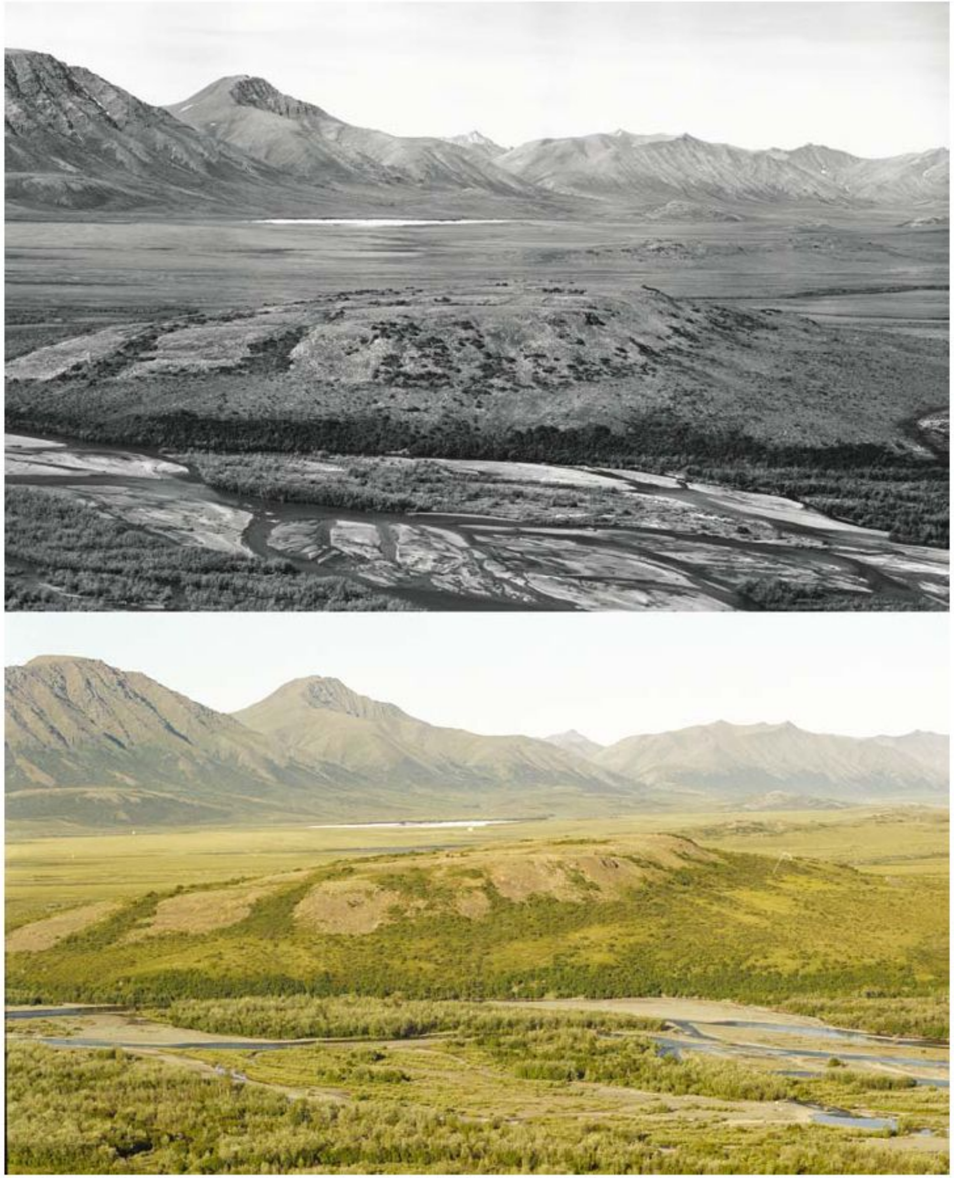
Water in the Changing North

- Sean Carey (Carleton University)

With contributions from

- Laura Chasmer (Wilfrid Laurier University)
- Laura Comeau (U of Sask)
- Mike Demuth (Natural Resources Canada)
- Rick Janowicz (Yukon Environment)
- Alain Pietroniro (Environment Canada, U of Sask),
- John Pomeroy (U of Sask)
- Bill Quinton (Wilfrid Laurier University)
- Hok Woo (McMaster U)

What is Change?



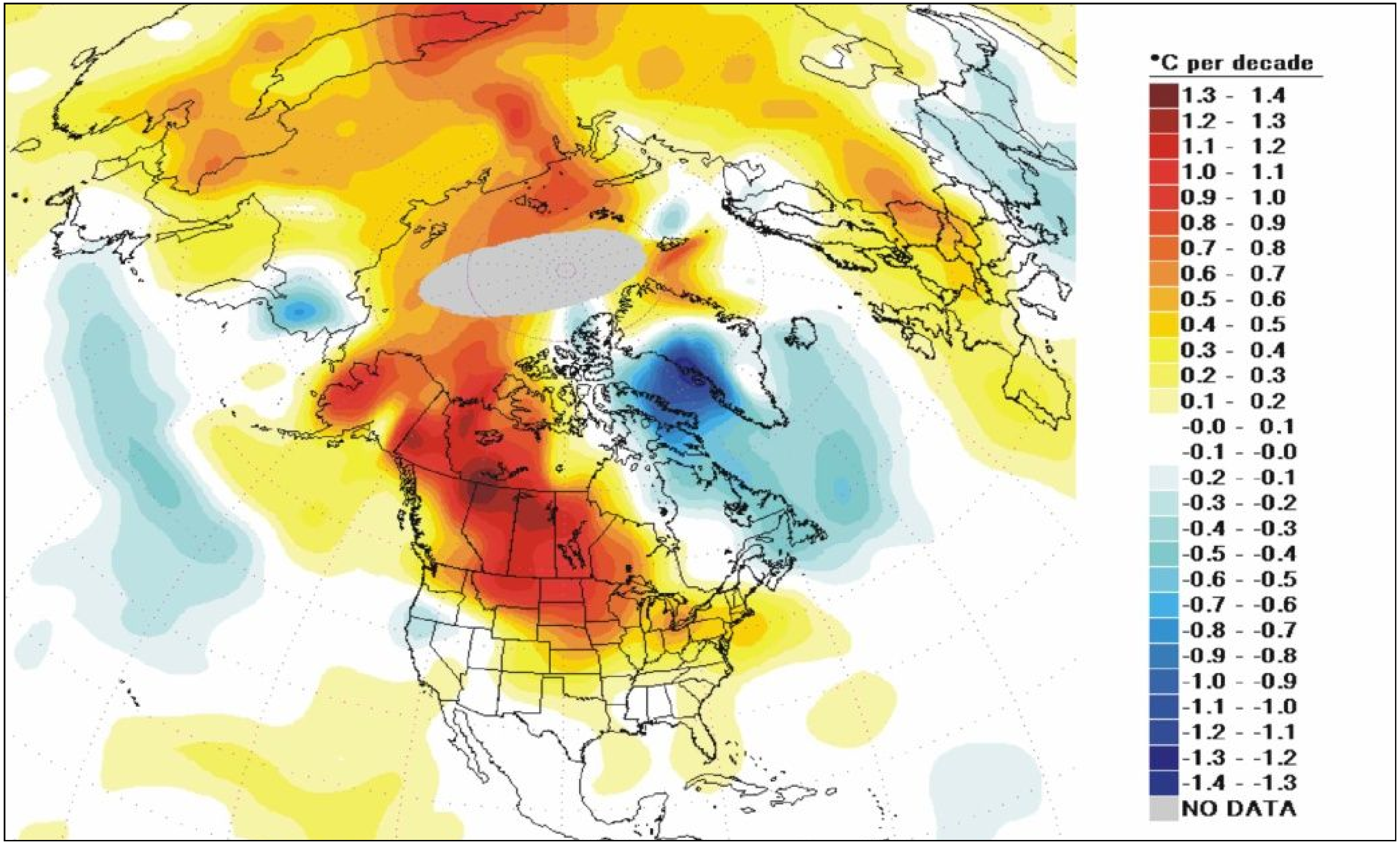
From Sturm et al. 2001

Change is the norm, not the exception

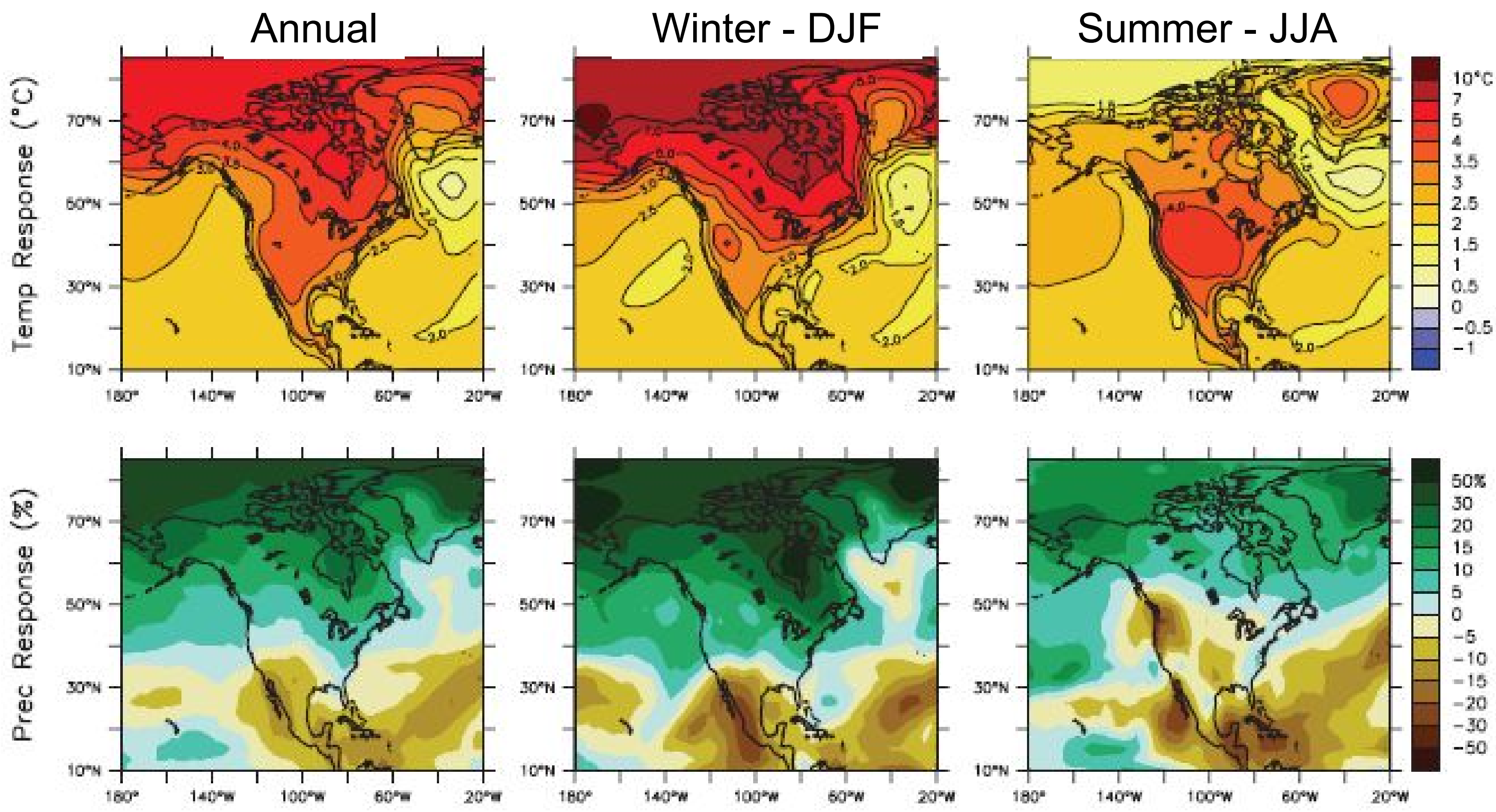
Change has been directly observed

Nowhere is this more notable than “The North”

Observed 20th Century Temperature Changes

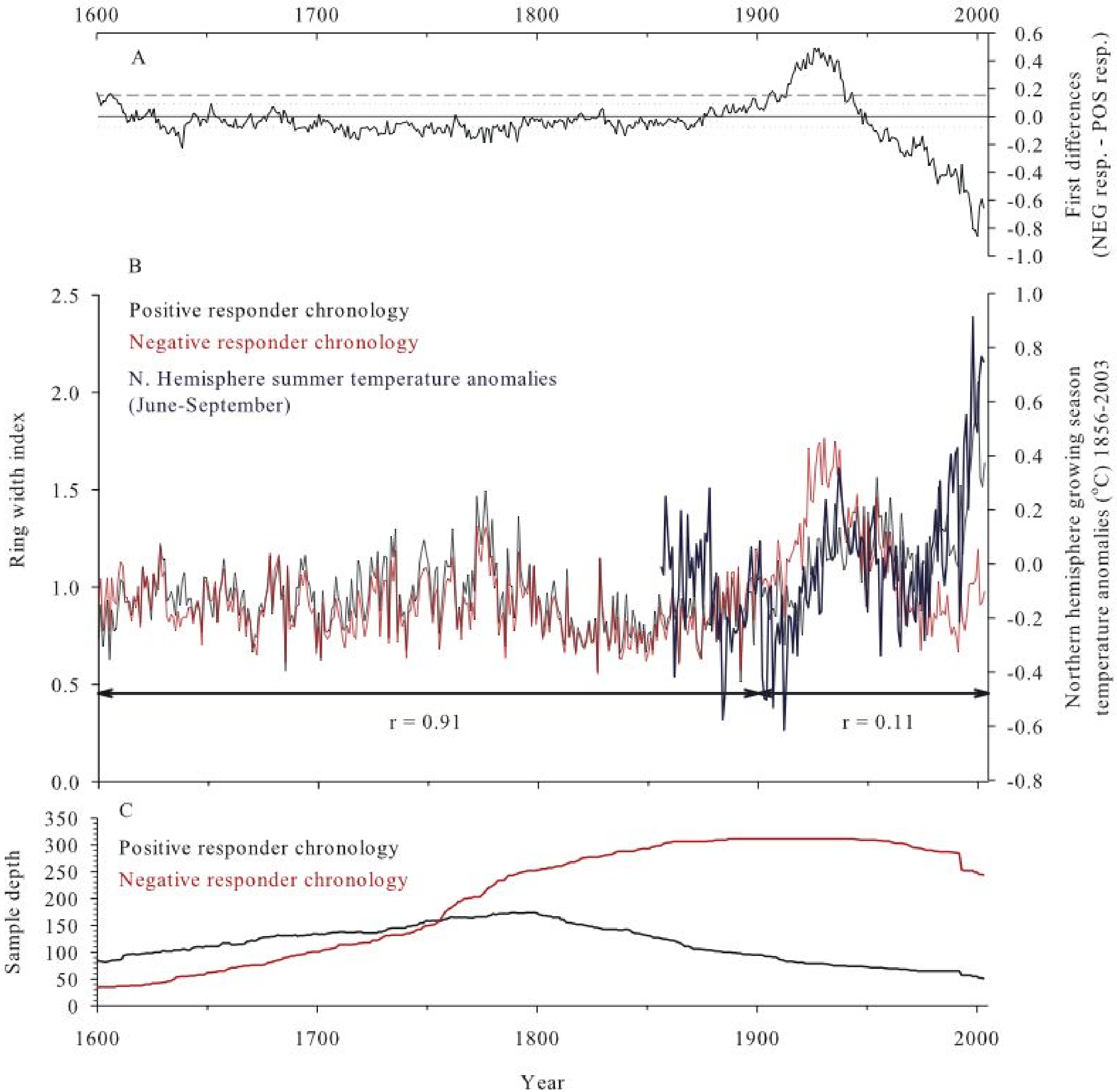


Regional climate change predictions
2080-2089 relative to 1980-1999



IPCC 2007

Warmer and Wetter generally; Drier regionally !



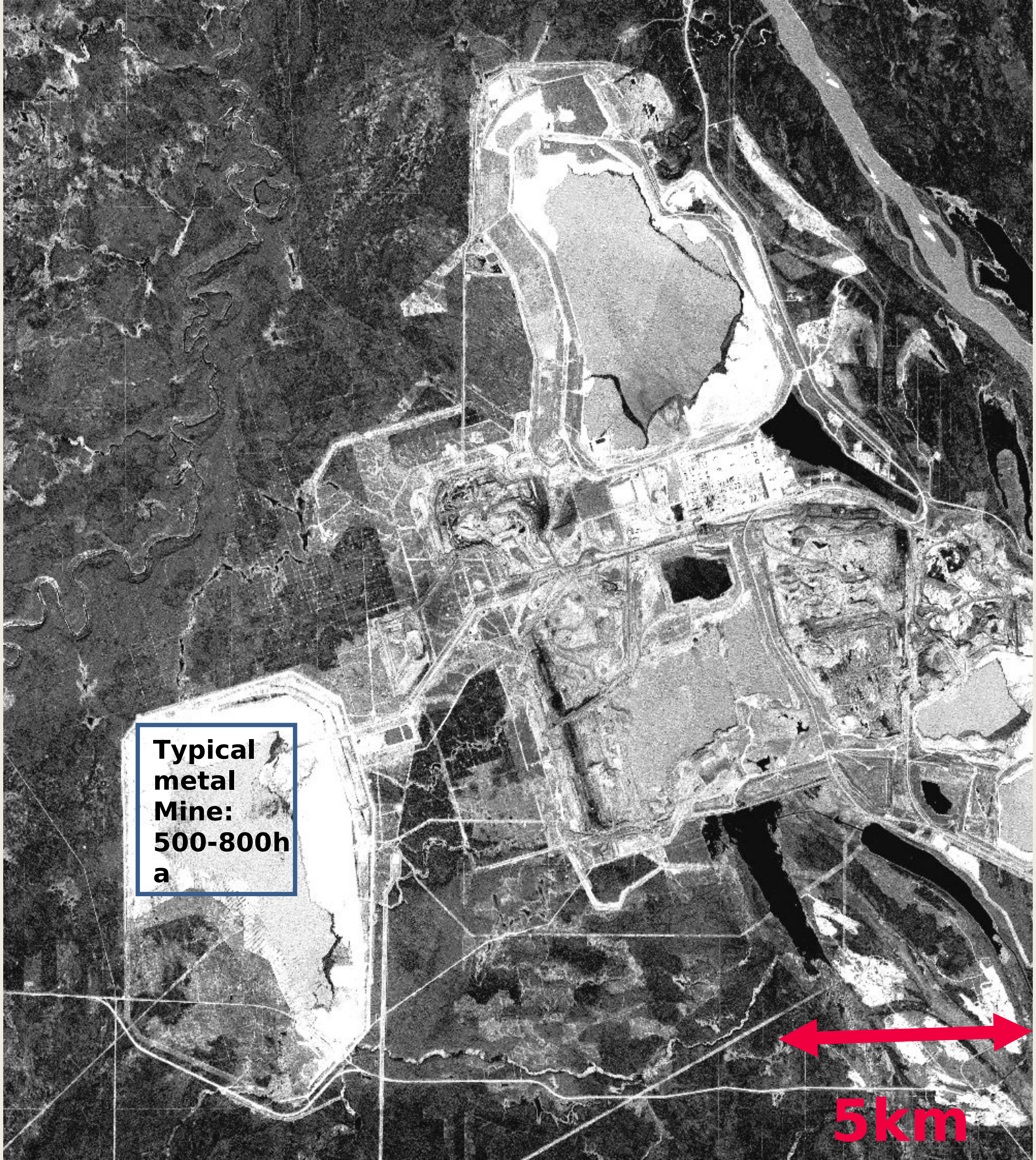
From Pisaric MJF, Carey SK, Kokelj S, Youngblut D, 2007, Geophysical Research Letters

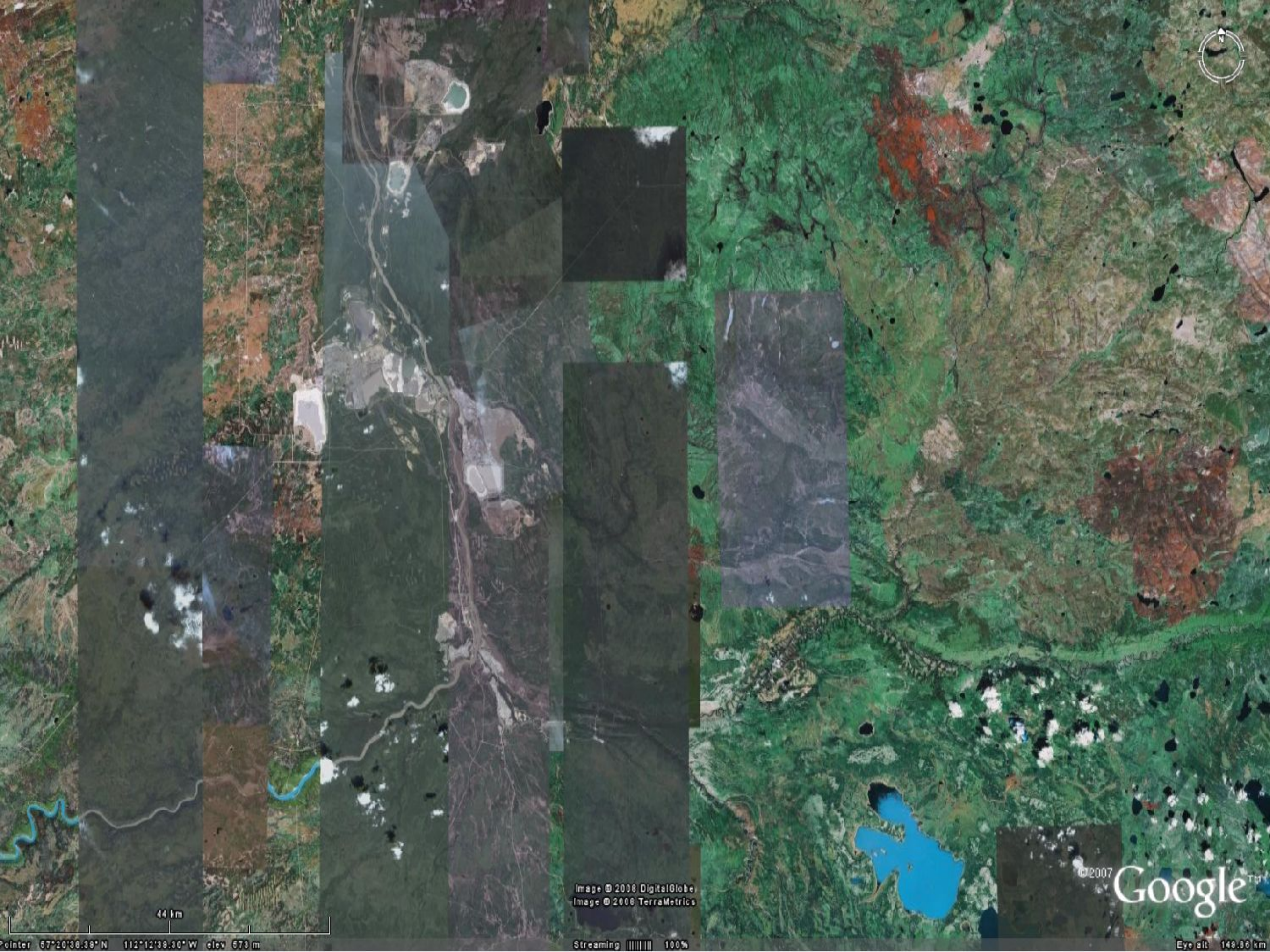
Across northwest NA, certain tree species no longer respond to climate signals as in the past half-millennia

Evidence that ecological thresholds have been reached

Ecosystem Change

But what else is changing in the north?



