

The Changing Cold Regions Network: Observation, Diagnosis, and Prediction of Environmental Change in the Saskatchewan and Mackenzie River Basins

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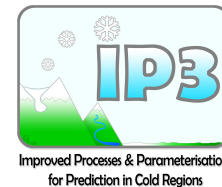
2016 GHP Meeting, Gif-sur-Yvette, France

October 3, 2016

Changing Cold Regions Network (CCRN)

“The 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.**”

CCRN builds on a strong legacy of past Canadian and international research initiatives



Changing Cold Regions Network (CCRN)

- Funded for 5 years (2013–2018) under the NSERC Climate Change and Atmospheric Research (CCAR) Initiative
- Leveraging \$24 million in-kind support
- Strongly 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
- 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

CCRN Research: Thematic Approach

Theme A: Observed Earth System Change in Cold Regions -
Inventory and Statistical evaluation

Theme B: Improved Understanding and Diagnosis of Local
Scale Change

Theme C: Upscaling for improved Atmospheric Modelling and
River Basin Scale Prediction

Theme D: Analysis and Prediction of Regional and Large Scale
Variability and Change

Theme E: User Community Outreach and Engagement

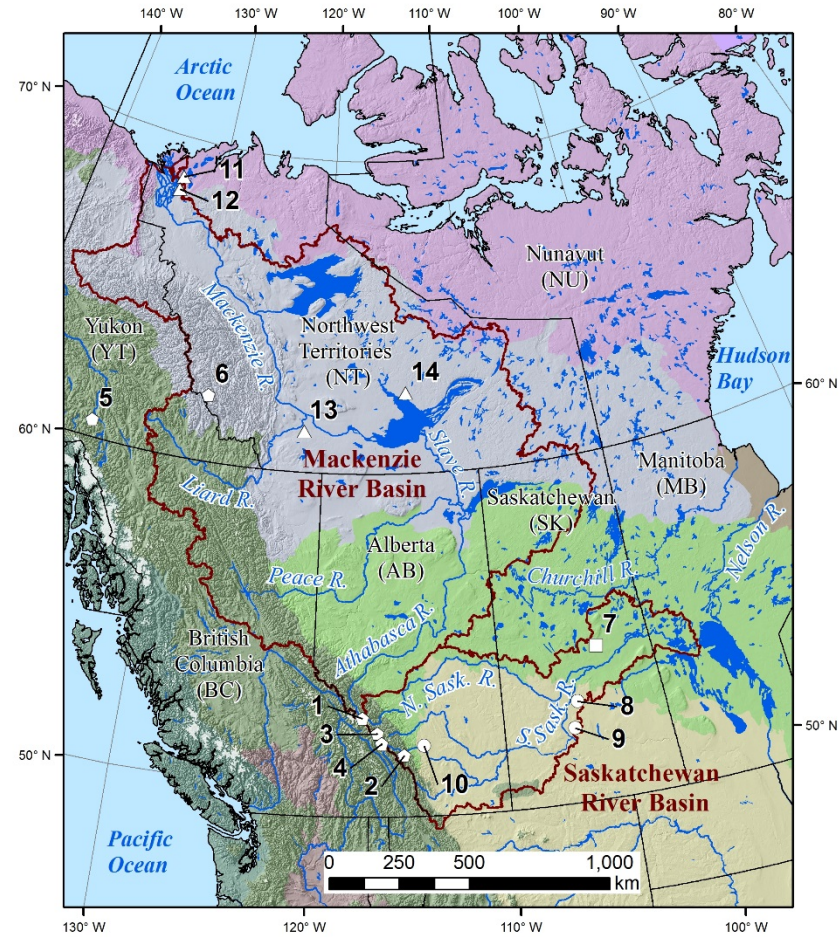
Geographic Focus:

The vast interior of western Canada, including the Saskatchewan River Basin (336,000 km²) and Mackenzie River Basin (1.8 million km²)



CCRN Research: 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



Water, Ecosystem, Cryosphere and Climate Observatories

◇ Western Cordillera

- 1: Columbia Icefield, AB
- 2: Marmot Creek, AB
- 3: Peyto Glacier, AB
- 4: Lake O'Hara, BC
- 5: Wolf Creek, YT
- 6: Brintnell-Bologna Icefield, NT

□ Boreal Forest

- 7: Boreal Ecosystem Research and Monitoring Sites (BERMS), White Gull Creek, SK

○ Prairie

- 8: St. Denis National Wildlife Area, SK
- 9: Brightwater Creek/Kenaston Mesonet Site, SK
- 10: West Nose Creek, AB

△ Taiga and Southern Arctic

- 11: Trail Valley Creek, NT
- 12: Havikpak Creek, NT
- 13: Scotty Creek, NT
- 14: Baker Creek, NT

