Hydrology in the Central Canadian Rocky Mountains: Change and Natural Processes

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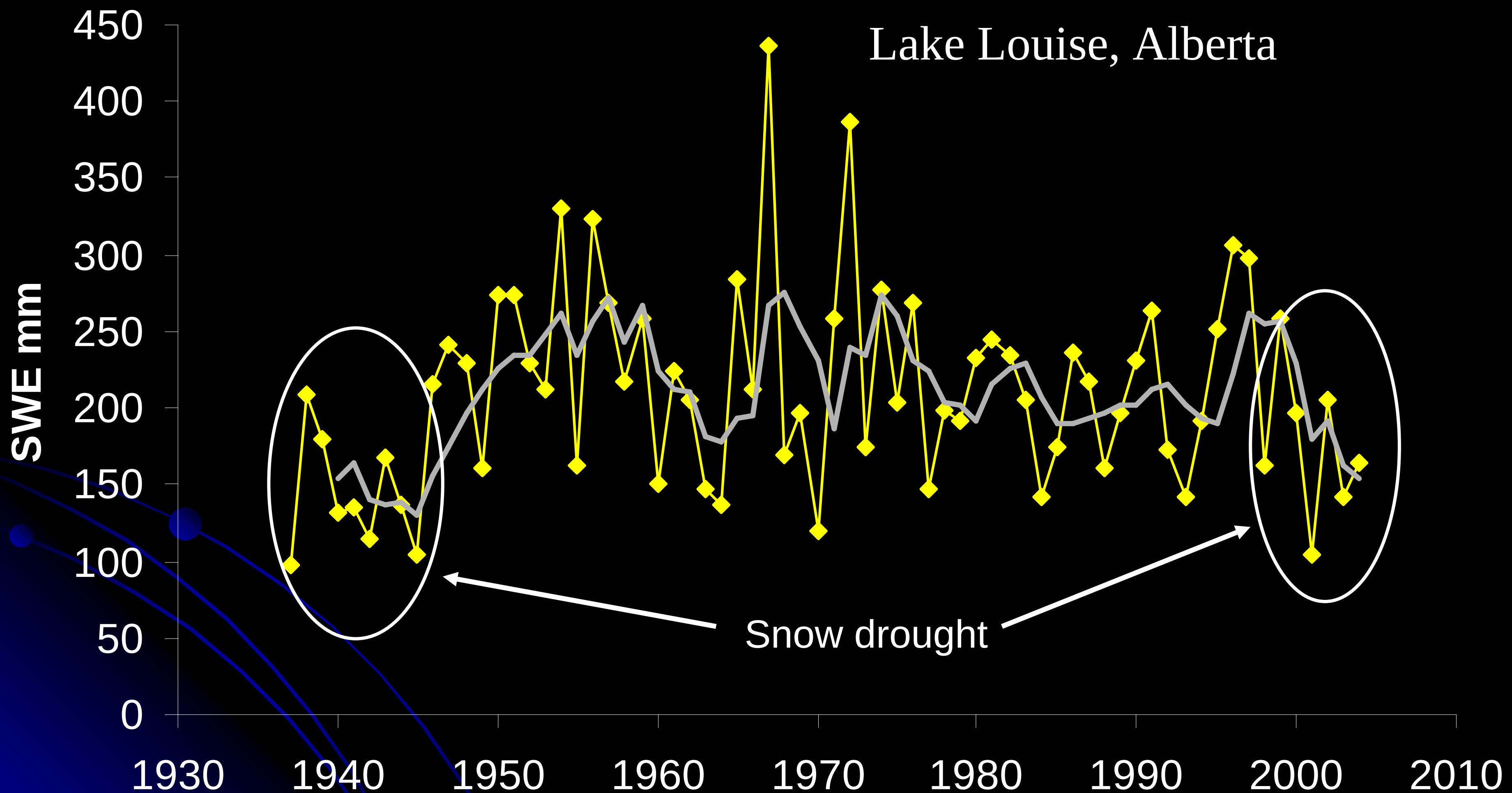
www.usask.ca/hydrology

