GENESYS Hydrometeorology Model

James M. Byrne
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University of Lethbridge

JB

Graduate Student Cast

Snow and ice

- Suzan Lapp; Robert Larson
- Ryan MacDonald et al
- Evan Booth

Soil water

- Suzan Lapp
- Sarah Dalla Vicenza

Ecosystem change

- Ryan MacDonald

Mountain Hydrometeorology?

Water source for much of the world

Micromet model - 1 ha pixels

Terrain classes

- Slope
- Aspect
- Elevation
- Land cover

Micromet model

- Temps
- Radiation
- RH
- Precip
- Daily time step

Hydrology

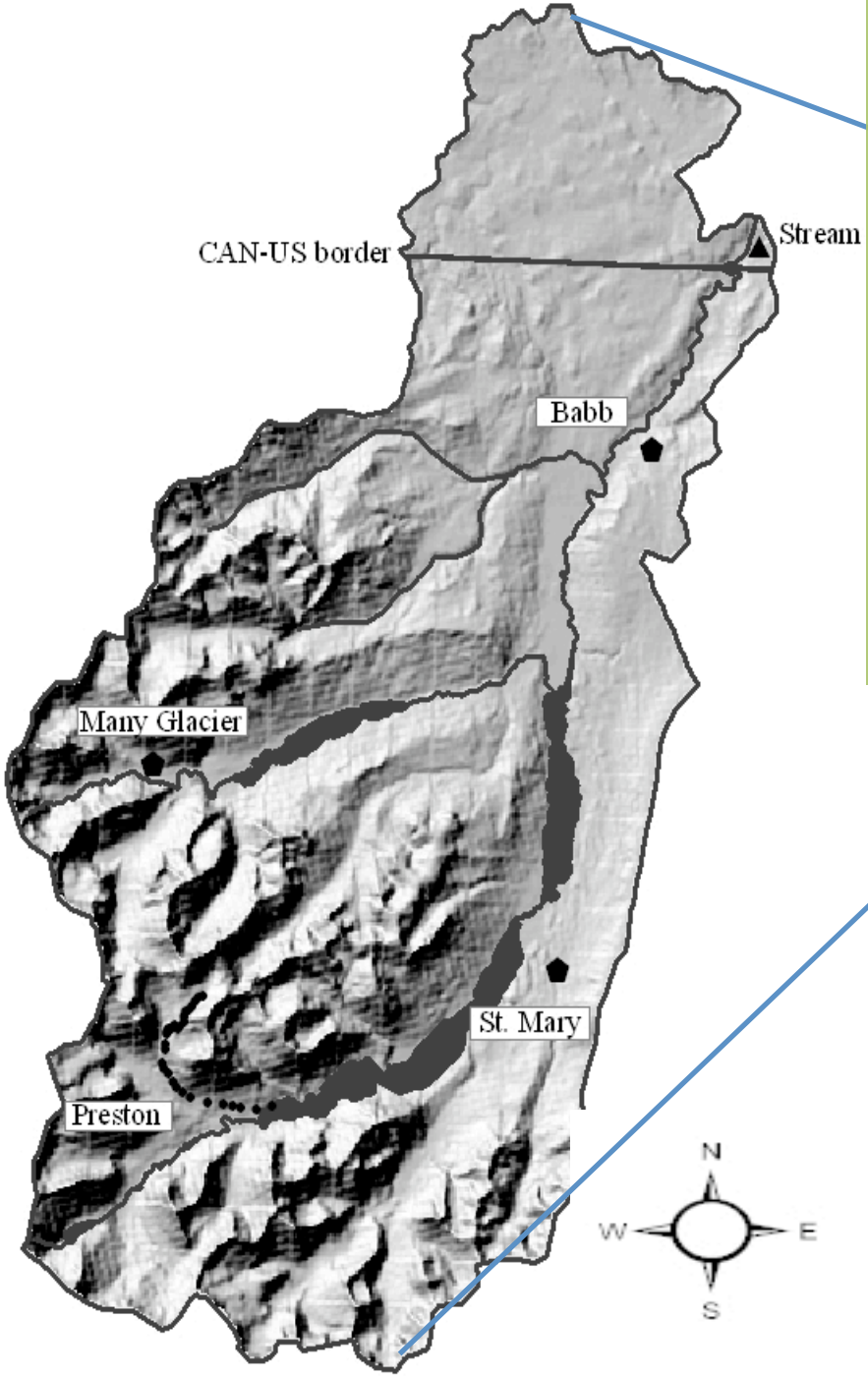
- Snowpack
- Soil water
- ET, ETP, Sublimation
- Interception

Study Watersheds

- St. Mary River, Montana-Alberta 2007-10
  - Transboundary watershed
- North Saskatchewan River, Central Alberta 2009-10

Ryan MacDonald MSc Research

Climate Change Impacts on the St. Mary River, Montana-Alberta

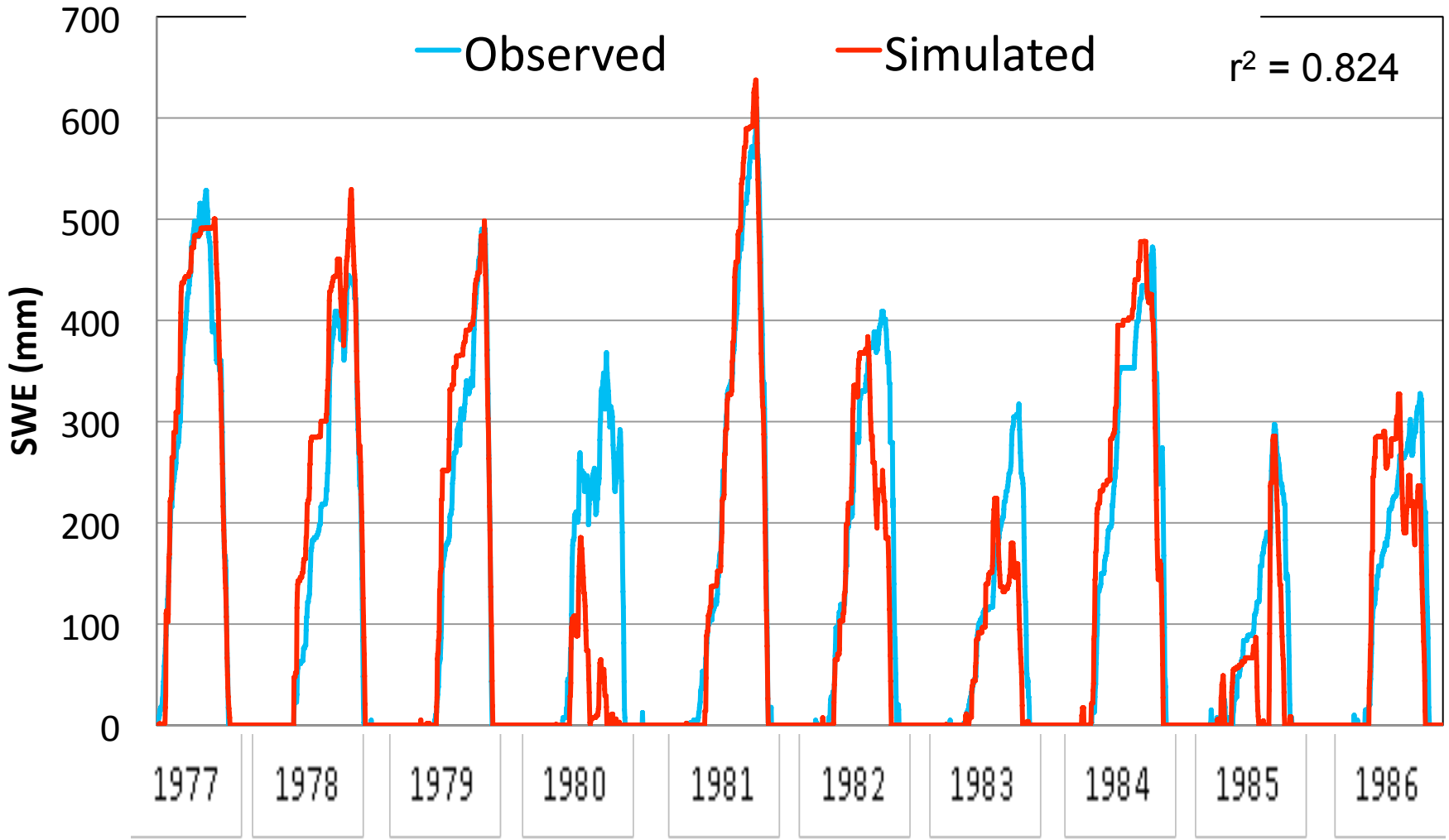


- 2000 km^2
- Water supply - 300,000 ha irrigation in Canada & USA
- Ecosystem change in Glacier National Park Montana