Ecoregions and Landcover

- Glaciers
- Tundra
- Taiga
- Hudson Plains
- Boreal Forest
- Northwestern Forested Mountains
- Marine West Coast Forest
- Great Plains
- N. American Deserts

CCRN Research:

Geophysical
Ecosystem
Cryosphere

Trail Valley
Creek



Water, Energy and
Observatories

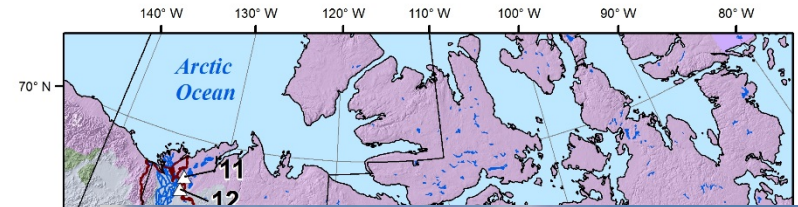
Observatories collect
data, and
models from
the surface to the atmosphere.

Observatories contain long-term

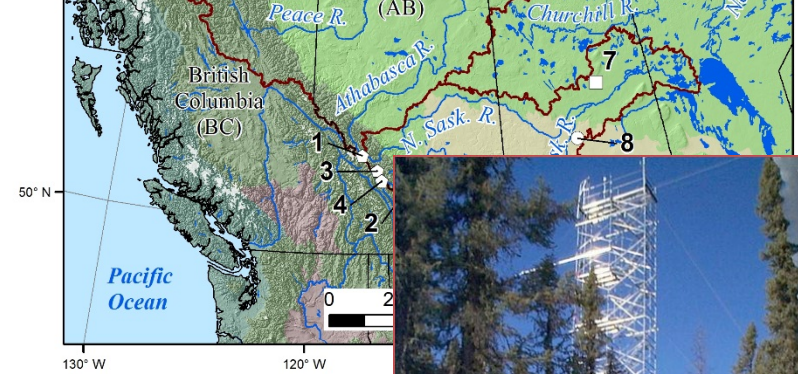
Kenaston /
Brightwater
Creek



hydro-
remote
AR
ology, and
n



Brintnell
Glacier



Water, Ecosystem, Cryosphere and Observatories

◇ Western Cordillera

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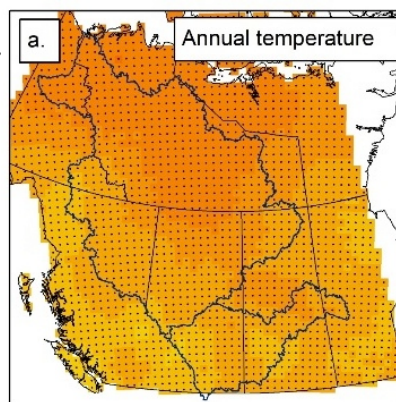
BERMS—Black
Spruce

Activities and Progress

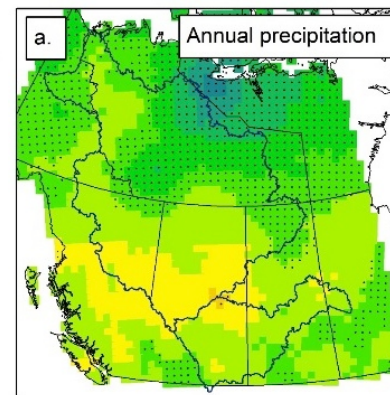
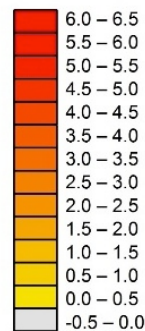
Theme A – Inventory of Observed Change

- Work in the network has produced local to regional scale assessments of change, with many publications and forthcoming papers
- A major review paper has pulled together and synthesized recent changes in the CCRN domain
 - DeBeer, C. M., Wheeler, H. S., Carey, S. K., and Chun, K. P.: **Recent climatic, cryospheric, and hydrological changes over the interior of western Canada: a review and synthesis**, *Hydrol. Earth Syst. Sci.*, 20, 1573-1598, doi:10.5194/hess-20-1573-2016, 2016.
- This points to systematic change in climate and cryospheric regime, but complex and mixed hydrological response signals

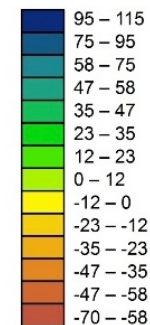
*Climate trends
(1950–2012)*



Trend value
(°C per 63 years)



Trend value
(% per 63 years)



Activities and Progress

Theme B – Local-Scale Understanding/Diagnosis

- A Special Observation and Analysis Period (SOAP) was carried out over the 2014–15 hydrological year, involving coordinated and intensive field campaigns at most WECC observatories
 - SOAP year was highly anomalous (warm, dry in much of the region)
 - Workshop (Oct 3-4) to address observations, key science questions, and data legacy
- Diagnosis of Change
 - Coordinated model runs using the Cold Regions Hydrological Model (CRHM) platform
 - Workshop to plan and coordinate the diagnosis of change at WECC observatories