Central Rocky Mountain Hydrology

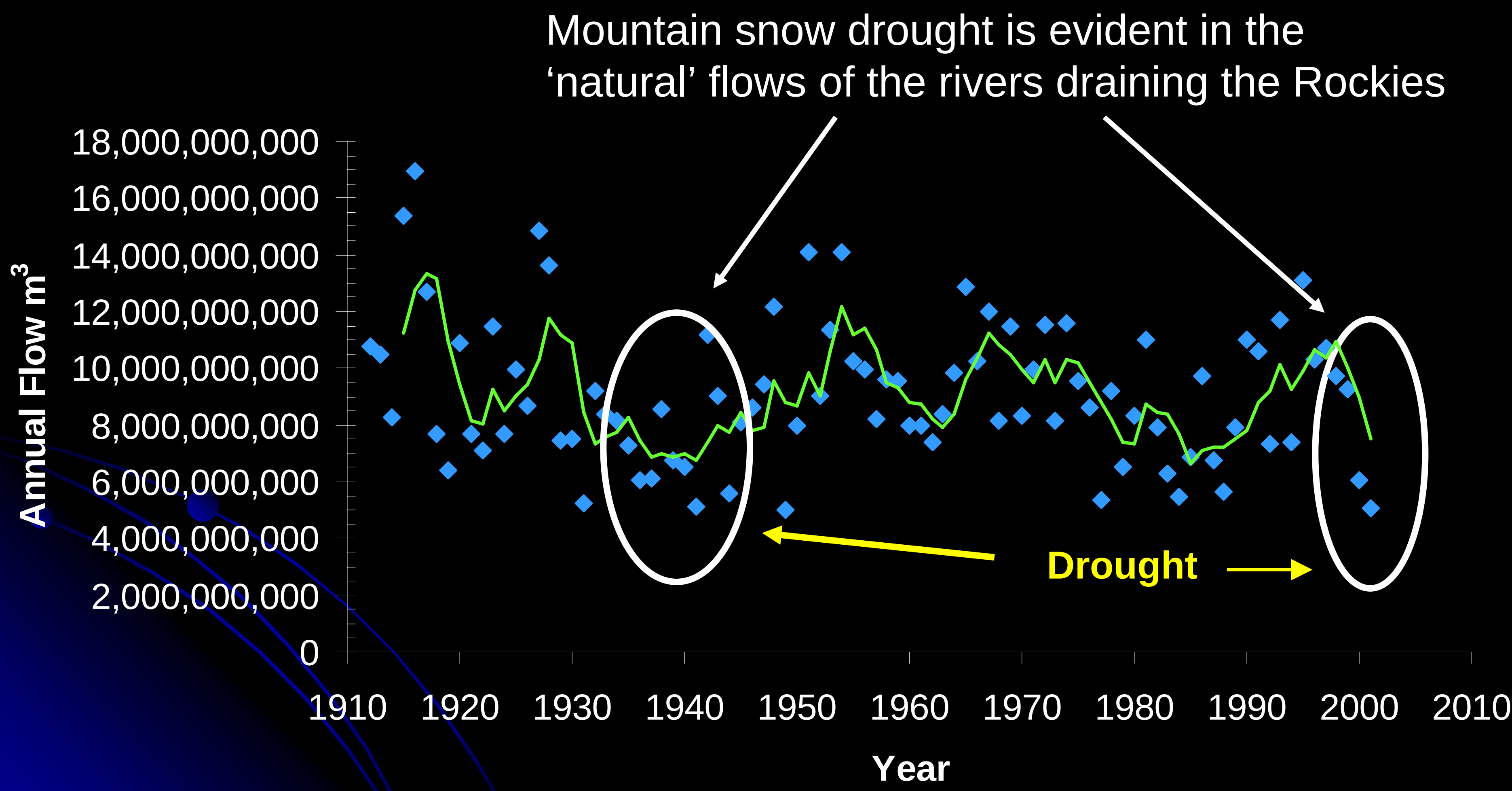
- A 'cold region' hydrological system –snowmelt dominated.
- Large variation from year to year
- What is Changing:
  - Precipitation ?
  - Forest cover - yes
  - Temperature - yes
  - Glacier size - yes
  - Groundwater ?
  - Dams, consumption, agriculture, industry – yes.
  - Structural change in the Rocky Mountain hydrological cycle??????
- Crucial support for our society. The Rockies provide >80% of flow of Saskatchewan River system that sustains the population and economy of much of Alberta and Saskatchewan.
- Ecosystems and the Earth System are intimately tied to hydrology –
  - Basin vegetation, soils, topography, groundwater, beaver, ice
  - Snow ecology – winter season
  - Aquatic ecology - streams, ponds and lakes
  - Climate system – local climate feedbacks, freshwater to Hudson Bay
  - Biogeochemical cycling