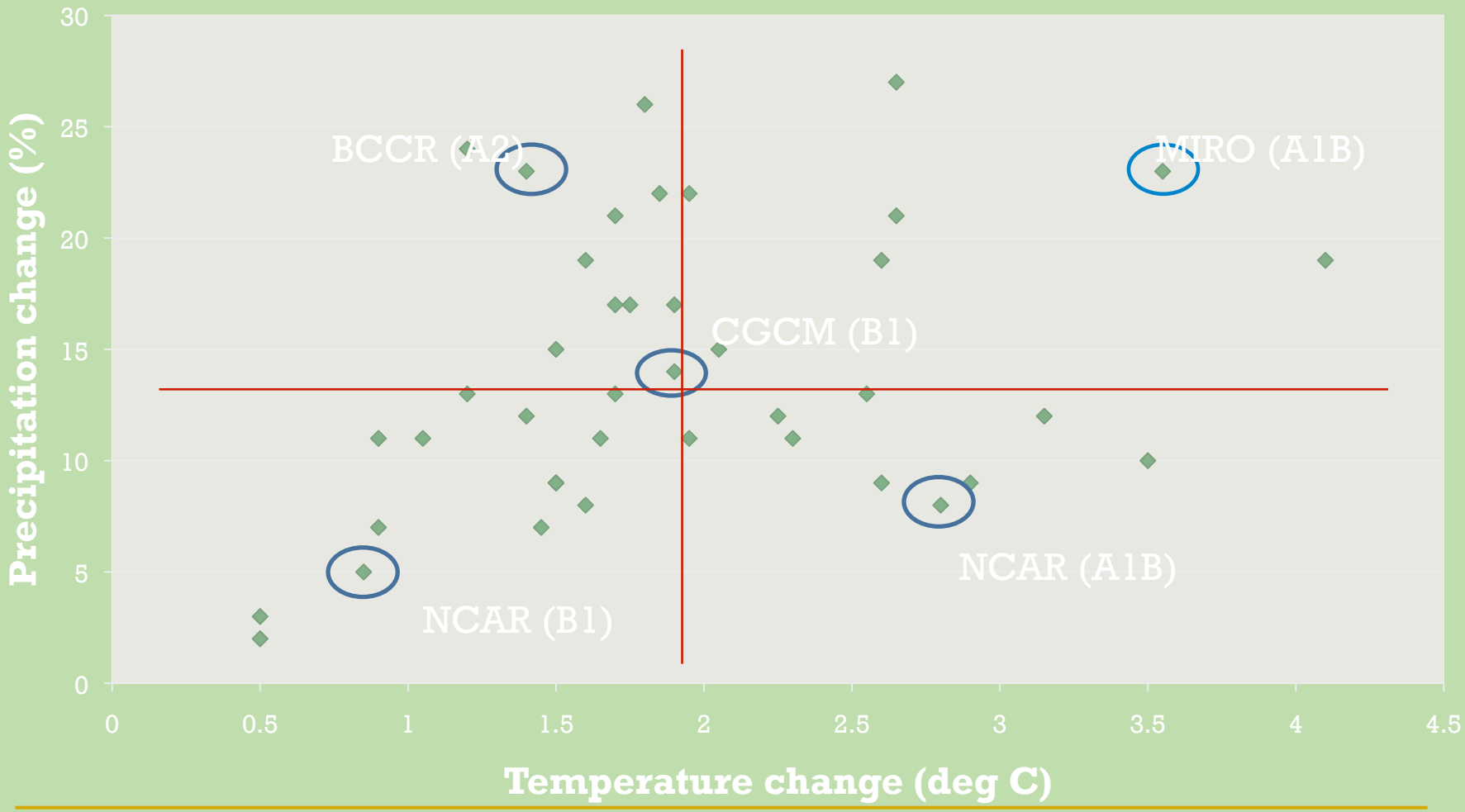
0 5 10 20 30 40 Kilometers

St. Mary Watershed

10 year daily SWE Simulation at Many Glacier SnoTel



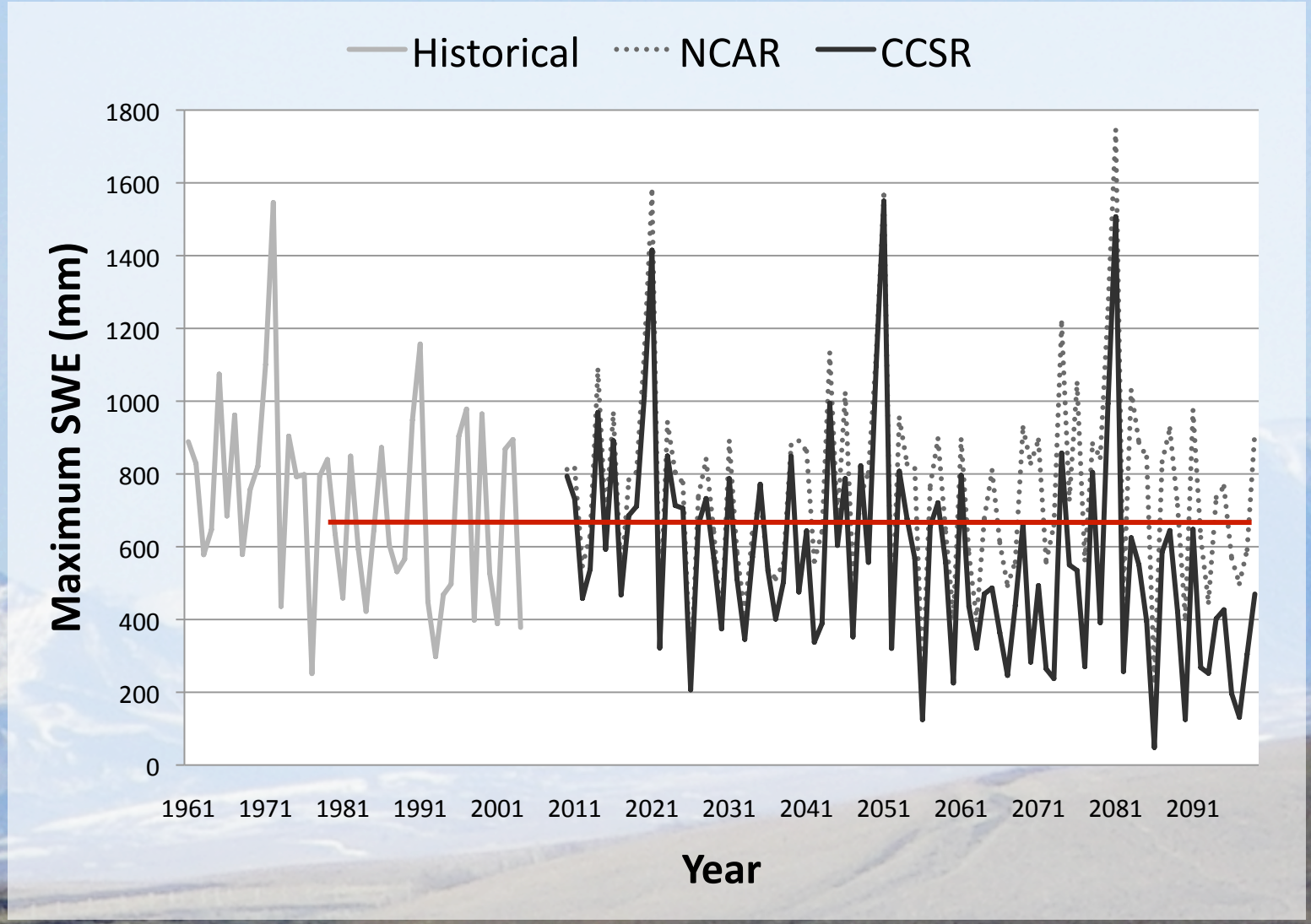
GCM scenario selection 2050s



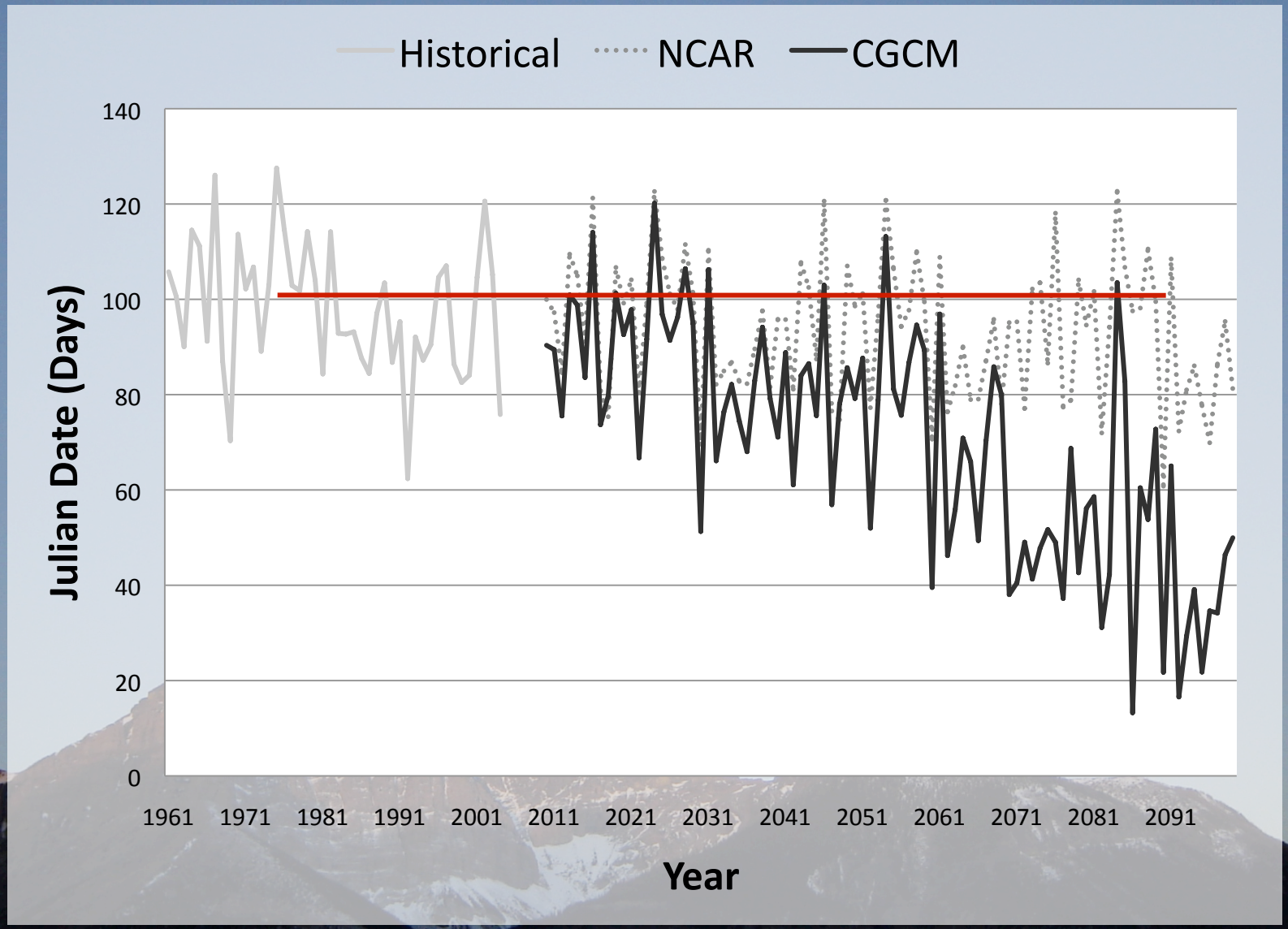
Scenarios?

- GHG emissions under control
- GHG close to business as usual

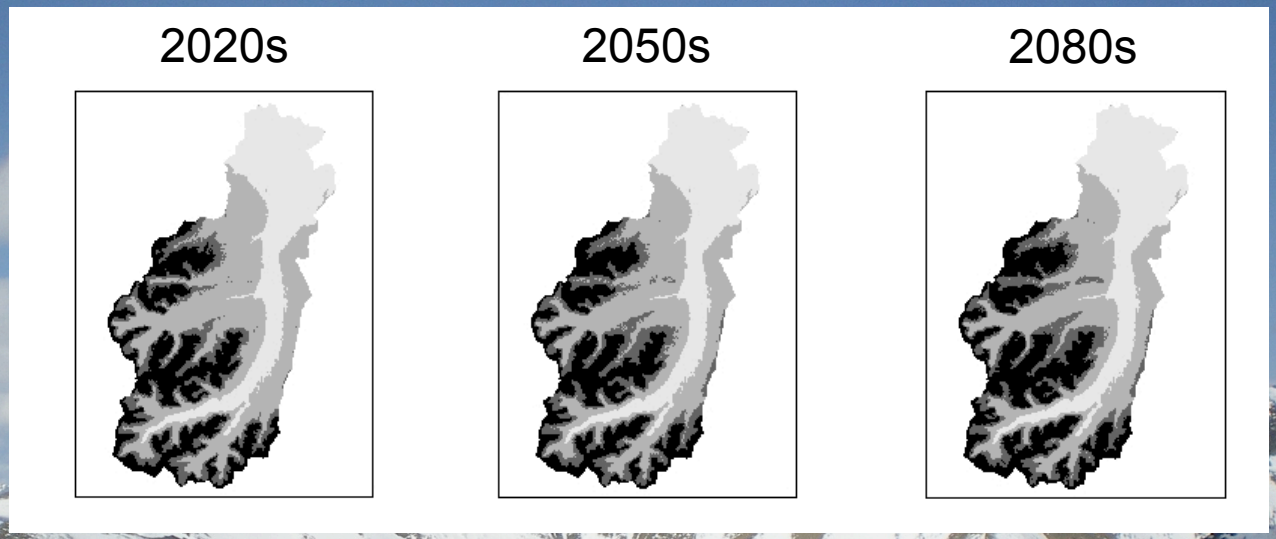
Maximum SWE (mm)

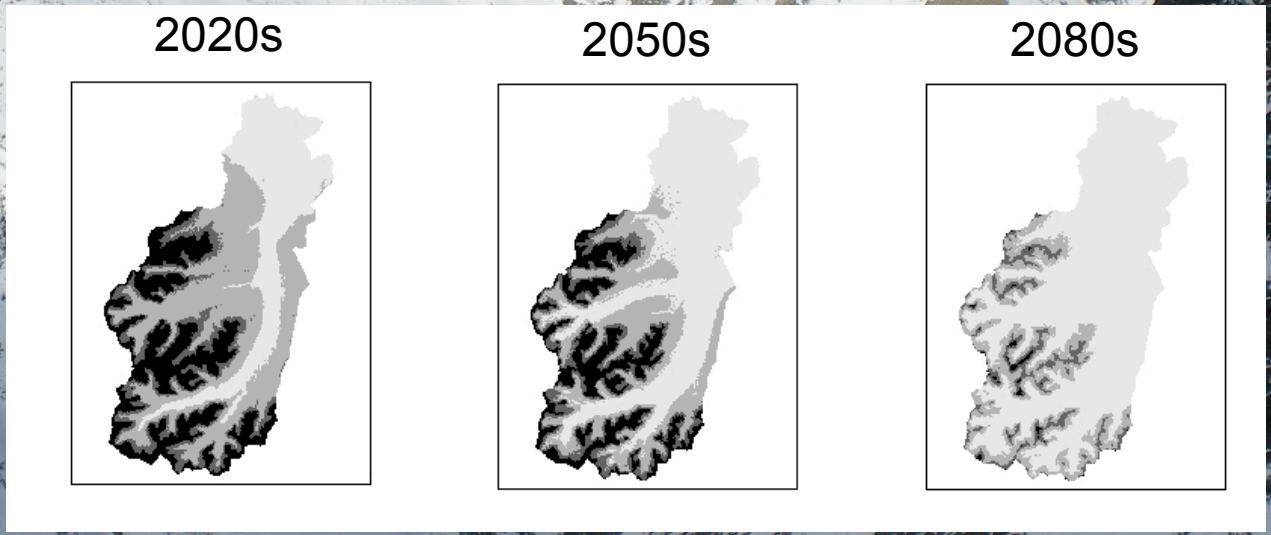


Date of Maximum SWE (Jday)

