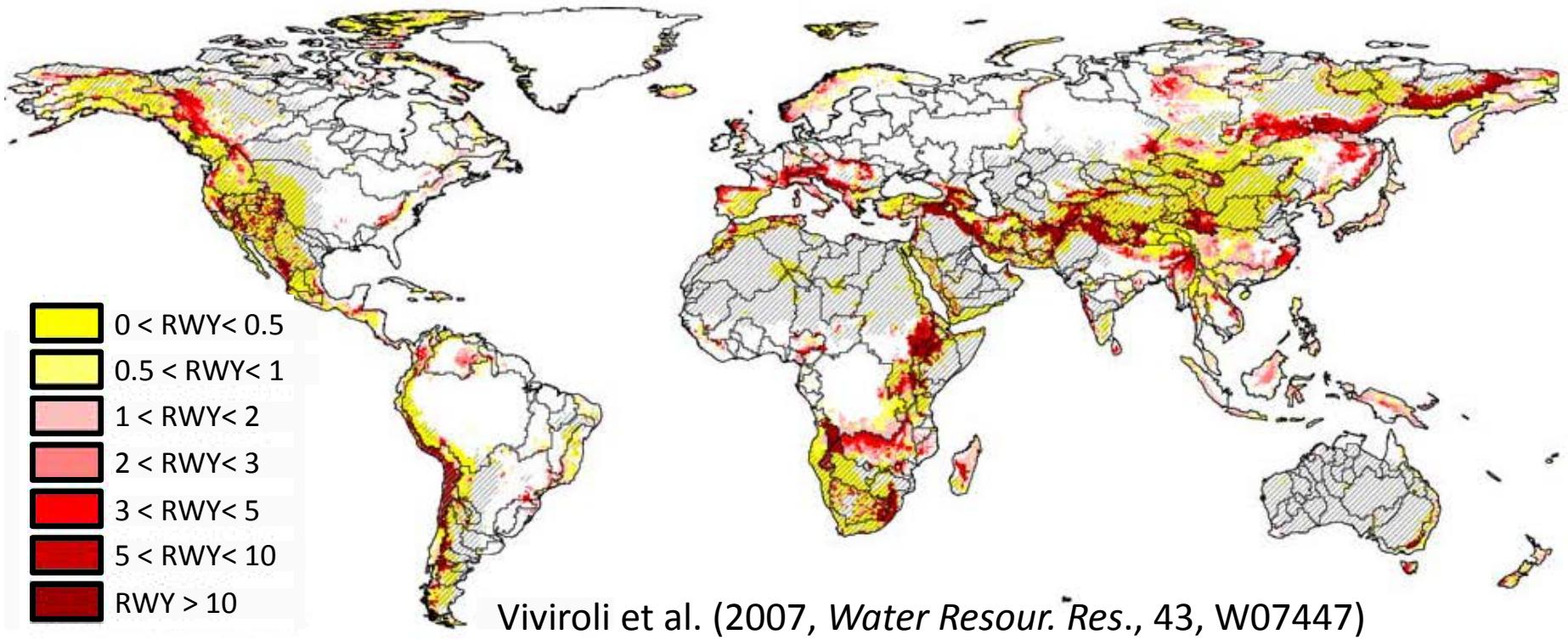
Mountain Waters: Change, Vulnerability and Opportunity

Mountains – the Water Towers of the World

$$\text{Relative water yield (RWY)} = \frac{\text{Mountain runoff (mm/y)}}{\text{Lowland runoff (mm/y)}}$$



Viviroli et al. (2007, *Water Resour. Res.*, 43, W07447)

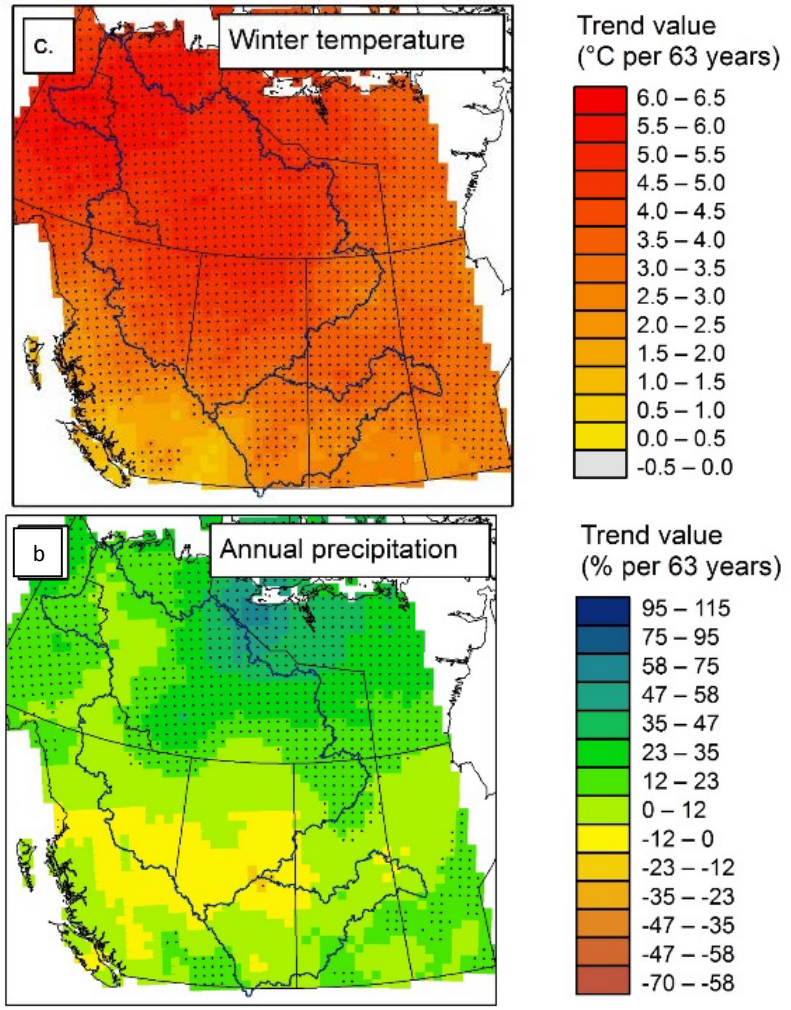
~40% of world's population relies on mountain rivers.
(D. Viviroli, *pers. comm*.)

Material from M. Hayashi

Region of Considerable Warming

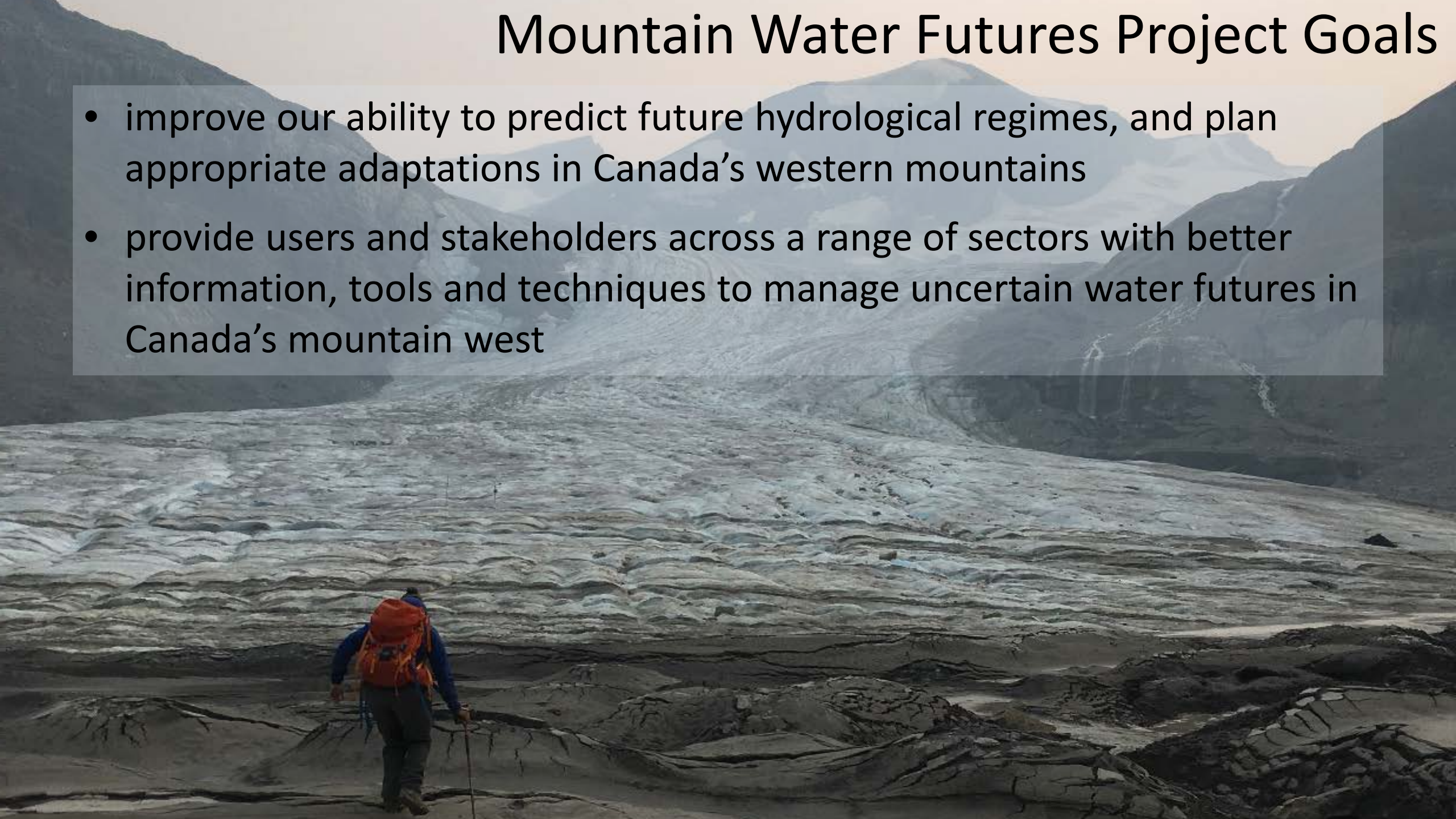
- Over the interior of western Canada, systematic patterns of change in climatic regime and cryospheric response
  - Pervasive warming
  - Decreased fraction of precip. as snow
  - Decreasing snow cover depth, extent, duration; retreating glaciers
  - Warming, thawing permafrost
  - Declining ice cover period
  - Earlier spring freshet
- Hydrological responses have been varied, reflecting complex process responses

Climate trends (1950–2012)

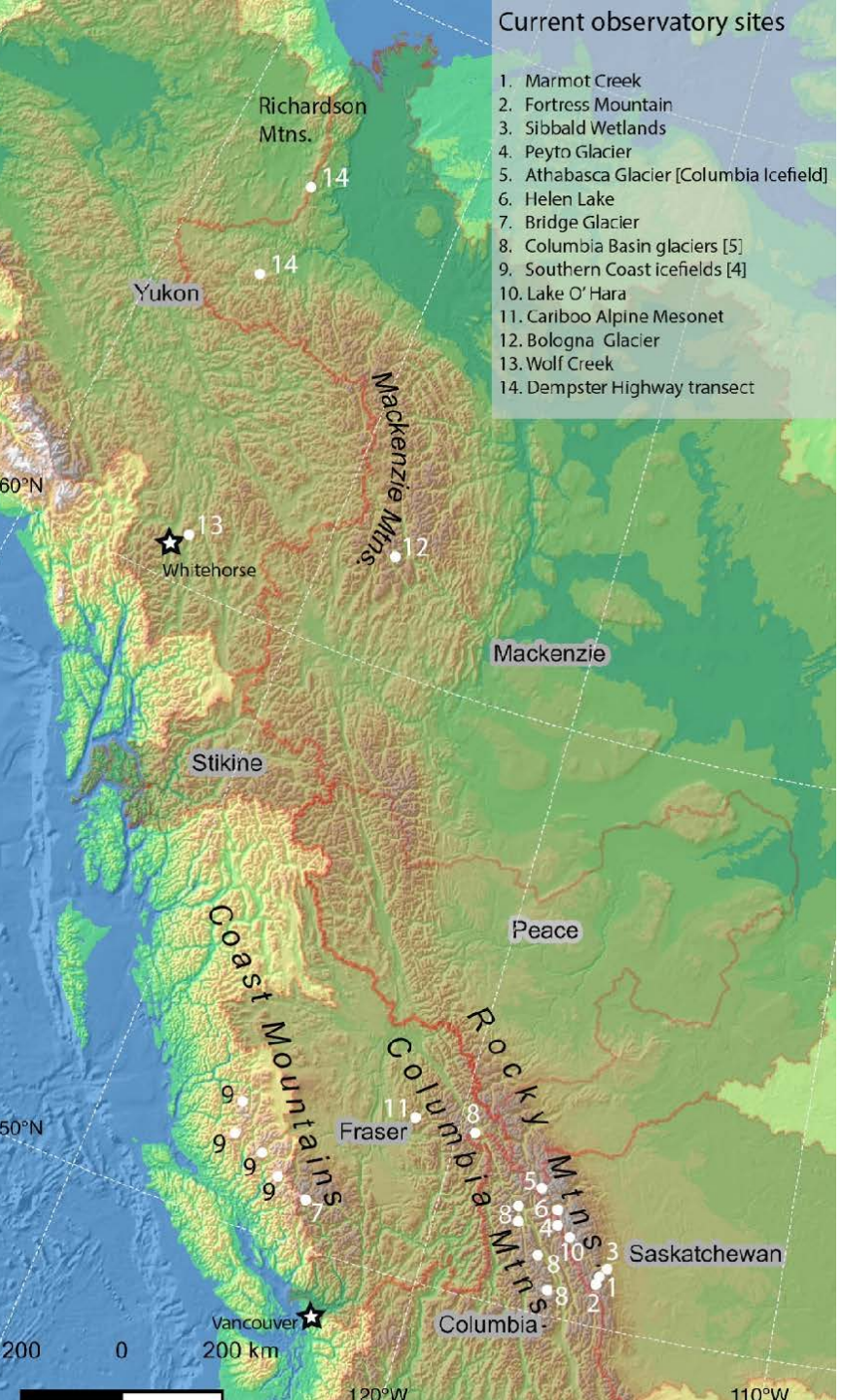


Mountain Water Futures Project Goals

- improve our ability to predict future hydrological regimes, and plan appropriate adaptations in Canada's western mountains
- provide users and stakeholders across a range of sectors with better information, tools and techniques to manage uncertain water futures in Canada's mountain west



