Water in the Columbia, Effects of Climate Change and Glacial Recession

IP3
Improved Processes & Parameterisation for Prediction in Cold Regions

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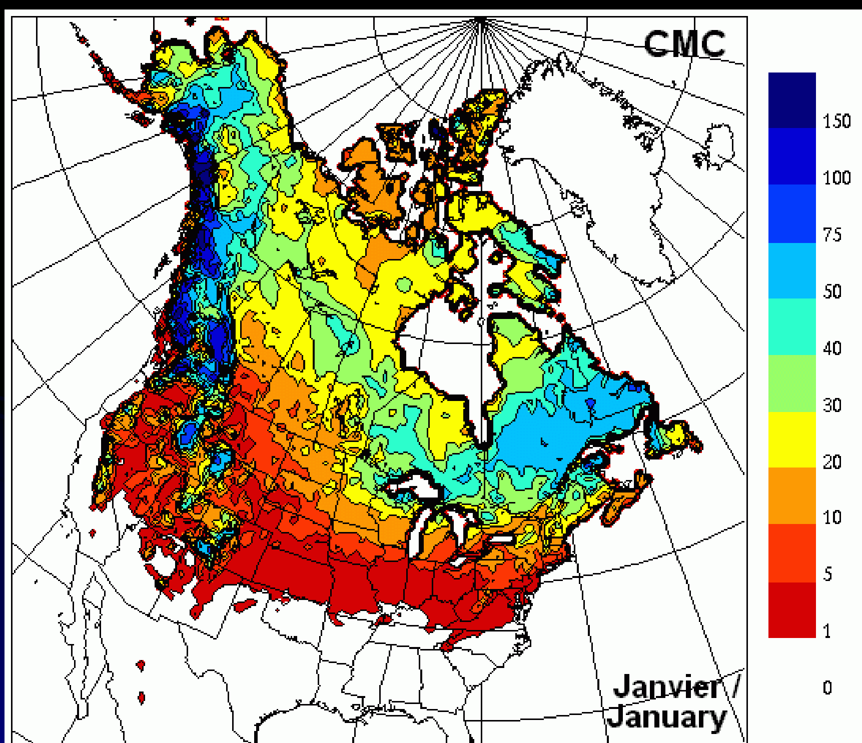
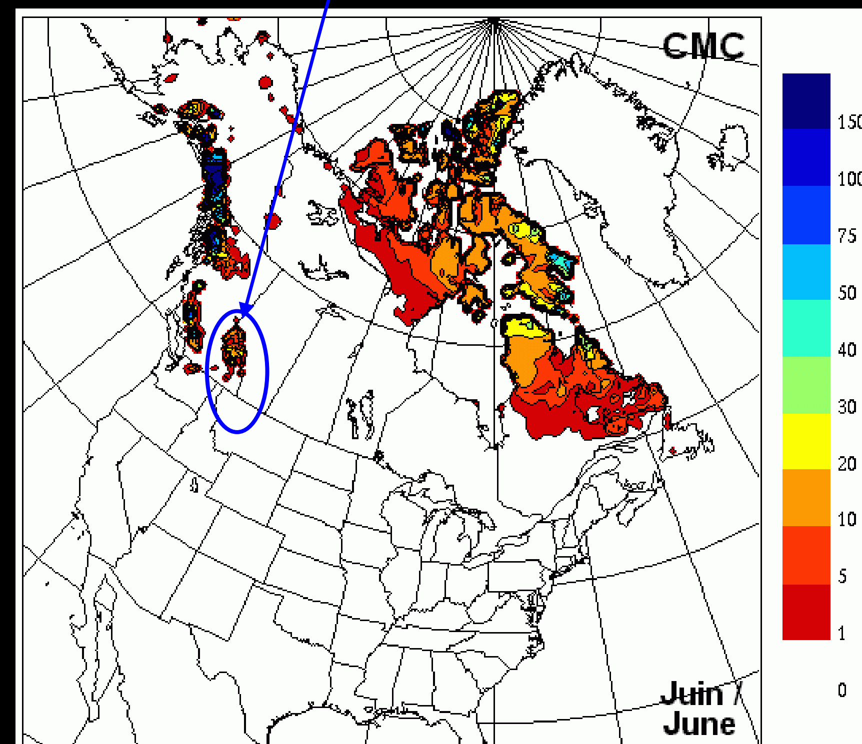
Columbia Basin Snow and Ice

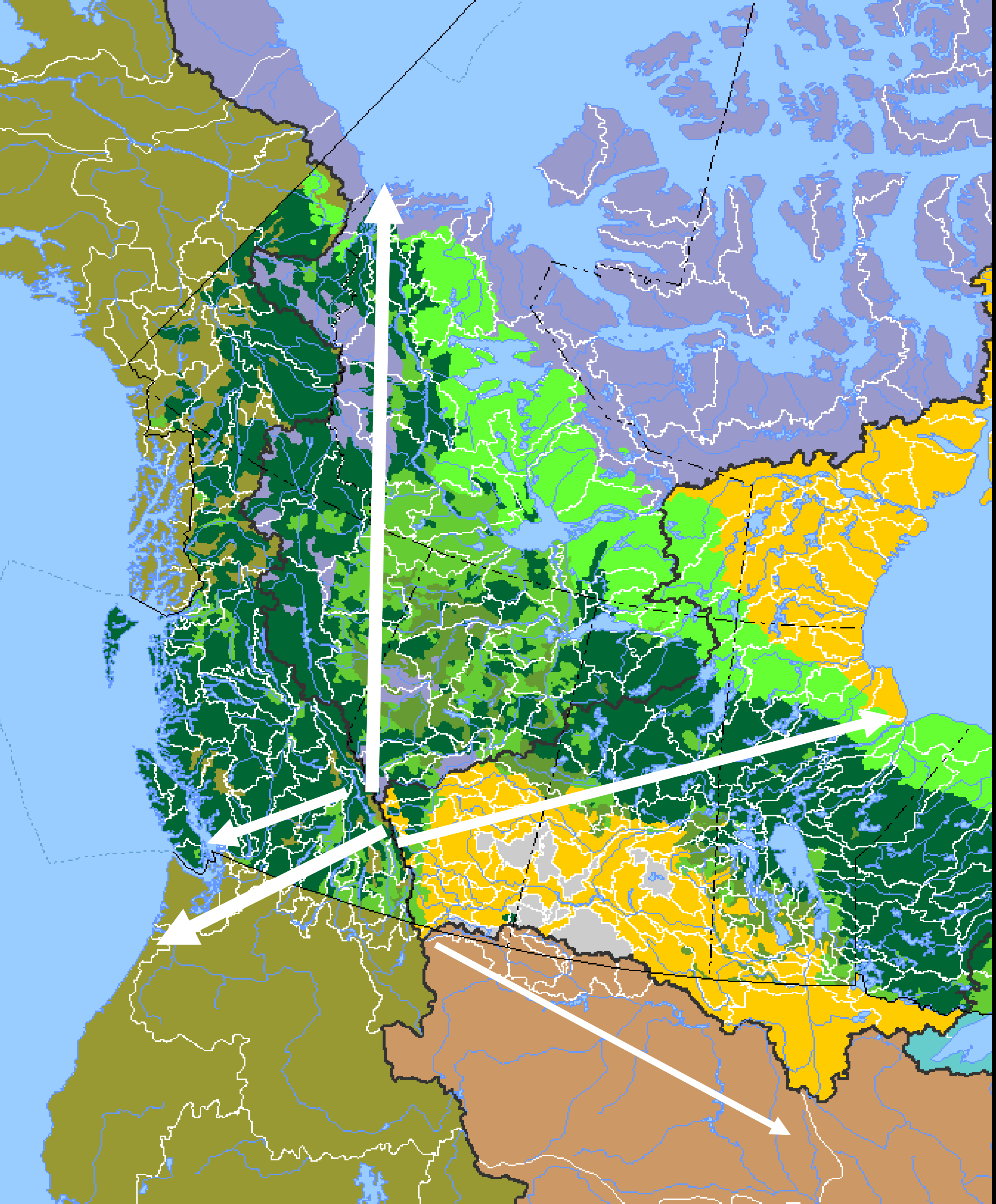
southernmost, interior
summer snow water reserves



Snow depth in January



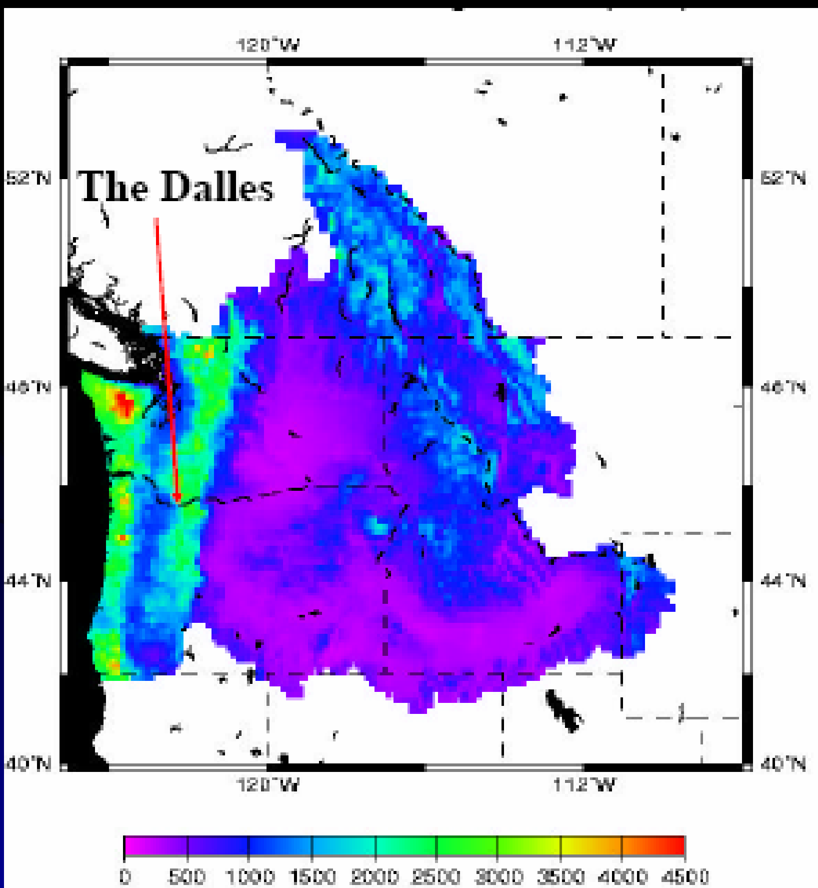
Snow depth in June



Canadian Rockies are the Hydrological Apex of North America

Columbia River Basin

Annual Precipitation

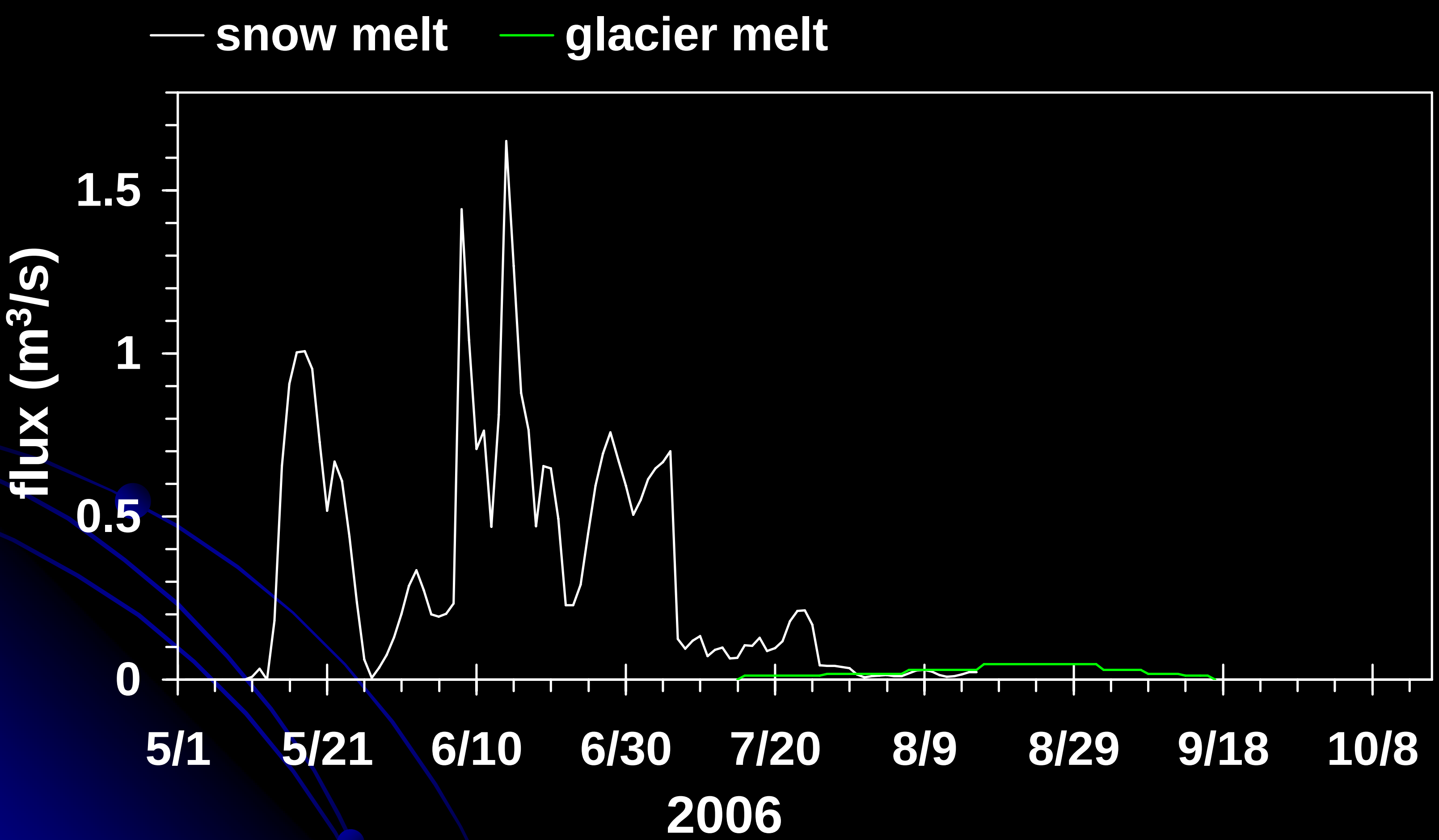


Sources of Mountain Streamflow

- Streamflow contribution related to glacier area
- Study of Lake O'Hara (5% glacier cover on Opabin Plateau)
- Flow to Lake O'Hara
  - 60% snowmelt
  - 35% rainfall
  - 5% glacier melt