Rocky Mountains, source of most Canadian Prairie surface water

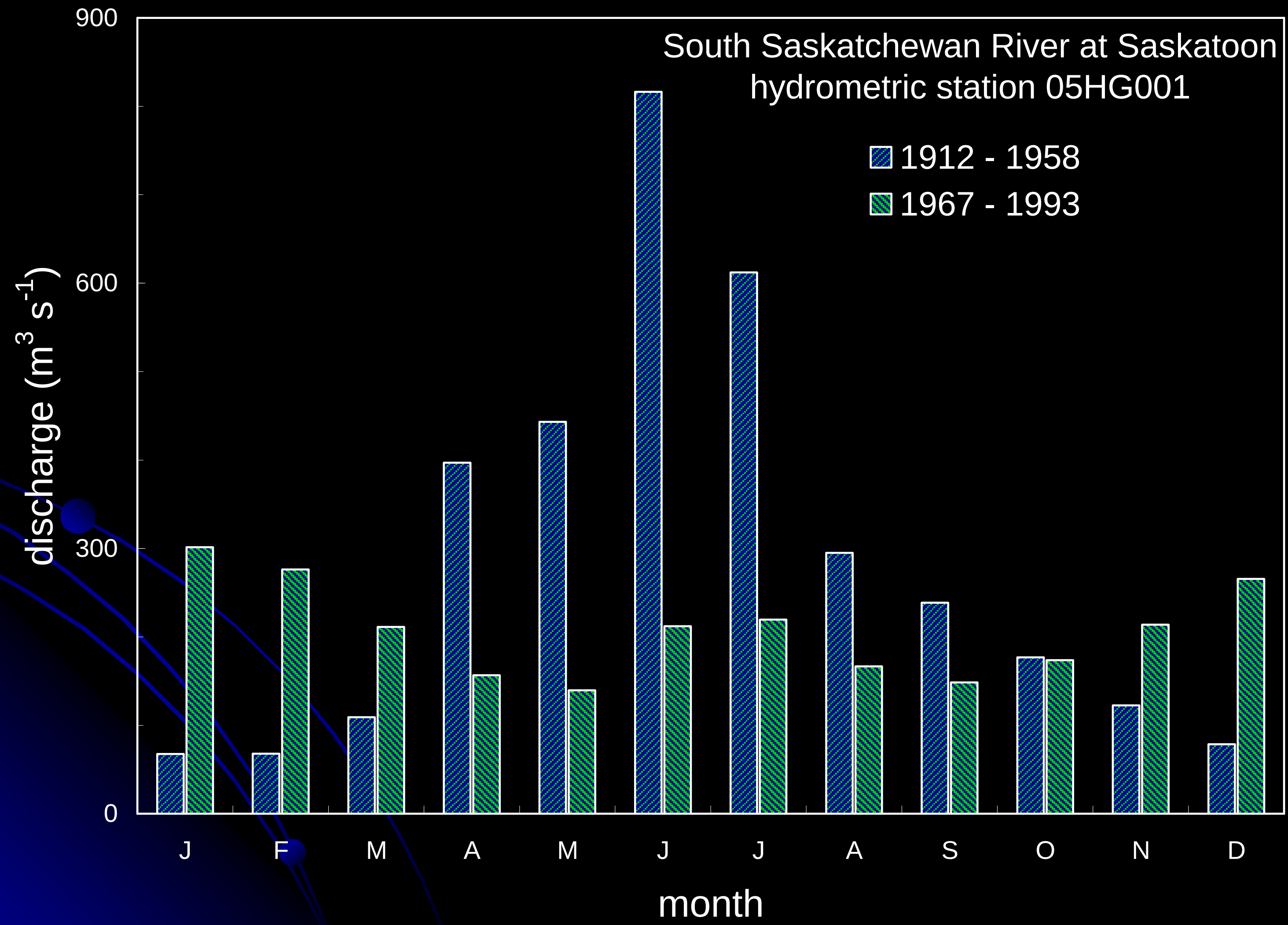
Rocky Mountain Snowpacks



‘NATURAL’ FLOWS OF THE SOUTH SASKATCHEWAN RIVER LEAVING ALBERTA

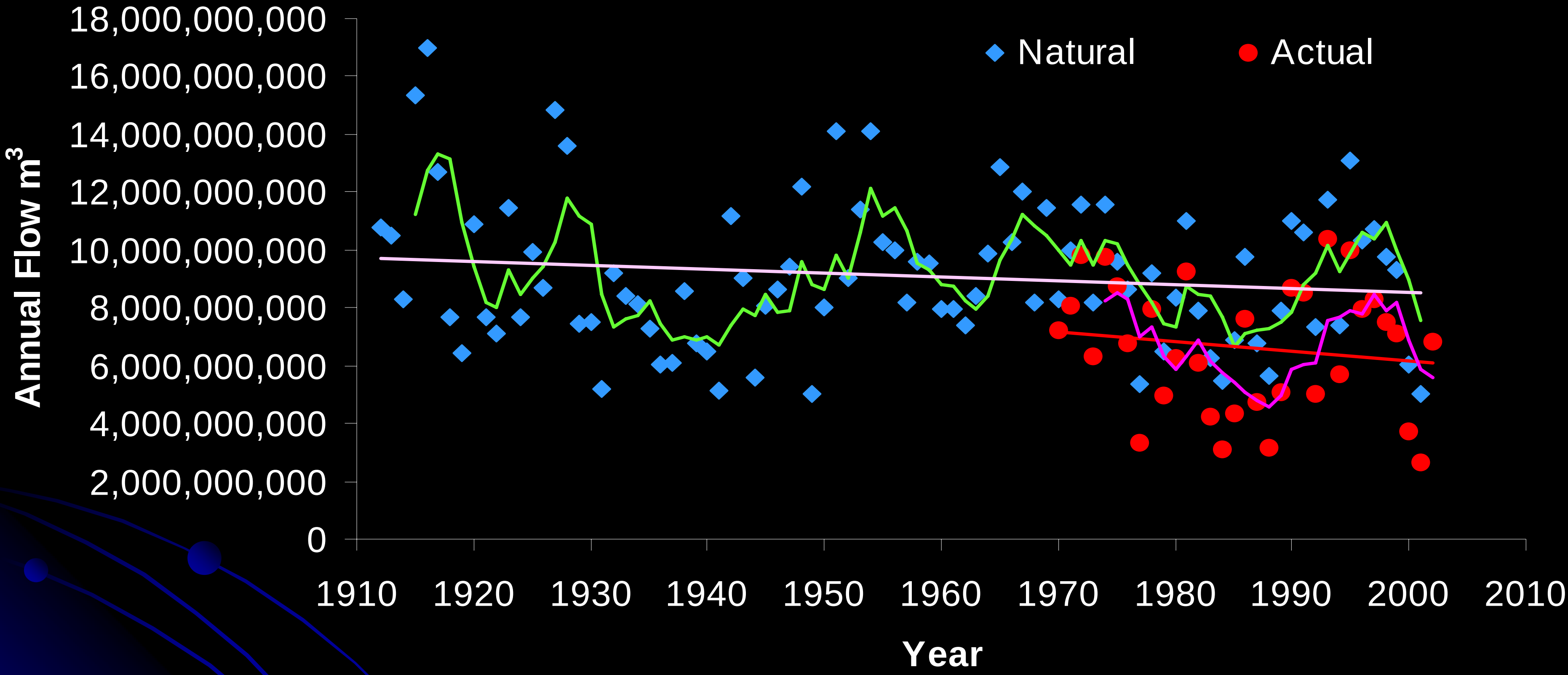


South Saskatchewan River is most strongly affected by Gardiner Dam



Lake Diefenbaker Results from Gardiner Dam