Observatories and Investigators



Previous CCRN sites:

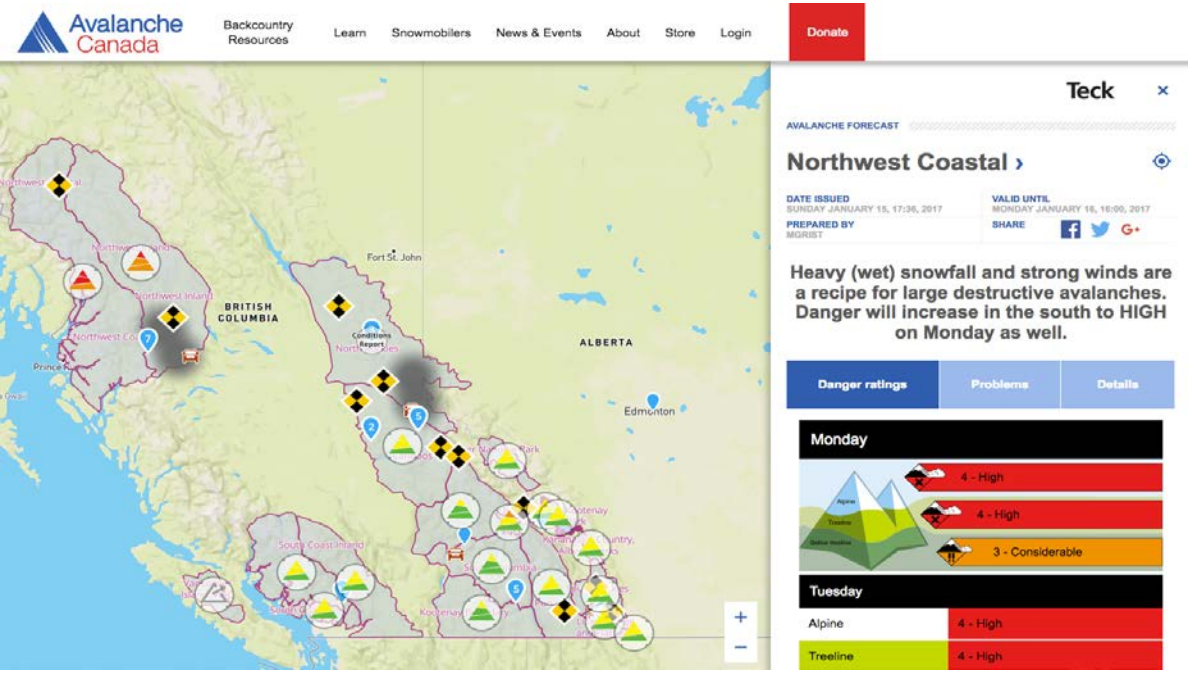
- Peyto Glacier
- Athabasca Glacier
- Marmot Creek
- Fortress Mountain
- Lake O'Hara
- Wolf Creek Research Basin

Additional Sites:

- Sibbald Wetlands
- Helen Lake
- Bridge Glacier
- Columbia Basin Glaciers
- Southern Coast Icefields
- Cariboo Alpine Mesonet
- Bologna Glacier
- Dempster Highway transect

- Dr. Sean Carey (PI), McMaster University
- Dr. Masaki Hayashi (Co-PI) U. of Calgary
- Dr. Brian Menounos (Co-PI) U. Northern BC
- Dr. Stephan Déry, U. Northern BC
- Dr. Jeffrey McKenzie, McGill University
- Dr. Richard Petrone, University of Waterloo
- Dr. John Pomeroy, U. of Saskatchewan
- Dr. Rebecca Rooney, University of Waterloo
- Dr. Ronald Stewart, University of Manitoba
- Dr. Julie Thériault, UQAM
- Dr. Cherie Westbrook, U. of Saskatchewan
- Dr. Francis Zweirs, U. Victoria, PCIC

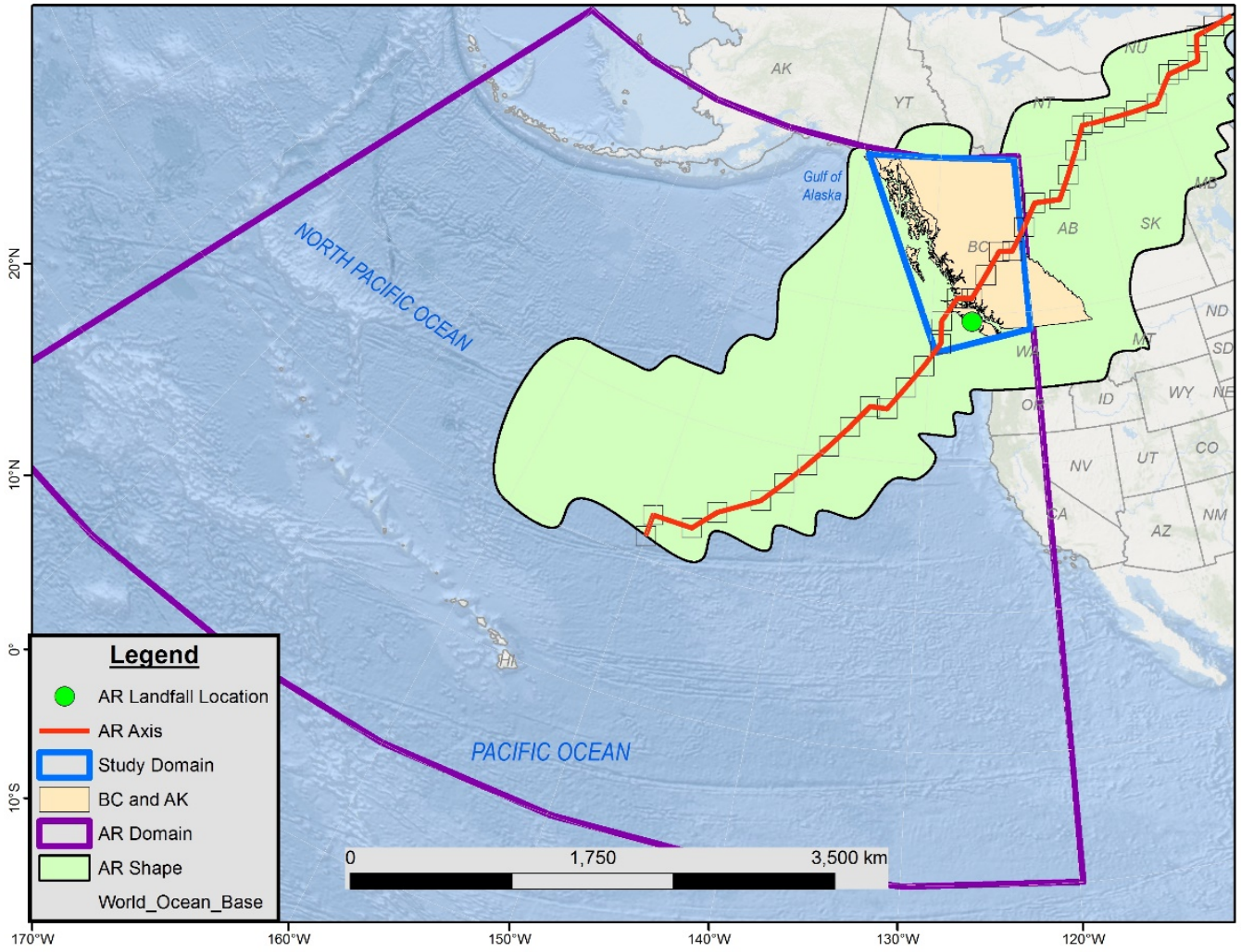
Mountain Climate and Extremes



Material from S. Dery

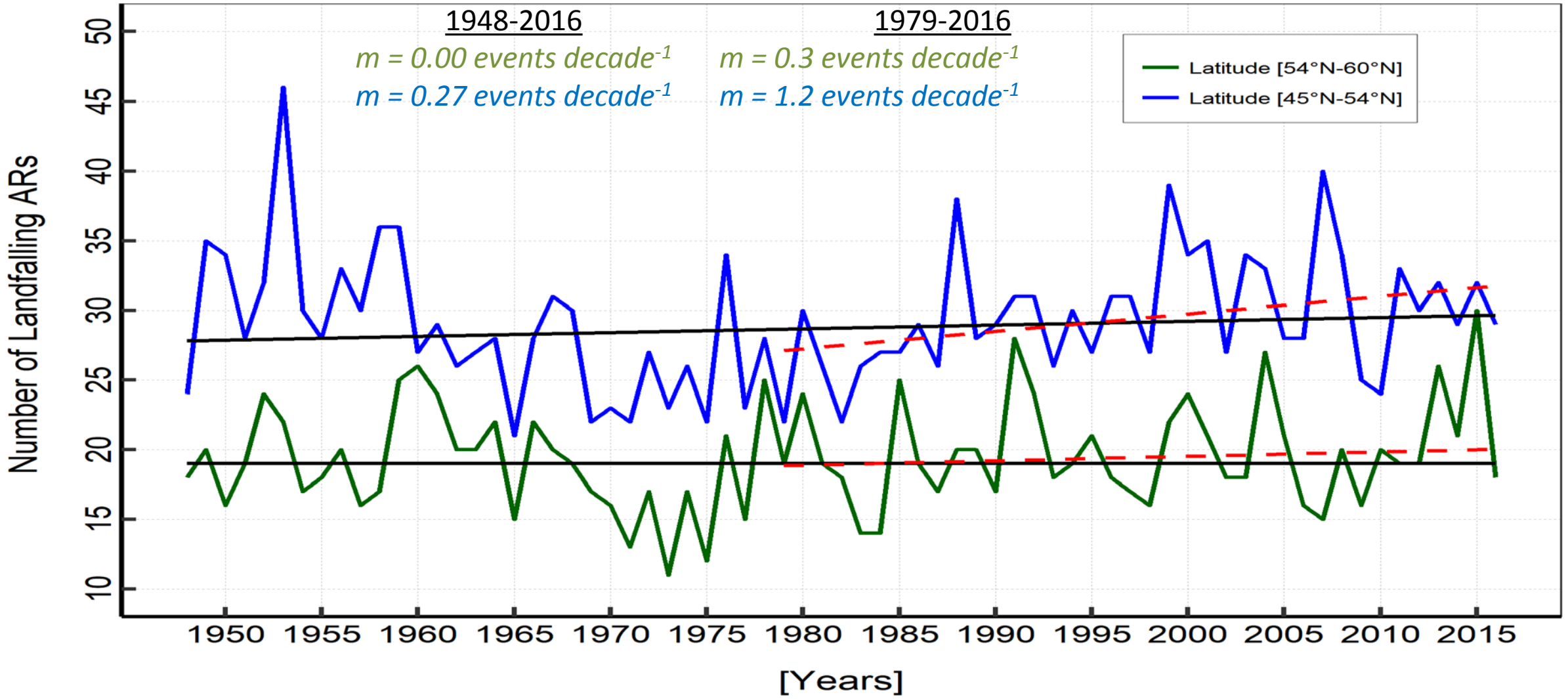
Mountain Climate and Extremes

- What is the influence and role of atmospheric rivers
- How much precipitation occurs and at what phase
- How does this all influence flow regimes over longer and shorter scales.



