Cold Regions Hydrology and Sustainable Water Management

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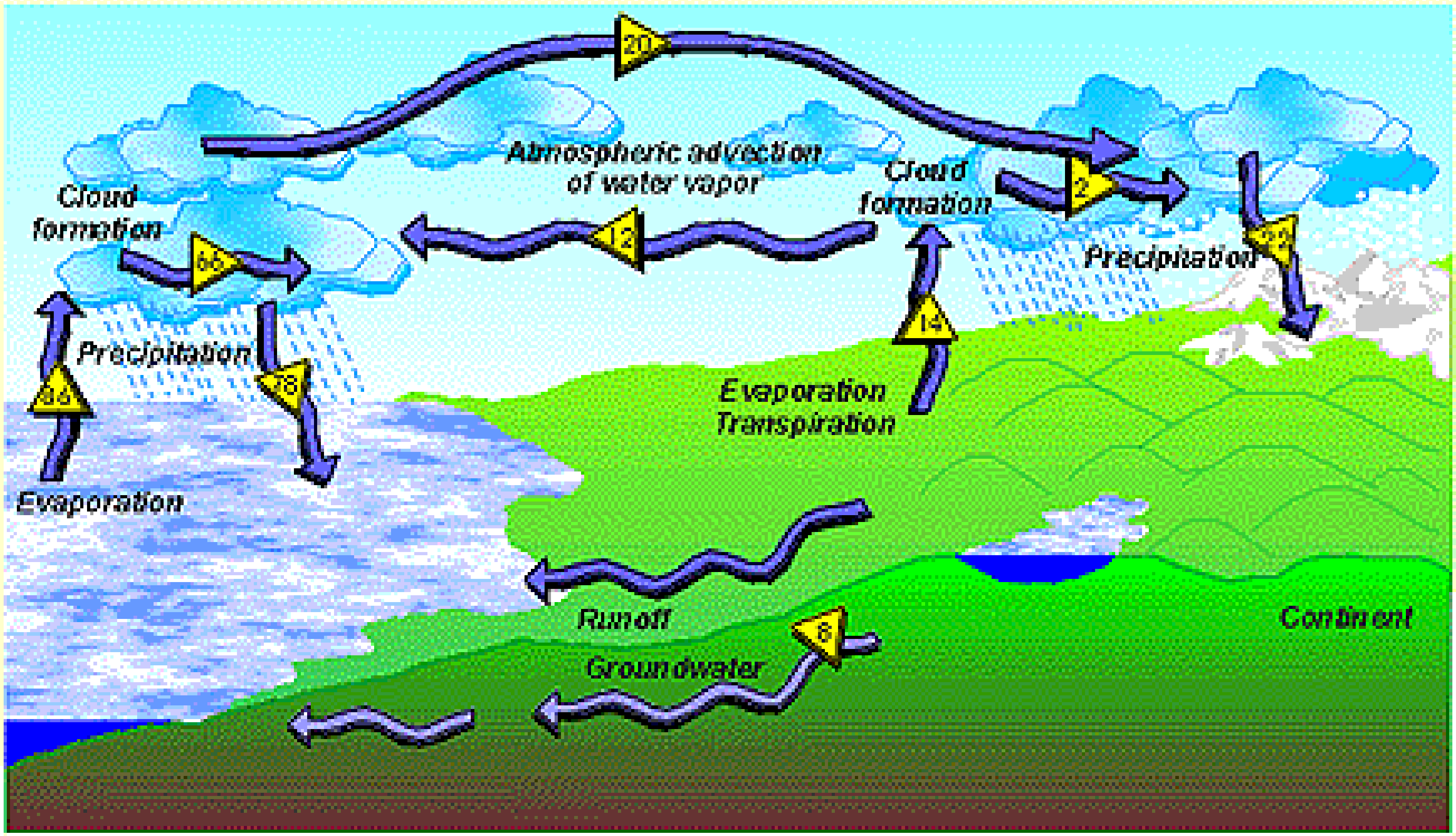
CENTRE FOR HYDROLOGY

UNIVERSITY OF SASKATCHEWAN

Purpose of Talk

- Show how water supplies in cold regions are governed by the hydrological cycle
- Show what is new in cold regions hydrological science that can be useful for sustainable water management
- Show how major hydrological changes are threatening sustainable water management in western and northern Canada
  - Land cover change
  - Climate change

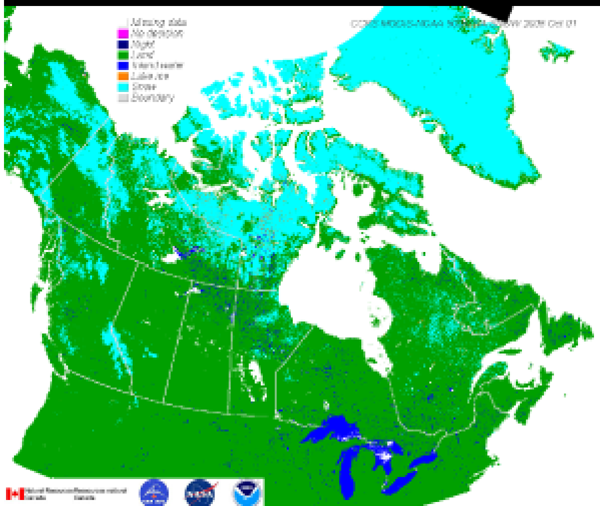
Hydrological Cycle – elsewhere….



The hydrological cycle model.

The hydrological cycle model with percentages and directional arrows denoting flow paths. Global average values are shown as percentages.

Where are the cold regions in Canada? Snow cover change over the year.



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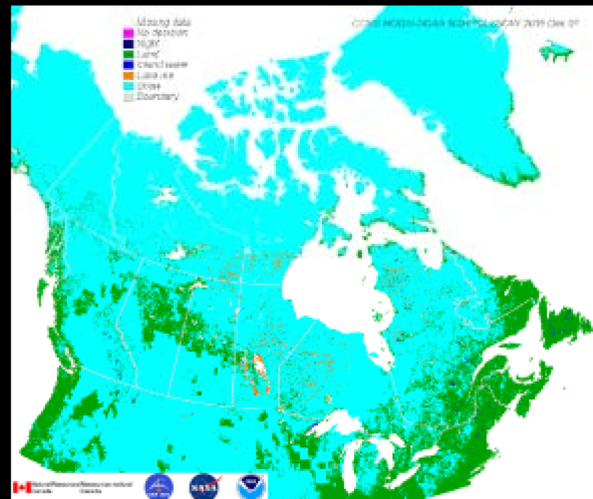

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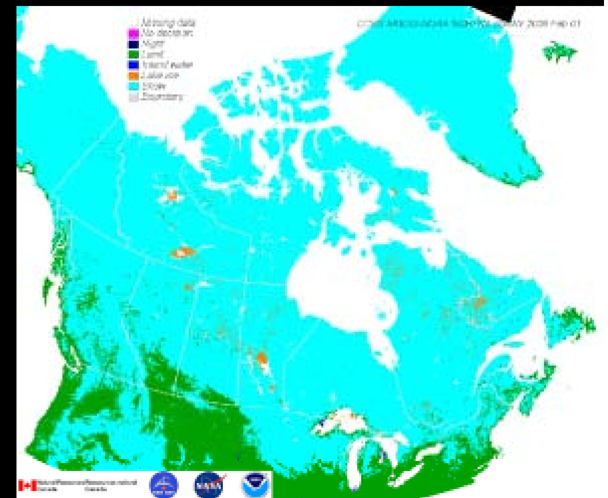

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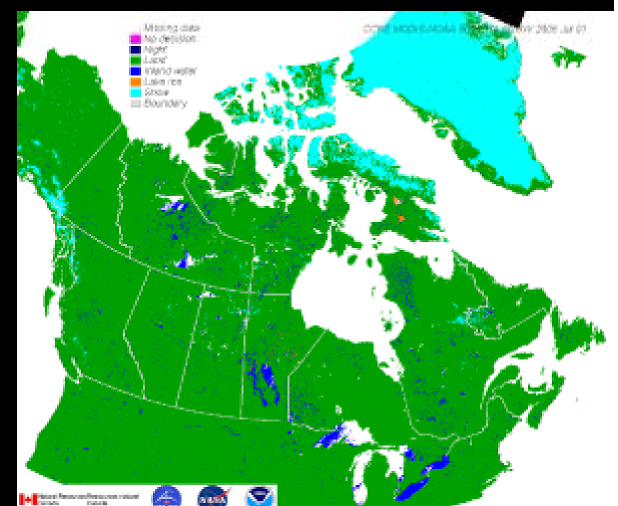

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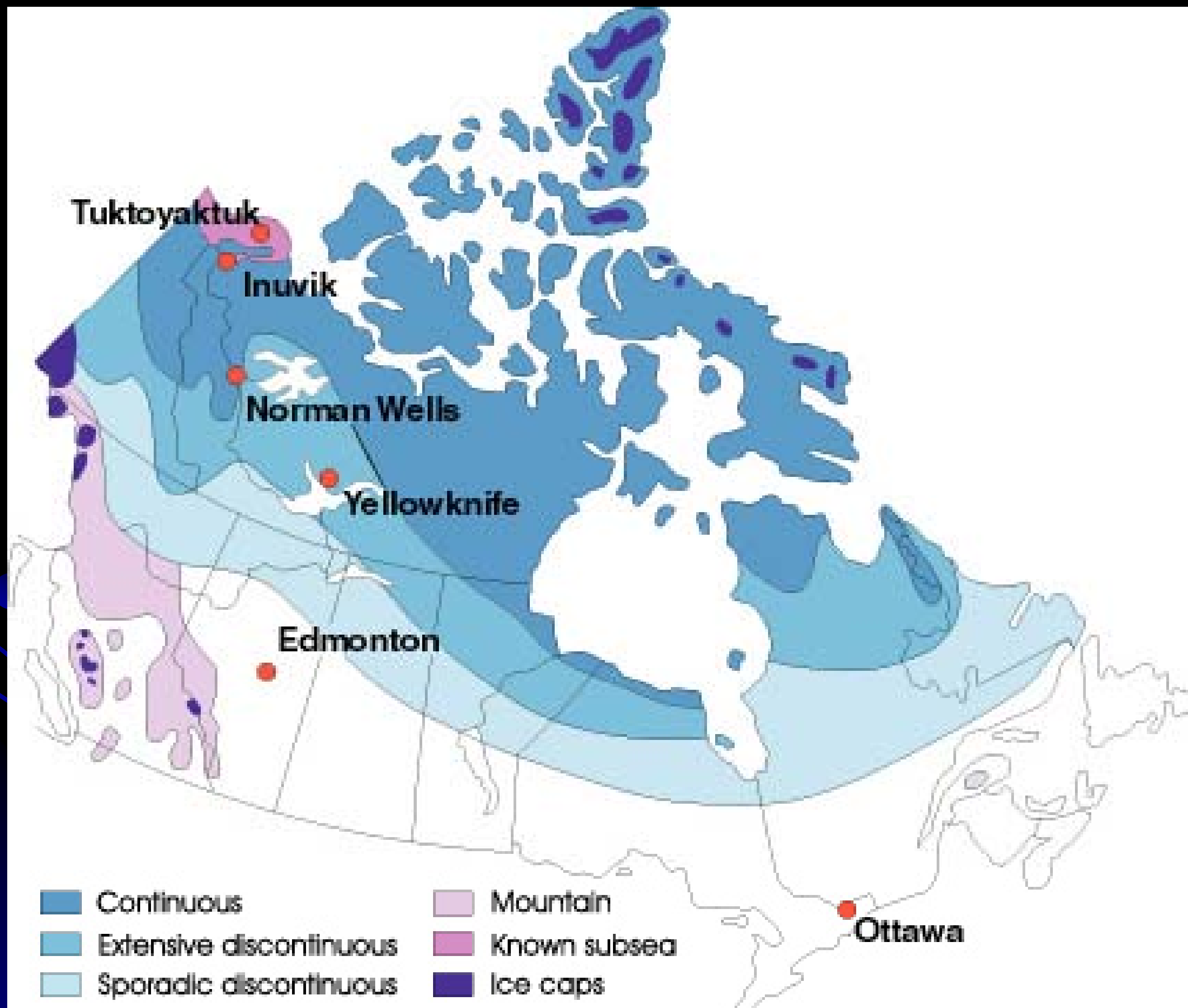
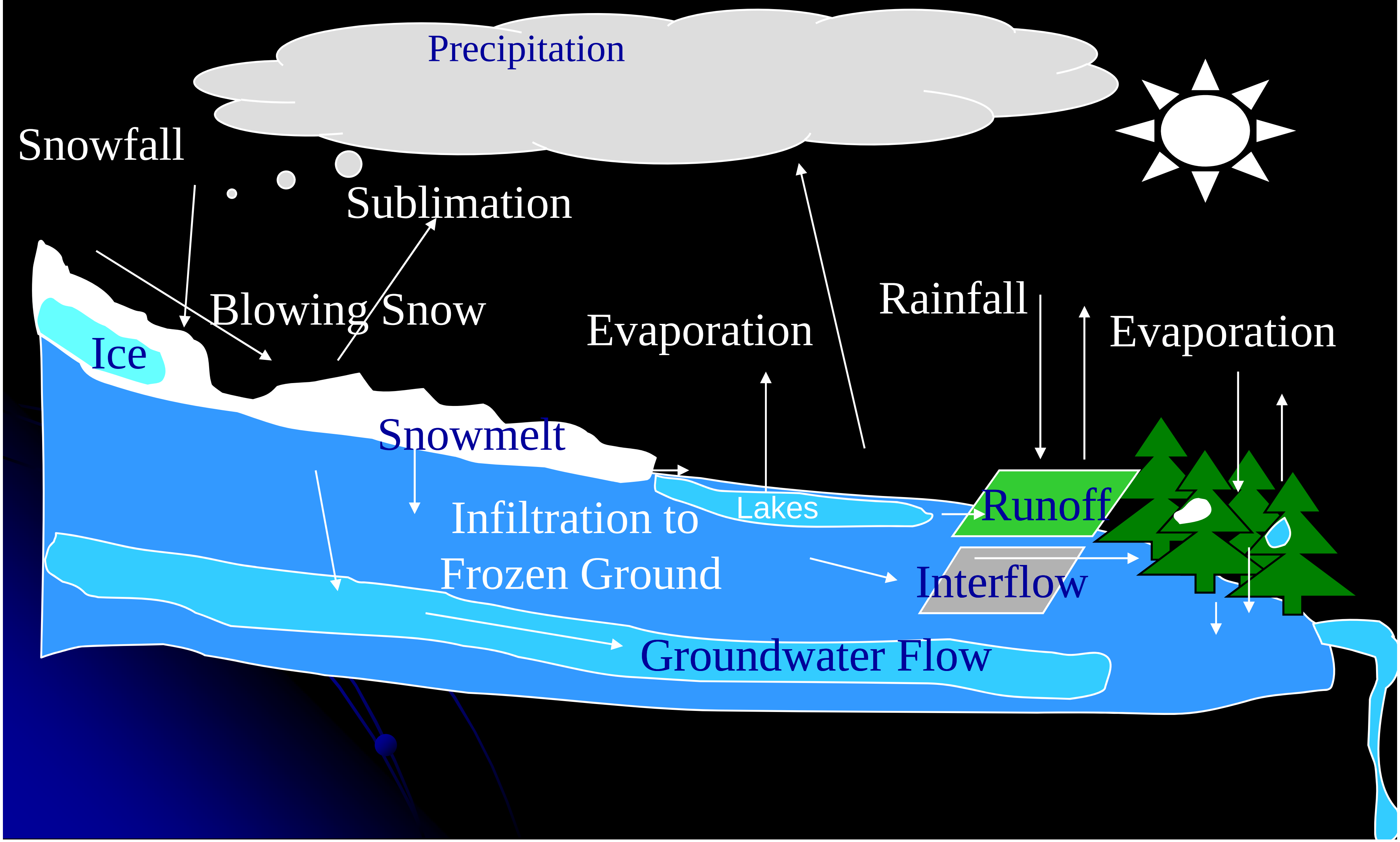
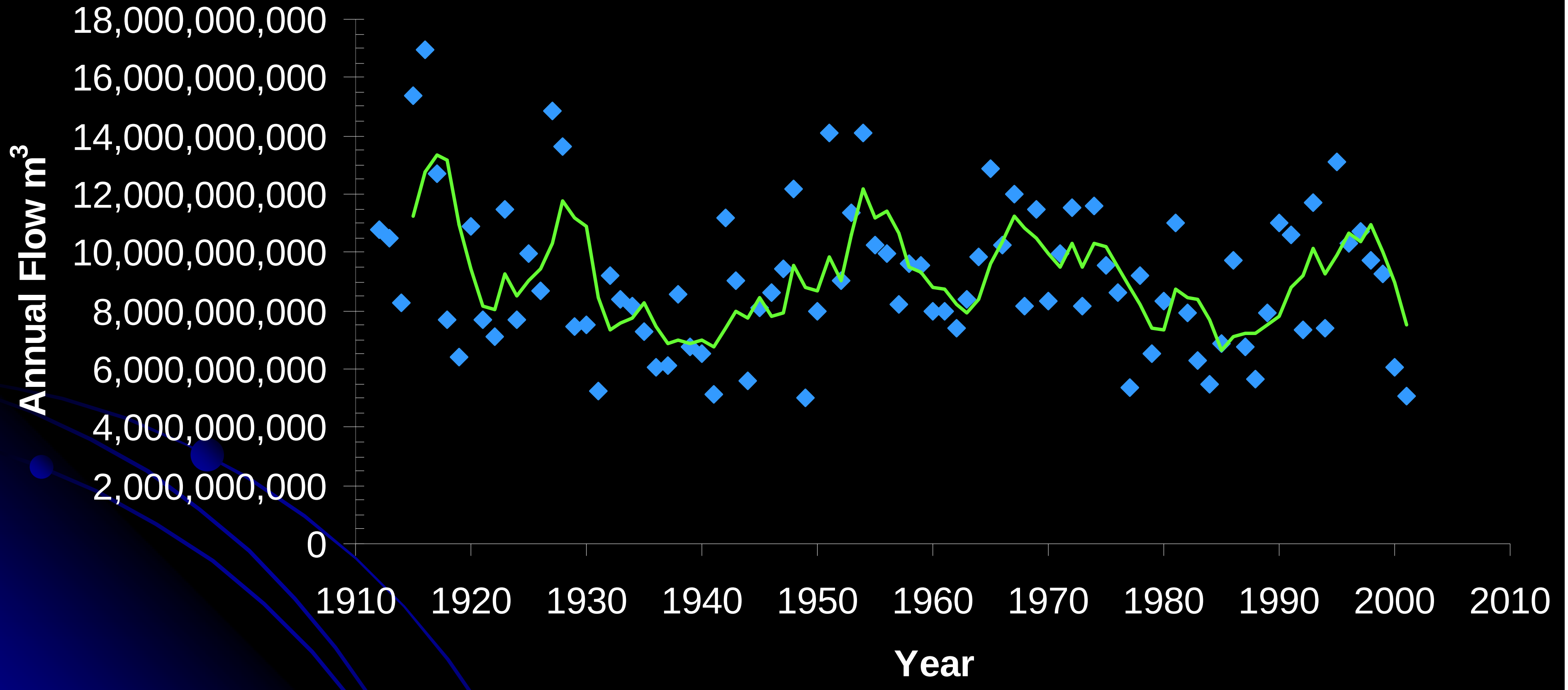
Permafrost in Canada



