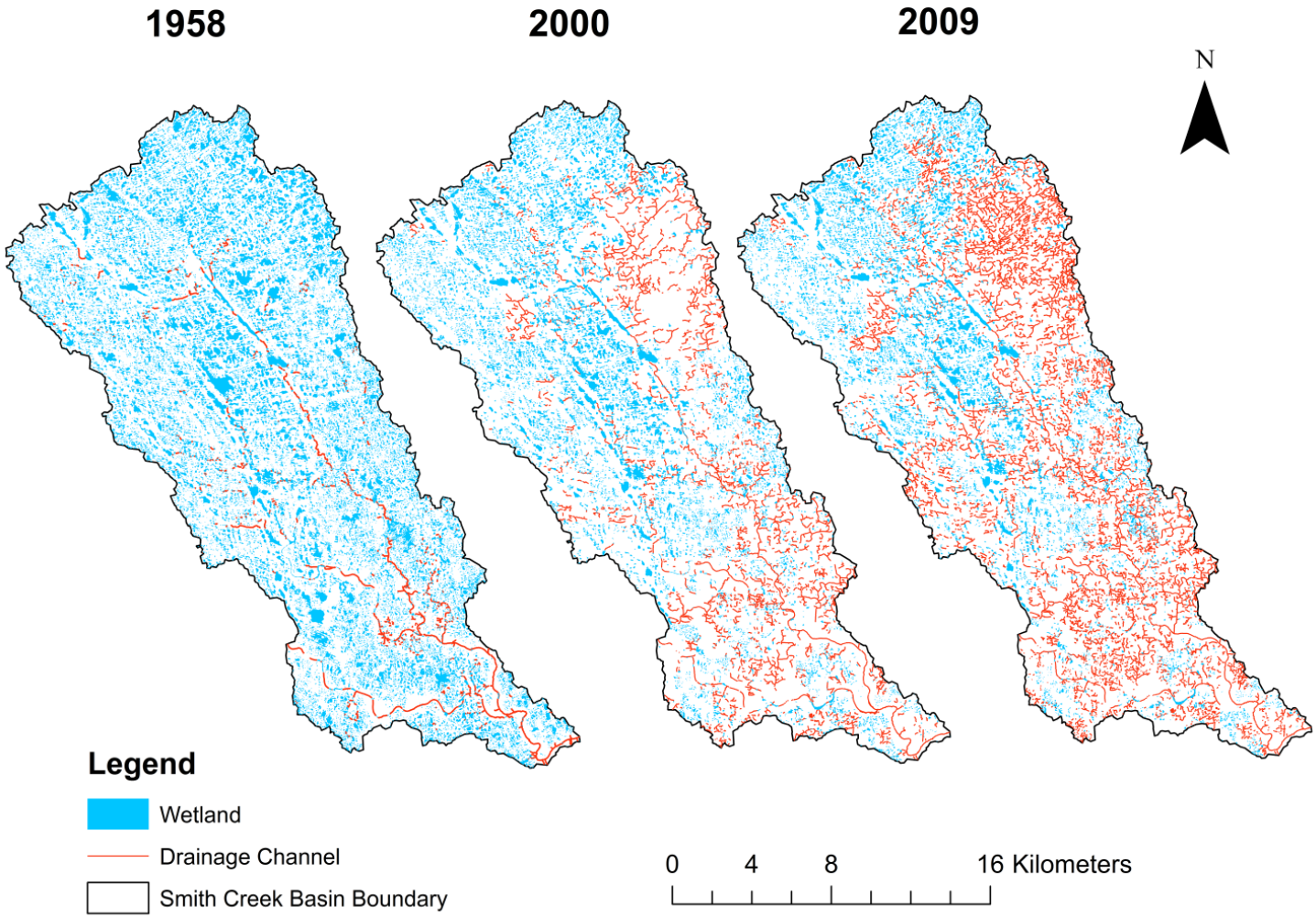
Rainfall Duration (May – Sept; 1942 - 2014)

- Multiple day vs. single day rainfall events (Frontal vs. Convective)
- 50% increase in number of multiple day events



Depressional Storage Drainage

- Depression extent reduced from 24% to 10% (58% reduction)
- Drainage channel length increased 8-fold