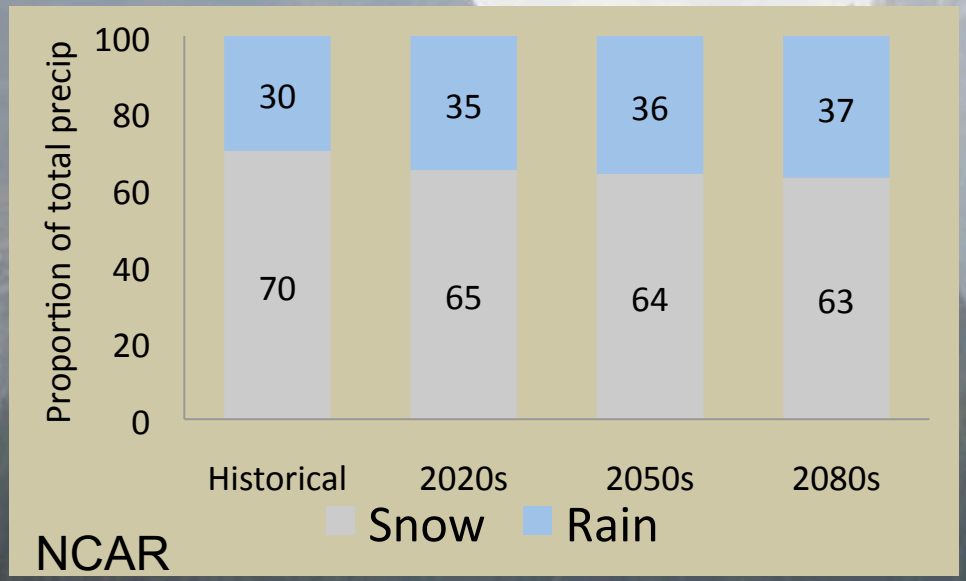


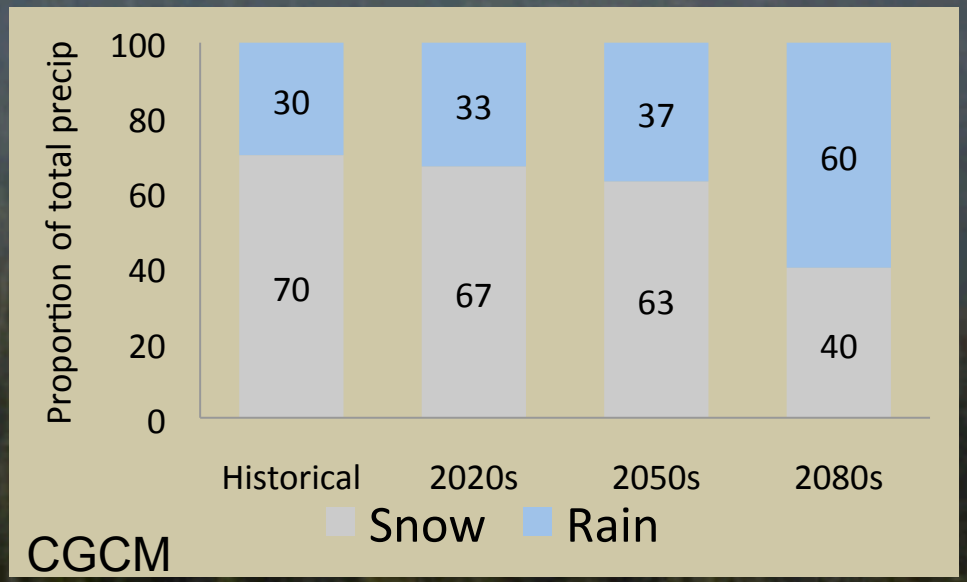
Spatial change in SWE – Black ☺





Precipitation phase change

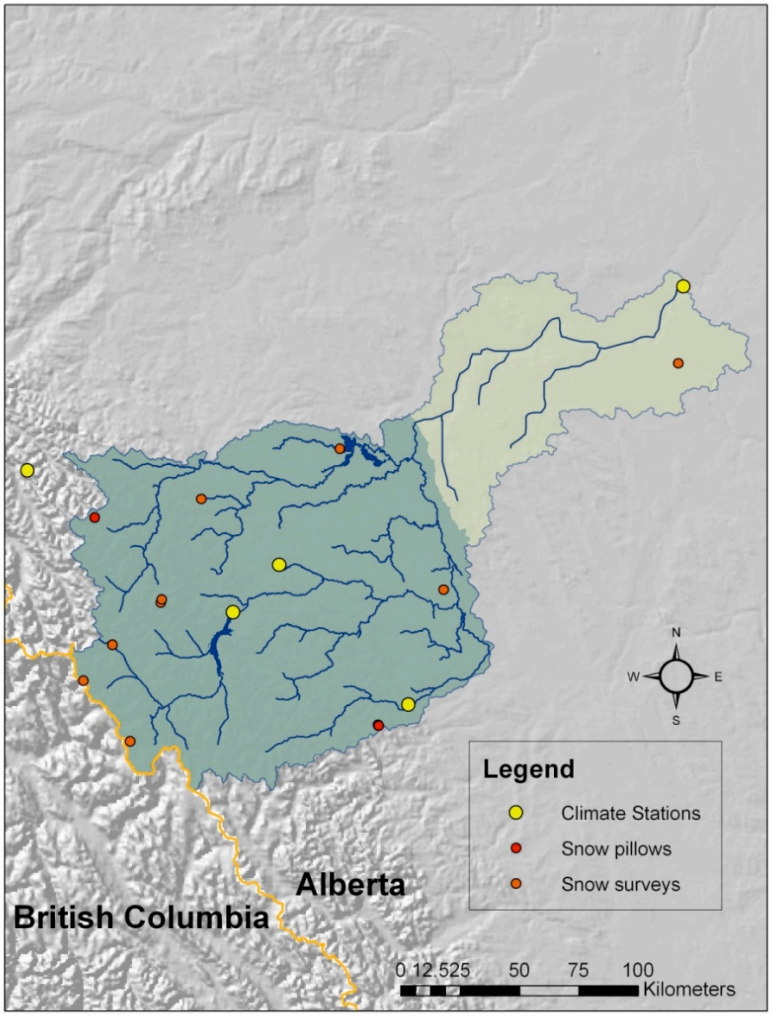




St. Mary under Climate Change?

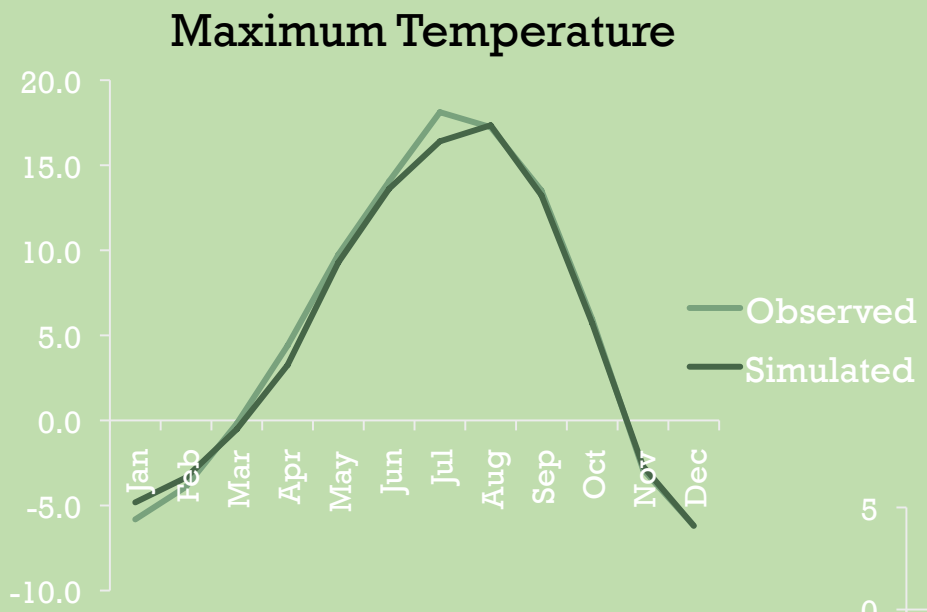
- Warming temperatures with increased precipitation
- Water supply decline with GHG business as usual
- Snowpack is sensitive to temperature changes
  - Changes in the phase of precipitation
  - Earlier onset of spring melt
    - Reduced late season water supply
    - Aquatic ecosystem health is at risk
- Glacier decline excluded

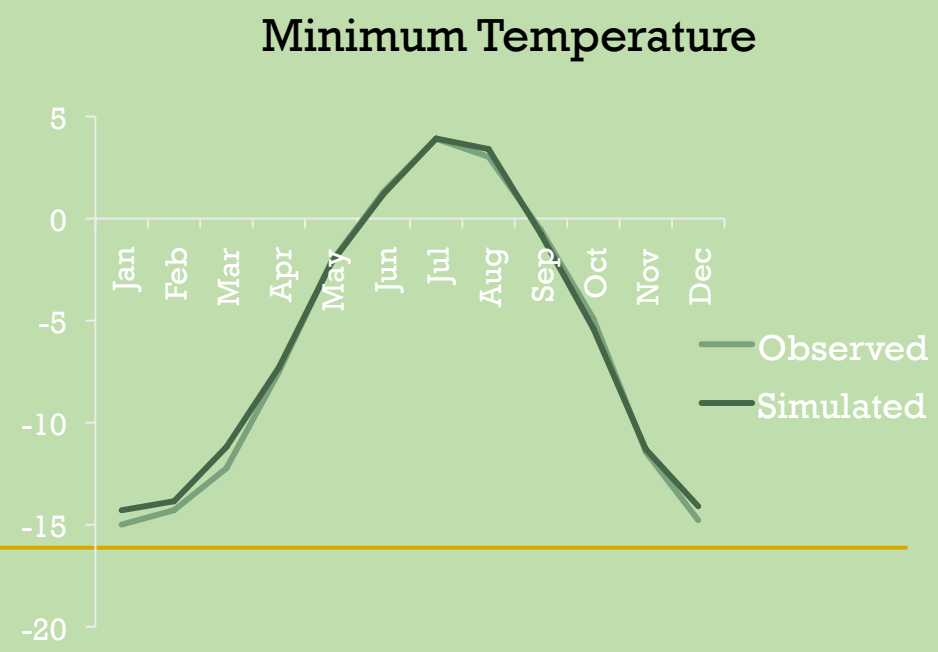
Upper North Saskatchewan River watershed



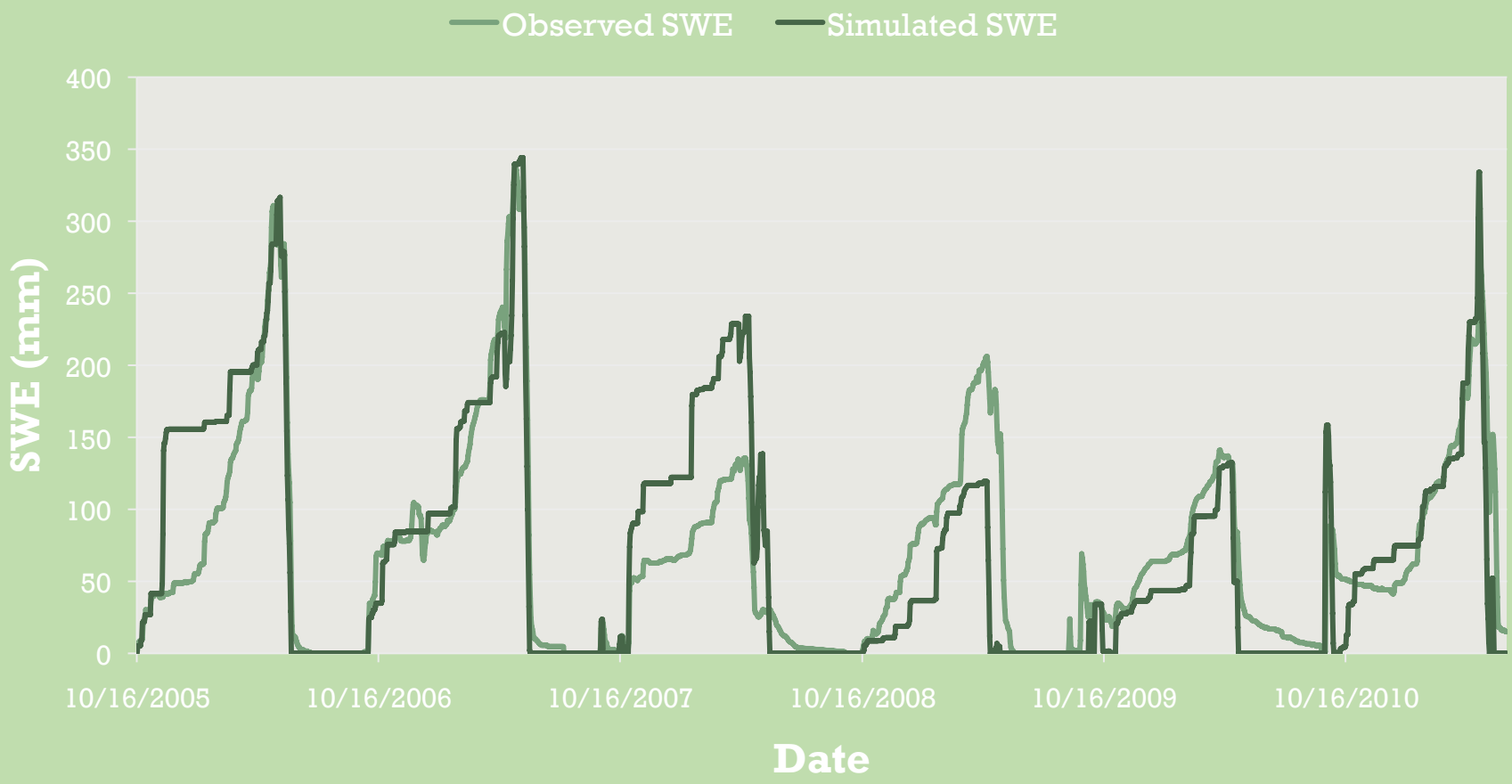
- Headwaters 20,527 km^2
- Elevation range from 752 m to 3484 m
- hydro-electric power, forestry, mineral mining and petrochemical extraction