Cold Regions Hydrological Cycle

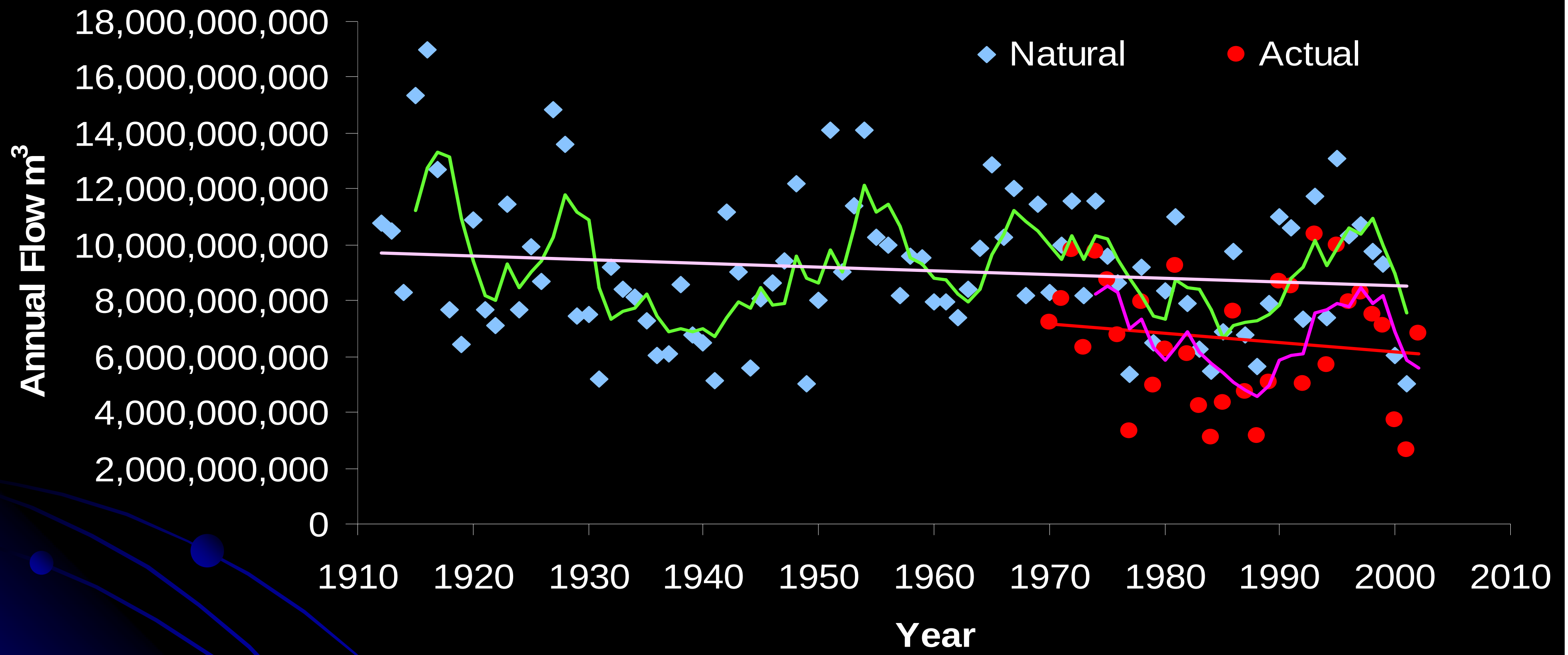


‘NATURAL’ FLOWS OF THE SOUTH SASKATCHEWAN RIVER LEAVING ALBERTA



Highly variable

Natural and Actual Flow of South Saskatchewan River leaving Alberta



Natural flow: Decline of 1.2 billion m^3 over 90 years (-12%)
Actual flow: Decline of 4 billion m^3 over 90 years (-40%)
Note: 70% of decline due to consumption, 30% due to hydrology
Upstream consumption: 7%-42% of naturalized flows in last 15 years

Where does river flow come from?

- Snowfall and Rainfall!

- Lakes, wetlands, soil water, groundwater, permafrost, snowpacks and glaciers are merely temporary storage reservoirs that are supplied by snowfall and rainfall and either store precipitation as water & ice, evaporate back to the atmosphere, or drain to streams & rivers

Snowfall

Super-cooled cloud water droplets form ice

Coalescence of crystals

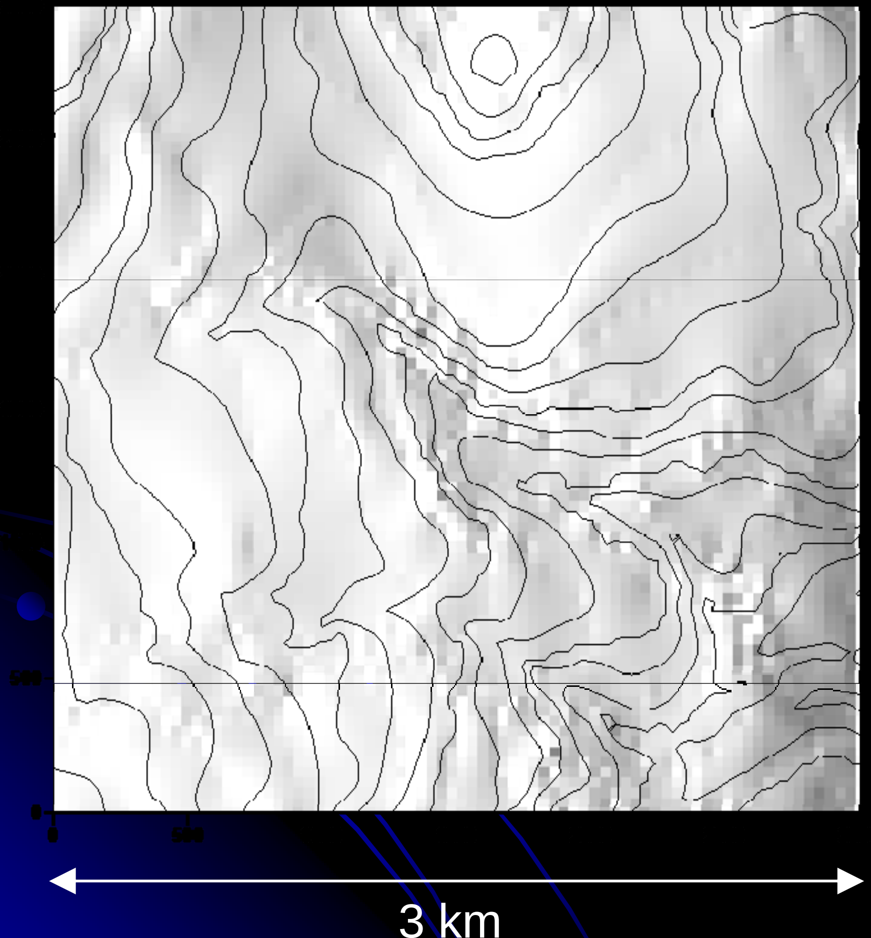
Heavier snowfall on upslopes, water to land transitions