<http://www.ccrnetwork.ca/science/workshops/crhm-workshop-2016>



The SOAP initiative involved 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

Activities and Progress

Theme C – Improved Large-Scale Modelling

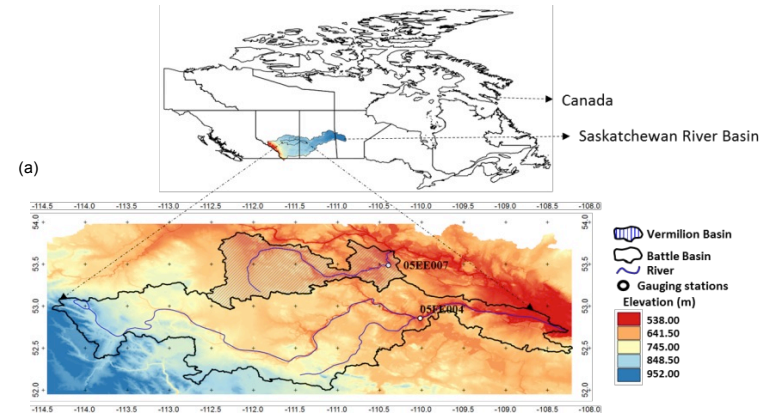
- Work in this theme has been done largely in close collaboration with our partner, Environment and Climate Change Canada
 - Improvements to Canadian LAnd Surface Scheme (CLASS),
Modélisation Environnementale Communautaire (MEC) – Surface and Hydrology (MESH),
Canadian Terrestrial Ecosystem Model (CTEM)
- Focus is on developing improved large-scale models of the Saskatchewan and Mackenzie River Systems
- CCRN is linked to a GEWEX cross-cut project on including water management in large scale models

Activities and Progress

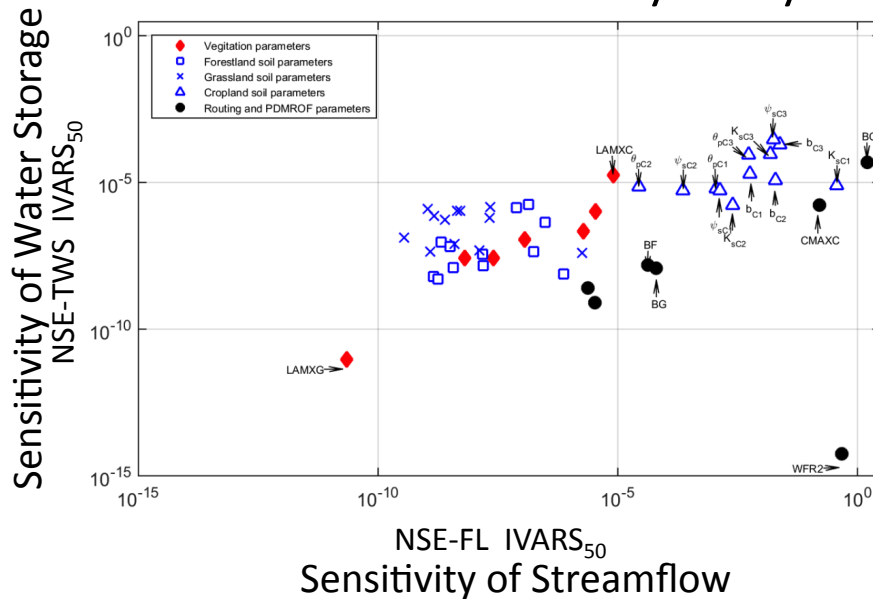
Theme C – Improved Large-Scale Modelling

Using GRACE for improved model parameterization

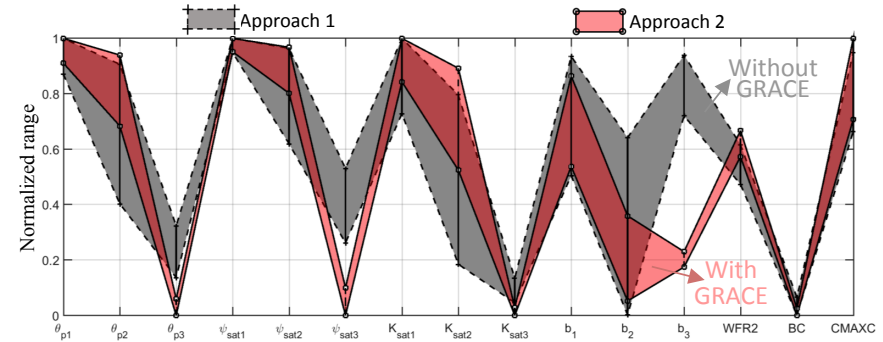
Yassin et al. (under review, WRR)