'Natural' and Actual Flow of South Saskatchewan River leaving Alberta



-Hydrology Change: Decline of natural flow by 1.2 billion m^3 over 90 years (-12%)

-Consumption of 7%-42% of natural flows during last 15 years

-Combined: Decline of 1.1 billion m^3 over 30 years (-15%) in actual flow,

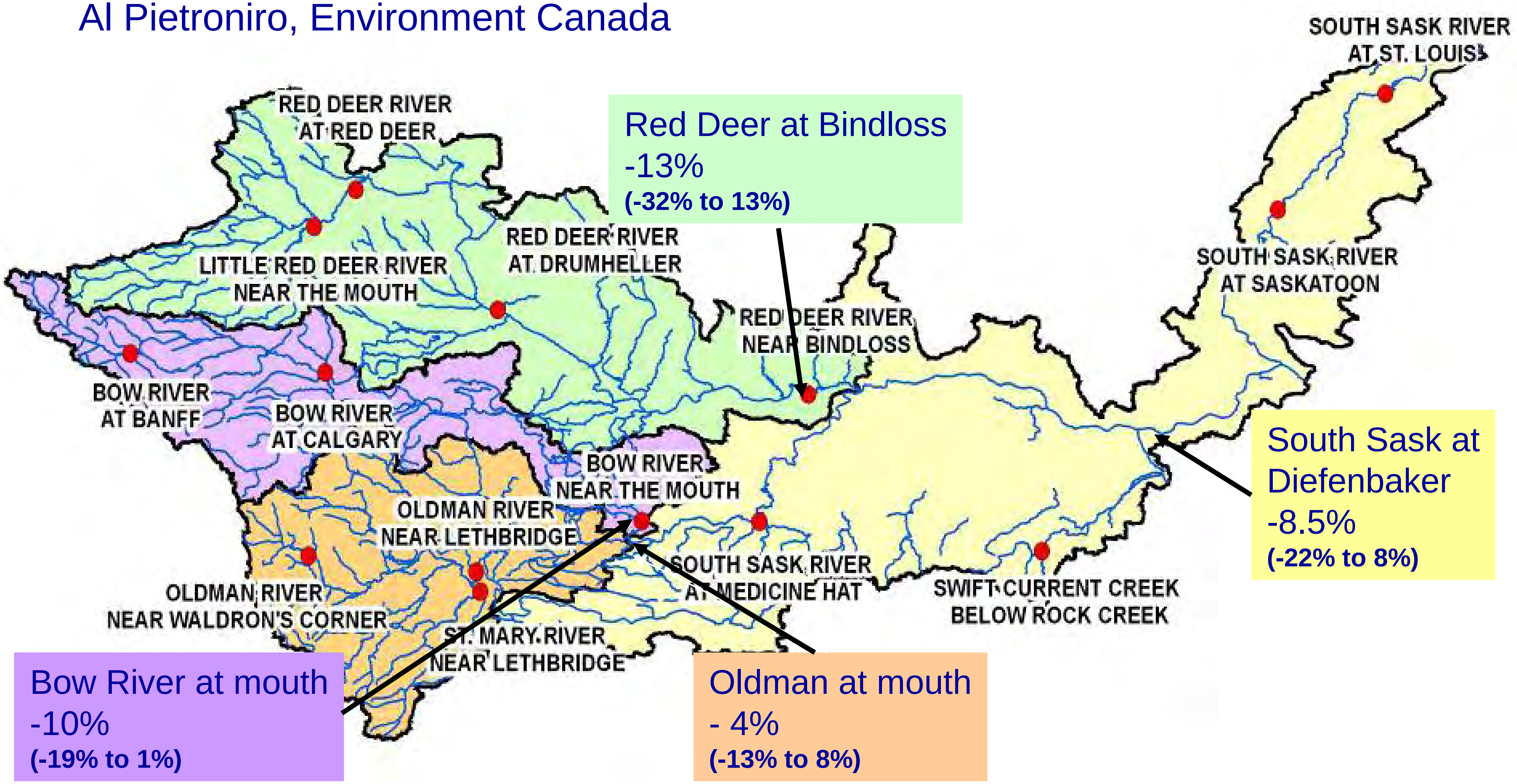
-Combined: Decline of 4 billion m^3 over 90 years (-40%) in actual flow,