Material from S. Déry

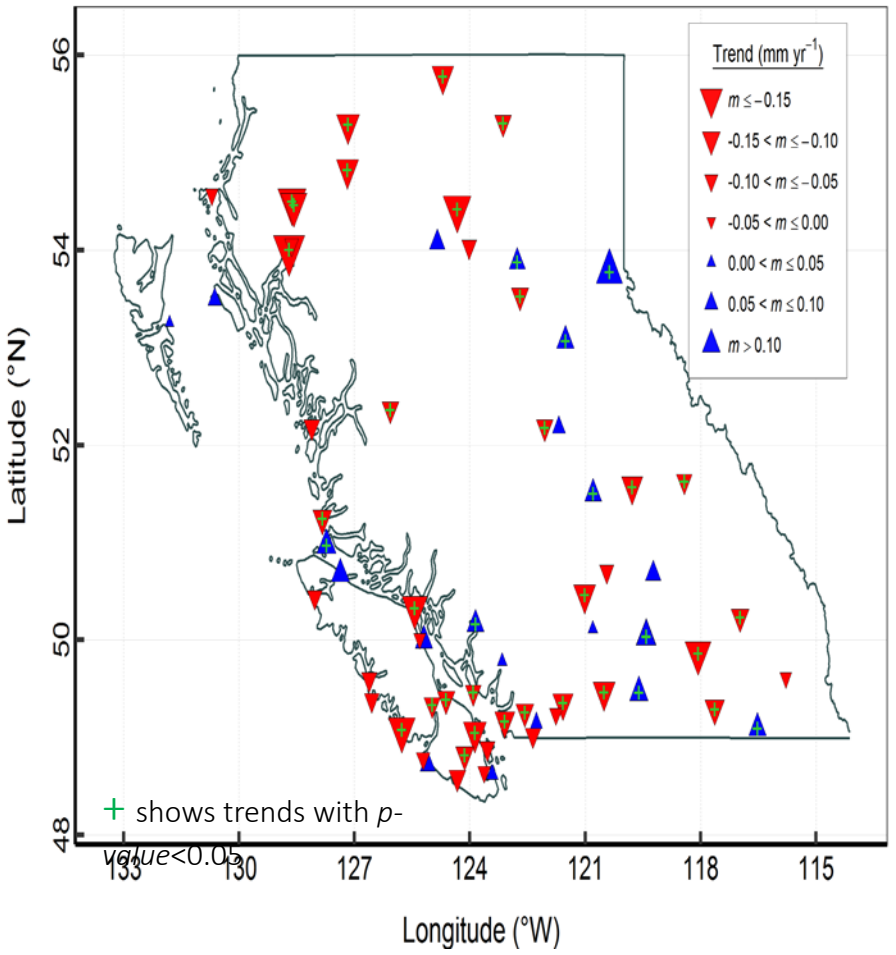
Landfall of Atmospheric River Trends



Long-term (1948-2016) and short-term (1979-2016) trends on landfalling ARs in BC

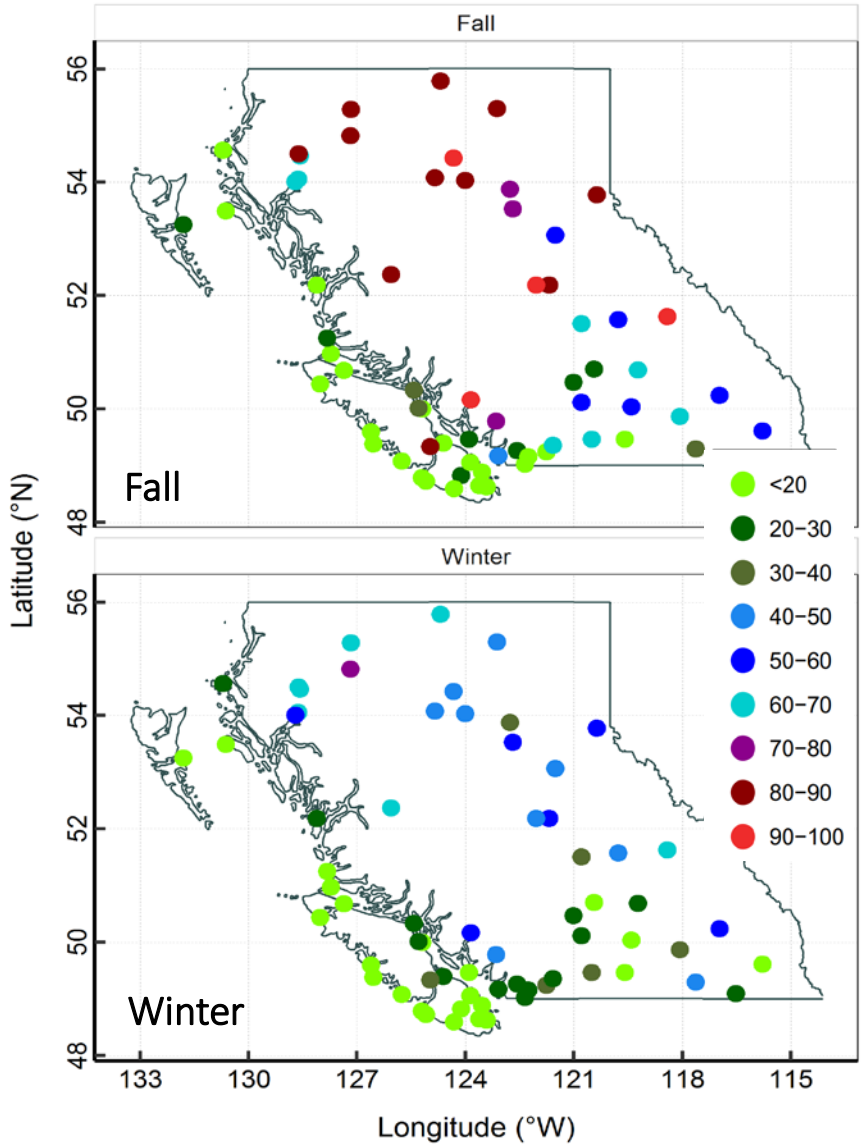
Material from S. Déry

Atmospheric Rivers and Extreme Snowfall



Normalized 3-day extreme snowfall shows significantly increasing trend at higher elevations, no trend at mid-elevations, and declining trend at lower elevations

ARs contribute on average 34% of 3-day extreme snowfall accumulations each year



Material from S. Déry

Temperature Changes

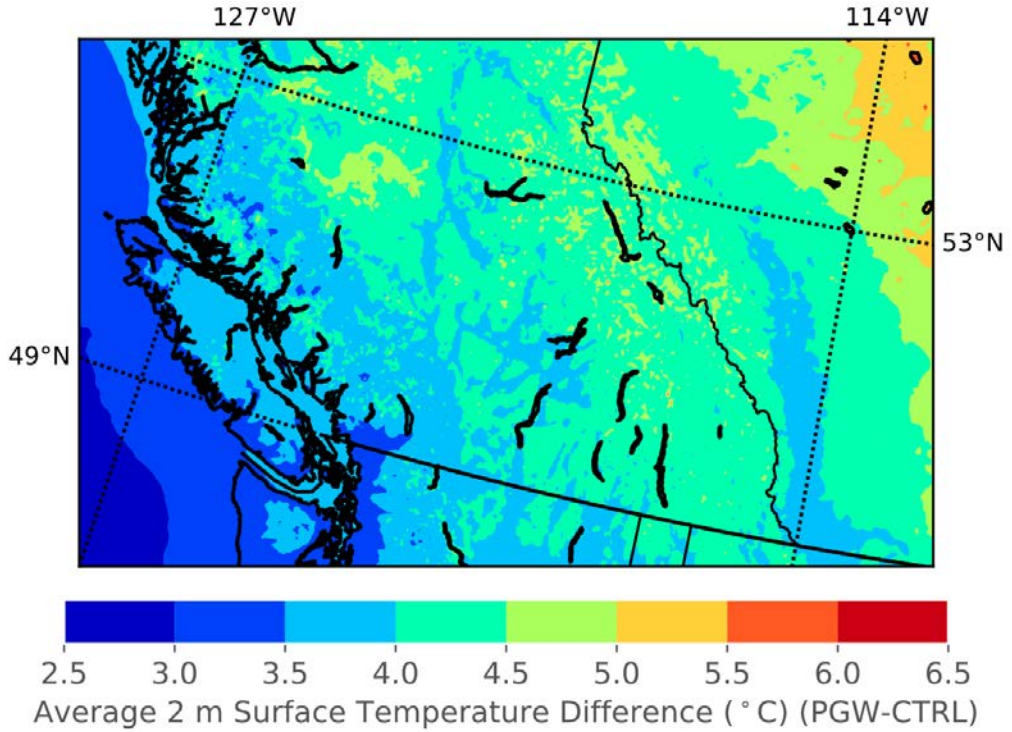
~Average 2 m temperatures during 4-month period and over study region

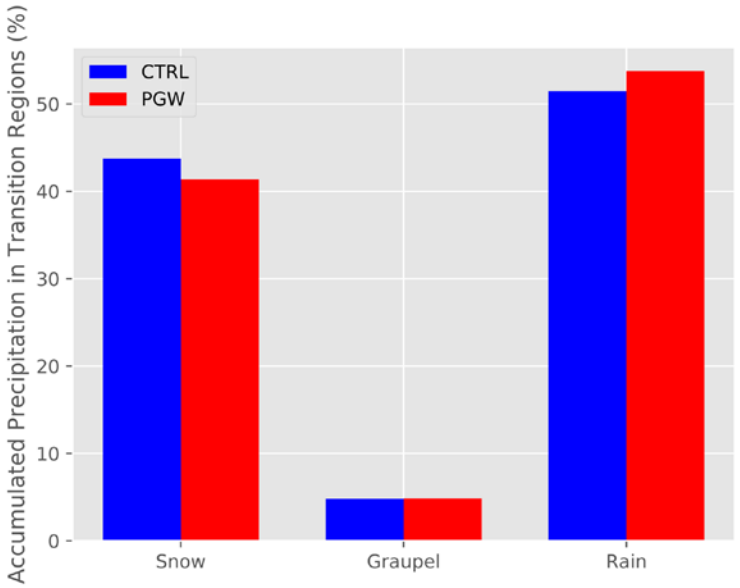
-1.3°C (CTRL)

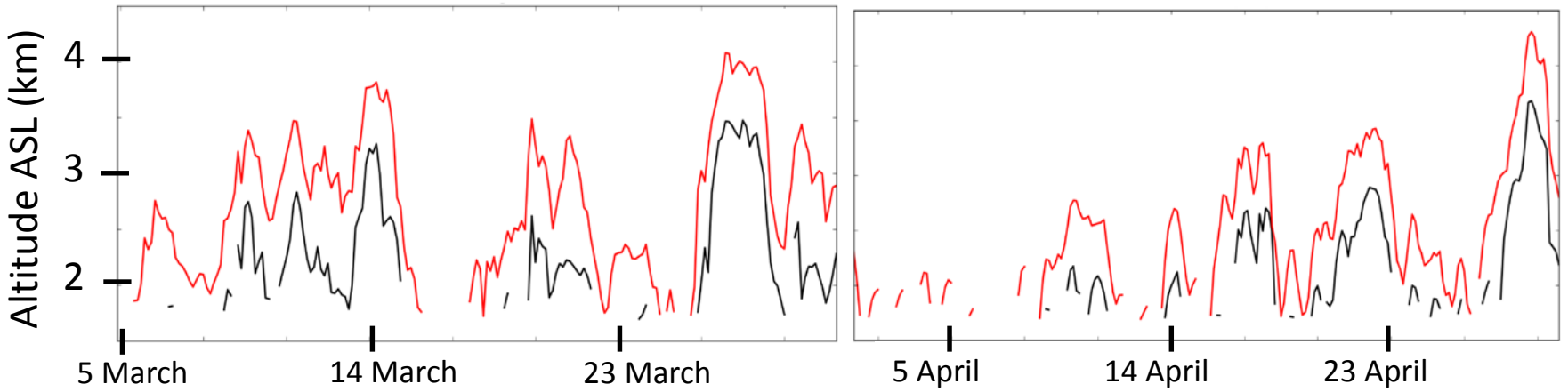
2.8°C (PGW)

~Difference (PGW-CTRL) 4°C

~Regional variation







WRF historical (2015) WRF-Pseudo Global Warming

Material from R. Stewart and J. Thériault

This really matters to me….

Ski resorts over western Canada are a major economic driver to alpine towns (Nicholson 2016)

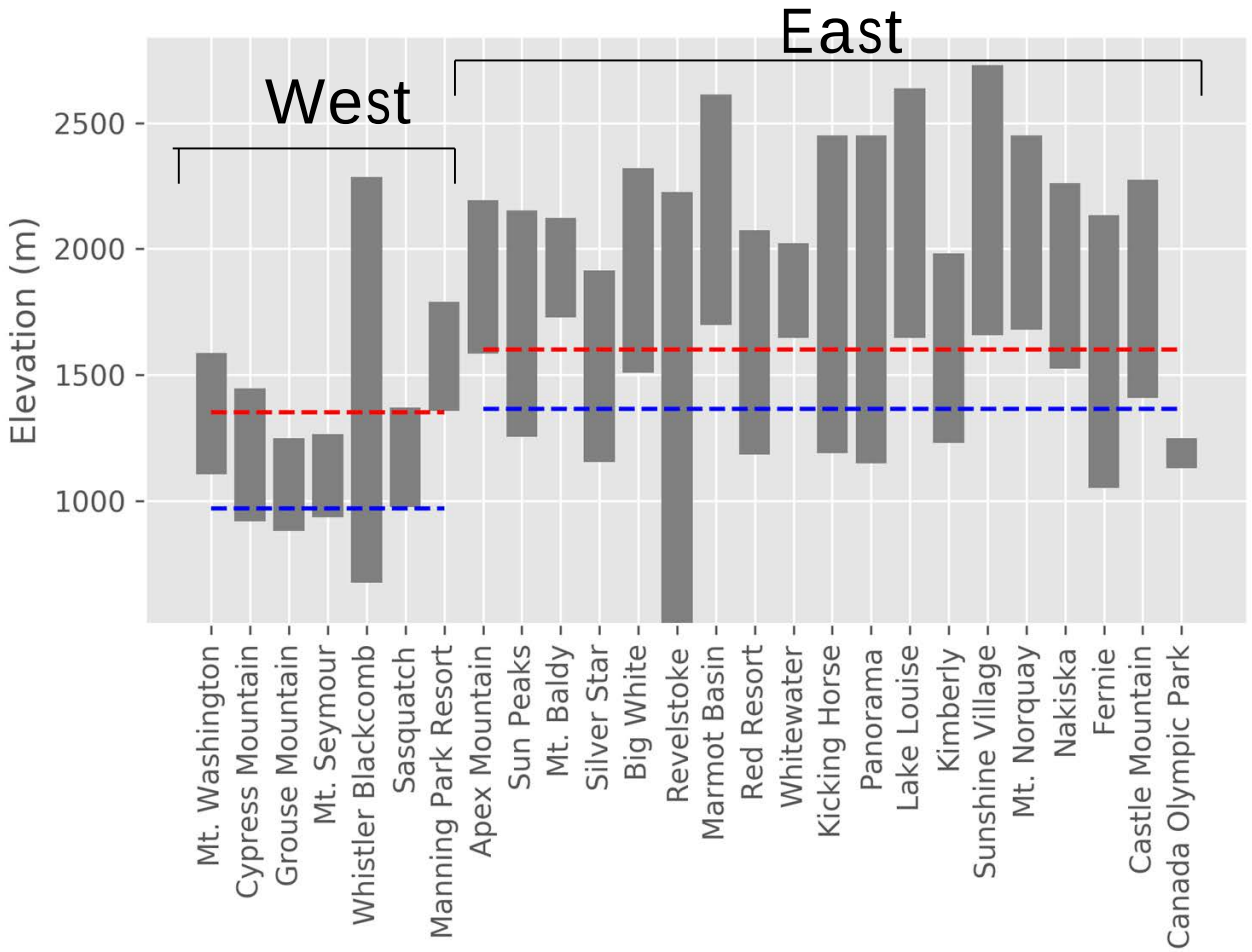
- $790 million
- 8.4 million visitors

Western domain

- 971 ± 380 m (CTRL)
- 1,351 ± 400 m(PGW)