Multi-criteria Sensitivity Analysis



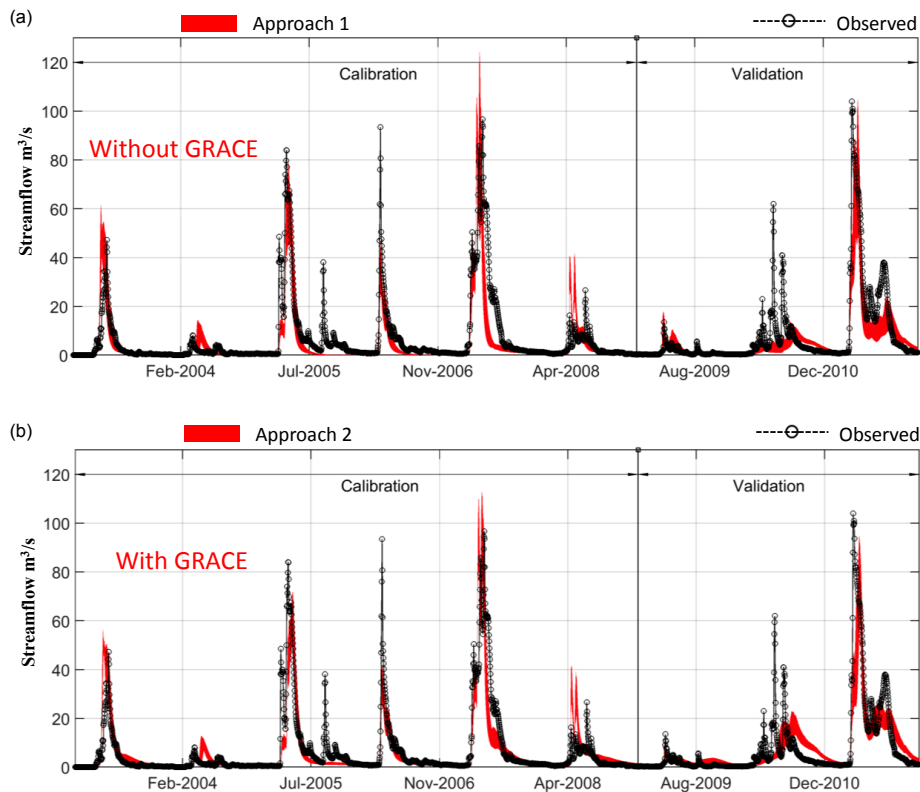
Multi-criteria Parameter Identification



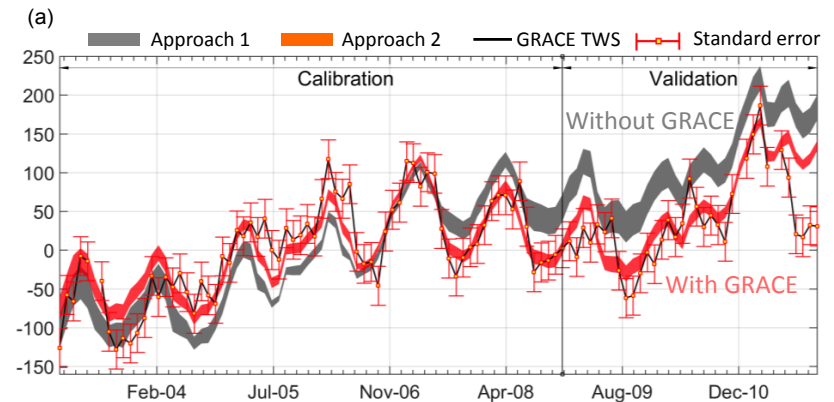
Activities and Progress

Theme C – Improved Large-Scale Modelling

Streamflow Results



Water Storage Results

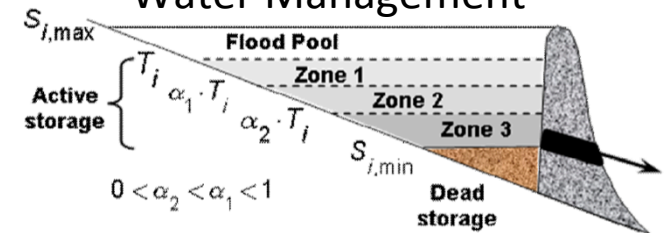


Activities and Progress

Theme C – Improved Large-Scale Modelling

Including Water Management in a Land surface-Hydrology Model
 Annis et al. (in prep.)