Model Calibration

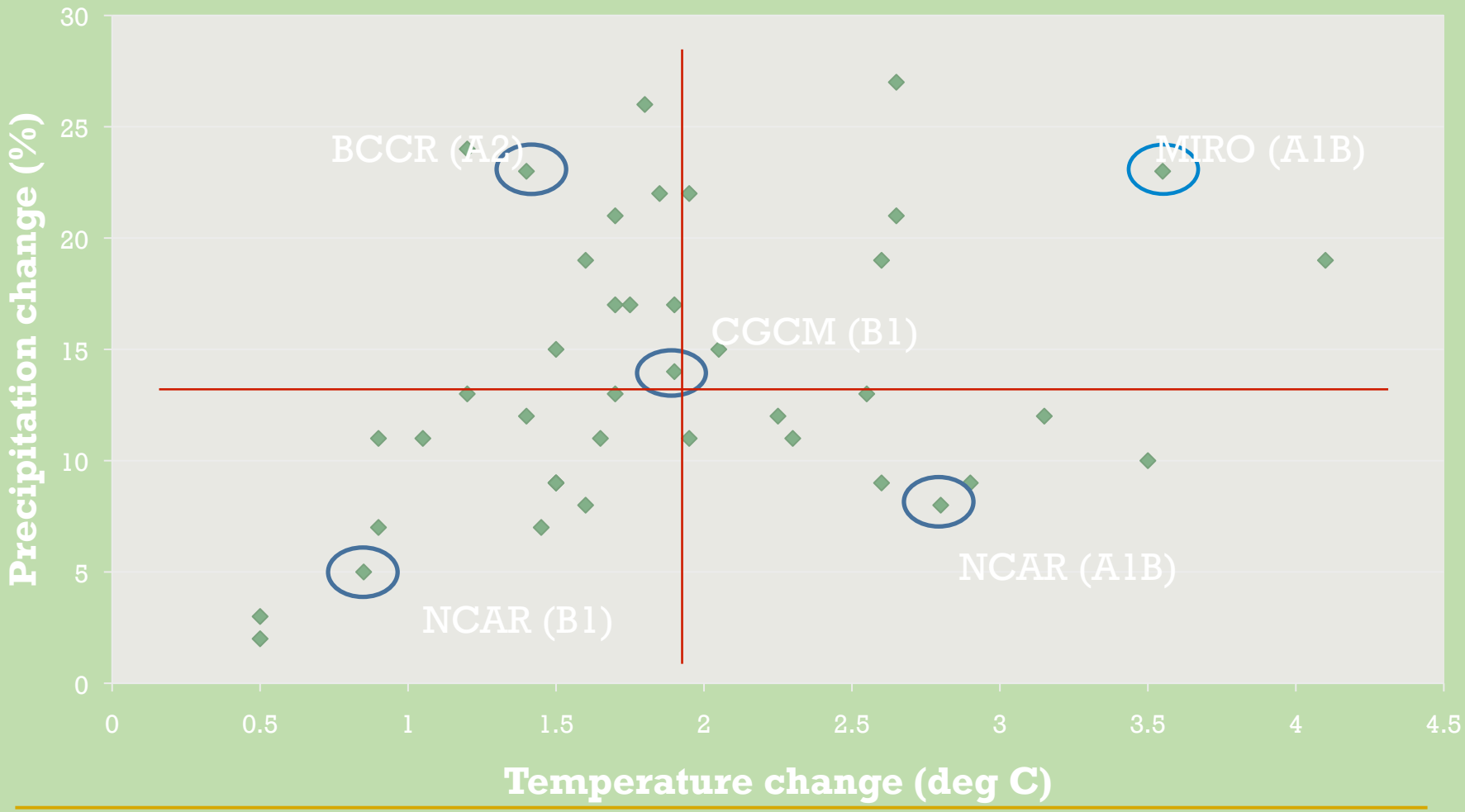




Model SWE Validation

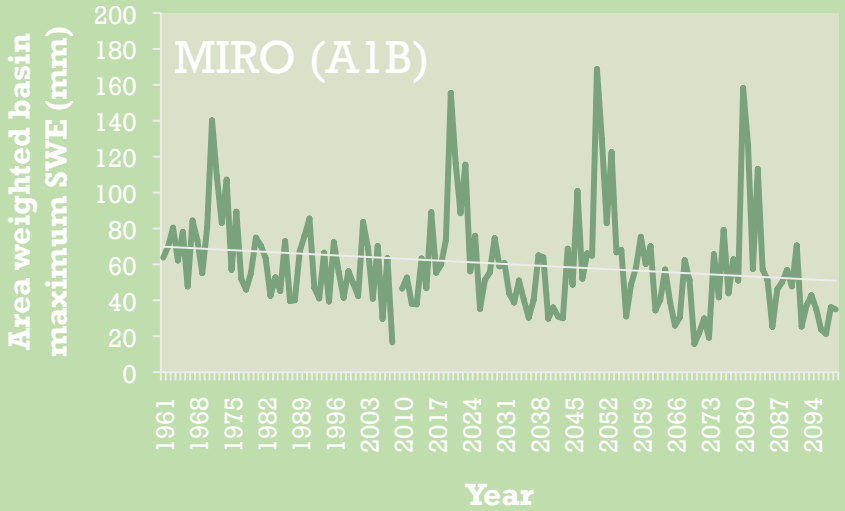


GCM scenario selection 2050s

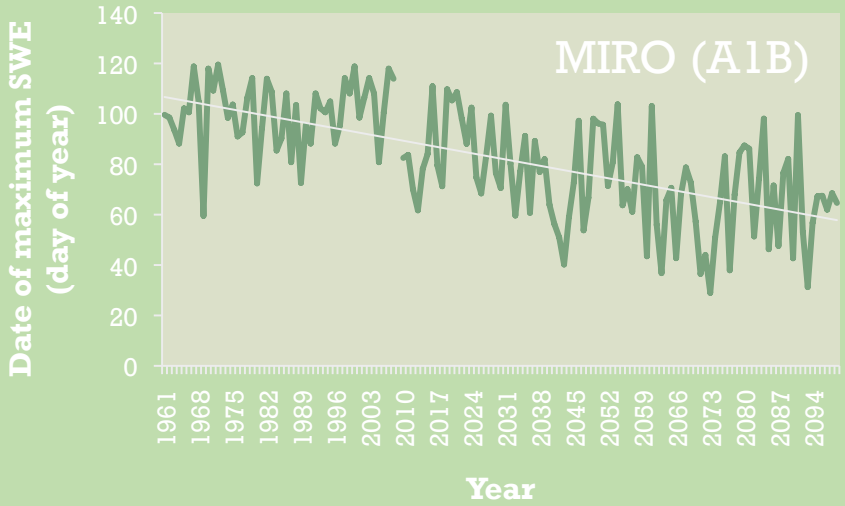


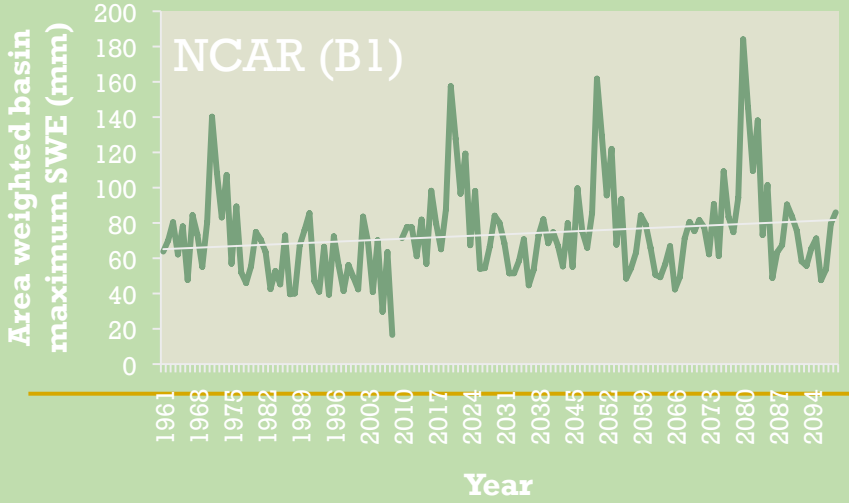
Future SWE predictions

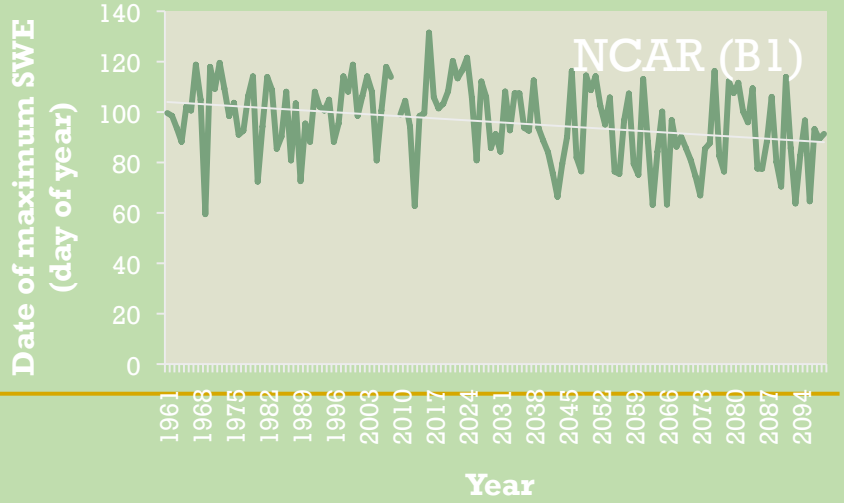
Maximum SWE



Date of maximum SWE







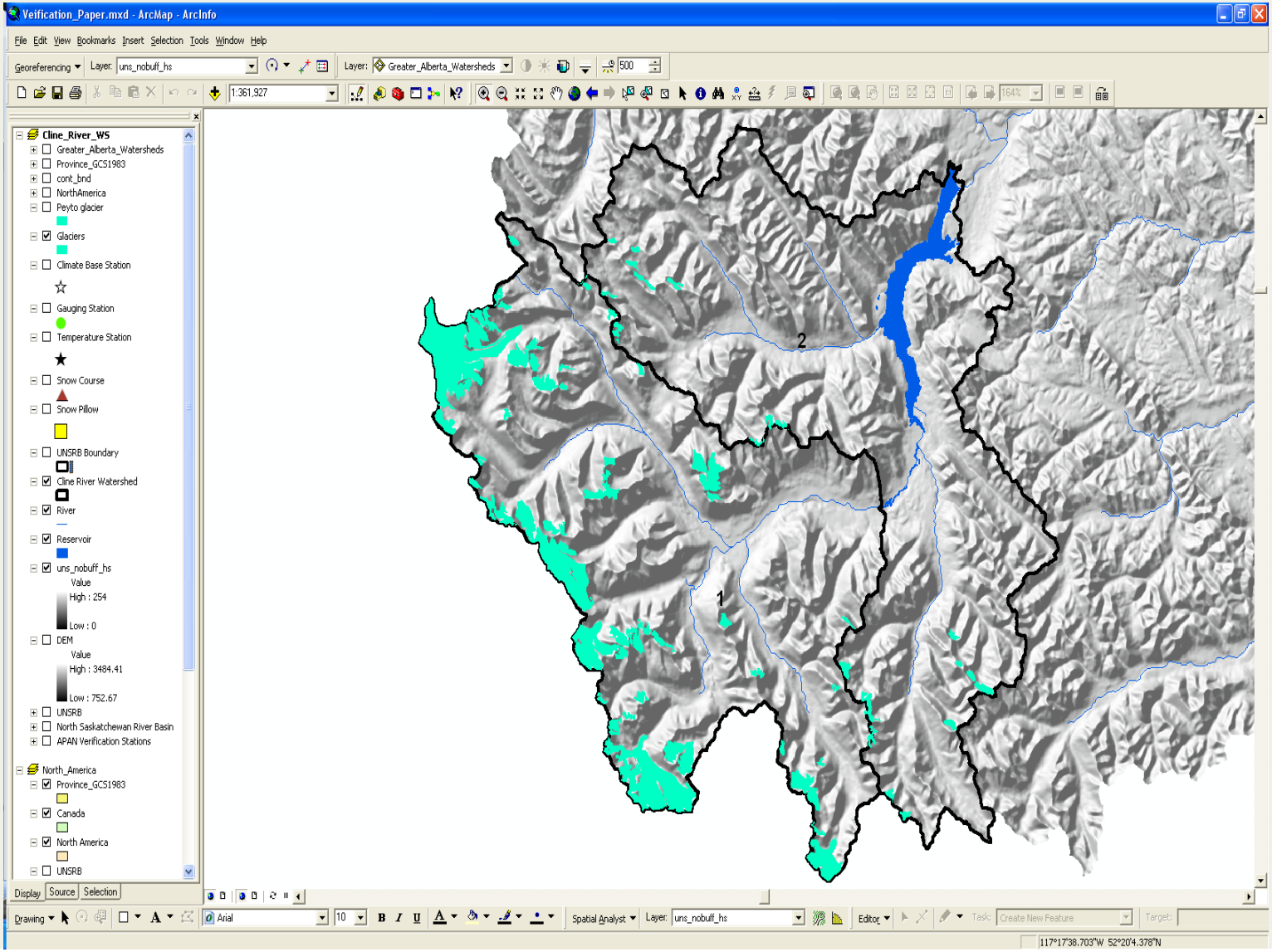
North Sask Conclusions

- GENESYS simulates complex terrain hydromet processes well with little input data
- Peak SWE change subject to emissions scenario
- Earlier spring snowmelt onset
- Water management?
  - Supply and timing

Evan Booth

Modelling the response of Glaciers to Climate Change in the Upper North Saskatchewan River Basin

Glaciers in the Upper North Saskatchewan Basin –Study Area for thesis?-



Thesis Objective

1. Mass balance model for alpine glaciers and ice fields

2. Incorporate glacier model into GENESYS and model historical ice melt contributions to runoff

3. Apply the Model to determine alpine ice decline under a range of global warming scenarios

Linking Dendrochronologies, historical and GCM based future scenarios and a fine scale hydrometeorology model

