UNIVERSITY OF SASKATCHEWAN

Global Institute for Water Security

www.usask.ca/water

Prof N S Govind Rao Memorial Lecture 2021

Water security in a Changing World

Howard Wheater FREng, FRSC, Canada Excellence Research Chair Laureate,
U Saskatchewan, Canada & Emeritus Professor, Imperial College London, UK

Water has multiple dimensions

-Competing demands for water

The threats of water extremes

Pakistan 2010

New York 2012

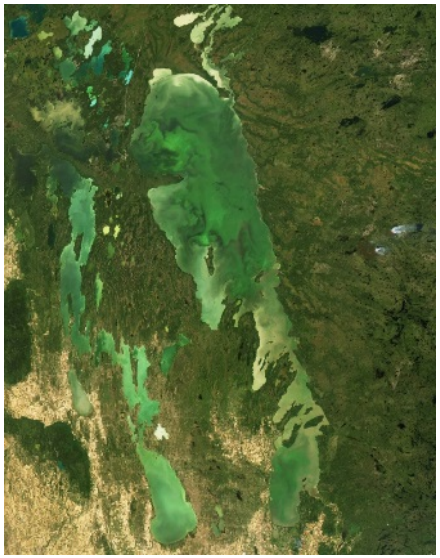
Queensland floods 2010

Aral Sea

California 2015

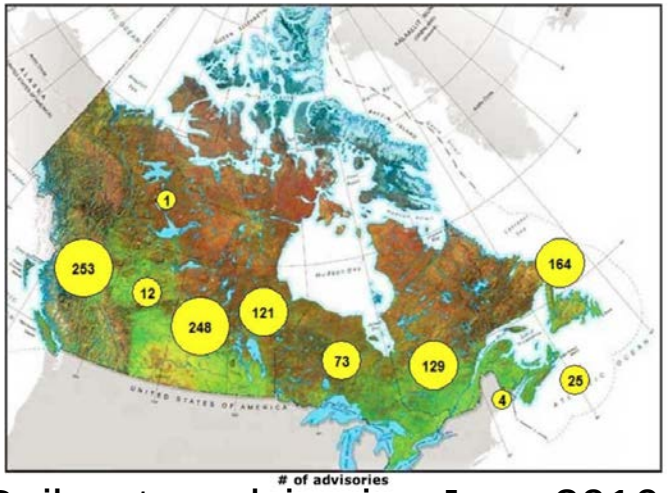
Australian drought 2001-2009

The threats to water quality



Lake Winnipeg 2007

Arsenic in Bangladesh



Boil water advisories June 2016

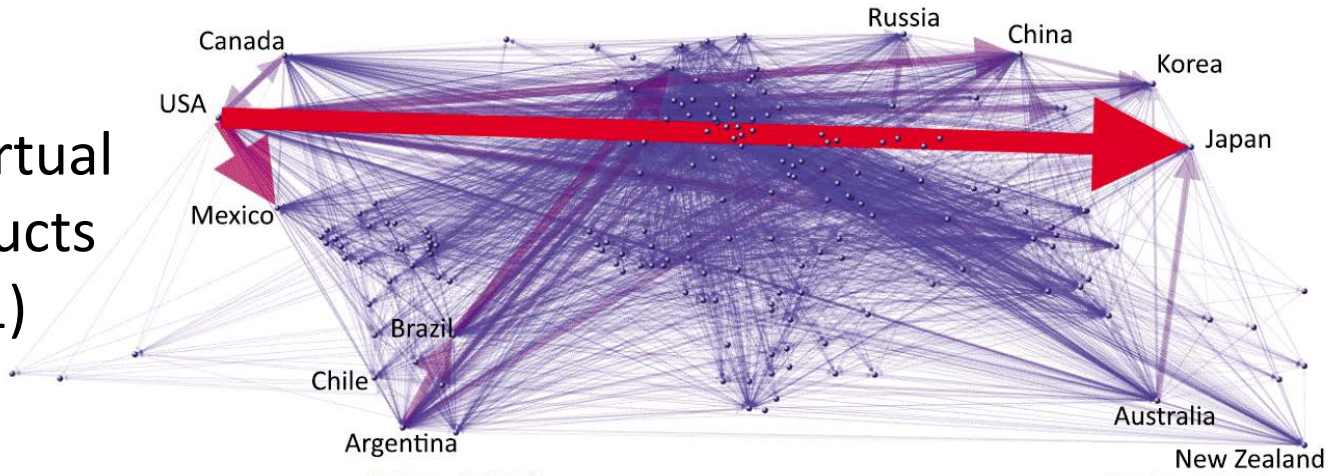
Lake Eyrie 2015

'Keeping salt out of the Murray'

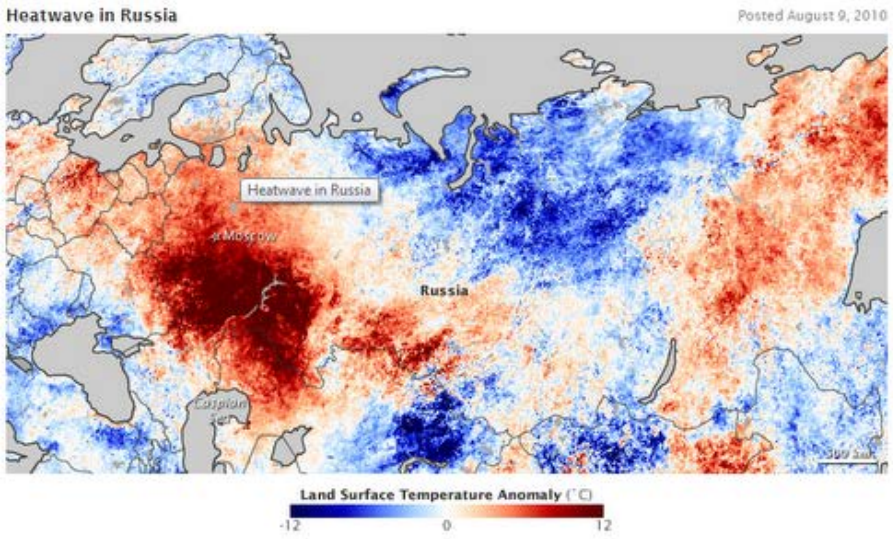
An era of 'global water'

2011 Thai floods shut down global chip production - $45.7billion losses

Global trade in virtual water- food products Konar et al. (2011)



Russian heat wave 2010 linked to Arab Spring? Economist. 2012 'Food and the Arab Spring'



Global water challenges

- **unsustainable use** of water – declining groundwater levels, dry rivers
- increasing **competition** for water resources – at local, regional and international scales
- **degradation of water quality** – from over-abstraction and pollution
- loss of **habitats and biodiversity**
- increasing **flood and drought risk**

And the future for water

- increased demand – population growth, economic development, agriculture
- environmental change
  - changing land and water management
  - climate change
- **increasing flood risk**
- **increasing pressures on water resources**
- **6 billion in water-scarce areas by 2050?**

Implications for water science?

These are Big Problems for science and society:

- Complex systems
- Unprecedented change
- Large scales

→ **Big Water Science**: To deliver the new science needed to sustain development and global ecosystems, tackling/ understanding interactions and feedbacks between climate-land-water-society

Challenges for water science

1. The effects of the **Anthropocene** on the water environment are pervasive and poorly understood.
2. Managing complex and dynamic **human-water systems** requires new understanding of process interactions and feedbacks across multiple scales.
3. **Trans-disciplinary science** is needed to capture the effects of human activities on the water environment.
4. The **social process of stakeholder engagement** with water science is at least as important as the knowledge yielded by the science.

University of Saskatchewan
Global Institute for Water Security

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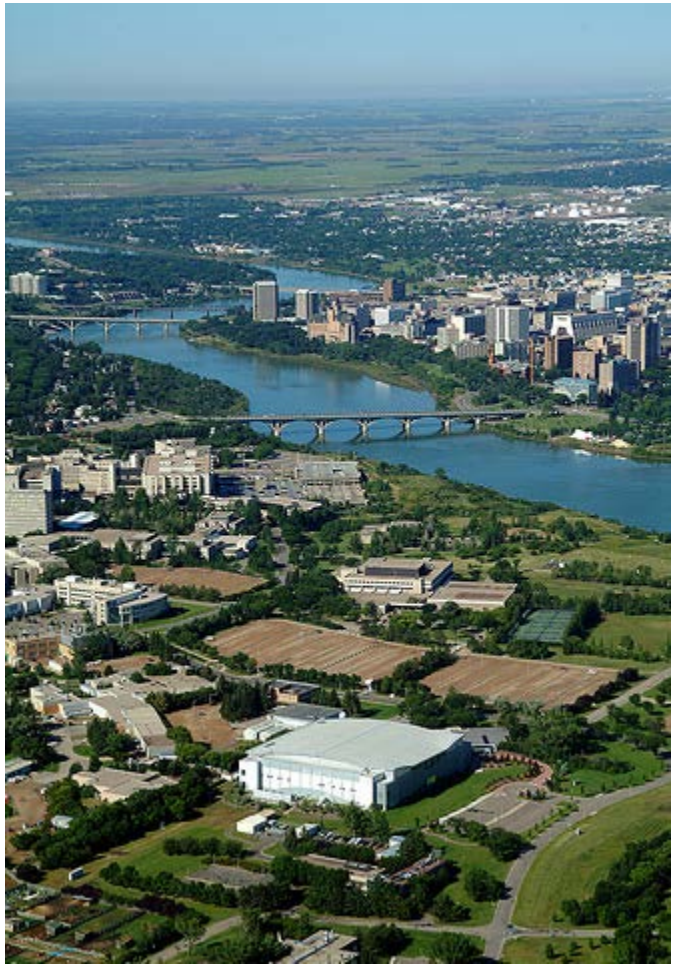


Founded 2011

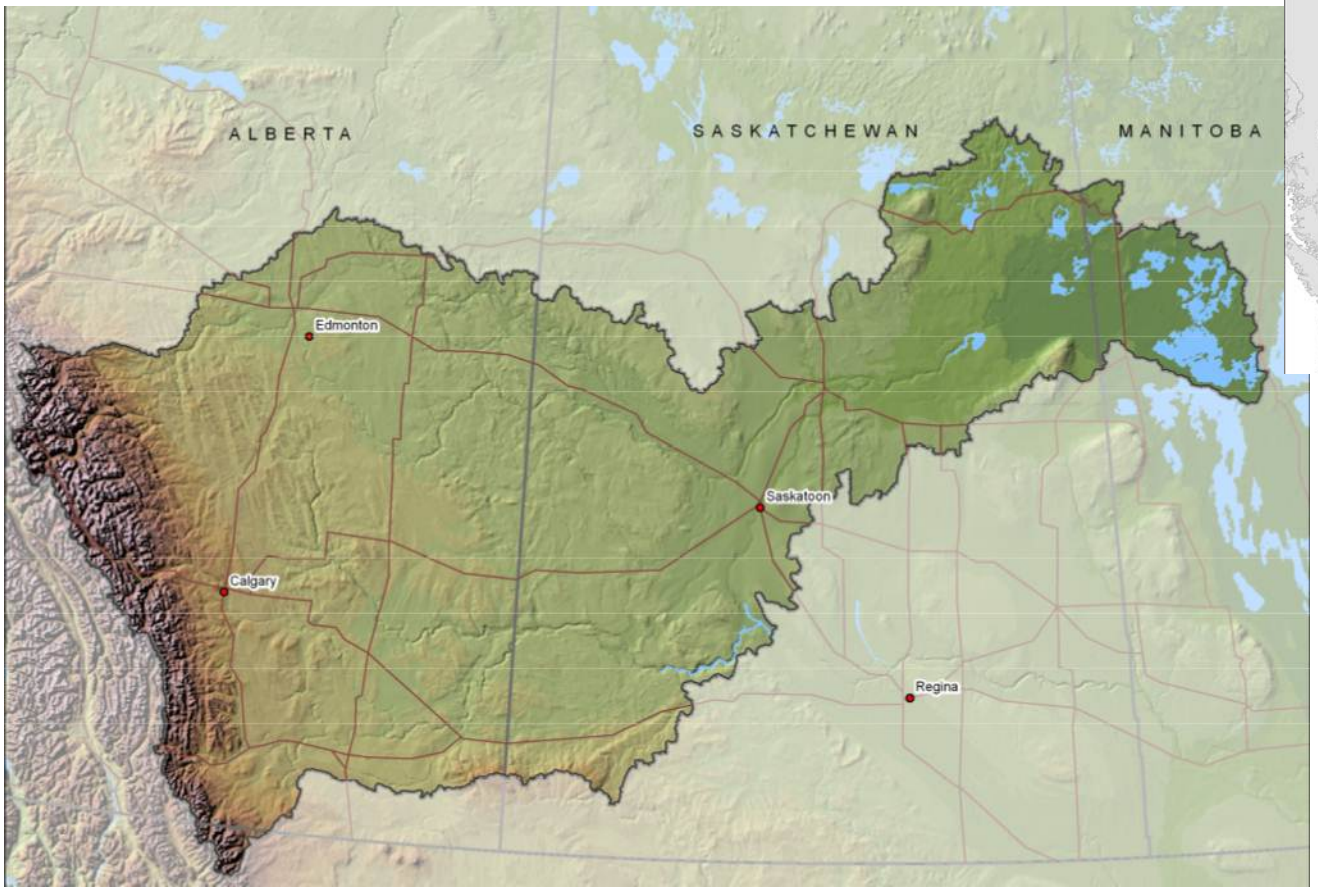
65 Faculty, 21 academic units

National Hydrology Research Centre

University of Saskatchewan
Global Institute for Water Security

Water in the Canadian Prairies

Saskatchewan River Basin

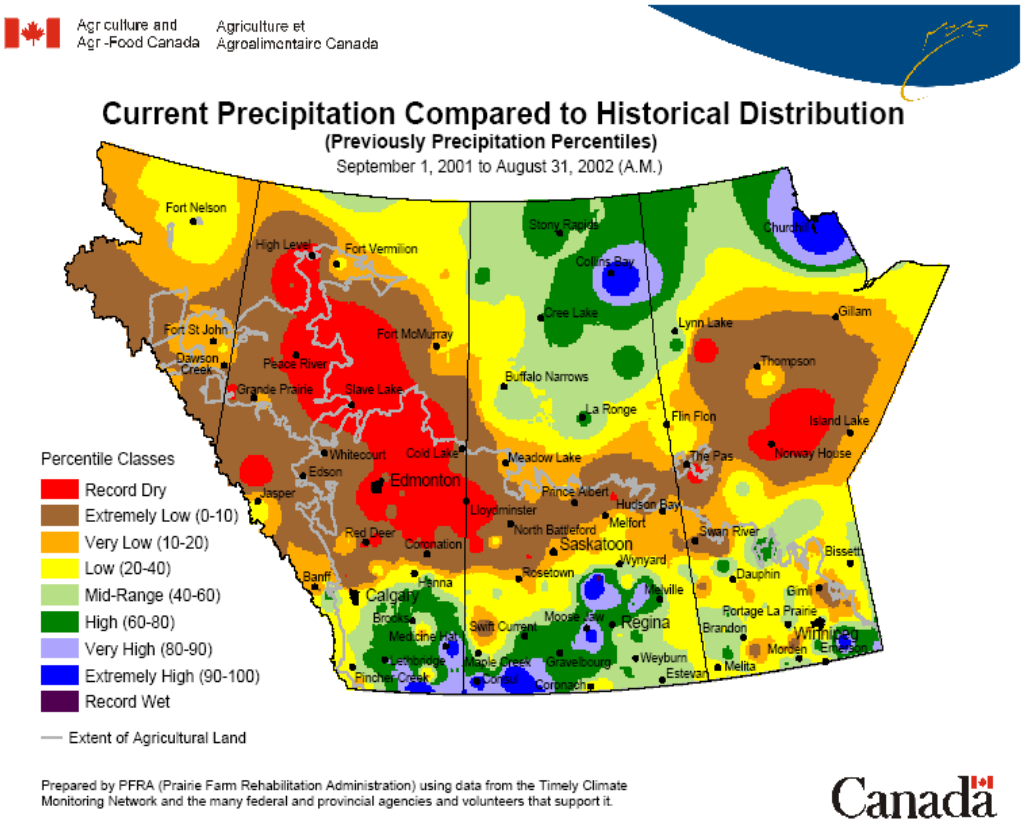


Some Challenges:

- The South Saskatchewan river has reached limits for use in southern Alberta
- Climate change and land management are changing the land and its water in complex ways, affecting river flows and prairie hydrology
- Pollution is changing its water quality
- Water governance in the prairie provinces is complex and fragmented
- Extreme events are damaging and expected to increase

Prairie Drought of 1999-2004

Described as Canada's most costly natural disaster



- $5.8 billion decline in GDP 2001-2002
- $3.6 billion drop in agricultural production, 2001-2002
- 41,000 jobs lost
- BC, Alberta forest fires
- Saskatchewan dust storms

Calgary floods June 2013

4 deaths, 100,000 evacuated
$6 billion direct damages

Town of ‘High River’ AB

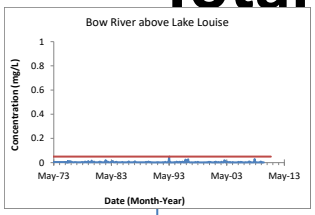
SE Saskatchewan July 2014

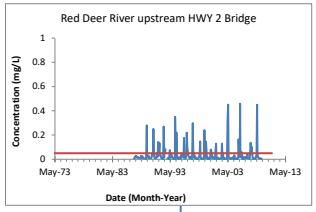
state of emergency in 40 rural municipalities