-Note 70% of decline is due to consumption, 30% of decline is due to hydrology

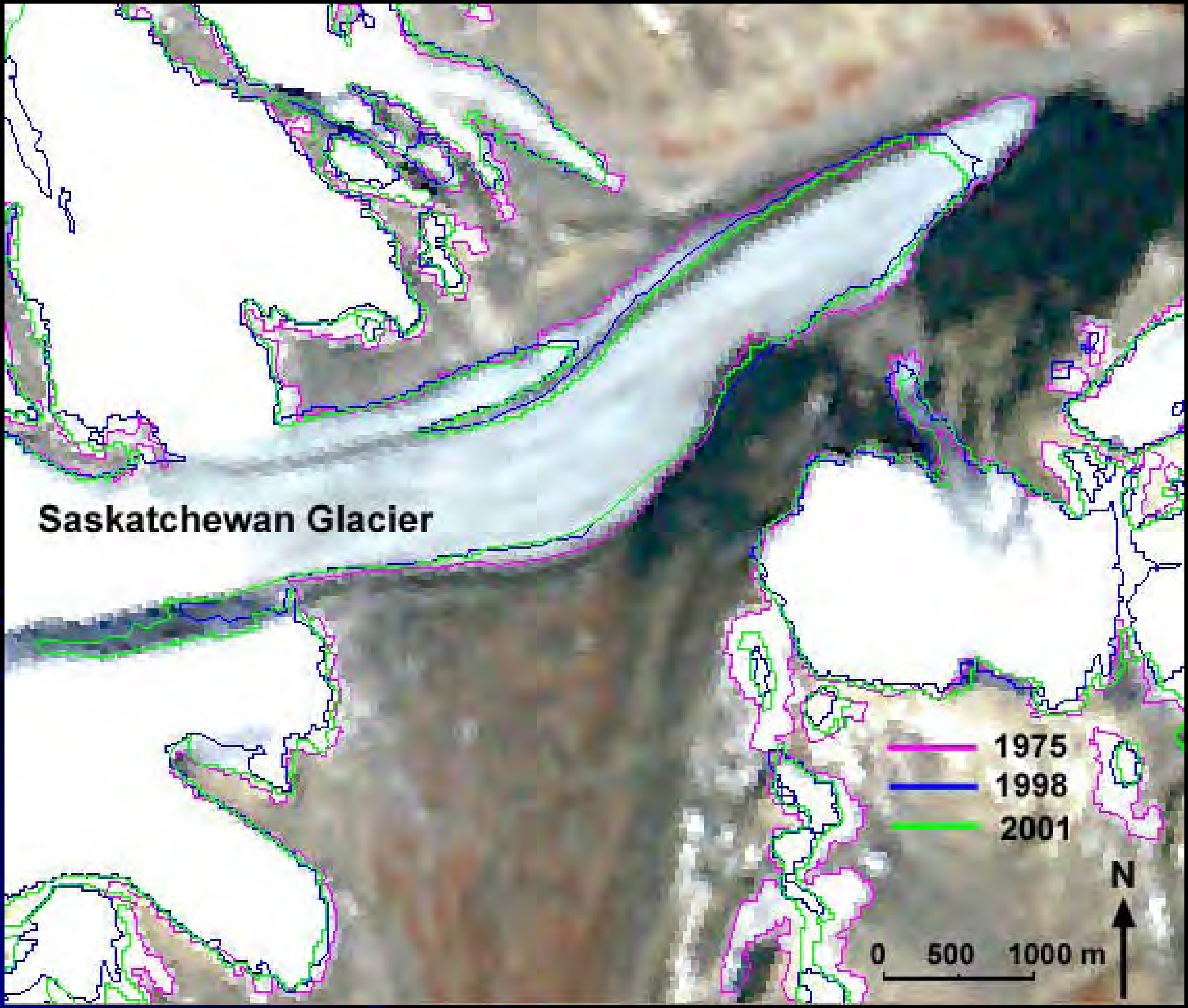
Climate Change Model Results:
2039–2070 Average, Change from Current Natural