Snowfall vs. rainfall. Depends on air temperature and humidity

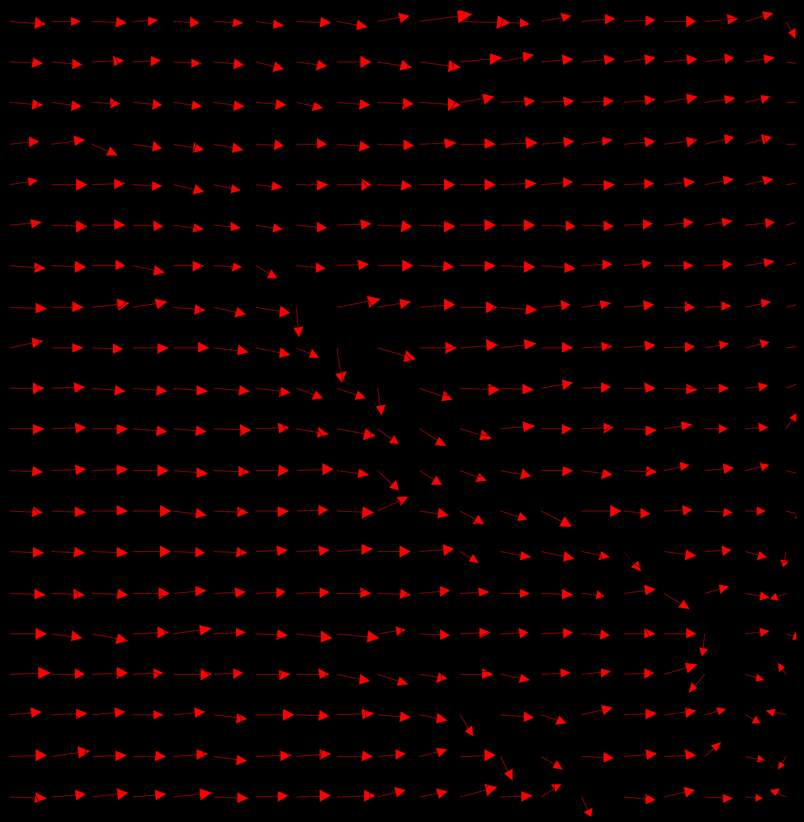
Blowing Snow Redistribution

Computer simulation of wind flow over mountains

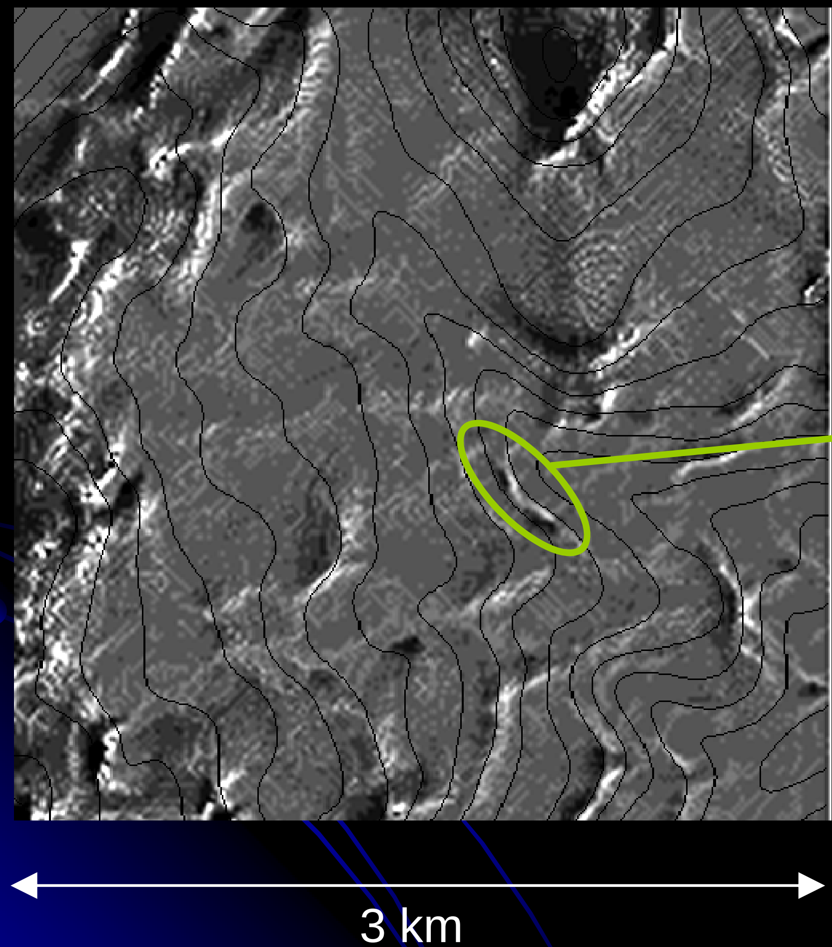
Windspeed



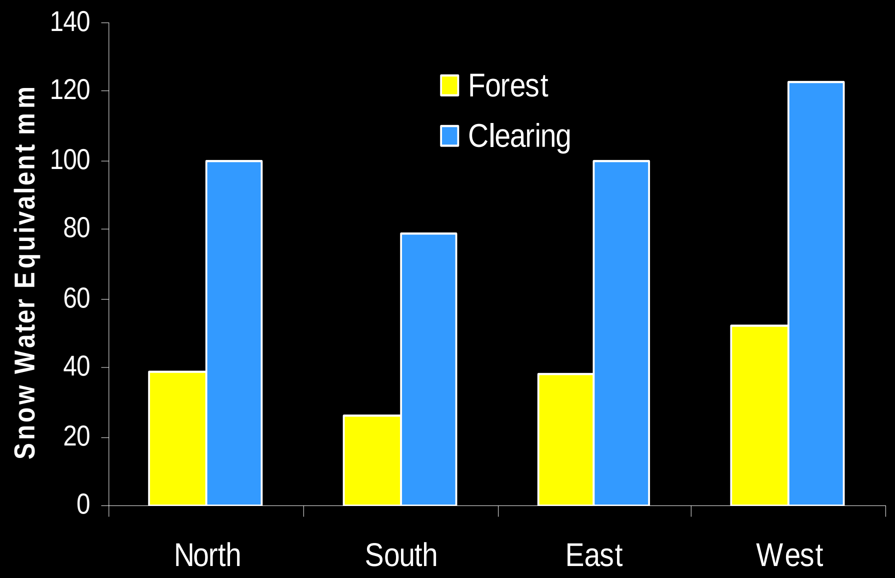
Direction



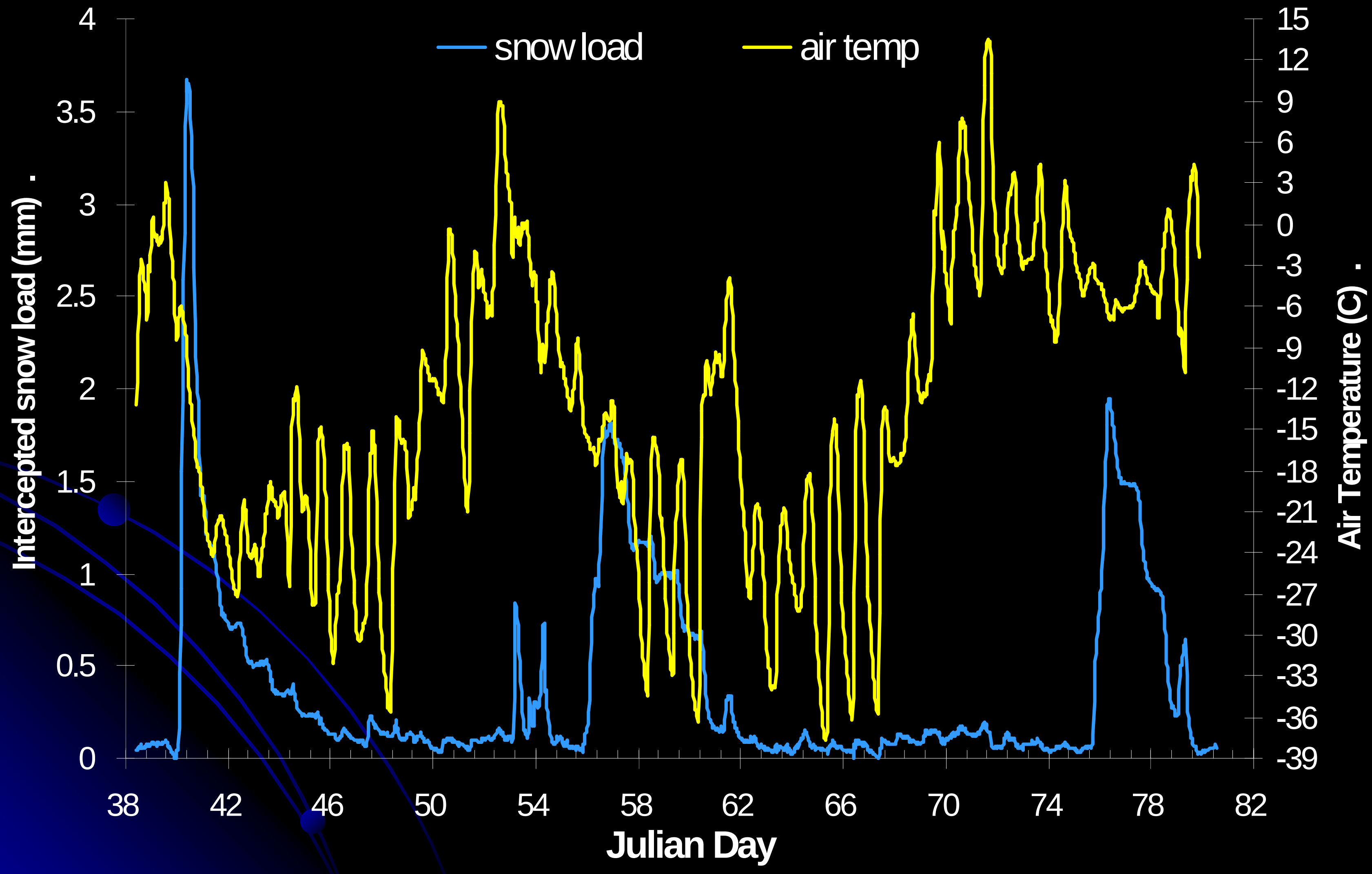
Simulation of Hillslope Snowdrift



Snow Interception



Interception & Sublimation of Snow on a Hanging Tree

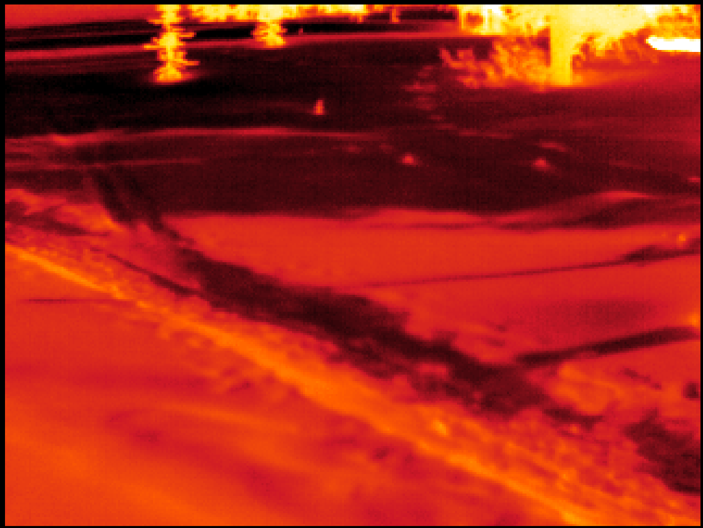


Snowmelt

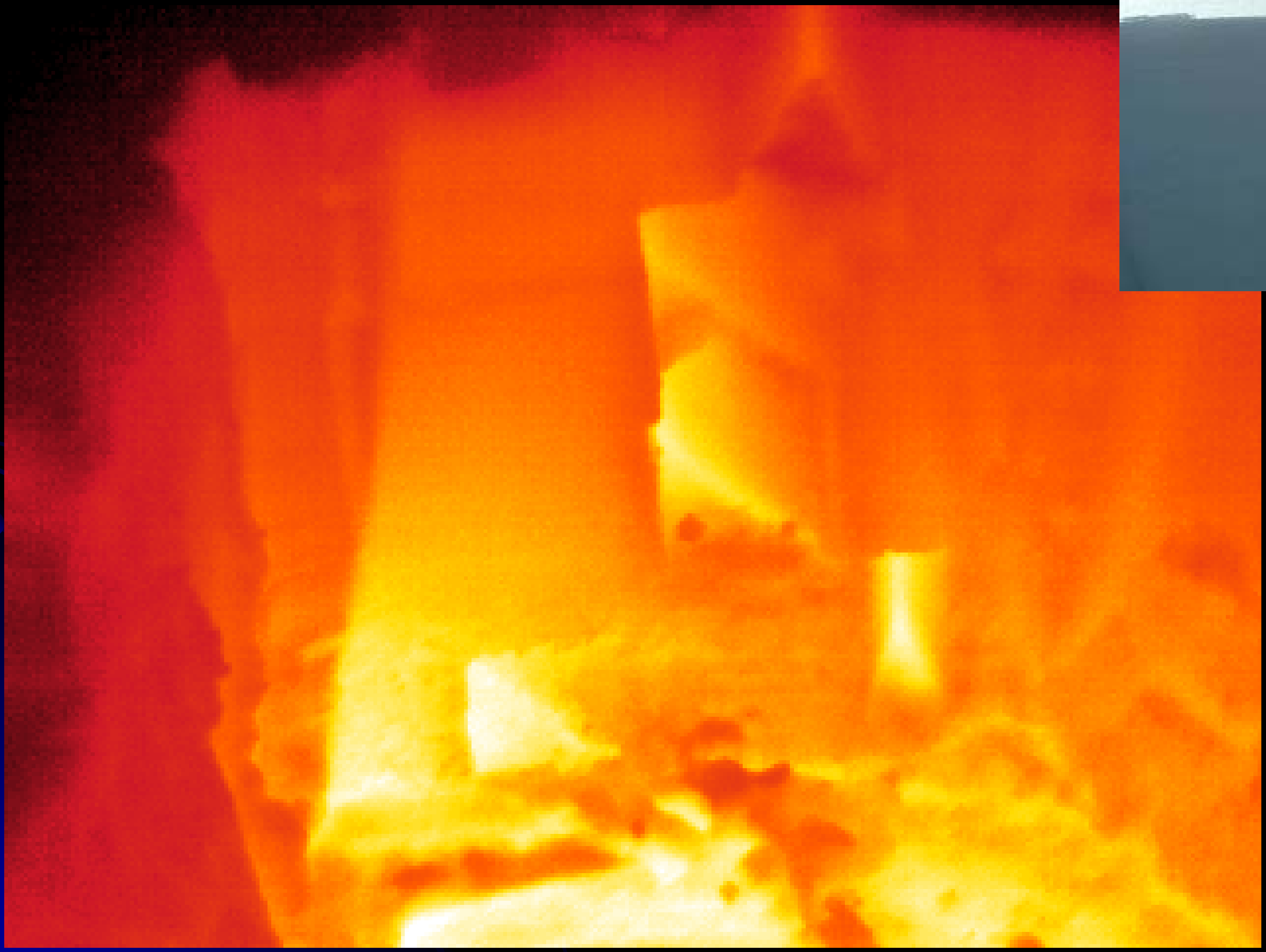
- Even though snowmelt is less than half of the annual water applied to land or glaciers it forms from 60% to 90% of runoff
- Snowmelt water can pass through glaciers, soils, groundwater, lakes and emerge as streamflow long after snowmelt occurs
- Snowmelt causes flooding in some cold regions

Snowmelt

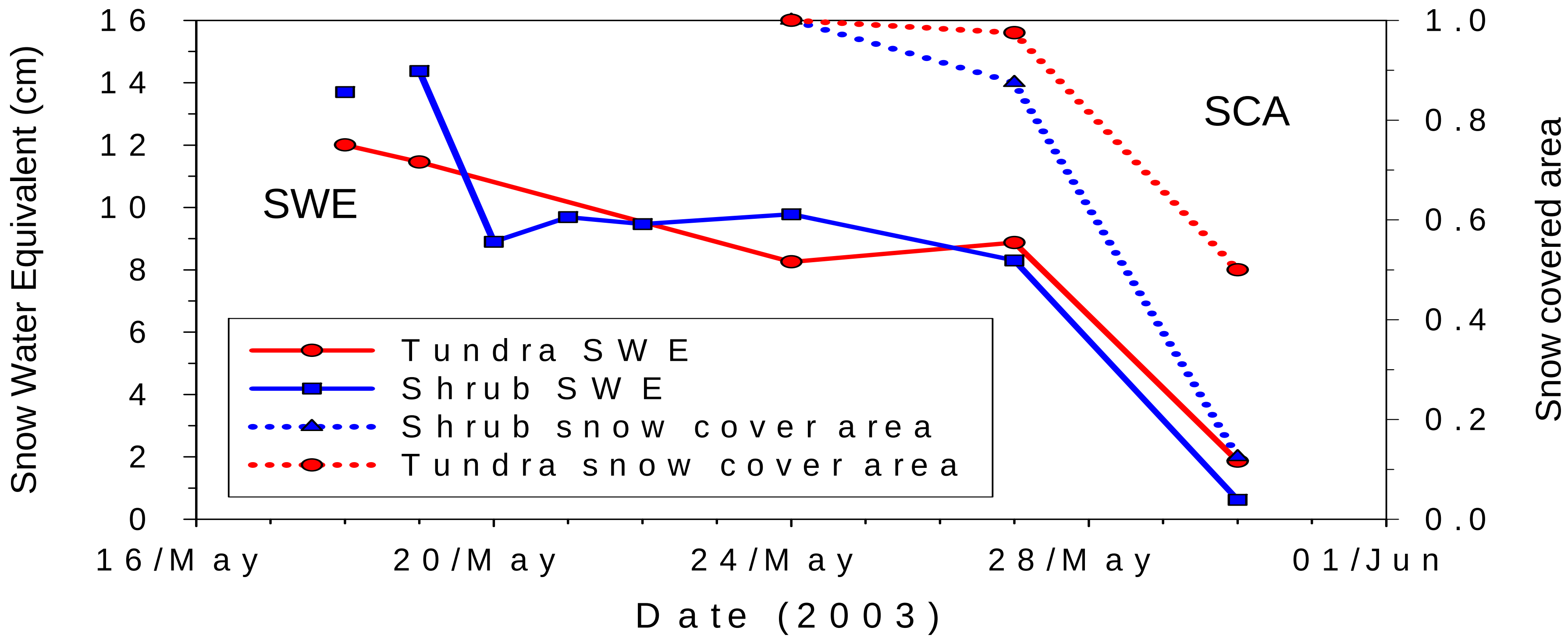
- Incoming solar and thermal radiation
- Warm air masses
- Terrain and vegetation effects



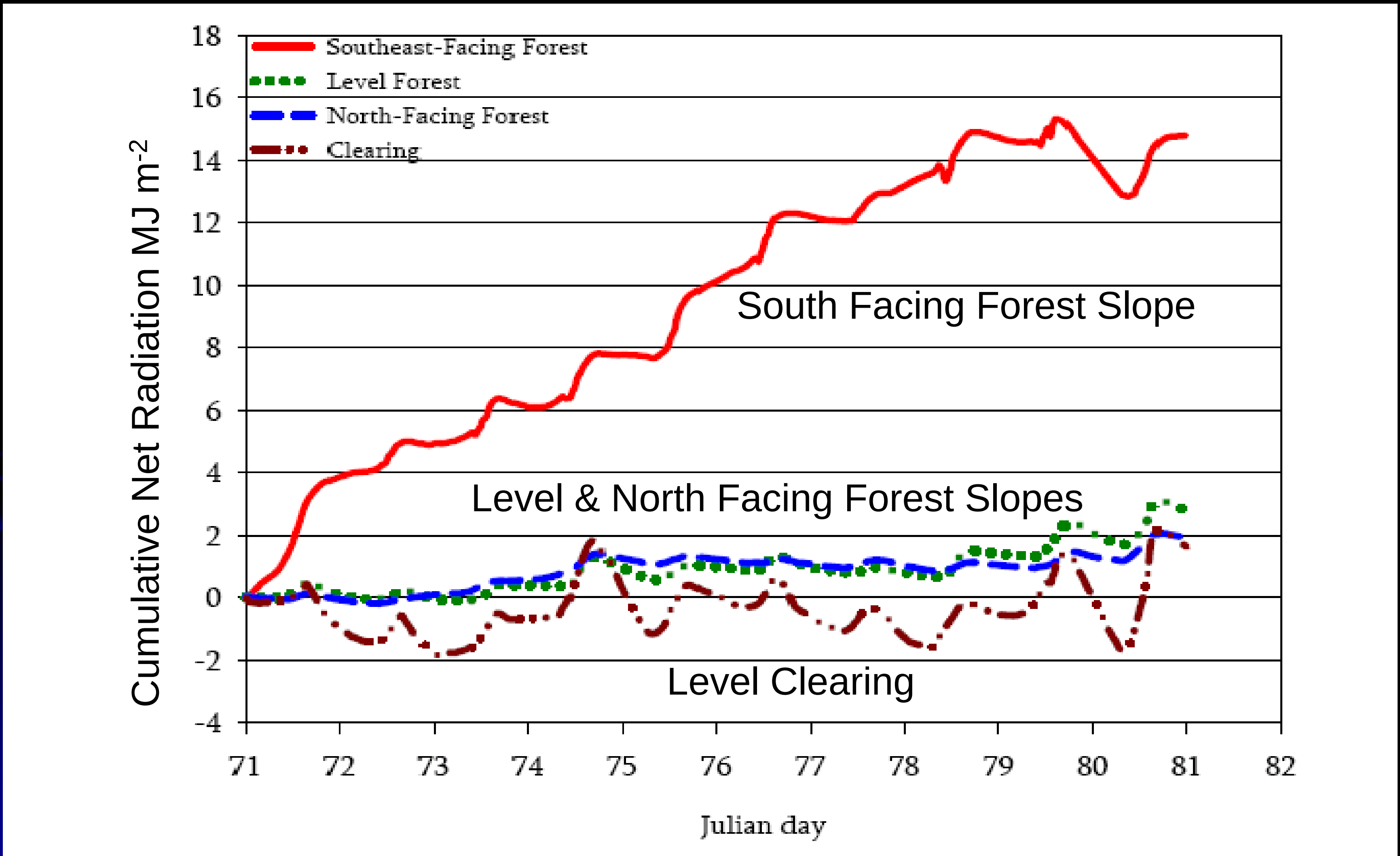
Snow Energetics



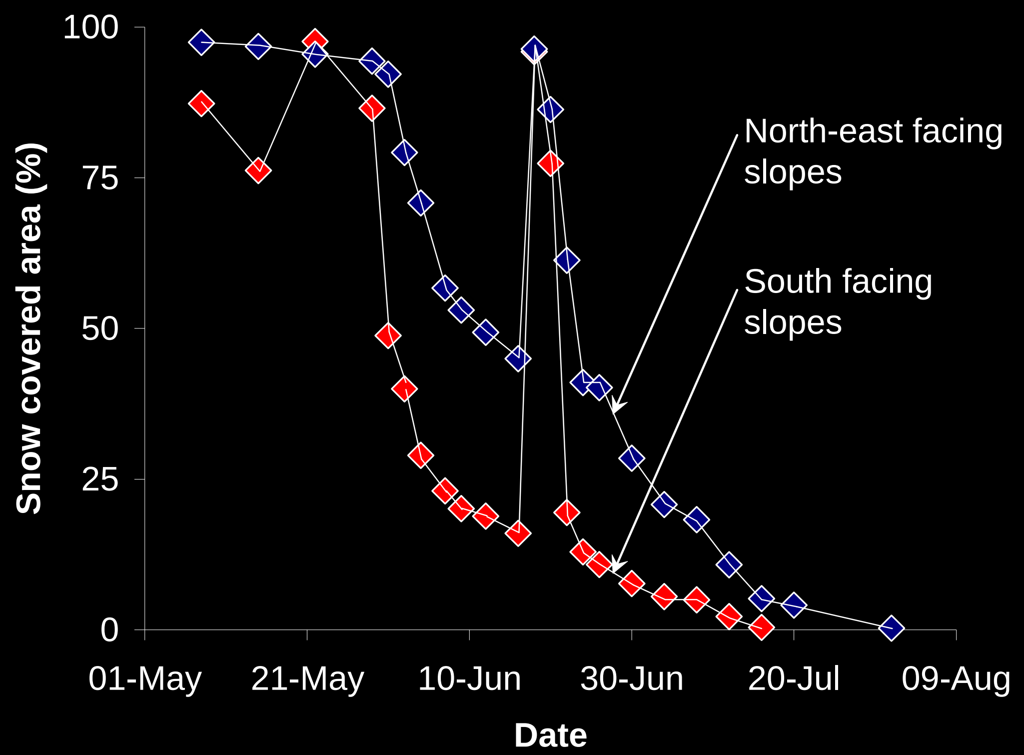
Change in snow covered area and snow water equivalent during melt at a tundra shrub site, Arctic