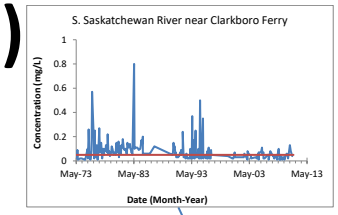
Total Phosphorous Concentration (1973-2009)

Concentration (mg/l)

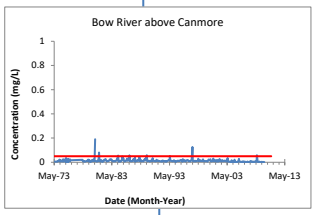
AB Surface Water Quality Guideline (0.05 mg/l)



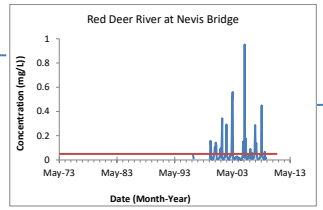


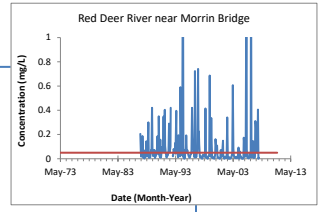


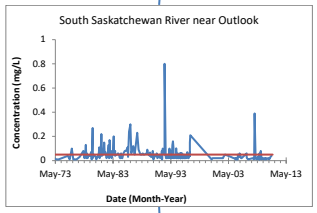
Saskatoon



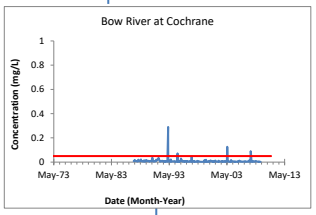
Red Deer







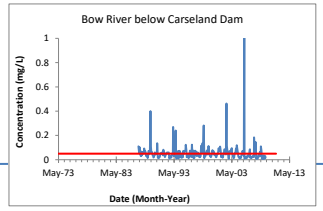
South Saskatchewan River

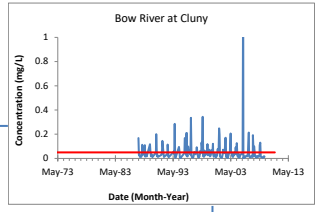


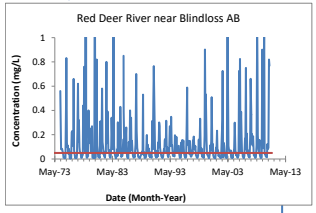
Bow River

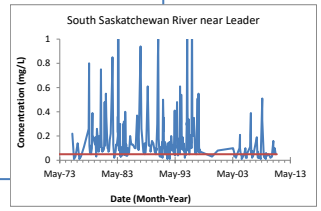
Red Deer River

L. Diefenbaker

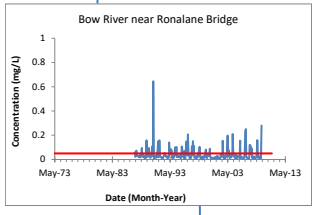


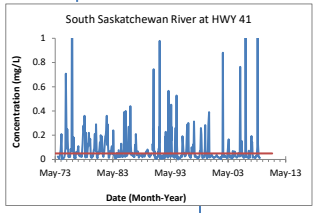




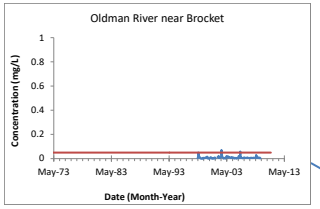


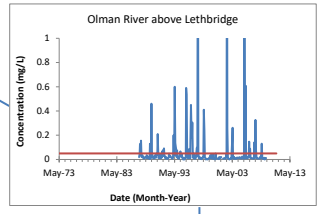
Calgary





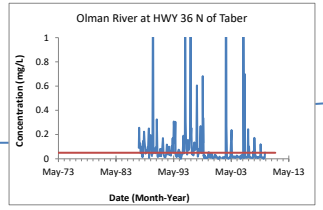
Oldman River

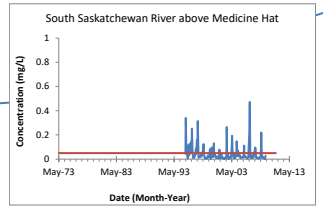




Medicine Hat

Lethbridge

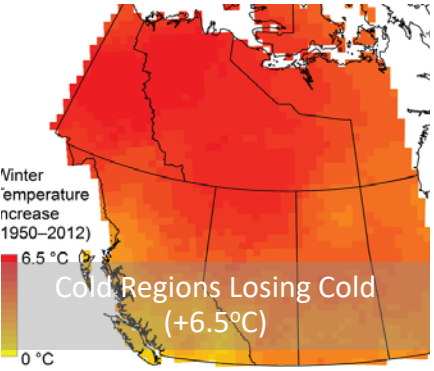




Effects of agricultural management?

Smith Creek, SK

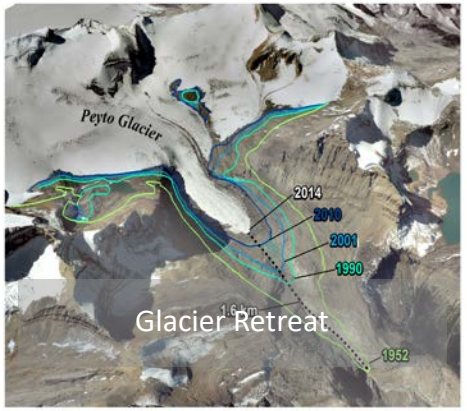
The Big Thaw



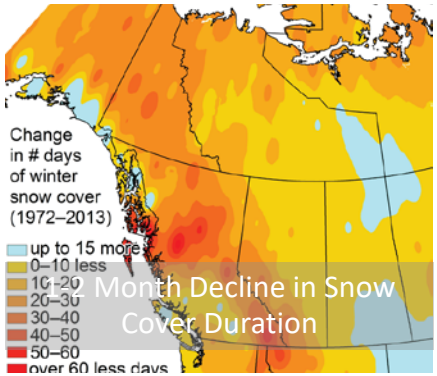
Cold Regions Losing Cold (+6.5ºC)


Permafrost Thaw


Unprecedented Prairie Summer Flooding



Glacier Retreat

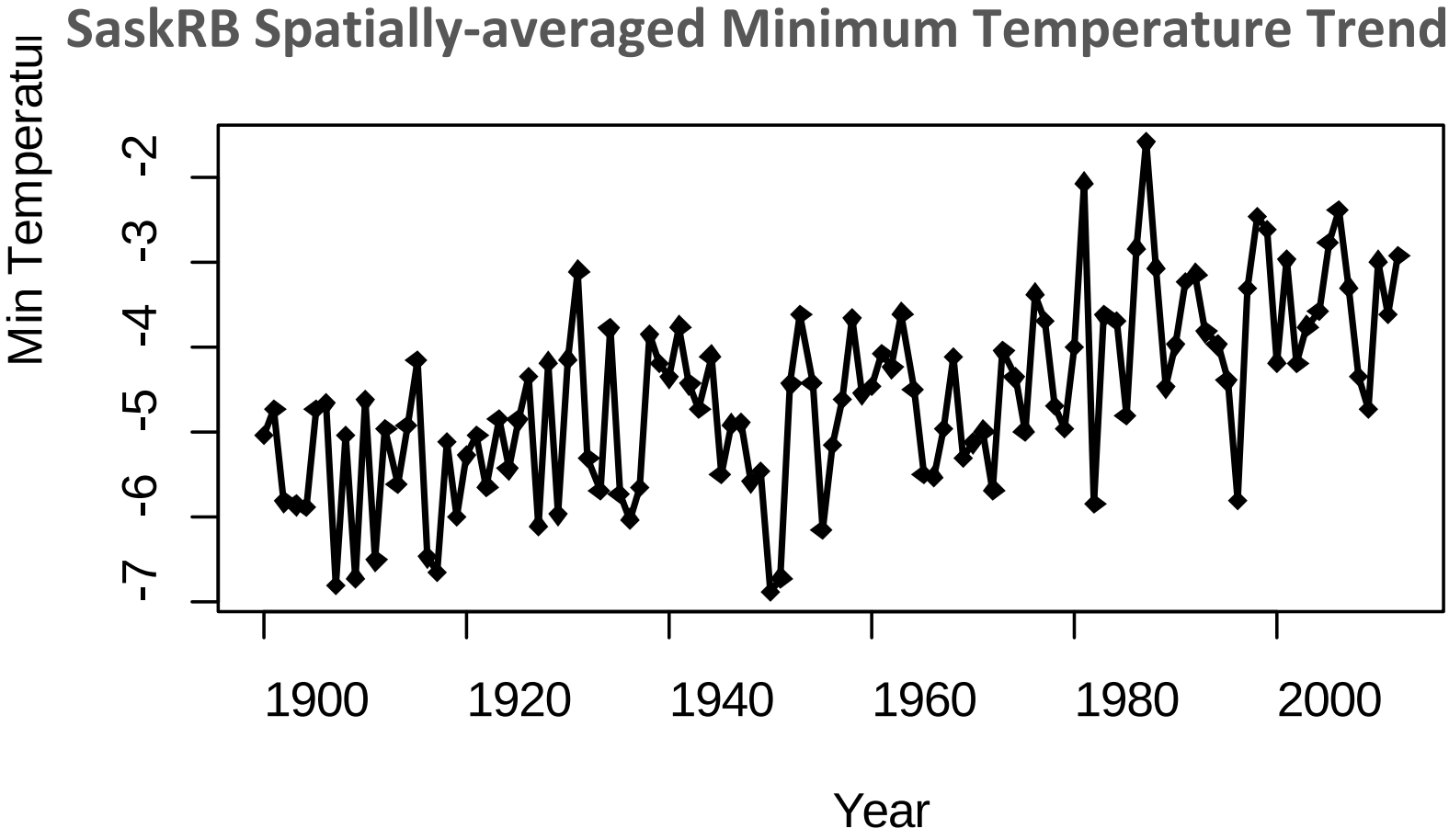


2 Month Decline in Snow Cover Duration


Extreme Wildfires

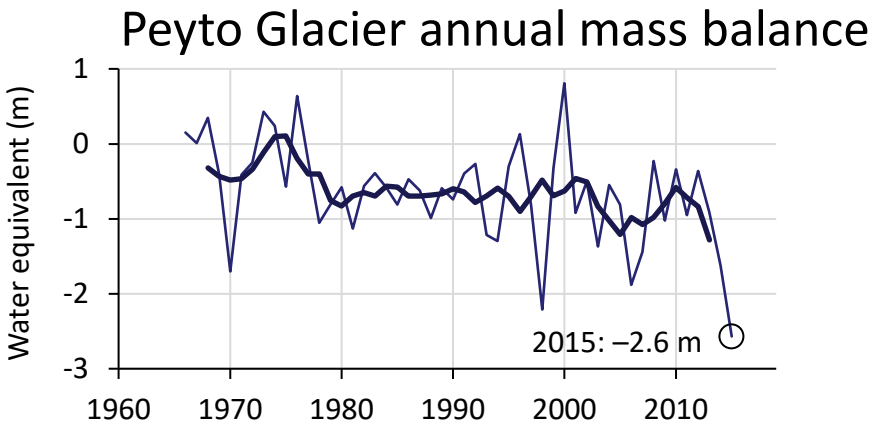

Yukon's Slims River Changes Flow Direction

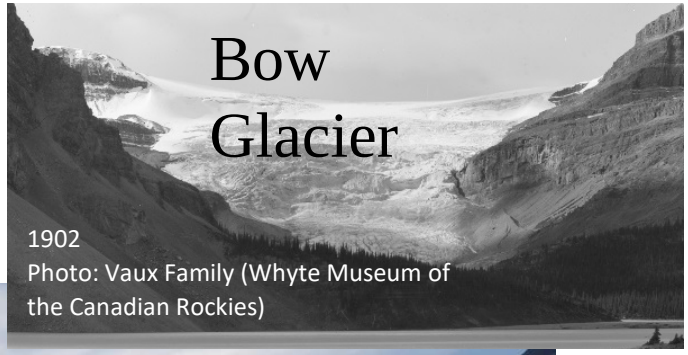
Warming climate – glacier retreat, changing snow accumulation/melt, rain/snow balance

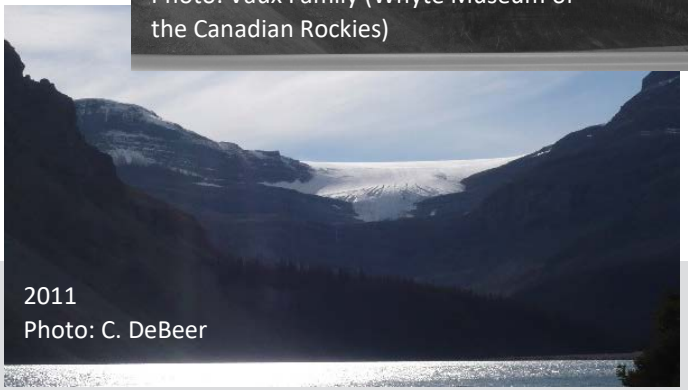


Mountain Glaciers and Ice Fields

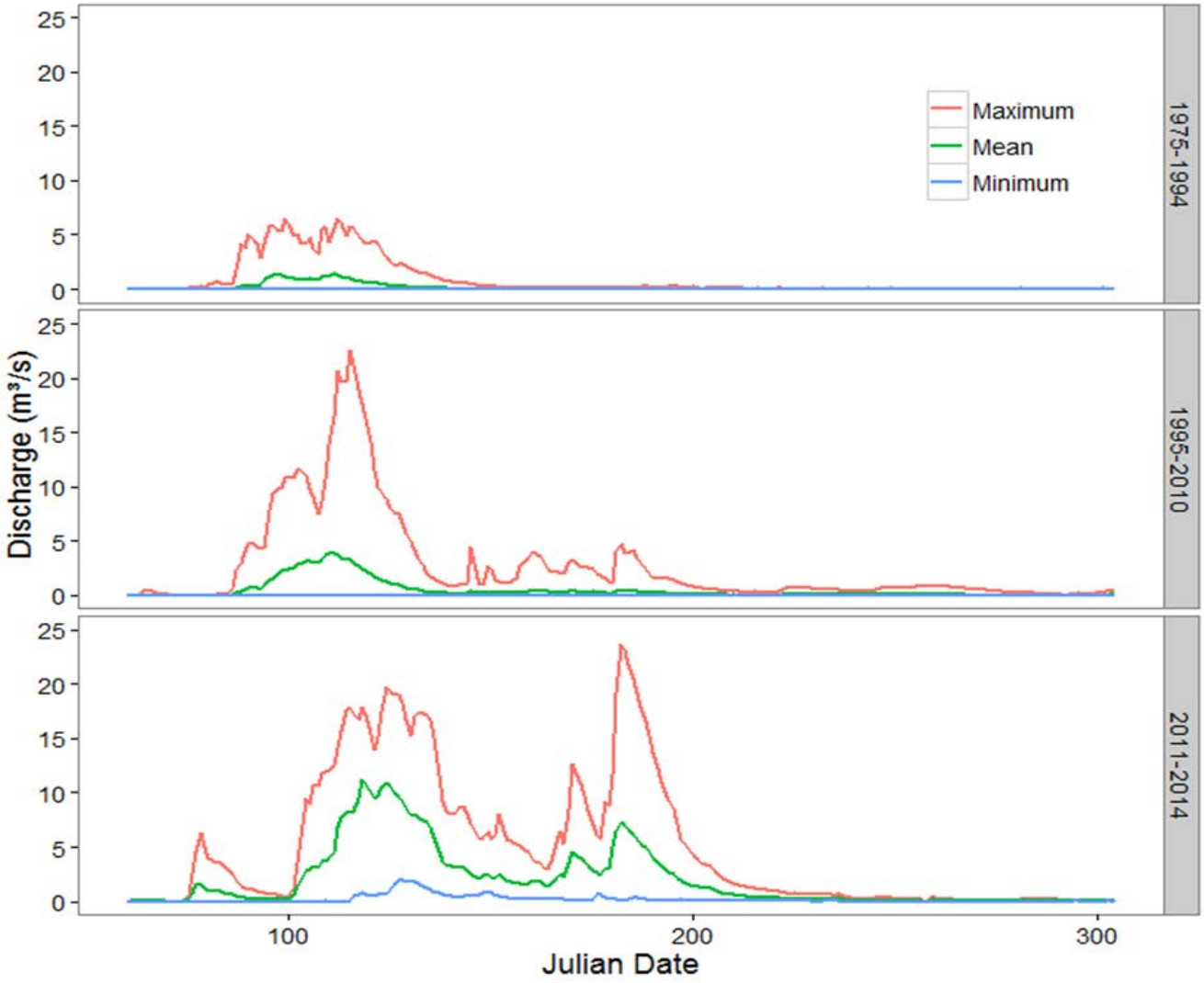
- Widespread glacier retreat across western Canada and globally
- Predominantly negative net mass balance—record ice loss in 2015 for many glaciers
- Many glaciers have exhibited an acceleration of their retreat and disintegration in the very recent past
- The ability of glaciers to augment flows leaving the Rockies is low—e.g. very lows flows last year despite record negative mass balance







Changing Prairie Hydrology



Smith Creek, SK

(Dumanski et al., 2015)

University of Saskatchewan
Global Institute for Water Security

GIWS Saskatchewan River Basin Research Facility

– a GEWEX Regional Hydroclimate Project

Area 406,000 km^2

Drains from continental divide in Alberta, through Saskatchewan to Manitoba and Hudson's Bay