20% decline in natural flow of the South Saskatchewan River over 1912 to 2070
BUT GREAT UNCERTAINTY IN THESE PRELIMINARY RESULTS!

Al Pietroniro, Environment Canada



Glacier Retreat in the Columbia Icefields



Mapped from LANDSAT satellite

Mike Demuth, Natural Resources Canada

How Important are Glaciers to Hydrology?

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

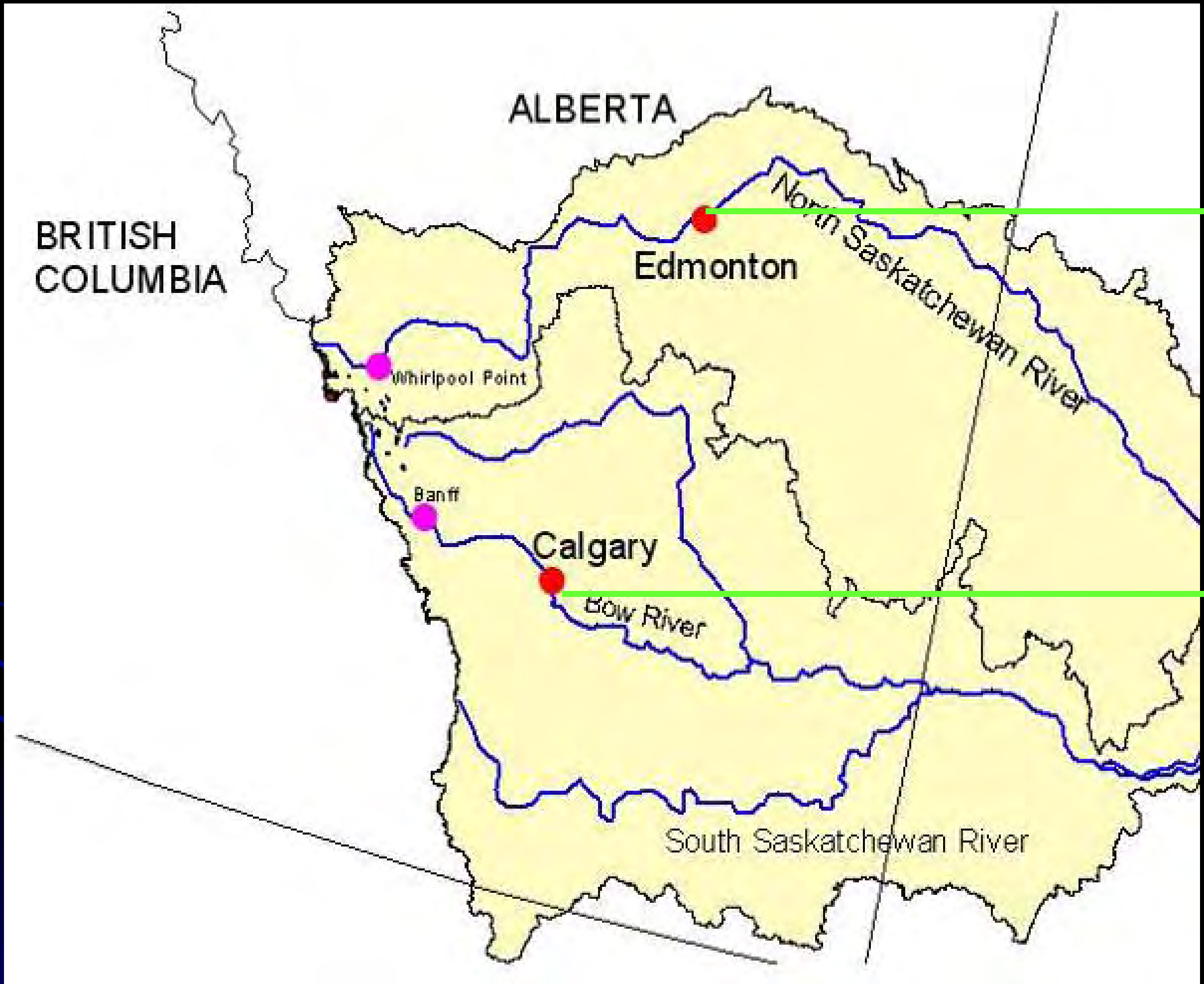
Jaime Hood and Masaki Hayashi, Univ Calgary