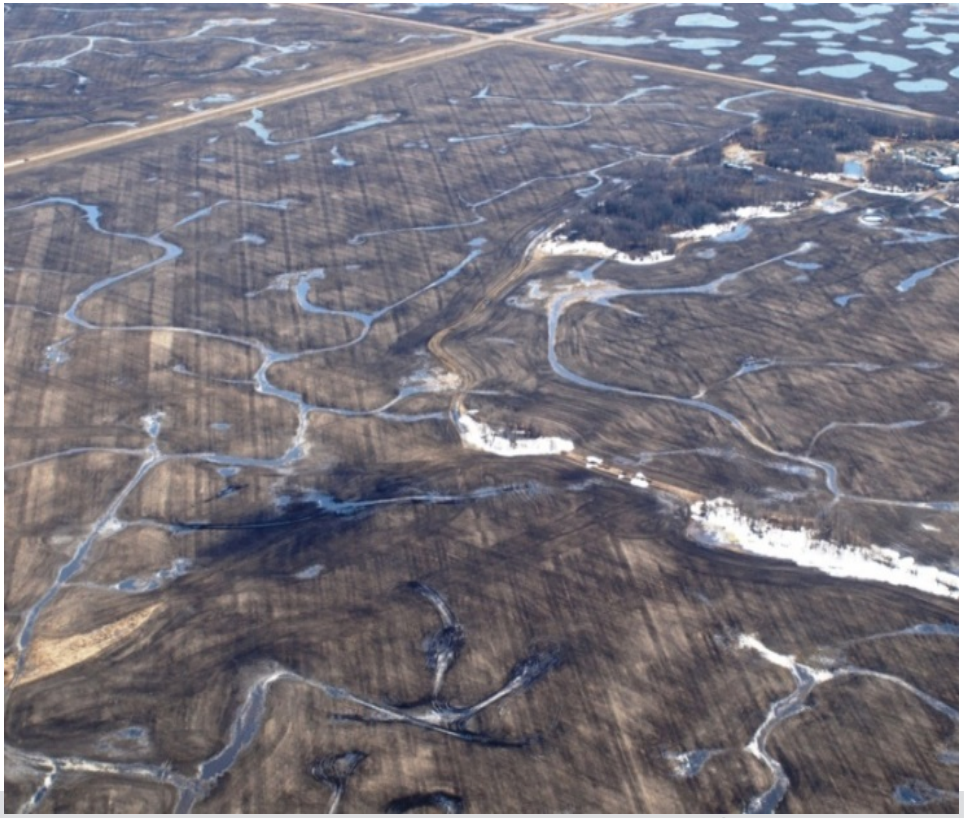


Depressional Storage Drainage

- **Loss of depressional storage capacity, increase in channelization**

No Drainage

Artificial Drainage



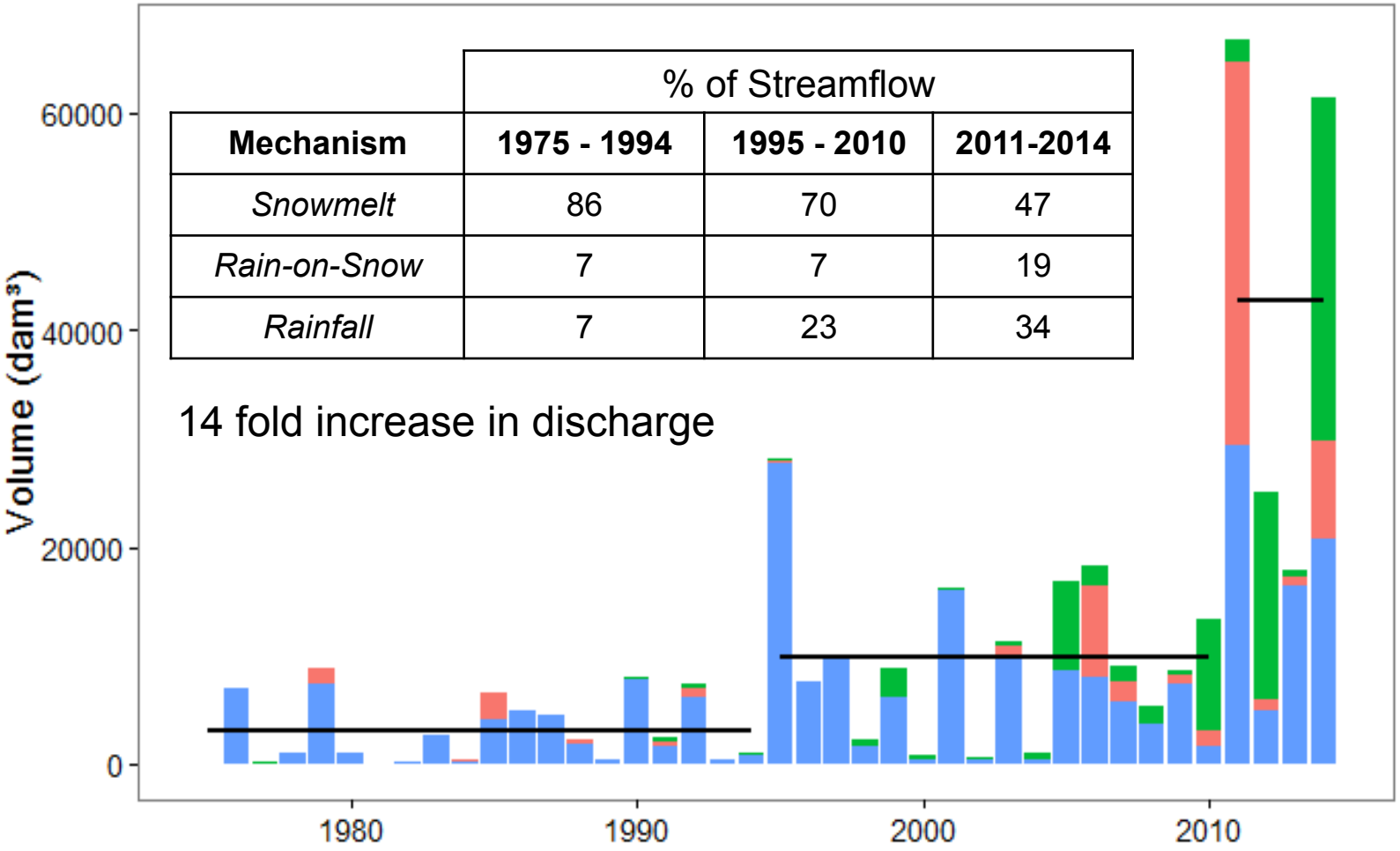
Basin Discharge Change

- Increased runoff contributions from:

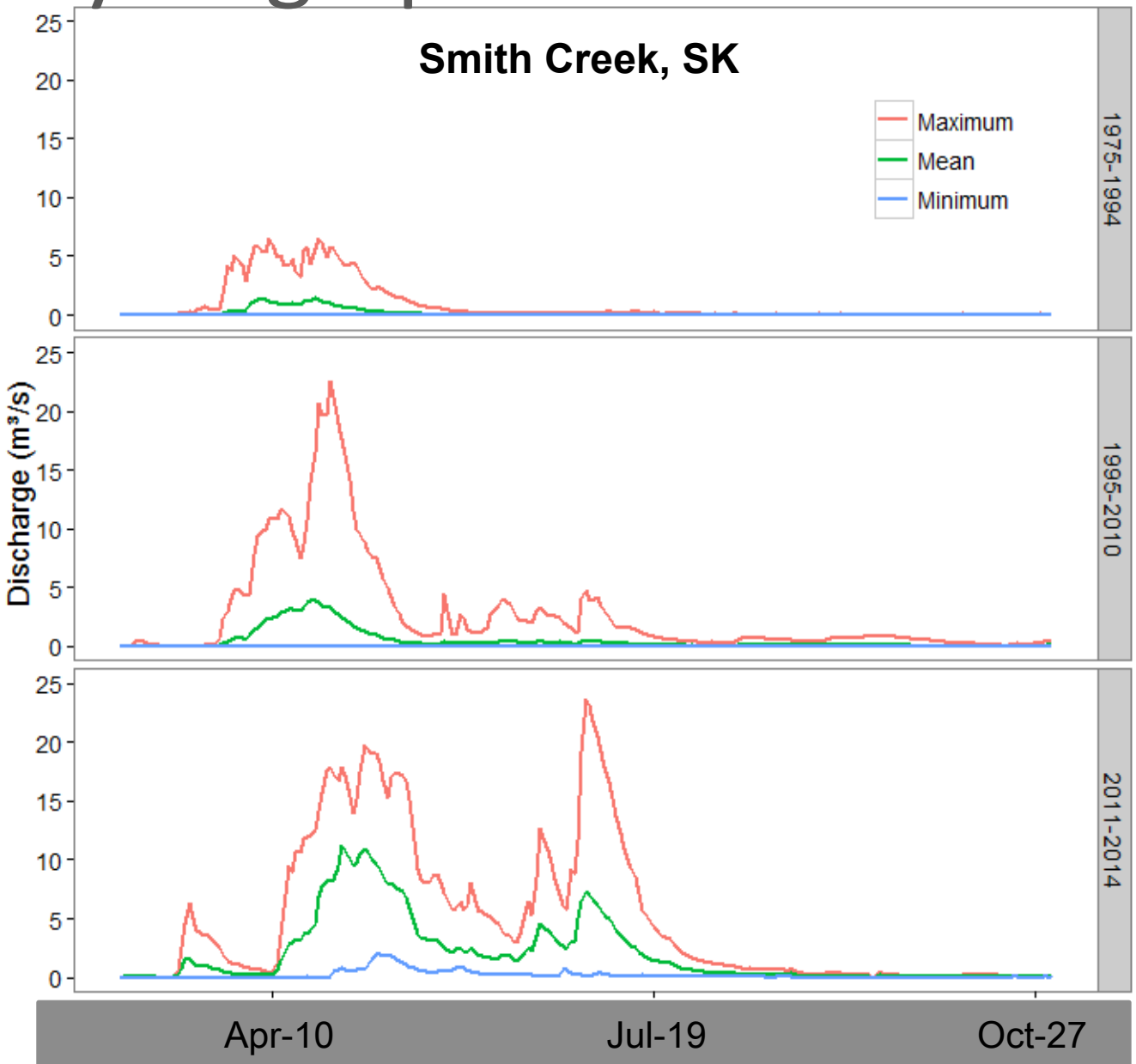
Snowmelt (**5-fold**), rain-on-snow (**34-fold**), rainfall (**150-fold**)

	% of Streamflow		
Mechanism	**1975 - 1994**	**1995 - 2010**	**2011-2014**
Snowmelt	86	70	47
Rain-on-Snow	7	7	19
Rainfall	7	23	34