Eastern domain

- 1,365 ± 346 m (CTRL)
- 1,600 ± 326 m (PGW)

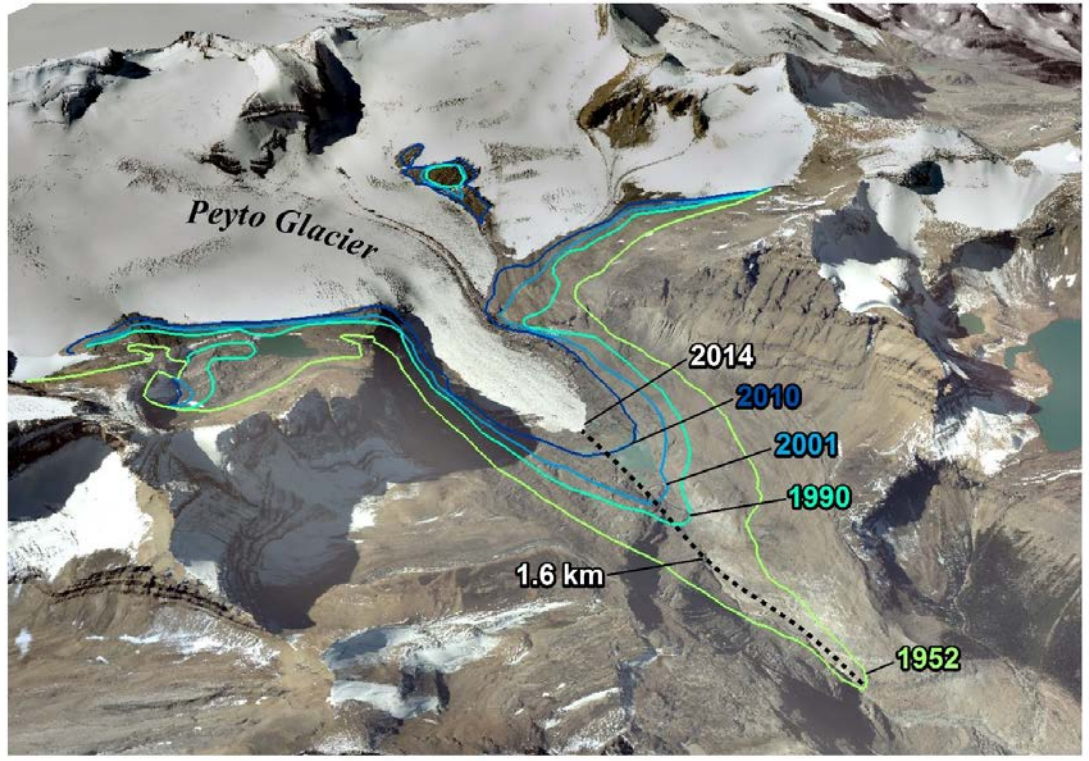


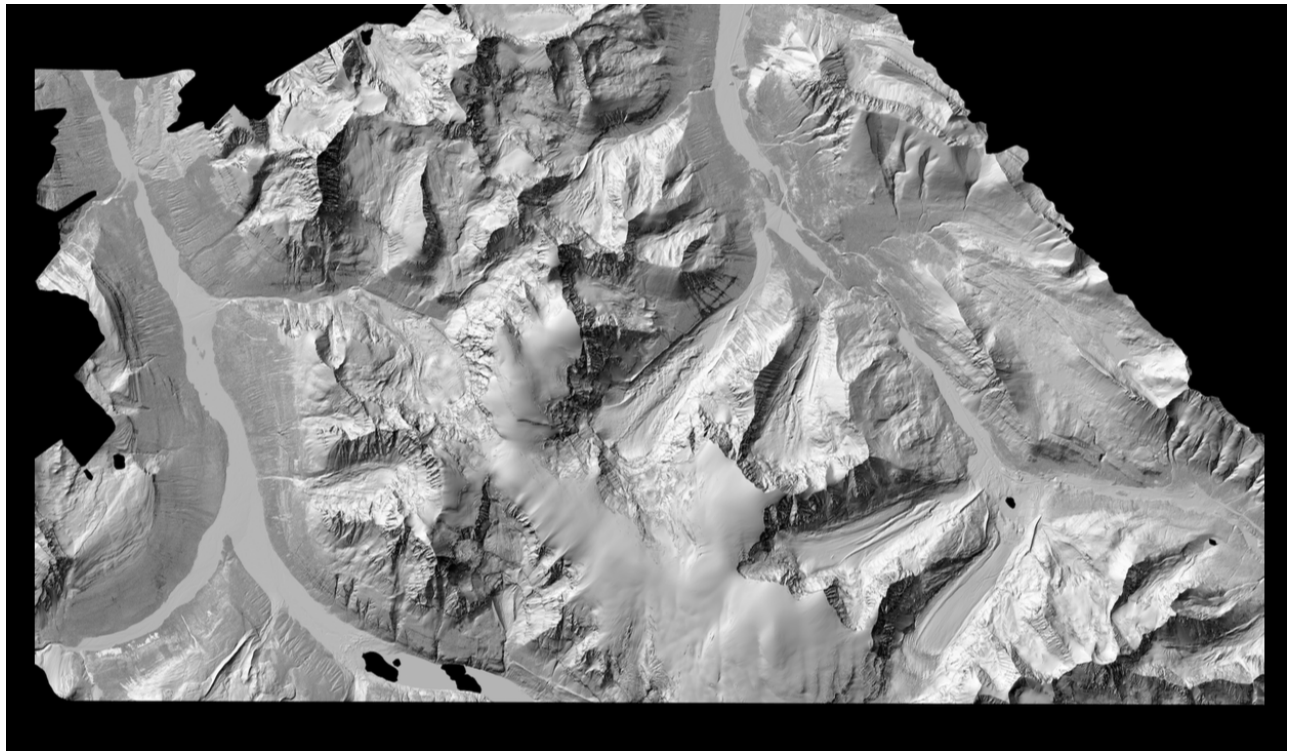
Elevation ranges from the ski resort base to the mountain summit. Dashed blue lines represent CTRL. Dashed red lines represent PGW.

Material from R. Stewart

Glacier Inventory and Change

How do we continue to build glacier mass balance, volume, and related data required to properly initialize and evaluate glacier mass balance and dynamics models that we are coupling to our hydrologic models? Is it possible to develop long-term data resources that can be used to evaluate model simulations of changes in mass balance and volume, and its implications for stream flow and stream temperature?