Typical metal Mine: 500-800ha
5km



44 km
Image © 2008 DigitalGlobe
Image © 2008 TerraMetrics
©2007 Google
Streaming 100%
Eye alt 149.86 km

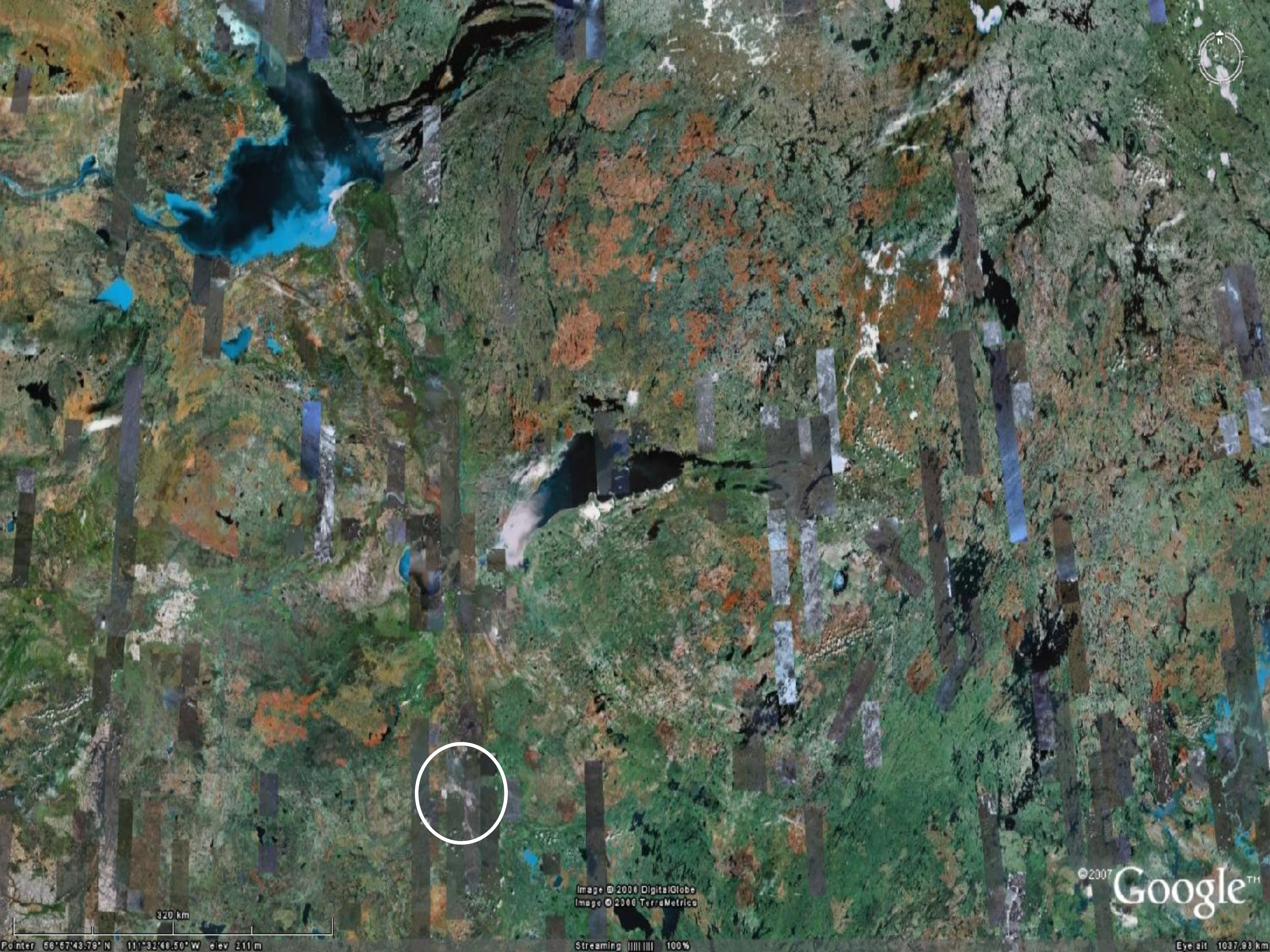
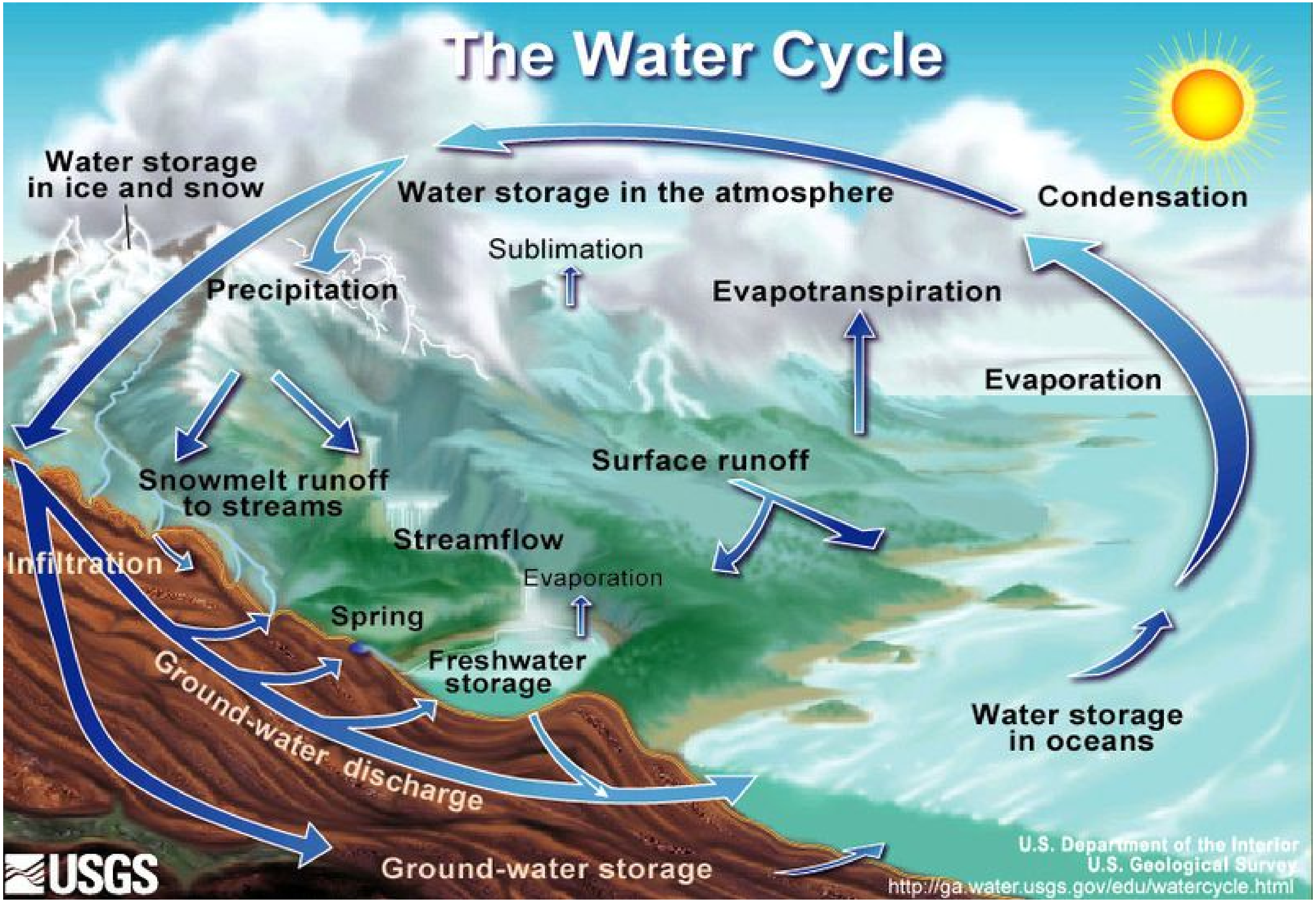


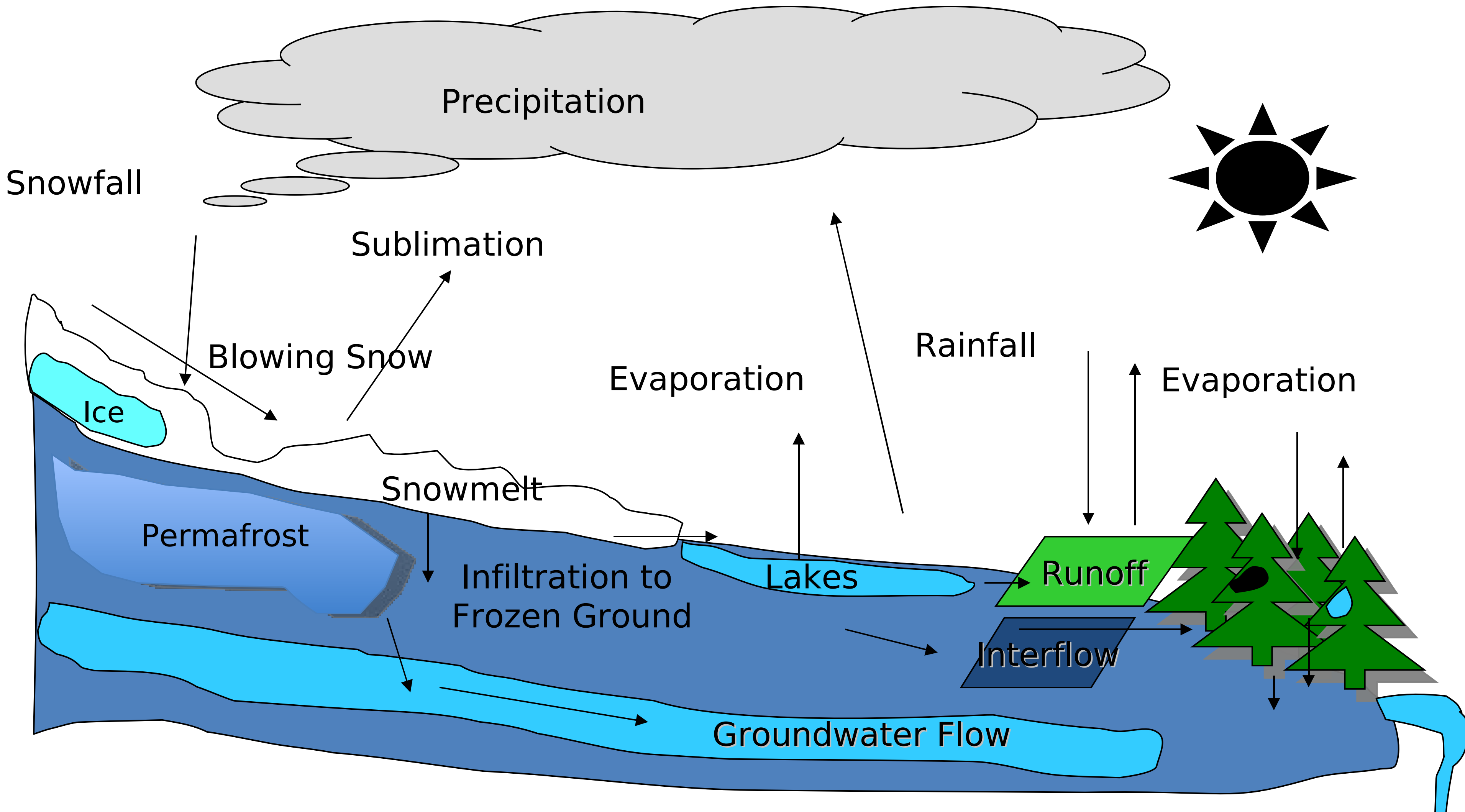
Image © 2008 DigitalGlobe
Image © 2008 TerraMetrics
320 km
Pointer 56°57'43.79" N 111°32'48.50" W elev 211 m
Streaming 100%
©2007 Google™
Eye alt 1037.93 km

The Global Water (hydrological) Cycle



As found on Wikipedia

Cold Regions Hydrological Cycle



Energy and Water are closely linked in cold regions

Slide courtesy J. Pomeroy

How will a changing climate and human activity affect the northern water cycle?

IP3

- ...is devoted to understanding **water supply** and **weather systems** in cold Regions at high altitudes and high latitudes (Rockies and western Arctic)

- ...will contribute to better prediction of regional and local **weather, climate, and water resources** in cold regions, including ungauged basin **streamflow,** changes in **snow and water supplies,** and calculation of **freshwater inputs** to the Arctic Ocean

- ...is composed over about 40 investigators and collaborators from Canada, USA, UK, Germany

- ...runs from 2006-2010

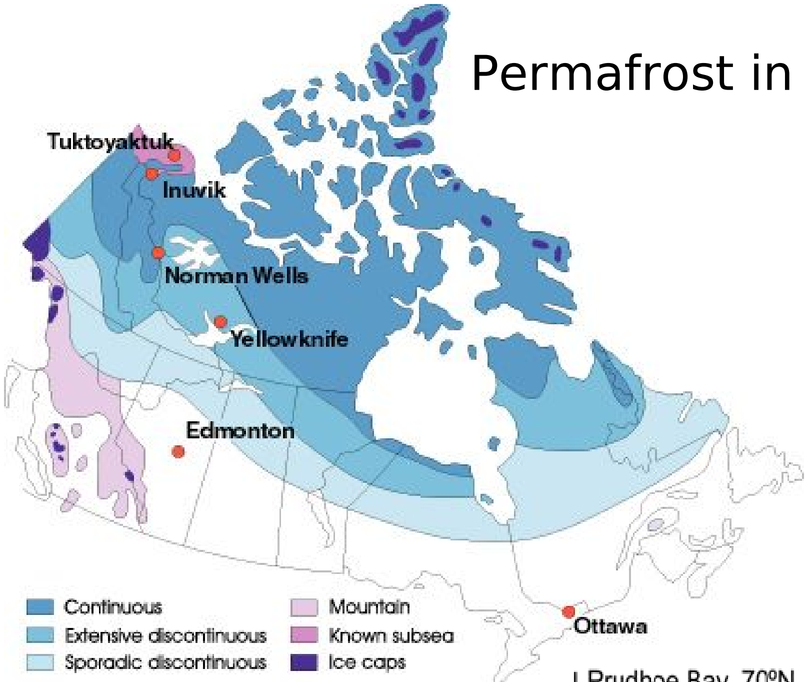
- **.....We are here in Whitehorse! There is a lot of experts here who know more than I.**

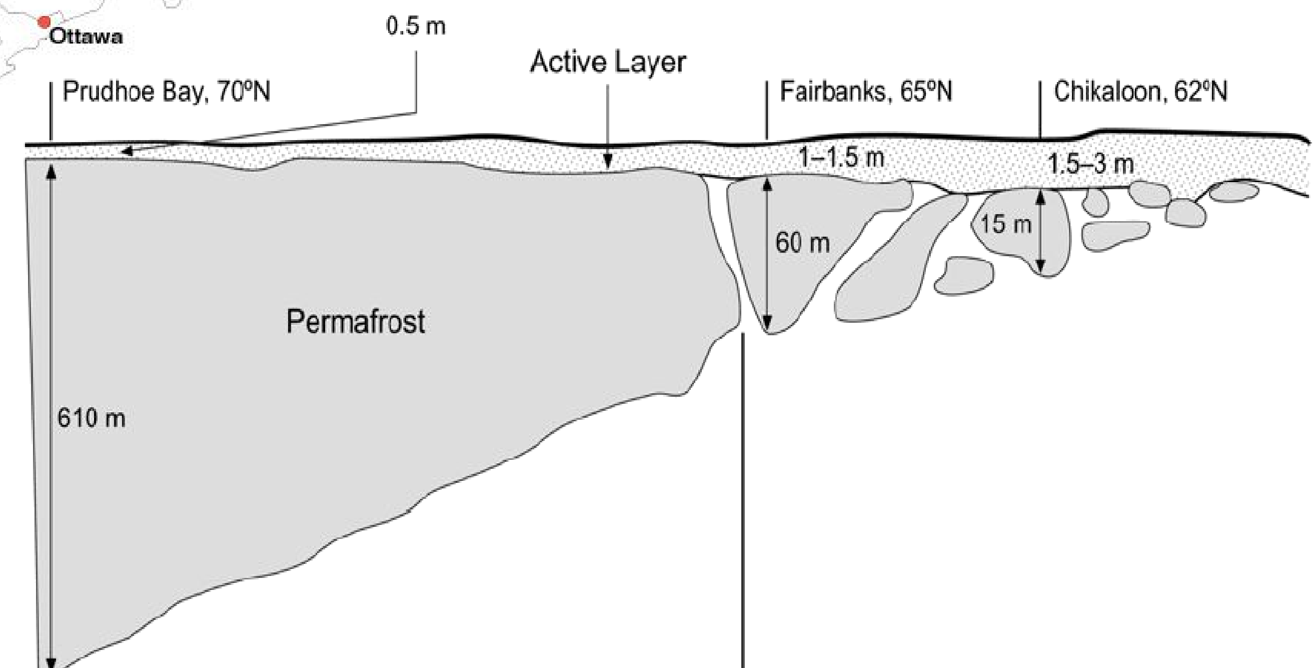
Improved Processes & Parameterisation for Prediction in Cold Regions

IPY·API
International Polar Year
Année polaire internationale
2007·2008

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

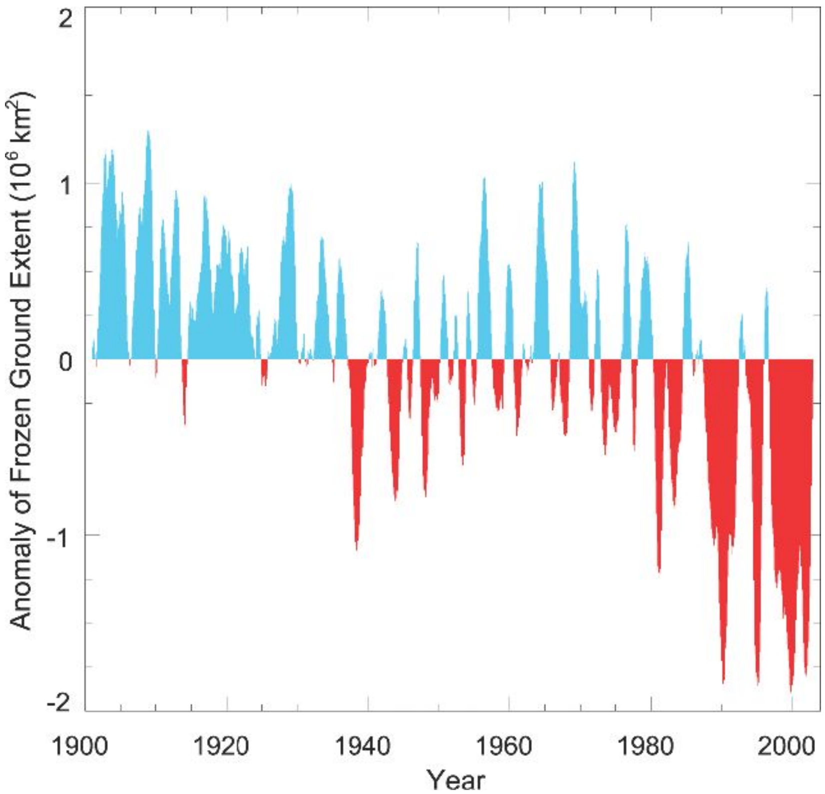
What makes northern regions so sensitive?





.... And projected to continue declining

Permafrost is Declining



IPCC 4th Assessment

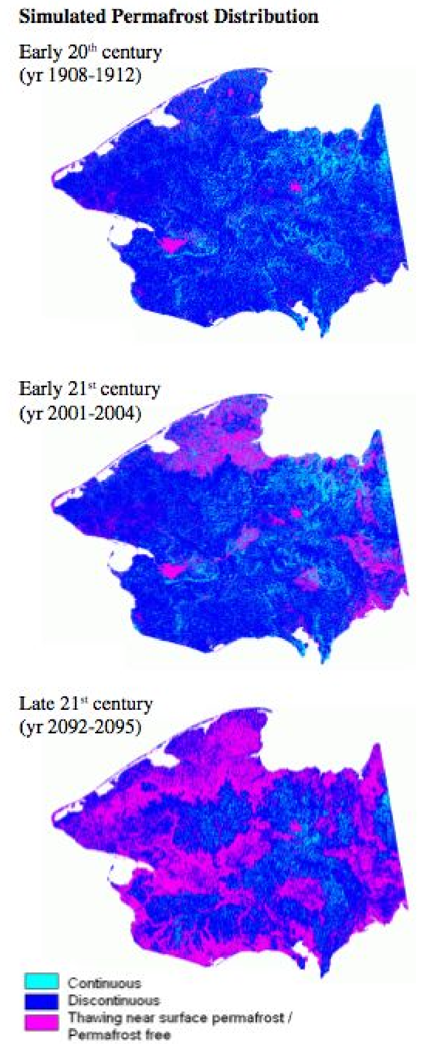
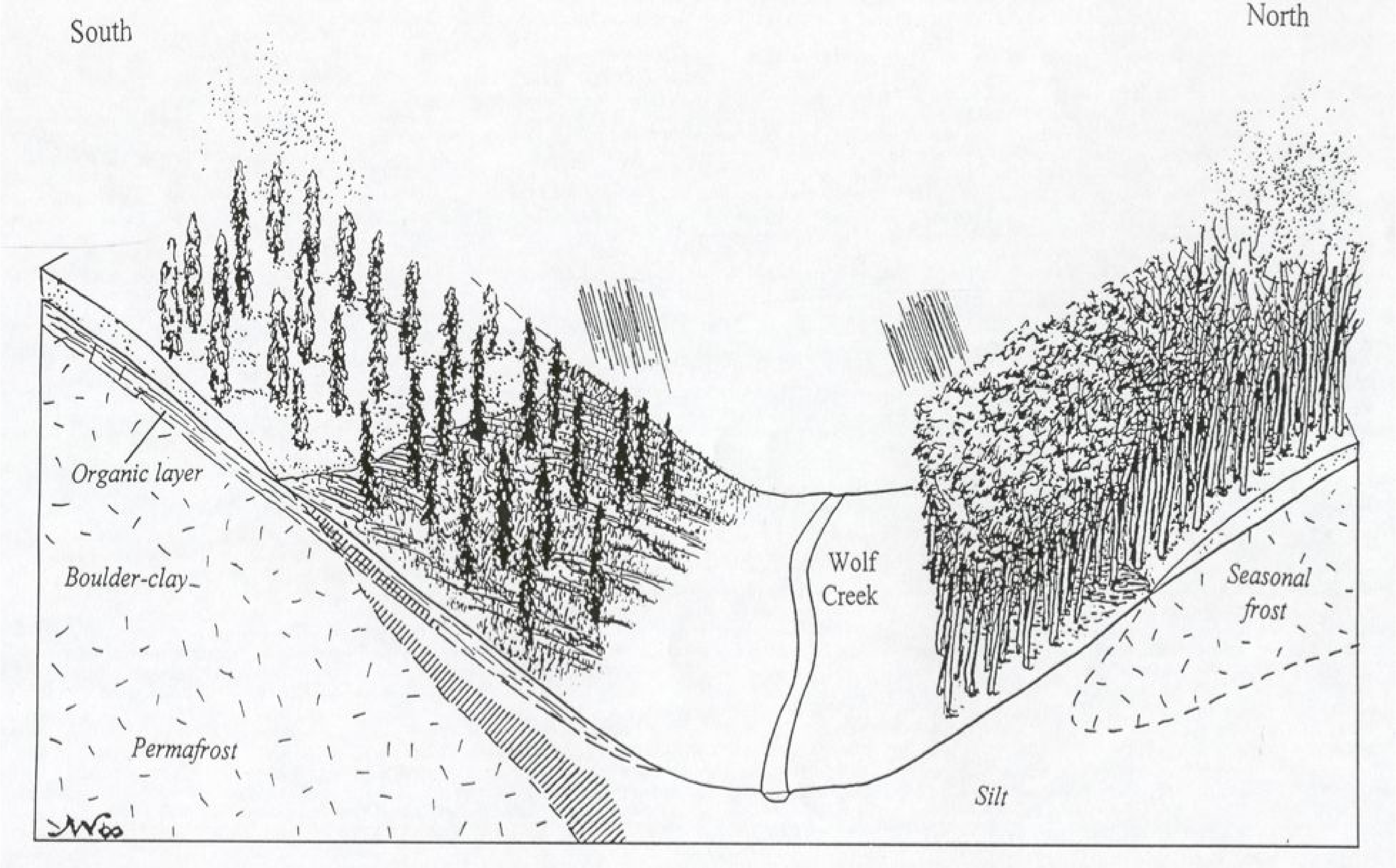


Figure 3. Simulated permafrost distribution at Seward Peninsula in the early 20th, 21st and late 21st century. Continuous permafrost represents annual average ground surface temperatures colder than 23°F and discontinuous permafrost colder than 32°F but warmer than 23°F.