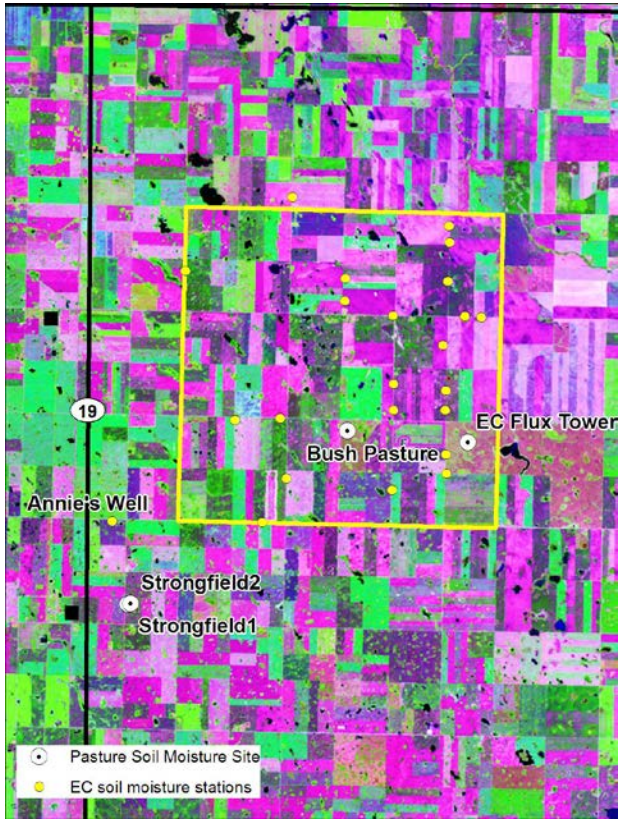
Rocky Mountain Research Basins
- Marmot Creek & Sibbald Wetland

Boreal Forest Research Sites BERMS/BOREAS

Prairie Research Sites

St Denis

Kenaston



Smith Creek

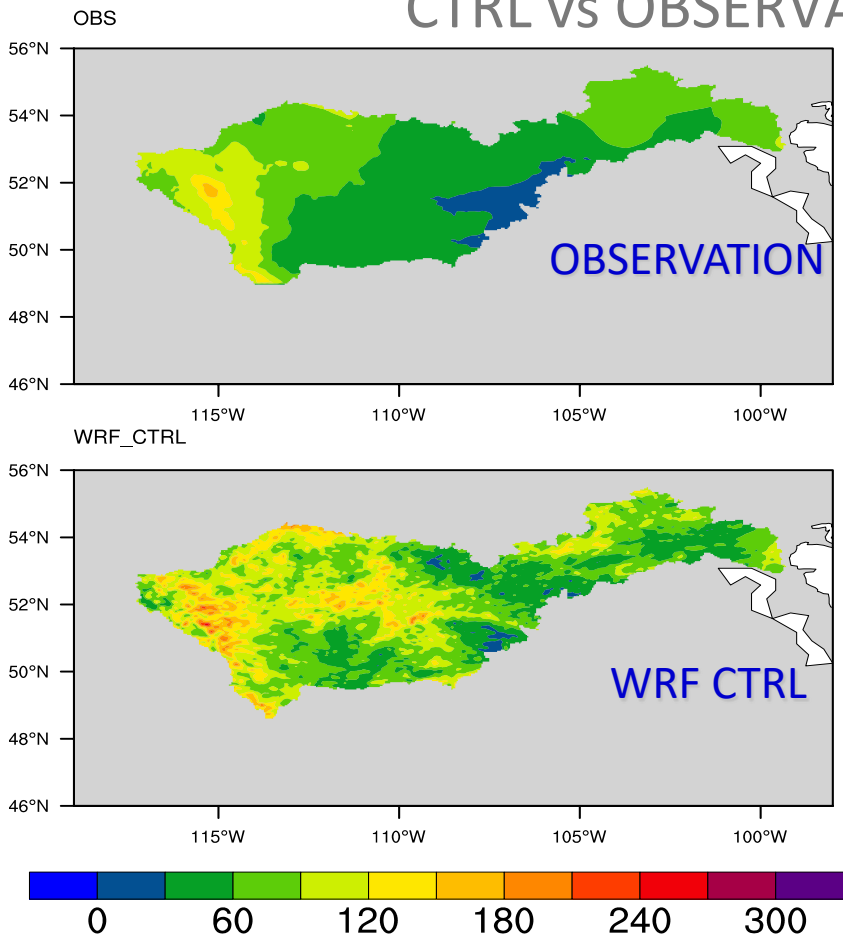
Lake Diefenbaker/Swift Current Creek

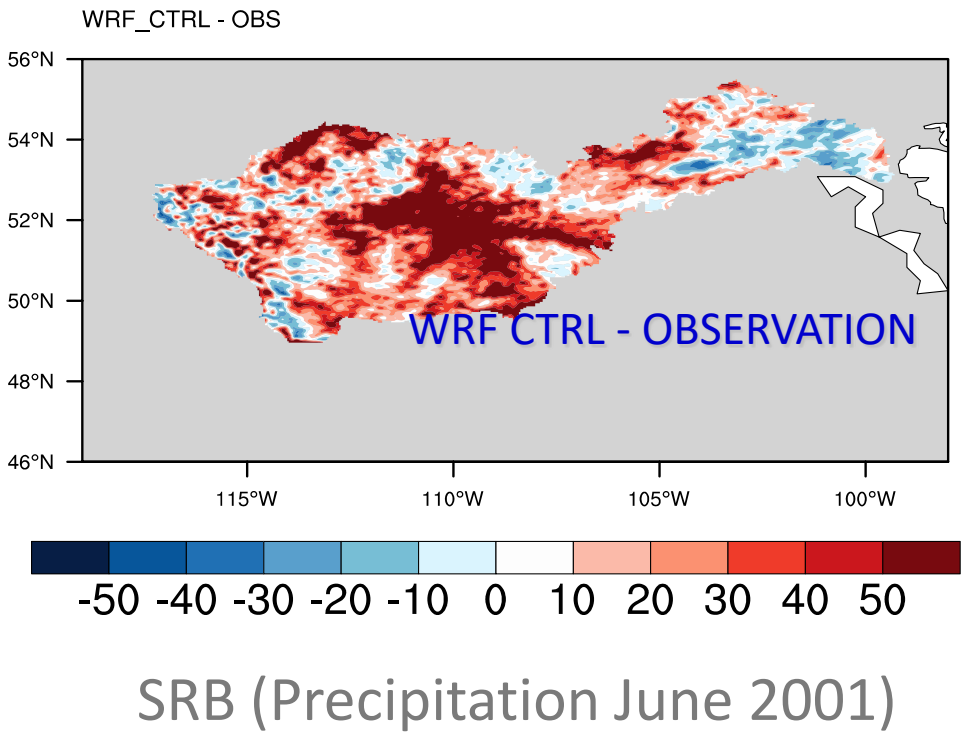
Algal bloom - Sept 24 2011

High resolution atmospheric modelling

4km WRF simulations (Yanping Li, Roy Rasmussen)

CTRL vs OBSERVATION comparison

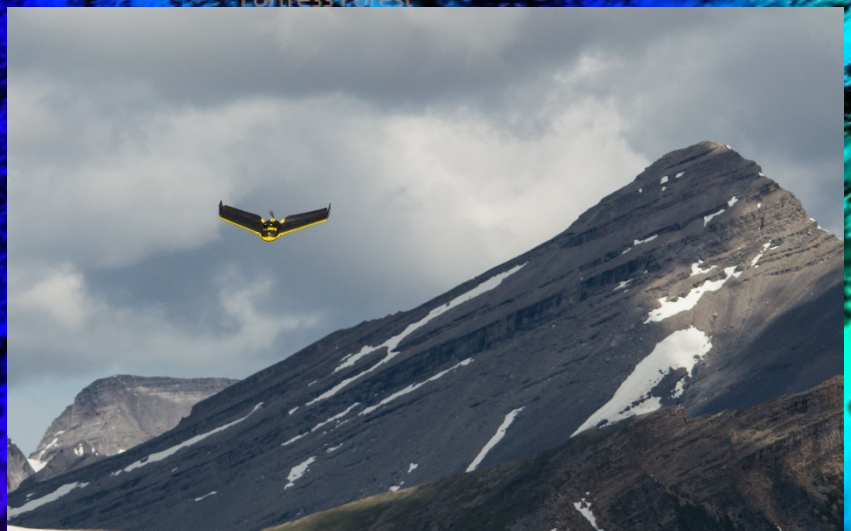


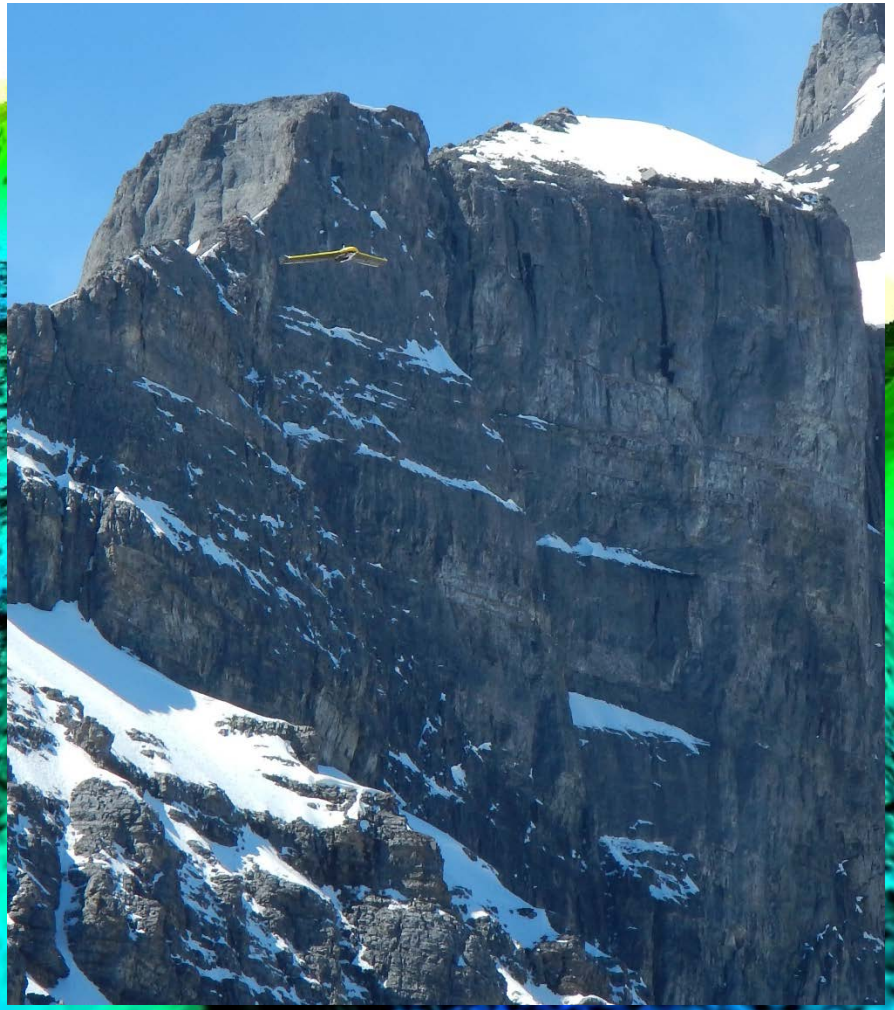


SRB (Precipitation June 2001)

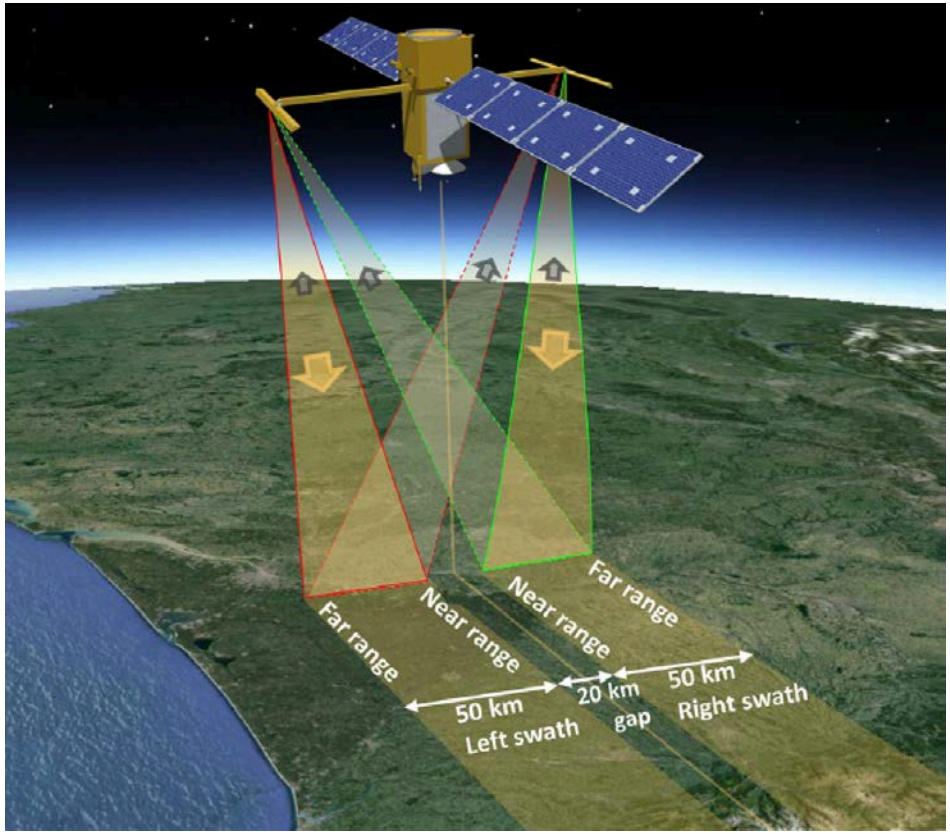
SnoDrone – Fortress Mountain

Fortress Mountain





The Surface Water and Ocean Topography Mission

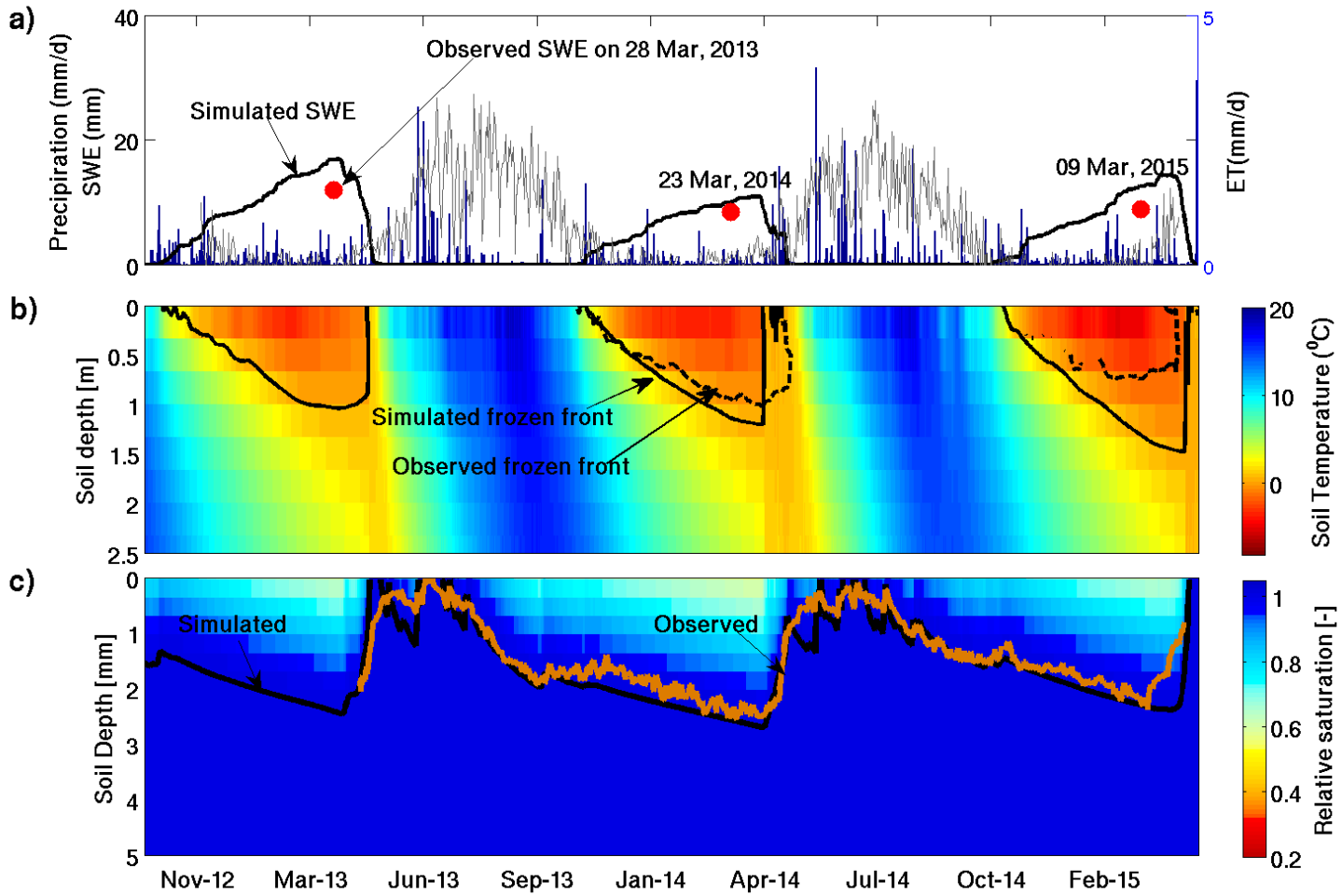


Ka-band Radar Interferometer (KaRIn) operating at 35.75 GHz (8.6 mm) with twin 50 km swaths pointing 1-4.5° off nadir.