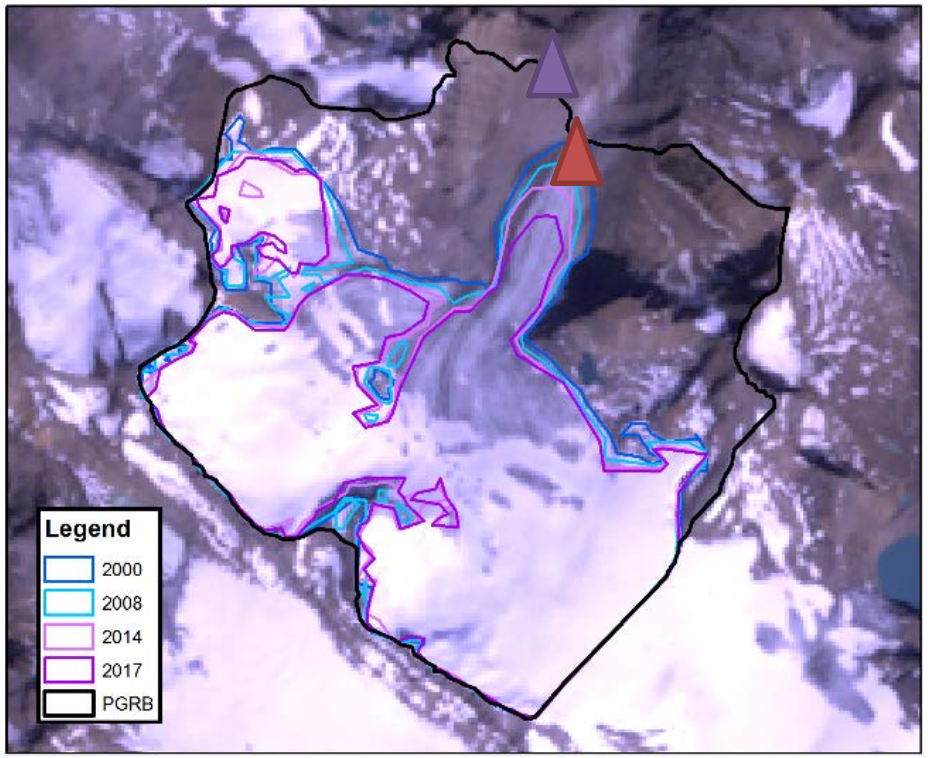


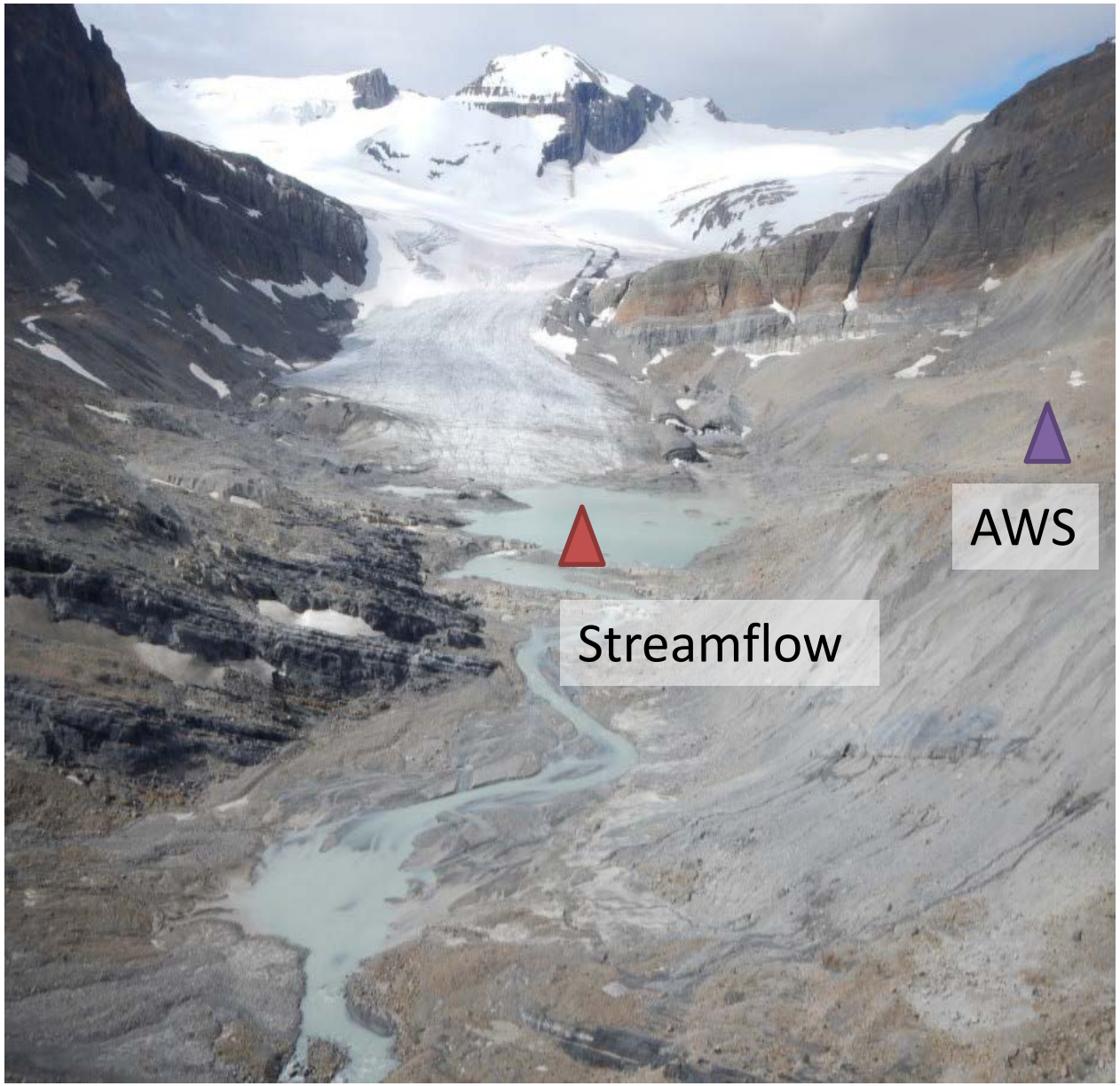


Material from B. Menounos

Peyto Glacier

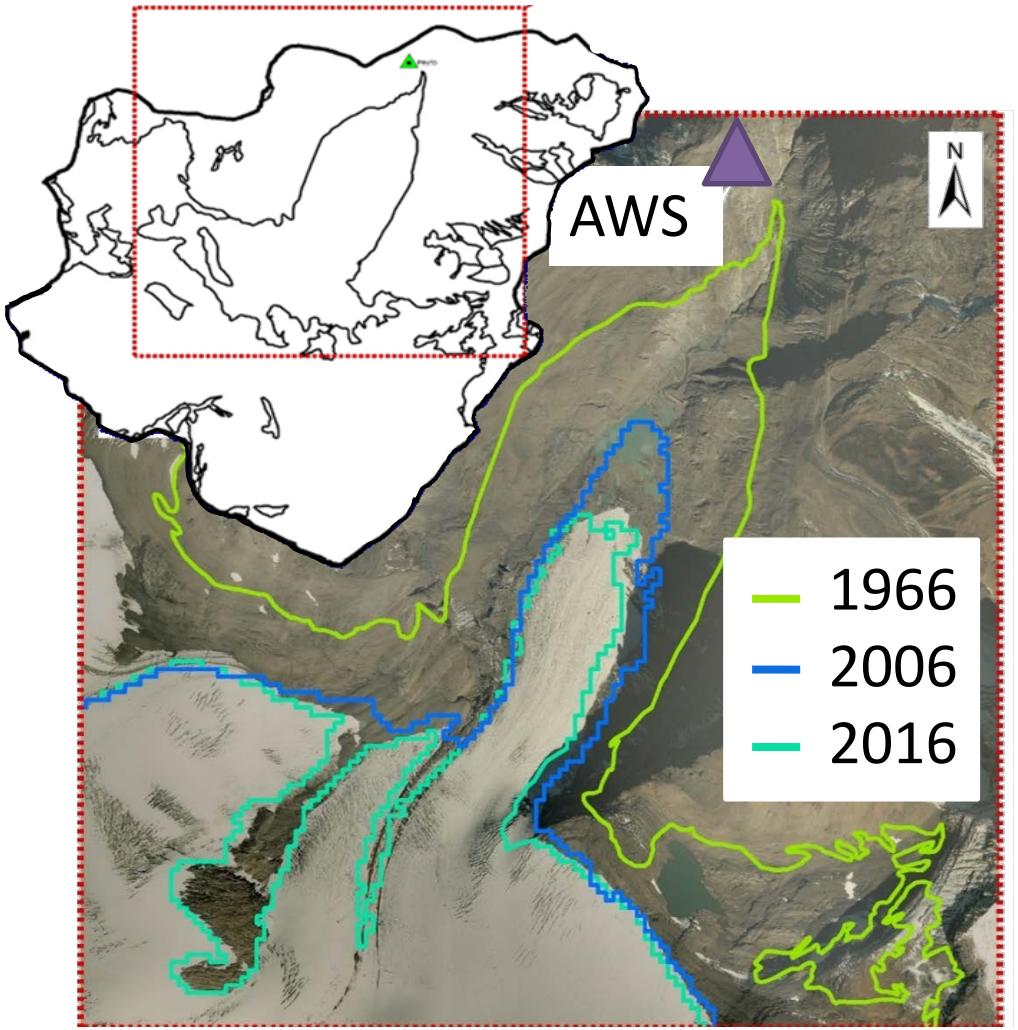
- 2100 - 3190 m a.s.l.
- AWS with T, RH, U, radiation budget
- Streamflow at outlet





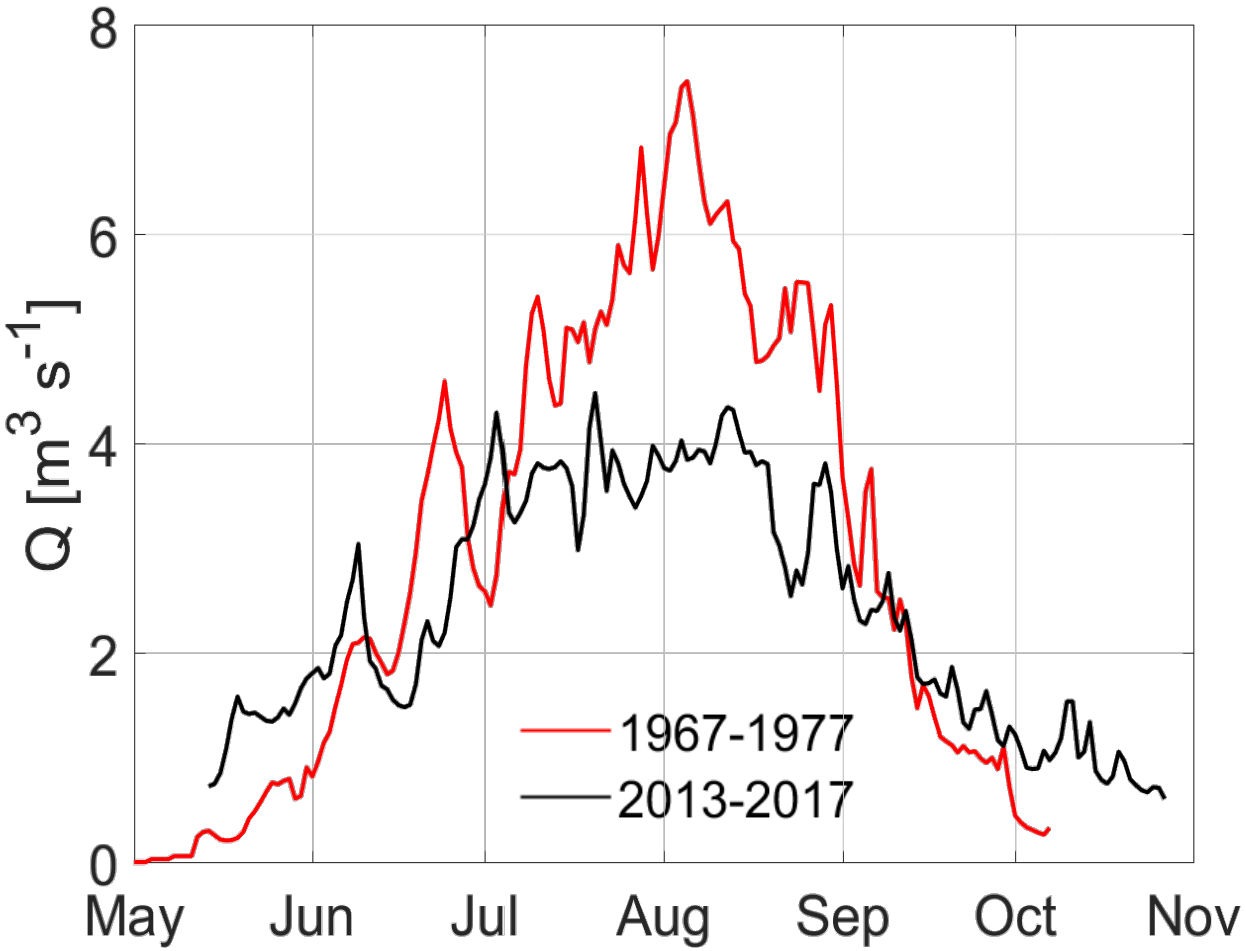
Material from J. Pomeroy

Historical Retreat and Runoff



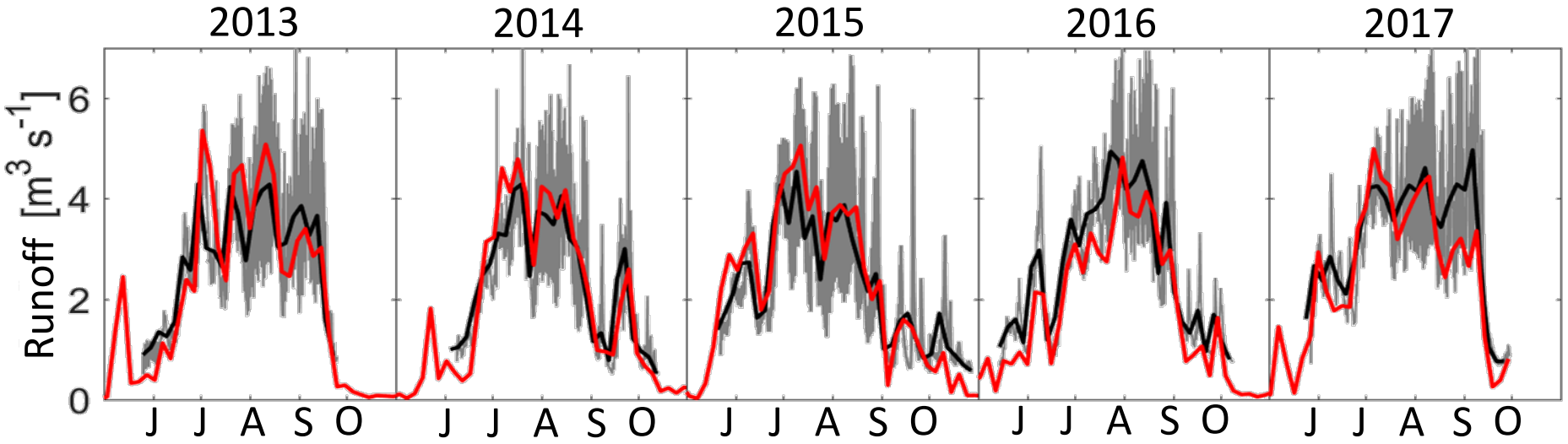
1966: 14.4 km^2

2016: 9.9 km^2



Material from J. Pomeroy

Understanding and Modelling Change



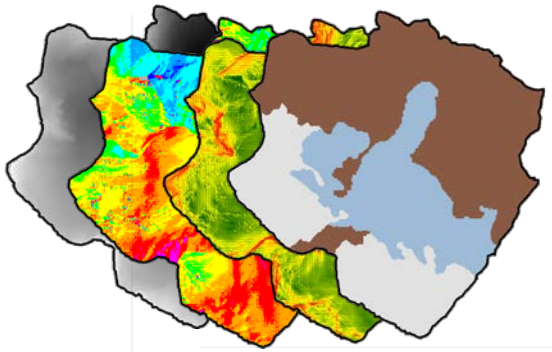
Runoff
Measured
Model

RMSE = 1.00
r = 0.75

Cold Region Hydrological Modelling Platform (CRHM)