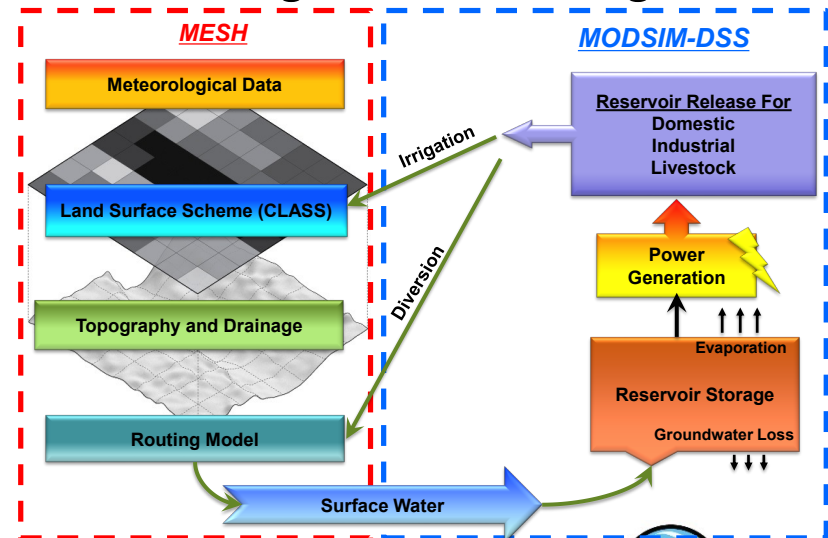
Basin-wide Priority-based Water Management



MODSIM-DSS



Integrated Modelling



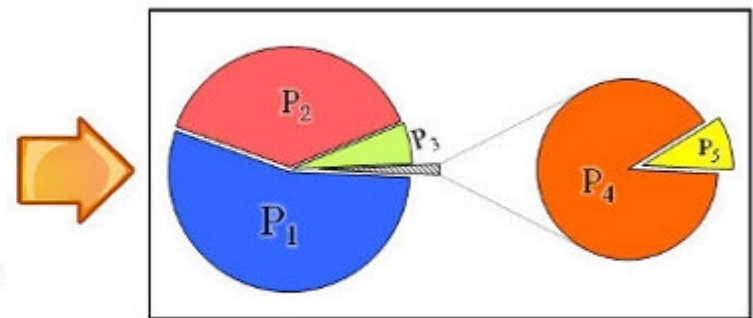
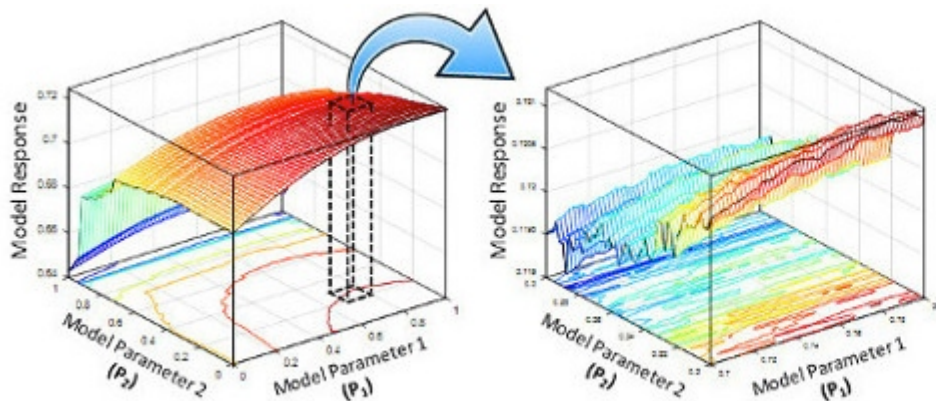
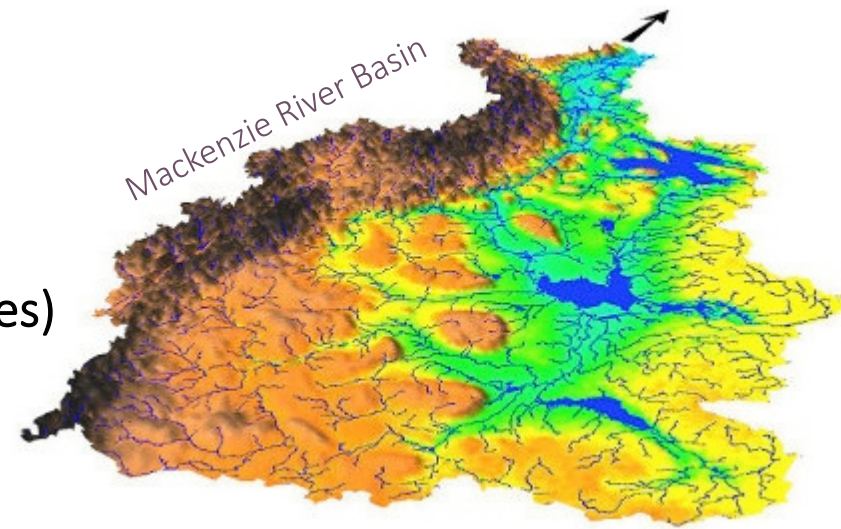
Activities and Progress