Courtesy L. Hinzman

Permafrost Hydrology

- Permafrost acts as an aquitard, restricting the vertical movement of of water



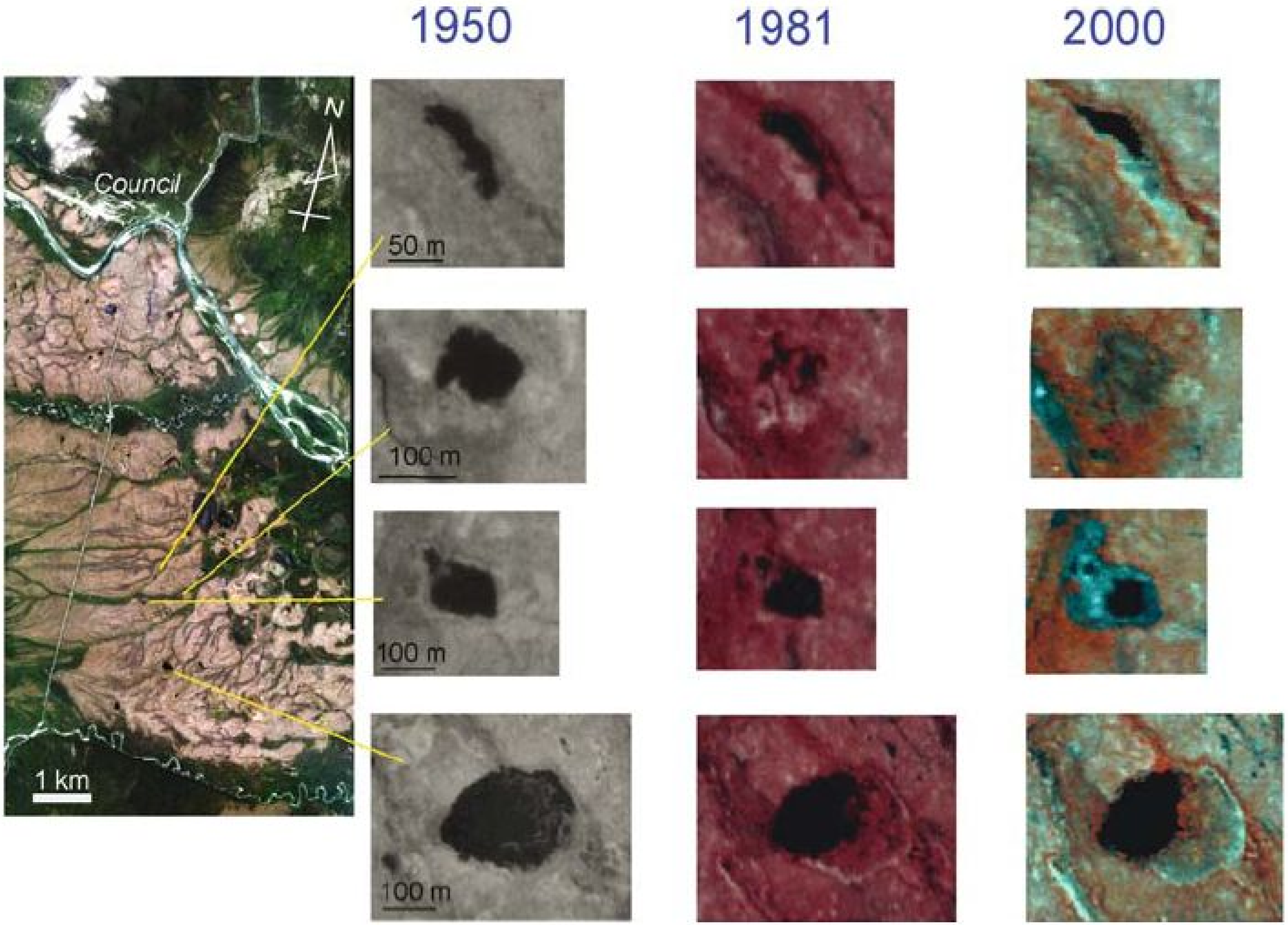
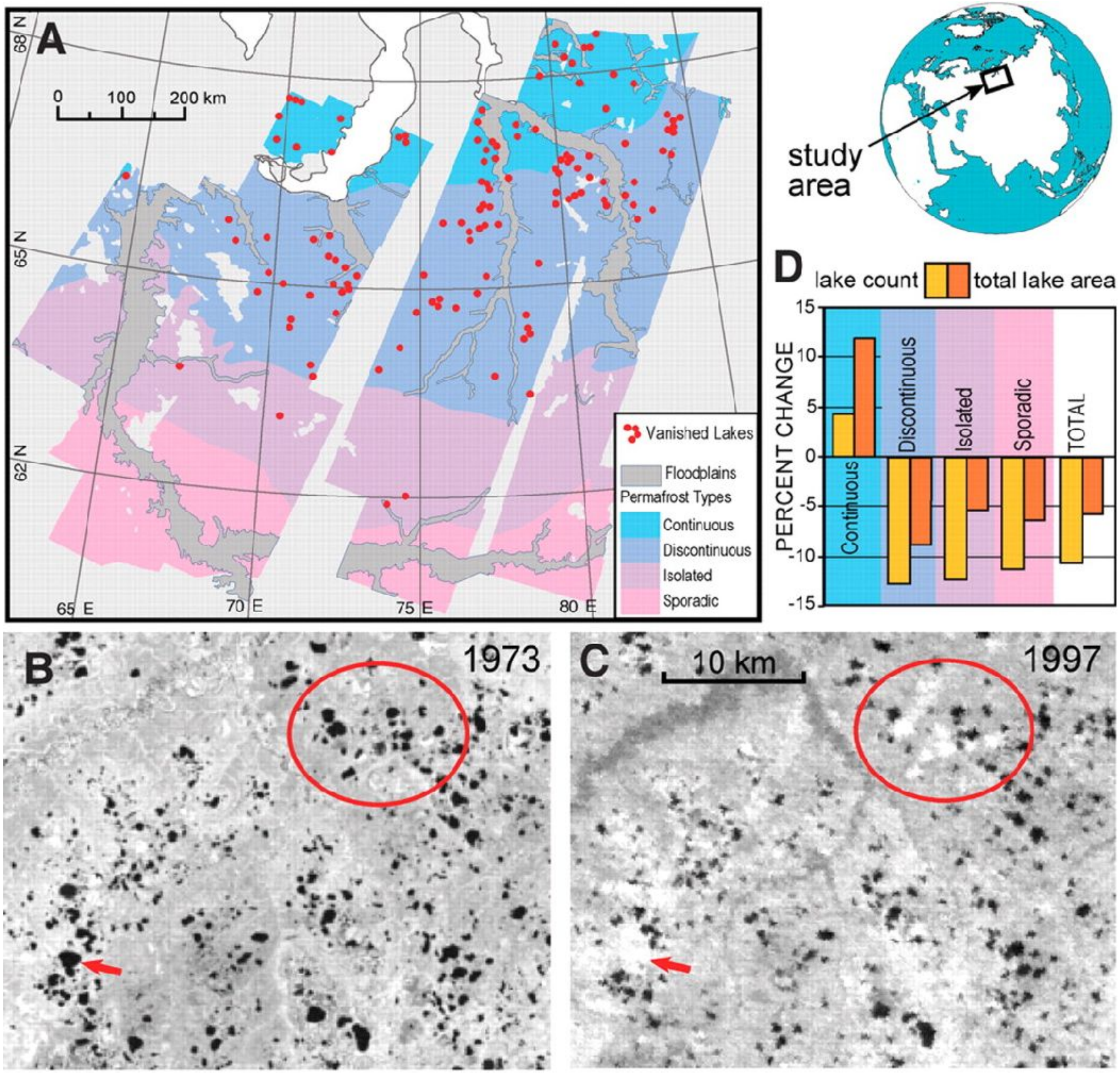
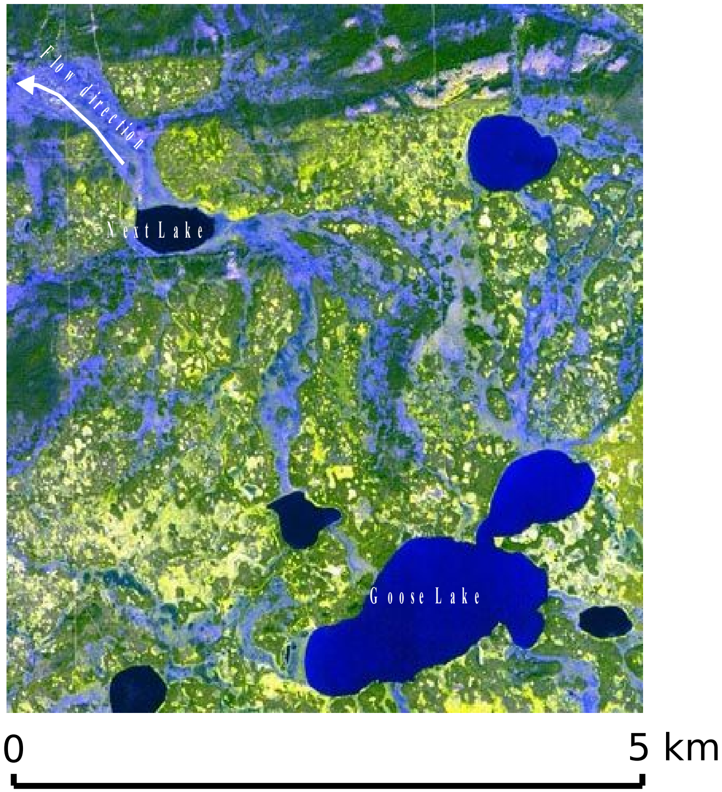


Figure 6. Numerous tundra ponds near Council, Alaska (64°51′N, 163°42′W) have decreased in surface area over the last 50 years. A probable mechanism for these shrinking ponds is internal drainage through the degradation of shallow permafrost (Yoshikawa and Hinzman, 2003).



From Smith et al. 2005

Northern Wetlands

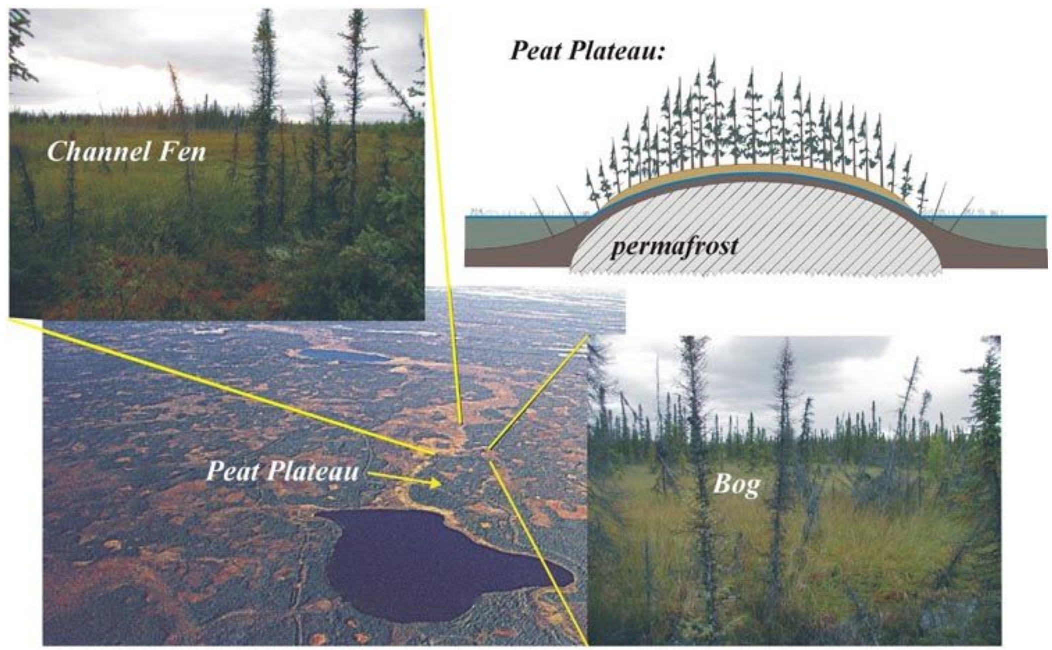


Major Landscape Types:

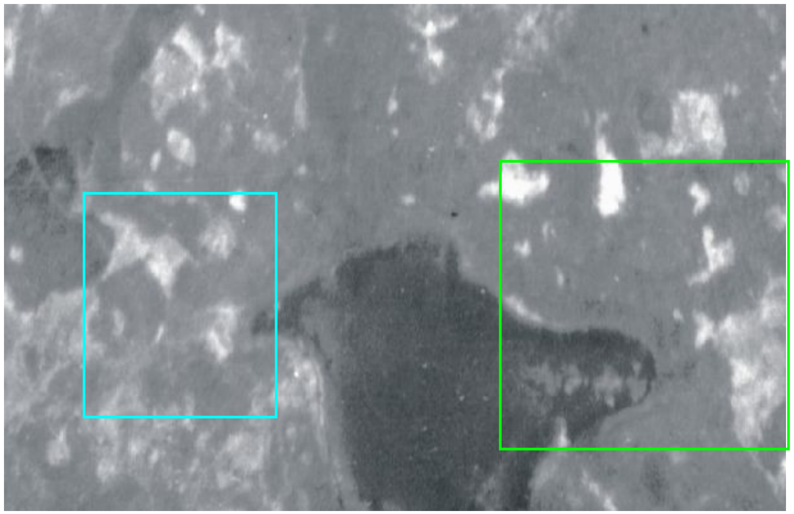
a) Peat Plateaus

b) Channel Fens

c) Flat Bogs

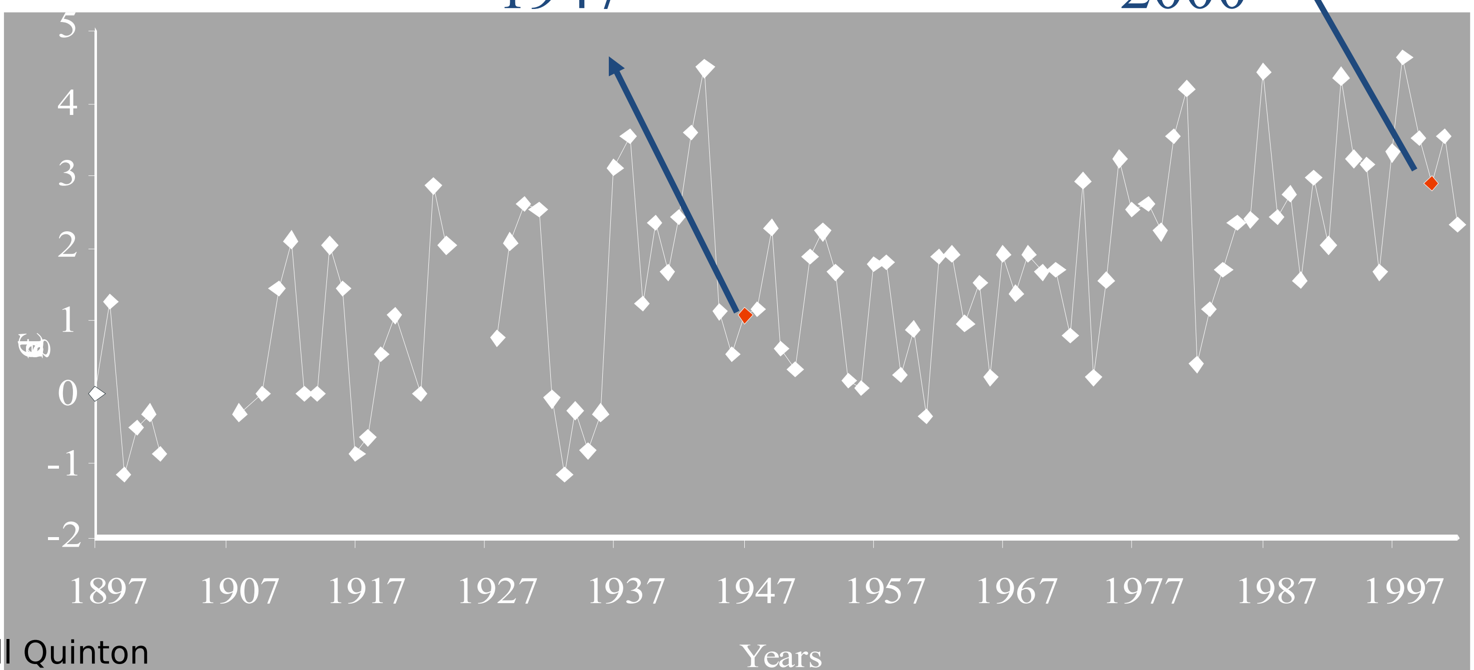


Fort Simpson NWT - Permafrost Decrease 30% in 53 Years

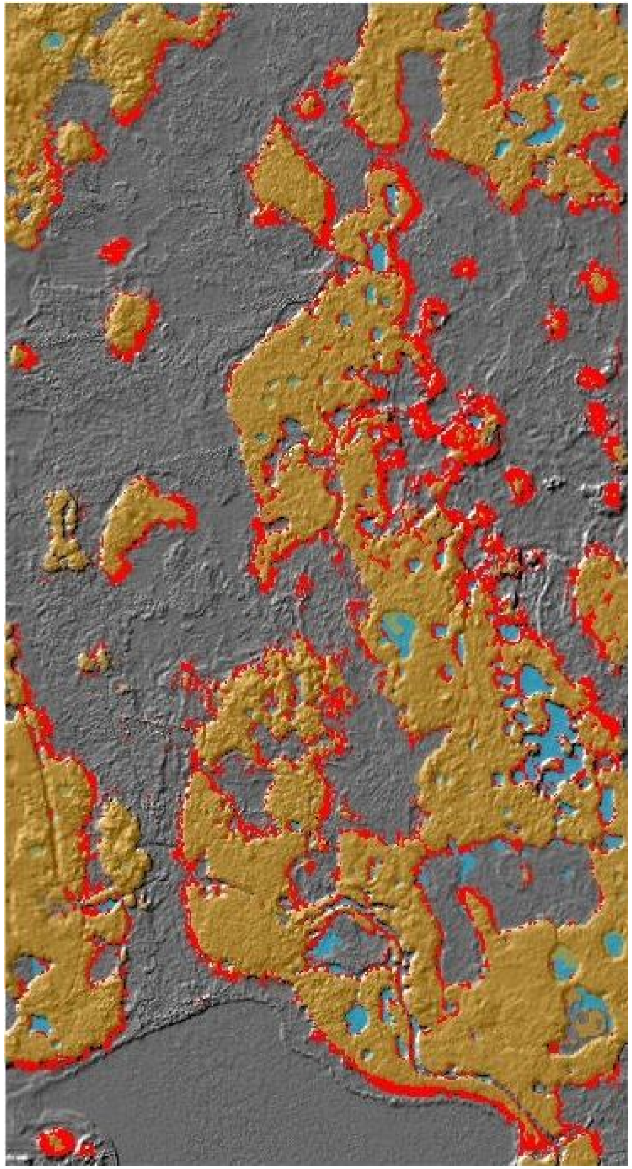


1947

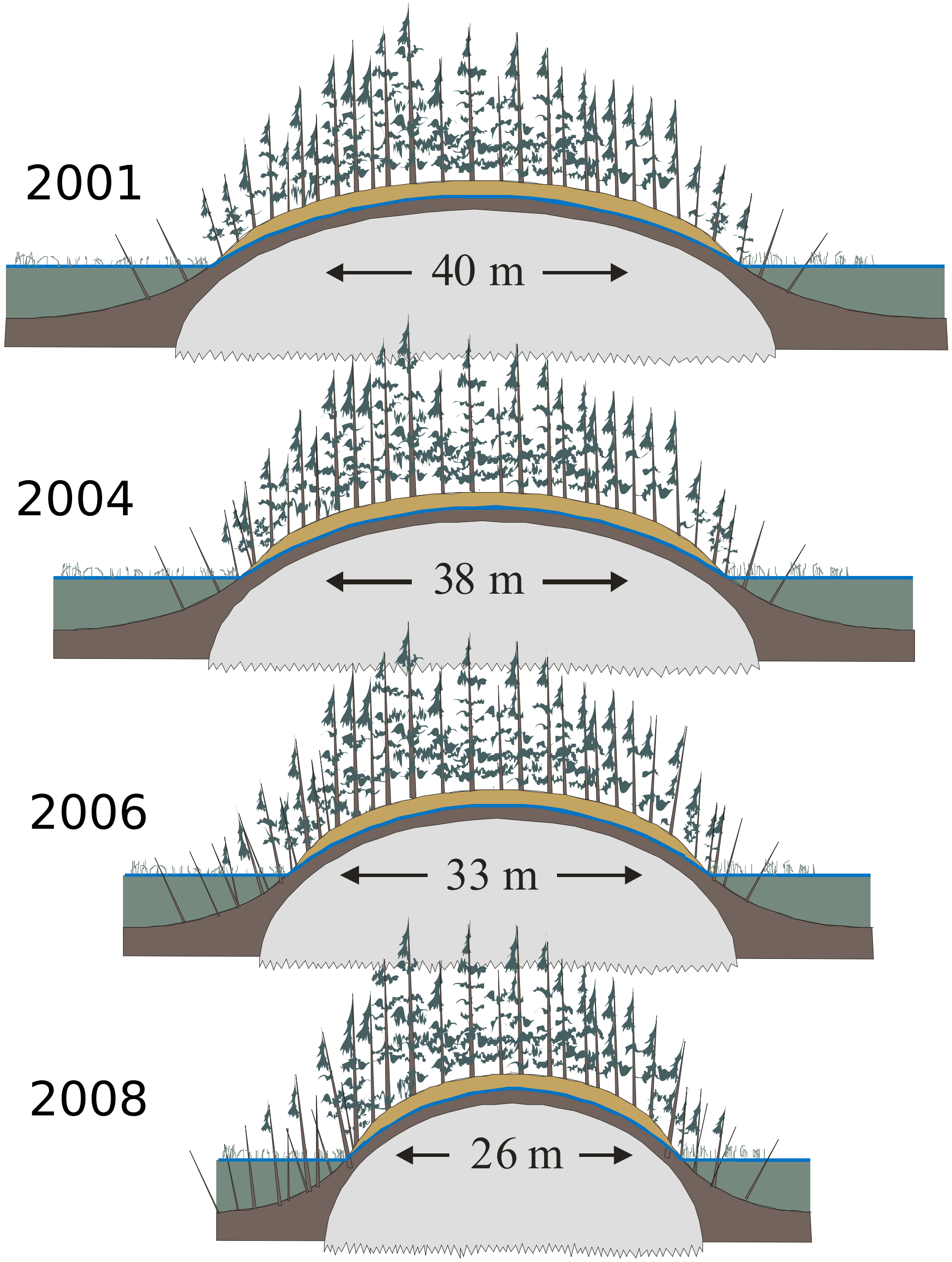
2000



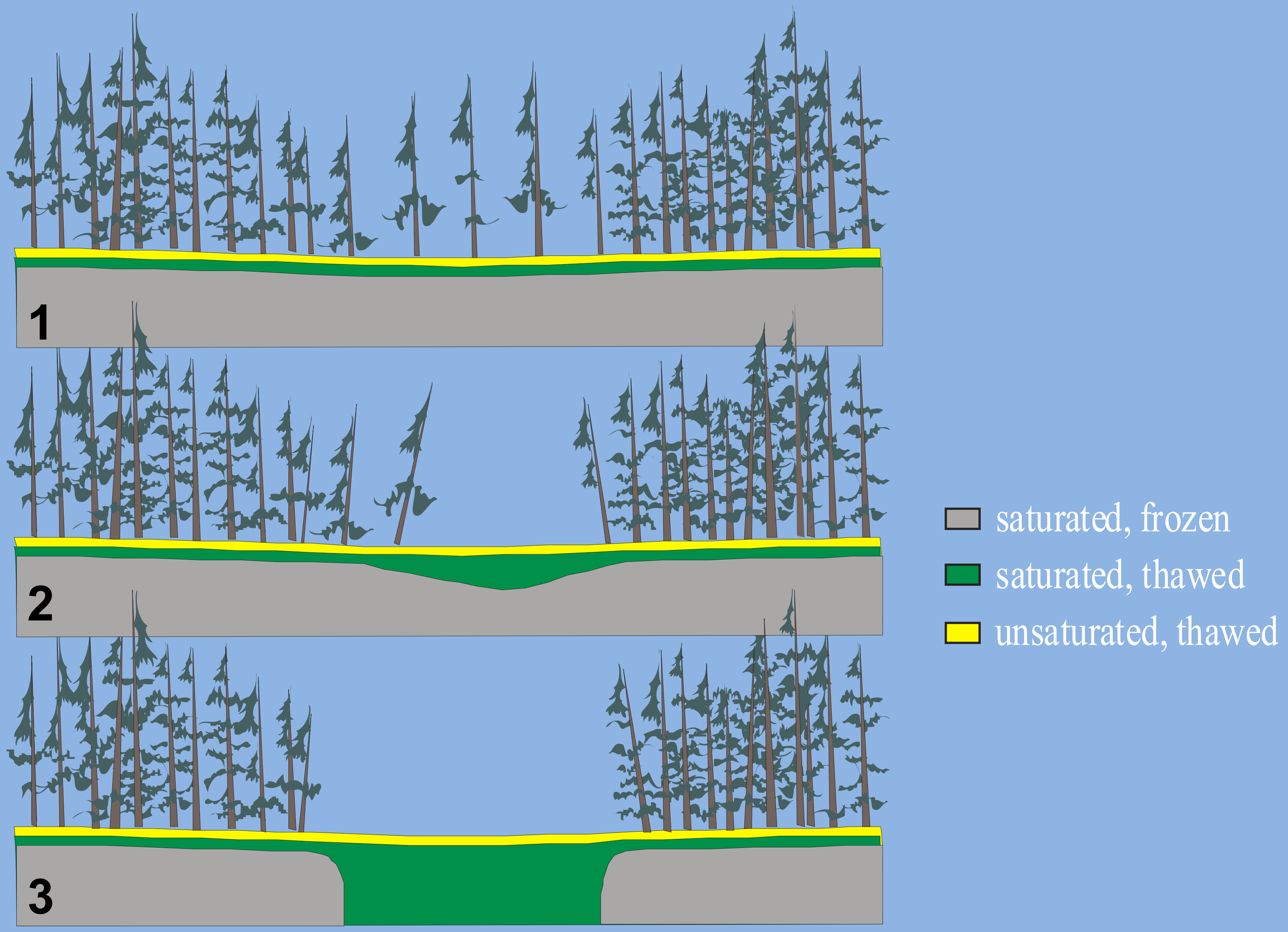
Courtesy Bill Quinton



Shaded lidar DEM with 2008 peat plateaus (brown) and disconnected sinks (blue). Red areas show retreat of peat plateaus from 2000 to 2008.



Images courtesy L. Chasmer and B. Quinton



Images courtesy B. Quinton

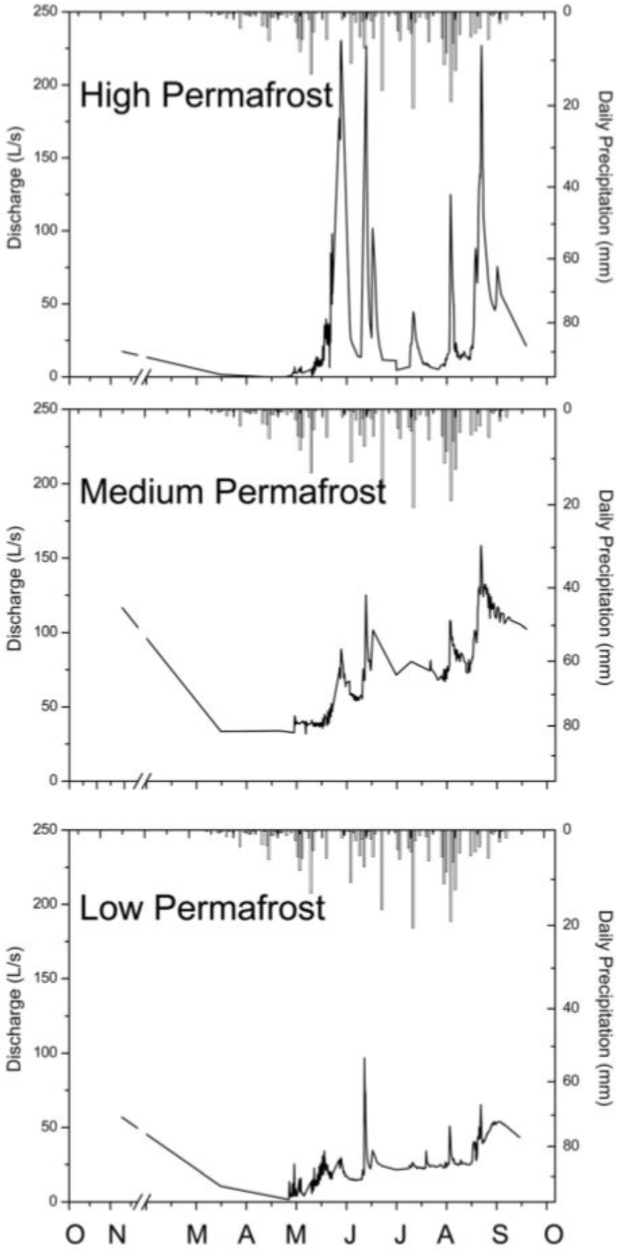
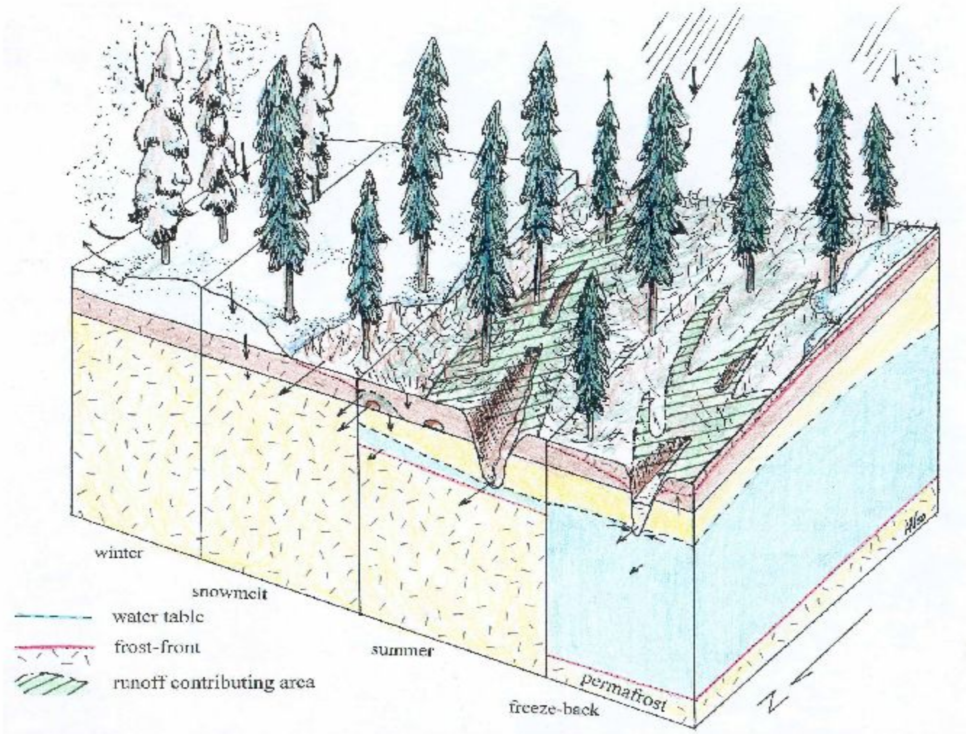
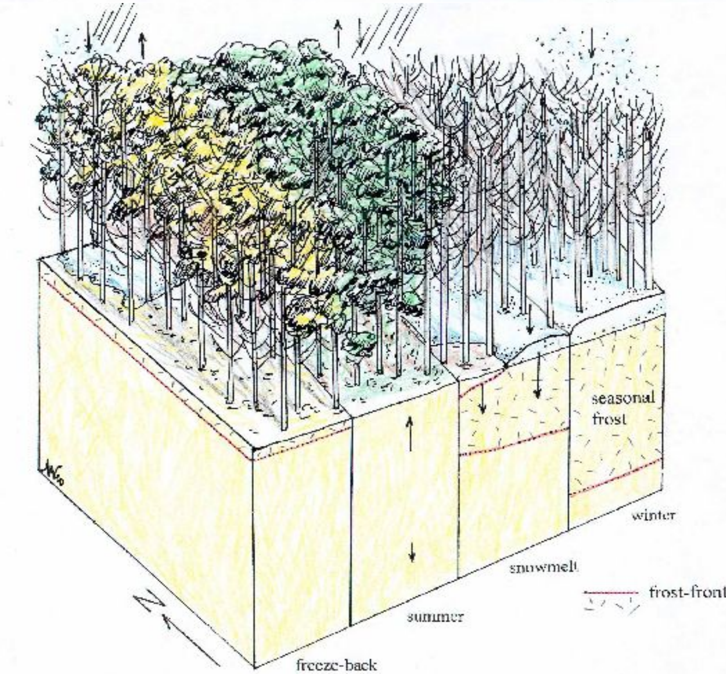


Figure 2. Hydrograph and daily precipitation for the high-, medium-, and low-permafrost watersheds, October 2000 through September 2001.





From Petrone et al. 2007, JGR-B

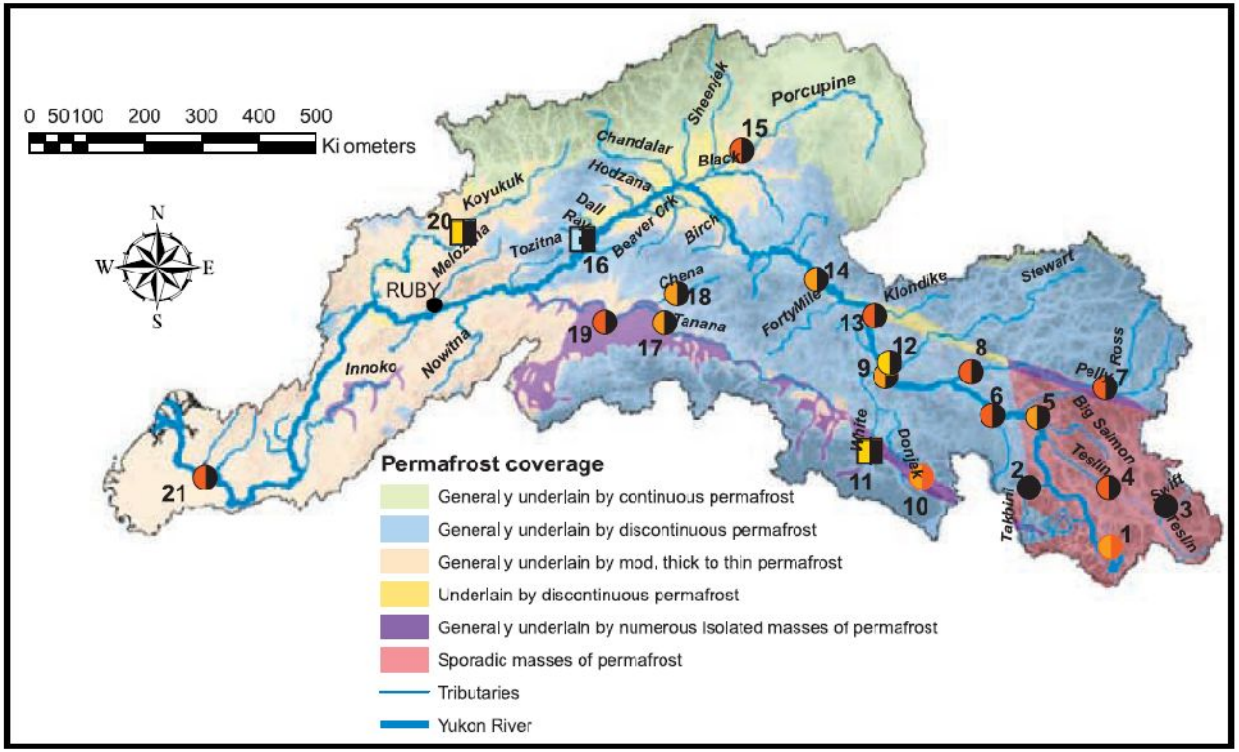
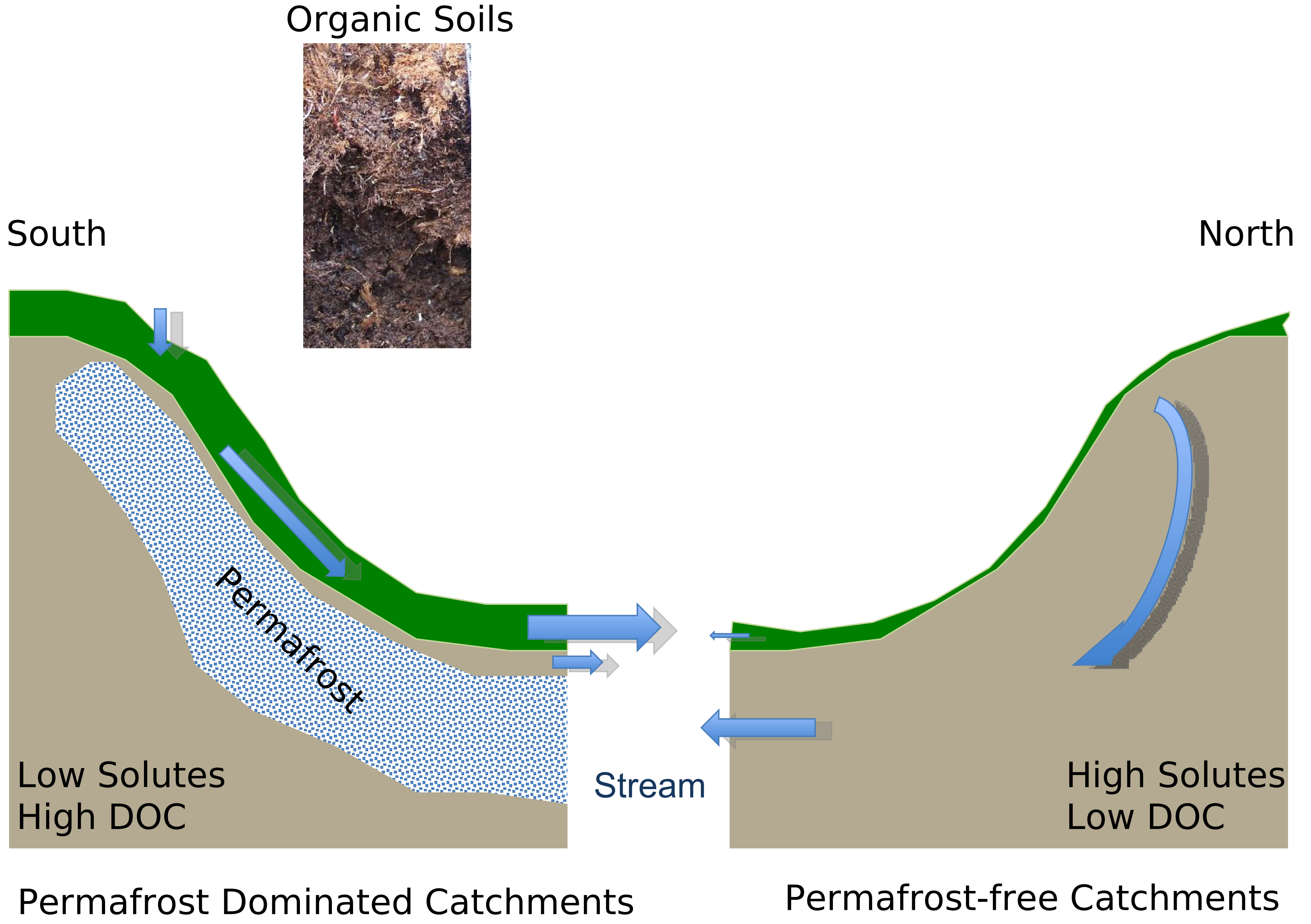
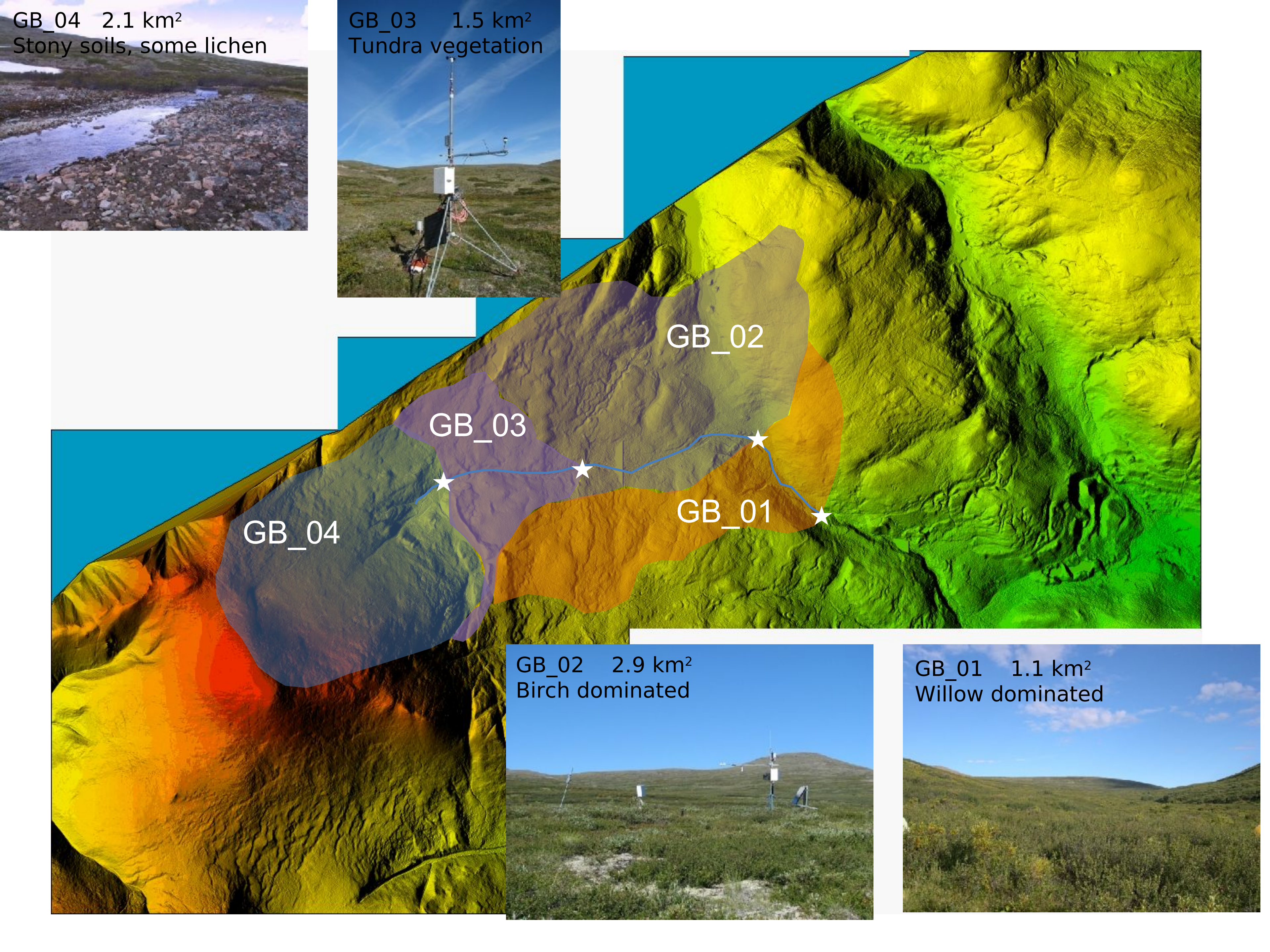


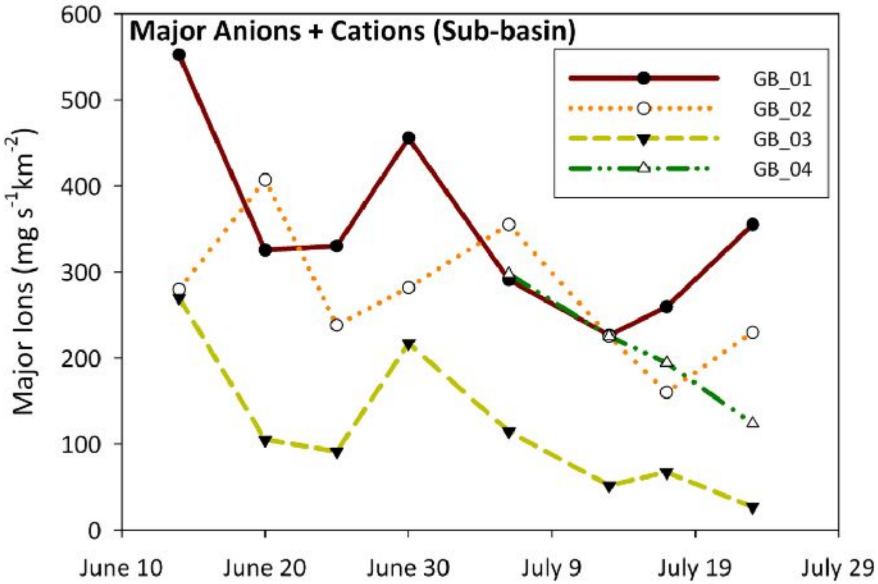
Figure 3. Observed trends in groundwater input (denoted by left side of marker) and annual flow (denoted by right side of marker) at YRB streamflow stations. Circle and square markers indicate flow records >30 years and <30 years, respectively. Marker color scheme indicates statistical significance of Mann-Kendall trend analysis: red, very highly significant ($P < 0.01$) upward trend; orange, highly significant ($0.01 < P < 0.05$) upward trend; yellow, moderately significant ($0.05 < P < 0.1$) upward trend; light blue, moderately significant ($0.05 < P < 0.1$) downward trend; and black, no significant ($0.1 < P$) trend.