- Scheduled for launch in 2021.
- Simultaneously measures inundation extent and water surface elevation
- Total budget: ~$1.1B

Biancamaria, Lettenmaier, and Pavelsky, *SoG*, 2016

Soil profile response, St Denis

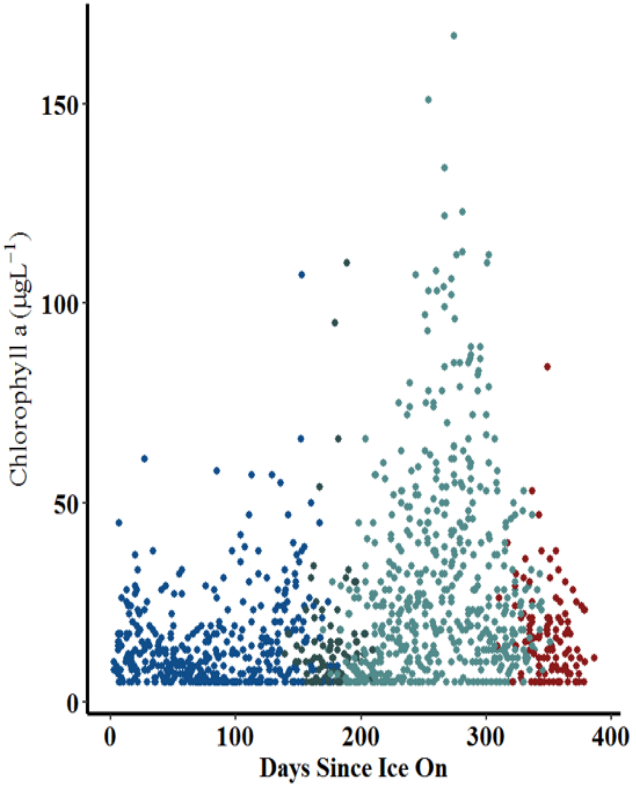


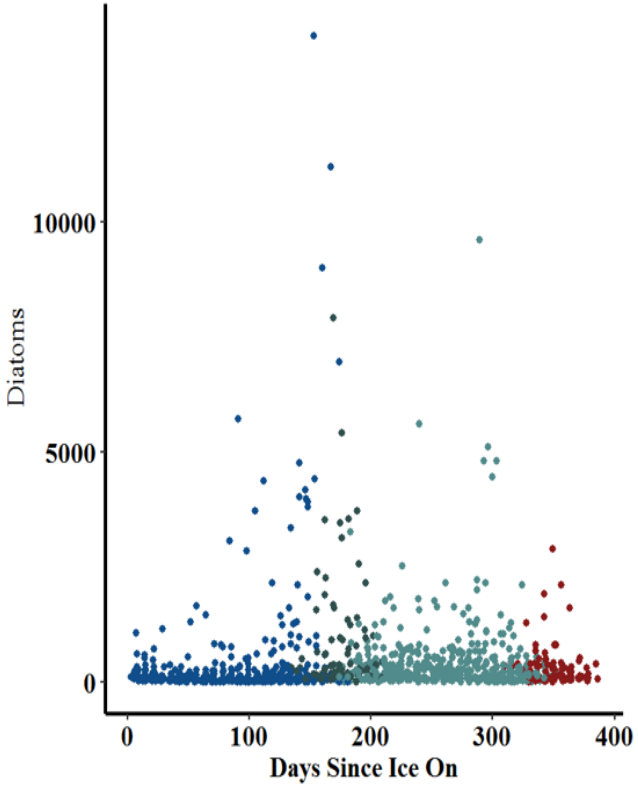
Biogeochemistry of frozen lakes

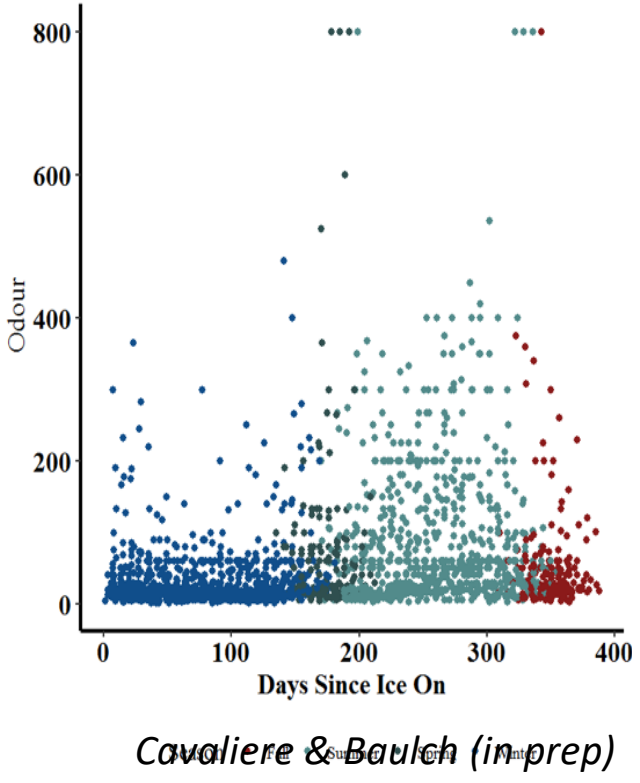
High chlorophyll *under ice*.

Spring diatom bloom often *under ice*.

Peak odour can occur *under ice*.



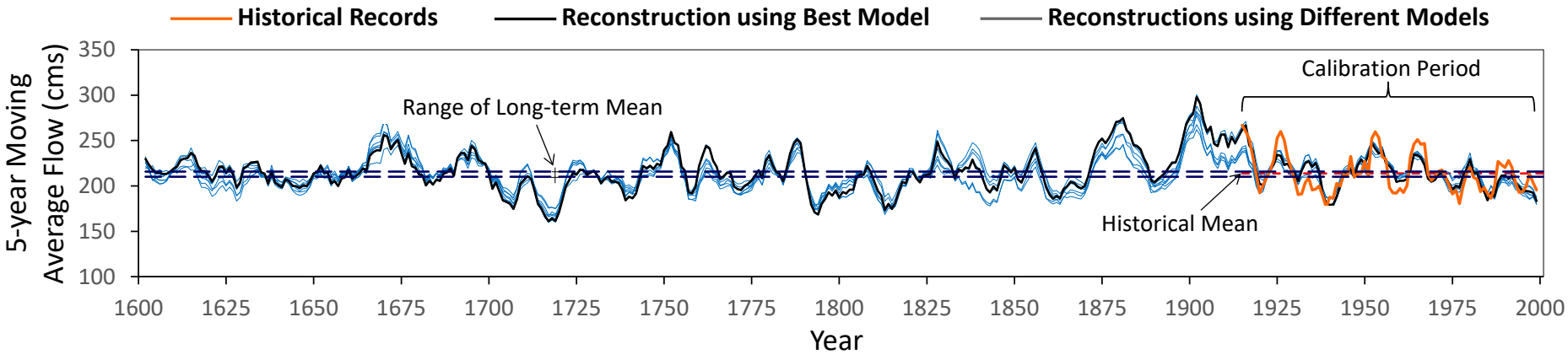




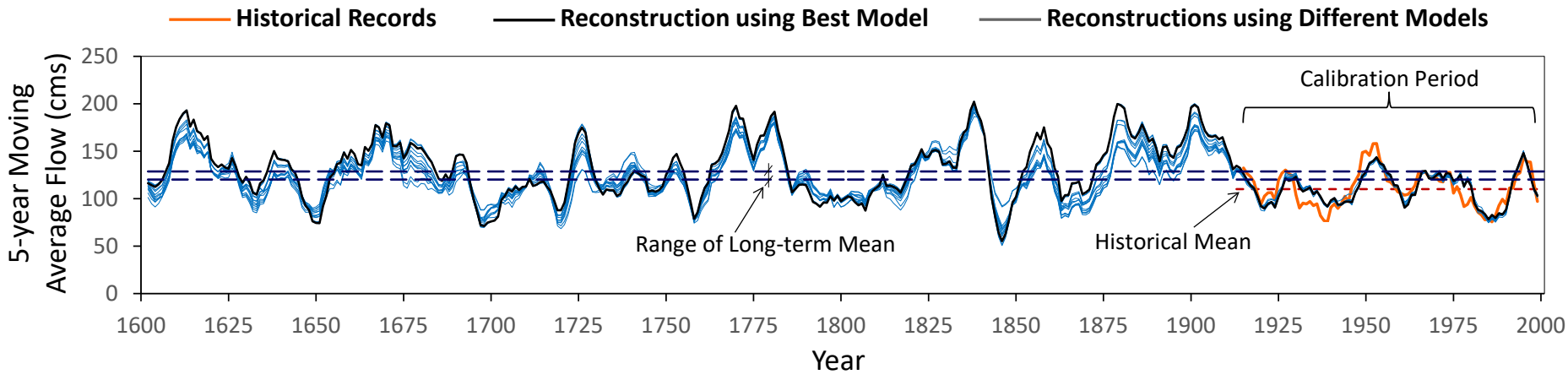
Cavaliere & Baulch (in prep)

Learning from the past

North Saskatchewan River

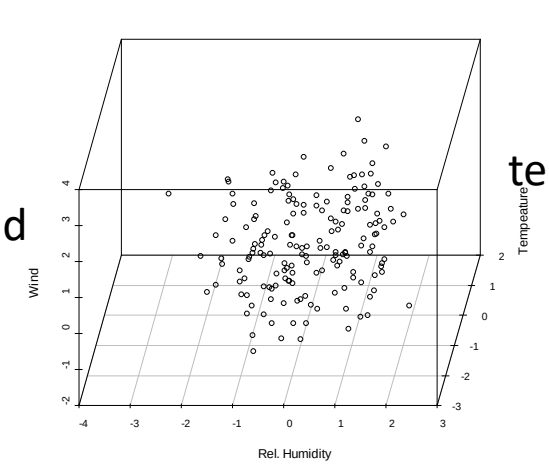


Oldman River



Diagnosis of Global Climate Models
Boreal forest data

CGCM3

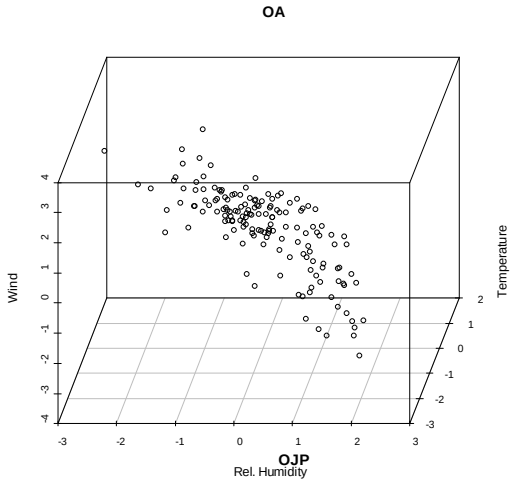


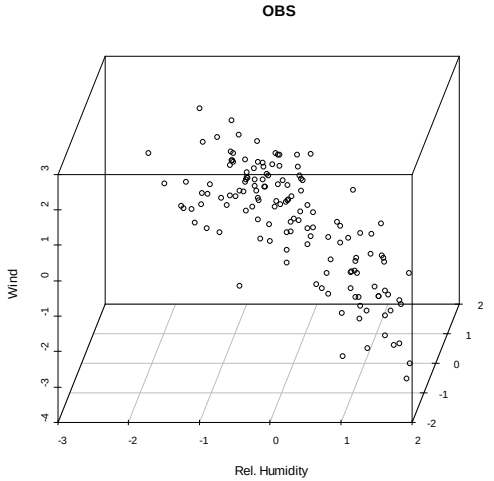
wind

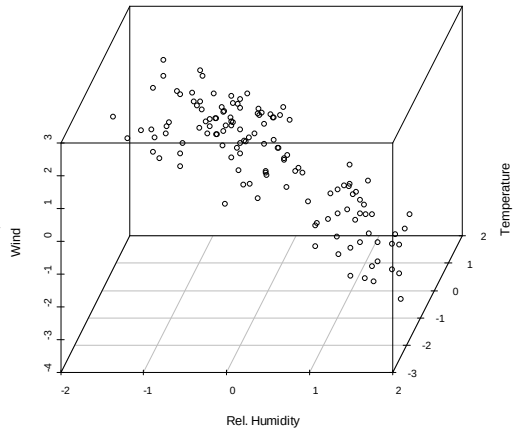
temperature

relative humidity

Observed



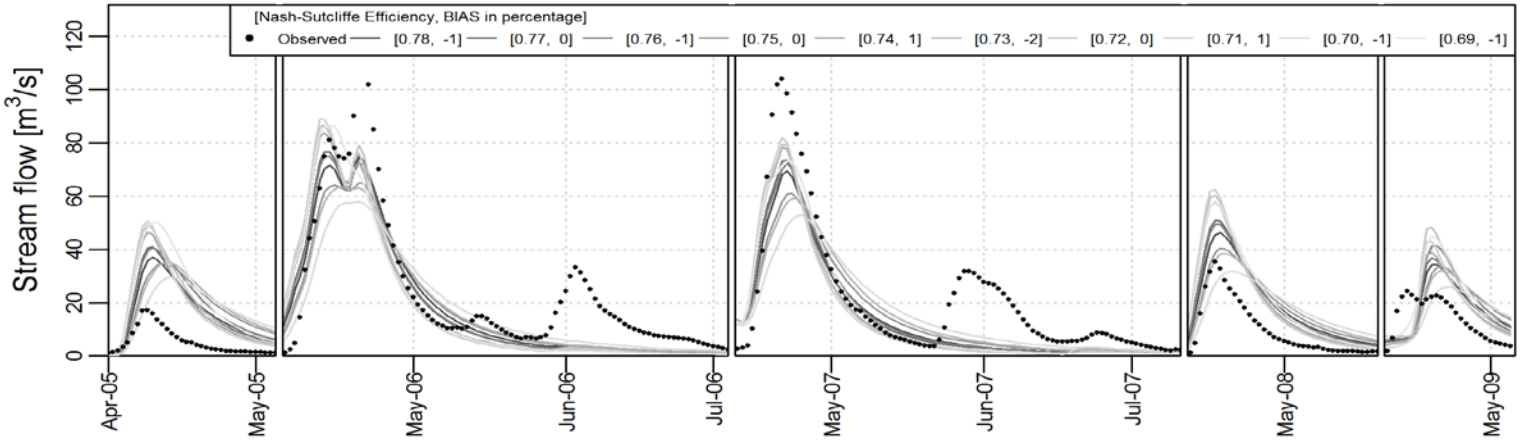




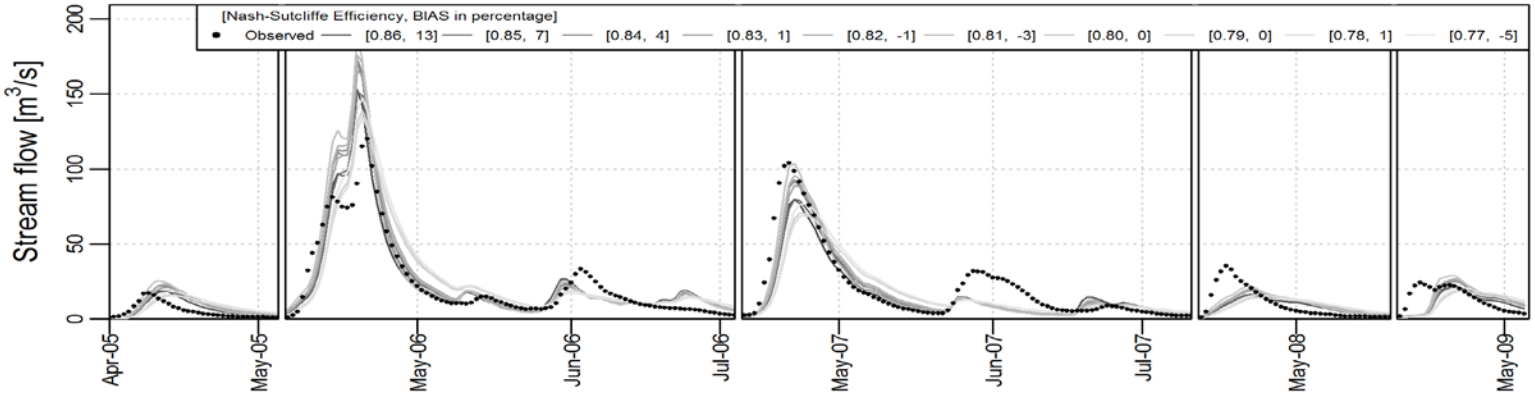
Chun, Wheater and Barr. J Hydrol. (2014) **519 Part B**: 1537-1550

Improved land surface schemes for weather, climate and large-scale hydrological models

Fixed contributing area



Variable contributing area

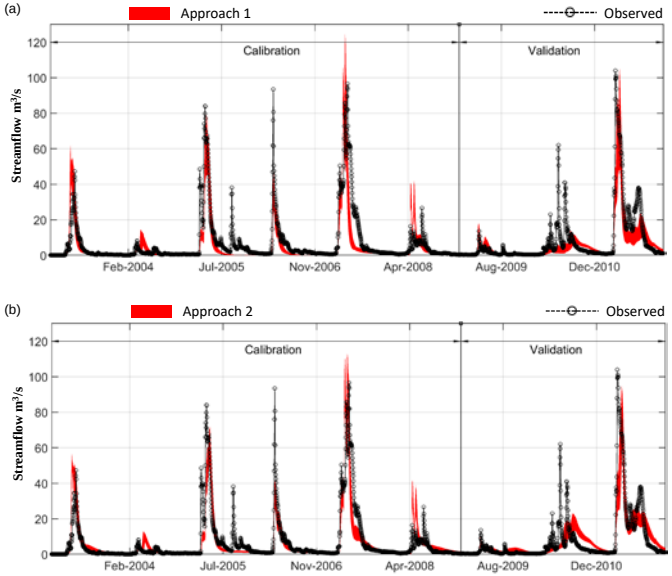


New CLASS/MESH model of prairie runoff – Assiniboine river

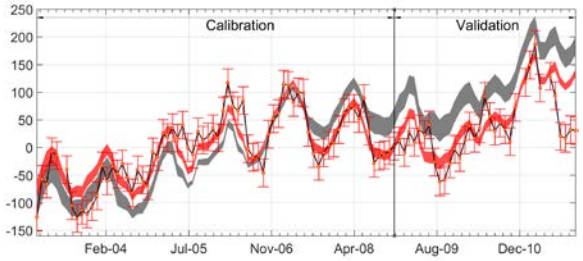
Mekonnen et al. (2014) J. Hydrol. 511: 106-116