Theme C – Improved Large-Scale Modelling

Sensitivity Analysis and Insights into Large Models By VARS Framework

(VARS: Variogram Analysis of Response Surfaces)

Razavi and Gupta (2015, 2016, WRR)



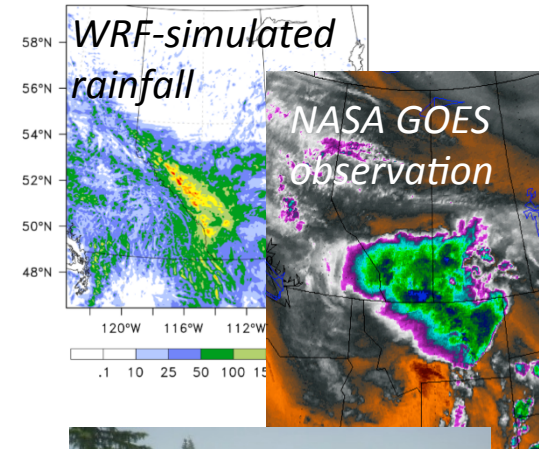
Activities and Progress

Theme D – Analysis/Prediction of Large-Scale Change

- Important analyses on large-scale variability and change have been undertaken and were reviewed at a recent workshop

<http://www.ccrnetwork.ca/science/workshops/theme-d-workshop-2016>

- A major focus is on examination of recent extremes in the domain
 - 2013 flooding in Alberta
<http://www.ccrnetwork.ca/science/2013-Alberta-flood>
 - Sequence of 3 record-setting wildfire seasons
 - Extreme dry conditions during 2015 (SOAP year)



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

Activities and Progress

Theme E – Outreach and Engagement

- Collaboration with our partners and outreach to communities and user groups across our domain has continued
- A recent focus on developing clear-language information products on aspects of the research program and on recent extreme events

See <http://www.ccrnetwork.ca/outputs/information-products>

The 2013 Alberta Flood
A Sign of Change in Cold Regions

*David M. Legler, University of Alberta, and
Cory J. Haywood, University of Alberta*

In June 2013, five people lost their lives when a combination of heavy rainfall and rapidly melting alpine snow triggered severe flooding in the Oldman, Bow and Red Deer River basins of Alberta and the Elk River basin of British Columbia, Canada.

The heavy precipitation and ensuing floods led to the evacuation of 100,000 people across three provinces, caused over \$6 billion of damage to roads, bridges and homes, and severely damaged scientific monitoring equipment.

What made this storm event unique

- Atmospheric moisture converged from the Pacific and from the anomalously wet US Great Plains and Canadian Prairies
- Substrate in the river systems developed over the 2 weeks
- The storm later transitioned to a cold developed precipitation over the northern part of the US border to Japan National Park
- Heavy rain fell at elevations in the river basins and foothills
- Rain fell in an abnormal time of the year, typically in fall or winter in the mountains including air conditioning and heating/cooling generation
- Rainfall is expected to be at high elevations, towards the head of the storm, slowing runoff generation
- A blocking pattern caused the weather system to stall over southern Alberta for three days

Genesis of the Storm

2013 Alberta flood



Key Science Messages: A number of things came together to create the Alberta June 2013 Flood event:

- Three meteorological conditions came together to bring record wet floods to the region: 1) an atmospheric moisture plume developed
- Two atmospheric features were relatively high in the local vertical, favoring and allowing an event like the US border to Japan for three days
- A cold front, with a period of quiescence in the high country, stalled with heavy rain, produced the largest amount of runoff from the region in over 100 years
- A block of storm clouds to the west of the mountains on the 1st day of the event on the east of the flood
- Although a flood of this magnitude occurs about once every 200 years, similar floods have previously been recorded on the Bow River, many of which times that were considered outside the anticipated flood plain were initiated by floodwaters

Changing trends: Where do we go from here?

- Scientists have observed rapid climate warming and significant increases in the highly variable hydroclimate during the last century, with significant rainfall and distribution on summer conditions
- The 2013 flood indicates the need for better coordination between the local government and province to be able to better understand the science of flood risk, extreme flows, late lands and winter capacity
- A comprehensive response to future flood requires better predictive assistance with the mitigation
- There is a long term trend for increases in duration of large multiple-day rainfall events in the Pacific Northwest, which needs to be realized to create a full understanding

The CCRN is a non-profit organization that provides information and resources to help communities understand and prepare for the risks of climate change. For more information, visit www.ccrnetwork.ca or contact us at 1-800-387-7222.