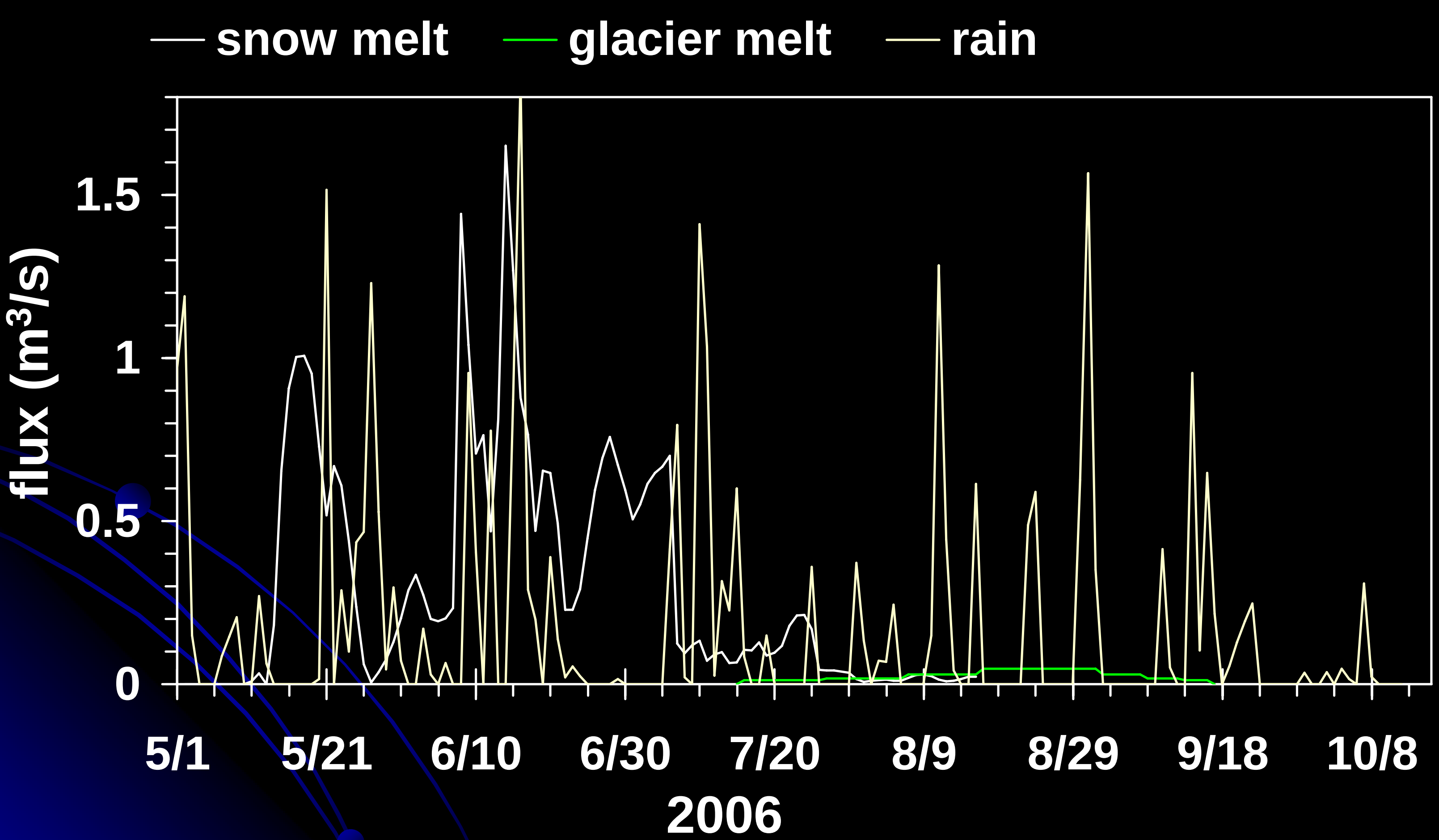
Hayashi

Water Input to the Opabin Watershed



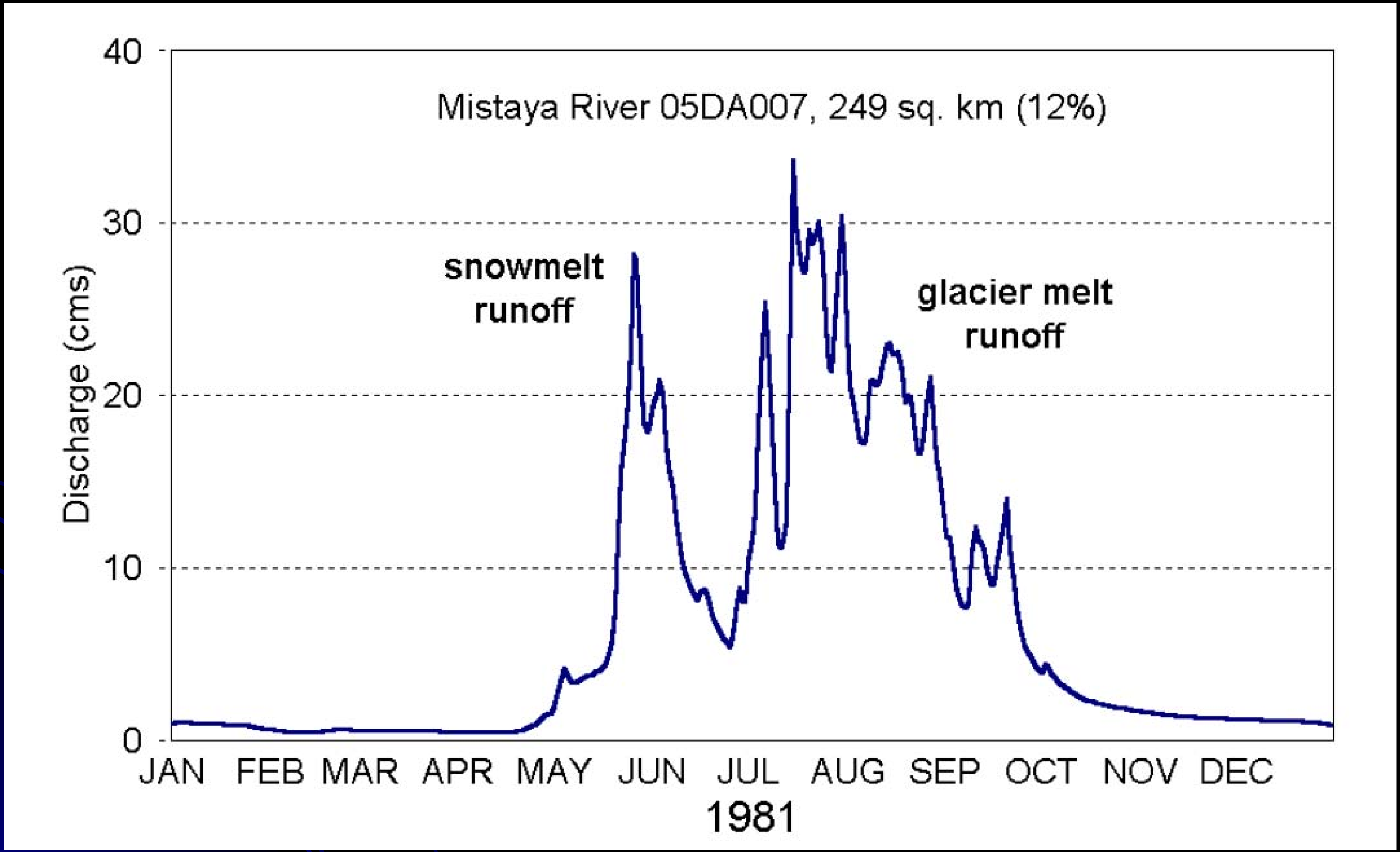
Hayashi

Water Input to the Opabin Watershed



Hayashi

Hydrograph of a Glacierised Stream, Rockies



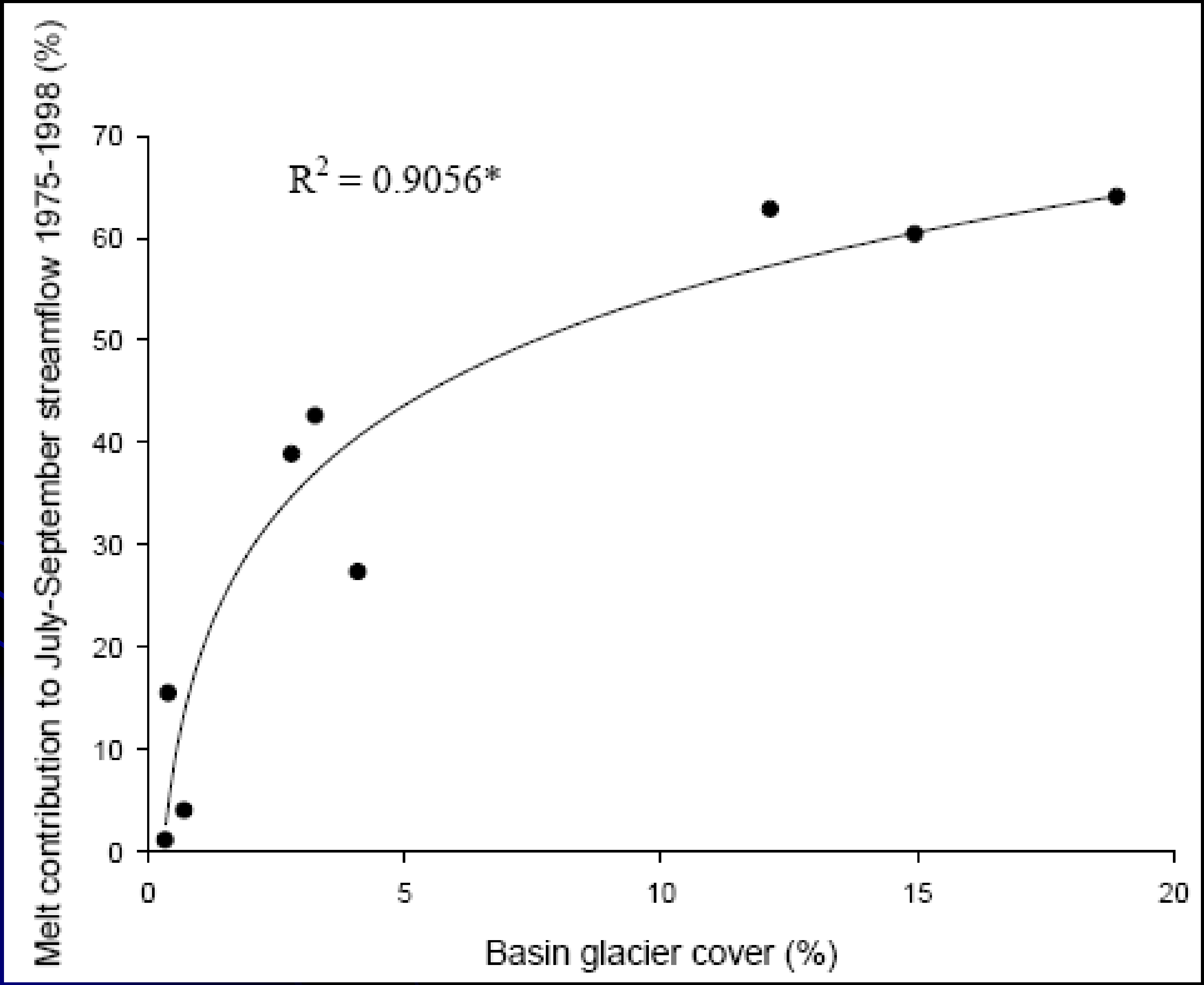
Young

Glacier Ice Wastage and Melt contribution to streamflow

- **Wastage** increases the total annual streamflow volume
- Glaciers receding at an increasing rate contribute increasing volumes of wastage in the short term
- Long term wastage contributions will decrease past a threshold where the declining glacier area limits the volume of wastage produced