Net Radiation to Snowmelt on 25º Mountain Forest Slopes, Marmot Creek

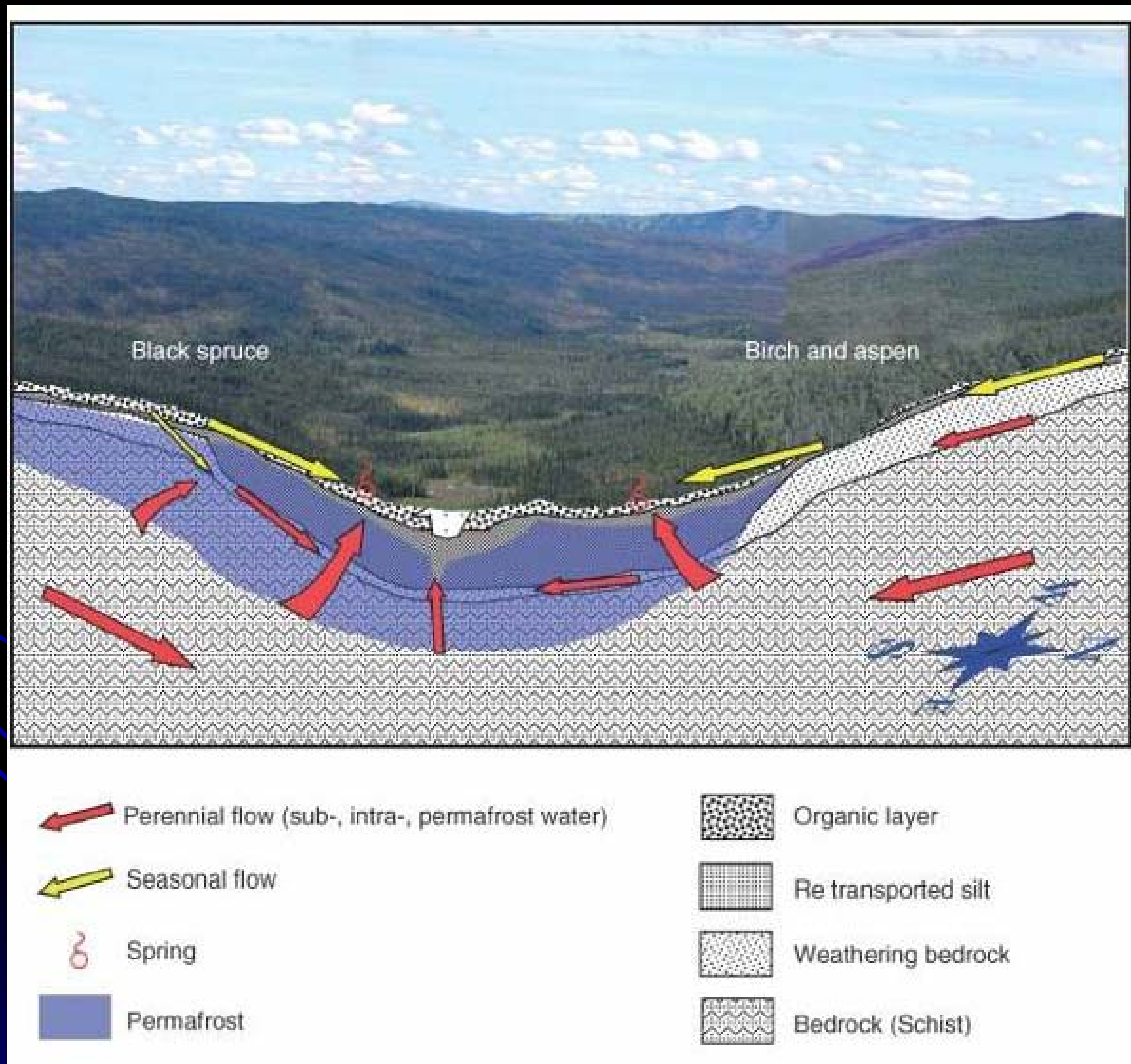


Snowcover Depletion in Alpine Basins



- ➢ Temporal snow cover depletion patterns differ considerably between slopes within ~1 km^2 cirque basin
  - ➢ Single snow cover depletion curve cannot be applied even for relatively ‘small’ scales in mountain terrain

Water to Soils and Runoff Generation for Streamflow over Frozen Ground



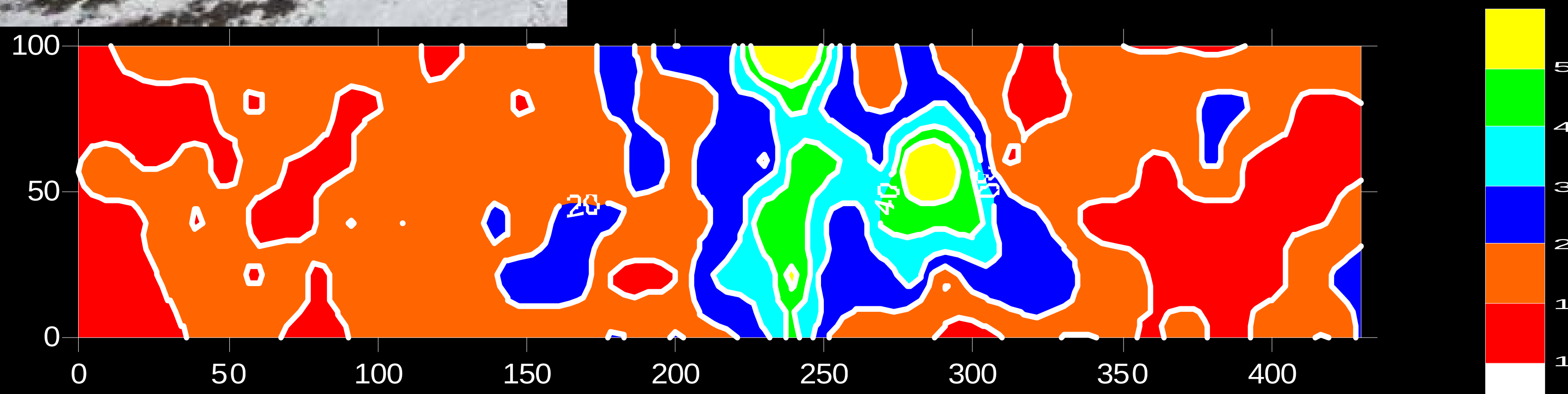
Thermokarst – thaw of permafrost causing subsidence and landslides.

We need to be able to predict runoff for small streams

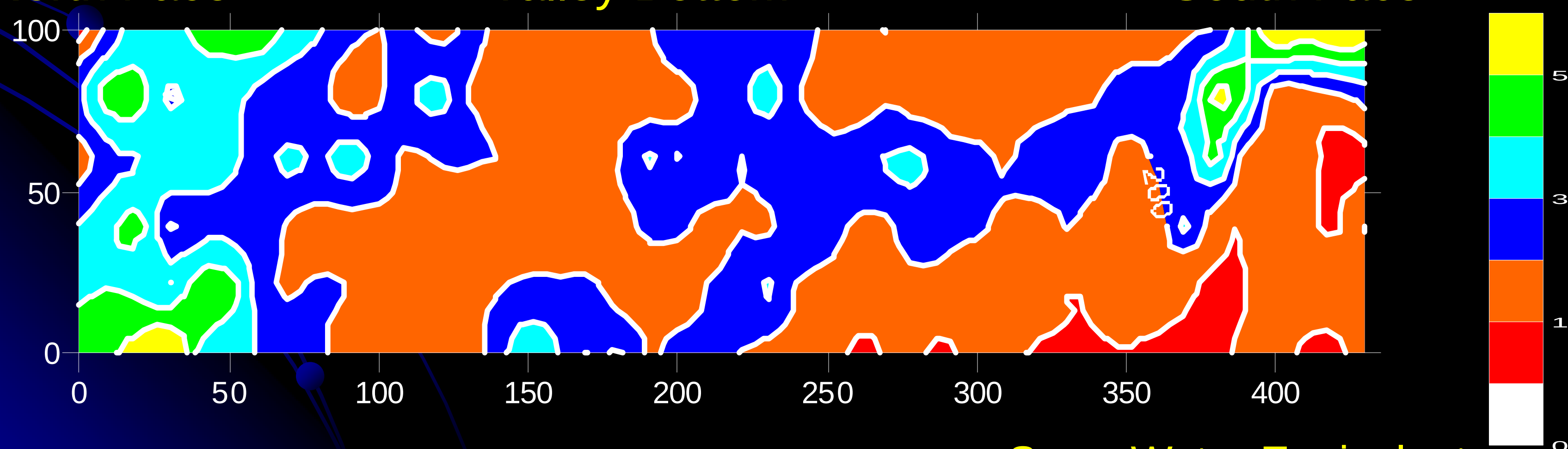
River crossings of roads (and pipelines) routinely fail because we have insufficient understanding of hydrology, runoff generation processes and permafrost or frozen ground in our designs.