Basin

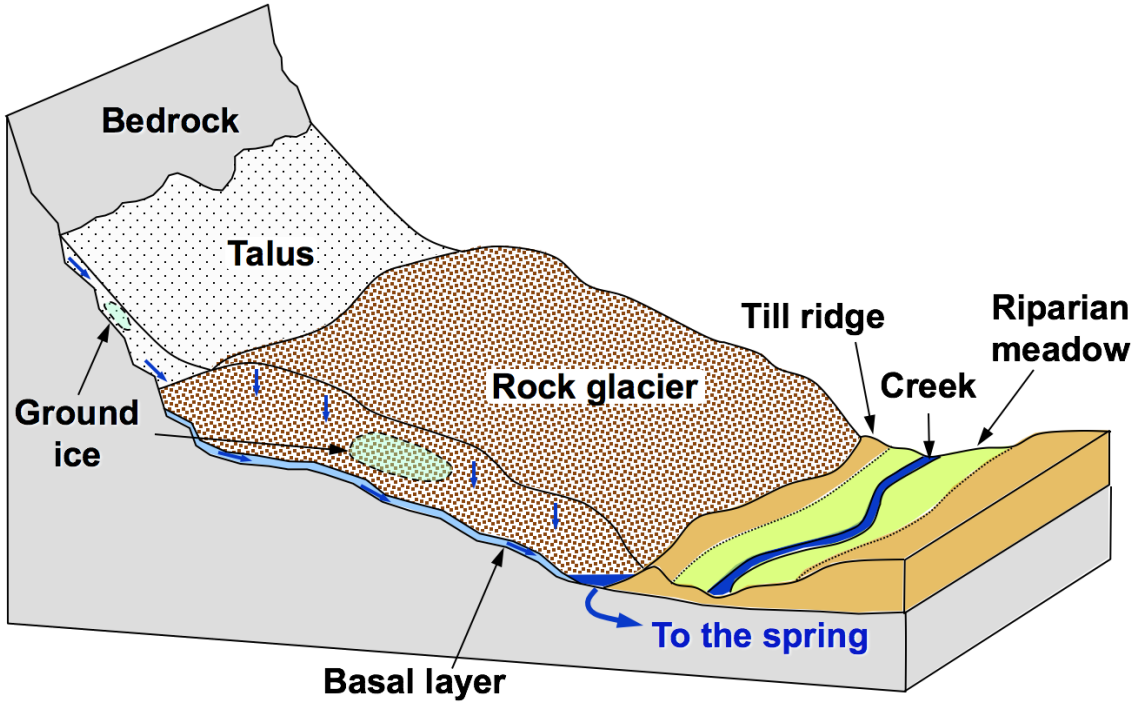
Elevation, slope, aspect, land cover



Hydrological Response Unit

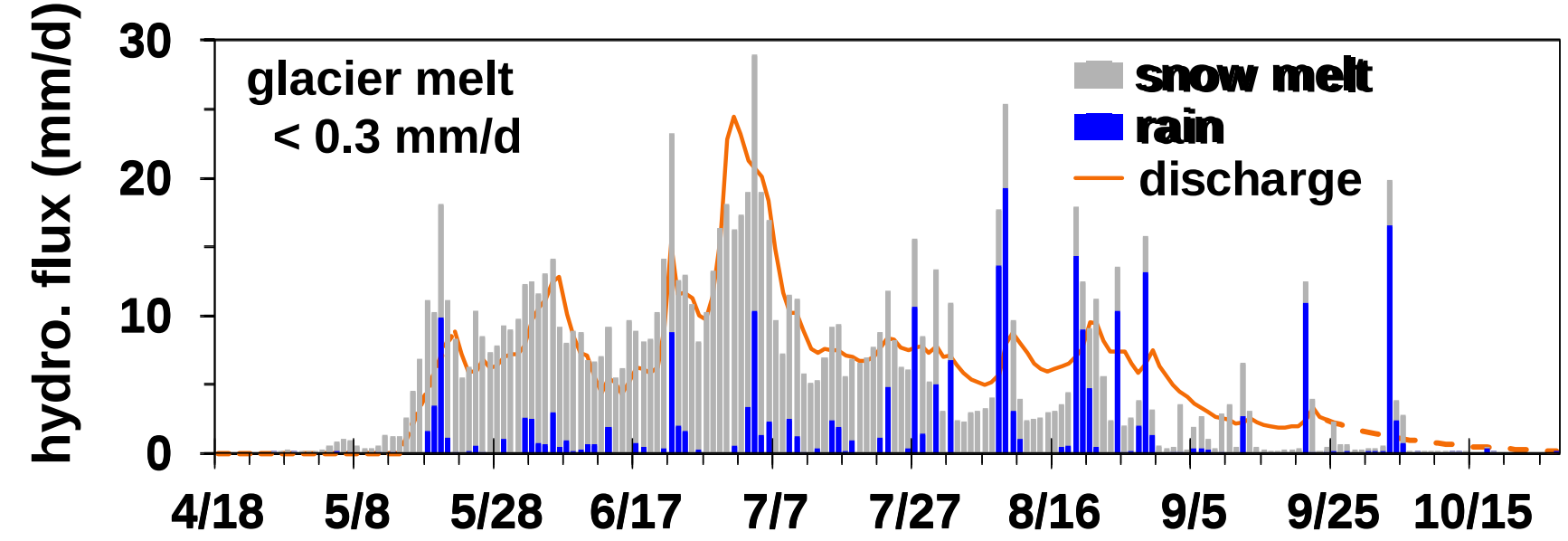
Material from J. Pomeroy

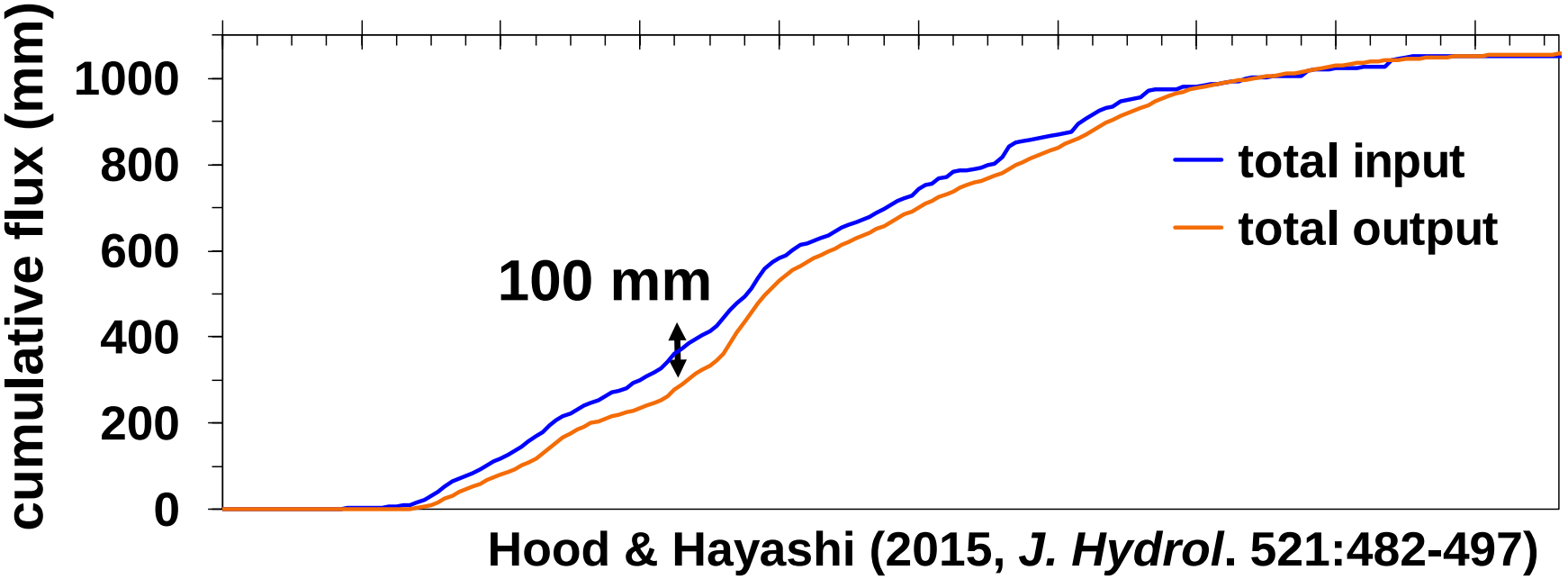
Groundwater and Surface Waters



Material from M. Hayashi

Opabin Basin Water Balance (2008)





Hood & Hayashi (2015, *J. Hydrol*. 521:482-497)

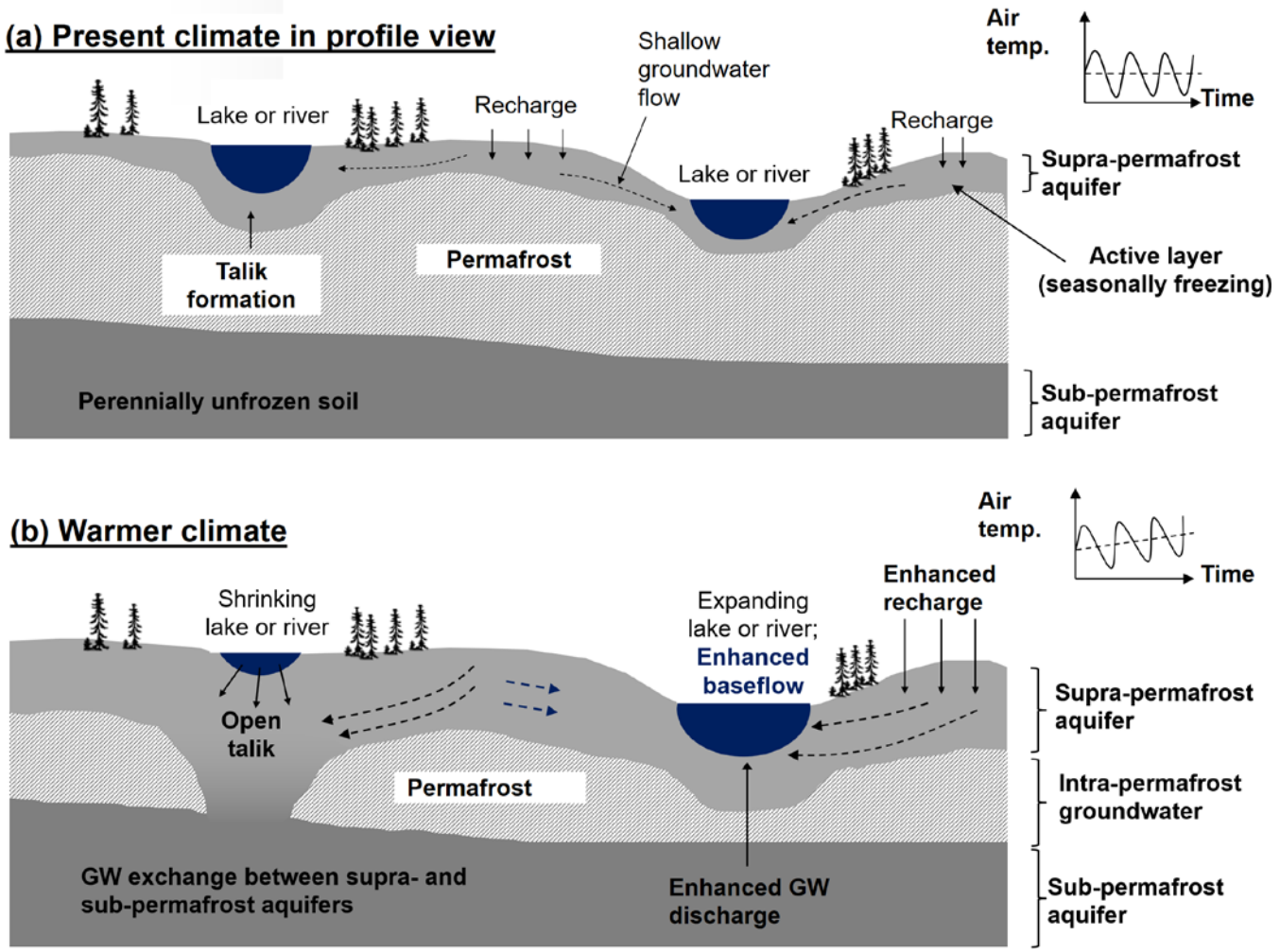
Material from M. Hayashi

Groundwater in ‘cold’ Mountains with permafrost

Little known about permafrost in mountain basins

Material from J. McKenzie

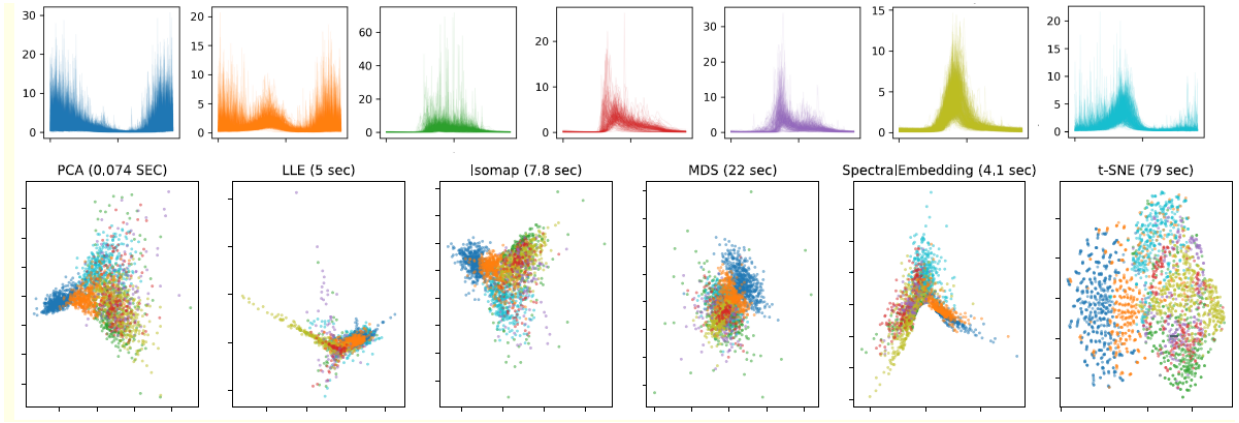
Most conceptual models for ‘flatter’ areas