Large Scale Hydrological Modelling

Use of GRACE data to constrain model parameters in MESH

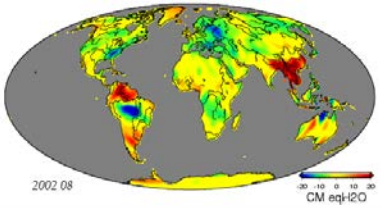


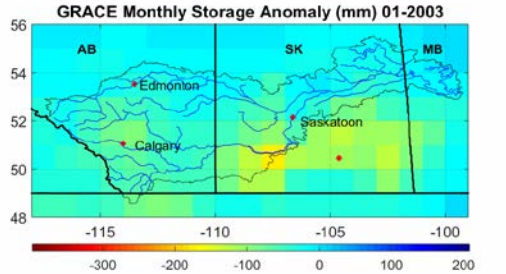
Streamflow comparisons

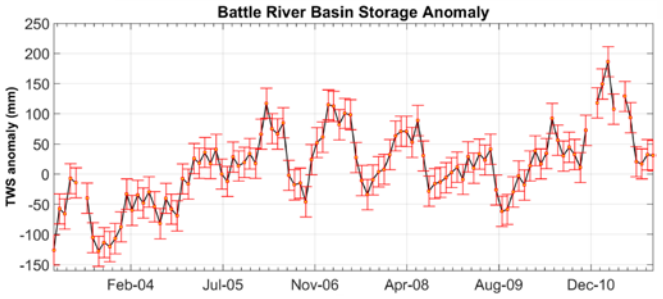


Calibration and validation of TWS anomaly

***GRACE** satellite*
(Photo credit: NASA)







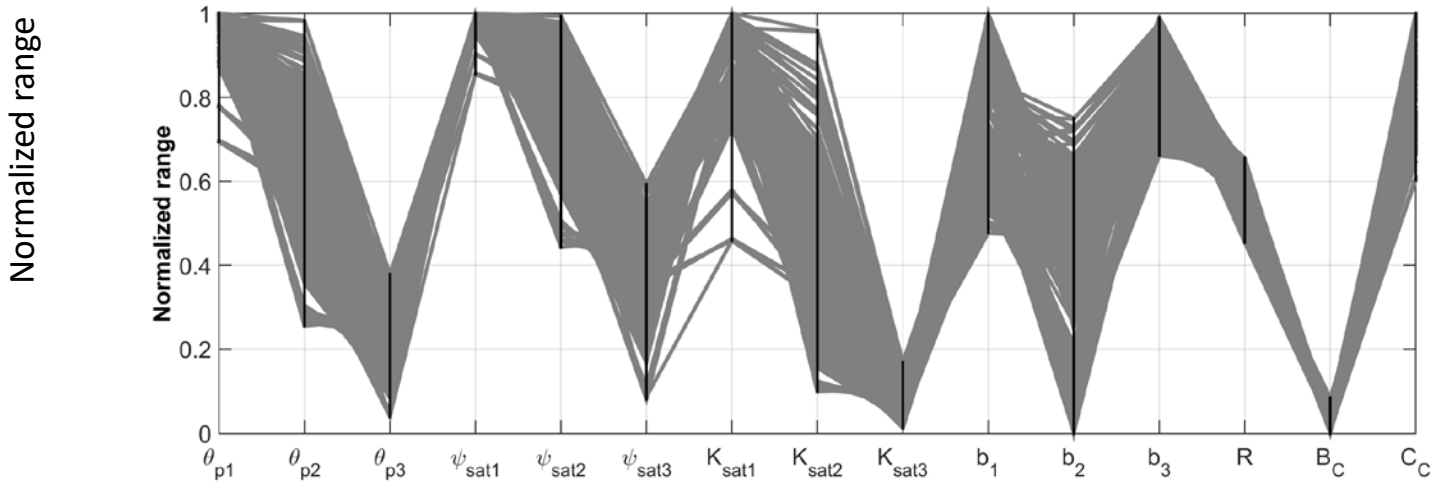
GRACE total water storage (TWS) anomaly

- Use of GRACE data helps to facilitate parameter identifiability and improve results

Parameter Uncertainties

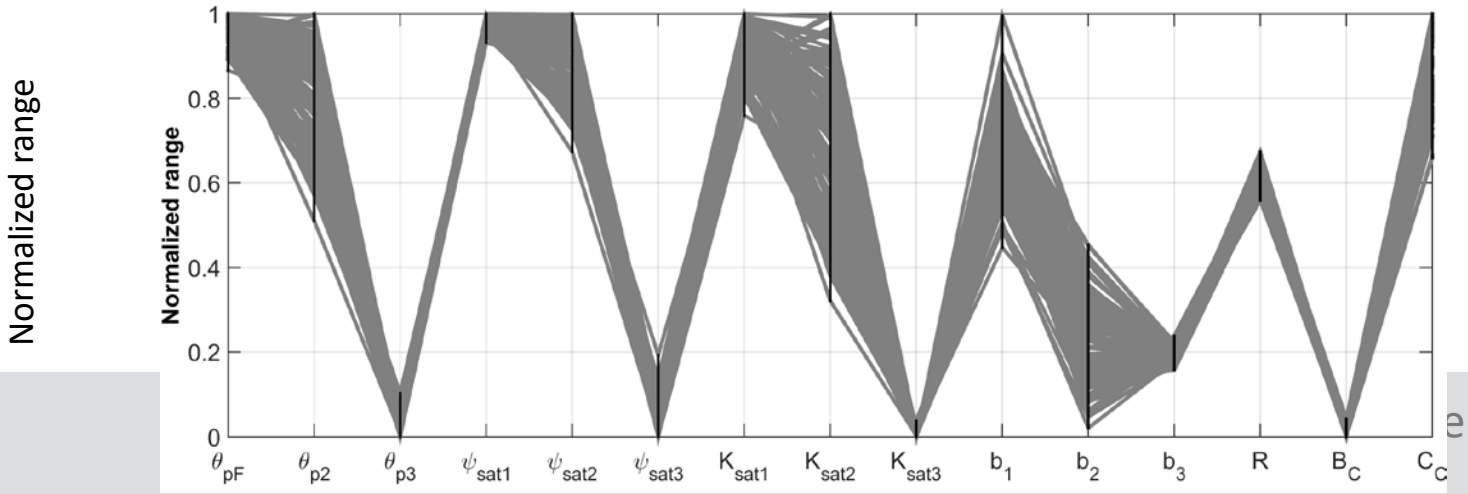
STREAMFLOW BASED

$PBIAS \leq 5$ &
$NSE \geq 0.5$ &
$lNSE \geq 0.5$

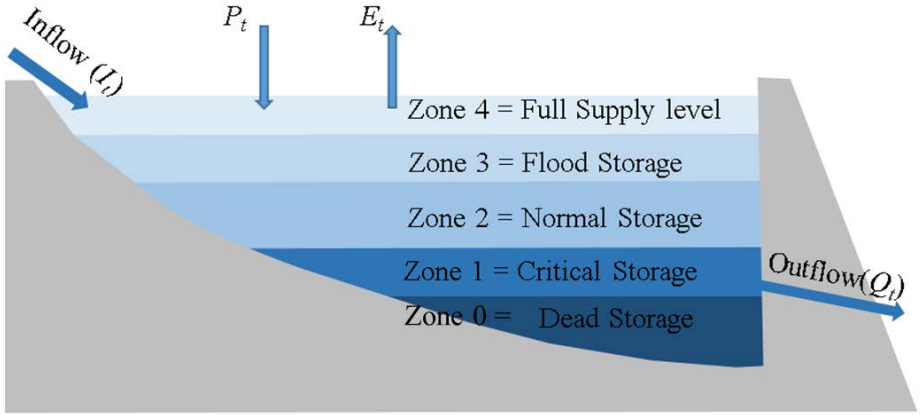


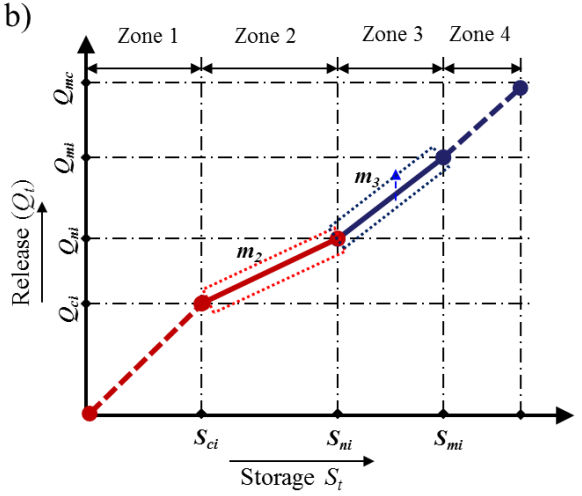
COMBINED STREAMFLOW & TWS ANOMALY BASED

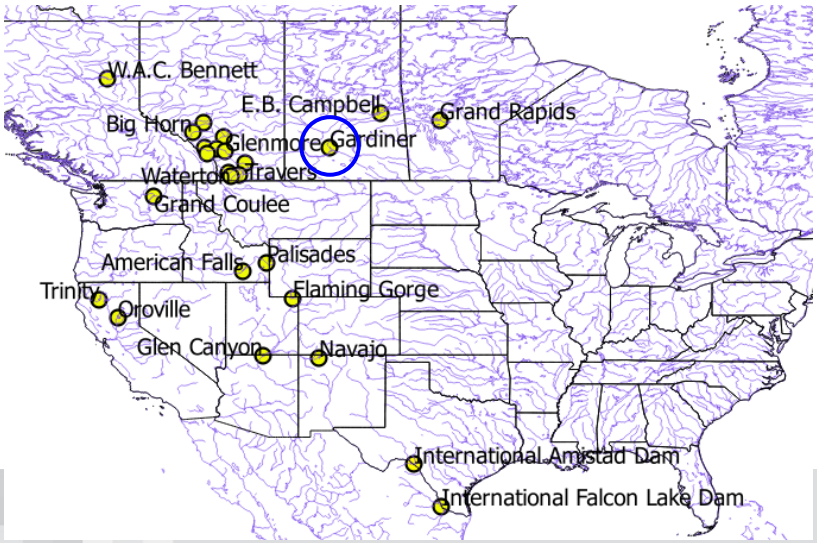
$PBIAS \leq 5$ &
$NSE \geq 0.5$ &
$lNSE \geq 0.5$ &
$STNSE \geq 0.5$



Improved Representation of Water Management in Hydrological Models (Yassin *et al.*, 2019)



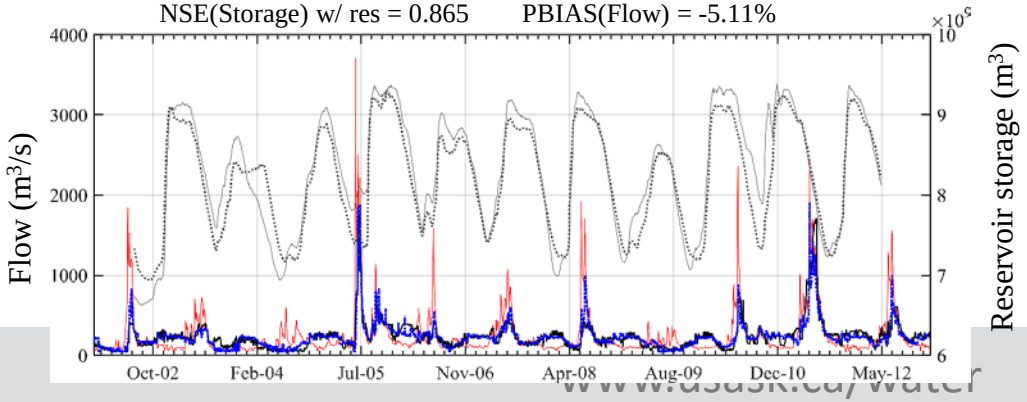




Lake Diefenbaker reservoir simulation

NSE(Flow) w/ res = 0.760 NSE(Flow) w/o res = -0.35

NSE(Storage) w/ res = 0.865 PBIAS(Flow) = -5.11%

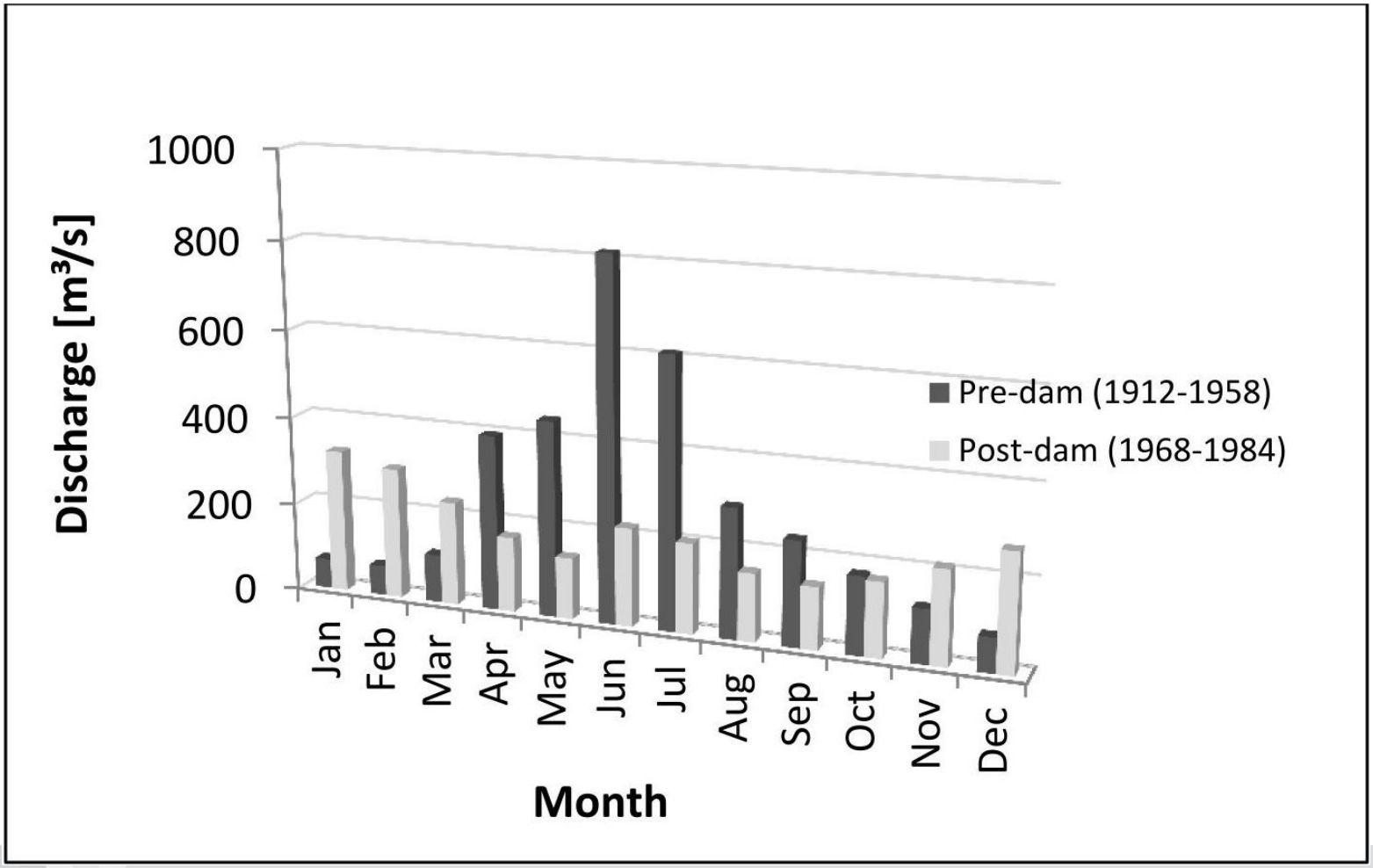


Water is a human-natural system

Flow in the Saskatchewan river in Saskatoon depends on:

- land and water use in Alberta
  (up to 50% of natural flow)
- the operation of Lake Diefenbaker
  (trading off power generation, water supply, flood protection, amenity and habitat)