S. Lapp, J. Byrne, R. MacDonald and D. Sauchyn

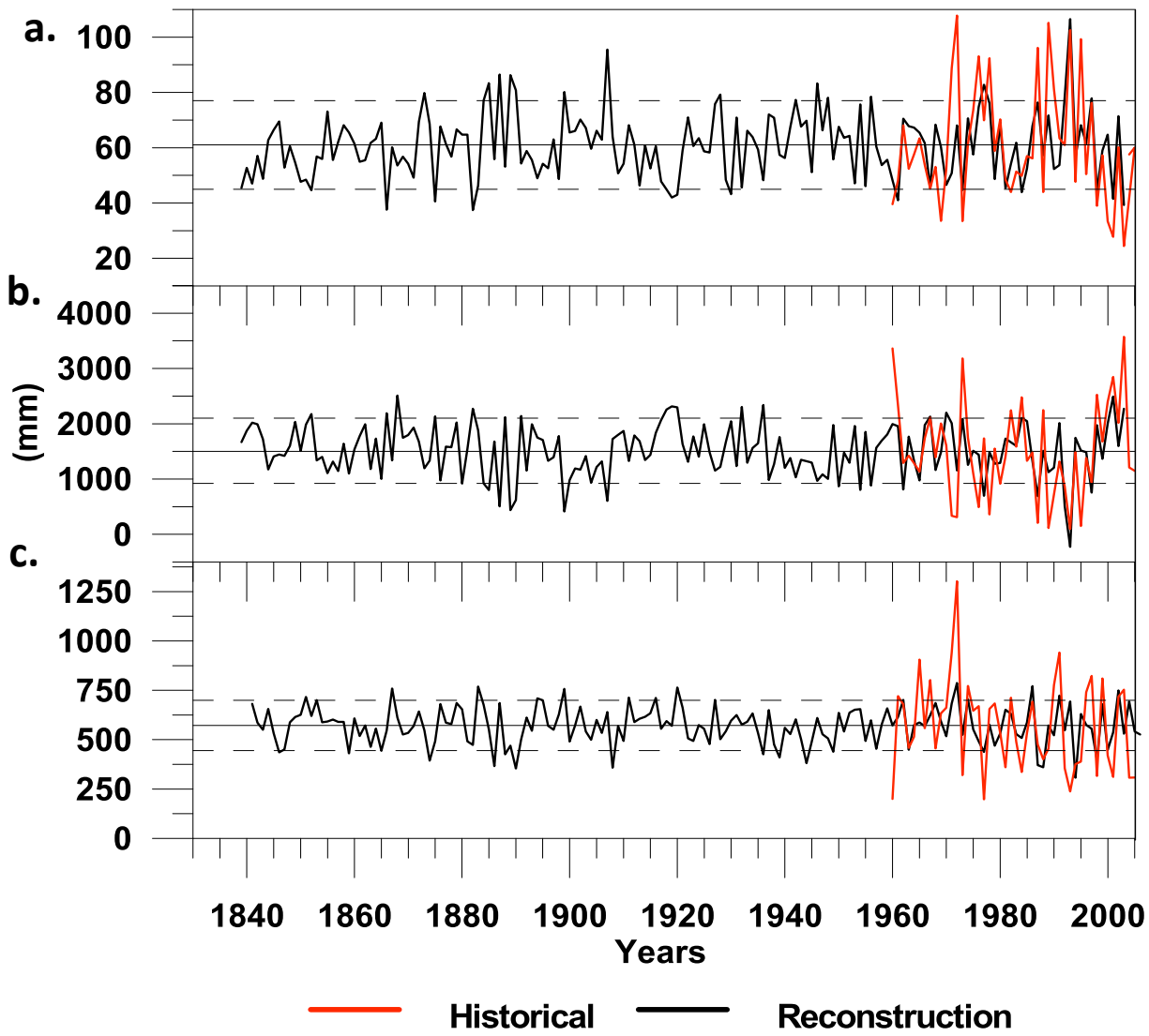


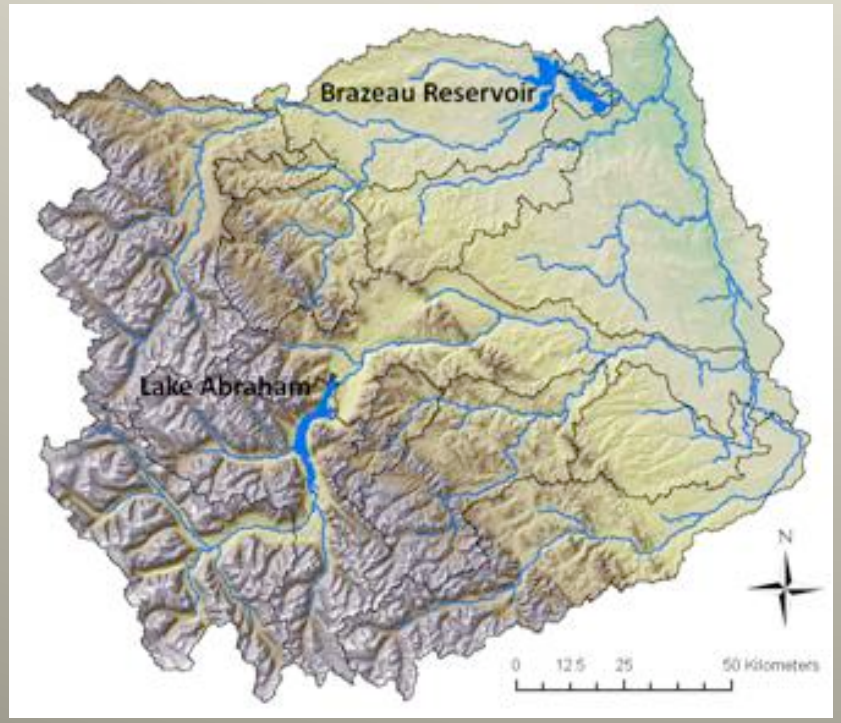
Figure 3. Average basin reconstruction for (a) Minimum SM, (b) Total Deficit , and (c) Maximum Snowpack,. The solid lines represents the calibration mean; the dashed horizontal lines represent the 10th and 90th percentiles.

Sarah Dalla Vicenza

- Alpine forest soil water balance
- Forest fire risk
  - historical conditions
  - future climate change scenarios
  - Currently looking at Rocky Mountain eastern slopes

Study Area

North Saskatchewan River watershed



Watershed Boundary
River
Reservoir

Maps courtesy of Mike Nemeth

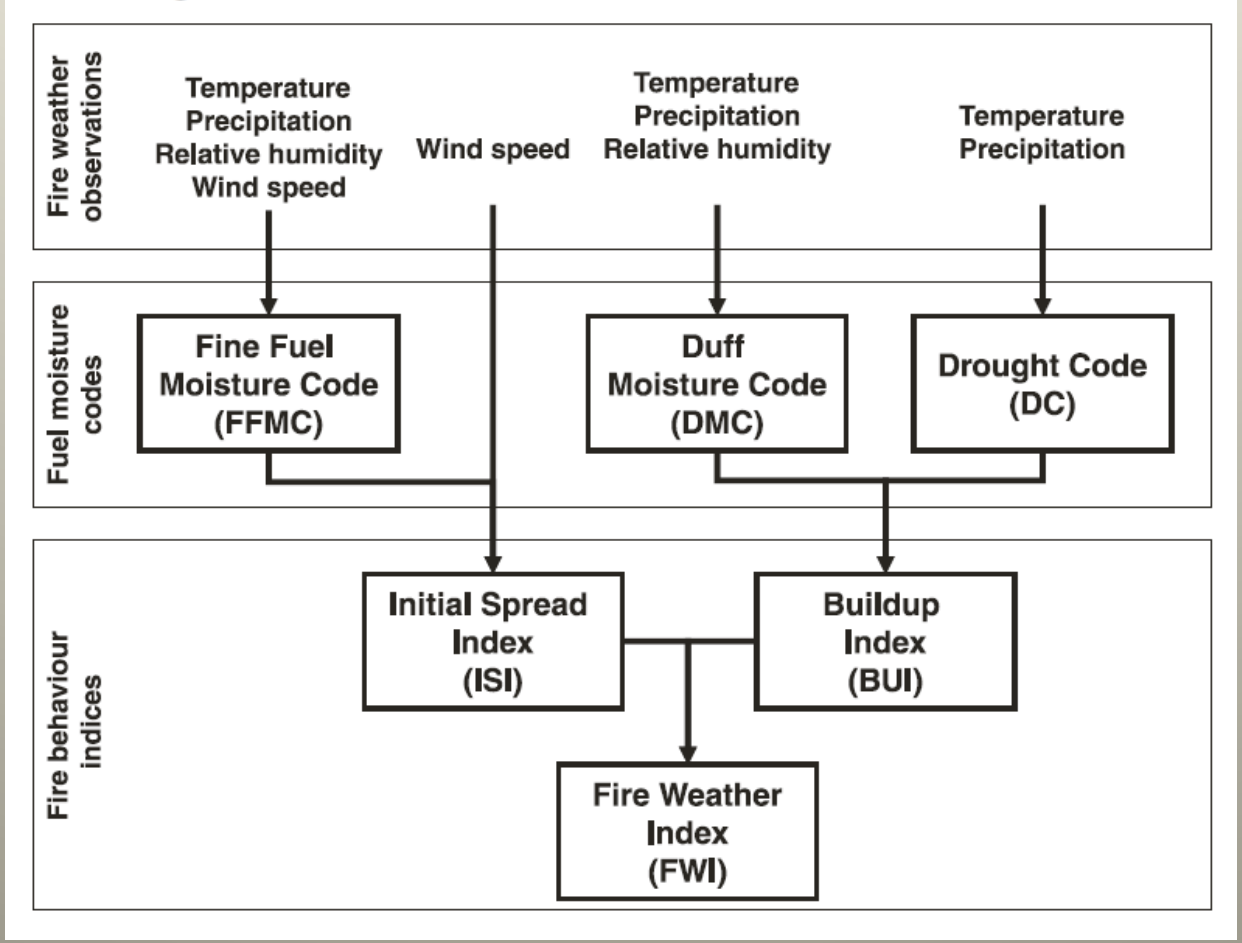
Research Objectives

- Determine how climate change affects soil moisture characteristics
- Determine forest fire risk under historical conditions and forest fire risk under future climate change scenarios

Research Methods

- GENESYS model development/application
  - Soil moisture
  - Develop subroutine for forest fire risk

Canadian Fire Weather Index Adapted from Van Wagner (1987)



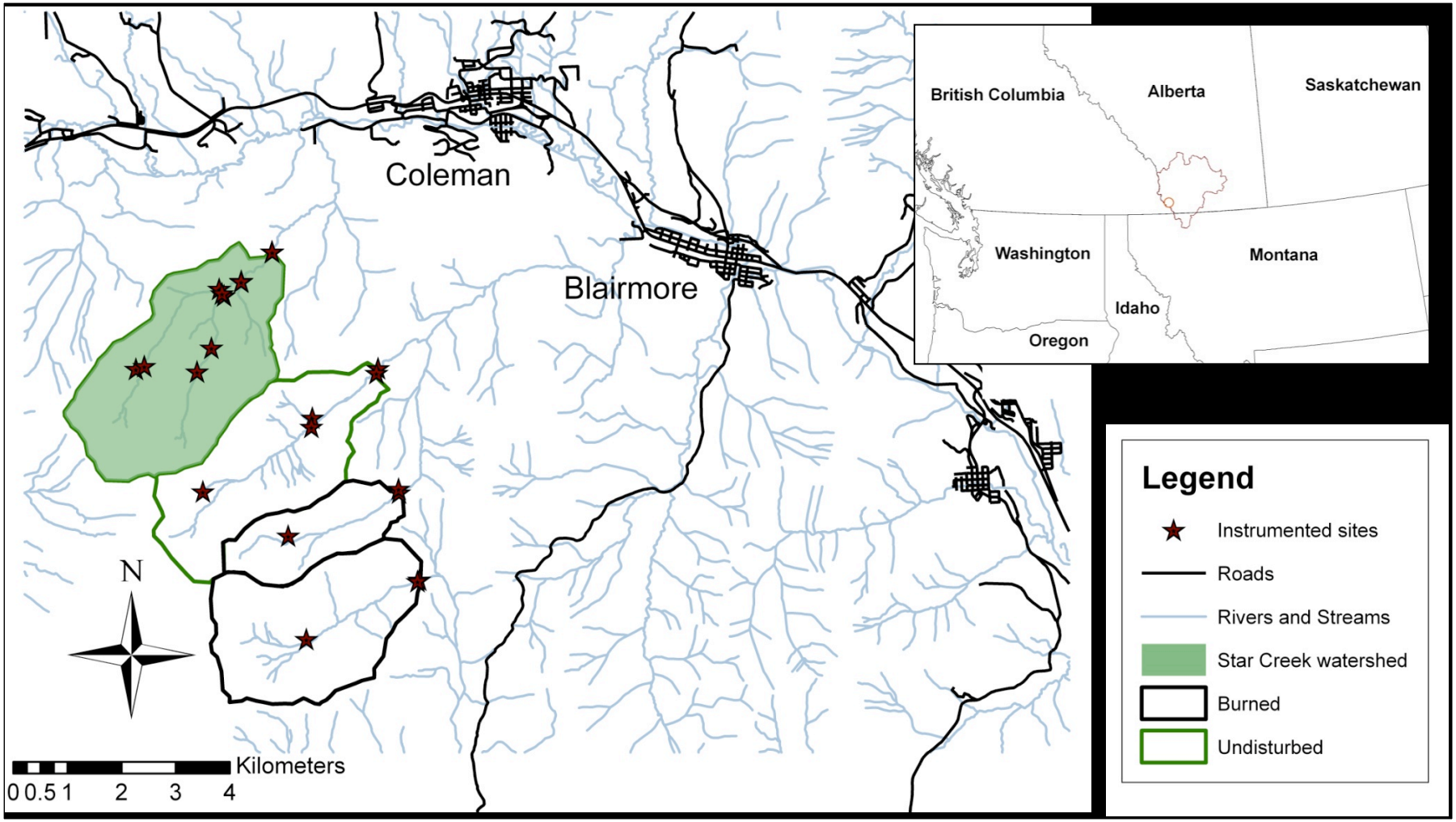
Ryan MacDonald PhD Research

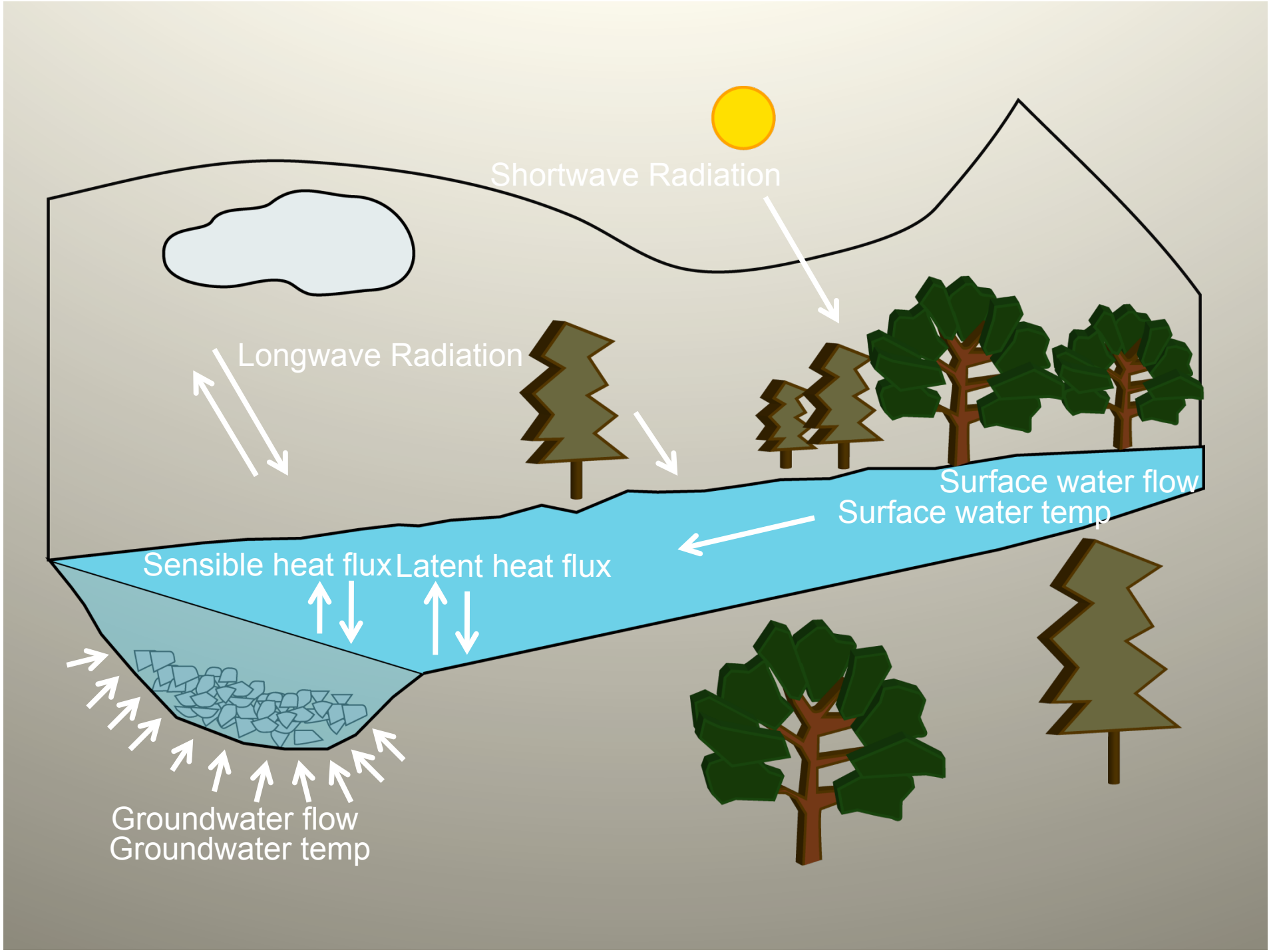
Stream temperature response to Environmental Change