14 fold increase in discharge



Hydrographs



1975-1994

Snowmelt driven

1995-2010

Increased spring and summer runoff

2011-2014

Second peak flow in summer months caused solely by rainfall runoff

Progress to Date and Future Directions:
Theme B—Local-Scale Understanding/Diagnosis

- Activities have included:
  - Targeted process studies in most WECC observatories;
  - Continued operation and enhancement of observatories, with a *Special Observation and Analysis Period (SOAP)* across the network of sites underway for the hydrological year Oct 2014 – Sept 2015
  - Development/improvement of many new process algorithms within the *Cold Regions Hydrological Model (CRHM)* platform
  - Set-up and initial testing of CRHM models, and for select basins, change detection and sensitivity analysis, with plans in place for extending this all observatories
- A major focus is on the diagnosis of change (September 2015 workshop)

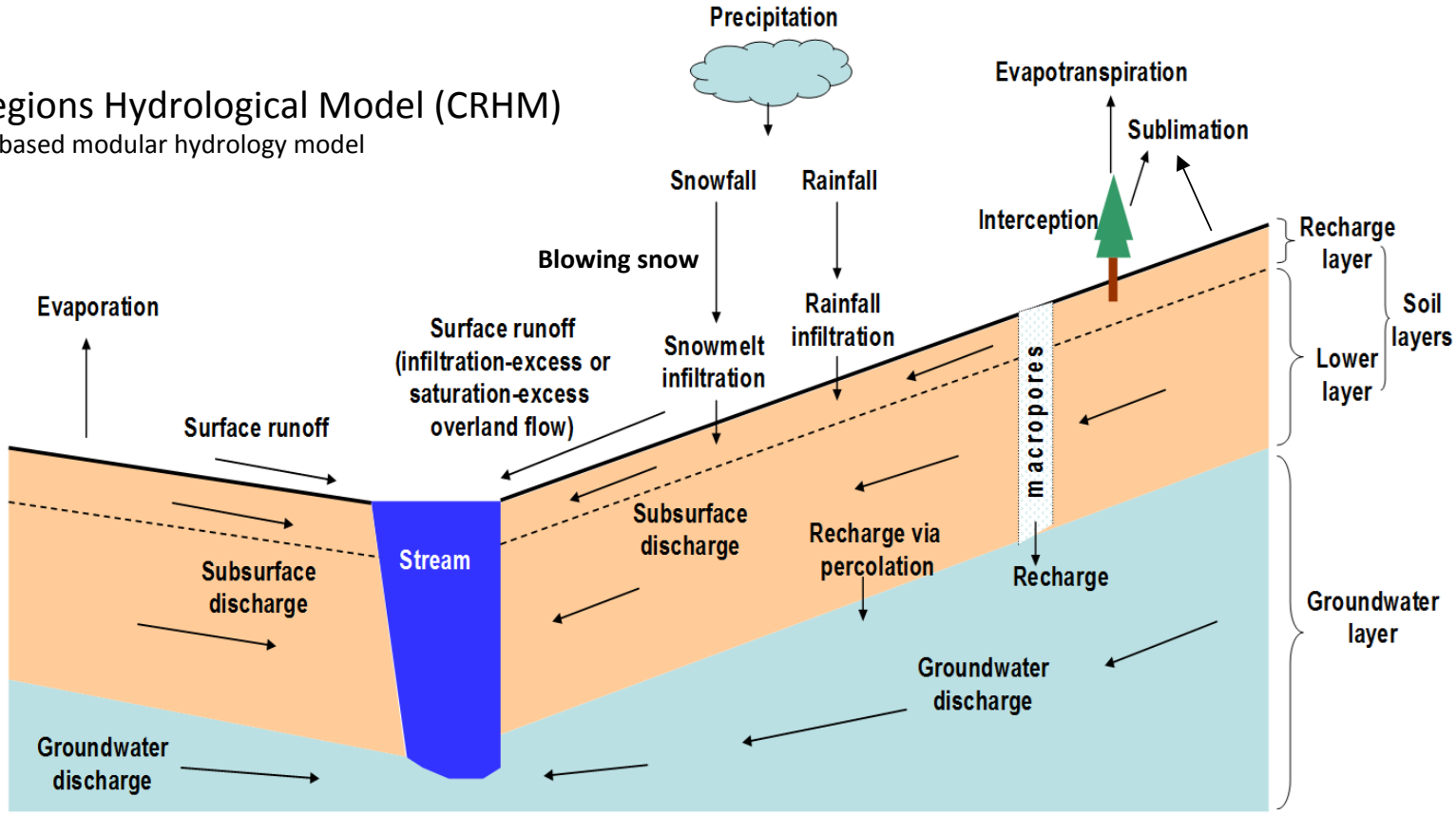
The SOAP initiative involves coordinated, consistent, high-quality observations—CCRN is positioned to provide a world-class legacy dataset for process insights and model application over interior western Canada

Diagnosis of Trends

- Measured trends instructive but lack explanation of mechanisms
- Cold Regions Hydrological Model (CRHM) employed to diagnose observed changes
- Physically based, modular platform that represents all the relevant cold region hydrological processes