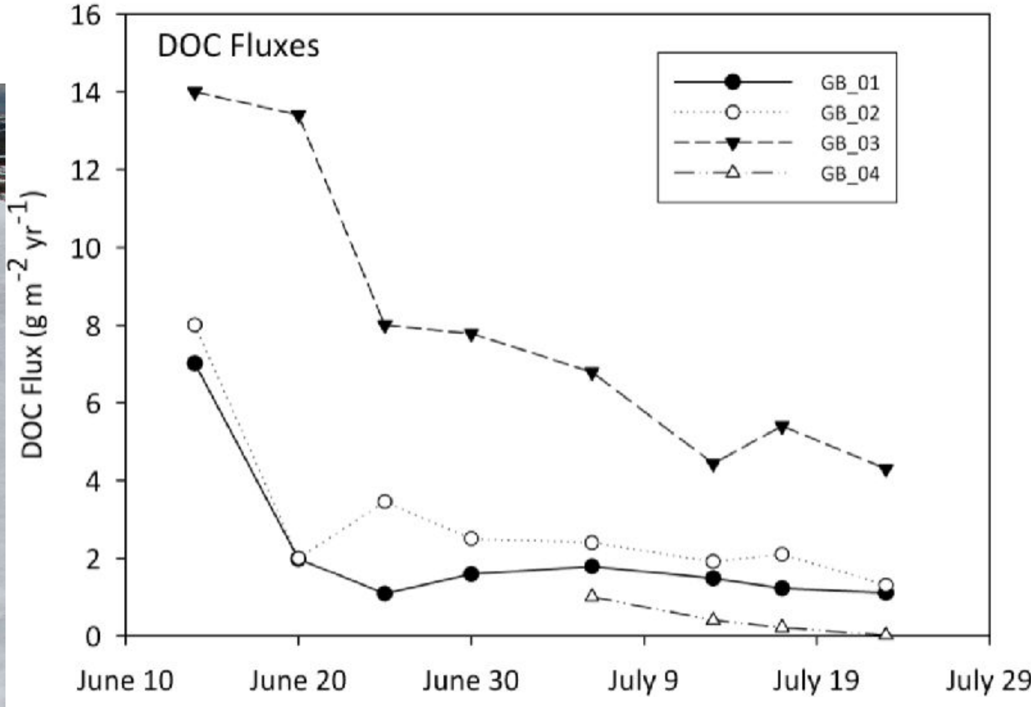
From Warvoold et al. 2007

Streamflow chemistry and water quality will also be impacted as the movement of water in the subsurface changes


Organic Soils
South
North
Permafrost
Stream
Low Solutes
High DOC
High Solutes
Low DOC
Permafrost Dominated Catchments
Permafrost-free Catchments


GB_04 2.1 km²
Stony soils, some lichen
GB_03 1.5 km²
Tundra vegetation
GB_02
GB_03
GB_04
GB_01
GB_02 2.9 km²
Birch dominated
GB_01 1.1 km²
Willow dominated


Major Anions + Cations (Sub-basin)
GB_01
GB_02
GB_03
GB_04
Major Ions (mg s-1km-2)
600
500
400
300
200
100
0
June 10
June 20
June 30
July 9
July 19
July 29


DOC Fluxes
GB_01
GB_02
GB_03
GB_04
DOC Flux (g m-2 yr-1)
16
14
12
10
8
6
4
2
0
June 10
June 20
June 30
July 9
July 19
July 29

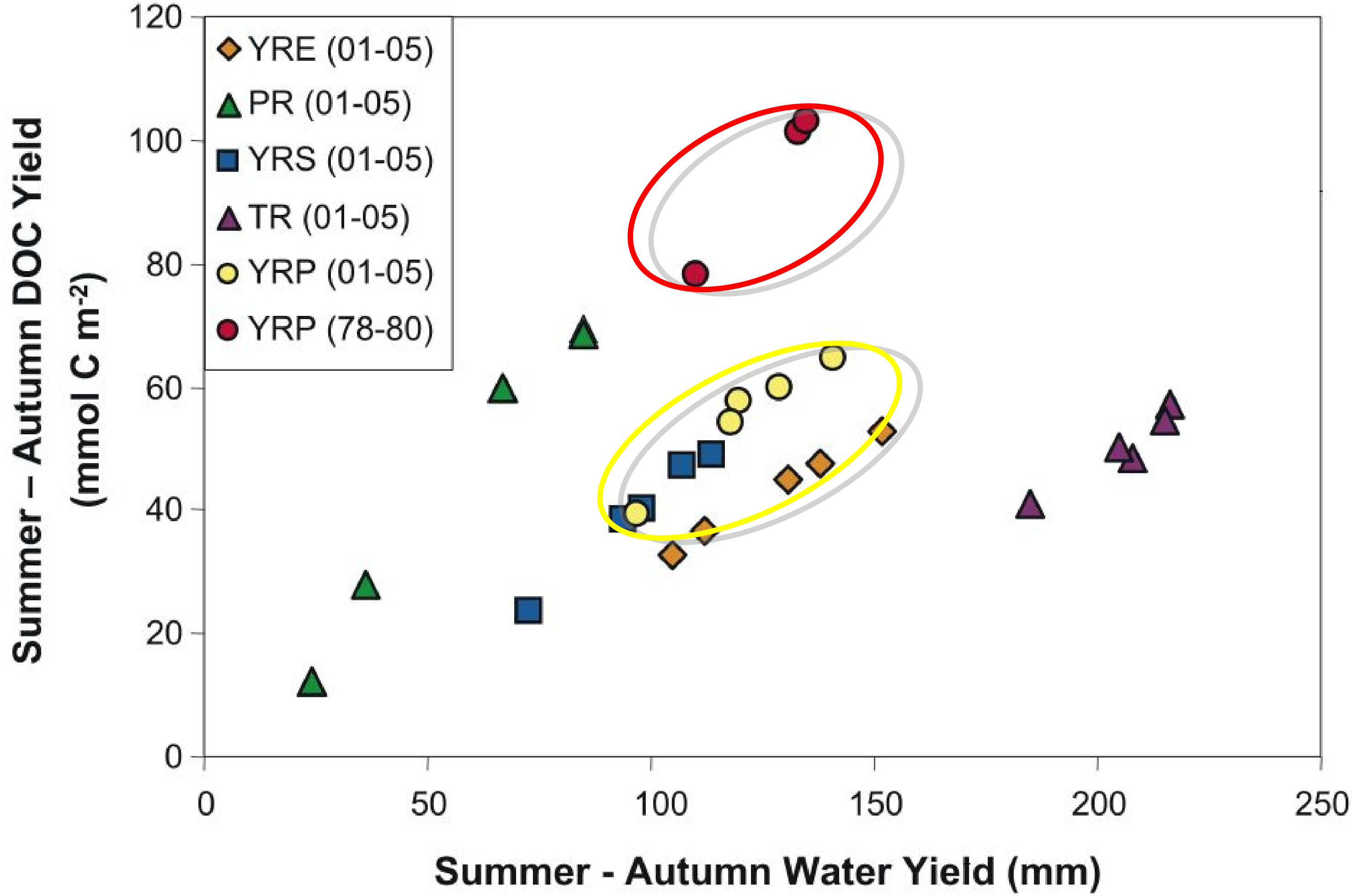
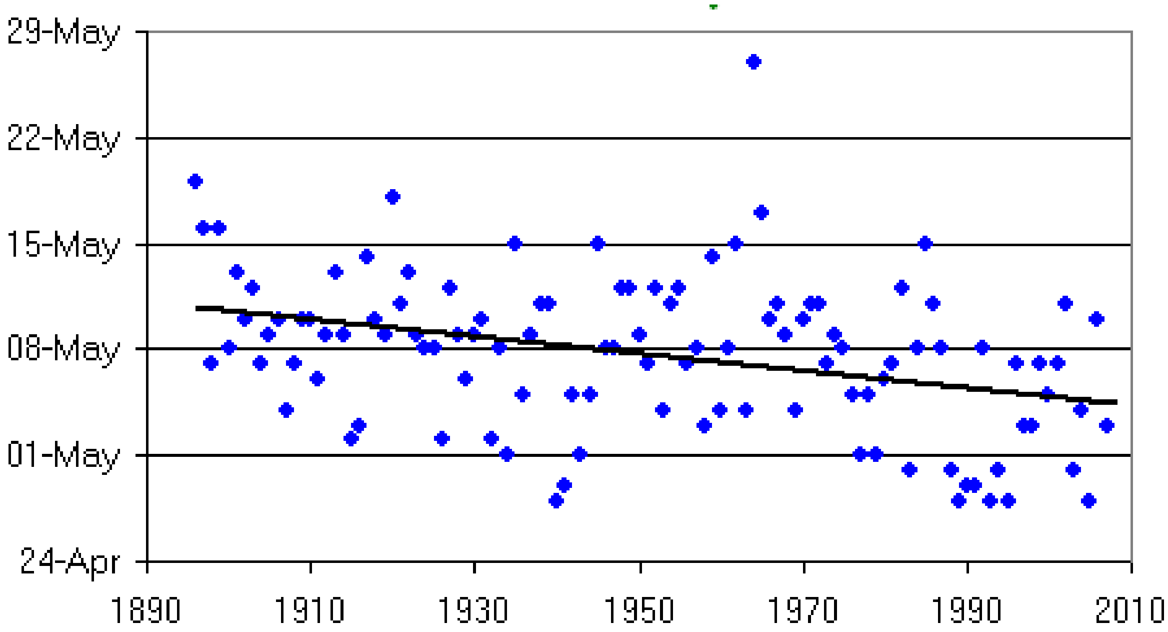


Figure 5. Summer–autumn DOC yields for the five measurement stations, 2001–2005, and for YRP, 1978–1980.

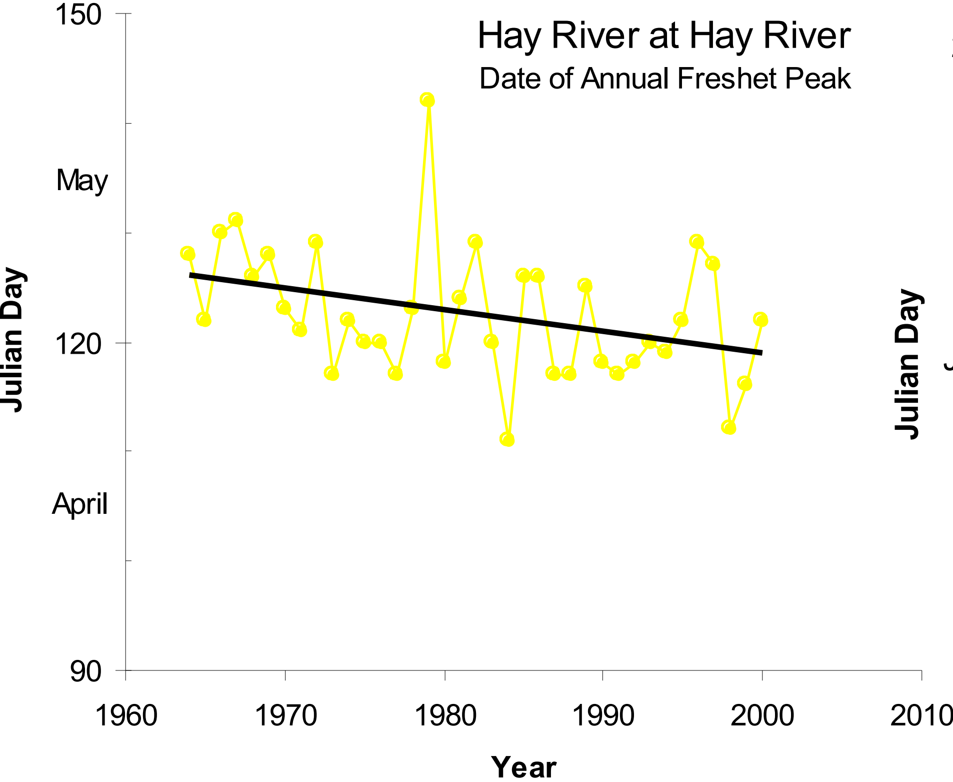
Changing climate also affects the timing and magnitude of floods, breakup and river freezing

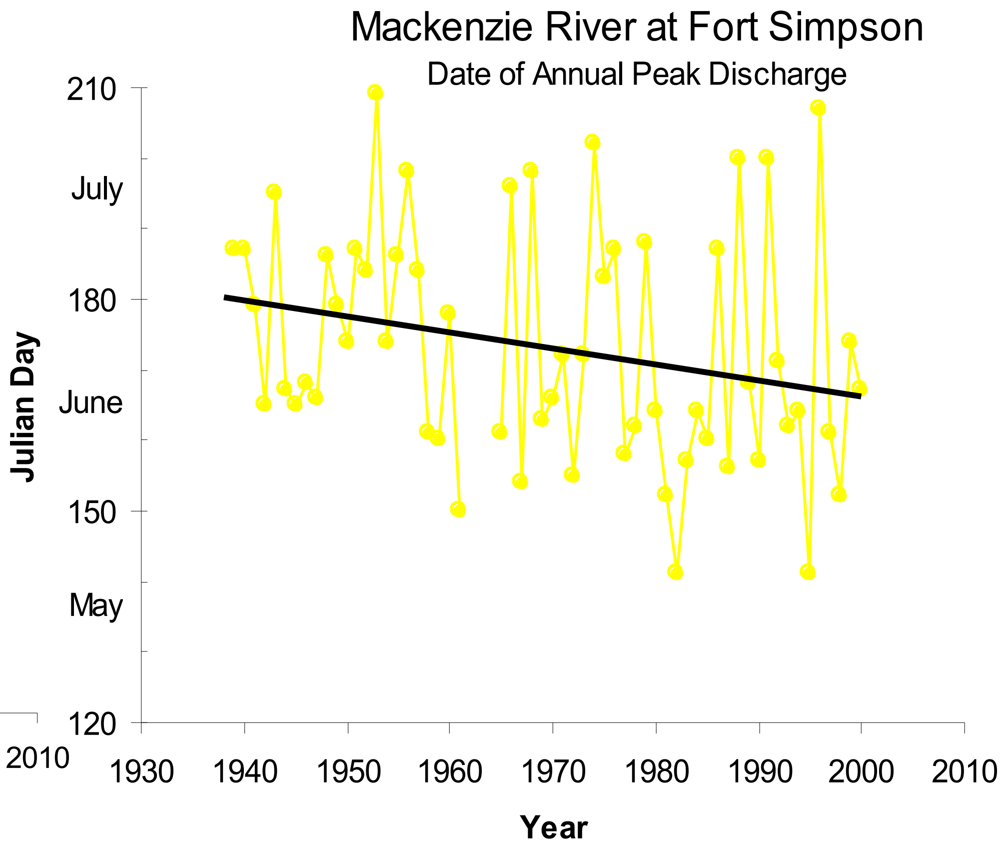
Yukon River Breakup at Dawson City

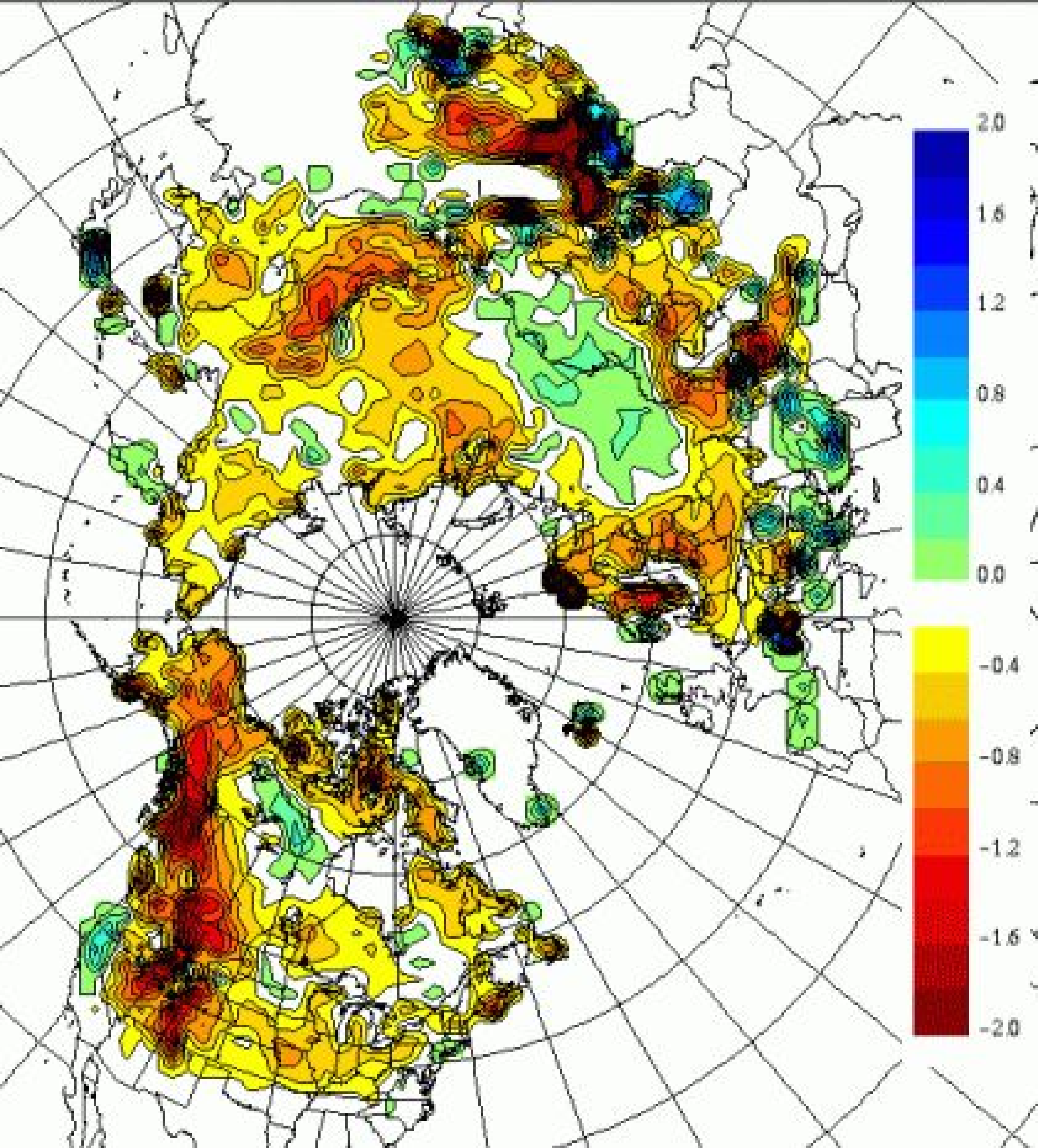


Data source: Water Resources, YTG

Date of Spring Peak Streamflow in Northern Canada







Snow-covered Period is Declining in many places

Average change (days/yr) in snow cover duration in the second half (Feb.-Jul.) of the snow year over the period 1972-2000.

Derived from the NOAA weekly satellite snow cover dataset

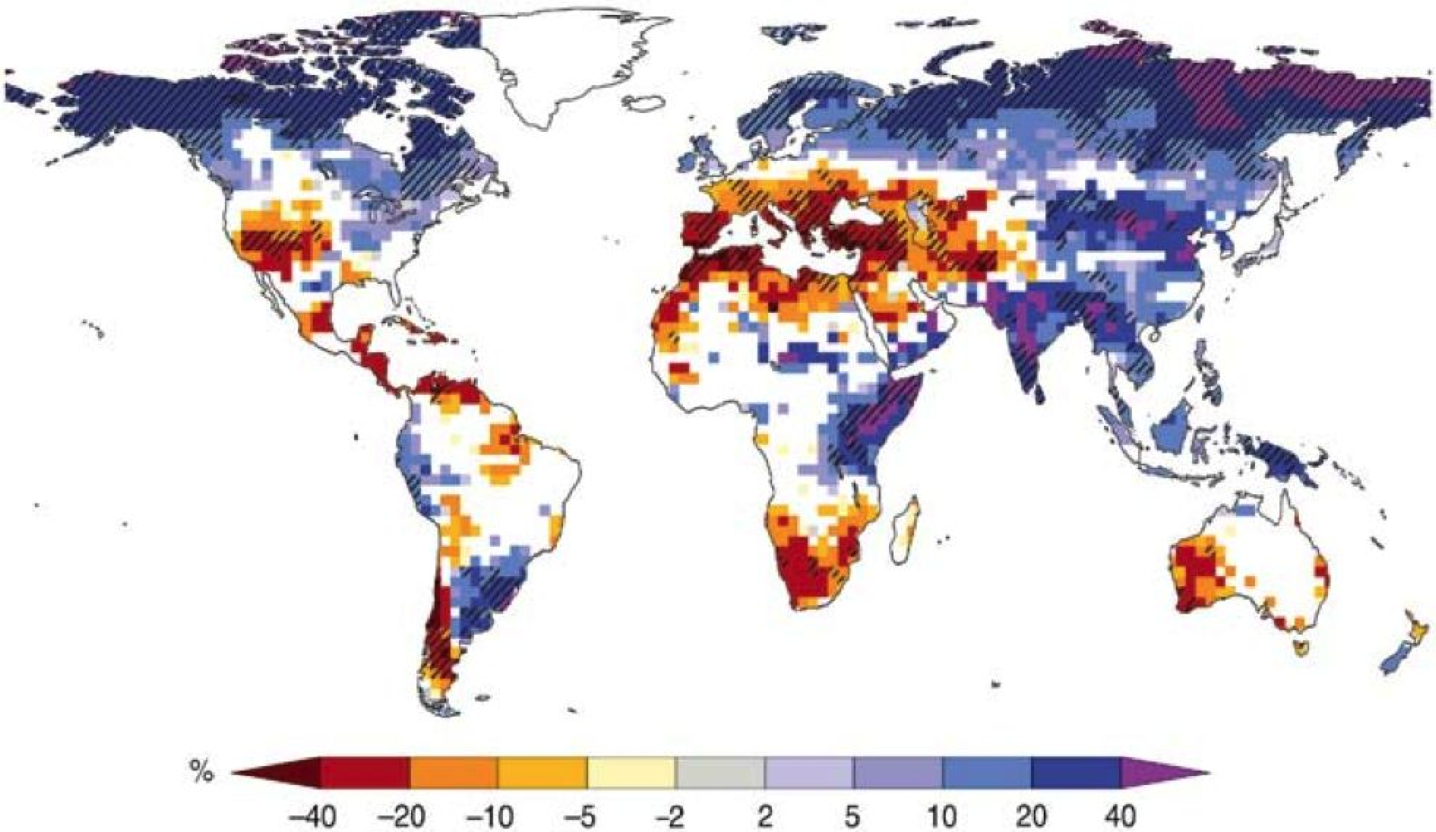


Figure 2.10: Large-scale relative changes in annual runoff for the period 2090–2099, relative to 1980–1999. White areas are where less than 66% of the ensemble of 12 models agree on the sign of change, and hatched areas are where more than 90% of models agree on the sign of change (Milly et al., 2005). [Based on SYR Figure 3.5 and WGII Figure 3.4]