Glacier Retreat – Recent 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 88 km^2 **(-22%)**
- The decline of the total glacier area of the South Saskatchewan basin between 1998 (76 km^2) and 1975 (152 km^2) was 76 km^2 **(-50%)**

Al Pietroniro, Environment Canada & Mike Demuth, Natural Resources Canada

Current Glacier Melt Contribution to River Discharge

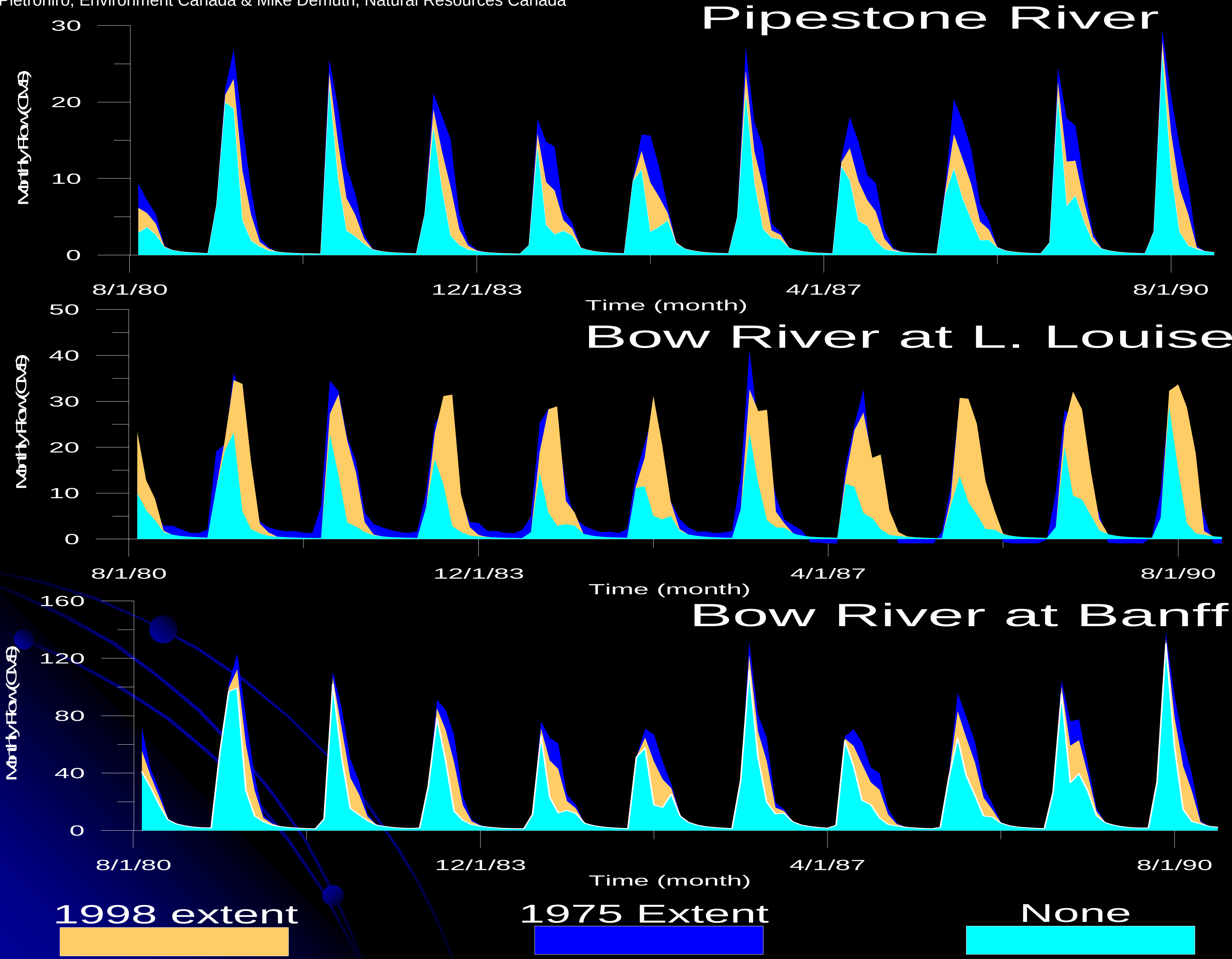


	Fall %	Annual %
Edmonton	**7.4**	**1.8**
Calgary	**2.4**	**0.6**

Glacier water no longer significant for Calgary

Al Pietroniro, Environment Canada & Mike Demuth, Natural Resources Canada

Al Pietroniro, Environment Canada & Mike Demuth, Natural Resources Canada



IP3

Improved Processes & Parameterisation for Prediction in Cold Regions

A Research Network of the

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)