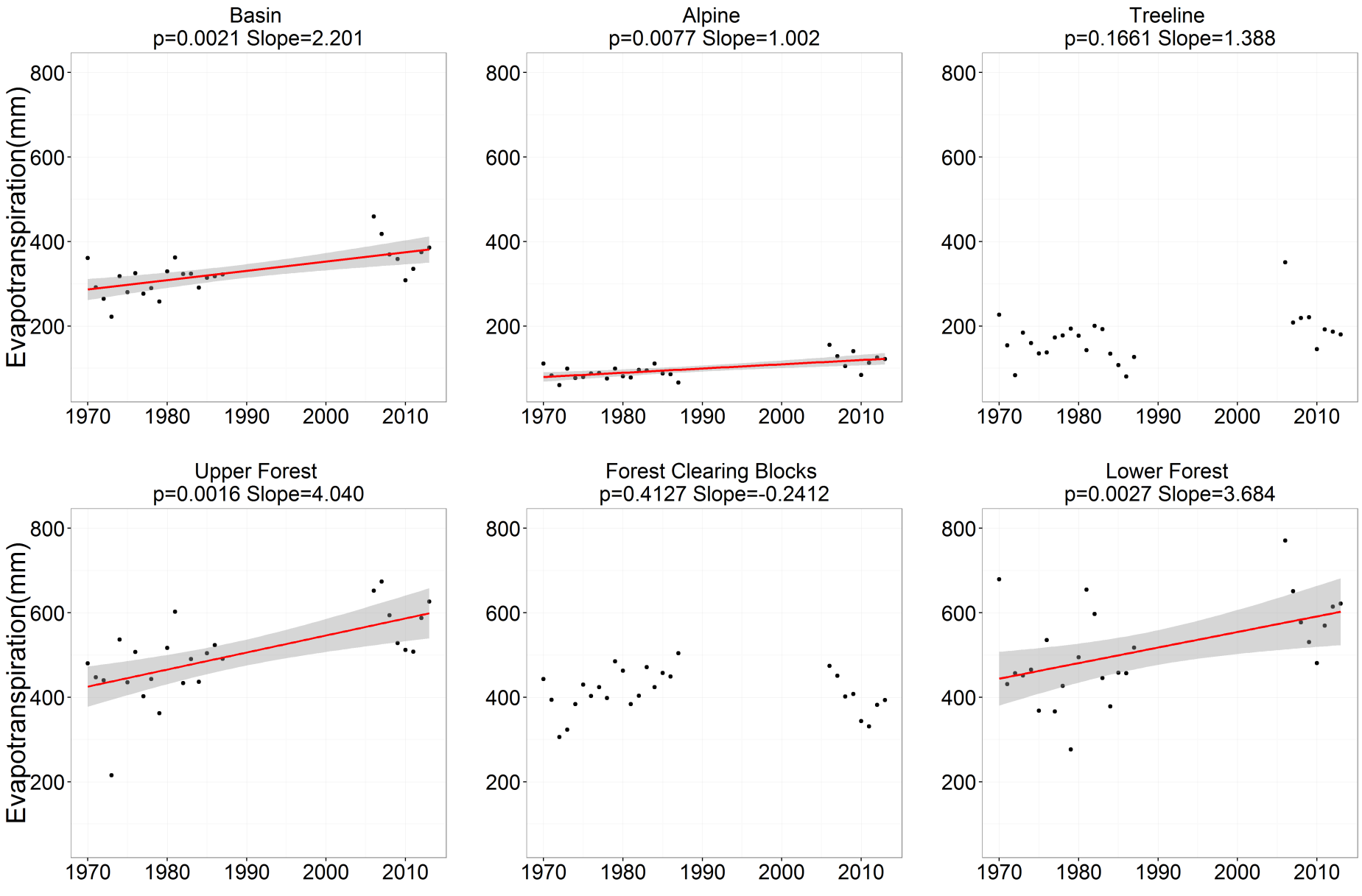
Cold Regions Hydrological Model (CRHM)