Soil Moisture and Snowpack in a Tundra Mountain Valley

Soil Water Content %

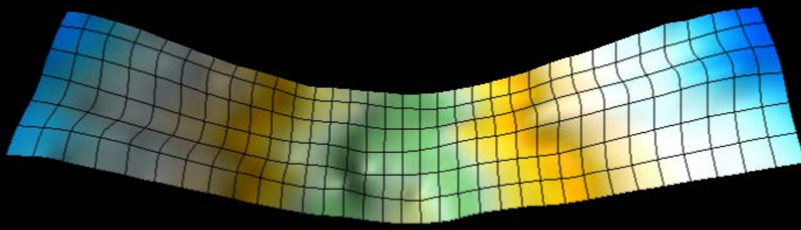


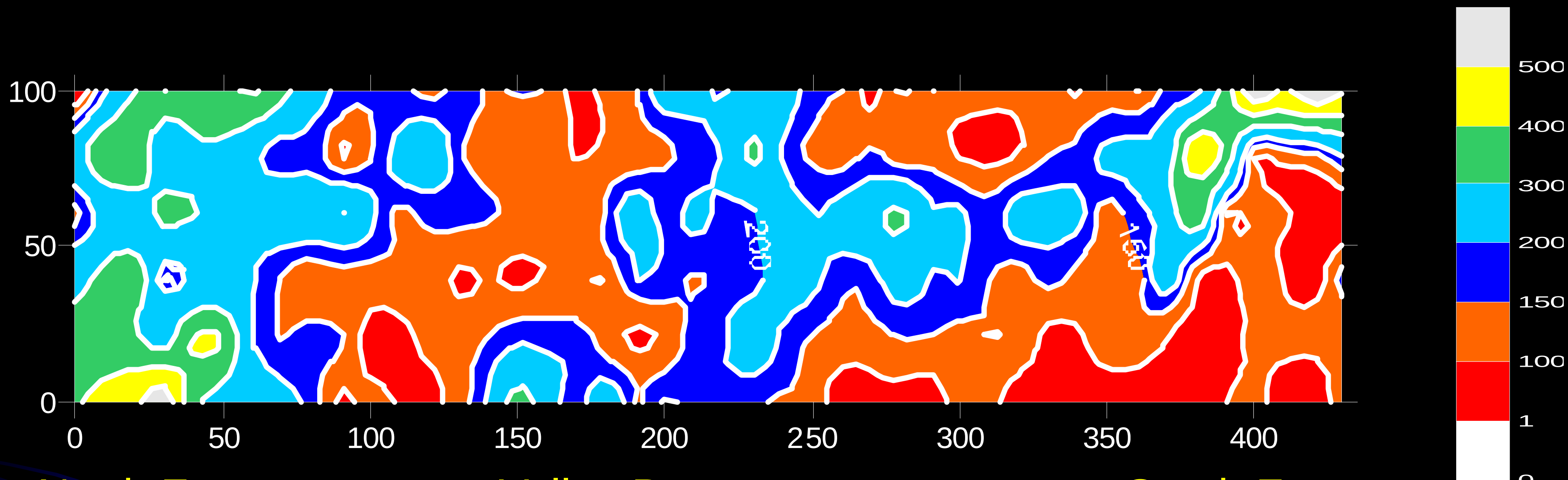
North Face Valley Bottom South Face



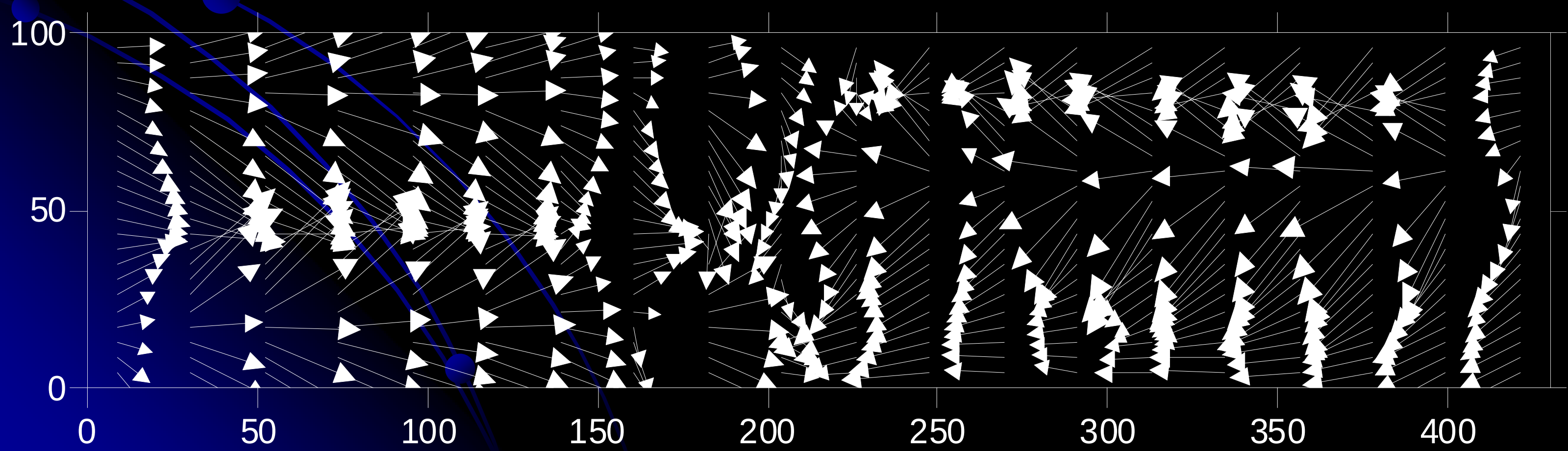
Snow Water Equivalent mm

Snowmelt Runoff

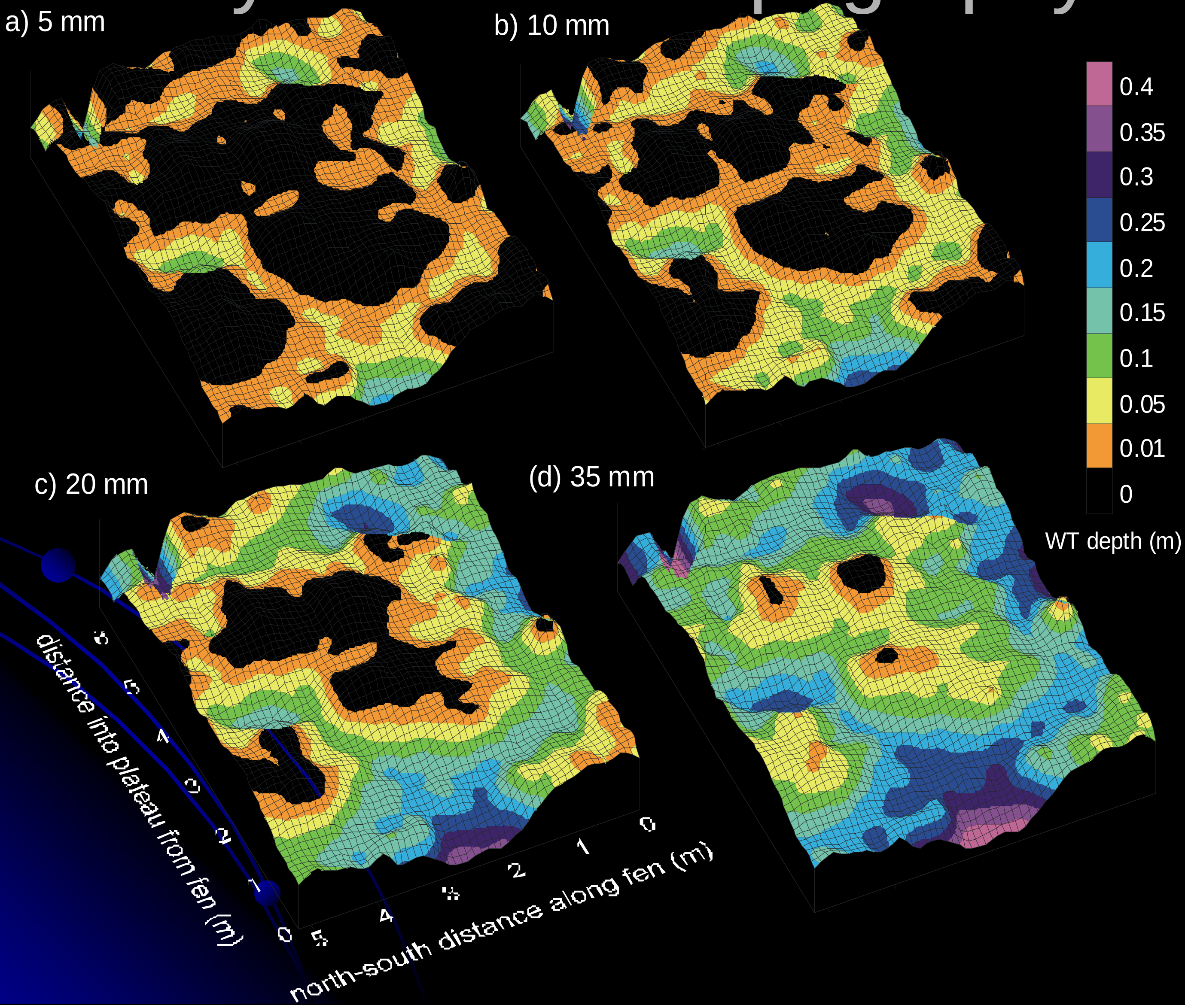




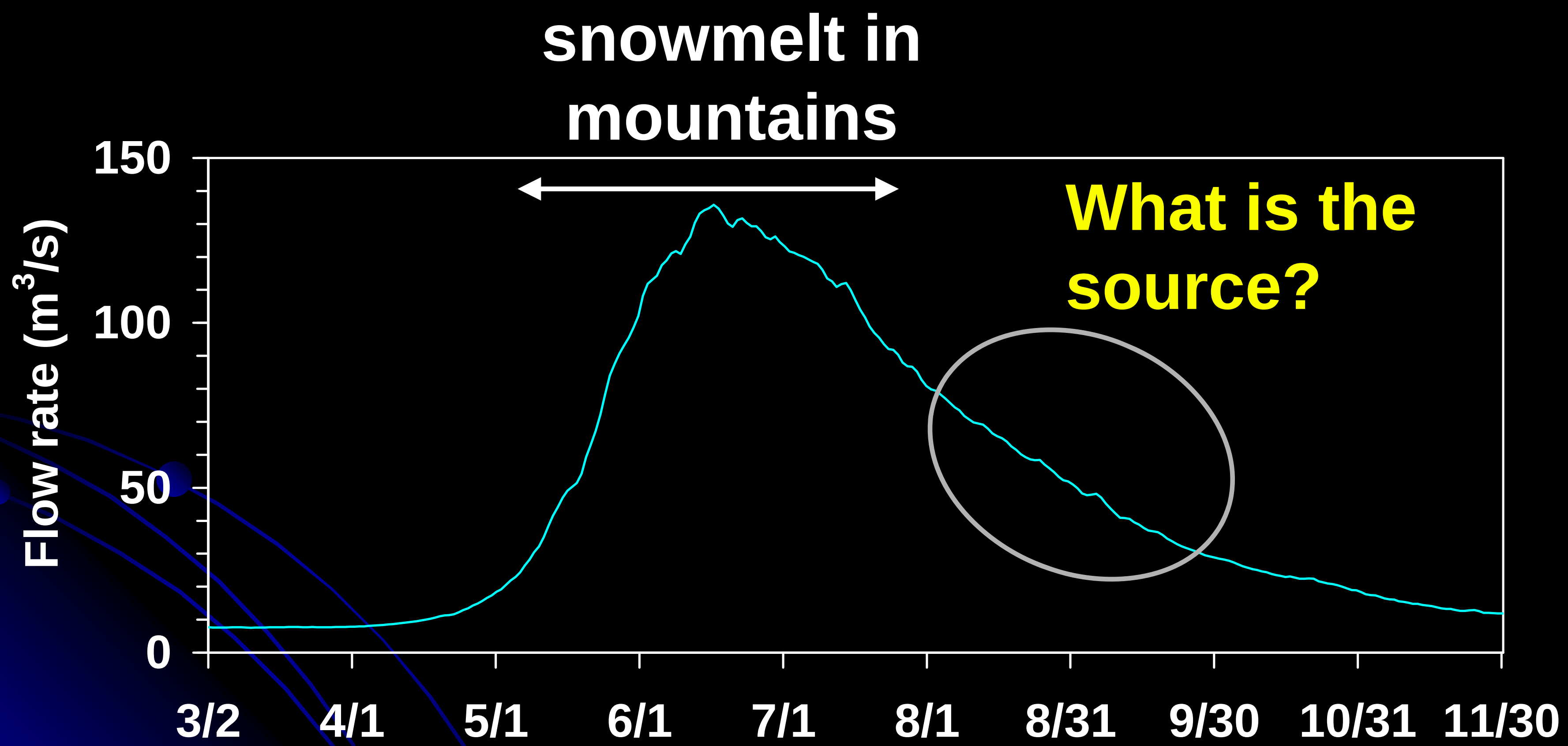
North Face Valley Bottom South Face



Permafrost wetland runoff is controlled by frost table topography



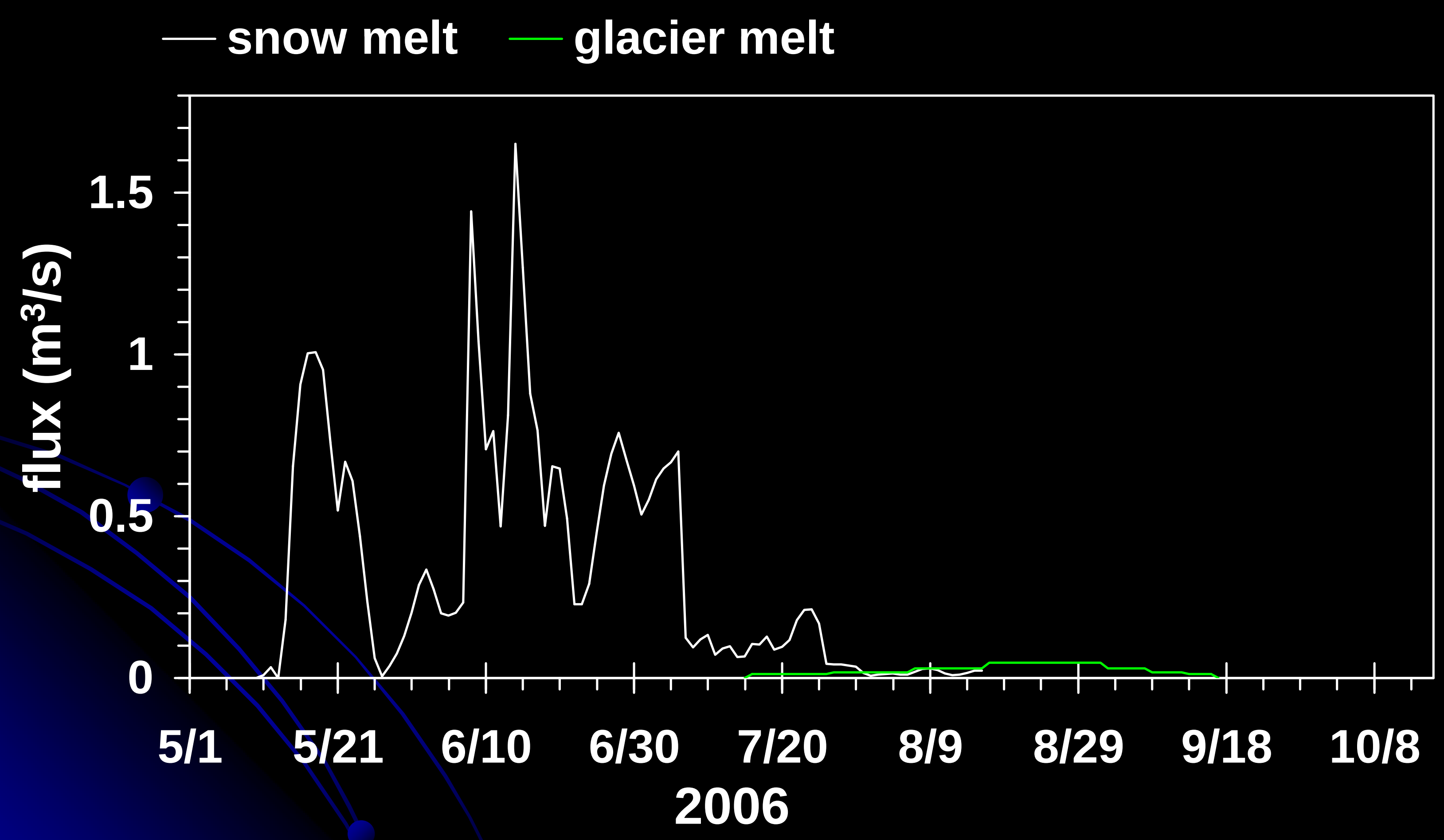
Average Flow in Bow River at Banff



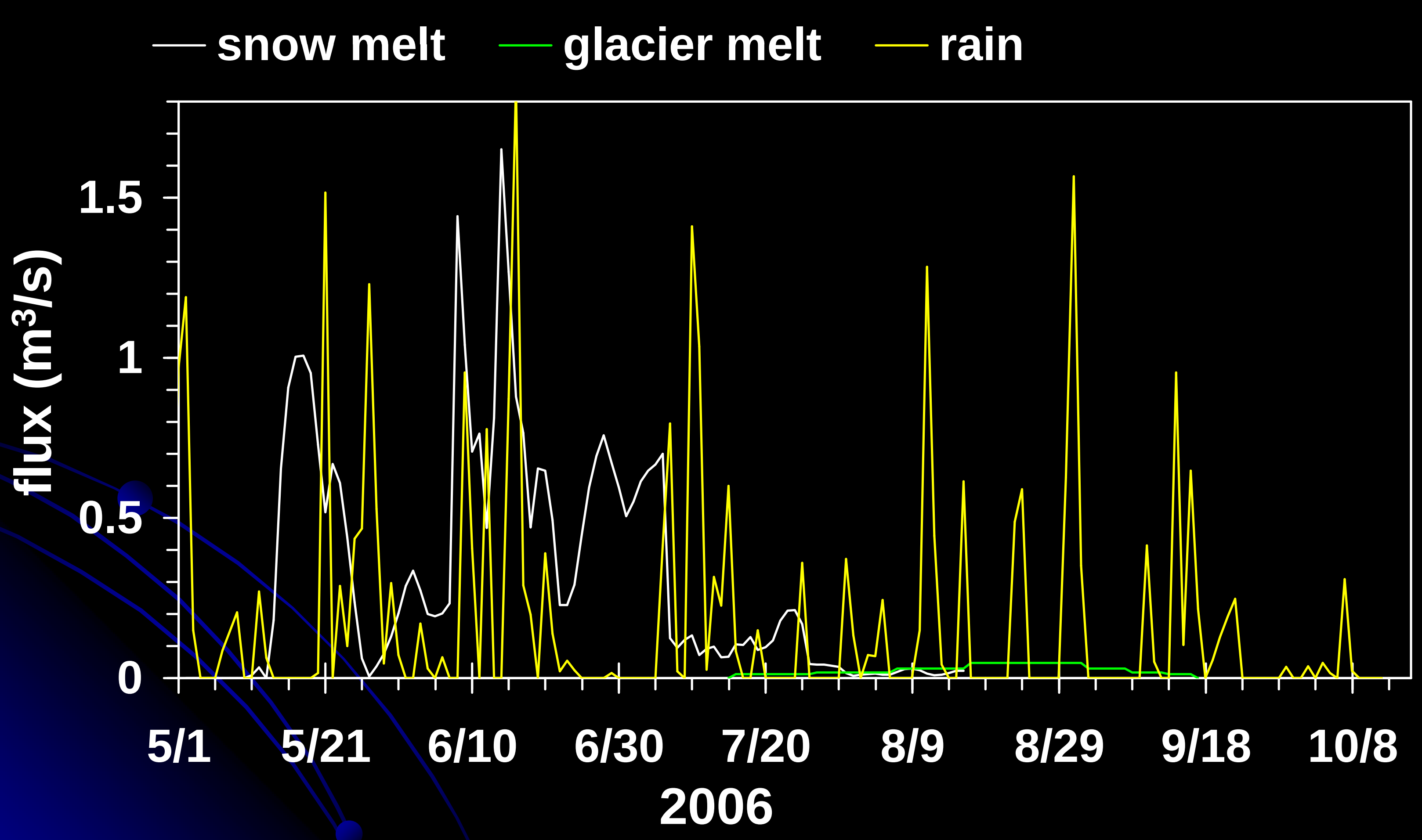
Sources of Mountain Streamflow