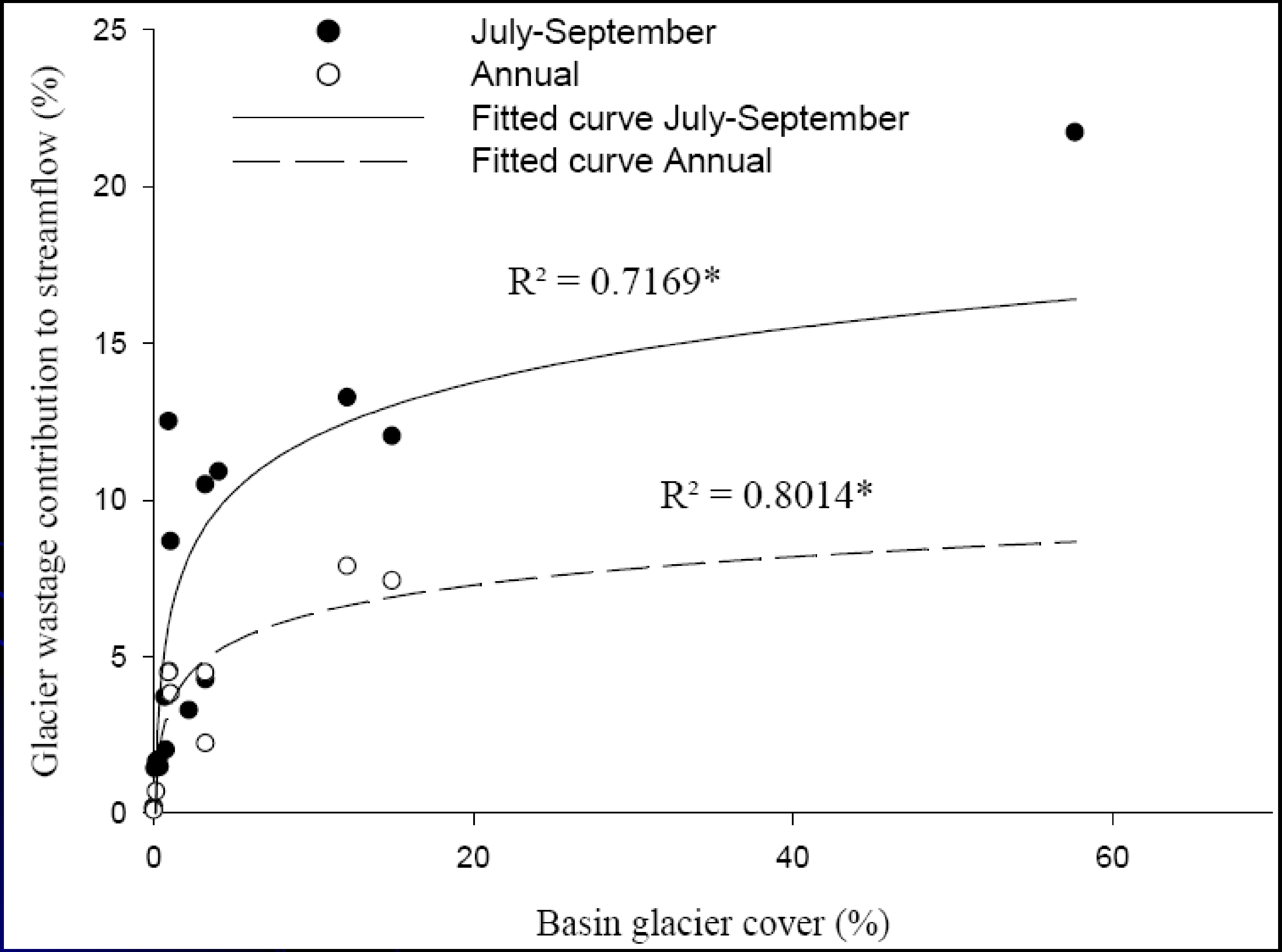
- **Melt** does not contribute to the total annual streamflow volume
- Snow is accumulated into the glacier system instead of melting and contributing to streamflow in May and June due to the cooler ice surface temperature
- The equivalent runoff volume contributes to streamflow as ice melt in July to September
- The glacier effectively delays runoff to the late summer months of otherwise low flow, and contributes to seasonal streamflow in terms of Melt.

Contribution of the Melt of Snow and Ice on a Glacier to Late Summer Streamflow



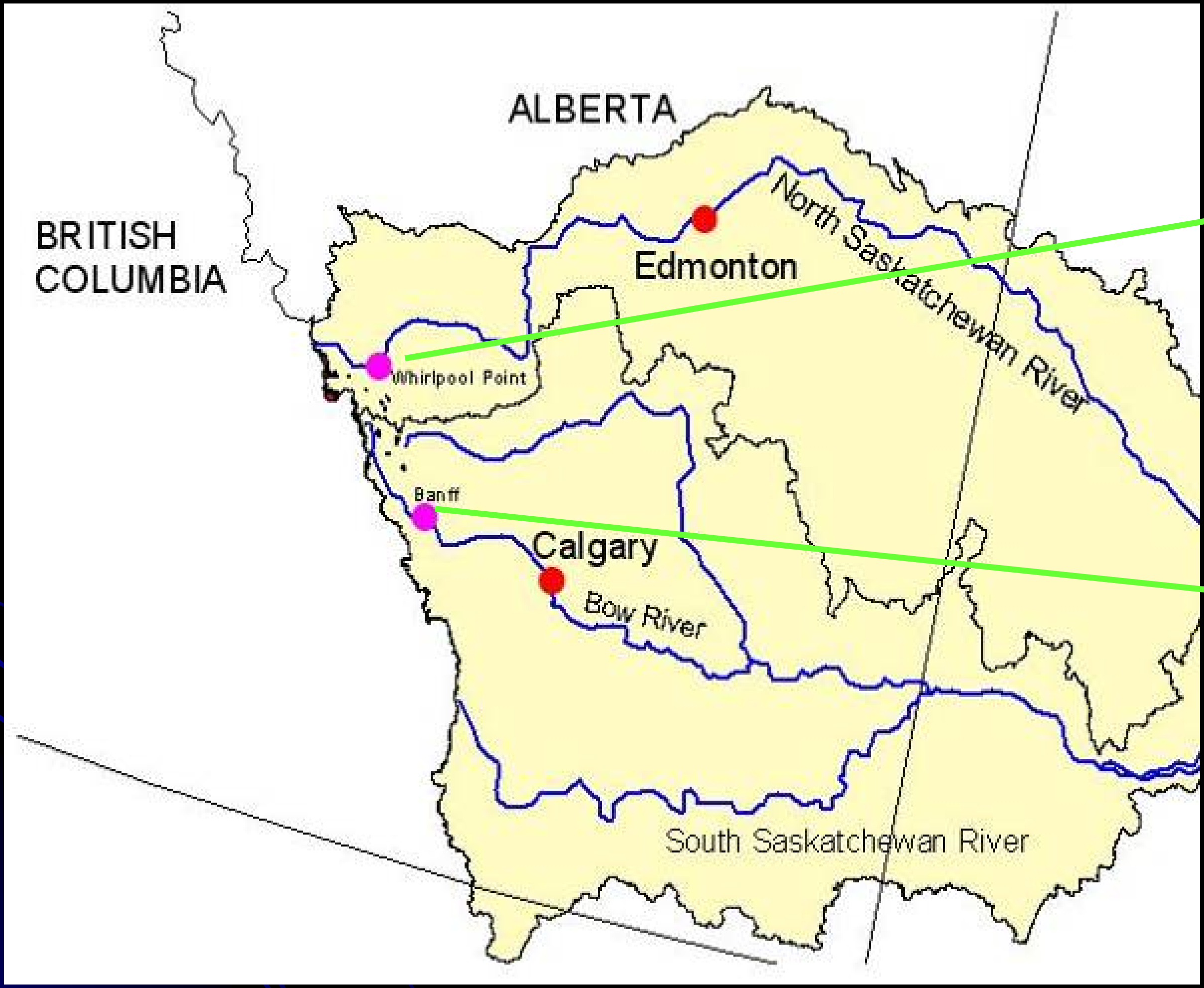
Comeau, 2008

Ice Wastage Contribution to Streamflow as a Function of Glaciation of a River Basin



Comeau, 2008

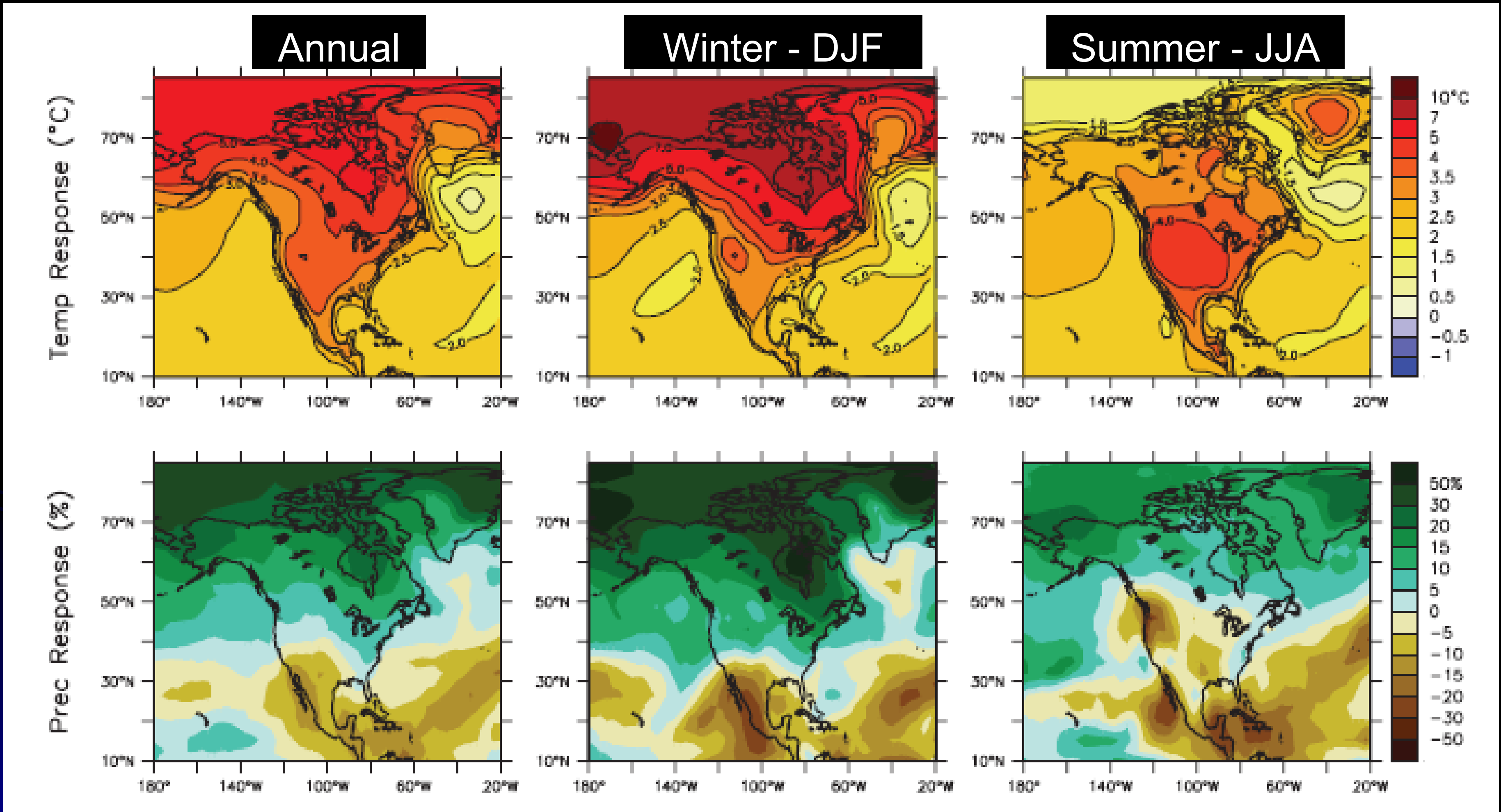
Current Glacier Melt Contribution to River Discharge