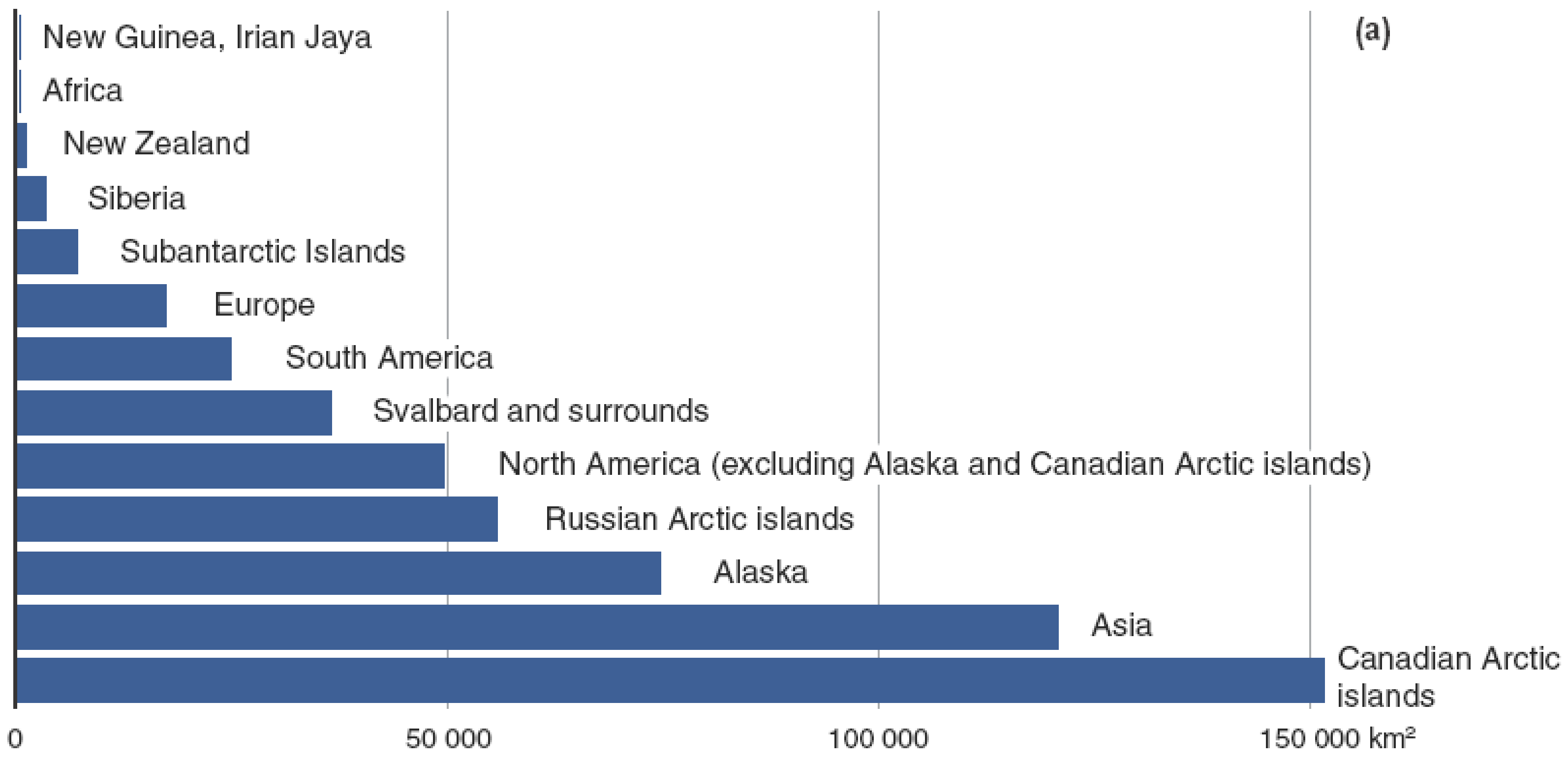
IPCC 4th Assessment

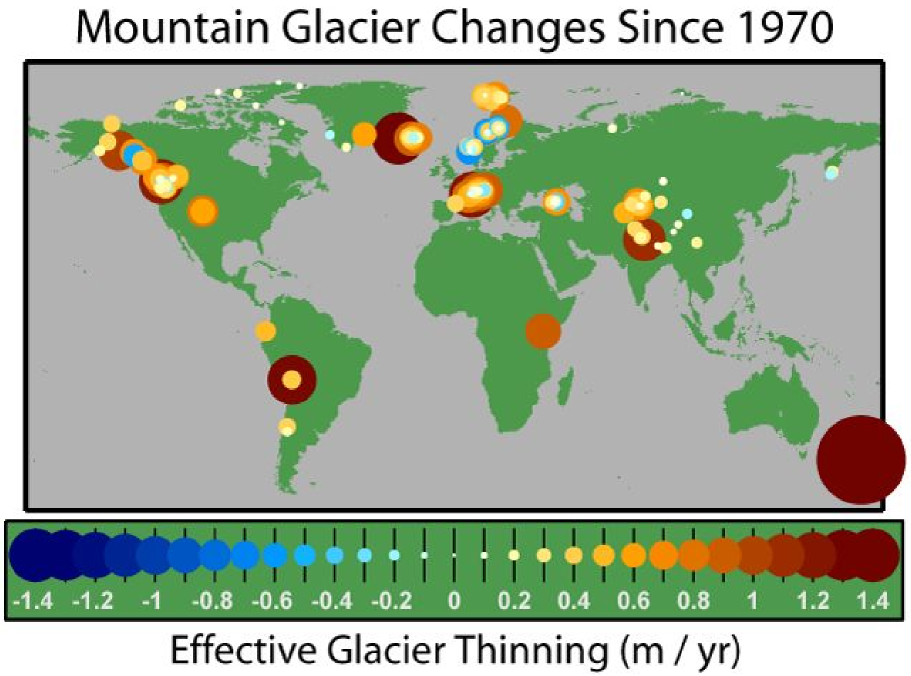
We have a poor scientific capacity to predict flow (and floods!) in small and medium sized northern streams

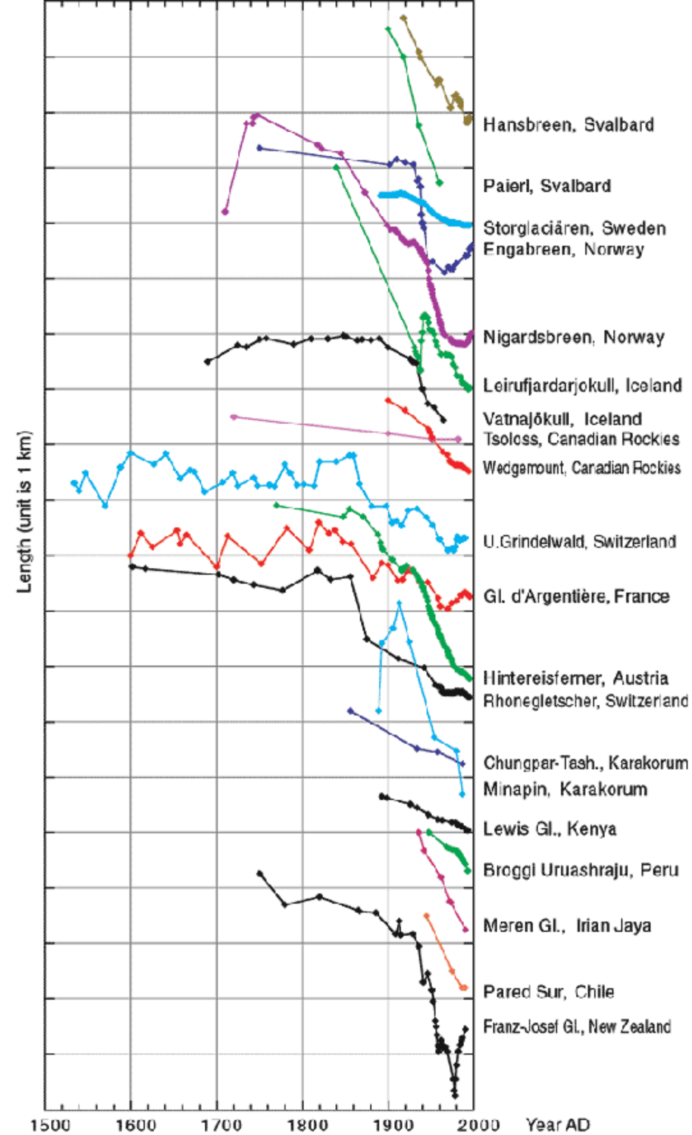
River crossings of roads (and pipelines) routinely fail because we have insufficient understanding of hydrology, runoff generation processes and permafrost or frozen ground in our designs.

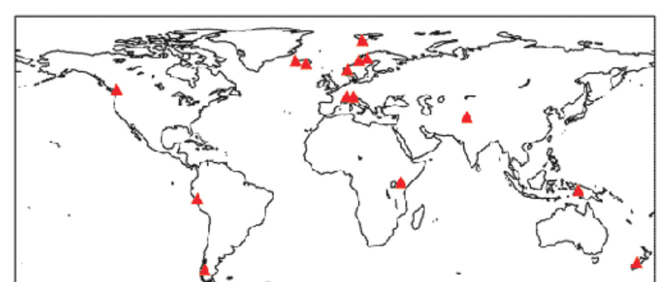
Glaciers and their influence on streamflow

Global Distribution of Glacial Area (excluding ice-caps)







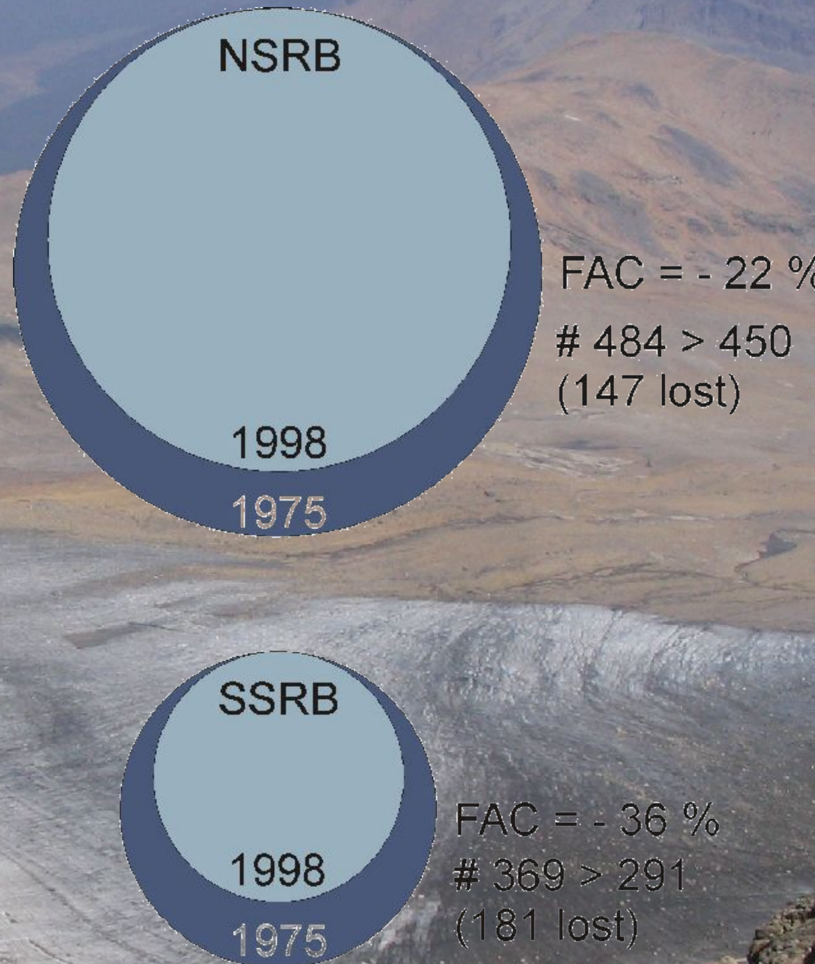


Worldwide, there is a broad trend towards glacial decline

Recent Glacier Diminution

Storage Effect
Moderate Flows

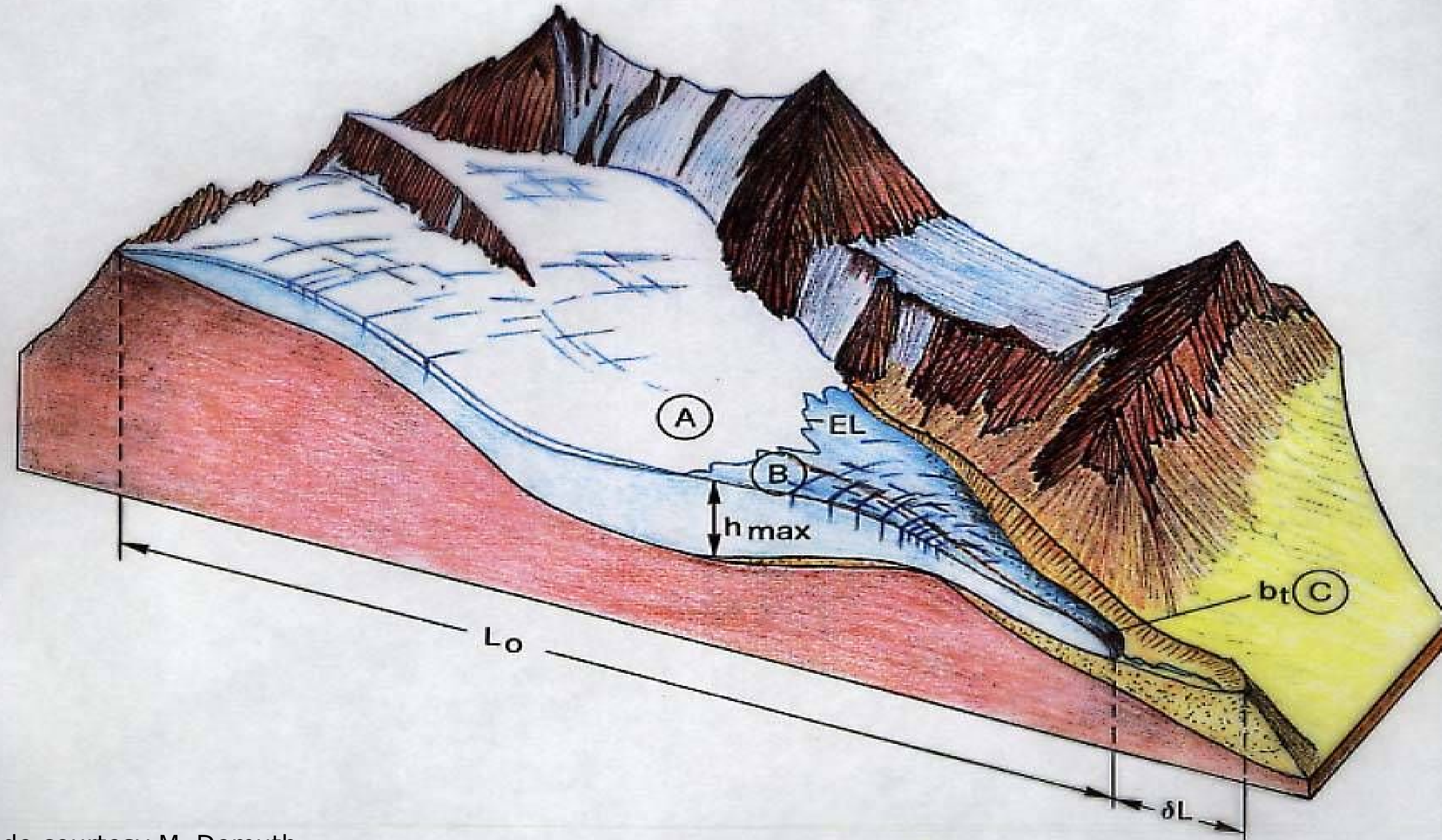
Hydropower
Groundwater recharge



Demuth et al. 2008 *Terra Glacialis*

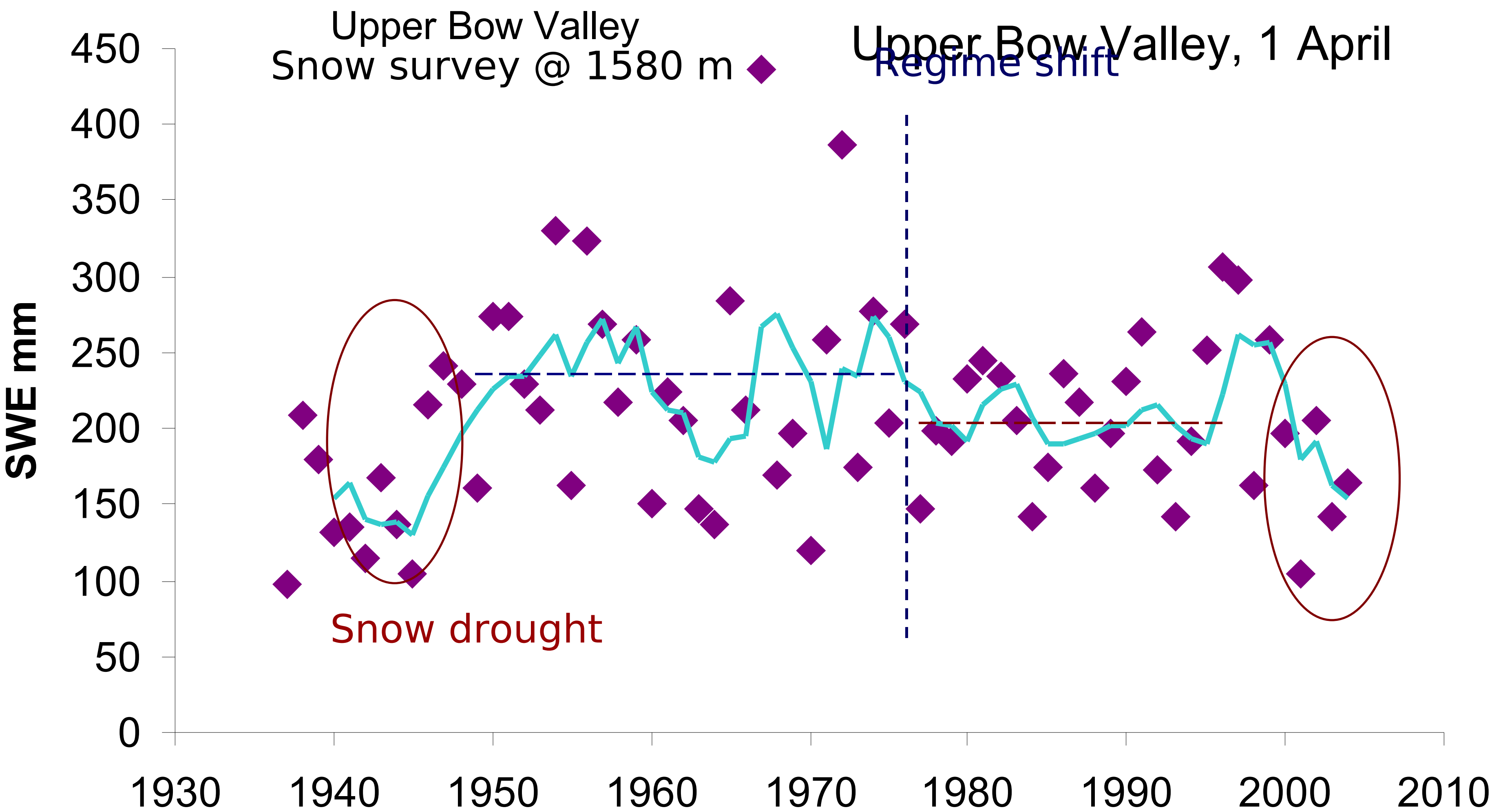
What influence do declining glaciers have on streamflow?