South Saskatchewan annual hydrograph: pre- and post-dam construction



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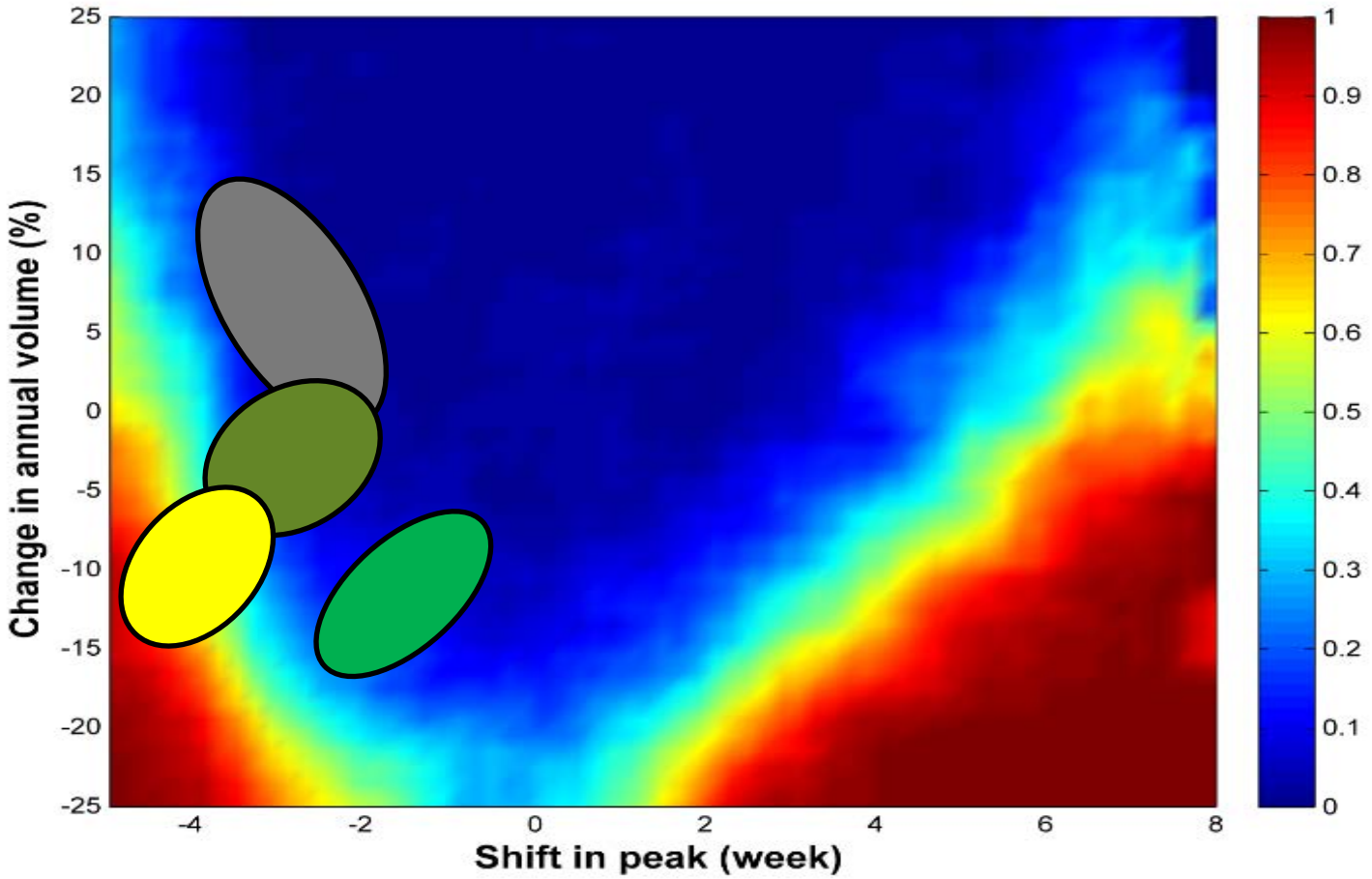
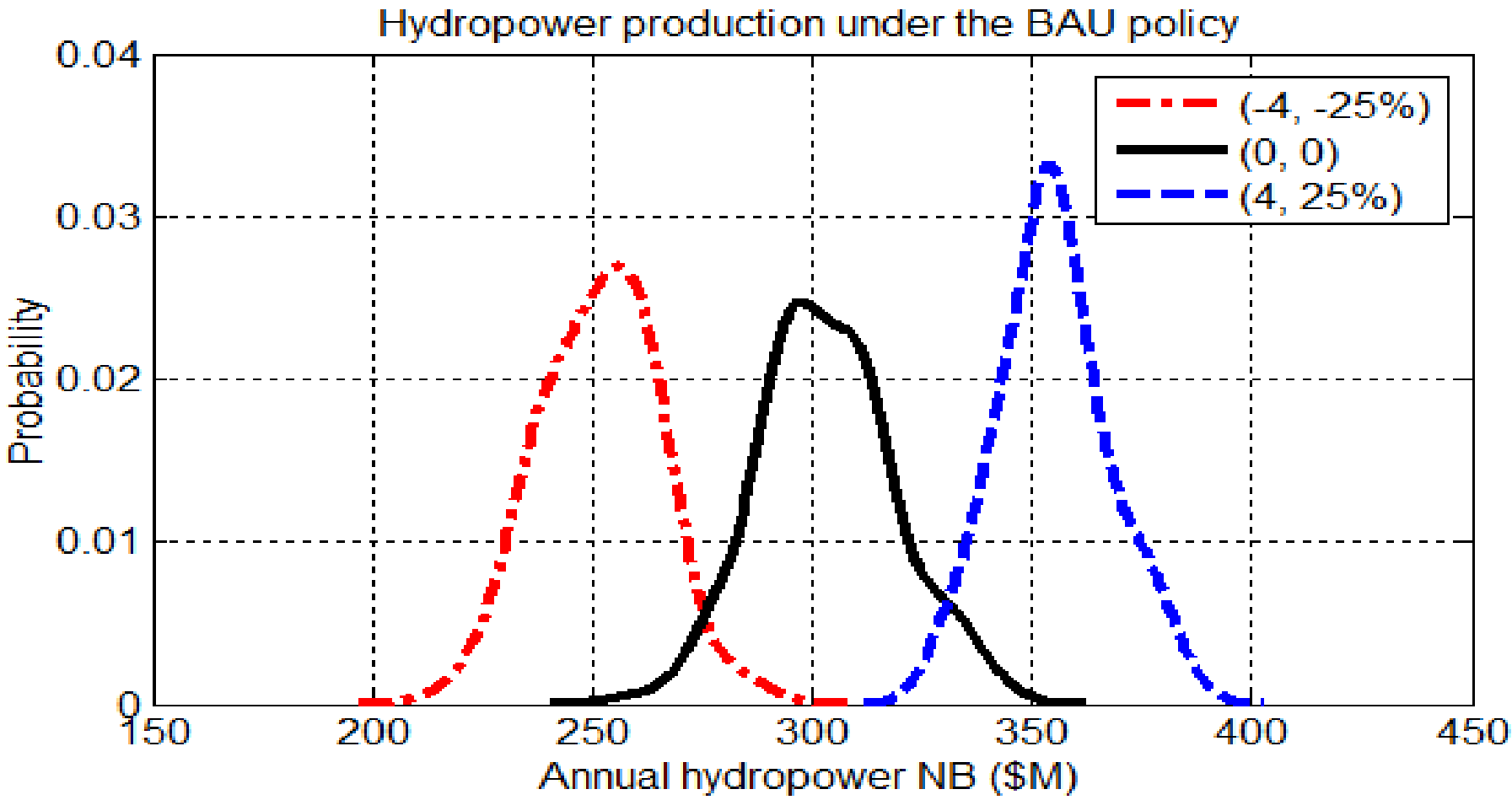
Water resources vulnerability analysis – South Saskatchewan River in Alberta

Probability of system failure under changing headwater flows (annual peak, Peak timing)

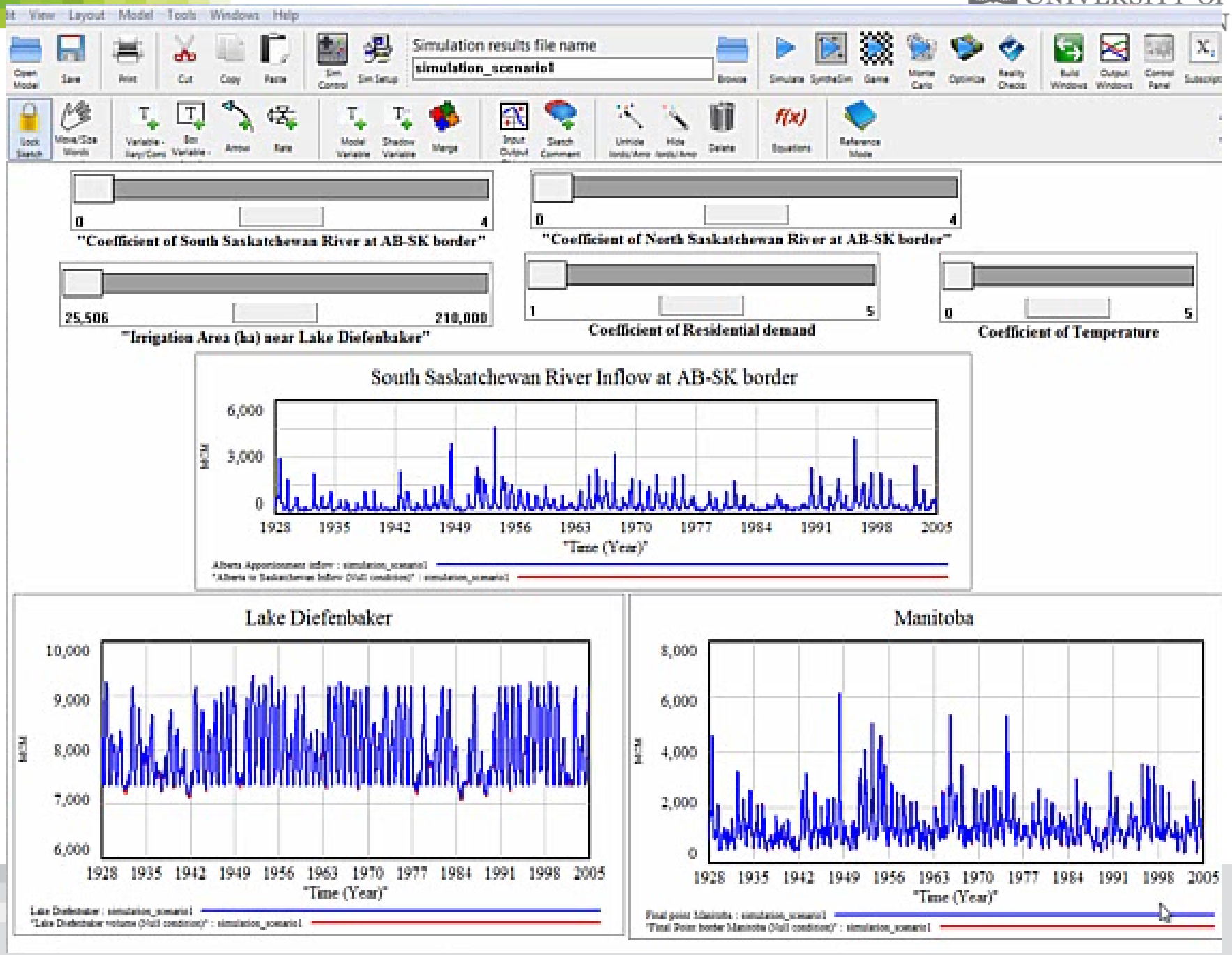


Nazemi et al. 2013 WRR **49**(1): 291-305

Risk-profiles for economic net benefit



Hassanzadeh, et al. 2015. *Journal of Water Resources Planning and Management*, doi:10.1061/(ASCE)WR.1943-5452.0000581


Simulation results file name
simulation_scenario1
"Coefficient of South Saskatchewan River at AB-SK border"
"Coefficient of North Saskatchewan River at AB-SK border"
"Irrigation Area (ha) near Lake Diefenbaker"
Coefficient of Residential demand
Coefficient of Temperature
South Saskatchewan River Inflow at AB-SK border
Lake Diefenbaker
Manitoba
"Time (Year)"

Socio-hydrology

- understanding social values and perspectives

Group mind-mapping exercise.
Stakeholder workshop, Canmore , Alberta

Community-based monitoring

Training trainers for fish health monitoring, Slave River Delta, North West Territories

Downstream – a play by Kenneth T. Williams

- Forum theatre production, *Downstream*, took audience members through an exercise in decision-making when floods threaten.
- Four performances across Western Canada - Calgary & Medicine Hat, Alberta, Saskatoon & Cumberland House, Saskatchewan.

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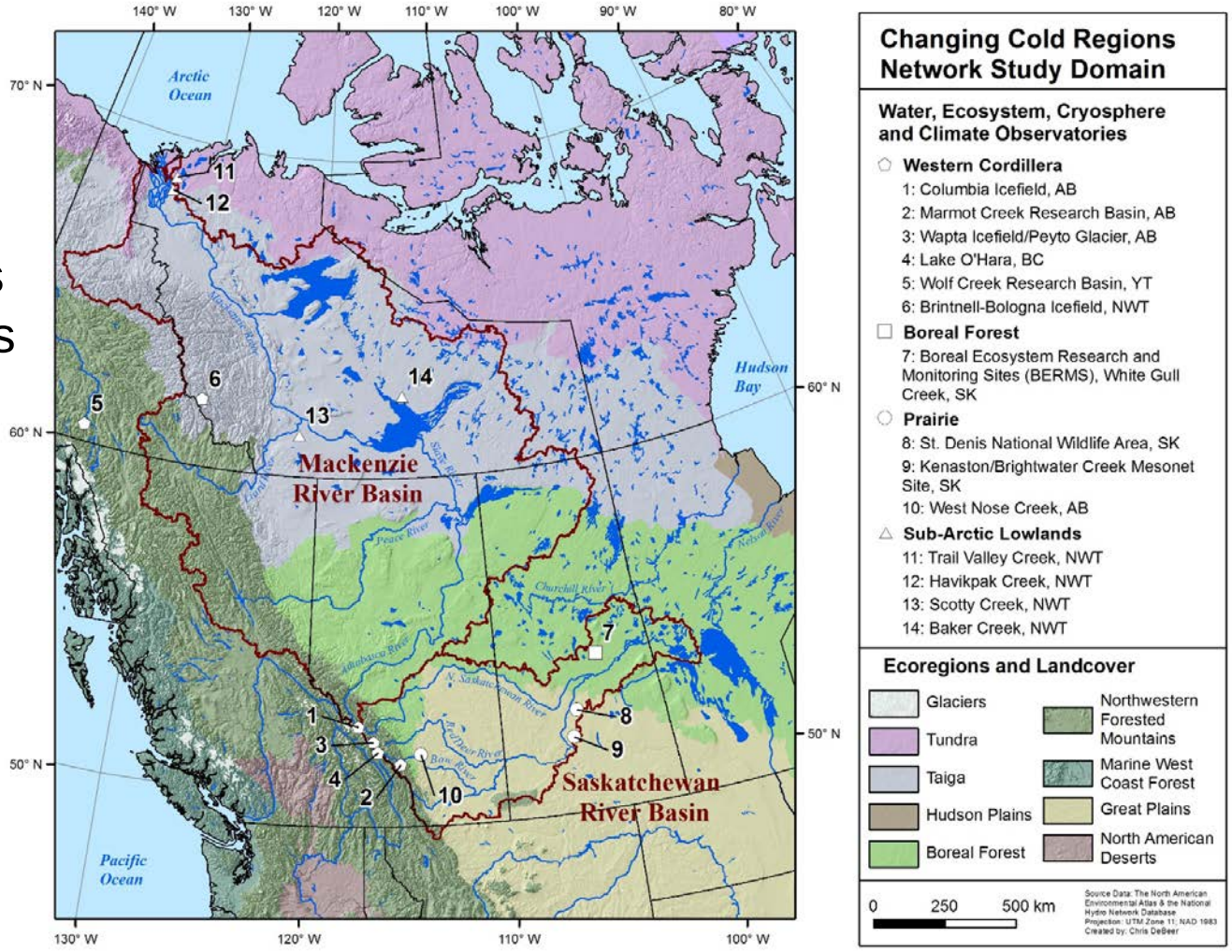
Global Institute for Water Security

Changing Cold Regions Network

2013-2018

8 universities
4 federal agencies
43 co-investigators
- links to multiple international programs and partners