	Fall %	Annual %
Whirlpool Point	11.5	7.1
Banff	6.2	2.8

Mike Demuth, Natural Resources Canada

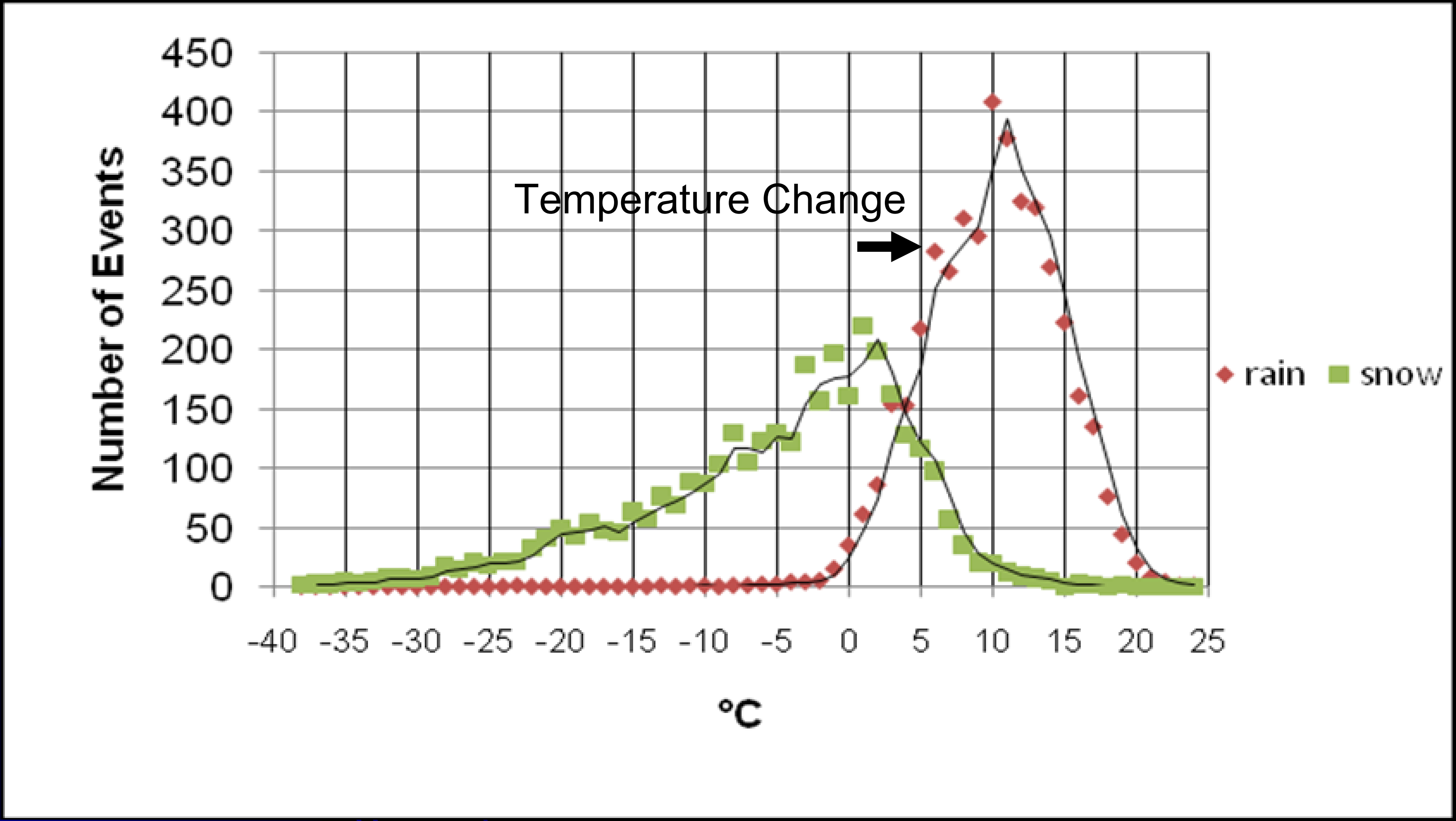
Regional climate change predictions 2080-2089 relative to 1980-1999



IPCC 2007

Warmer and Wetter generally; Drier in summer !

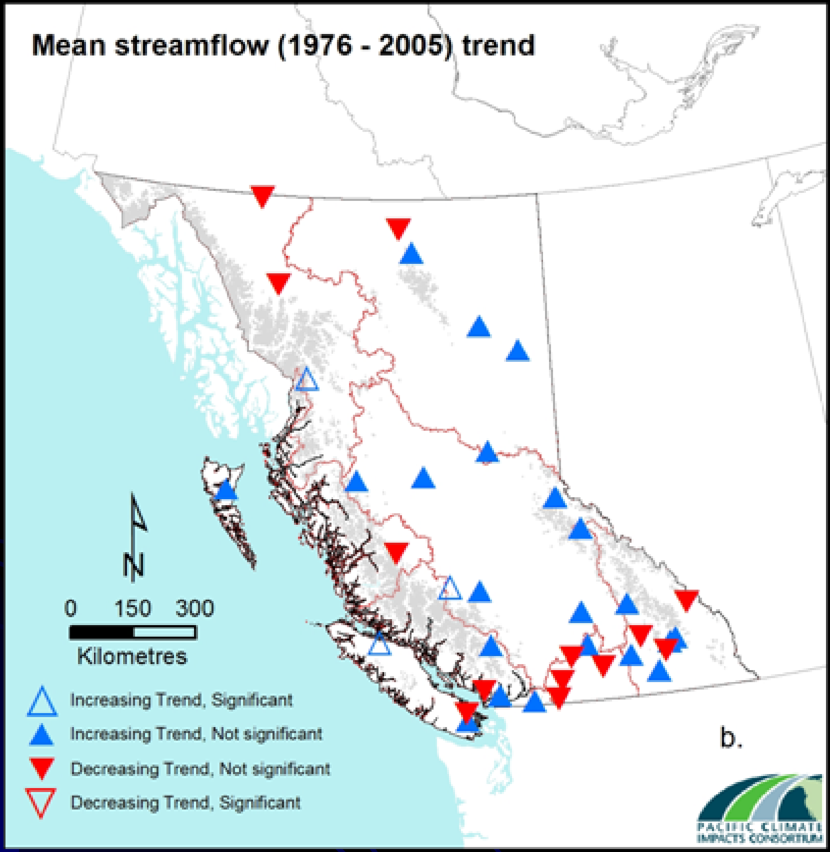
Rainfall versus Snowfall, Kananaskis Valley

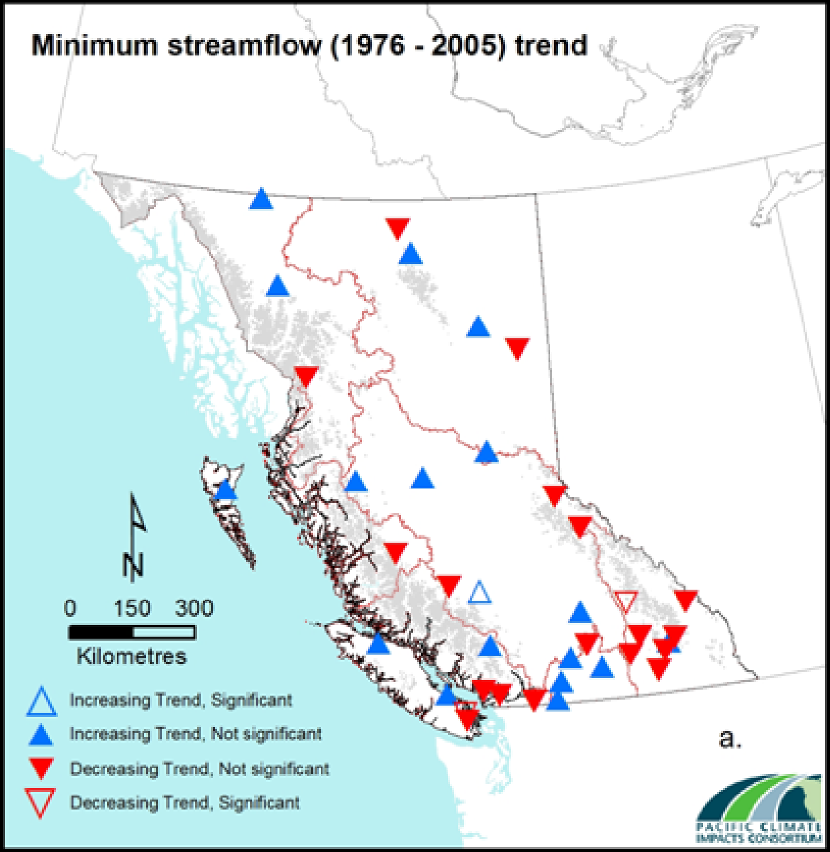


Warmer winters = less snowfall
Warmer winters = more rainfall

Harder & Pomeroy

Streamflow Trends





Bennett, PCIC

Glaciers in the Rocky Mountains

Glacial Decline:

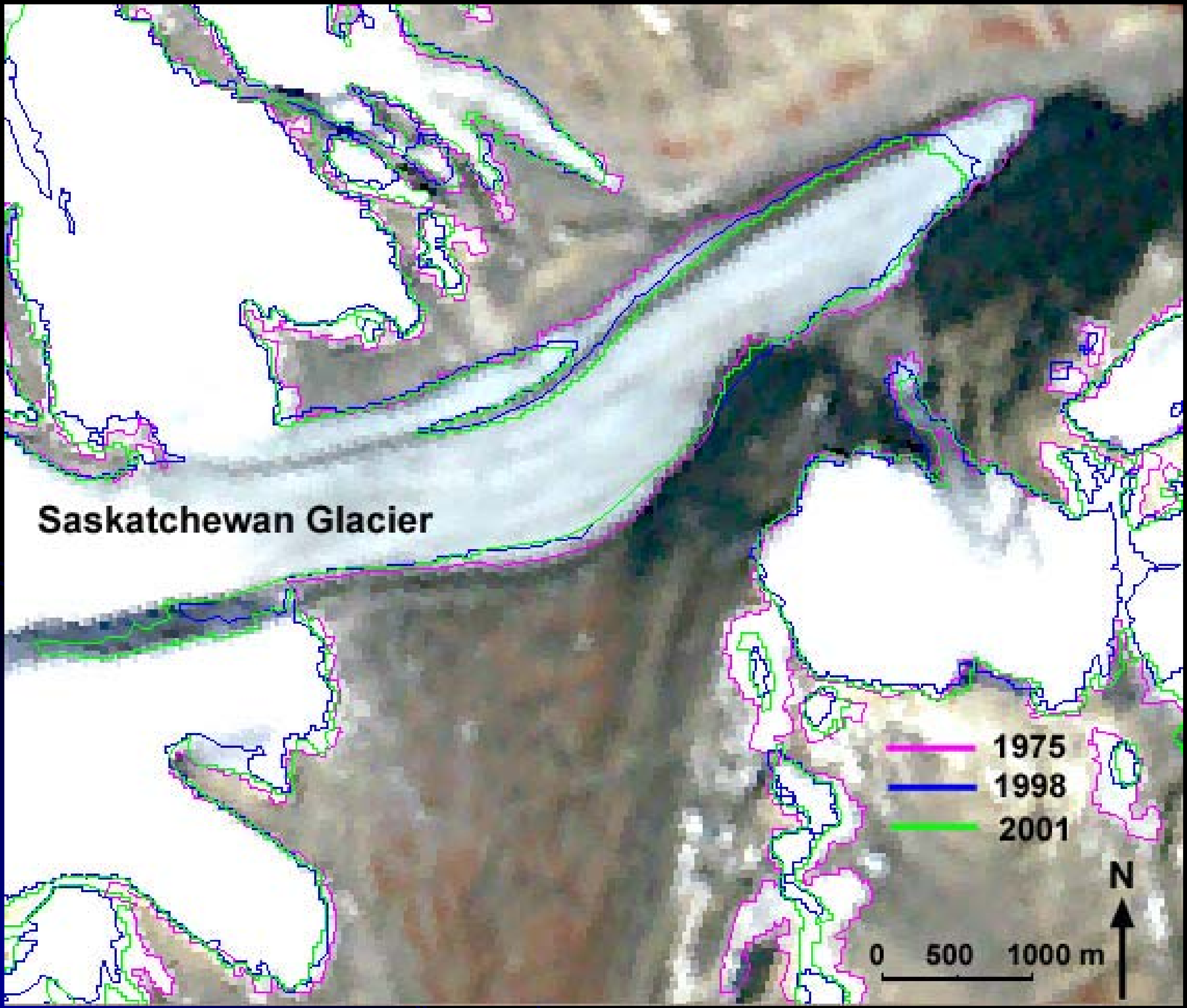
- Glaciers receding in the Rocky Mountains since the 19th Century
- 1975-1998 total glacier loss:
  NSRB 23% (395 – 306 km²)
  SSRB 37% (141 – 89 km²)
- Projected to continue into the future

Impacts:

- Reduced river flows in late summer months
- Increased streamflow variability

- Hydroelectric power plants
- Ecology
- Agriculture
- Domestic

Glacier Retreat – Rocky Mountains



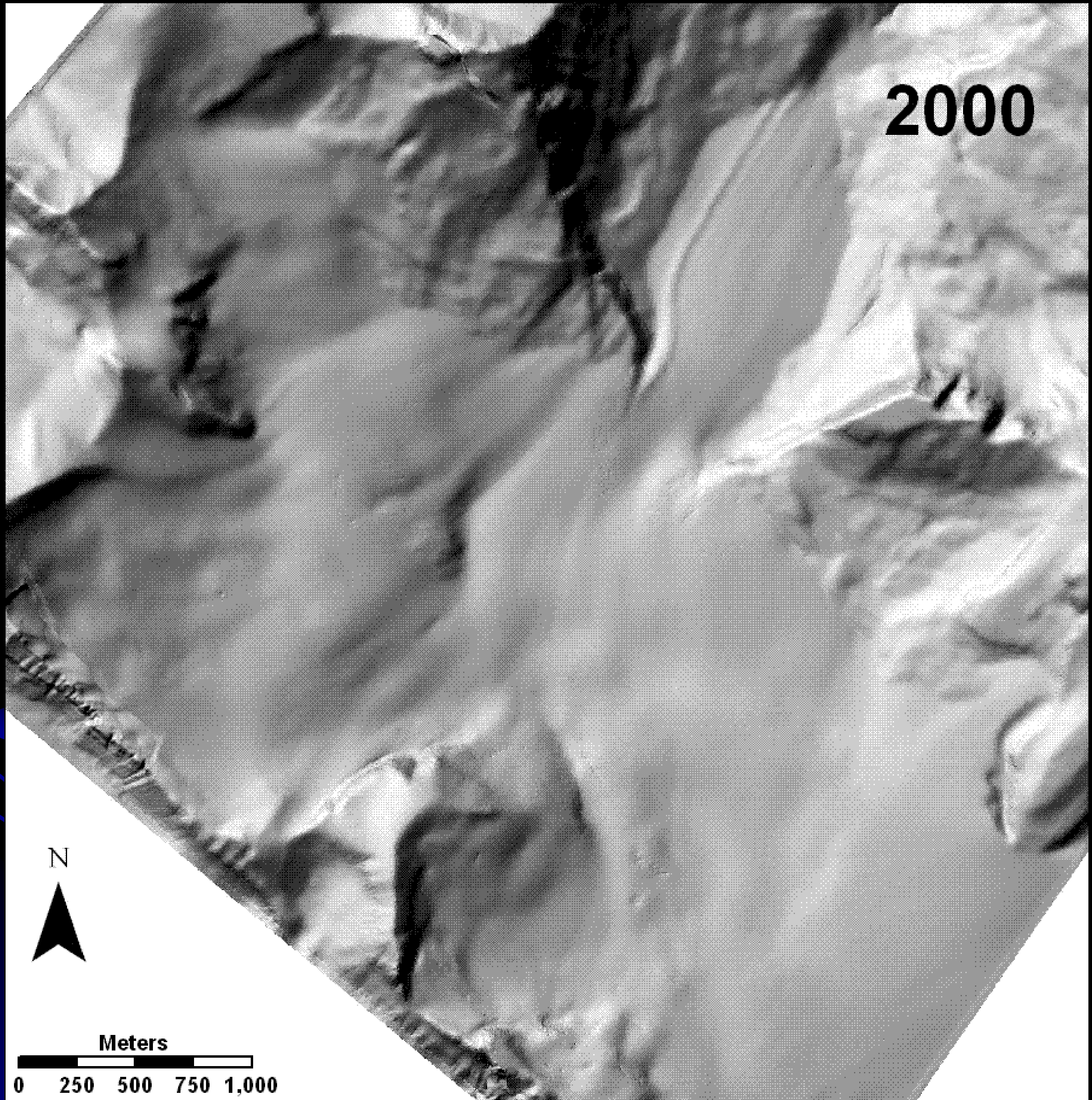
Mapped from NASA LANDSAT satellite

Glaciers are fed by alpine snow

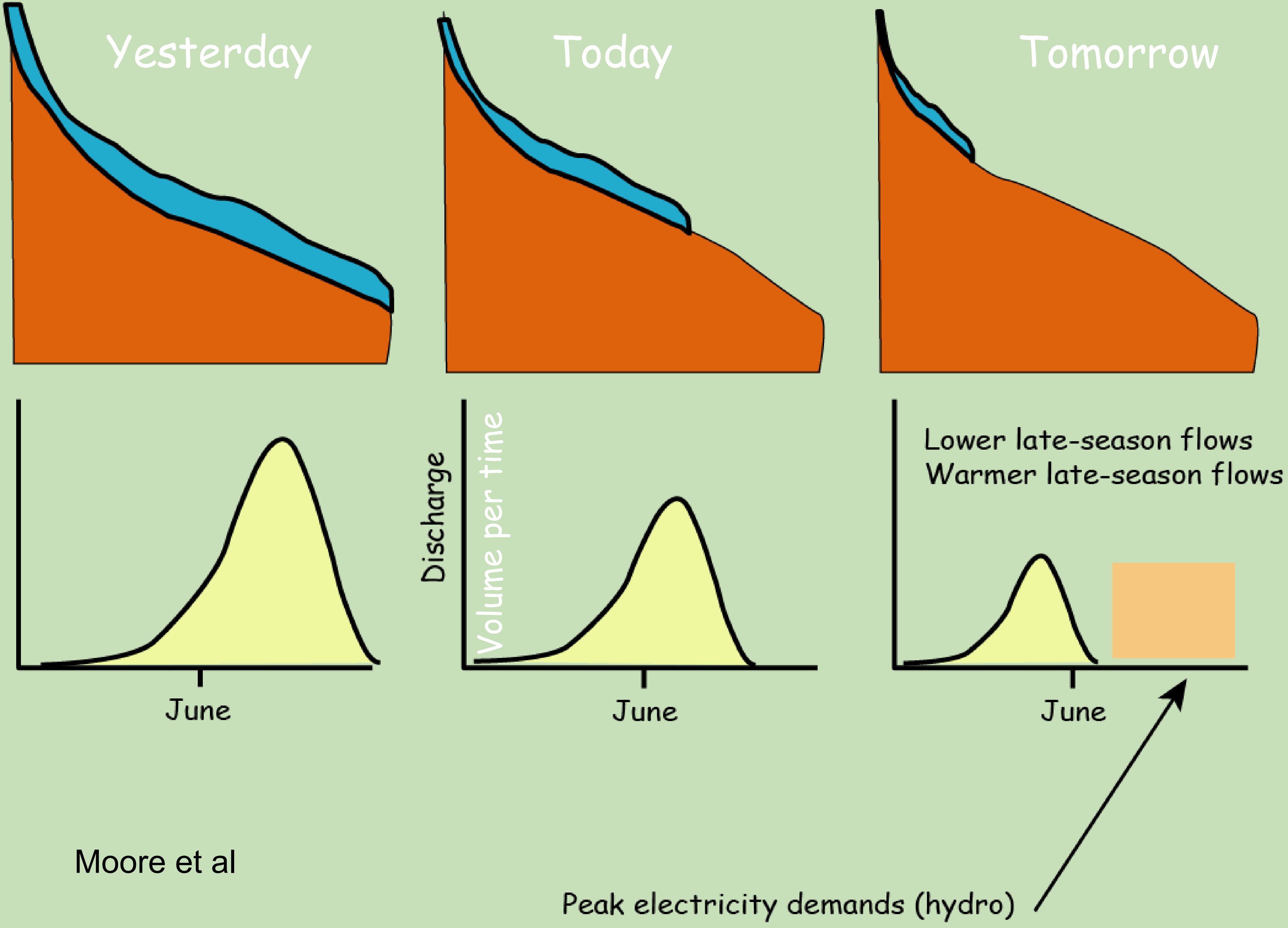
37% loss of glaciated area of South Sask River Basin 1975-1998

23% loss of glaciated area of North Sask River Basin 1975-1998

Demuth & Pietroniro



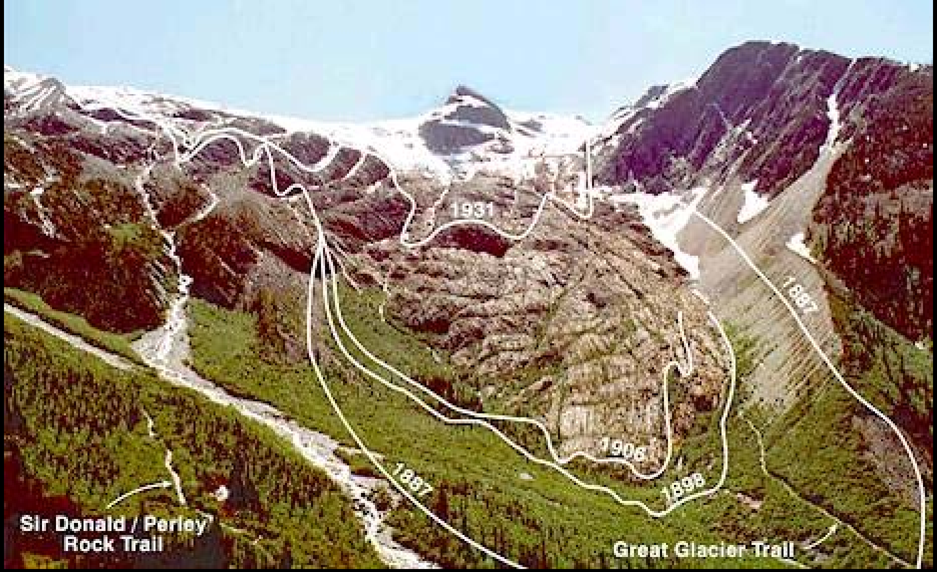
Demuth
Columbia
Icefield


Yesterday
Today
Tomorrow
Discharge
Volume per time
Lower late-season flows
Warmer late-season flows
June
June
June
Peak electricity demands (hydro)