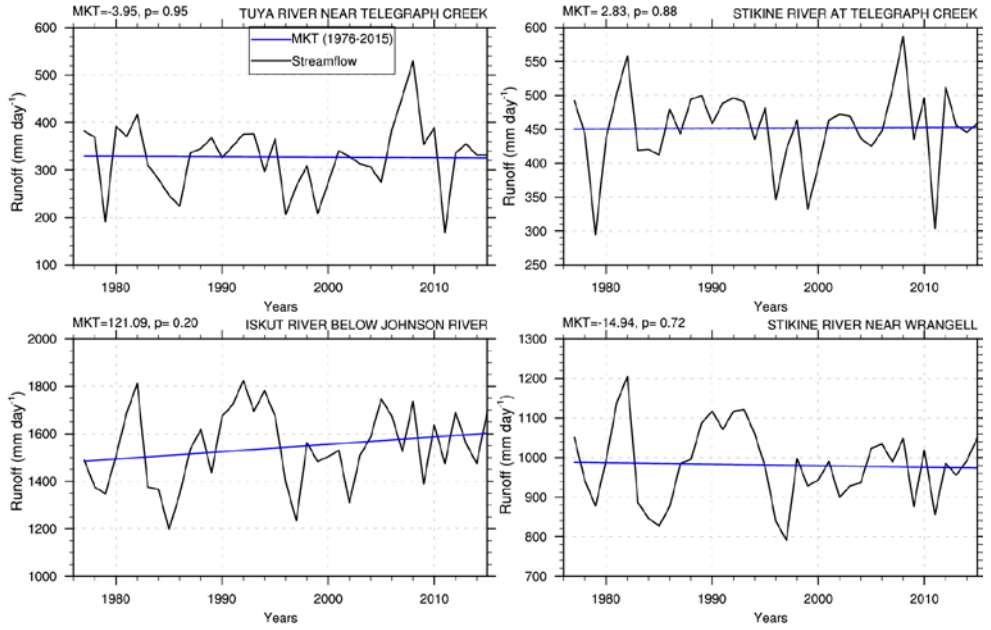


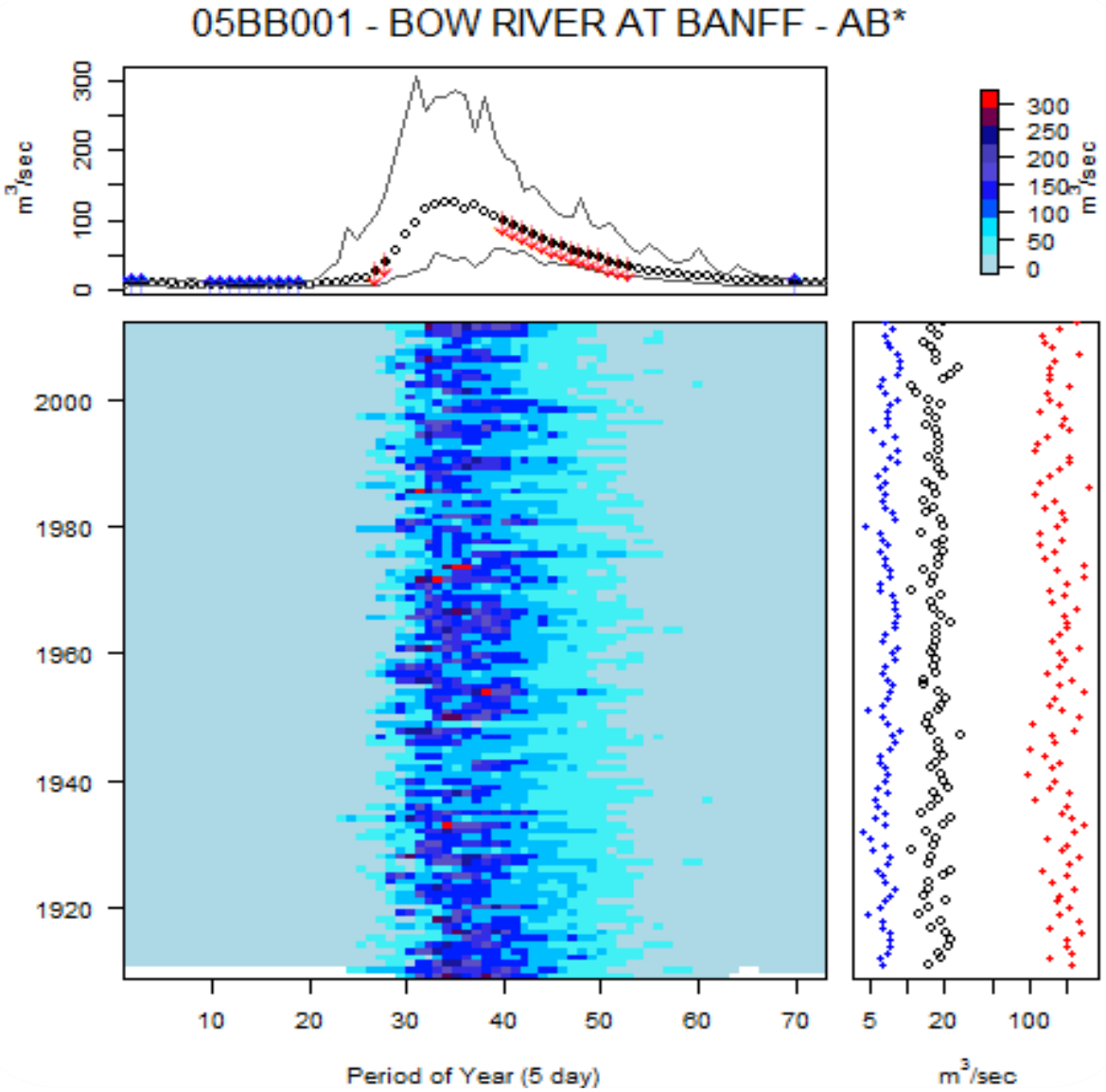
(Walvoord & Kurylyk, 2016)

Material from J. McKenzie

The ultimate streamflow impacts of all this

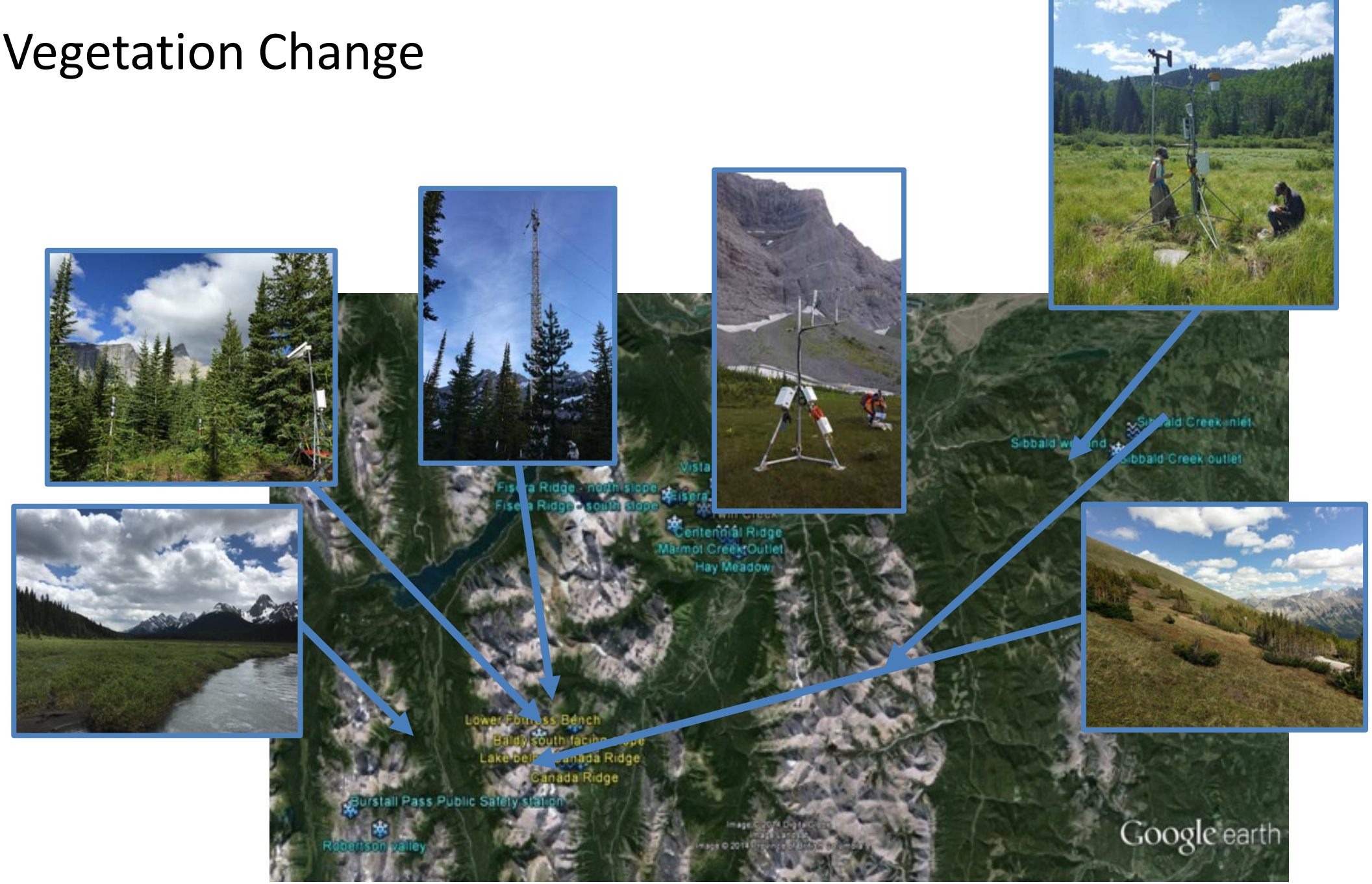






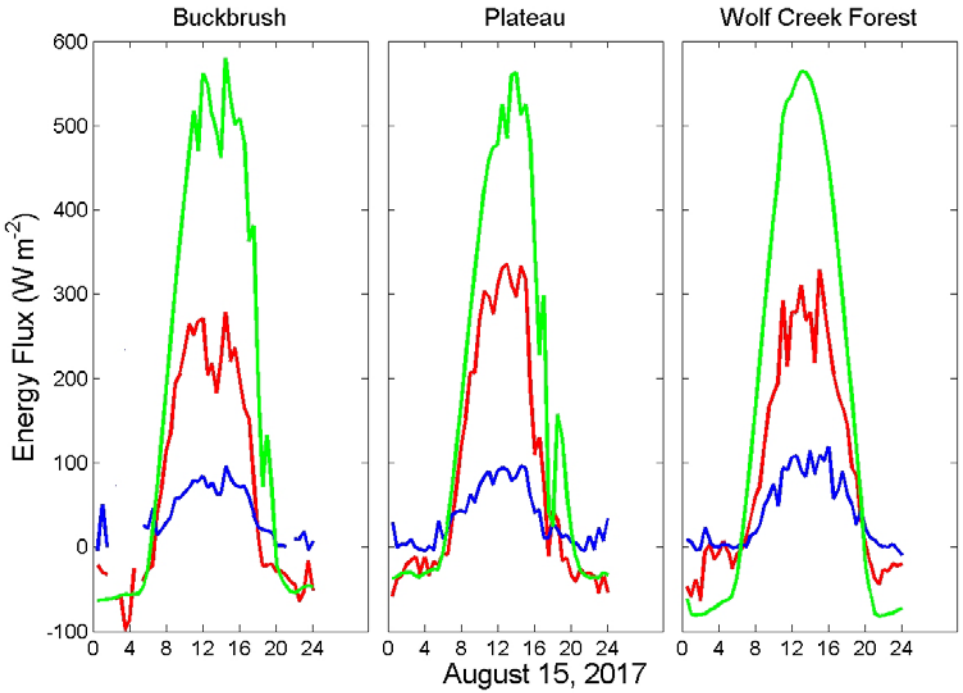
Material from W. Tang, P. Whitfield, S. Dery