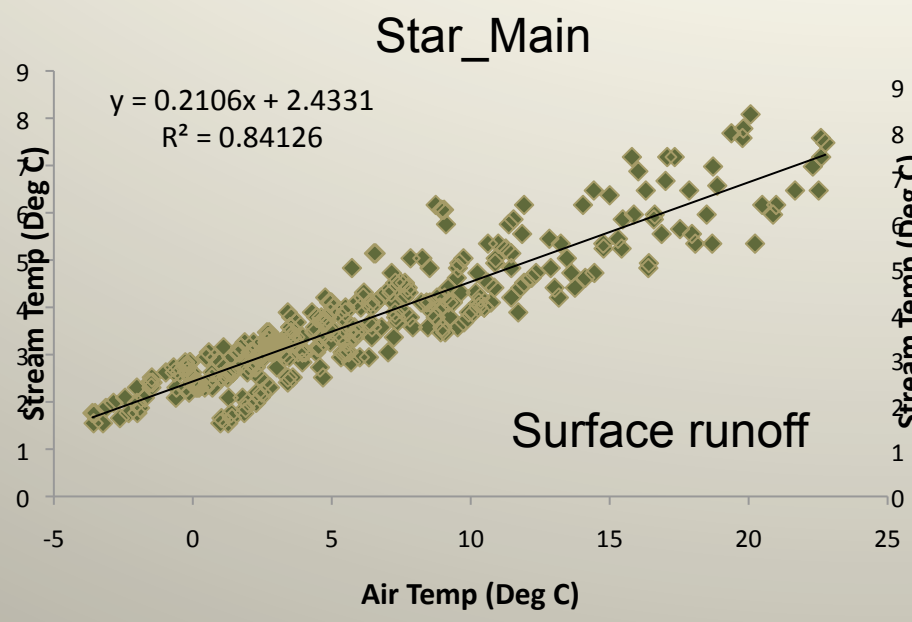
Stream temperature research

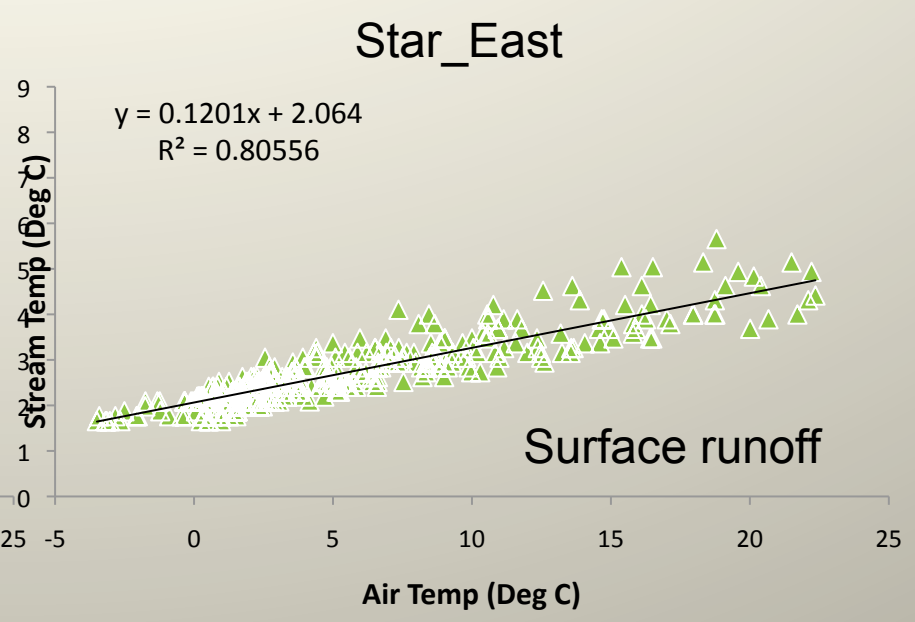
- Few studies have quantified the energy and mass balance components – particularly sub-surface
- Due to the complexities in energy and mass balance, few fine-scale physically based spatial models exist
- Little is known about the potential impacts of environmental change on stream thermal regimes

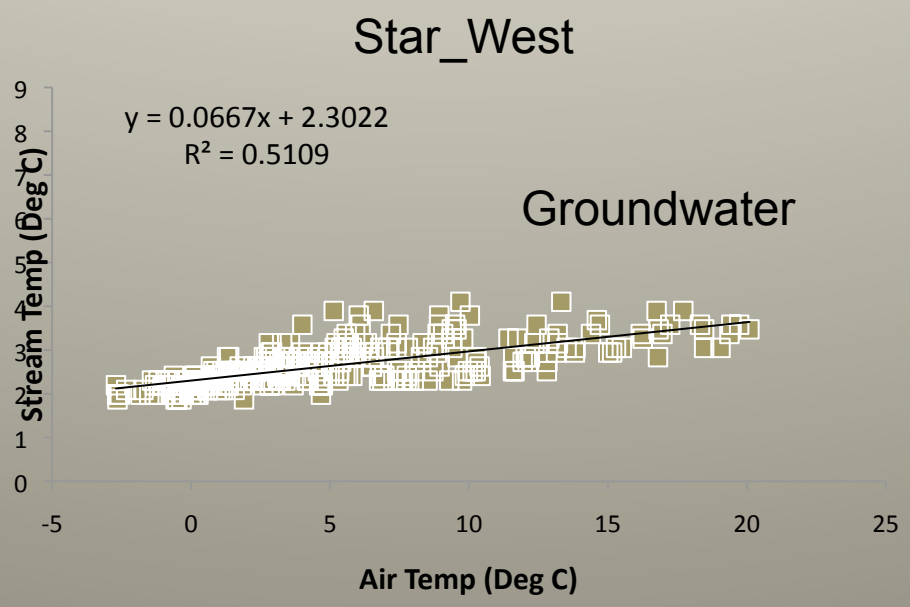
Study site – Crowsnest Pass




Shortwave Radiation
Longwave Radiation
Surface water flow
Surface water temp
Sensible heat flux
Latent heat flux
Groundwater flow
Groundwater temp

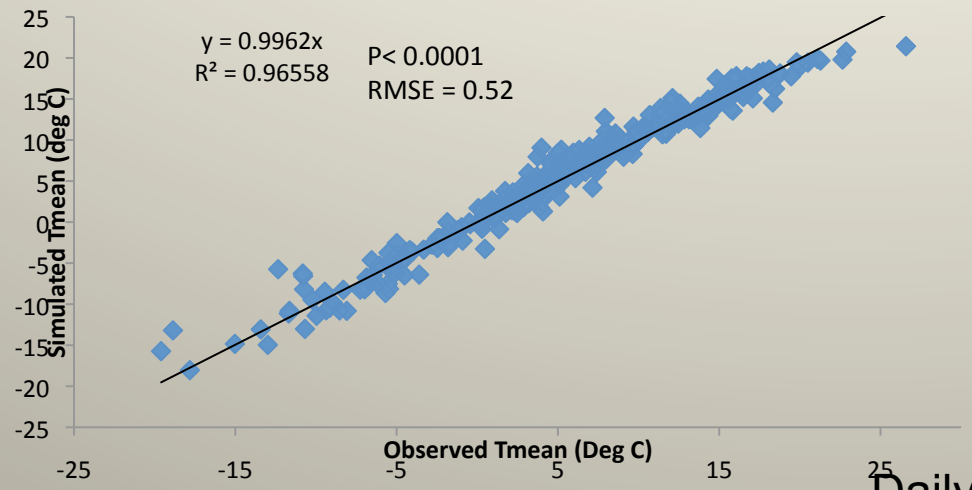

Star_Main
y = 0.2106x + 2.4331
R² = 0.84126
Surface runoff
Stream Temp (Deg C)
Air Temp (Deg C)
0
1
2
3
4
5
6
7
8
9
-5
0
5
10
15
20
25


Star_East
y = 0.1201x + 2.064
R² = 0.80556
Surface runoff
Stream Temp (Deg C)
Air Temp (Deg C)
0
1
2
3
4
5
6
7
8
9
-5
0
5
10
15
20
25

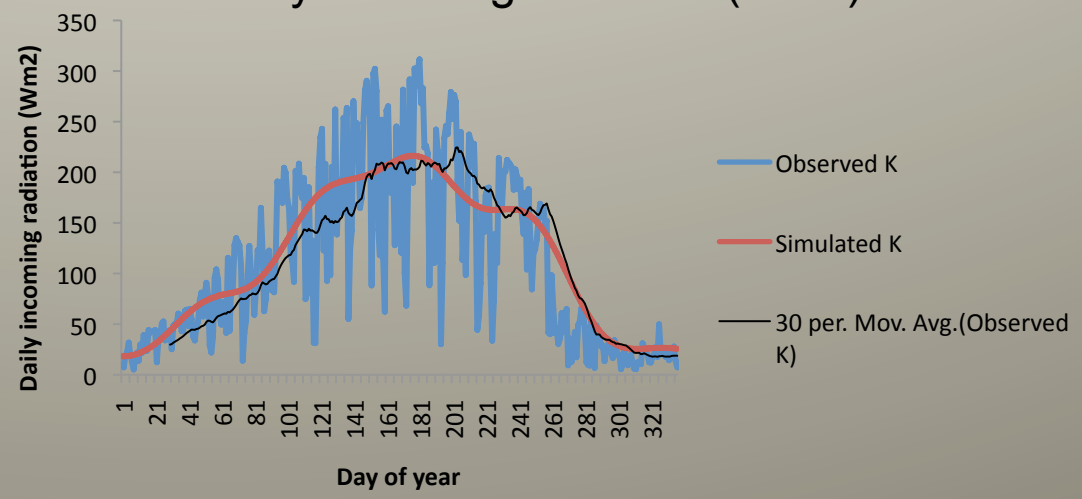

Star_West
y = 0.0667x + 2.3022
R² = 0.5109
Groundwater
Stream Temp (Deg C)
Air Temp (Deg C)
0
1
2
3
4
5
6
7
8
9
-5
0
5
10
15
20
25

Model Verification

Mean daily air temperature (2007)



Daily incoming radiation (2008)



Evan Booth

Historical Analysis of Recent Climate Change in Western North American

Analysis of Historical Changes in Extreme Temperature and Precipitation in Western North America

Evan J. Booth, James M. Byrne, Ryan J. MacDonald, Stefan W. Kienzle

Water and Environmental Sciences, University of Lethbridge, Alberta, Canada

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GC21A-0727

University of Lethbridge

ABSTRACT

Western North America produces a substantial portion of the world food supply. The sustainability of intensive agricultural operations is contingent upon favorable growing conditions and an adequate supply of fresh water. Water resources are coming under increasing pressure from societal demands related in large part to the growing population of Western North America. Global climate change is expected to alter the hydrologic cycle and place additional stress on water supplies and demands. Changing precipitation patterns and intensity, coupled with warming temperatures, could eventually spell disaster for agricultural productivity by increasing the risk of both drought and flooding in sensitive prairie and alpine environments. The goal of this research is to analyze historical climate data to determine the extent to which global warming may have altered the climatology of Western North America over the last 60 years. Daily temperature and precipitation data have been collected from over 1500 stations across Canada and the United States. Climate change indices developed by the WMO's Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) are applied to evaluate historical change. Trends are calculated using indicators that focus primarily on extremes related to the hydrologic cycle. Station-specific statistical output is then integrated into a GIS to identify spatially coherent trends in temperature and precipitation across Western North America.

METHODS

FORTRAN code was developed to identify and remove stations with substantial missing data. Following the procedure of Frich et al. (2001), annual records were considered to be missing if more than 10% of daily values were missing, or if more than 3 months contained more than 20% missing days. Stations were excluded that did not have at least 75% of years reporting. The final analysis included 490 USA and Canadian climate stations west of the Mississippi River. Indices were calculated on an annual basis for each station for the period 1950-2005 using our FORTRAN code and the RClimDex software developed in conjunction with the ETCCDMI. Trends were calculated using linear regression; significance levels were determined using a standard T-test. Slopes for each trend were then multiplied by 10 to represent change on a decadal scale. Calculated Trends were integrated in ArcGIS and displayed spatially using Local Polynomial Interpolation. Two spatial interpolations were produced for each climate index:

A. All station trends included regardless of statistical significance;

B. Using only stations reporting significance at or above 90% confidence level.

FUTURE DIRECTIONS

Further research will focus on applying hydro-meteorological models to utilize the output from this analysis to determine potential impacts of climate change on the soil-moisture balance in sensitive environments. This research will be submitted for publication in early 2010.

TEMPERATURE INDICES

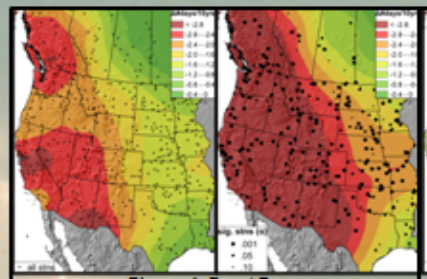


Figure 1: Frost Days

This index measures annual count of days when the daily minimum temperature falls below 0°C. A clear decline in frost days from the Cordillera west suggests substantial historical winter warming.

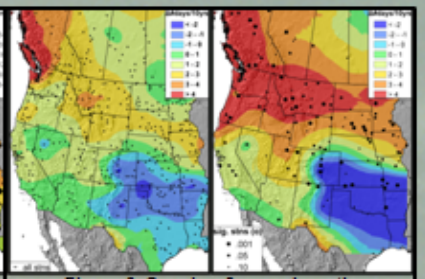


Figure 2: Growing Season Length

This index measures the annual count between the first span of at least 6 days when T>5°C and the first span after July 1 of 6 days when T<5°C. The growing season appears to be increasing in higher latitudes but is shortening slightly in the southeast.