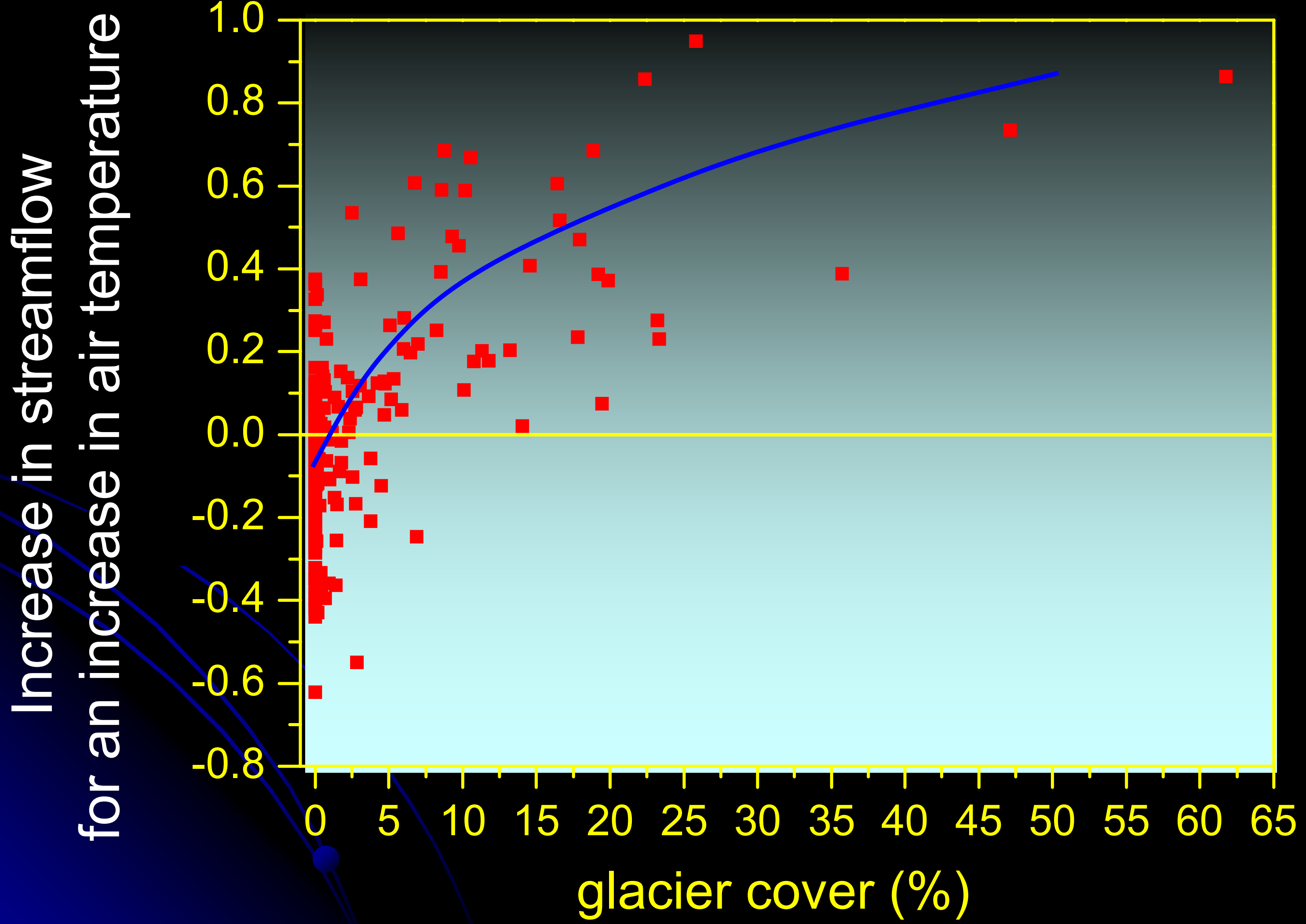
Moore et al

Historical variations of Illecillewaet Glacier

http://www.geog.utoronto.ca/info/facweb/Harvey/Harvey/harvey_images.htm

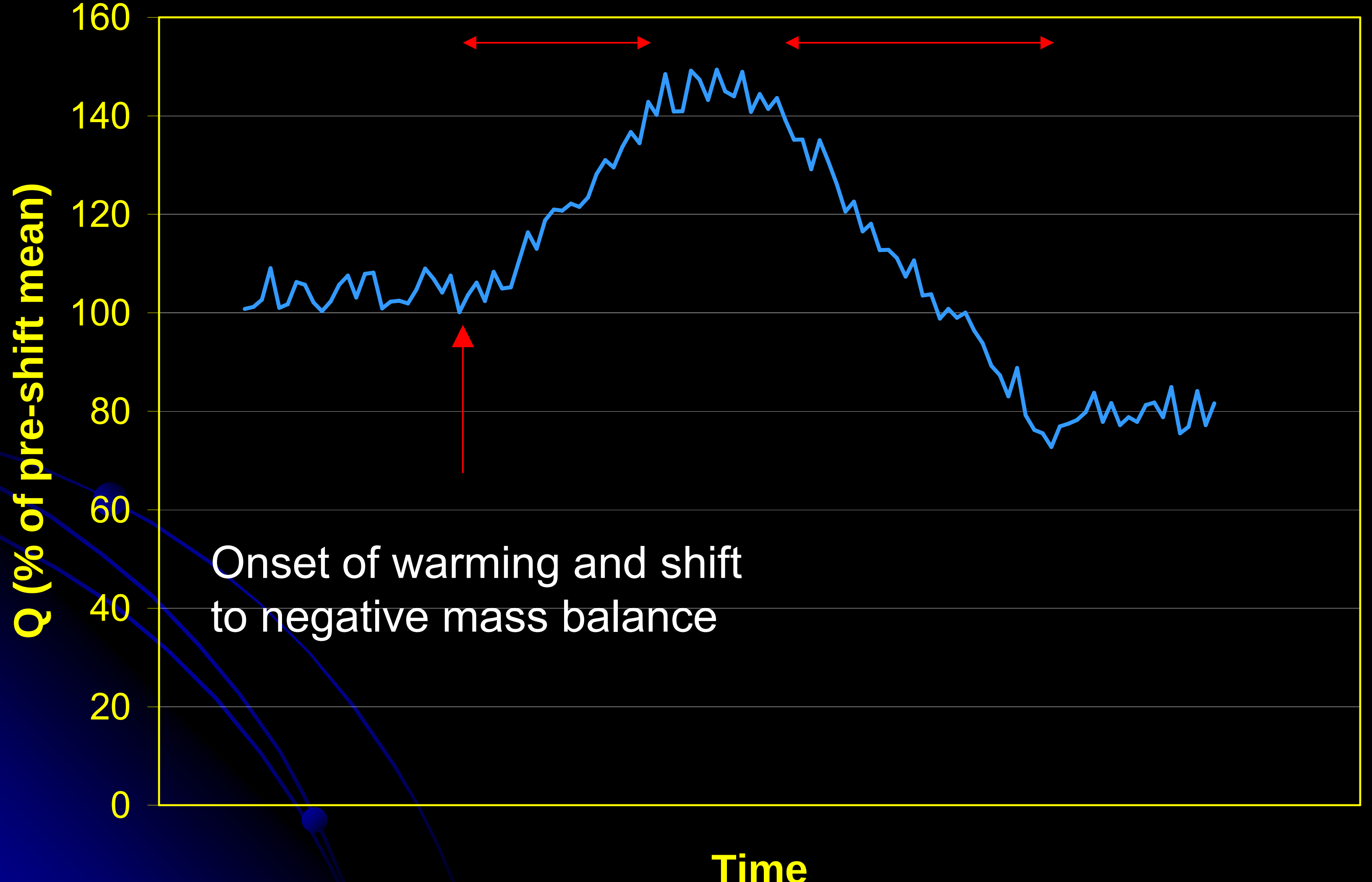


Sensitivity of August streamflow to August air temperature as influenced by glacier cover