The 2014 Assiniboine Flood
Understanding environmental change and extreme events in the cold region of Western Canada

In July 2014, the Assiniboine River Basin (ARB) experienced widespread flooding costing an estimated \$1.5 billion in damages. Unprecedented heavy rainfall in May and late June resulted in record and near-record water levels throughout the ARB.

Roadways, bridges, and riverbanks were severely damaged and thousands of homes were evacuated. Millions of acres of young crops drowned, accounting for over \$1 billion of the damages.

The 2014 summer flood was unprecedented in 130 years of observations: major flooding in the ARB has historically been driven by snowmelt and early spring rains whereas the 2014 flood was generated solely by rainfall and was significantly higher than any previous summer flood.

Leading up to the Flood...

- Spring flood risk was low: near-normal precipitation occurred during preceding fall and winter
- A cold spring deluge occurred as soils were unable to dry out before the region experienced one of the wettest May-June periods on record
- A series of significant rainfall events in May and June saturated soils and nearly filled reservoirs and depressional storage

What happened during the Flood

- A low-pressure, multi-centered low-pressure system that extended from the southwest Canadian Prairies into central U.S., facilitated the transport of moisture into and the development of long-lived heavy rainfall over the ARB
- From June 27 - 30, record-breaking rainfall amounts were observed over much of the ARB
- Some local areas received up to 200 mm of rain in just 6 days - which is more than the long-term average for May and June combined

Key Science Messages:

- Widespread flooding began very quickly, washing out roadways and bridges, flooding farmers' fields, and forcing hundreds to evacuate
- The magnitude and impacts of the 2014 flood were record only to the record-breaking 2011 ARB spring flood, but were significantly higher than any summer flood in the ARB on record

What happened during the Flood

The flood in the ARB was the result of a rare combination of factors: 1) a low-pressure system that extended from the southwest Canadian Prairies into central U.S., facilitated the transport of moisture into and the development of long-lived heavy rainfall over the ARB

From June 27 - 30, record-breaking rainfall amounts were observed over much of the ARB

Some local areas received up to 200 mm of rain in just 6 days - which is more than the long-term average for May and June combined

Key Science Messages:

- The short span between the 2013 and 2014 extreme floods has raised concerns as to whether climate and land use changes have increased the potential for extreme floods in the region
- Research has indicated that an increase in May-June rainfall and extensive removal of ponds could have amplified the runoff response to the changing climate
- This may be an indication of a change in the hydrological regime in the ARB, rather than climate change only by itself, increased summer flows are being driven by
- More pond construction in the ARB may be a viable mitigation/management measure to minimize impacts of climate change in the region

The Changing Cold Regions Network (CCRN) is a multi-disciplinary network that aims to understand, address and prevent the rapid environmental change occurring in the heart of western Canada. CCRN focuses on the study of any form of cold climate and high-latitude environmental change, including hydrological, climate, biological, and geological changes. The network is based on the work of the National Science and Engineering Research Council of Canada (NSERC) through its Strategic Change and Adaptation Research program. For more information, visit www.ccrnetwork.ca

A rare flood event...

Initial assessments have estimated that the flood event to be a 1,000 to 1,000 year event, although it is difficult to assess the return period as it does not resemble any other flood on record.

Changing Conditions

- May-June rainfall events the greatest impact on early summer streamflow and floods
- Rainfall in the ARB in the ARB has increased significantly since the mid-1980s and is expected to continue to increase
- Analyses of observed and model results suggest that the magnitude of potential floods in the region (200, 201) was exceeded by the magnitude the severe was likely for the 2014 flood

Key Science Messages:

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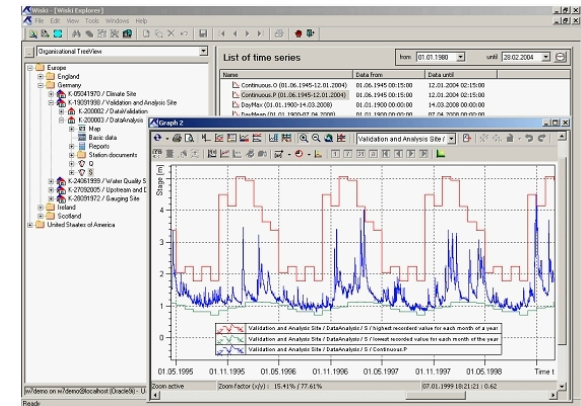
2014 Assiniboine River flood

Activities and Progress

Data Management

- *“We are committed to produce, document, and archive our results in an integrated, long-term repository.”*
- Data archiving for all WECC observatories and other special projects has been progressing and CCRN will deliver a world-class legacy dataset.