- 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

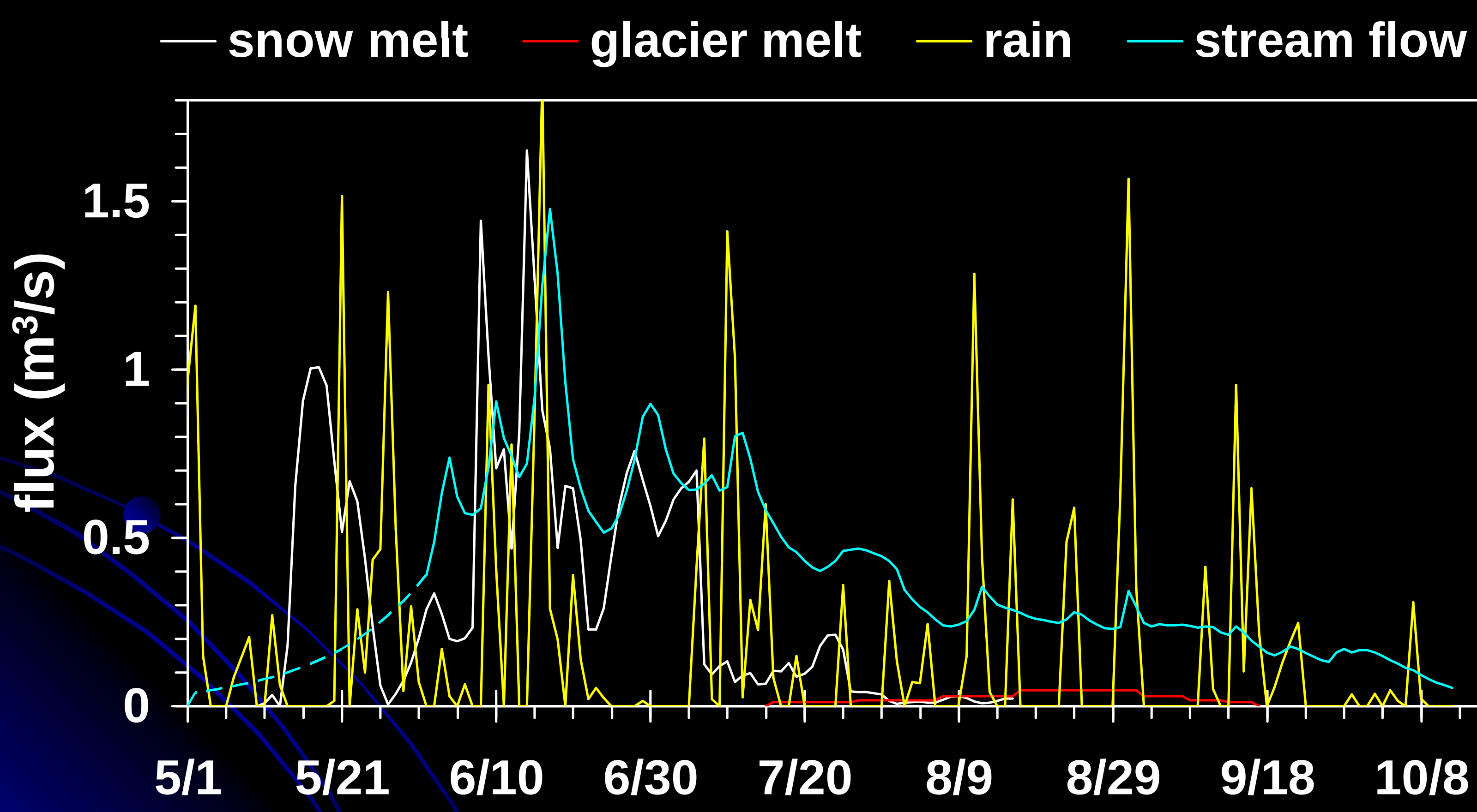
Water Input to the Opabin Watershed



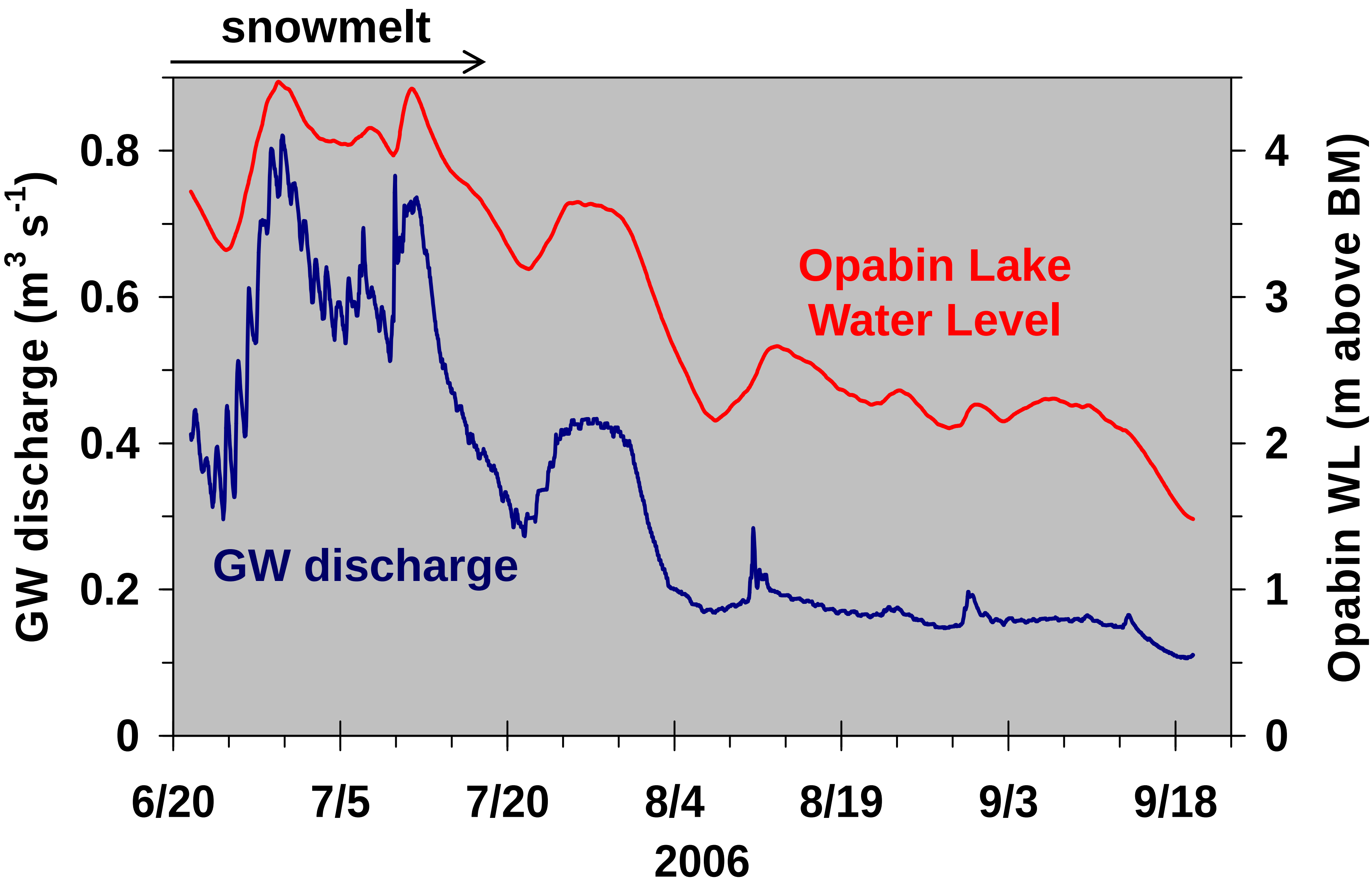
Water Input to the Opabin Watershed



Lake O'Hara Water Inputs and Output in 2006



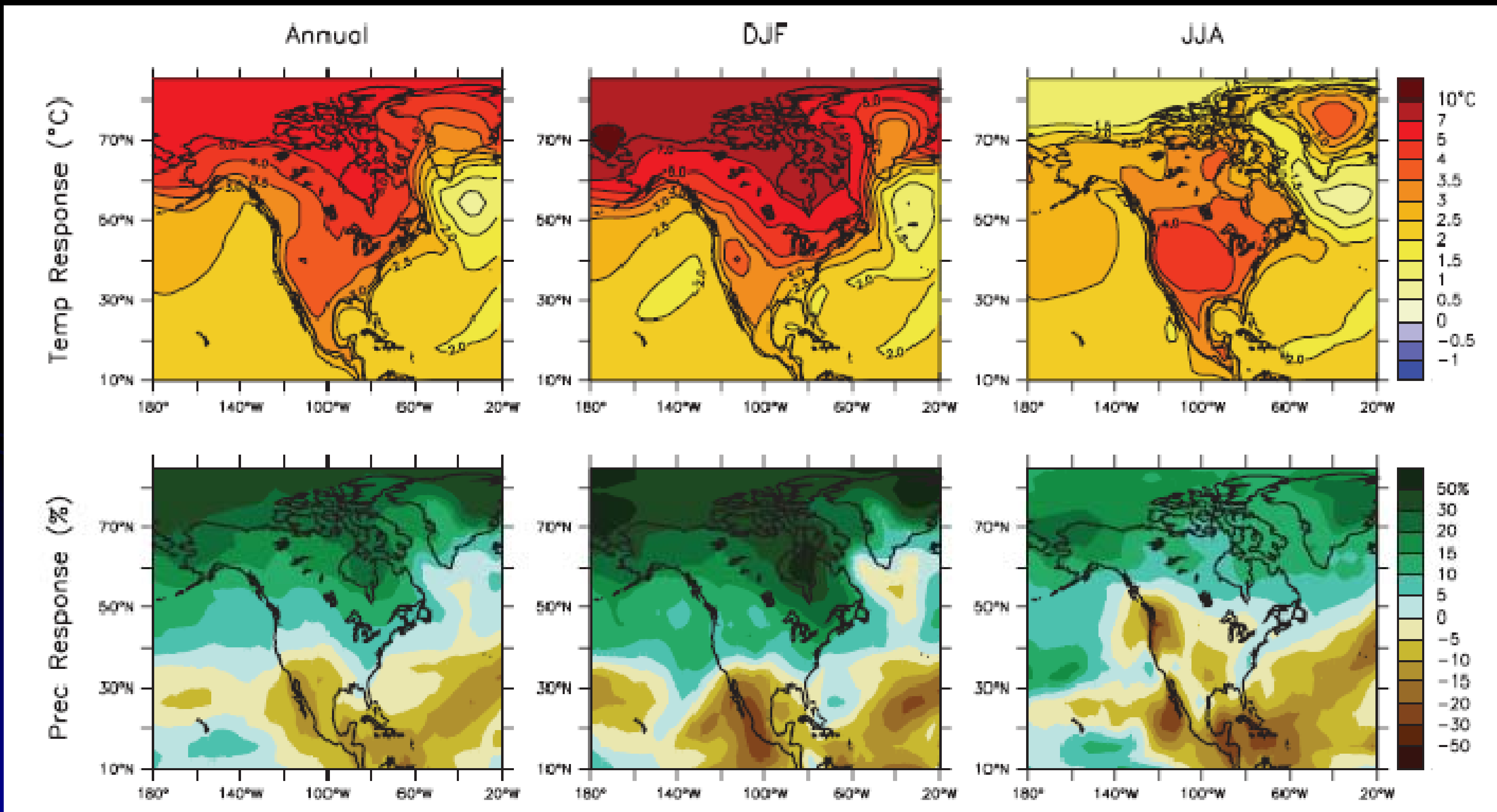
Groundwater Discharge Rate Controls Opabin Lake Water Level



Climate Change Predictions

Difference from 1980-1999 to 2080-2089

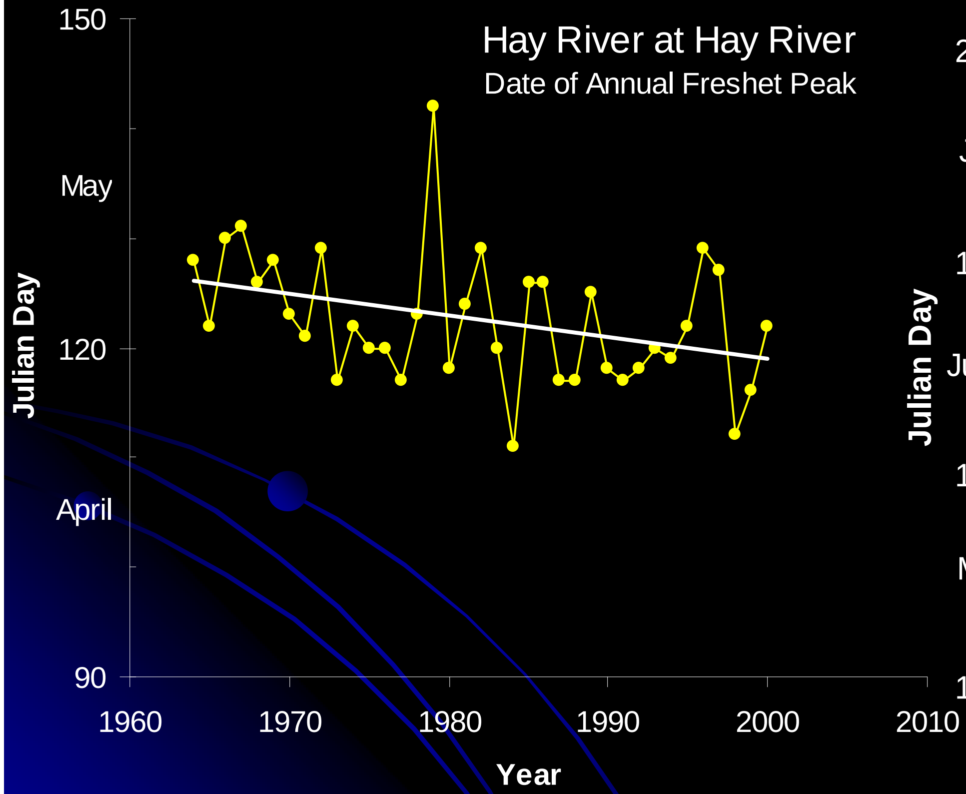
A1B – balanced scenario

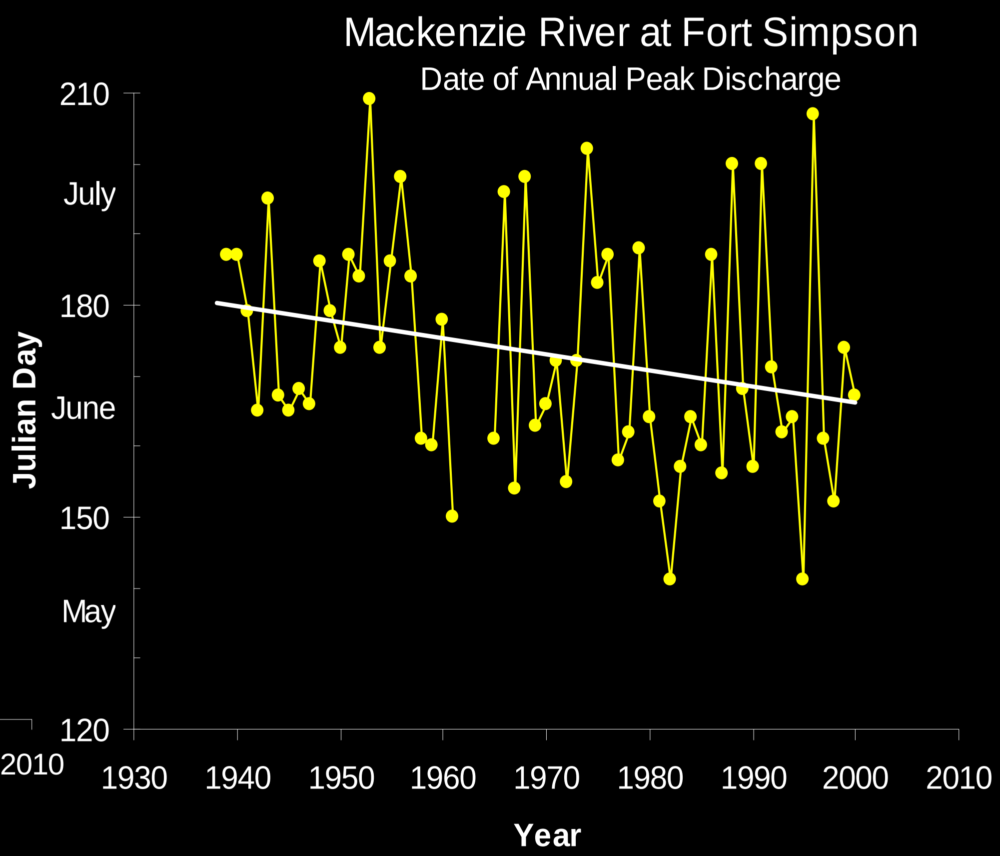


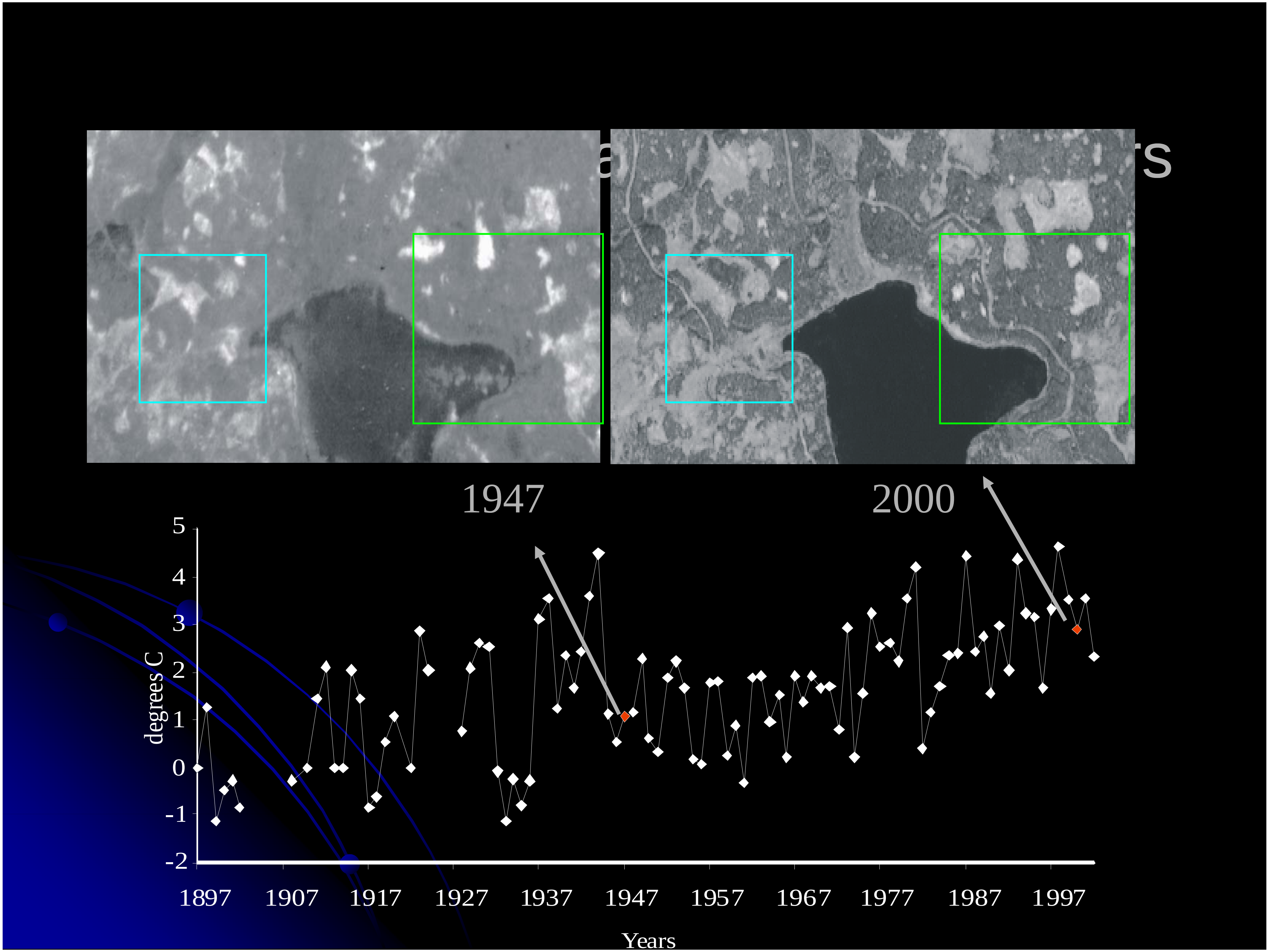
Wetter and warmer, more to come!