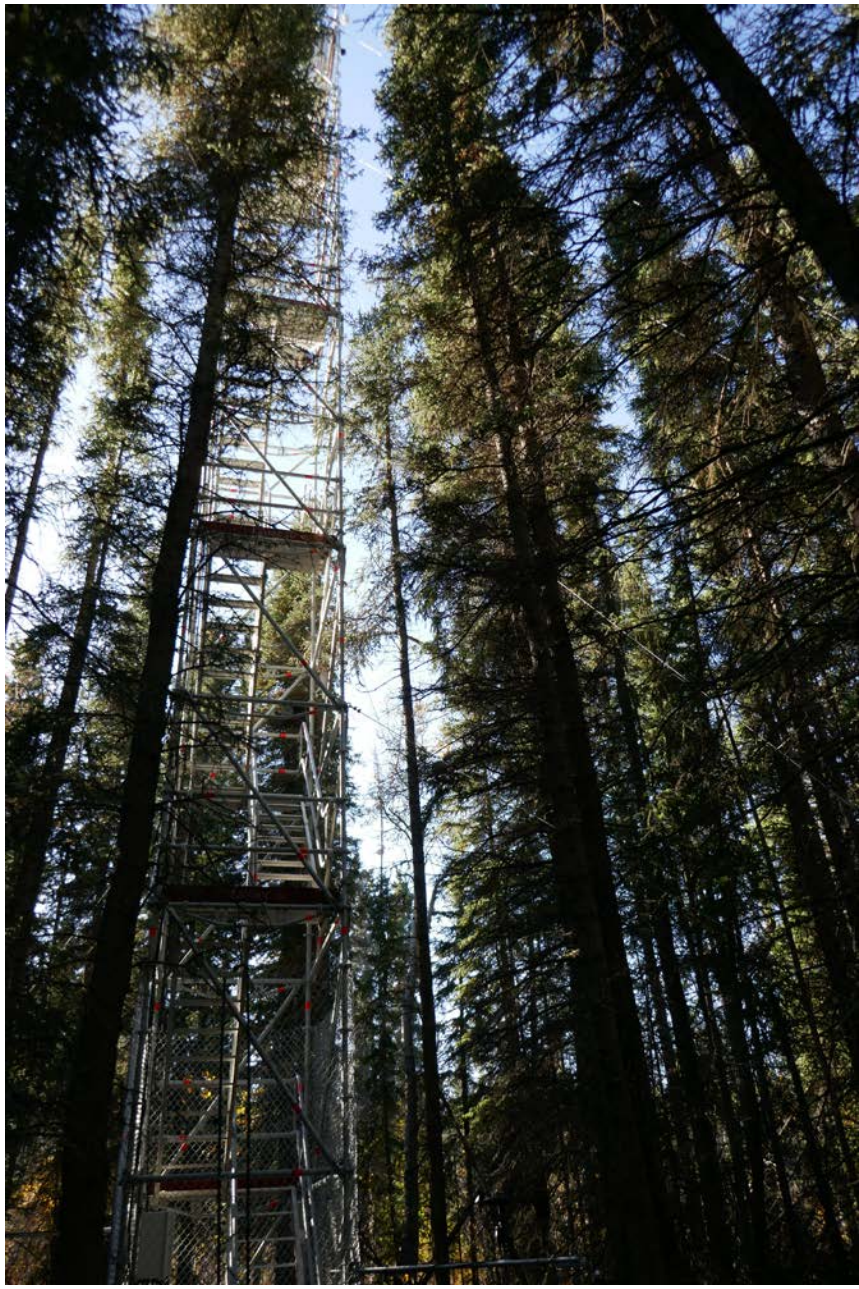
Vegetation Change



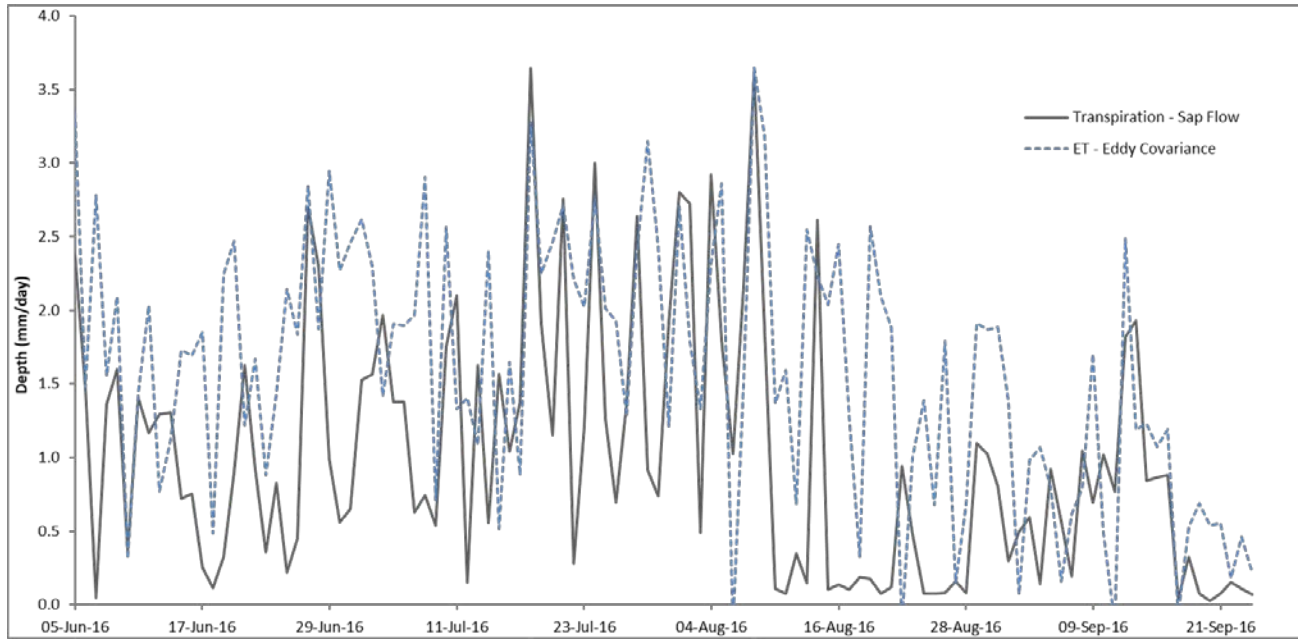
Material from R. Petrone

Vegetation Change

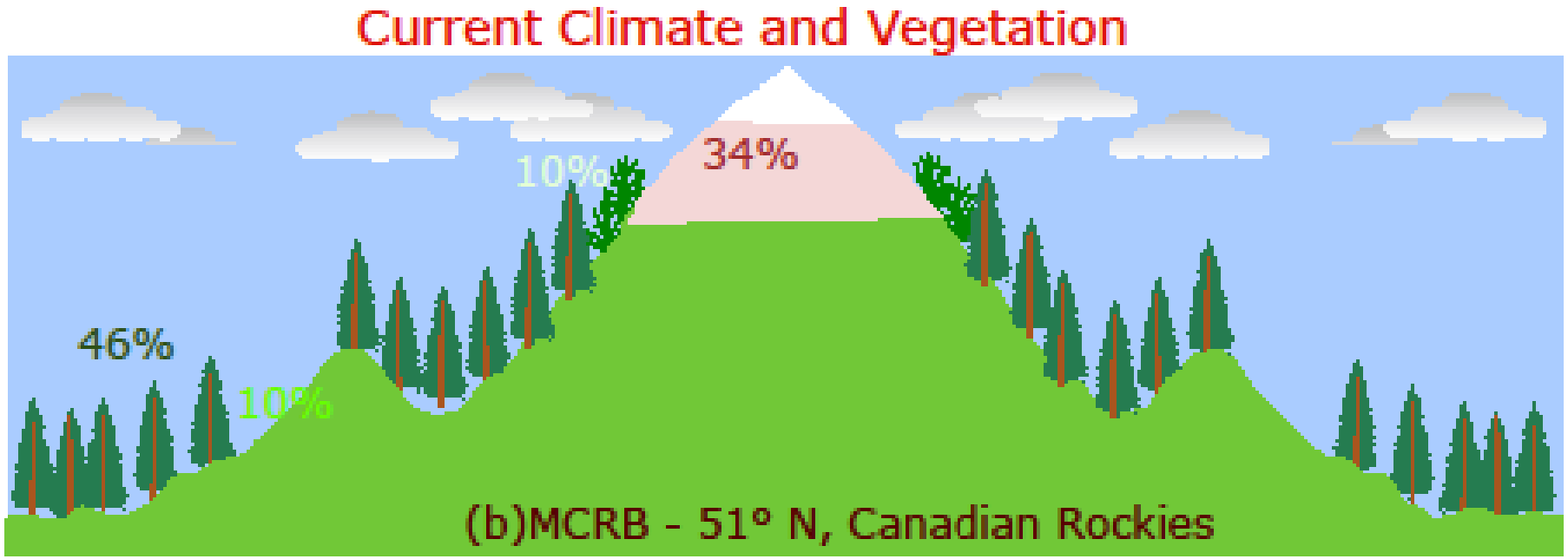


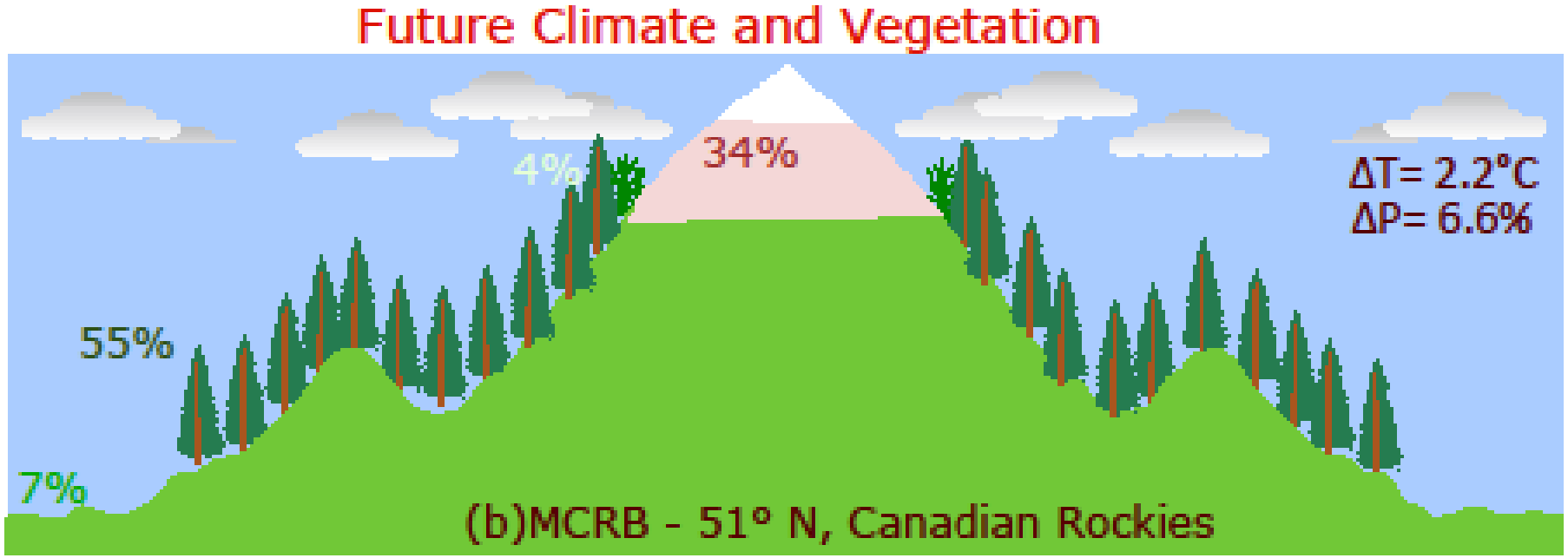


Specific Role of Vegetation and Species



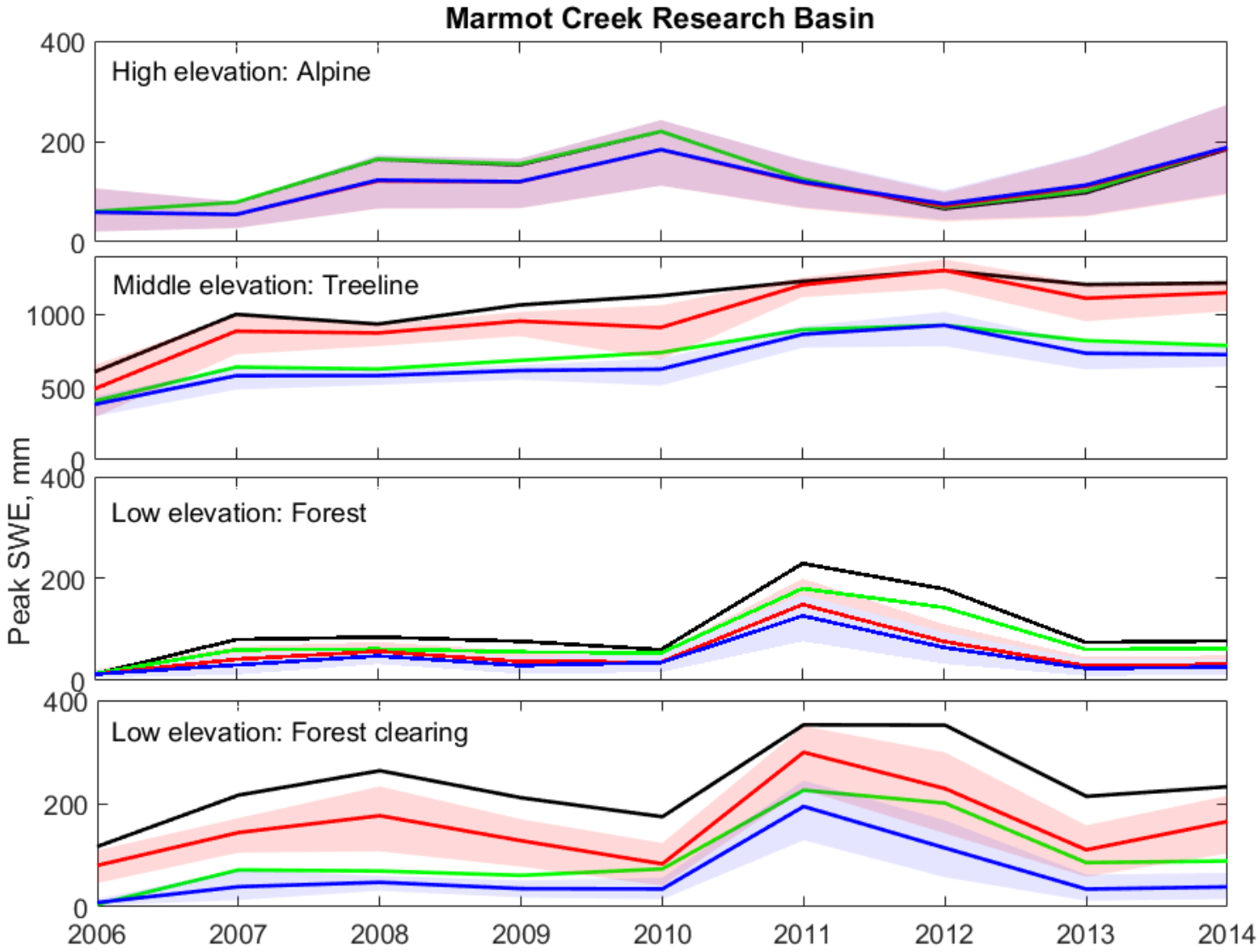
Simulating the effects of vegetation and climate change





Material from J. Pomeroy

Impacts of climate and vegetation changes and uncertainty



Baseline observations

Perturbations: Climate change Vegetation change Both vegetation & climate changes

Material from J. Pomeroy

Wetlands

What is the eco-hydrological function of alpine wetlands, including ‘emergent’ wetlands following glacial retreat?

- Wetlands have considerable assets from an ecosystem services perspective:
  - Mitigate downstream effects of extreme precipitation through water retention & reduced flow velocity
  - Provide water back to ecosystems during periods of drought
  - Critical wildlife habitat
  - Improve water quality
  - Viable cost alternative to built infrastructure (e.g. levees, bypasses)

Material from R. Petrone

Wetlands

- Establish the basic eco-hydrological function of alpine wetlands
  - How this function varies among wetland types across an elevation gradient
- Assess their overall hydrological role in the changing mountain environment → interactions with ecology
- Determine the role of upslope hydrological processes, and importance of surrounding forests in regulating ET losses
- Implications for responses to landscape and climatic disturbances

Material from R. Petrone

Thank You.