See: <http://www.ccrnetwork.ca/outputs/data>



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

Upcoming Activities

Meetings and Workshops

- We have several key workshops coming up this fall
<http://www.ccrnetwork.ca/science/workshops>
 - **Special Observation and Analysis period (SOAP) Workshop (Oct 3-4)**
 - Review observations from across the domain during this anomalous year
 - Synthesize network activities and address common science questions
 - Plan data archiving and publication, and special issue papers on SOAP
 - **CCRN 4th Annual General Meeting (Nov 2-4)**
 - Review network progress and plan future activities
 - Plan for our final deliverables around scenarios of change
 - **CCRN Fall Modelling Workshop (Nov 28-29)**
 - Synthesize activities to date
 - Plan the final round of model runs, focused on projections of change at our sites and over the region

New Funding: Global Water Futures

- The University of Saskatchewan, in partnership with University of Waterloo, McMaster University and Wilfrid Laurier University, has been awarded \$77.8 million over 7 years from the Canada First Research Excellence Fund to lead the ***Global Water Futures: Solutions to Water Threats in an Era of Global Change***.
- Aims:
 - deliver new capabilities for providing disaster warnings
 - diagnose and predict water futures
 - develop new models, tools and approaches to manage water-related risks
- For more information, visit the GWF website at <http://gwf.usask.ca/>



The final 18 months of CCRN

- 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 (CCAR Theme 3);
 - Advance water, weather, climate and environmental prediction (CCAR Theme 2); and
 - Improve our understanding of Earth system processes and their representation in hydrological, atmospheric and ecological models (CCAR Theme 1).
- In doing so, we will:
 - Enhance our capability for water management;
 - Train the next generation of Earth System Scientists; and
 - Provide high quality datasets for change assessment and model verification.

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.)**
- Garry Clarke (U. British Columbia)
- 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)
- Warren Helgason (U. Sask.)
- **Al Howard (Ag. and Agri-Food Can.)**
- Dave Hudak (Env. Can.)
- Andrew Ireson (U. Sask.)
- Richard Janowicz (Yukon Environment)
- Ed Johnson (U. Calgary)
- Jill Johnstone (U. Sask.)
- Bob Kochtubajda (Env. Can.)
- Yanping Li (U. Sask.)

- **Murray MacKay (Env. Can.)**
- **Phil Marsh (Wilfrid Laurier U.)**
- Sean Marshall (U. Calgary)
- Jeff McDonnell (U. Sask.)
- **Al Pietroniro (Env. Can.)**
- **John Pomeroy (U. Sask.)**
- **William Quinton (Wilfrid Laurier U.)**
- Garry Scrimgeour (Parks Can.)
- Chris Spence (Env. Can.)
- Craig Smith (Env. Can.)
- Saman Razavi (U. Sask.)
- **Ron Stewart (U. Manitoba)**
- Kit Szeto (Env. Can.)
- Julie Thériault (U. Québec à Montréal)
- **Merritt Turetsky (U. Guelph)**
- Garth van der Kamp (Env. Can.)
- **Howard Wheeler (U. Sask.; CCRN PI)**
- Daqing Yang (Env. Can.)
- Xuebin Zhang (Env. Can.)

Board of Directors

- Jim Bruce (Env. Can., ret.)

- Wayne Dybvig (SK WSA)
- Ken Greenway (AB Env. & Sus. Res. Dev.)
- Michel Jean (Env. Can.)
- Donna Kirkwood (Nat. Resources Can.)
- David Livingstone (Gov. NWT, ret.)
- 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)

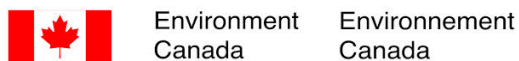
Secretariat (@ GIWS, U. Sask.)

- Chris DeBeer (CCRN Project Manager)
- Stacey Dumanski (Outreach Coordinator)
- Michelle Martel-Andre (Executive Assistant)
- Chris Morin (Communications Specialist)
- Sherry Olauson (Clerical Assistant)
- Graham Strickert (Theme E lead)
- Tim Zagozewski (Finance Officer)
- Branko Zdravkovic (Database Manager)

***Indicates member of Science Committee**

www.ccrnetwork.ca





For further information visit the webpage at www.ccrnetwork.ca



Or contact the network manager, Chris DeBeer (chris.debeer@usask.ca) or Principal Investigator, Howard Wheeler (howard.wheater@usask.ca)

Upcoming Activities

Science Focus and Directions

- Theme A
 - Development of conceptual models of change, to be diagnosed quantitatively in Theme B
- Theme B
 - Historical diagnostic modelling of change and examination of local-scale future variability and change (driven by WRF pseudo-global warming runs)
- Theme C
 - Working models of the major river basins in place by late fall and transfer of improved large-scale models for analyses in Theme D
- Theme D
 - Application of models to predict and understand regional changes in hydrology under scenarios of landscape and ecological change for 21st Century
 - Focus on occurrence of wildfires, aspects of change in 0°C, and chain-of-events surrounding several recent disasters in the CCRN domain