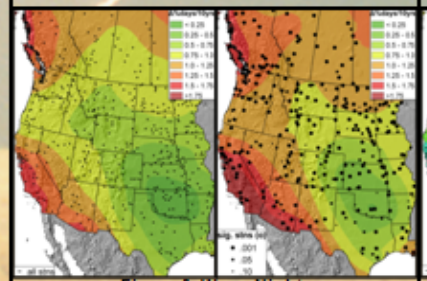


Figure 3: Warm Nights

This index measures the percentage of days in a year when the minimum temperature is greater than the station-specific 90th percentile, calculated from the 1961-90 base period. ALL regional trends indicate warming nighttime temperatures with the greatest increases in the west and north.

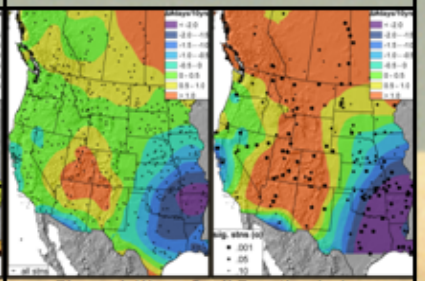


Figure 4: Warm Spell Duration Index

This index measures the greatest annual count of consecutive days when maximum temperature is greater than the station-specific 90th percentile. (1961-90 base). The continent interior shows the greatest warming but there is a negative trend over the SE region.

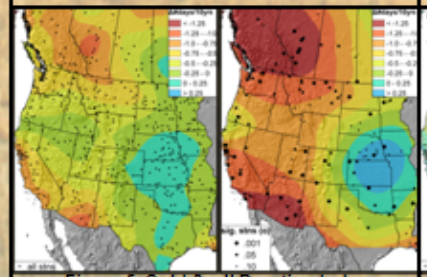


Figure 5: Cold Spell Duration Index

This index measures the greatest annual count of consecutive days when minimum temperature falls below than the station-specific 10th percentile. (1961-90 base period). Cold spell occurrence has weakened over the NW quadrant of the study area.

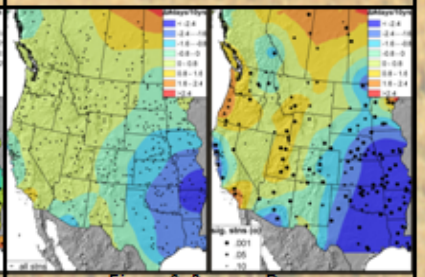


Figure 6: Summer Days

This index measures the annual count of days when maximum temperature is greater than 25°C. Again negative trends are apparent in the SE but trends are positive for the interior regions.

PRECIPITATION INDICES

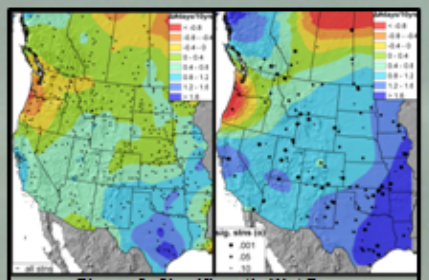


Figure 9: Significantly Wet Days

This index measures the annual count of days with at least 5mm of precipitation. 5mm was deemed to be a meaningful threshold at which precipitation events begin to have an effect on soil moisture content and groundwater recharge.

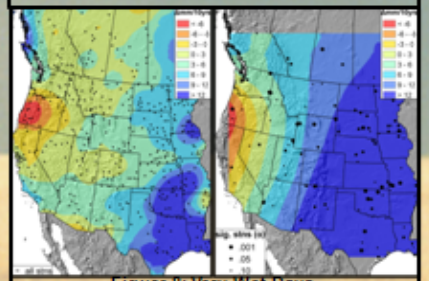


Figure 8: Very Wet Days

This index measures the amount of annual precipitation delivered by daily precipitation events in the station-specific 95th percentile, calculated from the 1961-90 base period. This index represents extreme precipitation events. Extreme events are increasing over the eastern half of the study region.

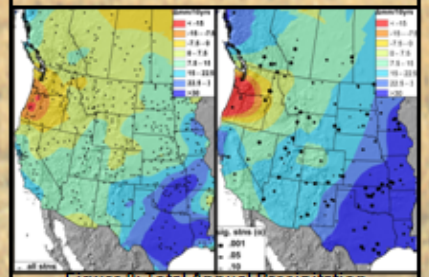
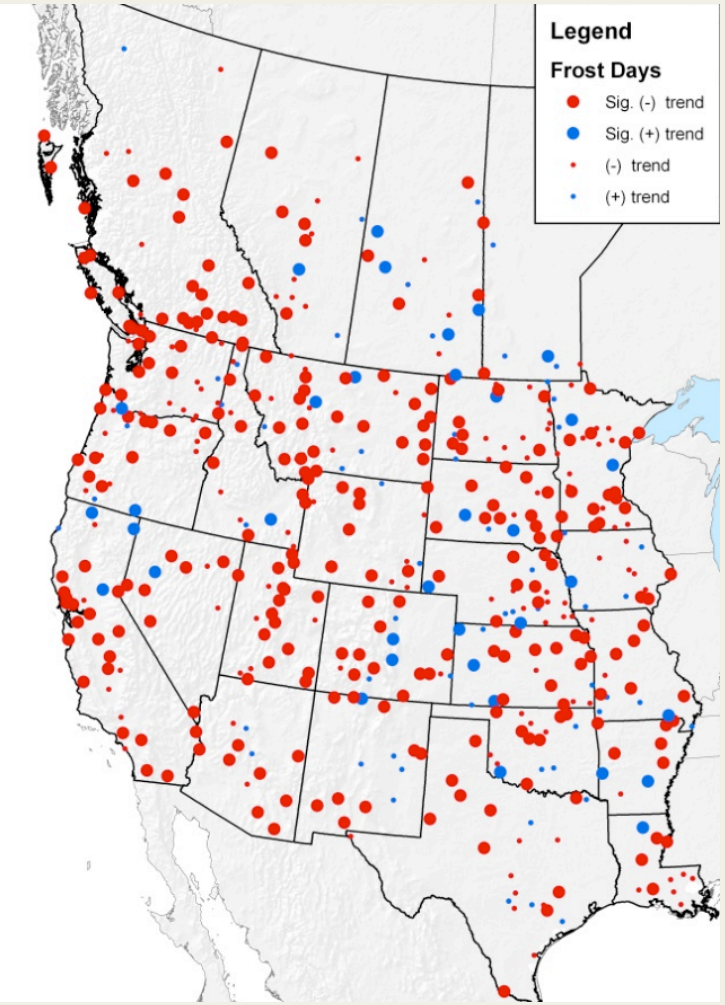
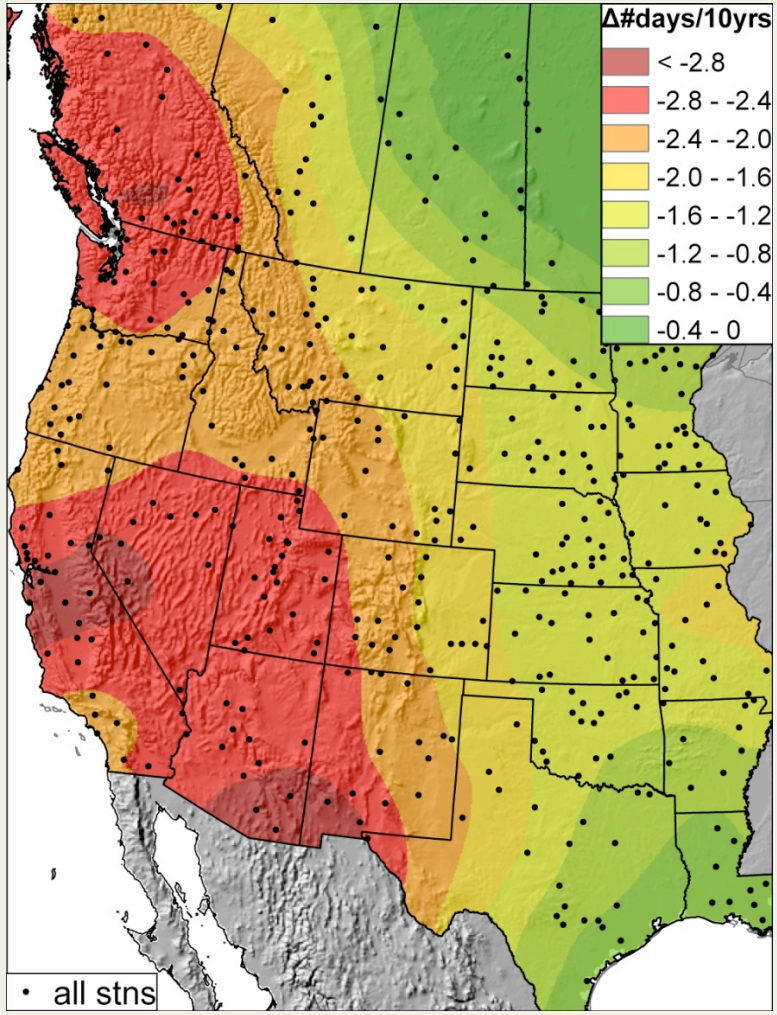


Figure 9: Total Annual Precipitation

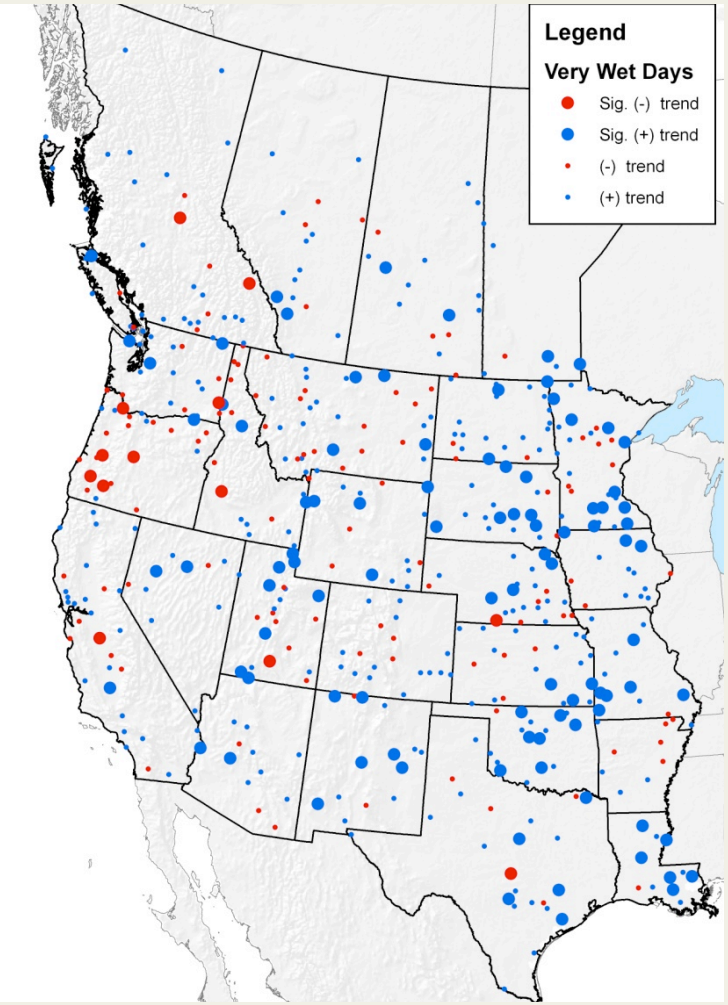
This index measures total annual precipitation received from events greater than 1mm. The spatial pattern echoes the very wet day precipitation, indicating that much of the increase in annual precipitation can be explained by increasingly frequent extreme events in the central part of the continent.

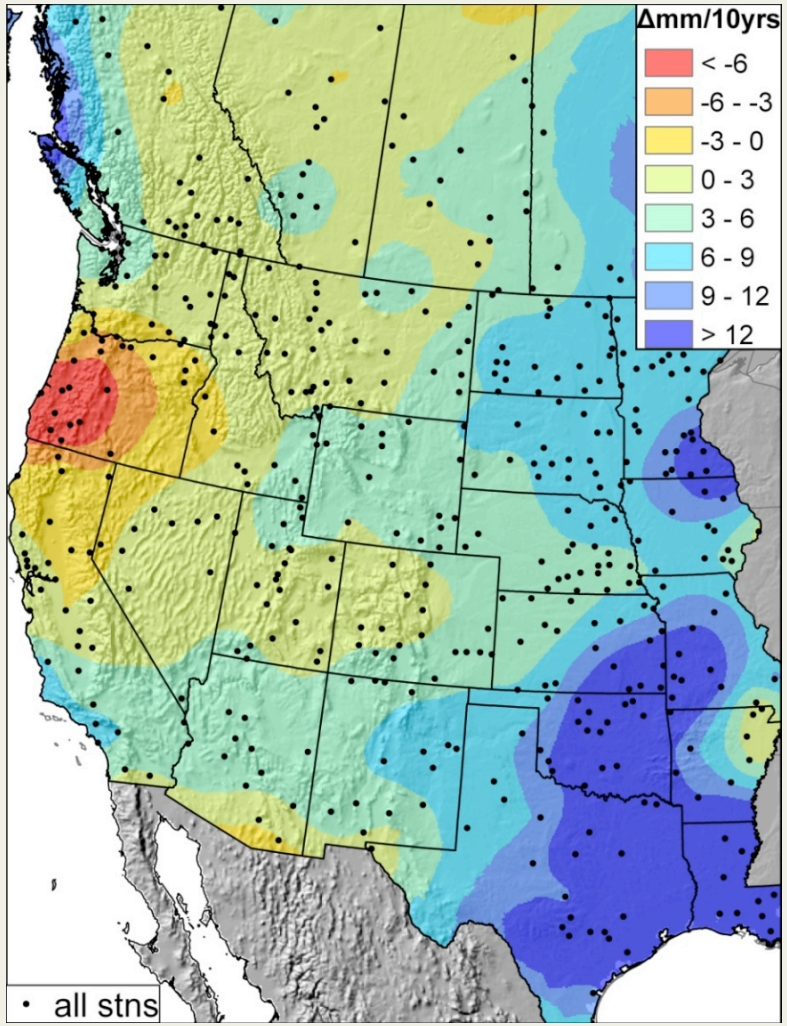
Frost Days (FD0)