CLIMATE → **ENERGY/MASS BALANCE** → **GEOMETRY TEMPERATURE** → **ADVANCE RETREAT**



Slide courtesy M. Demuth

High Elevation Snow Accumulation



Slide courtesy M. Demuth

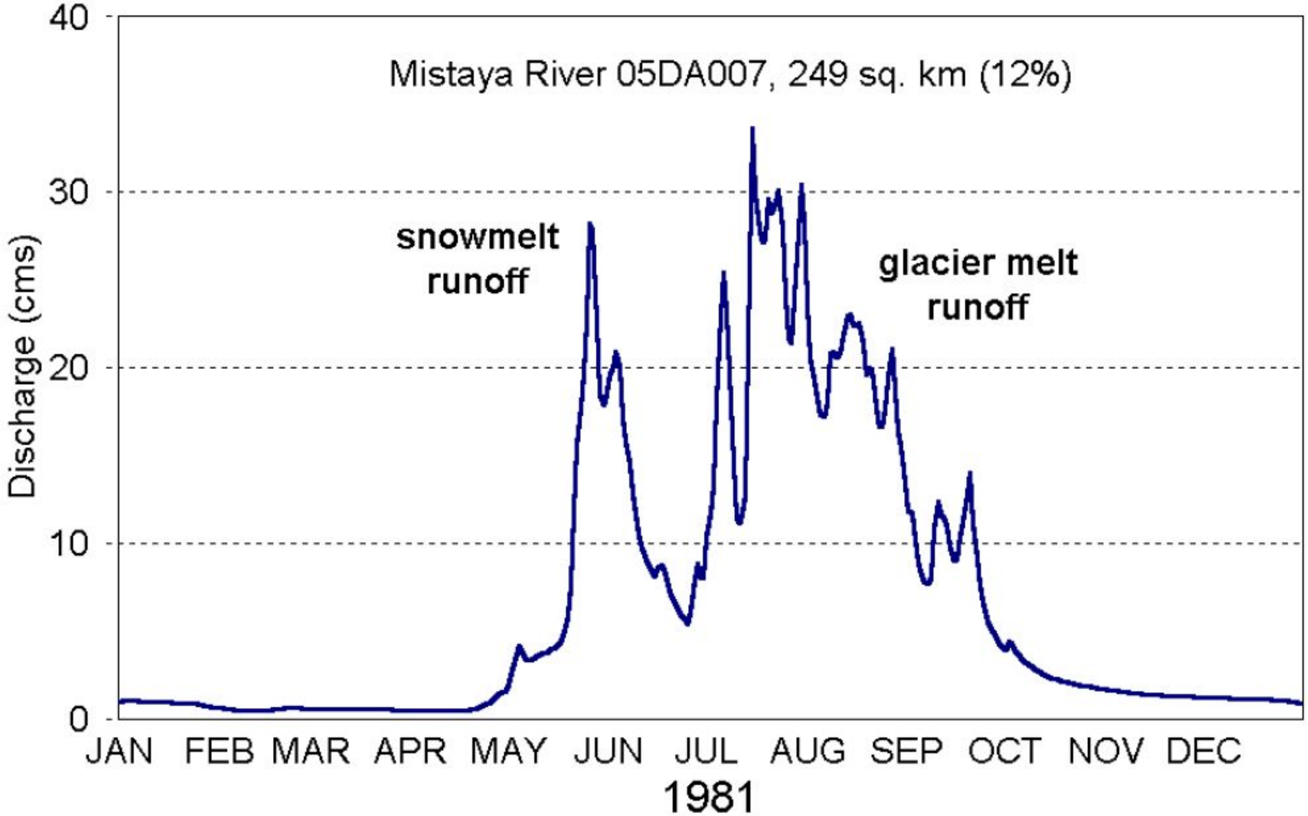
Glacier Wastage and Melt

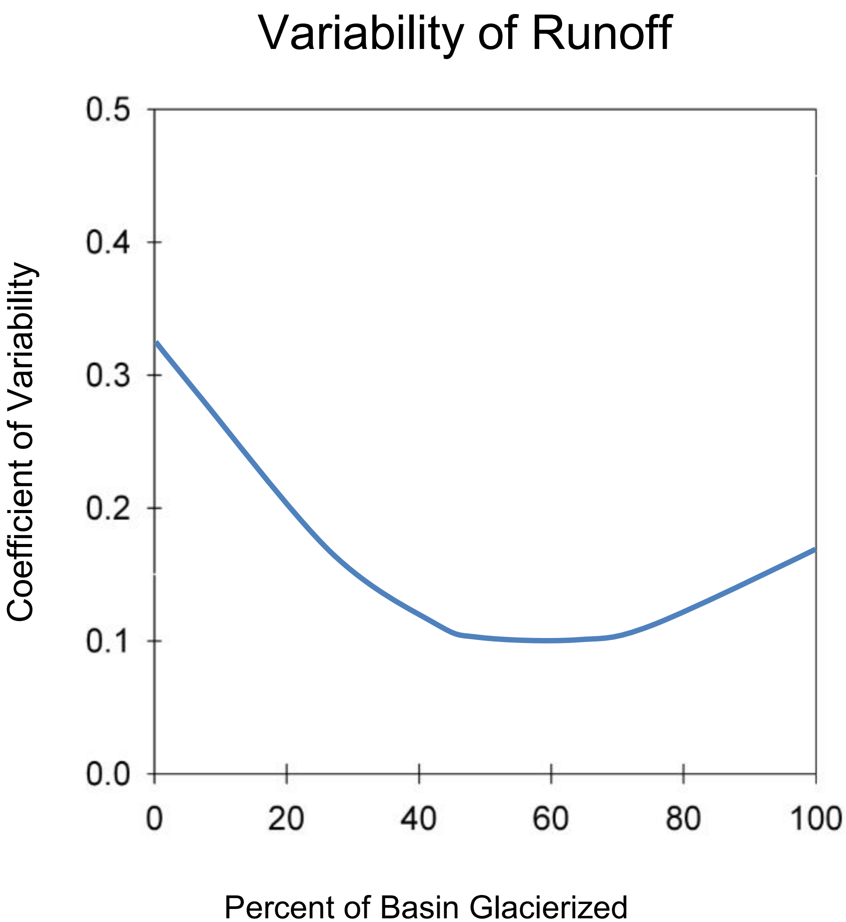
- **Melt:**

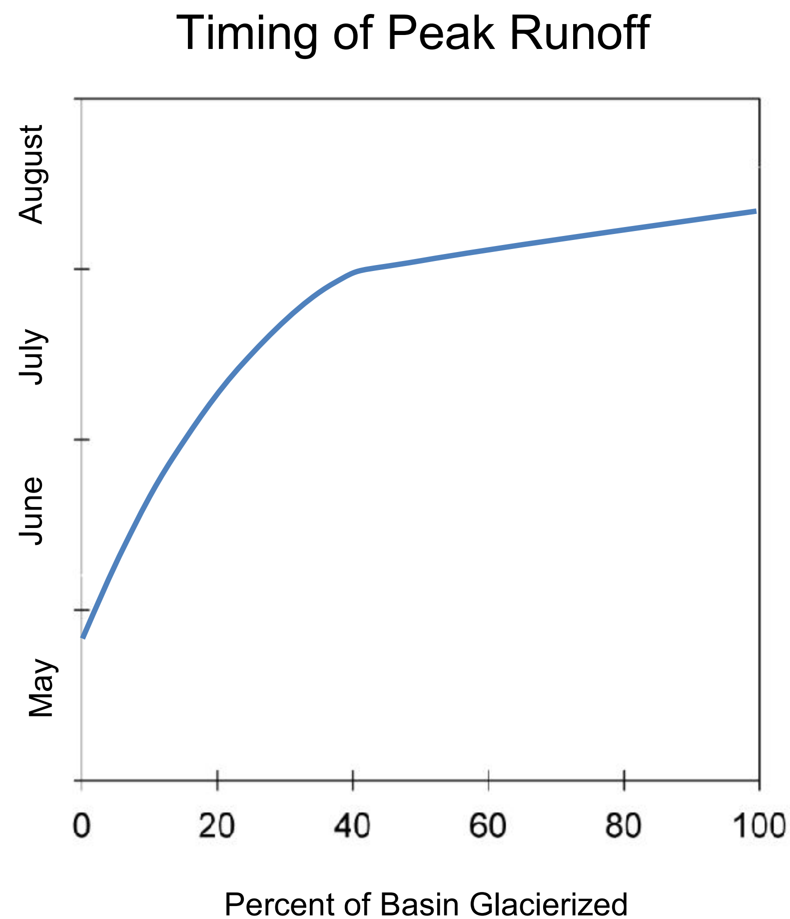
  Annual volume of glacier ice melt that is equal to, or less than, the annual volume of snow that does not melt from the glacier and instead accumulates into the glacier system

- **Wastage:**

  Annual volume of glacier ice melt that exceeds the annual volume of snow accumulation into the glacier system, causing an annual net loss of glacier volume


Mistaya River 05DA007, 249 sq. km (12%)
snowmelt runoff
glacier melt runoff
Discharge (cms)
0
10
20
30
40
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1981


Variability of Runoff
Coefficient of Variability
0.5
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
Percent of Basin Glacierized

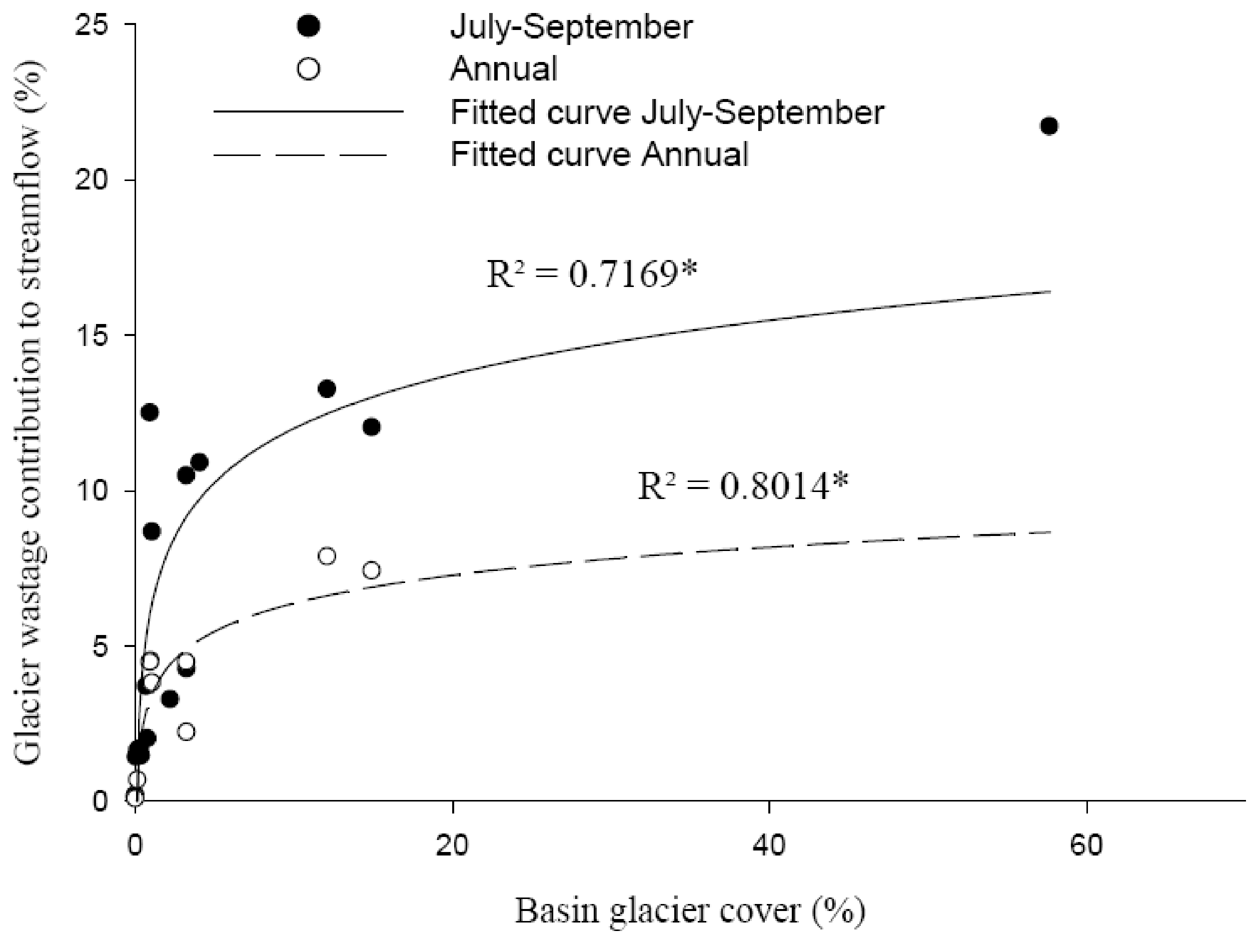

Timing of Peak Runoff
August
July
June
May
0
20
40
60
80
100
Percent of Basin Glacierized

Results: Wastage (1975-1998)

Wastage contribution to streamflow:

- Ranges from 1 – 22% July-Sept, 1 – 8% annually
- Percentage basin glacier cover ranges from 0.02% - 58%

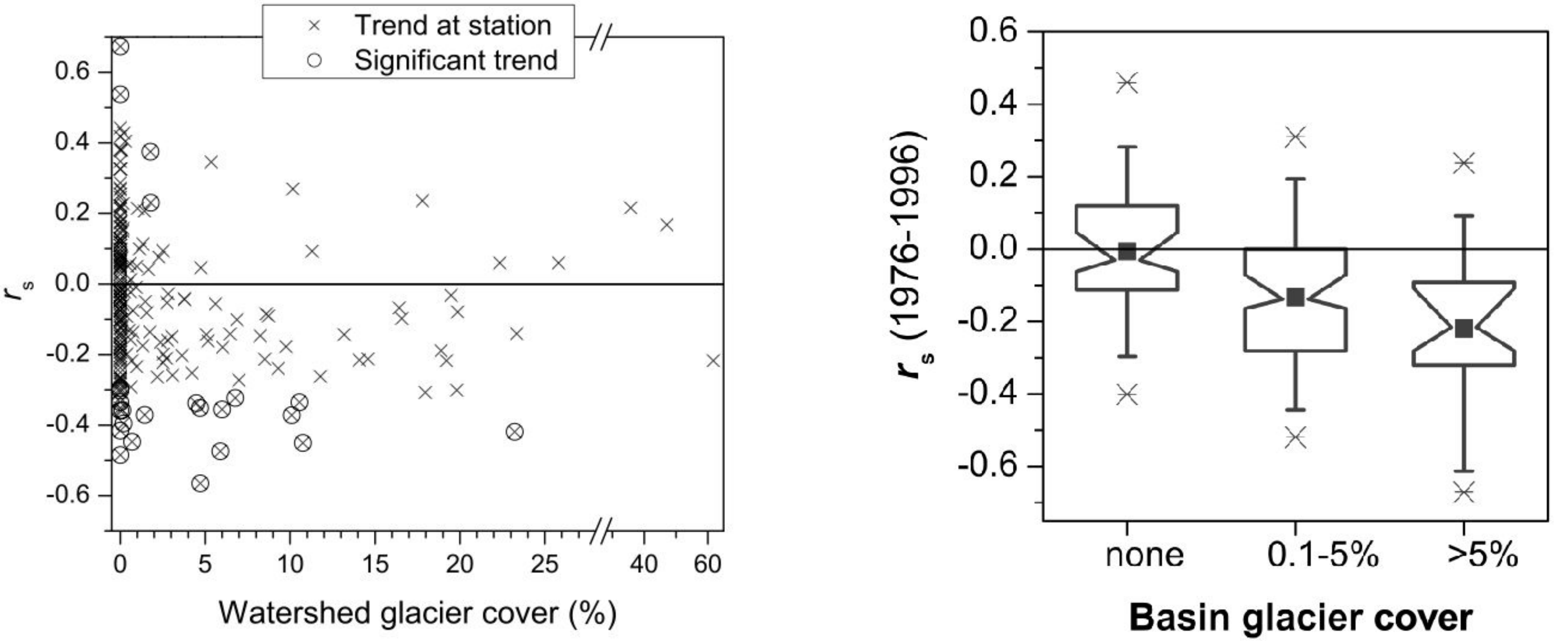
- Snowmelt is the most significant contributor
- **Annual** glacier contribution is relatively small
- Seasonal contribution is more significant:



* significant at $\alpha = 0.05$

Slide courtesy L. Comeau

Declining August flows in BC



Stahl and Moore 2006
Water Resources Research

- Some regions are already experiencing reduced streamflows predicted by the IPCC – *increased flow phase already past*:

Rocky Mountain eastern slopes

Demuth and Pietroniro 2003 CCAF-PARC

Demuth et al. 2008 *Terra Glacialis*

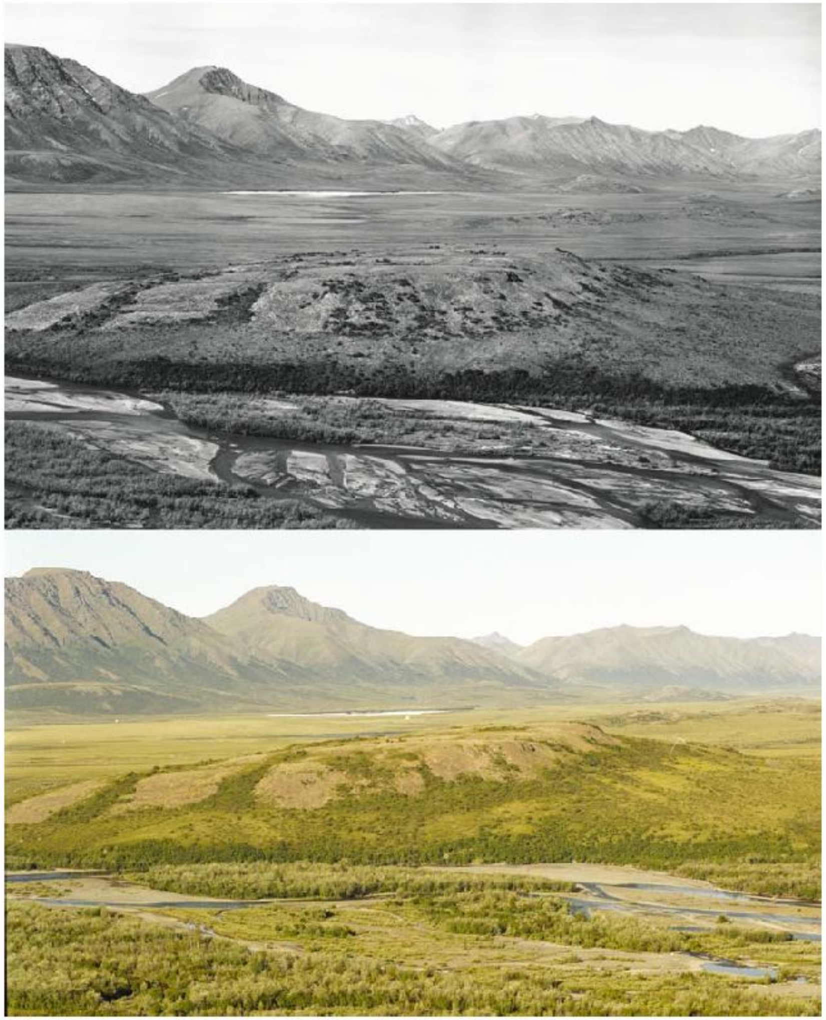
South-central British Columbia

Moore and Demuth 2001 *Hydrological Processes*

Stahl and Moore 2006 *Water Resources Research*

- Glacier cover *contraction* over the last Century has been fuelled by regional warming and reduced nourishment – *there is simply much less glacier cover, resulting in reduced contribution when other sources may be absent or are know to be in decline*

Ecosystem change has a profound influence on water cycling



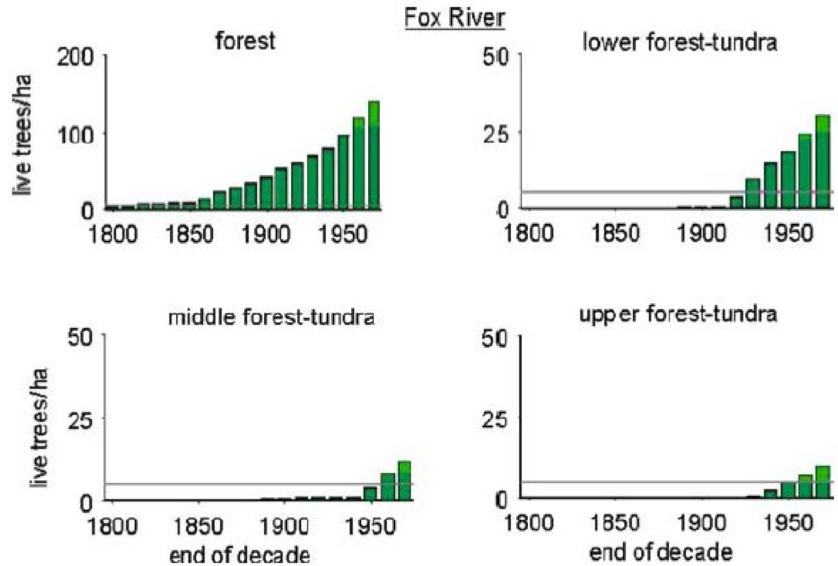
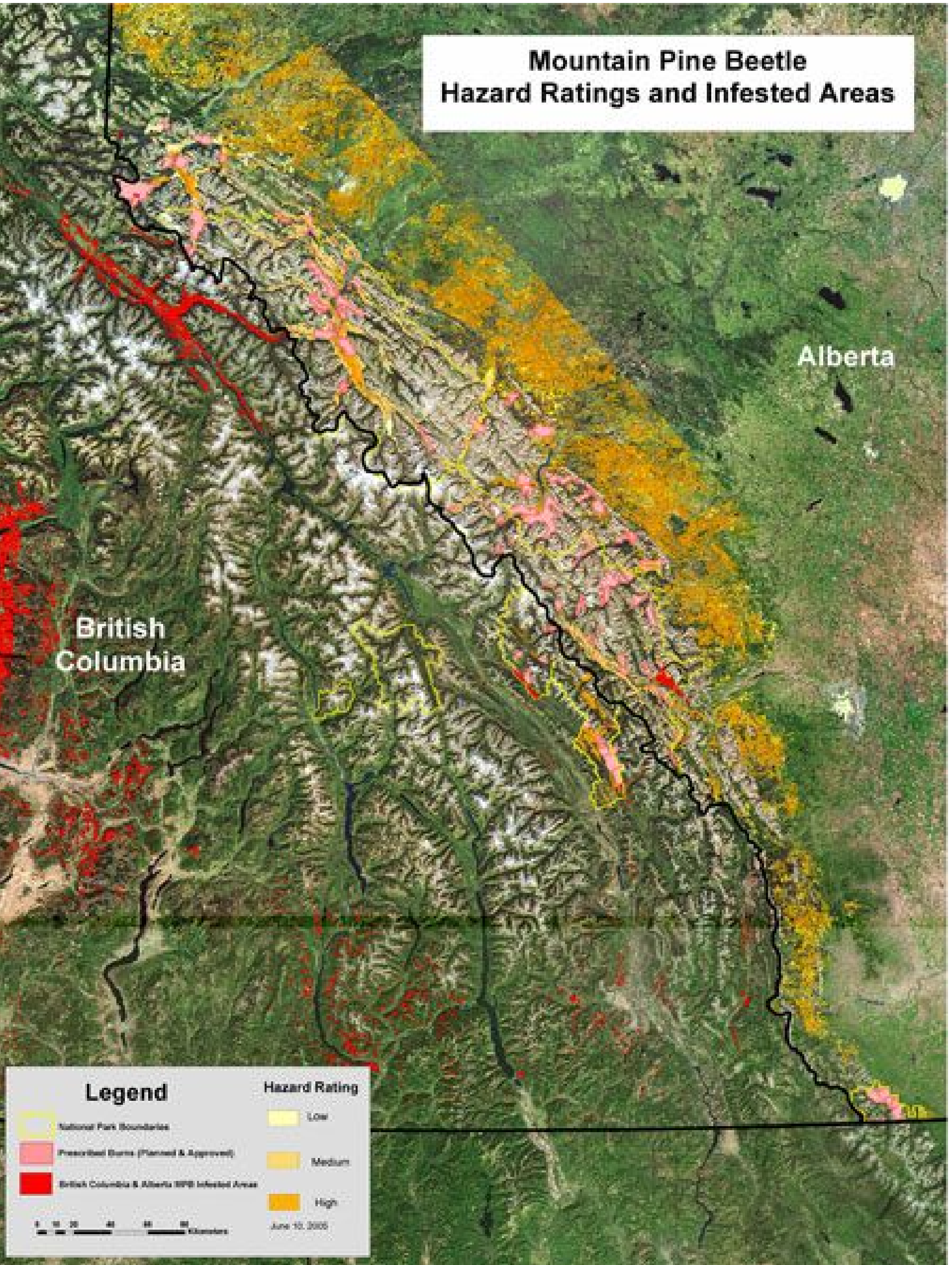


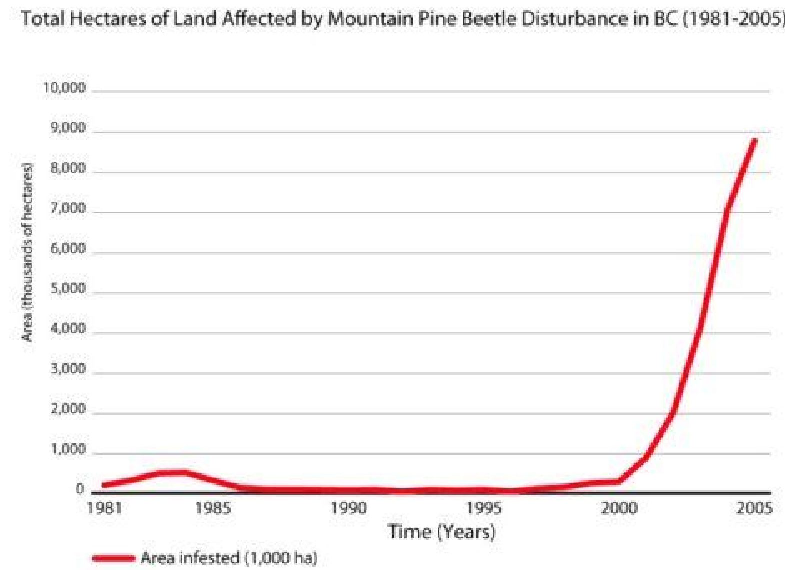
Figure 13. Density of live spruce in each decade from 1800 to 1970 at latitudinal treeline on the Seward Peninsula. Sites are located along a transect across the treeline boundary, from contiguous forest ("forest", upper left panel) to unforested tundra ("upper forest-tundra", lower right panel). Bar shading indicates the data source. Light green portions represent seedlings whose age was estimated from counts of annual rings; Dark green portions represent trees whose age was estimated from cores. A density threshold of 5 trees/ha (horizontal line on each panel) was used to identify the decade in which an ecologically significant density of trees established at a particular site.