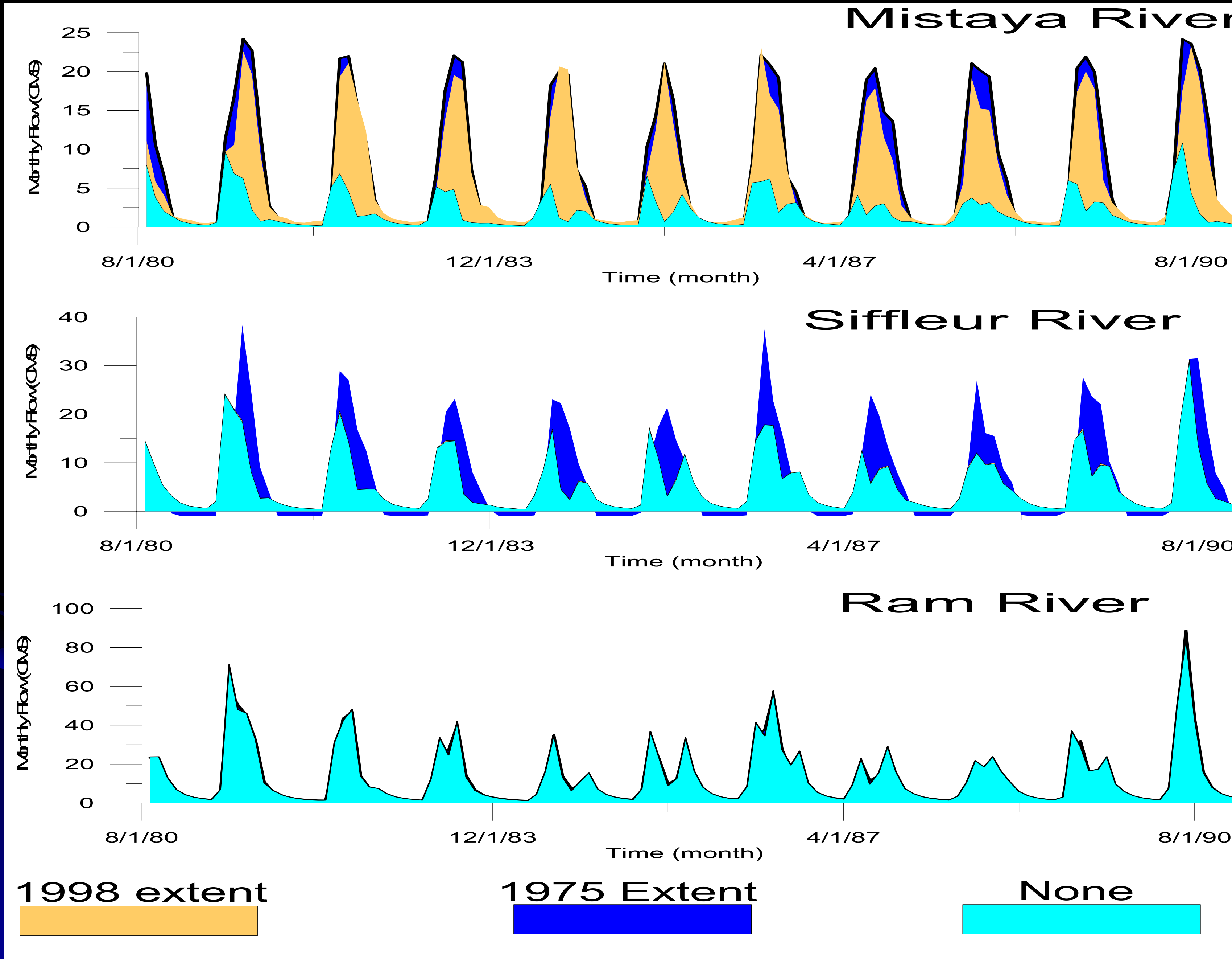


Moore

Streamflow response to climate warming: <u>hypothesis</u>



Moore



Pietroniro and Demuth

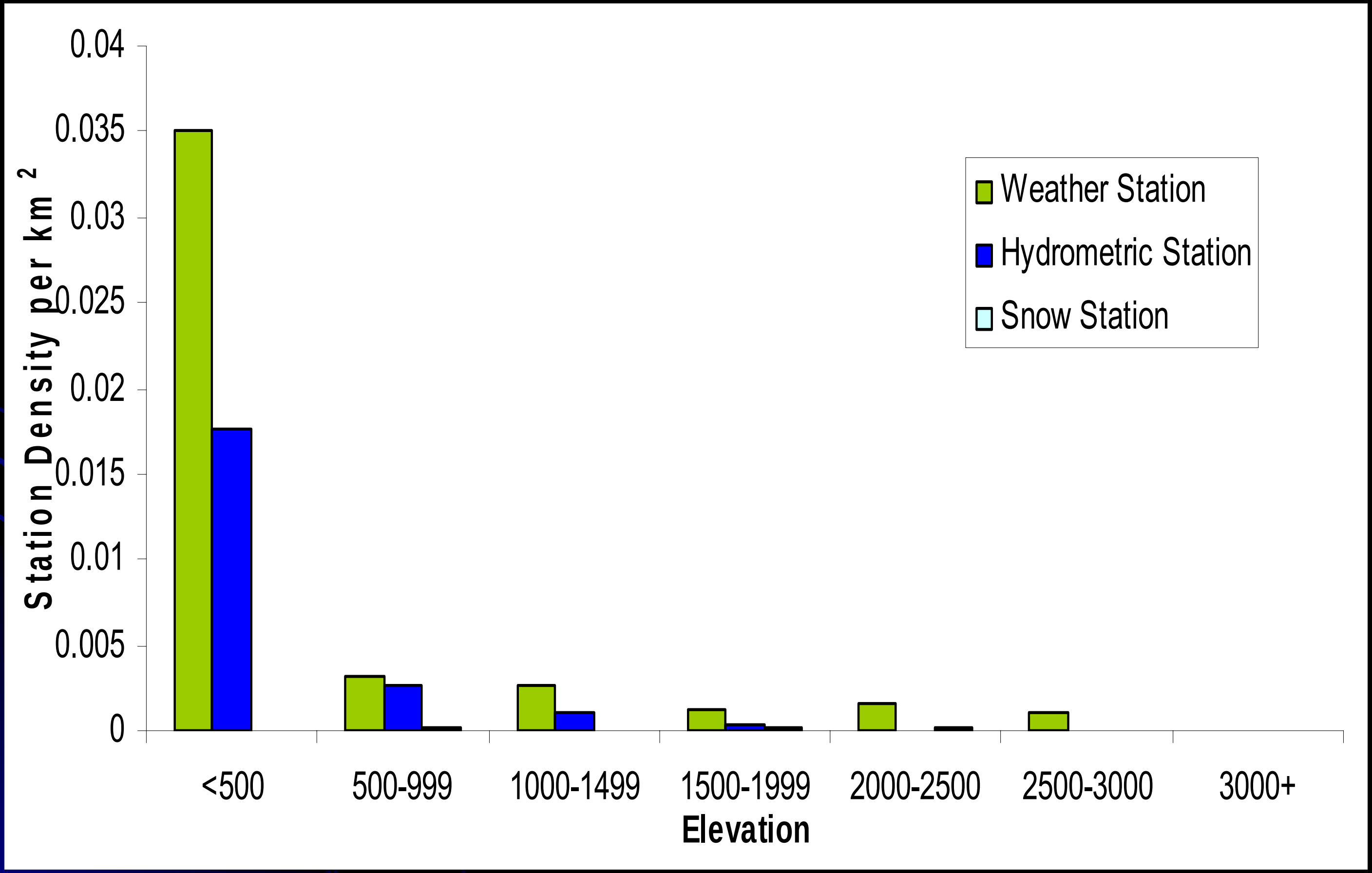
Meteorological Stations

Hydrological Observation

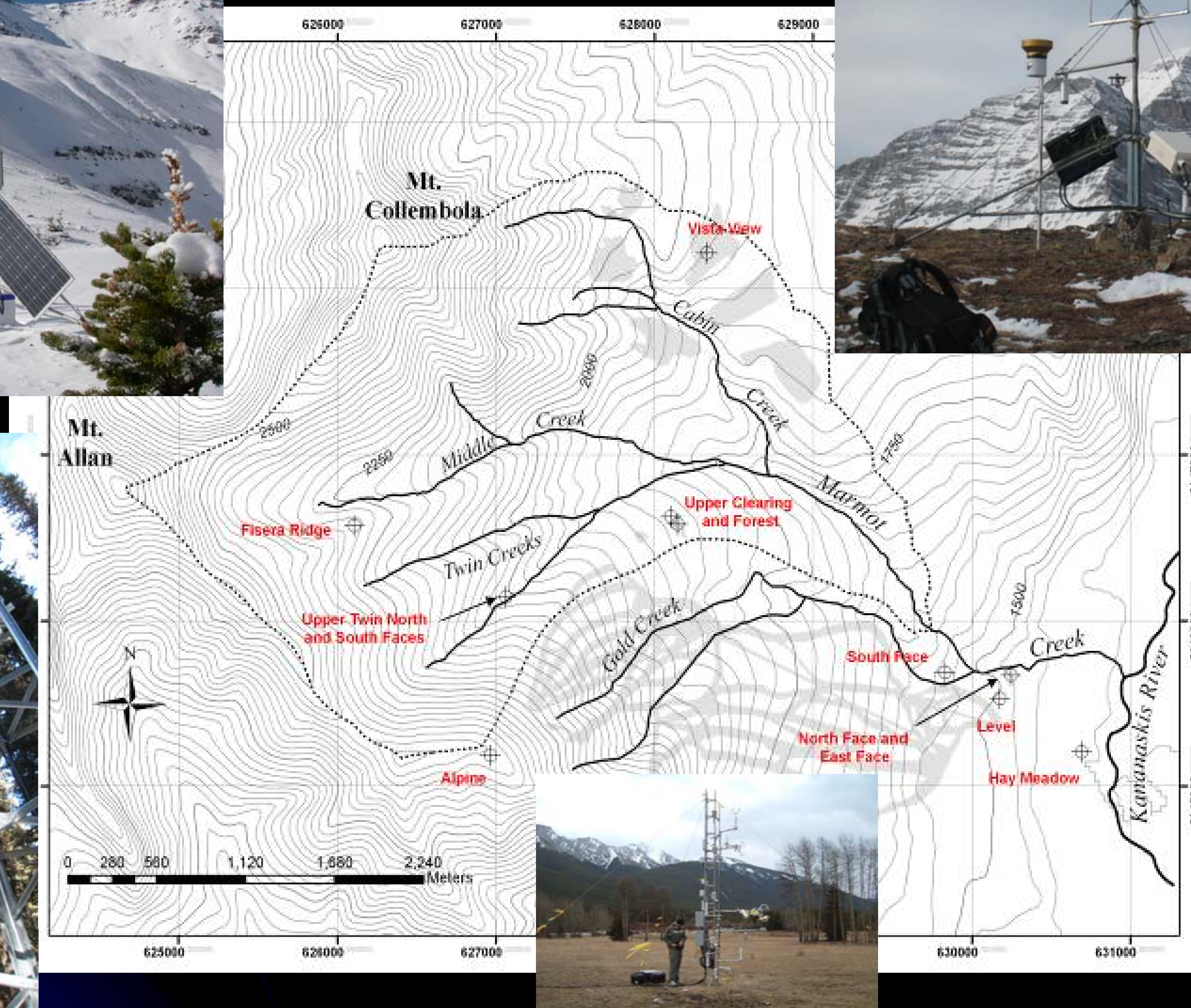
New Observations Needed

Station density is too low. To meet World Meteorological Organisation standards for mountain regions we need

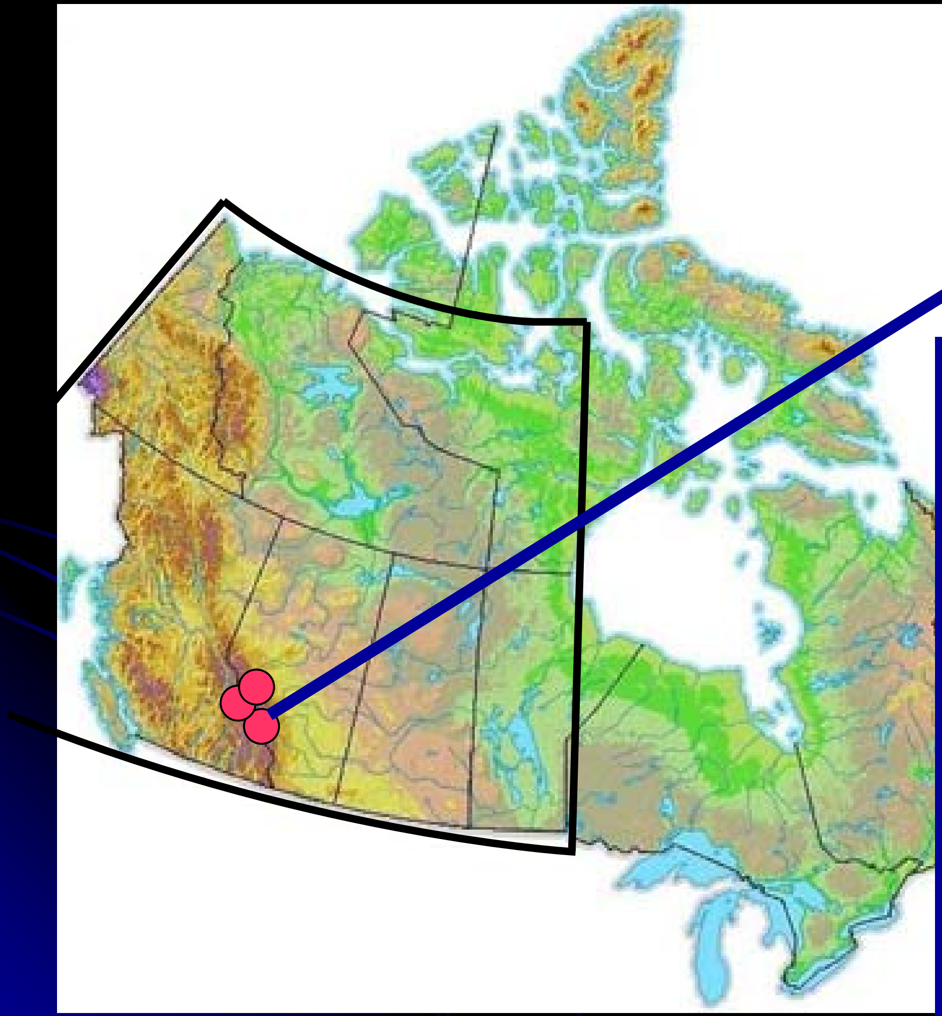
- 4.5 fold increase in streamflow (hydrometric) stations
- 22.5 fold increase in precipitation stations

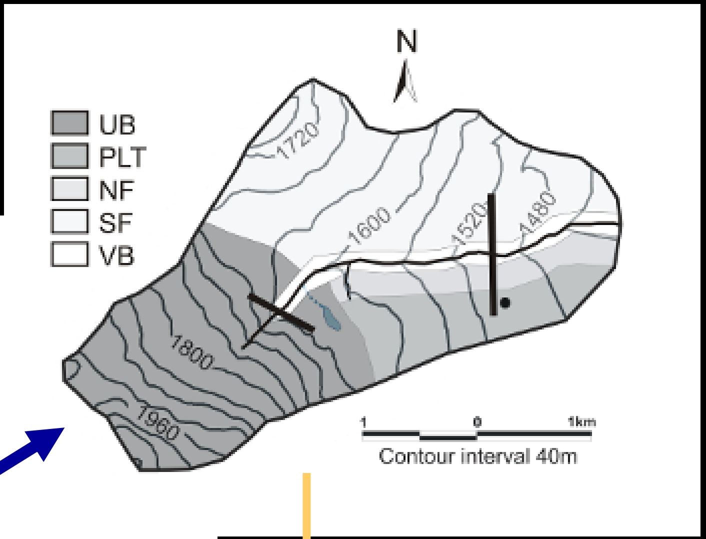


Observations Clustered in Small Basins Improve Understanding

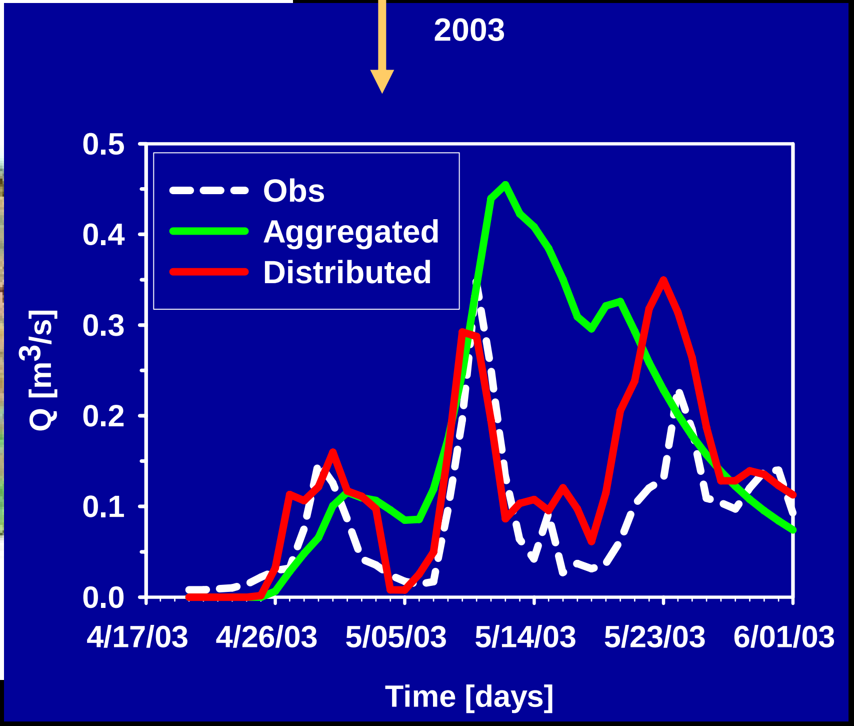


Prediction





N
UB
PLT
NF
SF
VB
1720
1600
1520
1480
1800
1960
1
0
1km
Contour interval 40m

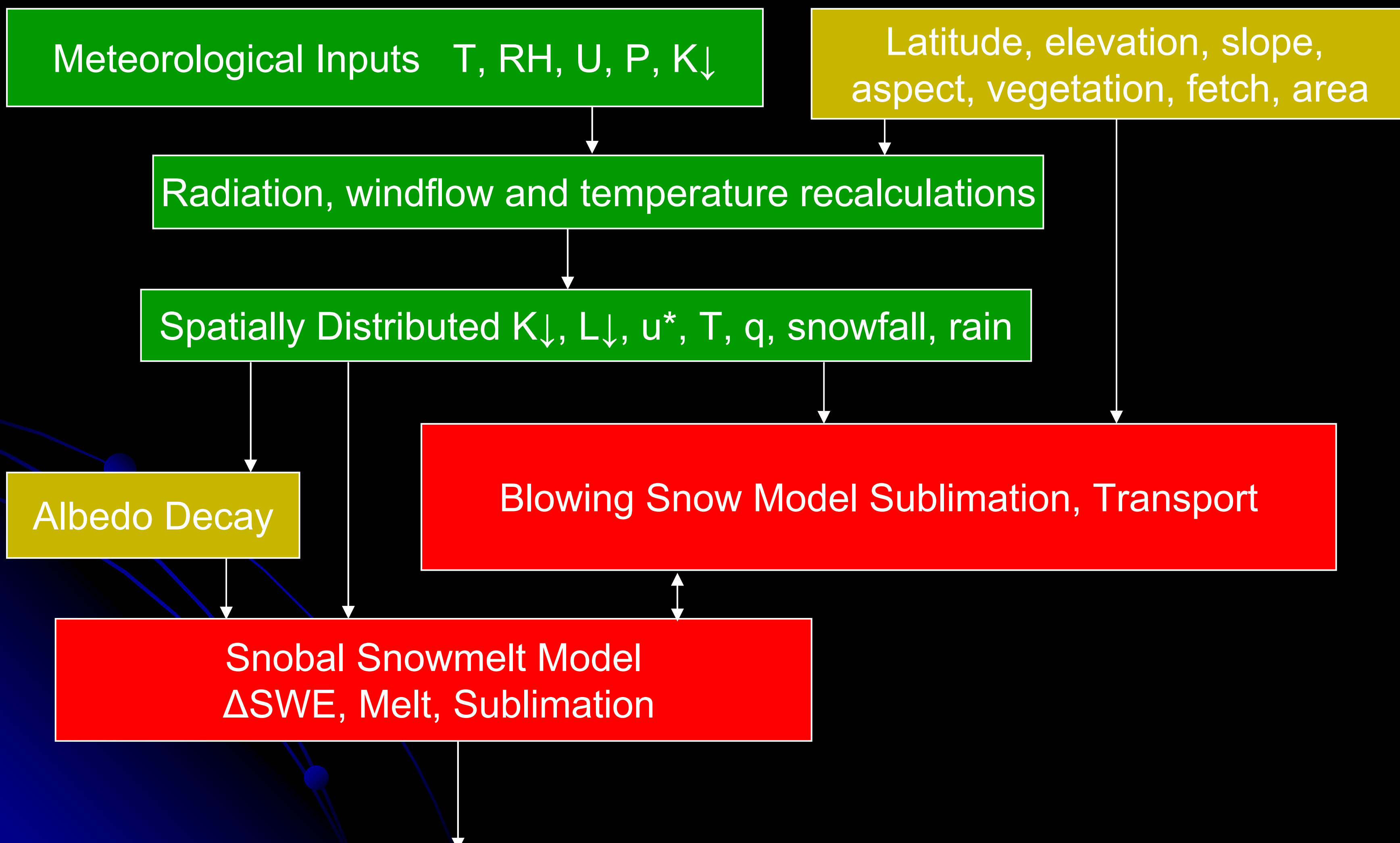


2003
Obs
Aggregated
Distributed
Q [m3/s]
0.5
0.4
0.3
0.2
0.1
0.0
4/17/03
4/26/03
5/05/03
5/14/03
5/23/03
6/01/03
Time [days]