IPCC 2007

Date of Spring Peak Streamflow in Northern Canada



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degrees C
1897
1907
1917
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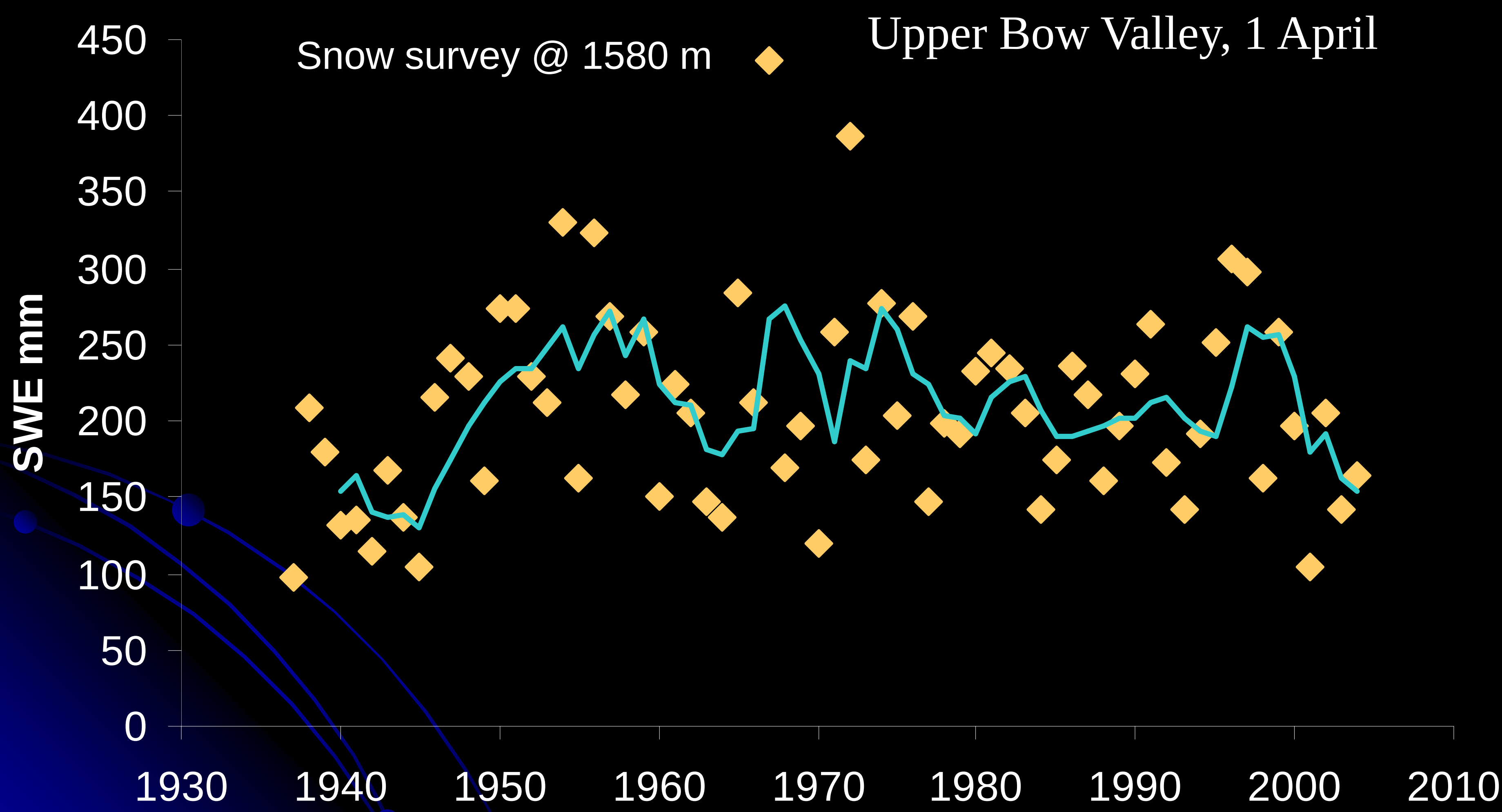
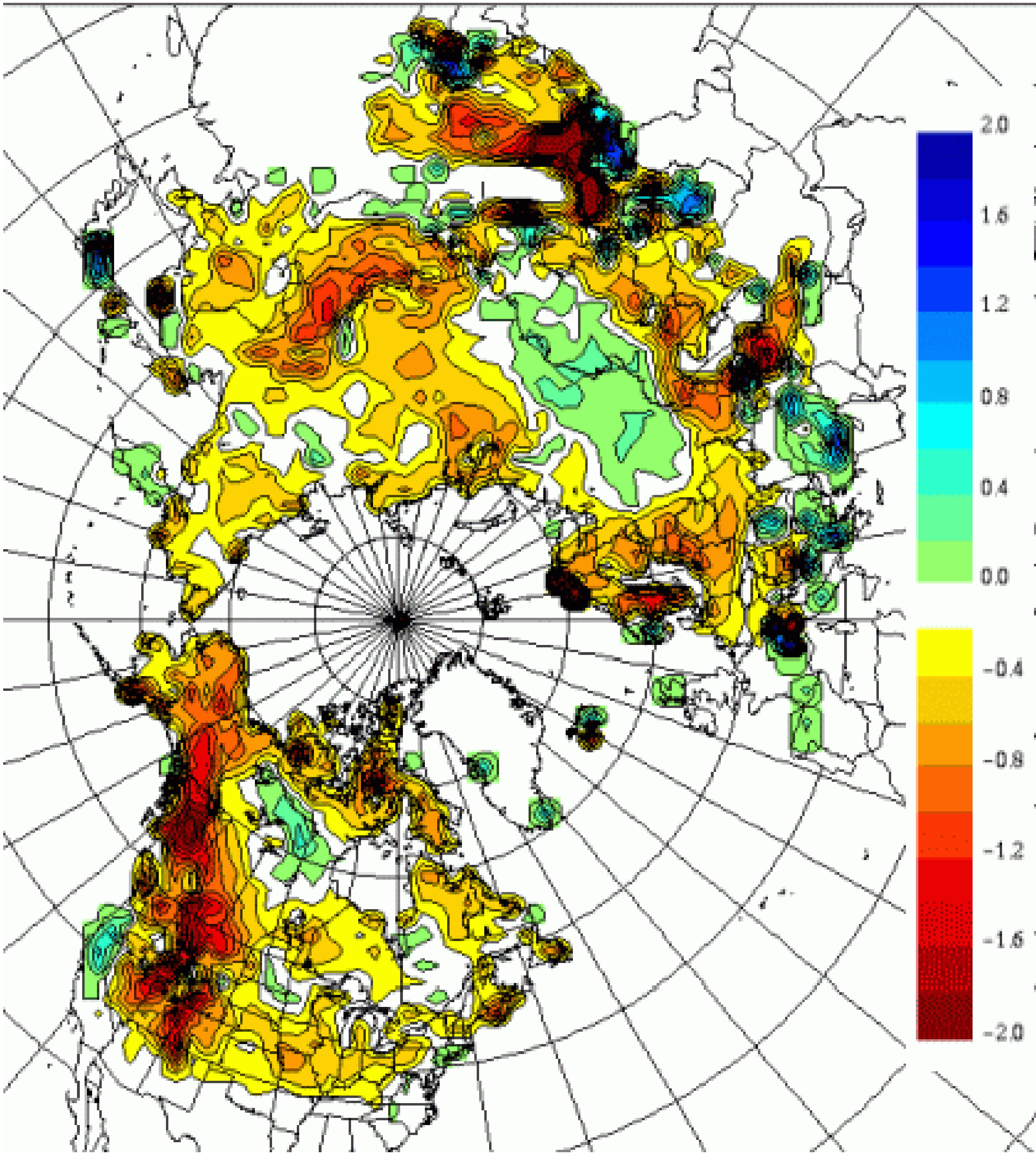
1937
1947
1957
1967
1977
1987
1997
Years

Mountain High Elevation Snow Accumulation in Spring



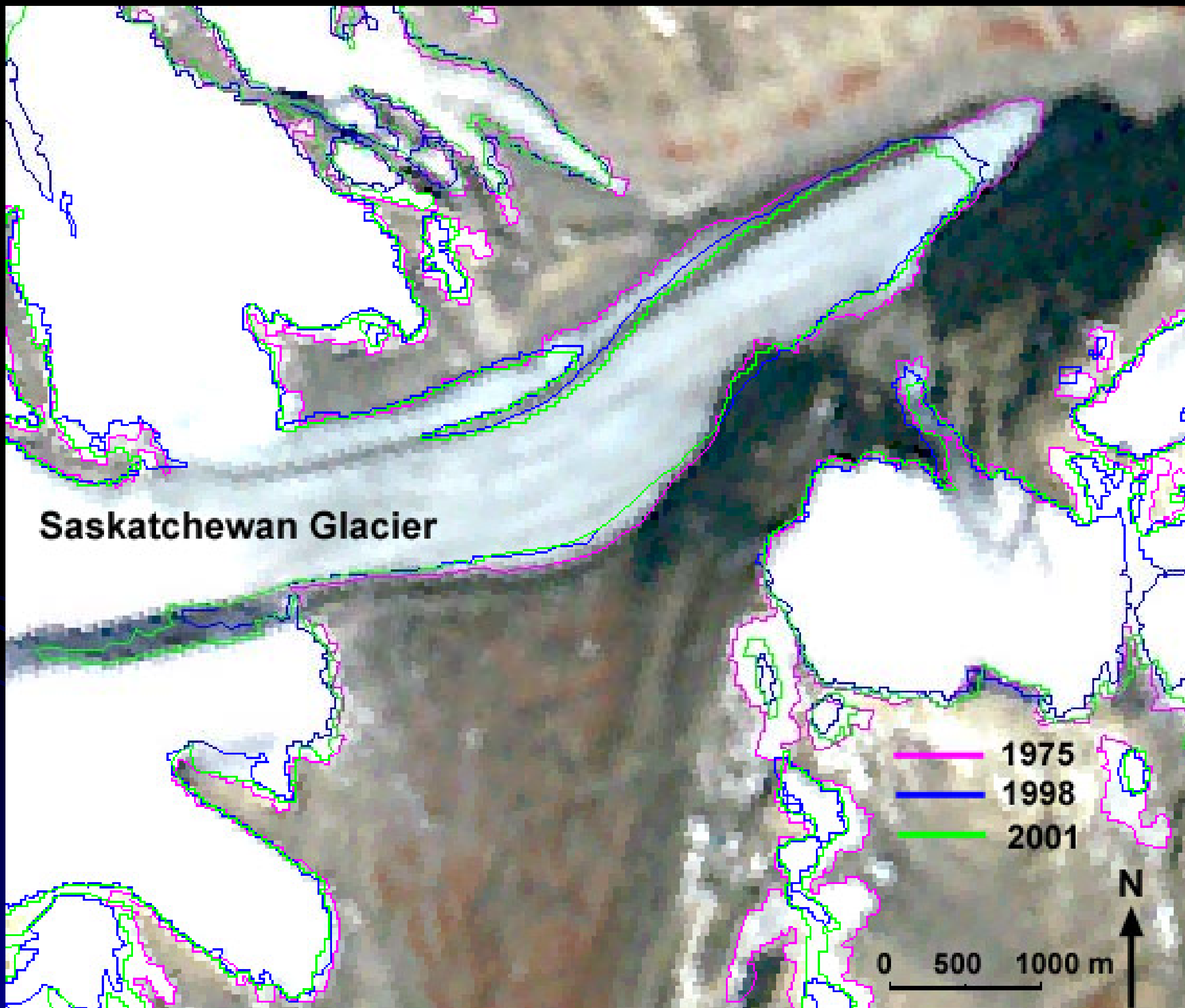


Snow-covered Period is Declining in many places

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

Glacier Retreat in the Columbia Icefields



Mapped from LANDSAT satellite

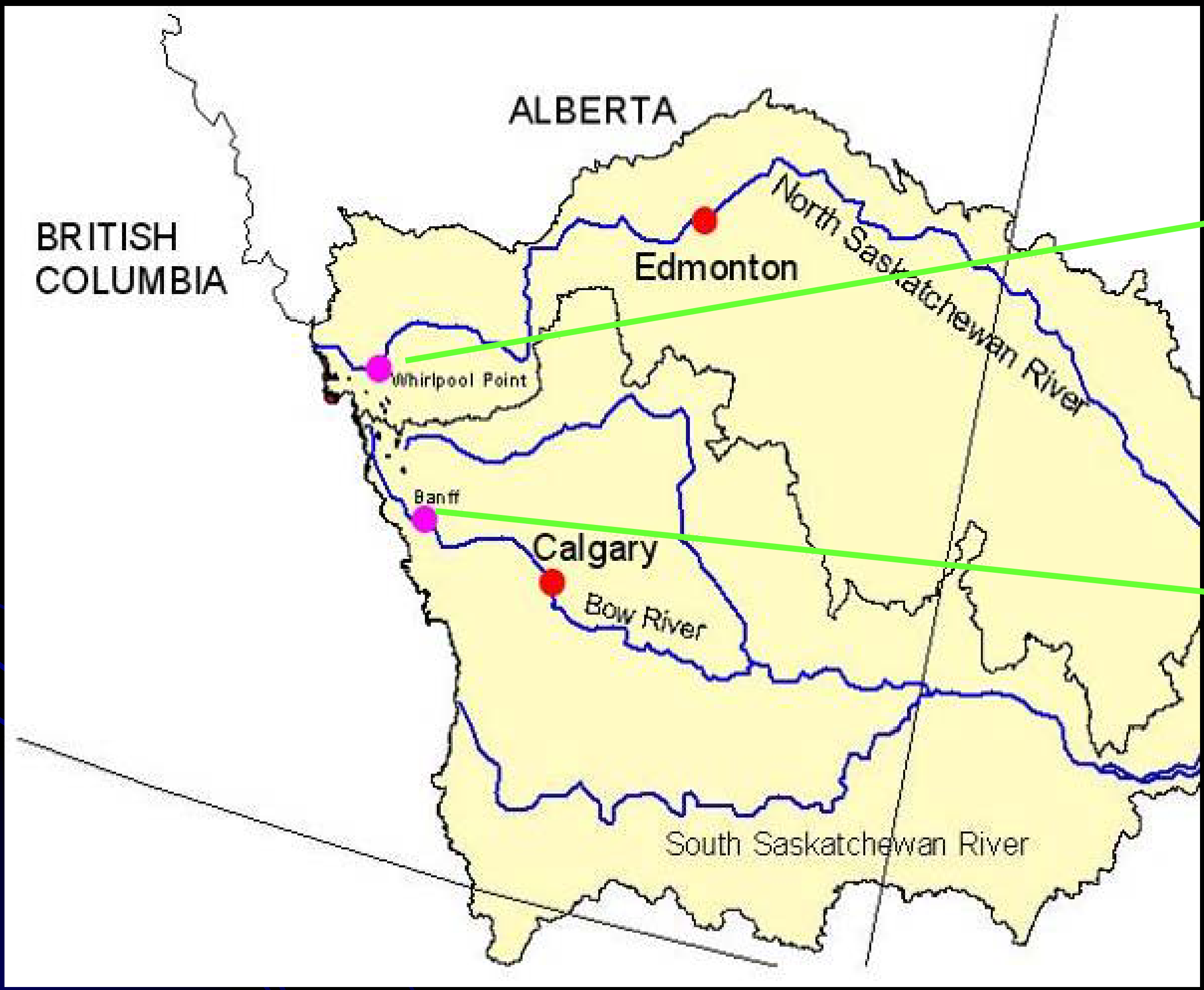
Shrinking glaciers release water, growing glaciers store water

Glaciers are also a valuable record of climate variability and change

Glacier Retreat – Satellite Analysis

- LANDSAT satellite, 1975 and 1998.
- The decline of the total glacier area of the North Saskatchewan basin between 1998 (306 km^2) and 1975 (394 km^2) was -22% of glaciated area
- The decline of the total glacier area of the South Saskatchewan basin between 1975 (138 km^2) and 1998 (88 km^2) was -36% of glaciated area