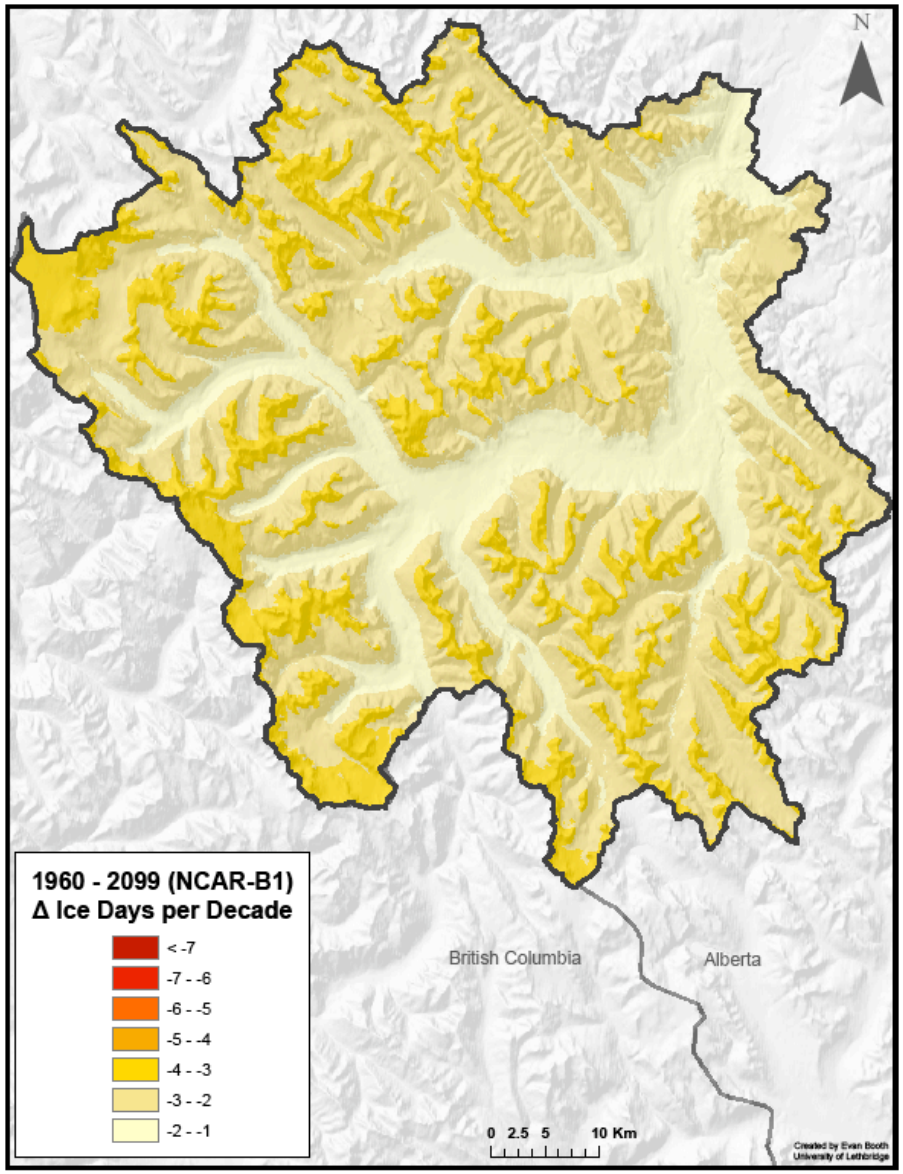


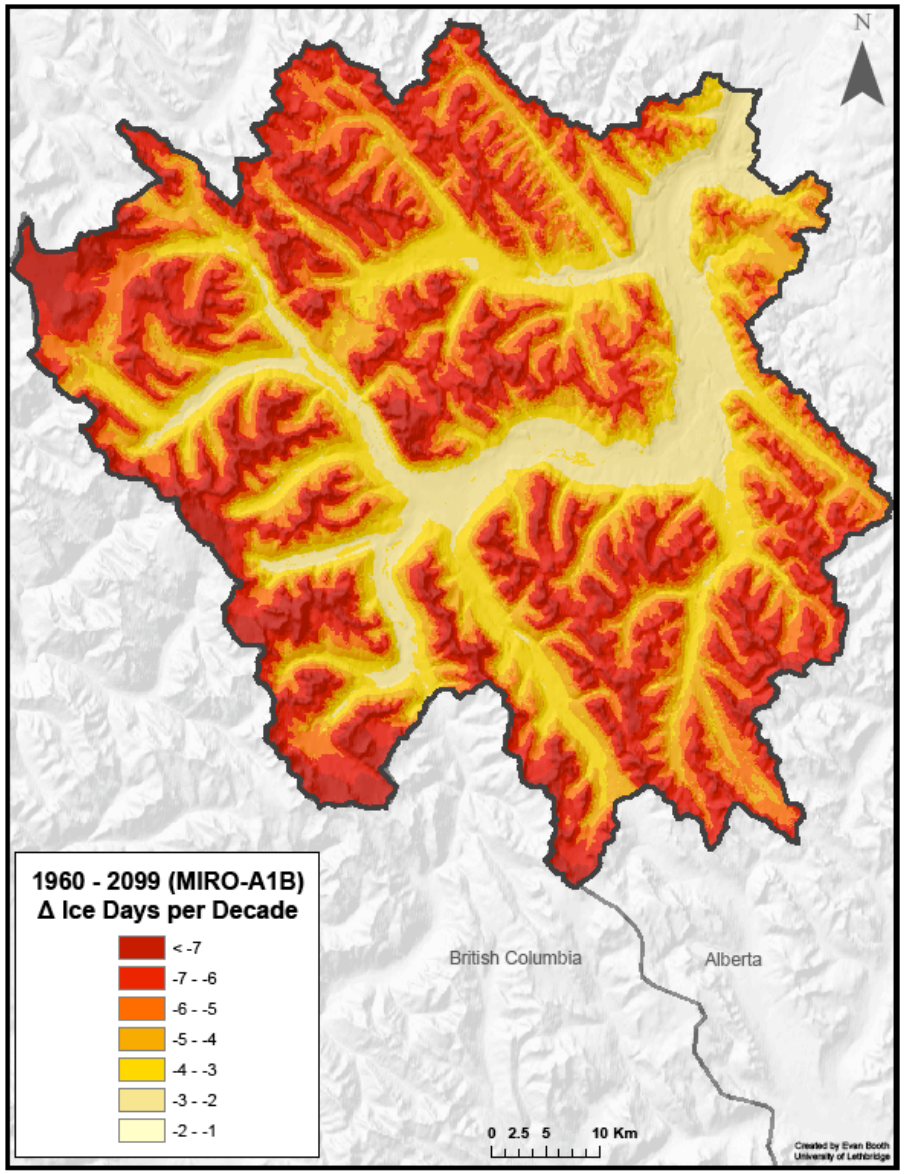
95th Percentile Annual Precip





1960–2099: Trend in Annual Ice Days (Tmax < 0˚C)





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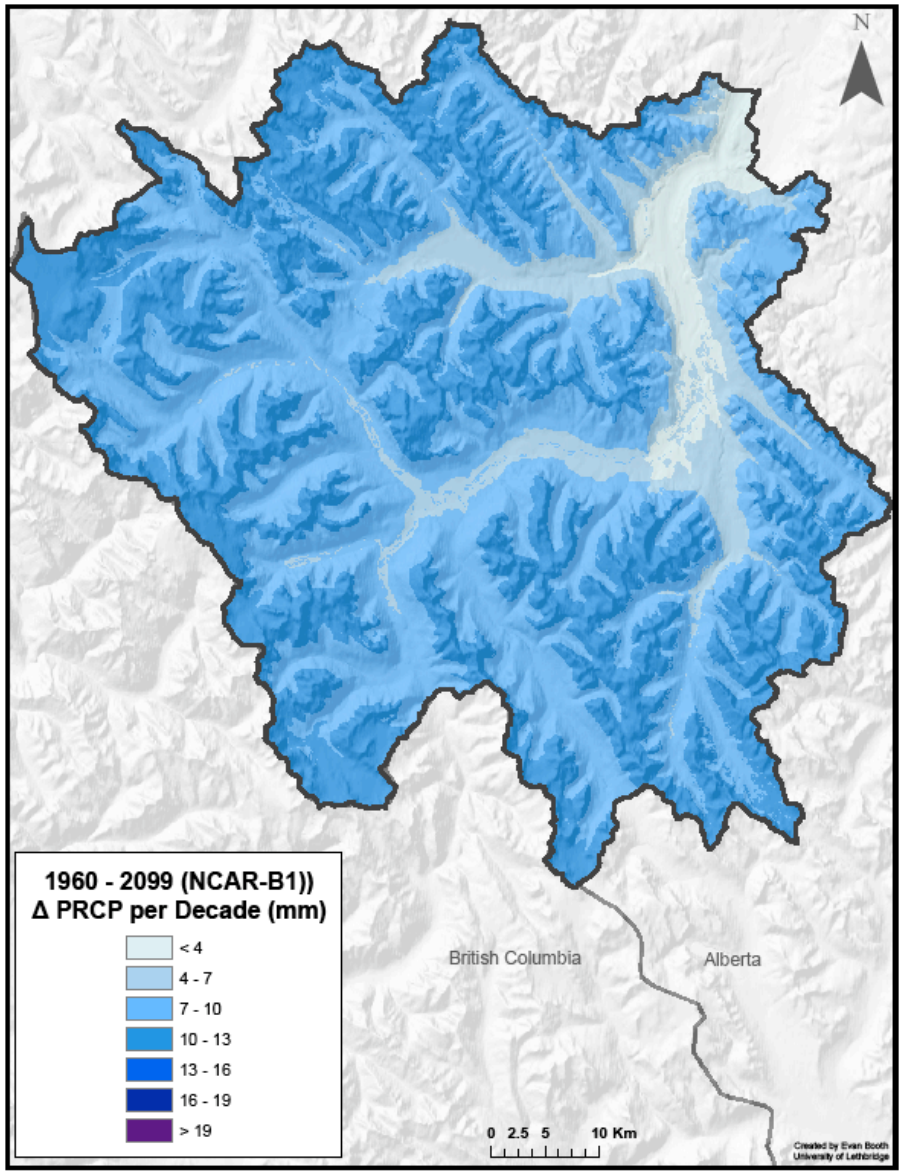
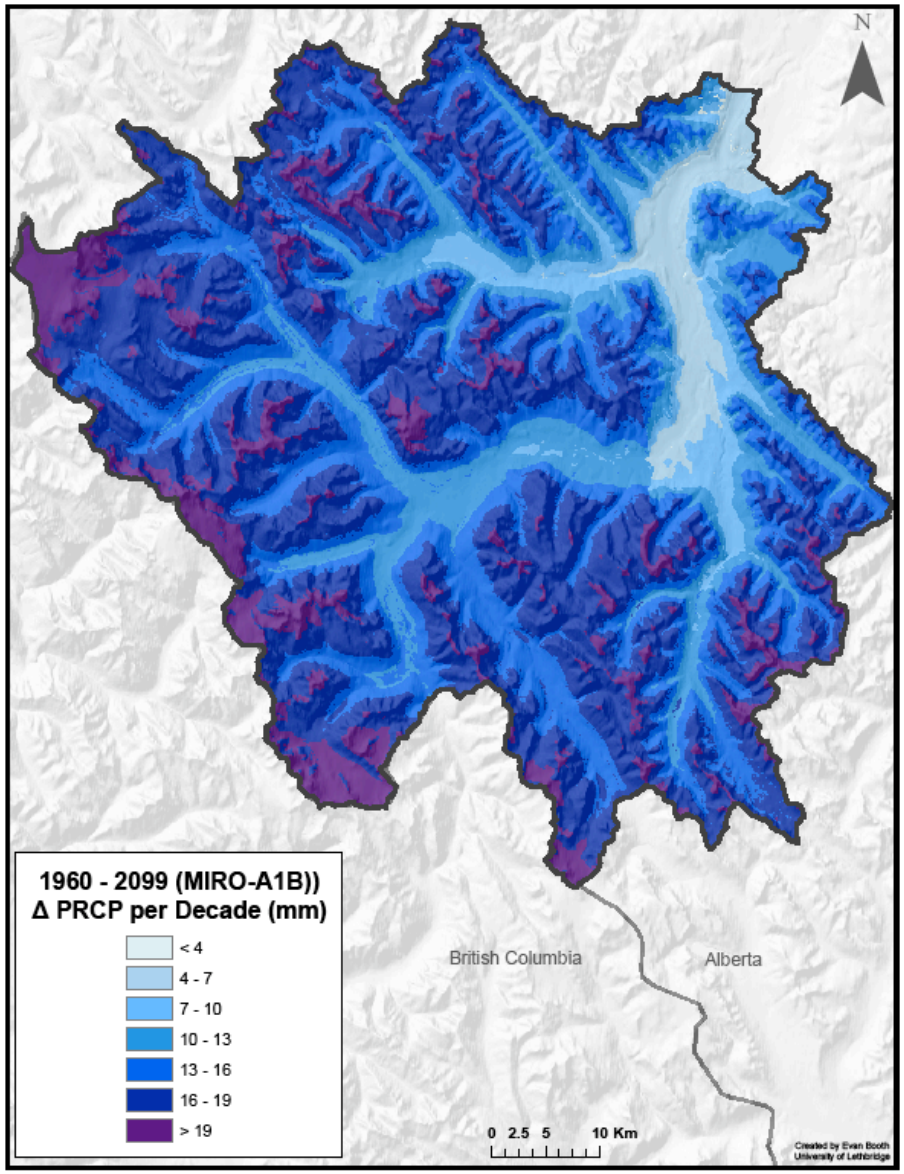
- Alberta Water Research Institute
- Canadian Water Network

Questions?

1960–2099: Trend in Total Annual Precipitation (PRCP > 1mm)





- Characterize rate and spatial extent of climate change over WNA for the period 1950 – 2005
- Used FORTRAN code and Visual Basic to process and analyze vast quantities of data
- 27 WMO Climate Indicators calculated for 500 stations west of Mississippi
- Found significant trends in temperature and precipitation in many regions