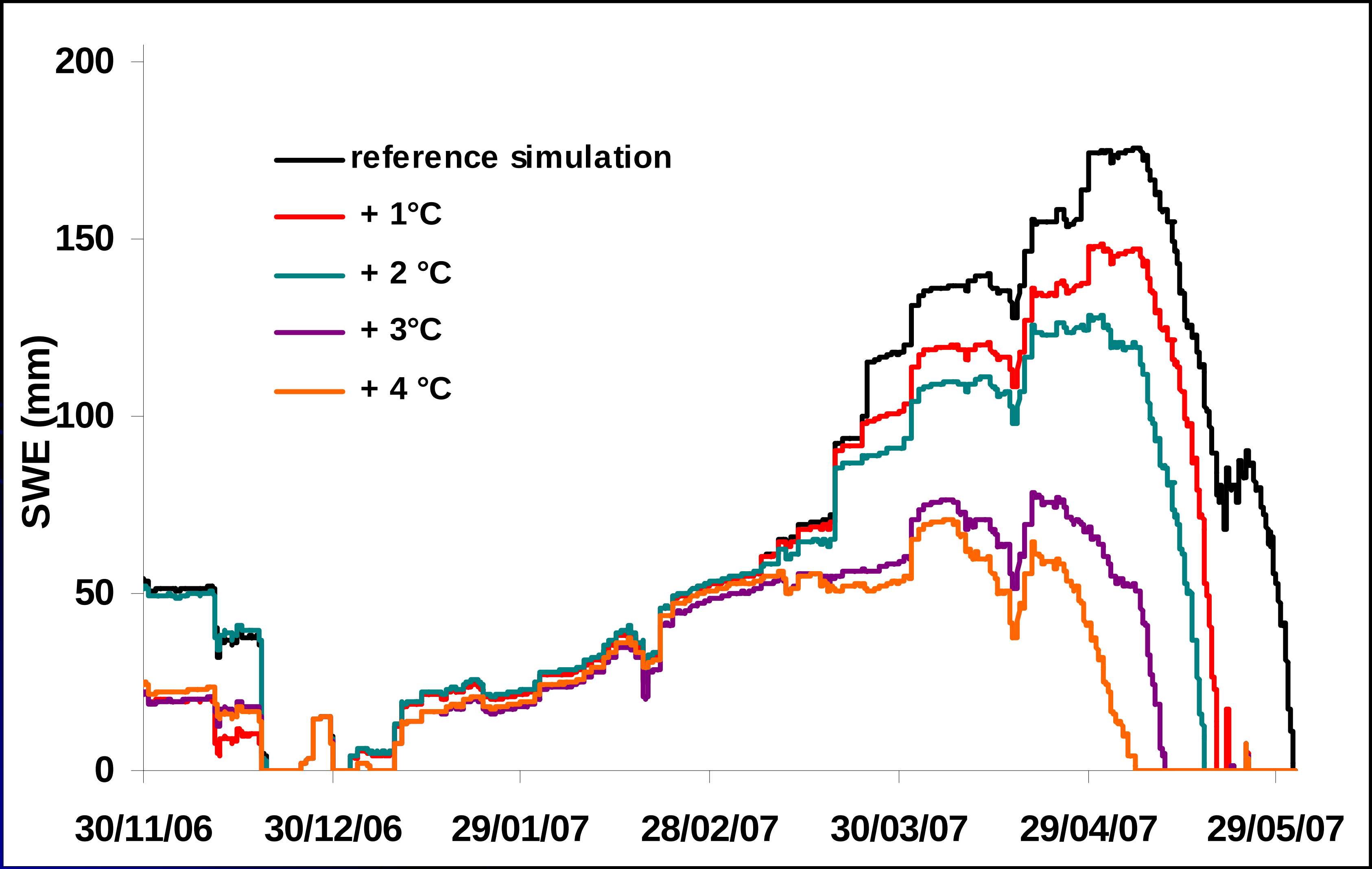
Modelling in Columbia

- Models should be physically based
  - Temperature index unsuited for climate change or land use change snowmelt calculations
  - Radiation can estimated accurately from temperature range and output from climate models
- Models should have realistic snow and glacier components
- Models must explicitly recognize the influence of topography, slope and aspect on watershed response

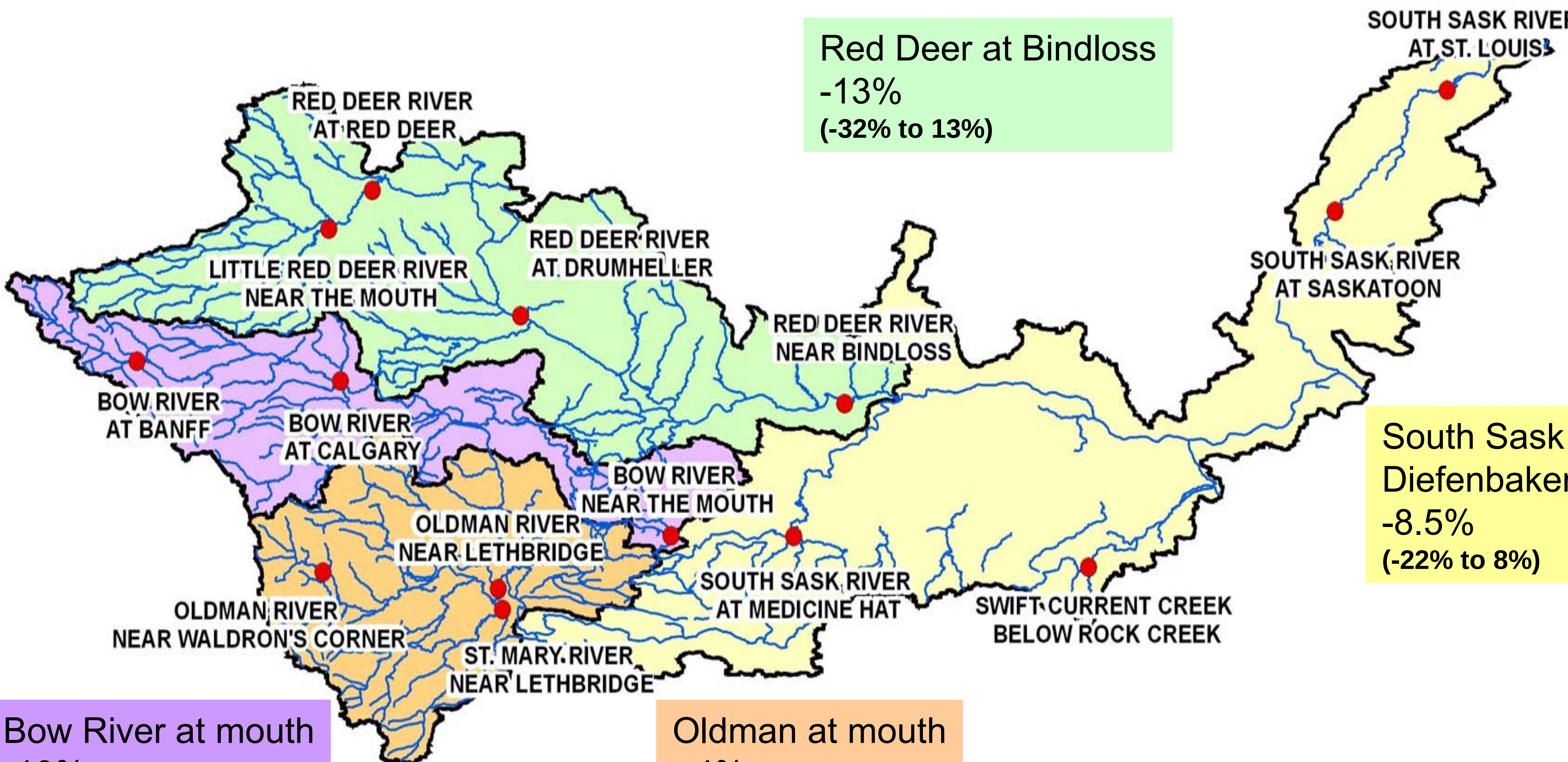
CRHM Coupled Blowing Snow and Snowmelt Modelling for Mountains



Winter Warming Scenario Impact on Mid-Alpine Ridge Snow Regime



GCM scenario results – hydrological model 2039 – 2070 cumulative flows of South Saskatchewan River



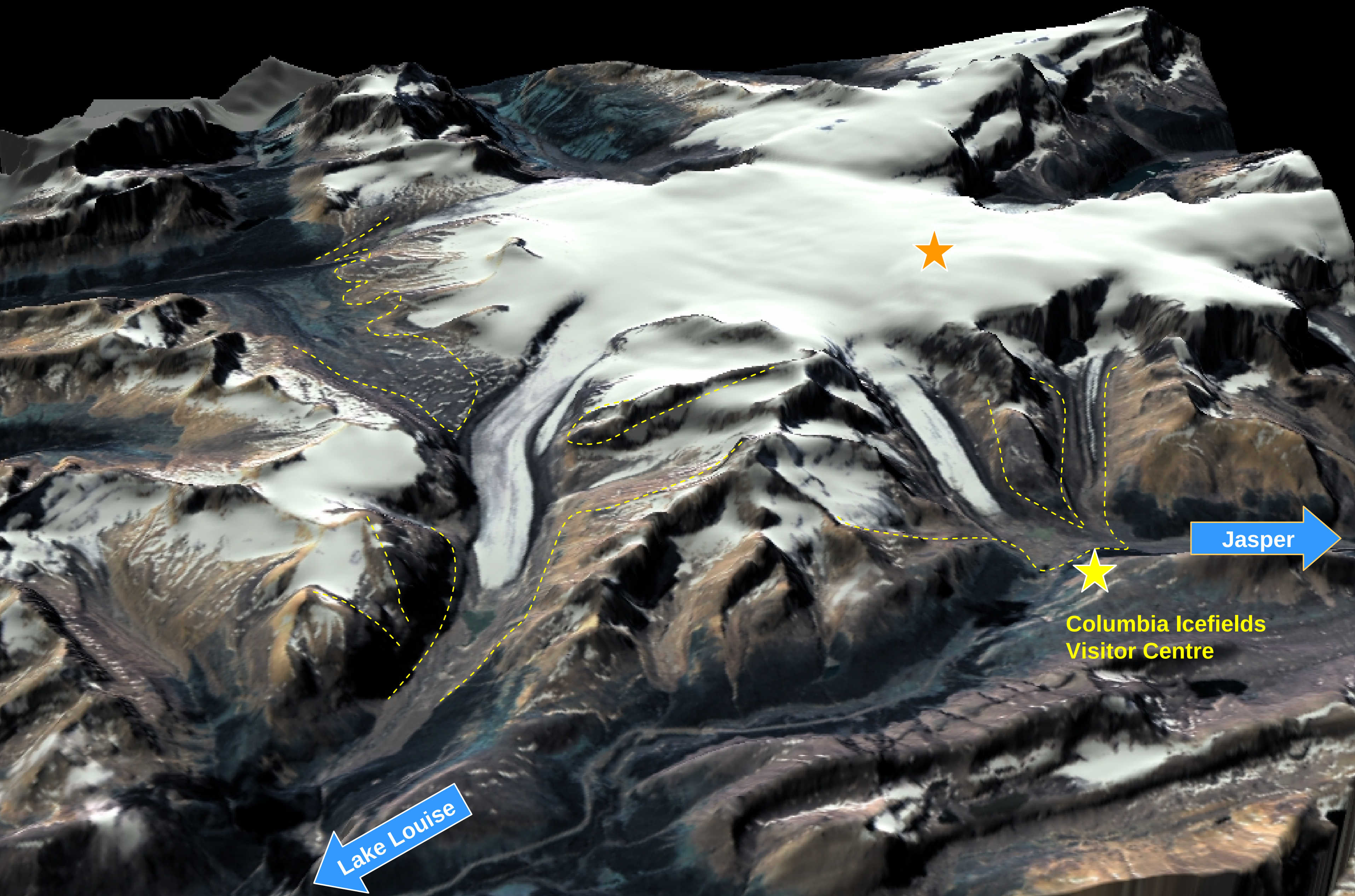
Red Deer at Bindloss
-13%
(-32% to 13%)

South Sask a
Diefenbaker
-8.5%
(-22% to 8%)

Bow River at mouth
-10%
(-19% to 1%)

Oldman at mouth
- 4%
(-13% to 8%)

Columbia Icefield Research Initiative



Conclusions

- Glacier contribution to streamflow depends on climate & glacierised area – this contribution is incompletely quantified in the Columbia basin.
- Further deglaciation likely to result in lower and more variable late summer streamflow
- Change in hydrology due to climate change and deglaciation depends on what land cover replaces glacier cover (tundra, forest, rock)
- Current hydrological modelling has simple or no representation of glaciers, snow and alpine energy balance – adds considerable uncertainty to estimating the future water resources of the region.