Physically based modular hydrology model

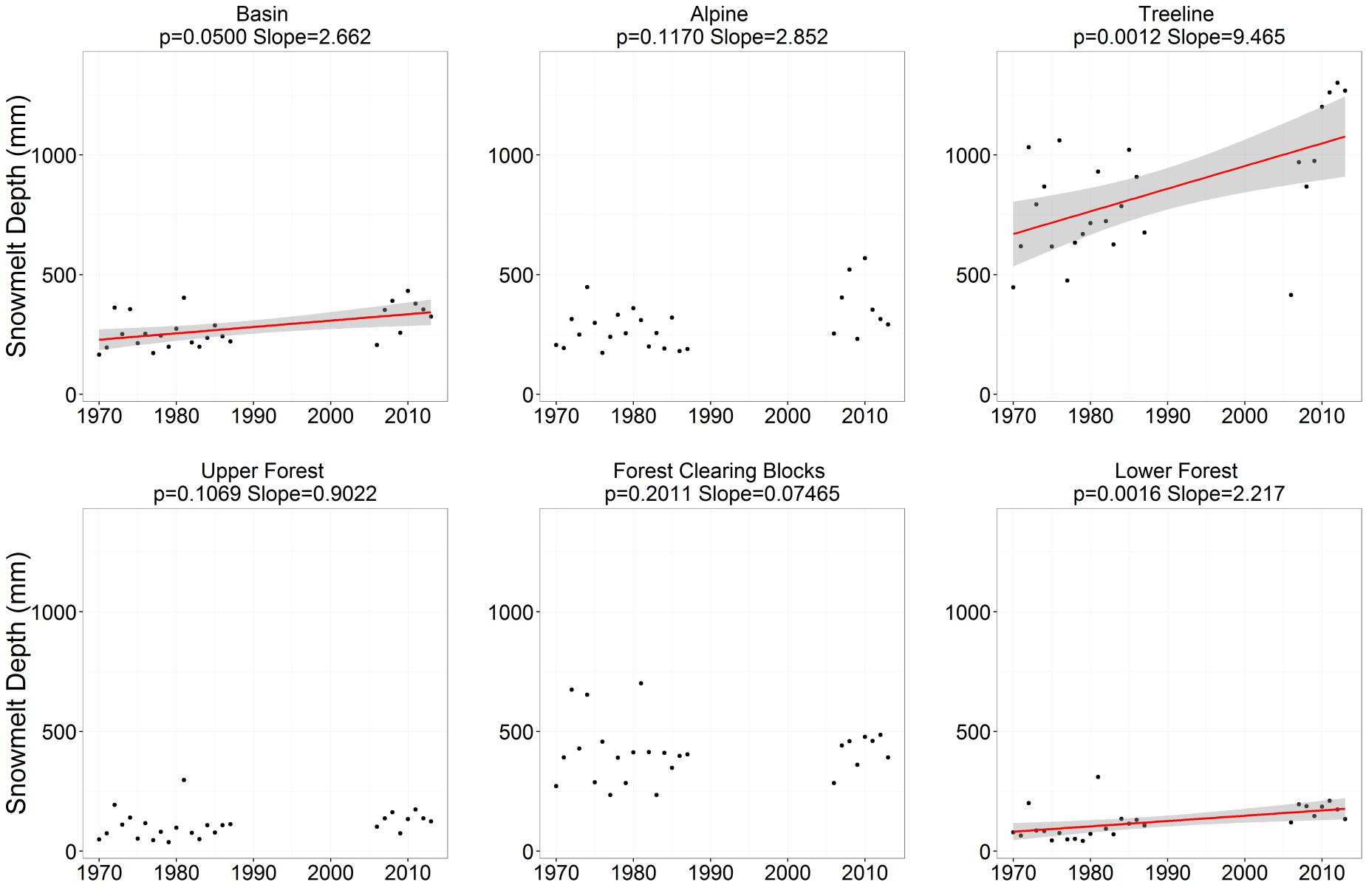


Pomeroy et al., Hydrol. Proc. 2007

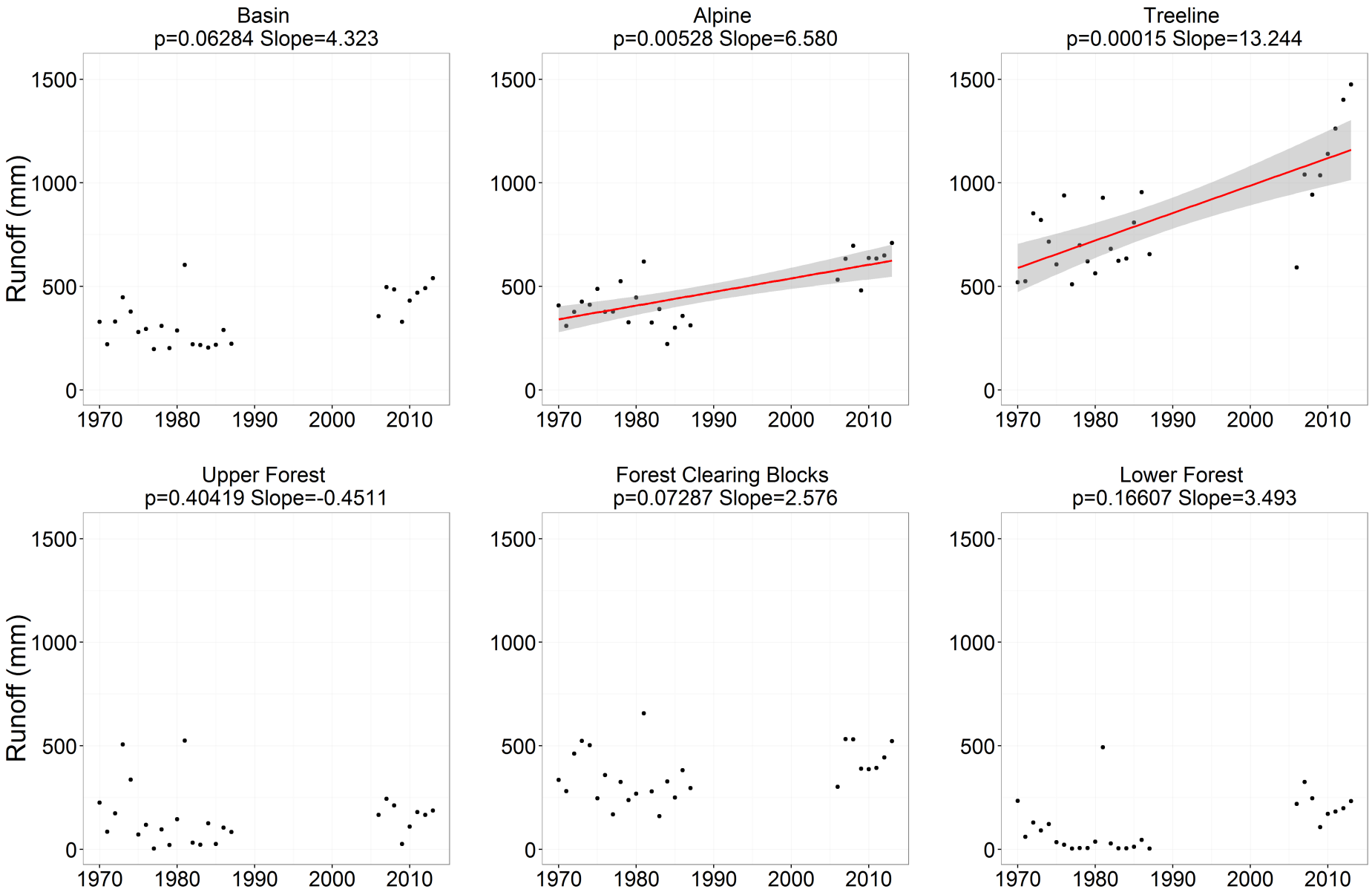
Marmot Creek Annual Actual ET



Marmot Creek Snowmelt Volume



Marmot Creek Runoff



Marmot Creek Future Warming – % Decrease per °C

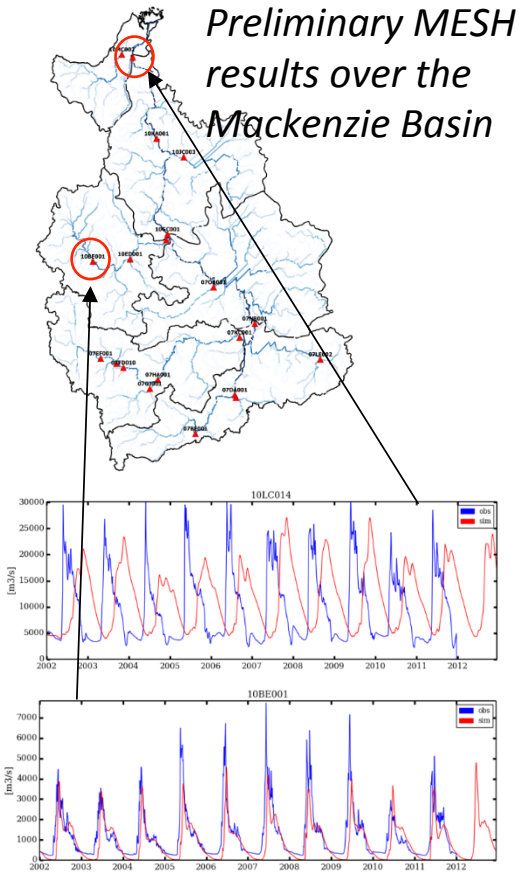
	Snowfall	Peak SWE	Blowing Snow Transport	Blowing Snow Sublimation	Intercepted Snow Sublimation	Melt Rate	Snow Free Date
Alpine	8.3	11	9.4	7		10.8	6.4
Forest	11	18.6			14.3	18.7	7.4
Clearing	10.9	17.3				17.6	5.5

Pomeroy et al., 2015

Progress to Date and Future Directions:
Theme C—Improved Large-Scale Modelling

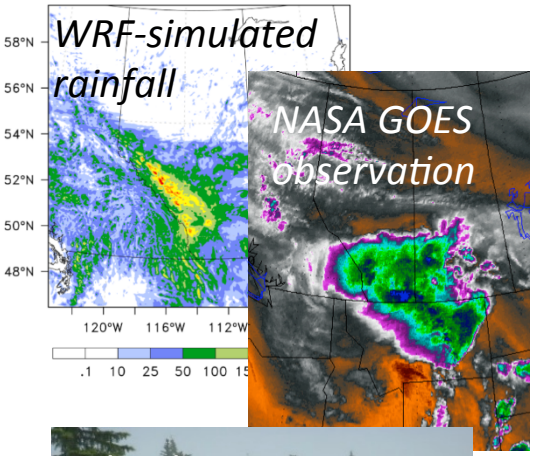
- Activities are aligned with the needs of many of our government partners, and have included:
  - Completion of baseline CLASS simulations at most WECC observatories, together with other international LSS's (e.g. **WRF, JULES**);
  - Various improvements to CLASS for Prairie landscapes and cold-region lakes and wetlands;
  - Setup and evaluation of MESH over the Mackenzie and Saskatchewan River Basins;
  - Publication of key research reviews on water managemen representation in large-scale models
  - Use of soil moisture monitoring networks for observation and scaling properties at resolutions applicable to SMAP
  - Quantification of effects of uncertainty in driving variables
- Collaboration with EC CLASS/MESH
- Collaboration with NCAR WRF Noah-MP