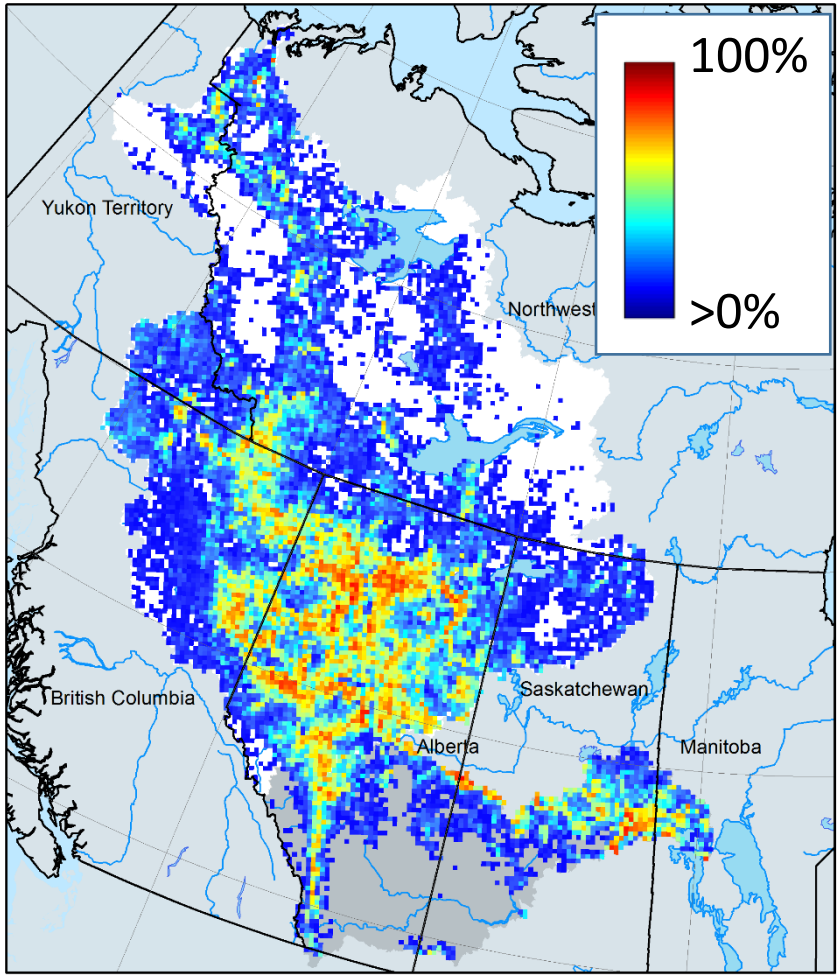


www.usask.ca/water

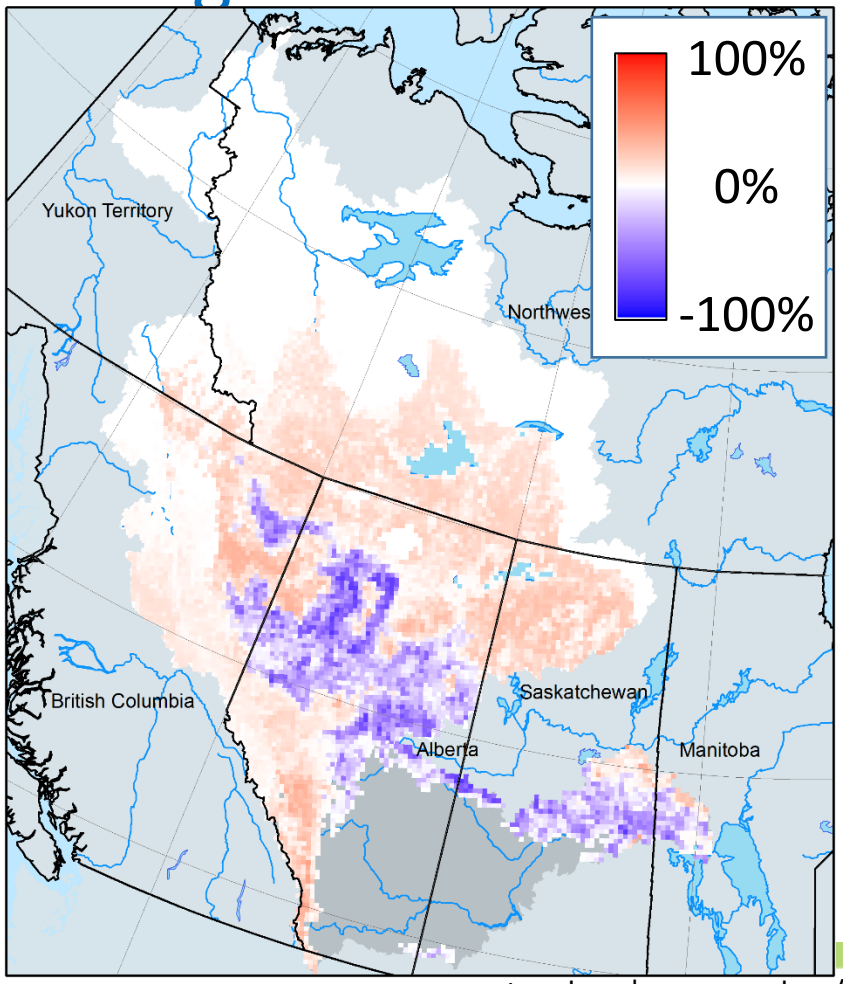
Scenarios of change

e.g. Mixedwood Forest: Displacing Evergreen Forest After Fire, Displaced by Cropland

2005



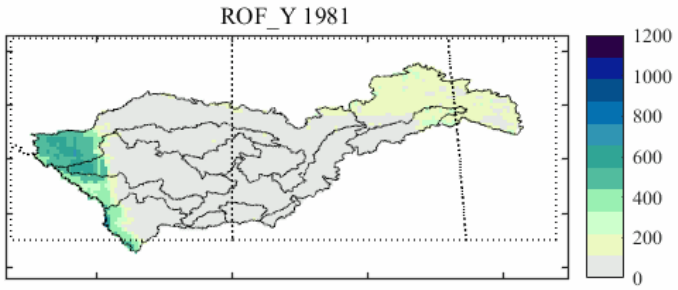
%Change 2005 to 2085



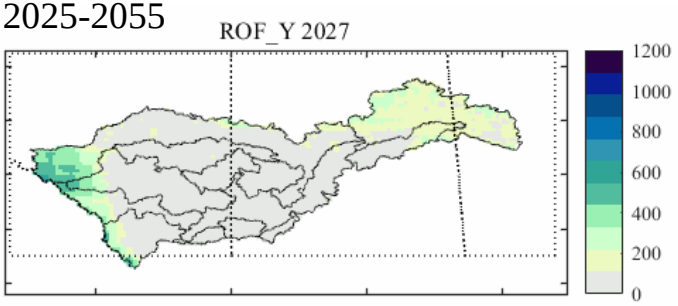
Saskatchewan River Basin – Changes in Streamflow

1970-2010 2025-2055 2070-2100

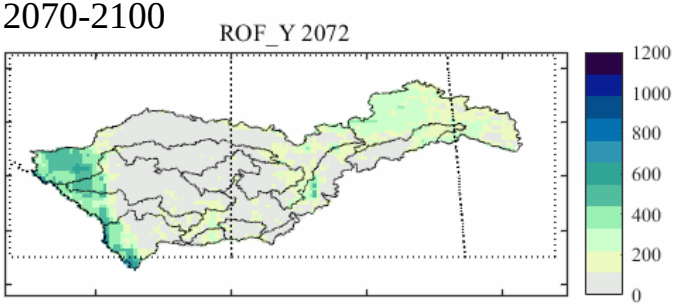
1970-2010



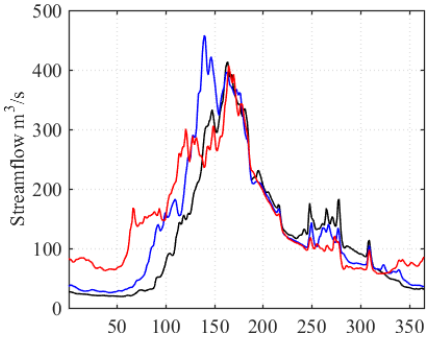
2025-2055



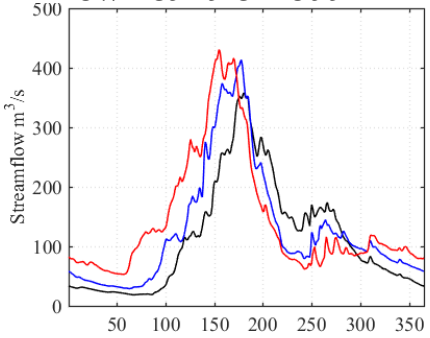
2070-2100



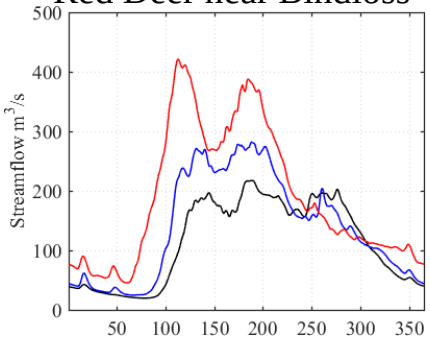
Oldman near the mouth



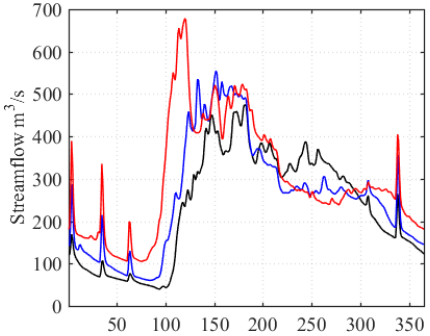
Bow near the mouth



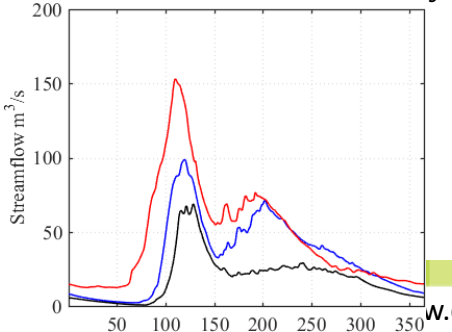
Red Deer near Bindloss



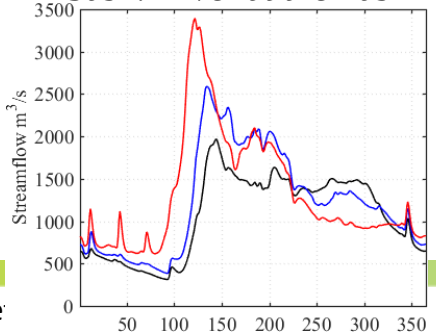
N. Sask @Edmonton



Battle near Sask boundary

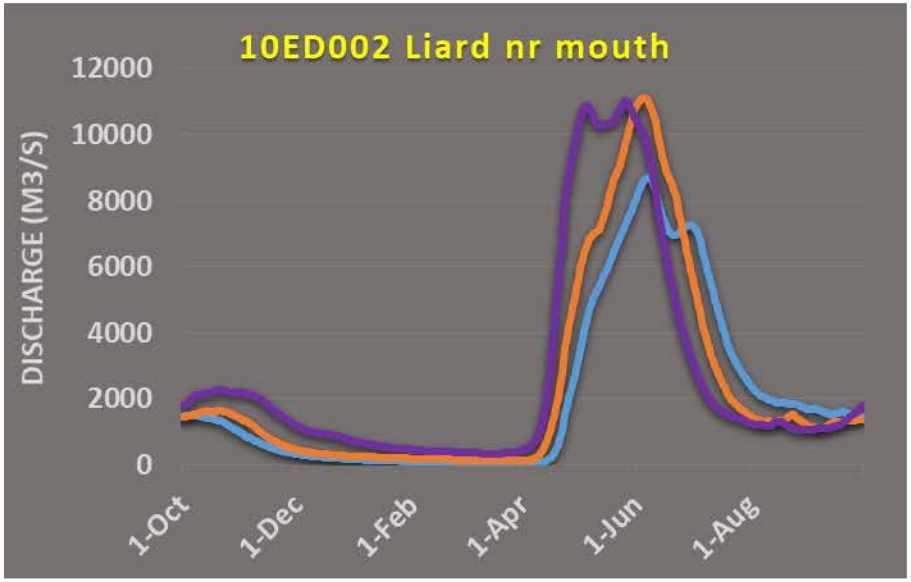


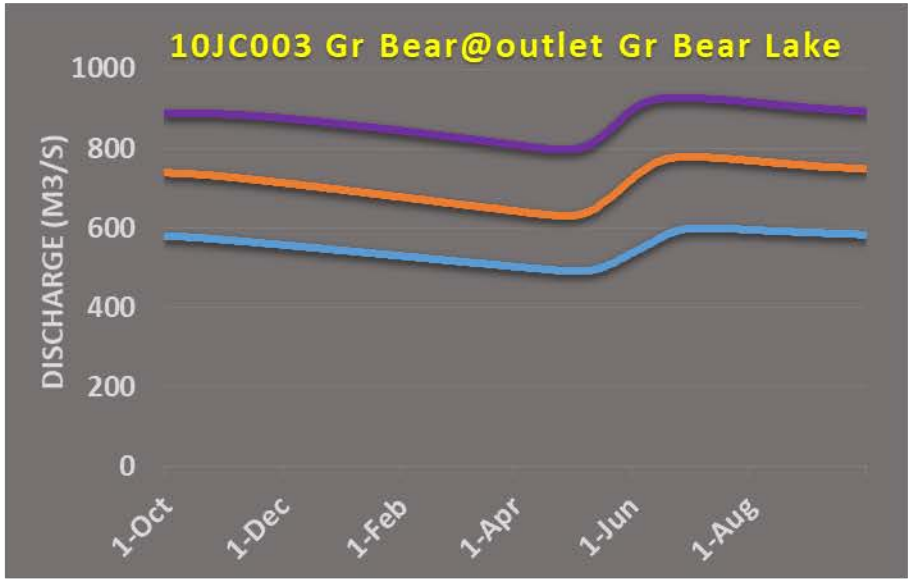
Sask. River at the Pas

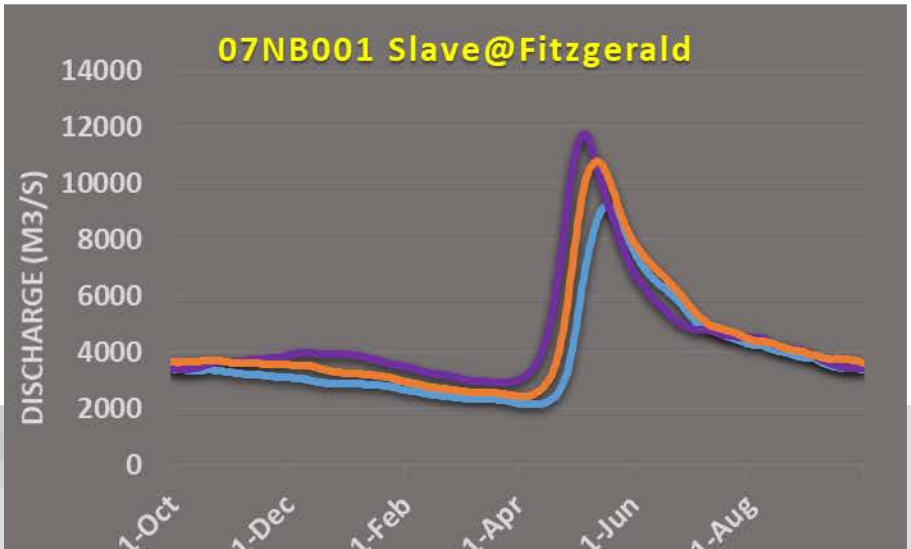


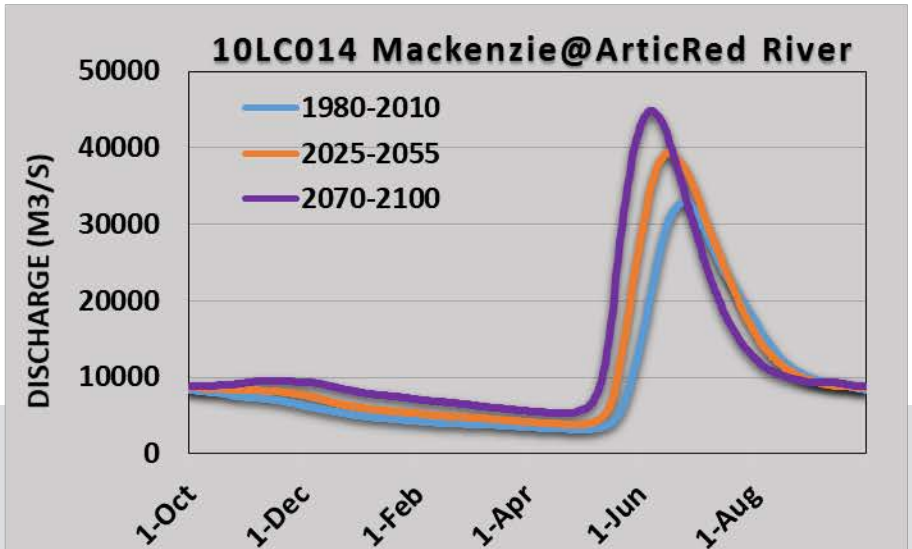
w.ccrne

Mackenzie Basin- Changes in streamflow









Global Water Futures: Solutions to Water Threats in an Era of Global Change

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

- Canada First Research Excellence Fund Competition $1.5B CDN
- **Global Water Futures 2016-2023**
  - **$78 M CDN grant**
  - **$143 M CDN initial program budget**

University of Saskatchewan | University of Waterloo | McMaster University | Laurier – Inspiring Lives.