Hinzman et al. 2005

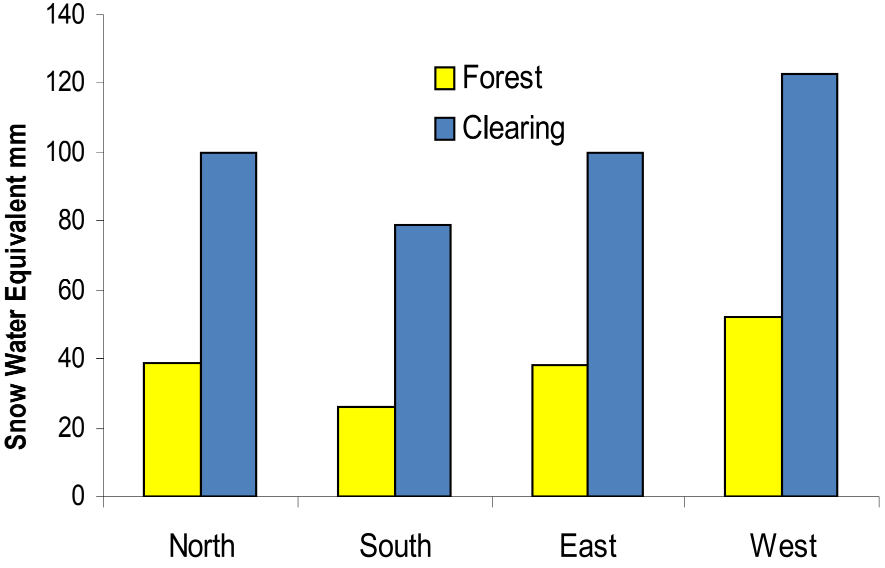
Sturm et al. 2001

Forest Change

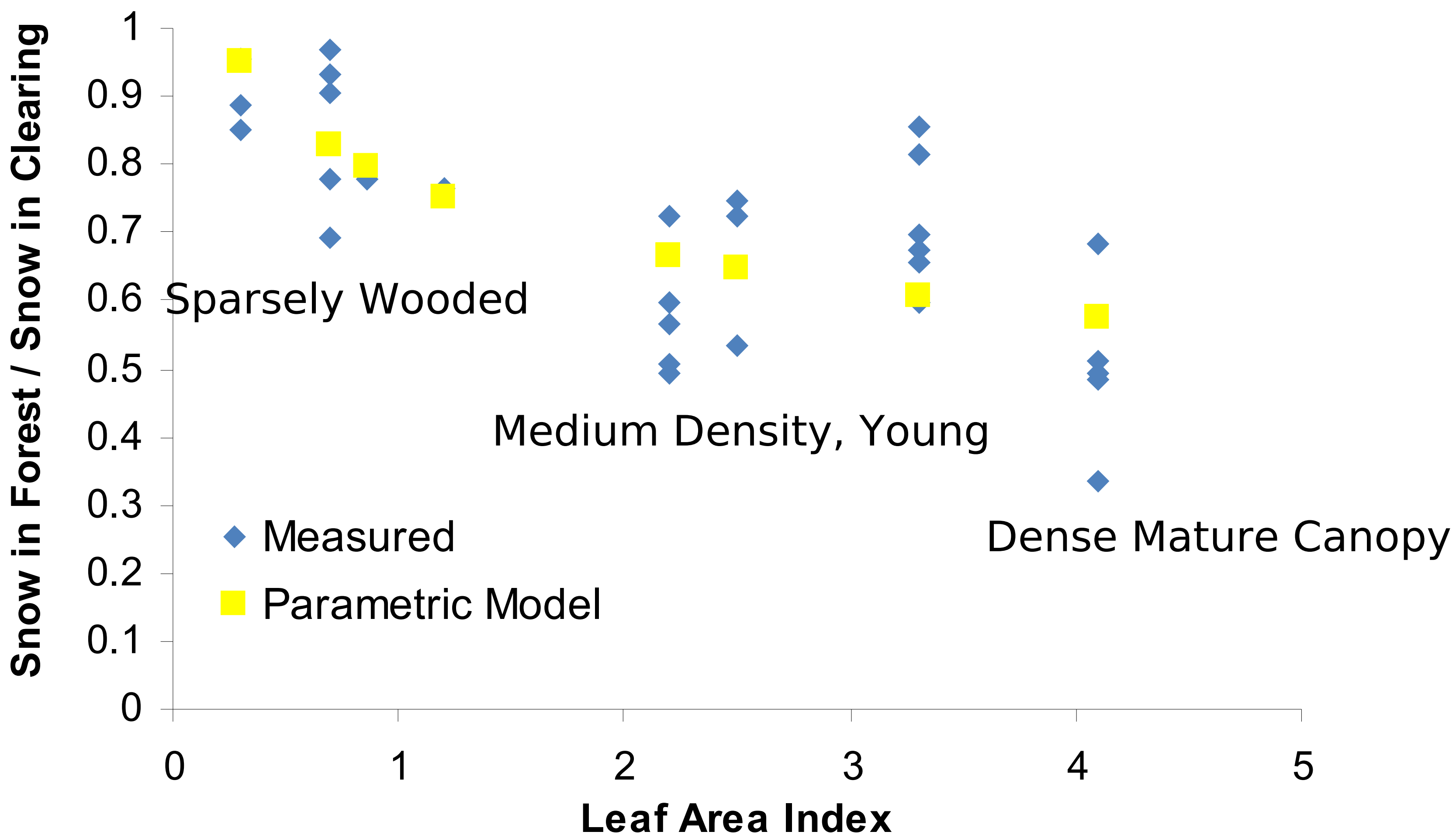




Snow Interception

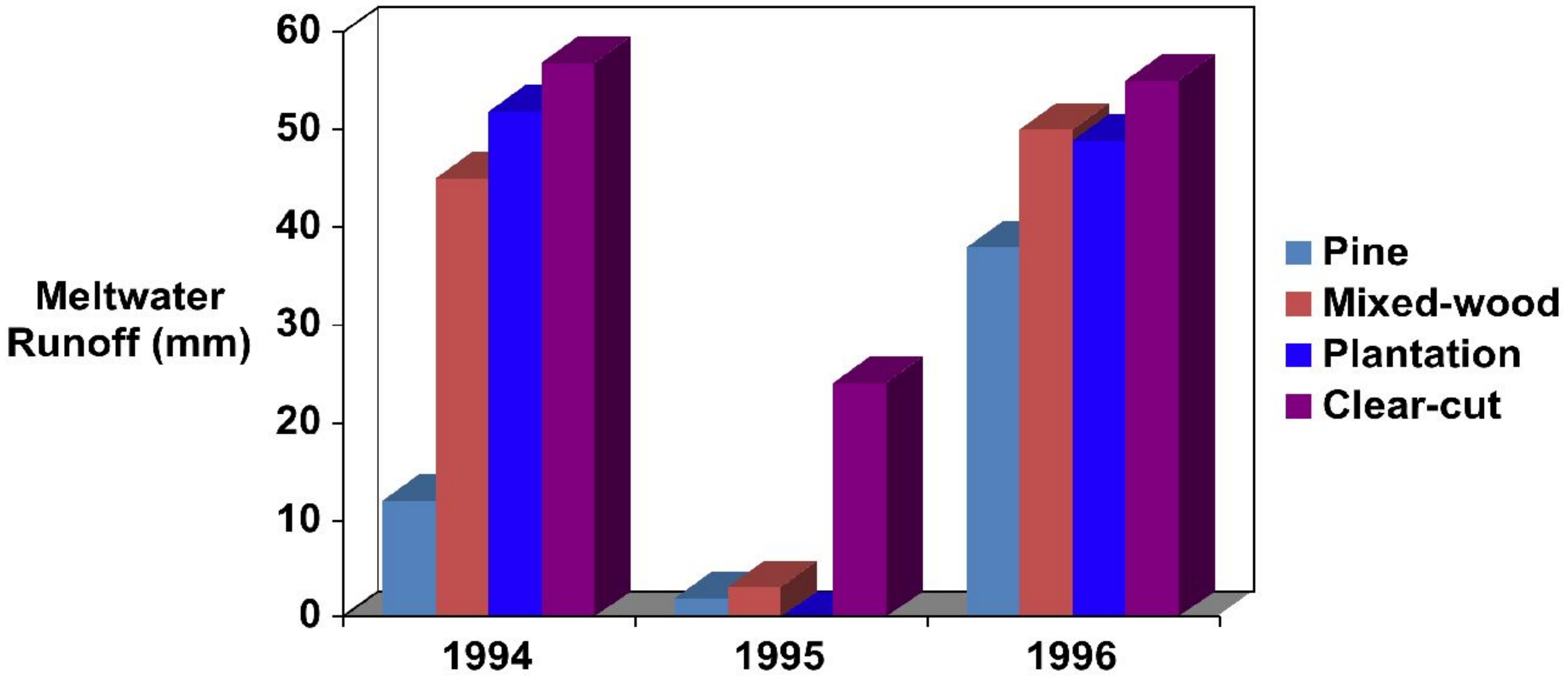


Effect of Forest Removal on Snow Accumulation



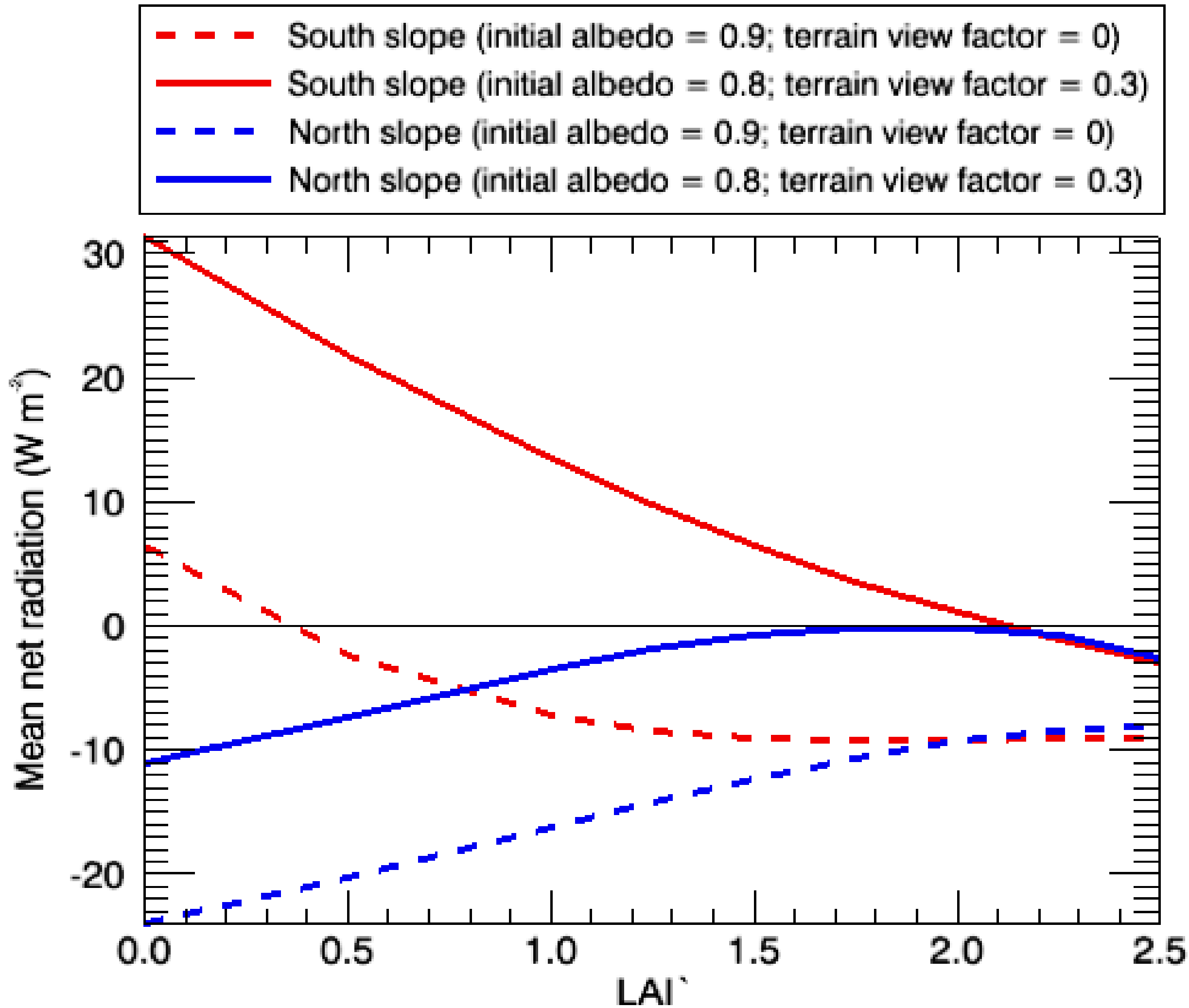
Courtesy J. Pomeroy

Snowmelt Runoff Decreases with Increasing Forest Cover
- infiltration to frozen soils –



Courtesy J. Pomeroy

Forest Density Impacts Snowmelt Energy



Courtesy Ellis & Pomeroy

Development

There are strong practical implications for improved understanding of hydrology based on rapid expansion of development in the west and north.

IP3

- ...is devoted to understanding **water supply** and **weather systems** in cold Regions at high altitudes and high latitudes (Rockies and western Arctic)

- ...will contribute to better prediction of regional and local **weather, climate, and water resources** in cold regions, including ungauged basin **streamflow,** changes in **snow and water supplies,** and calculation of **freshwater inputs** to the Arctic Ocean

- ...is composed over about 40 investigators and collaborators from Canada, USA, UK, Germany

- ...runs from 2006-2010

- **.....We are here in Whitehorse! There is a lot of experts here who know more than I.**

IP3

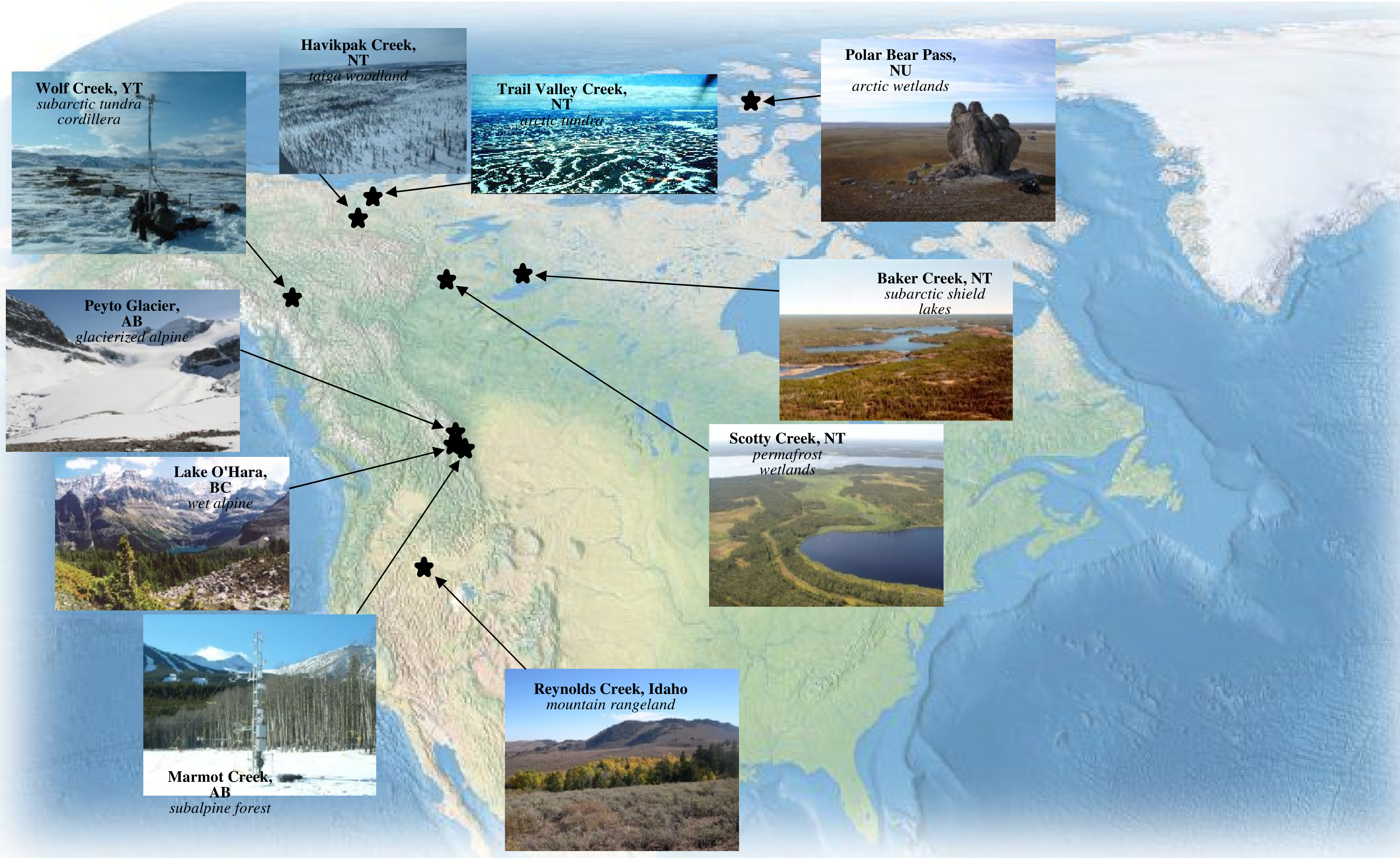
Improved Processes & Parameterisation for Prediction in Cold Regions

IPY·API International Polar Year Année polaire internationale 2007·2008

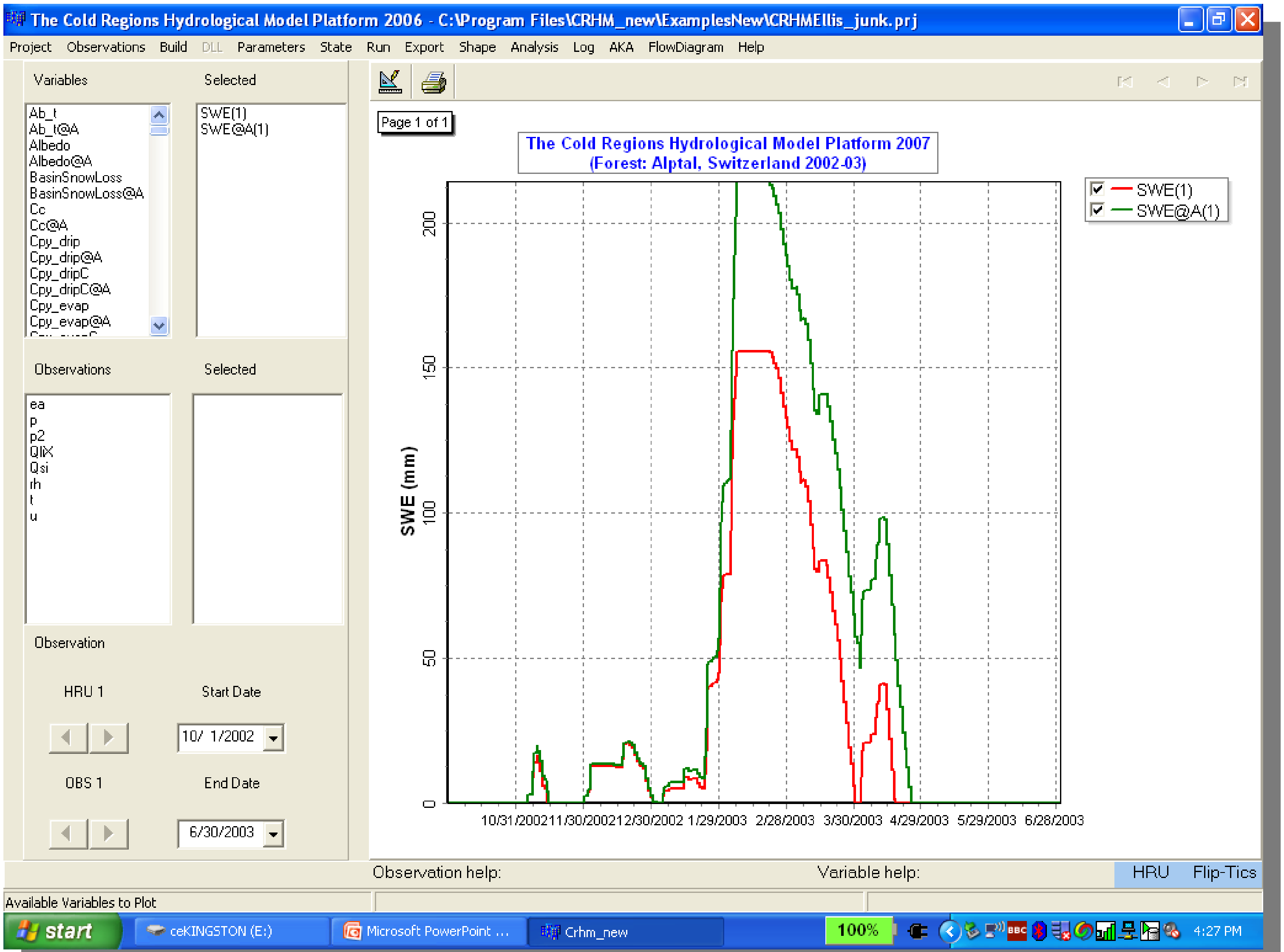
Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)

Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

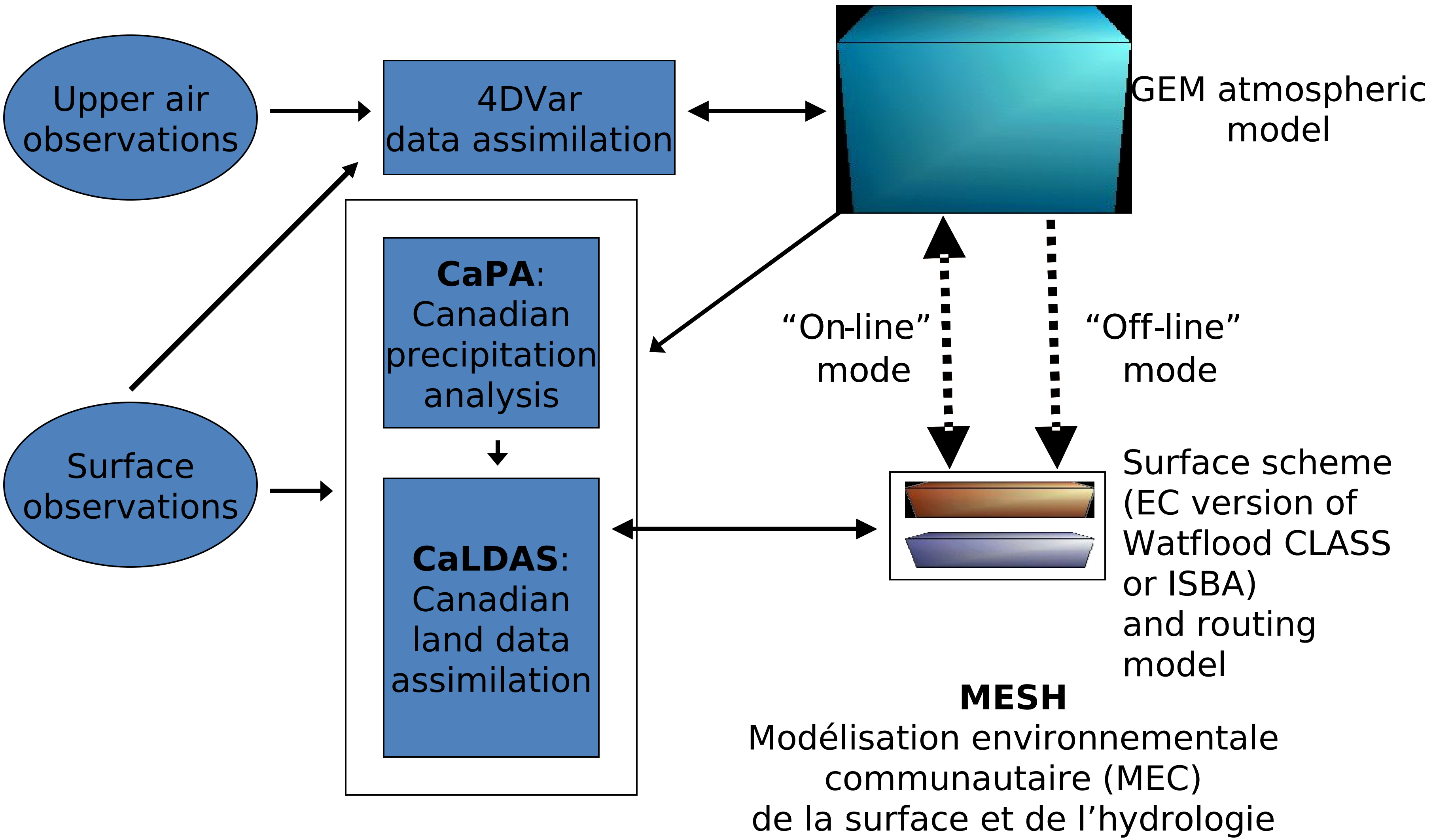
IP3 Research Basins



Physically Based Hydrological Modelling can answer water management questions



Environment Canada Environmental Prediction Framework



Thank You - Merci