Preliminary MESH results over the Mackenzie Basin



Progress to Date and Future Directions:
Theme D—Analysis/Prediction Large-Scale Change

- Most deliverables slated for later years of CCRN, but accomplishments include:
  - Work on atmospheric circulation patterns, instabilities for generating convection, precipitation phase changes, surface hydrologic changes, runoff
  - A comprehensive investigation of the June 2013 extreme weather and flooding events;
  - Initial work toward an interdisciplinary examination of the 2014 forest fires in the Northwest Territories
  - Focal examination of extreme events (floods, drought, fire) in CCRN domain from 2009–11; pubs. forthcoming
- Collaboration agreed with CNRCWP (CanRCM5 - algorithm testing, simulation results)
- 4km WRF simulations available for CCRN domain – historical and pseudo warming (Y. Li)

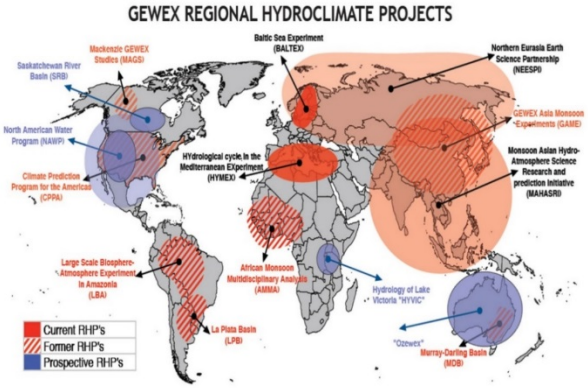


The extreme weather & flooding events of June 2013 are a focus of CCRN research activities

Progress to Date and Future Directions:
Theme E—Outreach & Engagement

- Through our members, we are linked with 106 different groups
  - 11 First Nations; 11 Canadian and U.S. federal departments, 2 regional water boards, 24 provincial/ territorial agencies, 4 urban municipalities, 7 NGOs, 19 environmental stewardship societies, 26 industrial companies, 6 research and education centres, 2 consultancies
- Activities have included:
  - Grassroots level engagement with various groups;
  - Member participation in science conferences, publication in major journals, and media engagement;
  - 5 focused workshops to engage government partners;
  - Linkage with various national/international scientific organizations, including WCRP, NCAR, NASA, CHARS
  - Delivery of CRHM training courses

Global Energy and Water Exchanges Project
GEWEX
WCRP

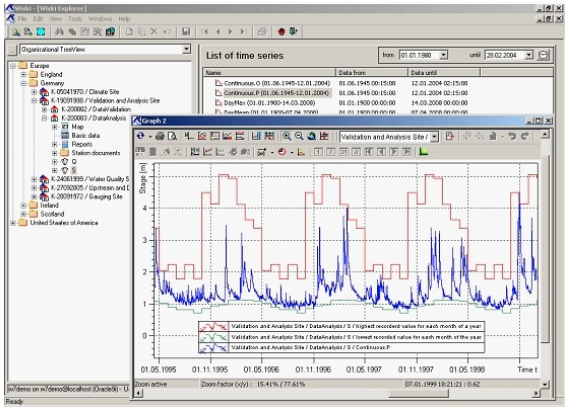


CCRN as a GEWEX RHP places us in an important international scientific context as the only active North American RHP

Progress to Date and Future Directions:
Data Management

- *"We are committed to produce, document, and archive our results in an integrated, long-term repository."*
- Data management activities have included:
  - Creation of data access policies and a data management planning document;
  - Setup of a data platform (the Water Information System, KISTERS (WISKI) tool);
  - Provision of training and tutorials on WISKI;
  - Imports of recent and historical WECC data, in coordination with members and partners;
  - Coordination with EC to develop protocols for acquisition and archiving of GEM model outputs;
  - Access provision to select real-time data streams

KISTERS Pioneering Technologies.



CCRN uses the WISKI tool to manage, process, and edit time series information

CCRN Annual General Meeting – Nov 2015

- Reviewed science developments, SOAP, data progress
- Reviewed cross-cut activities (2013 Calgary Flood, 2014 NWT Wildfire)
- Developed new cross-cut themes (2015 Drought; Threshold Behaviour, Regime Change, Responses to Climate Change)
- Checked progress towards network strategic goals; identify gaps and opportunities
- Reported to and received feedback from our International Advisory Panel and Board of Directors

The Future:

- Over the remainder of the CCRN programme, we will continue to:
  - Improve our understanding of recent Earth system change in the cold interior of western and northern Canada;
  - Advance water, weather, climate and environmental prediction; and
  - Improve our understanding of Earth system processes and their representation in hydrological, atmospheric and ecological models.
- In doing so, we will:
  - Enhance Canada's capability for water management;
  - Train the next generation of Earth System Scientists; and
  - Provide high quality datasets for change assessment and model verification.

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