University of Guelph

University of British Columbia

University of Northern British Columbia

University of Calgary

University of Laval

McGill University

University of Quebec at Montreal

University of Alberta

University de Montreal

University of Manitoba

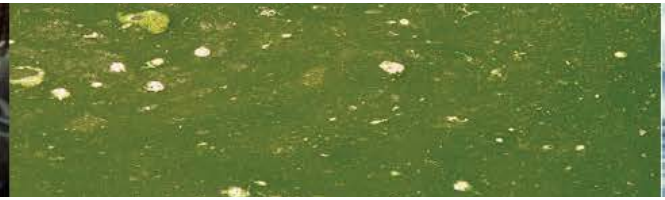
University of Victoria

Brock University

Canadian Rivers Institute (University of New Brunswick & University of Prince Edward Island)

Yukon College

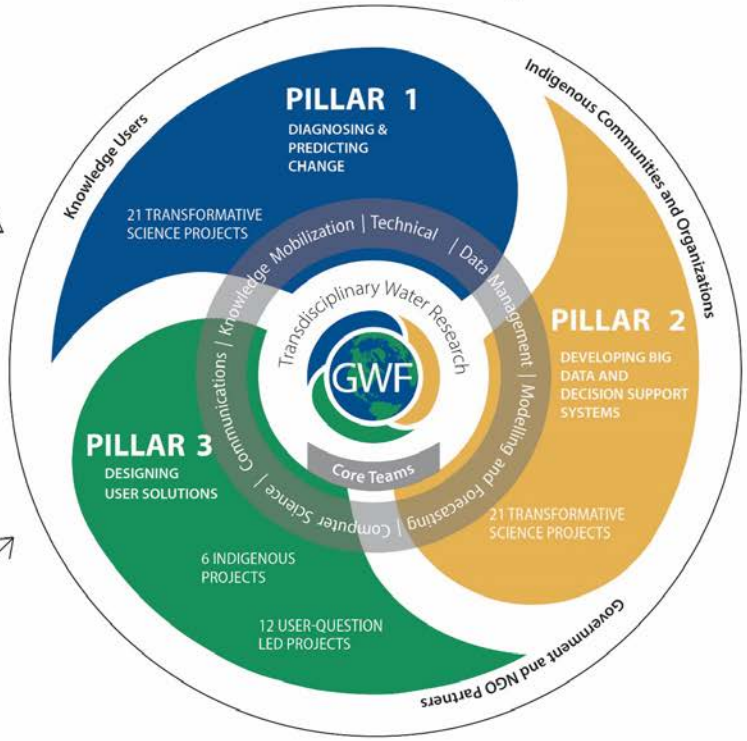




Global Water Futures at Mid-term

FUNDING
$78 M CFREF
$113 M IN-KIND
$90 M LEVERAGED CASH

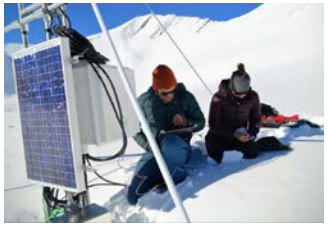
UNIVERSITIES
18 CANADIAN UNIVERSITIES
189 FACULTY

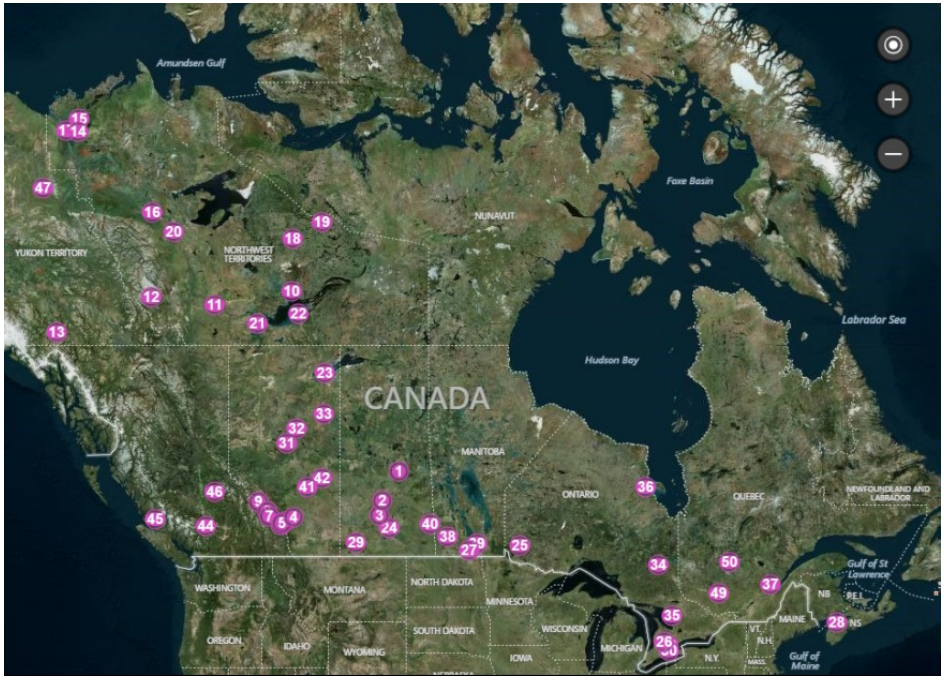


OUTCOMES
965 HQP
786 PUBLICATIONS
1852 PRESENTATIONS
150 THESES
3200 STORIES IN THE MEDIA

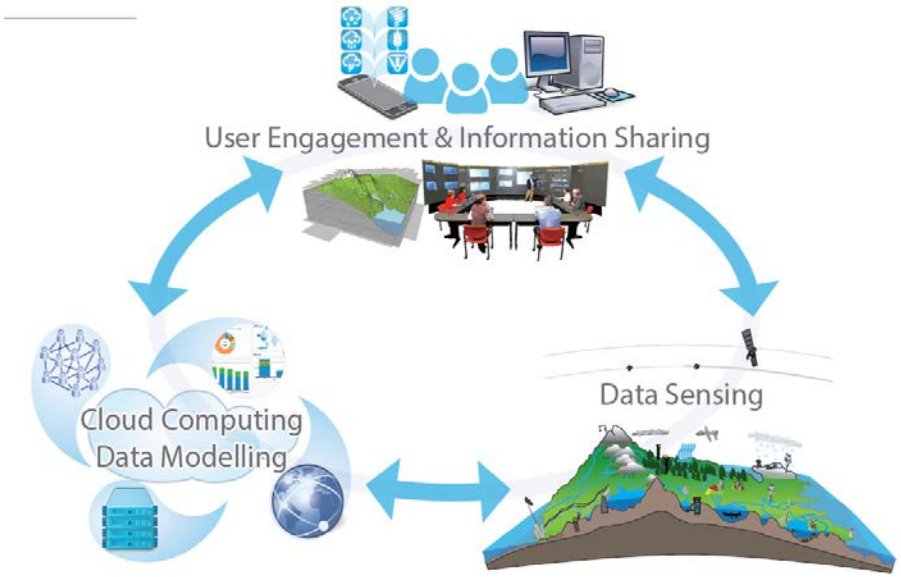
- WATER PREDICTIONS ACROSS CANADIAN RIVER BASINS UNDER CLIMATE CHANGE
- OPERATIONAL FLOOD FORECASTING SYSTEM DEVELOPMENT
- CO-CREATION OF FRESHWATER RESEARCH WITH 76 INDIGENOUS COMMUNITIES
- 60 WATER OBSERVATORIES ACROSS CANADA PROVIDING BIG DATA
- WATER, SOCIETY, HEALTH, EQUITY, DIVERSITY AND INCLUSION
- INFORMING DEVELOPMENT OF THE CANADA WATER AGENCY
- ENVIRONMENTAL DNA ANALYSIS FOR INVASIVE SPECIES
- SOLUTIONS TO USER LED QUESTIONS FROM ALMOST 500 USERS
- INTERNATIONAL SCIENCE LEADERSHIP: WMO, UNESCO, UN, FUTURE EARTH

GWF Observatories – ‘Big data’ for water

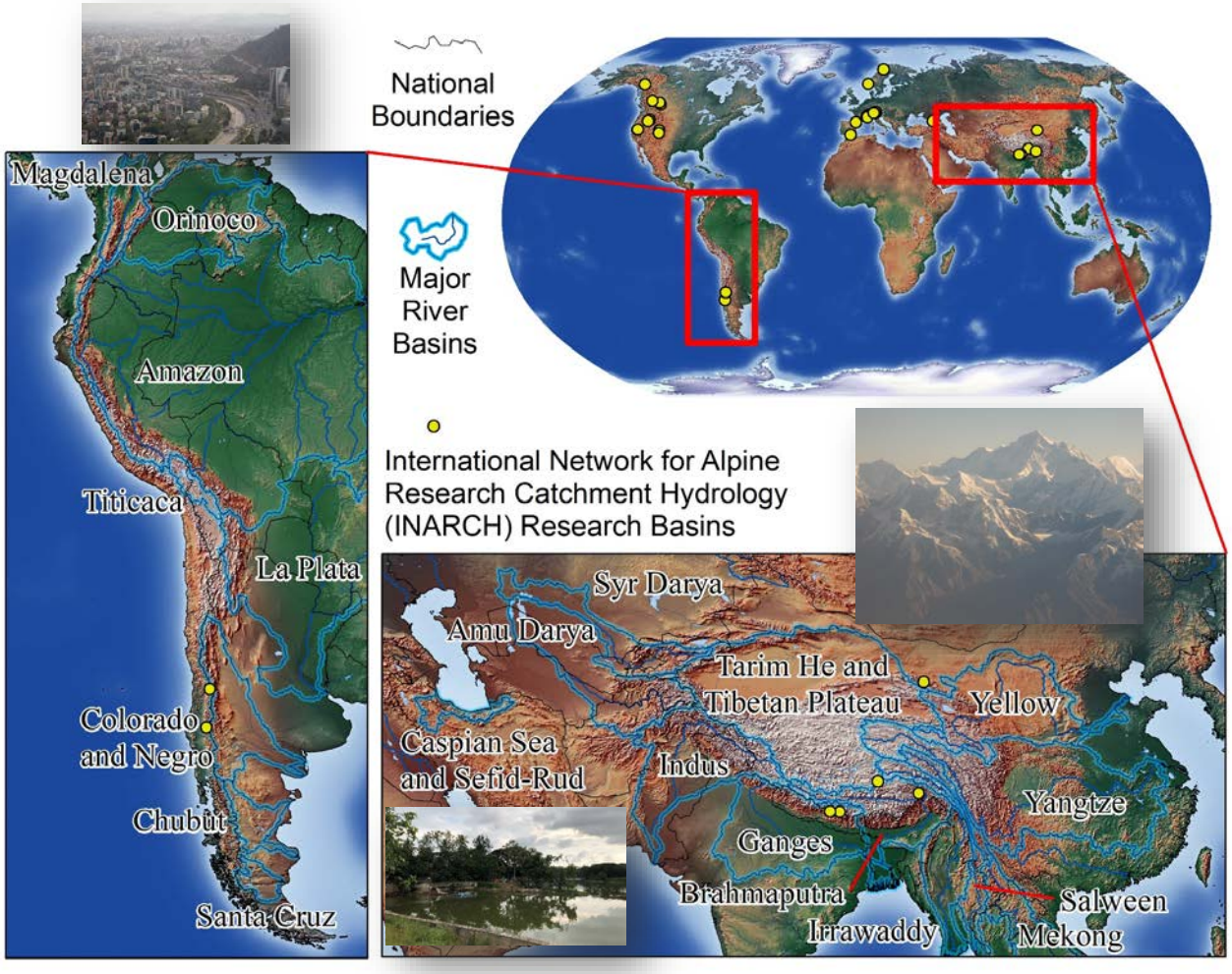




GWF core water observation, prediction, and knowledge mobilization strategy



GWF Planetary Water Prediction Initiative



GEWEX GEWEX INARCH ANDEX

UNESCO United Nations Educational, Scientific and Cultural Organization · Intergovernmental Hydrological Programme · WORLD METEOROLOGICAL ORGANIZATION

WATER ACTION DECADE 2018-2028 · waterfuture Sustainable Water Future Programme

UNIVERSIDAD DE CHILE · GW4 Water Security Alliance · ARCTIC COUNCIL

TPE THIRD POLE ENVIRONMENT · 中国科学院青藏高原研究所 Institute of Tibetan Plateau Research Chinese Academy of Sciences

Gorgan University of Agricultural Sciences & Natural Resources

CAMP4ASB Climate Adaptation & Mitigation Program for Aral Sea Basin CENTRAL ASIA

See https://gwf.usask.ca/projects-facilities/global-programs.php

These are times of unprecedented water challenges for society and for science

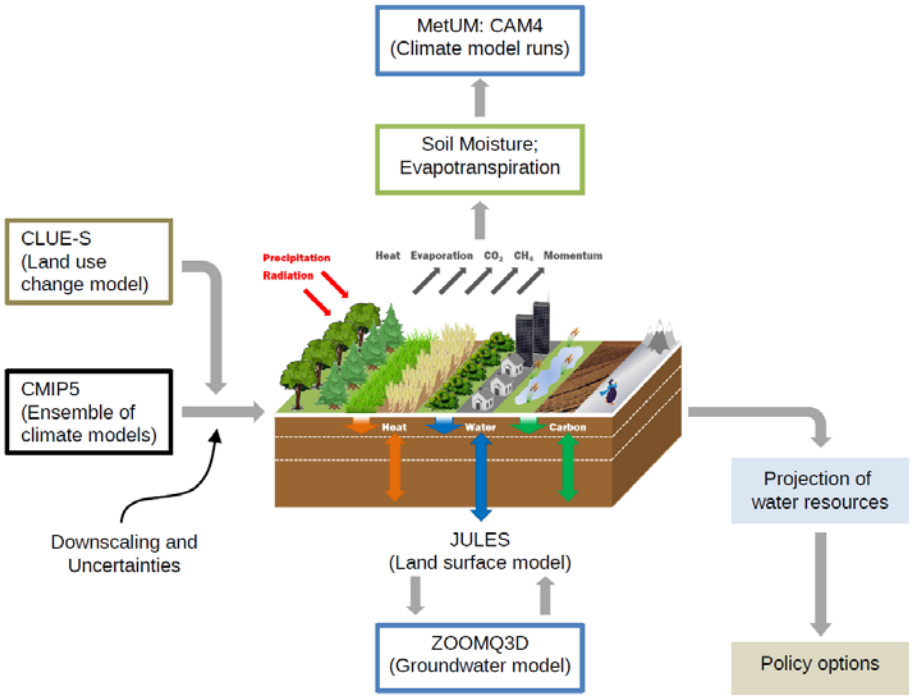
The way forward:

- New disciplinary science
- Trans-disciplinary science
- Science-society connection
- Large-scale research infrastructure
- *National and international investment*

Hydroflux India (2012-2016) (NERC-MoES)

PIs: Buytaert (IC), Mujumdar (IISc)

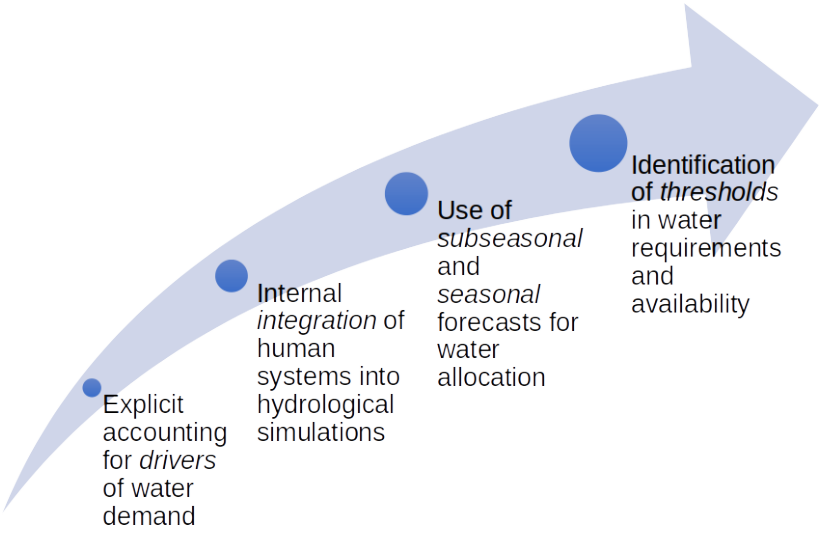
- Aim: To investigate two-way feedbacks between irrigation activities and climate
- State of the art model ensemble to simulate various fluxes
- We identified multiple coupling mechanisms at various scales



CHANSE (2016-2018) (NERC-MoES)

PIs: Mijic (IC), Ghosh (IITB)

- Aim: To improve mapping and quantification of interactions and feedbacks between human activities and the hydro-meteorological system of the Indo-Gangetic Plain (IGP)
- *In situ* data collection and bottom-up model development
- Focus on water management



Land surface coupling experiments

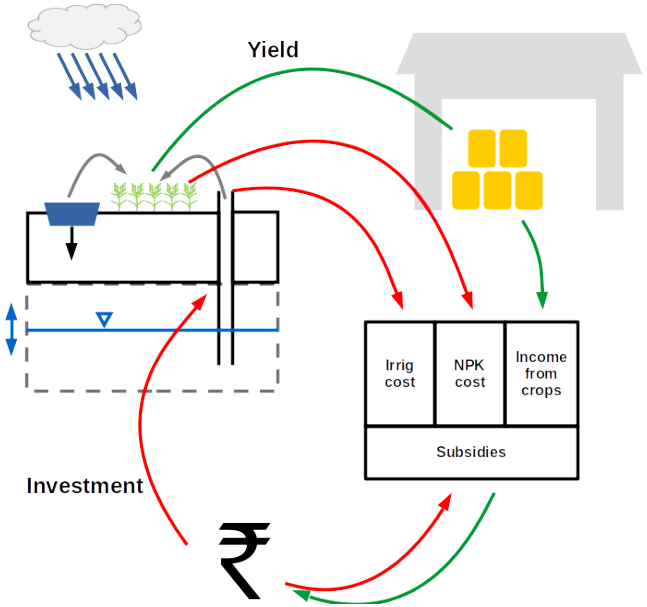
We used the maps of land use/land cover change to construct various scenarios of soil moisture using JULES, which were then used to force regional climate models (Agarwal *et al.* 2019):

- **Increased irrigational activity over the Gangetic Plains has the potential to affect regional and remote climate**
- **Winter-time irrigation has a strong effect on large-scale circulation pattern, intensifying the Indian summer monsoon**
- **Irrigation during Rabi and Kharif seasons was associated with a decrease in monsoon precipitation over the Gangetic Plain in the annual irrigation scenario, consistent with previous studies focussing on global impact of irrigation (Tuinenburg et al. 2014; Cook et al. 2015)**
- **Negative trends in observed precipitation could be related to enhanced irrigational activities over the Gangetic Plains in the recent decades**

Agrawal, S., Chakraborty, A., Karmakar, N., Moulds, S., Mijic, A., Buytaert, W. (2019). Effects of winter and summer-time irrigation over Gangetic Plain on the mean and intra-seasonal variability of Indian summer monsoon. *Clim Dyn* **53,** 3147–3166. https://doi.org/10.1007/s00382-019-04691-7

Socio-hydrological modelling

Semi-structured interviews were carried out to inform a coupled human-environment model linking farmer decision-making (wrt irrigation), livelihood, and groundwater depletion



O'Keeffe, J., Buytaert, W., Mijic, A., Brozovic, N., & Sinha, R. (2016). The use of semi-structured interviews for the characterisation of farmer irrigation practices. Hydrology and Earth System Sciences 20, 1911-1924.

Prof N S Govind Rao 1907-1995

Water means the WORLD to Us...

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www.usask.ca/water