Current Glacier Melt Contribution to River Discharge

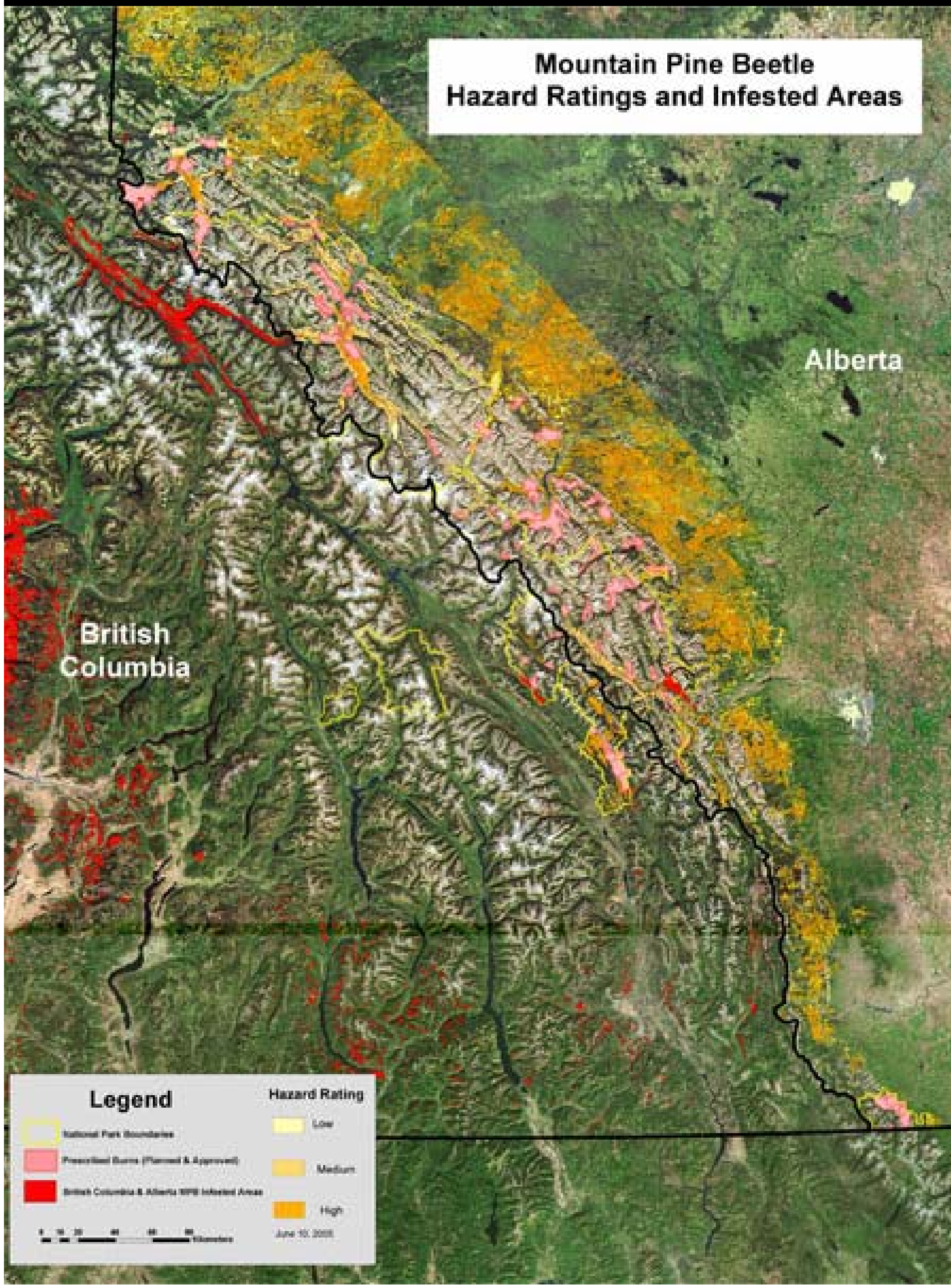


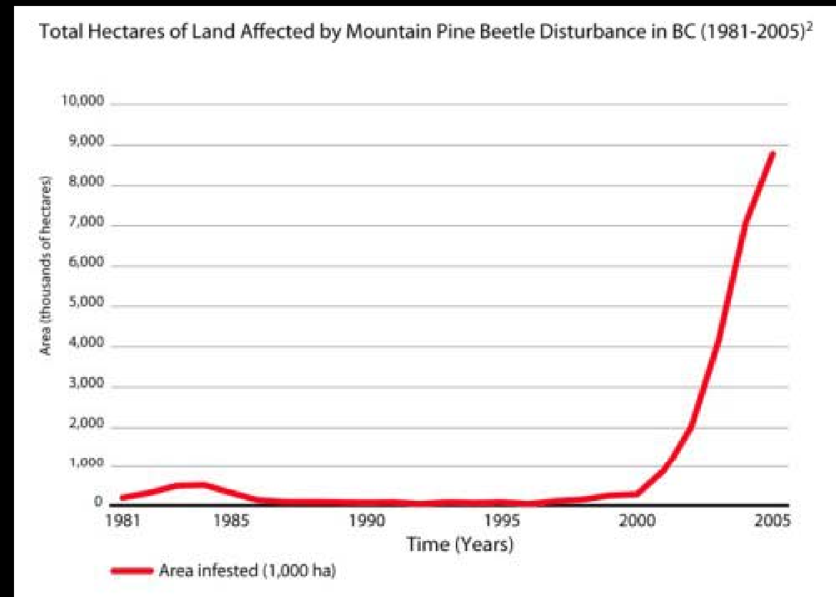
Fall %	Annual %
11.5	**7.1**

Fall %	Annual %
6.2	**2.8**

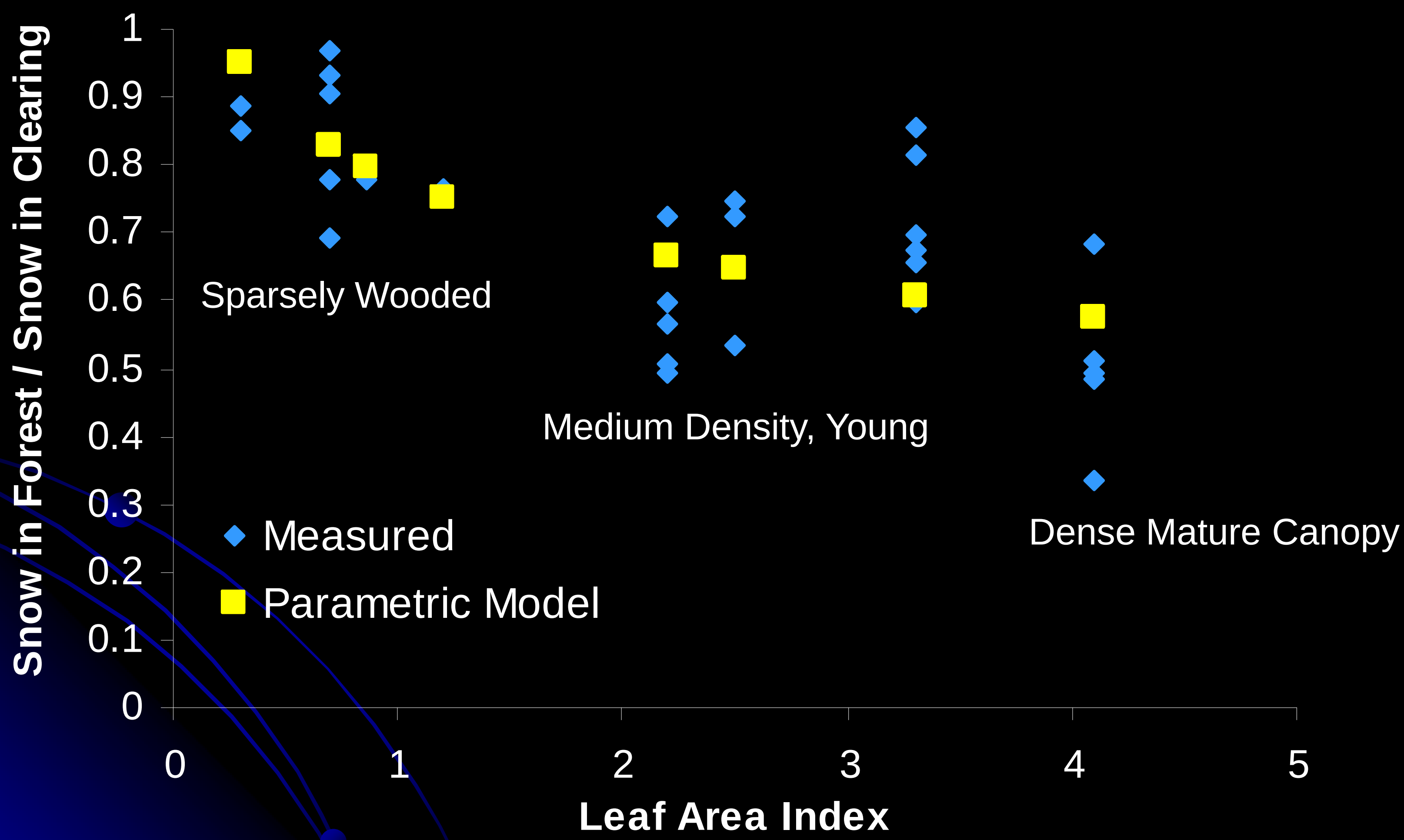
Mike Demuth, Natural Resources Canada

Deforestation

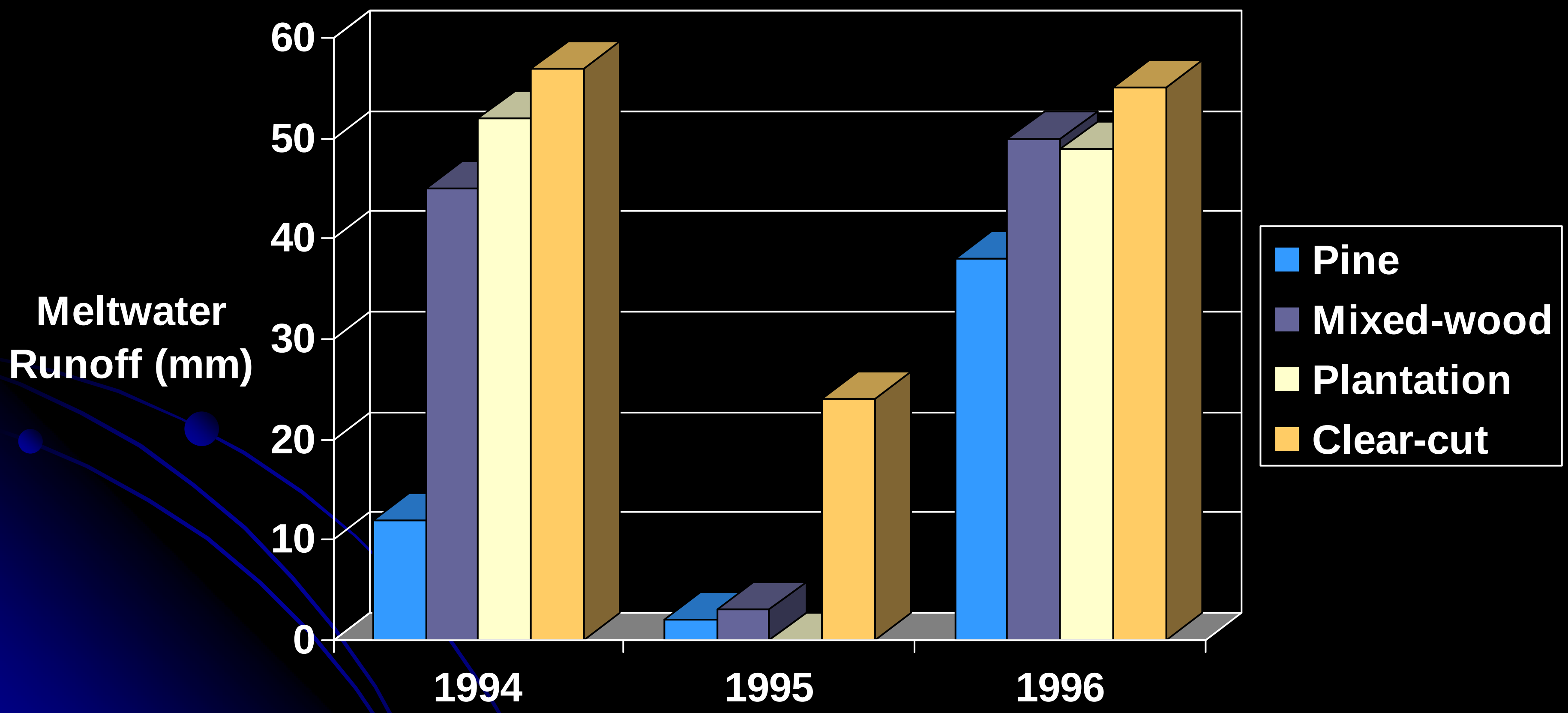




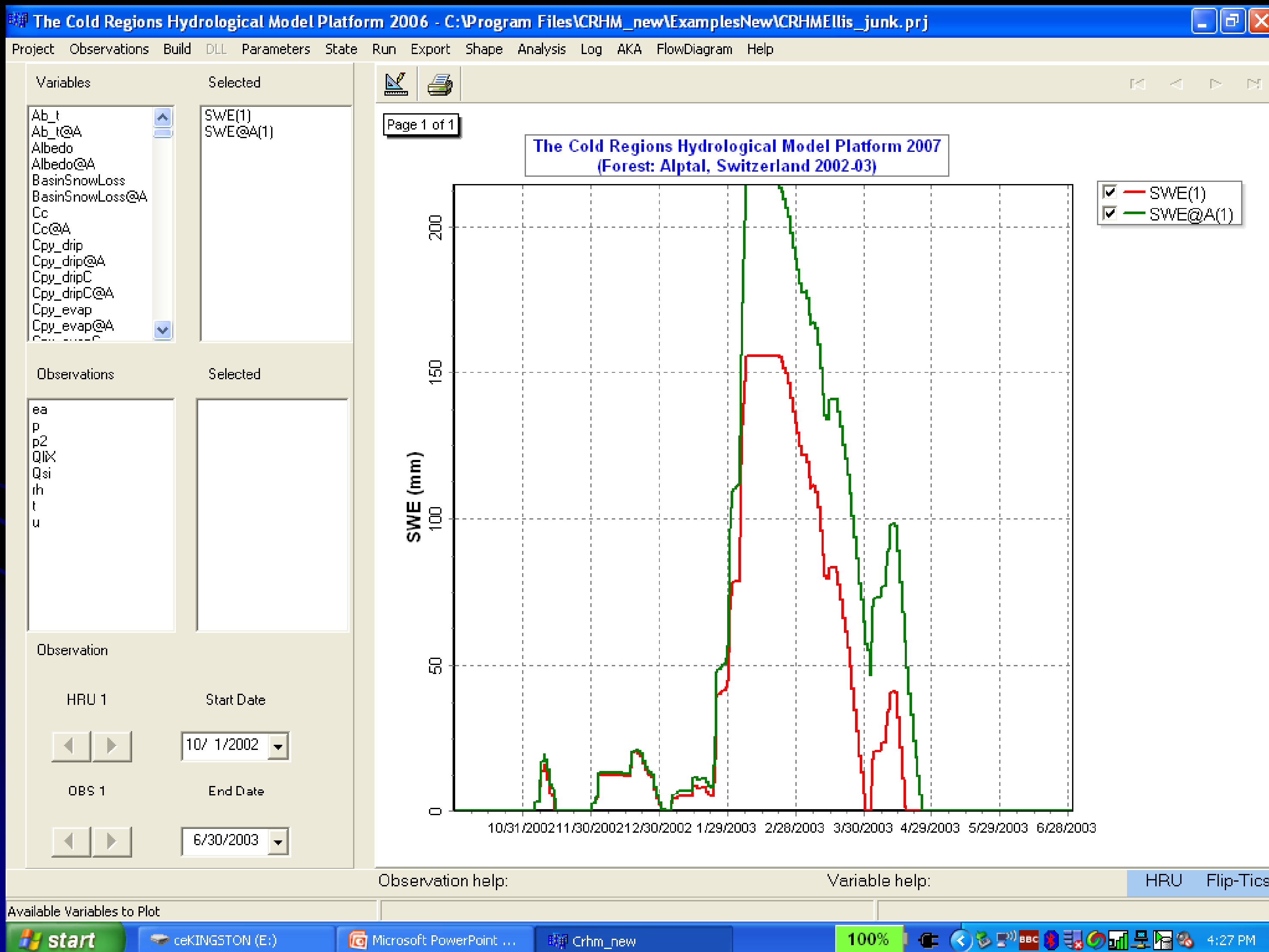
Effect of Forest Removal on Snow Accumulation



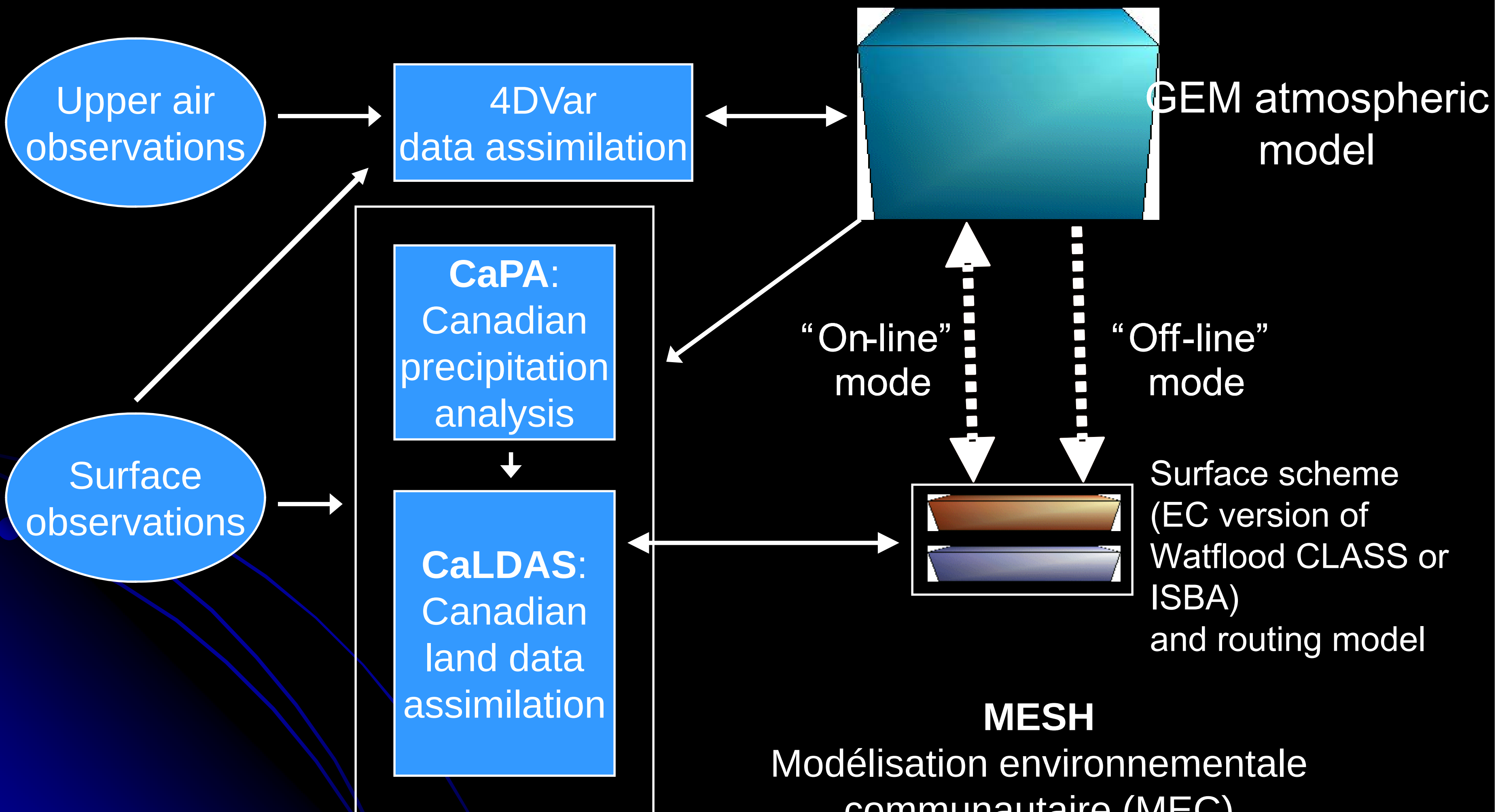
Snowmelt Runoff Decreases with Increasing Forest Cover
- infiltration to frozen soils –



Physically Based Hydrological Modelling can answer water management questions



Environment Canada Environmental Prediction Framework



MESH
Modélisation environnementale communautaire (MEC) de la surface et de l'hydrologie

IP3...

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

Improved Processes & Parameterisation for Prediction in Cold Regions

- ...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

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)

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

Concluding Remarks

- Cold regions hydrology is very sensitive to both precipitation and "energy" inputs
- Snowpack, vegetation, permafrost, glaciers, wetlands, lakes and groundwater all play an important role in governing streamflow in cold regions
- Physically-based computer models are having initial successes in estimating these effects for water resource prediction
- Changes in climate (wetter, warmer) are having complex effects on cold regions hydrology – streamflow could go up or down depending on latitude and complicating factors (pine beetle, permafrost thaw, glacier melt, groundwater depletion)
- With dramatically increasing use of water from cold regions in southern Canada, water managers will have to take into account both the changing precipitation and energy inputs and the cold regions hydrology processes with much greater precision in order to manage the competing demands for limited water as the 21st Century unfolds.
- Our observation and hydrological modelling capacity will require further development to meet the needs of precision water management.

Thank You!

This research is supported by:
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-Natural Sciences and Engineering Research Council of Canada
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-Natural Resources Canada
-Indian Affairs and Northern Development Canada
-Biogeoscience Institute, Univ of Calgary
-Kananaskis Country,
-Nakiska Ski Area,
-Parks Canada
-Yukon Environment
-UK Natural Environment Research Council
-USDA Agricultural Research Service
-many others