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

http://www.usask.ca/ip3

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Ken Snelgrove (Newfoundland),
Ric Soulis (Waterloo),
Chris Spence (Saskatchewan/EC),
Diana Verseghy (Waterloo/EC)

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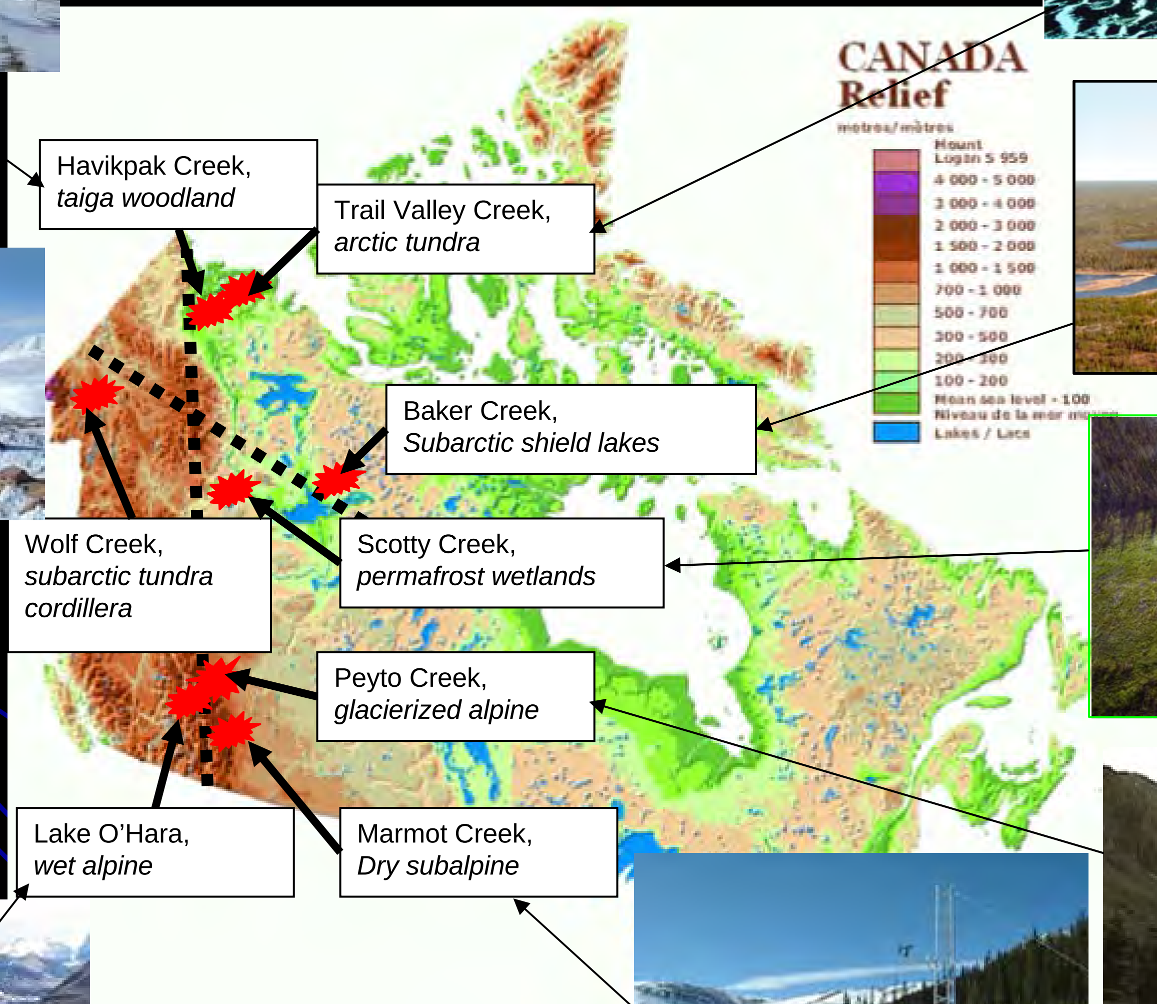
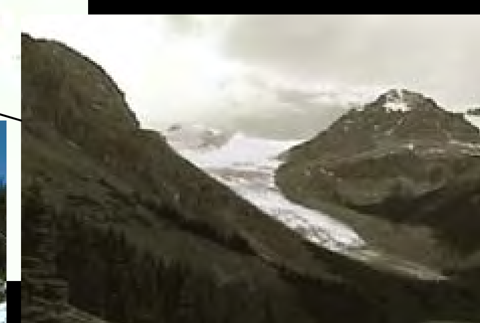
Alberta Environment,
Indian & Northern Affairs Canada,
Natural Resources Canada,
Univ Guelph, Univ Idaho,
Univ Saskatchewan, Univ Western Ontario,
Univ Waterloo,
USDA-ARS

IP3 – Goals and Theme Structure

- ***Theme 1 Processes:*** Advance our understanding of cold regions hydrometeorological processes
- ***Theme 2 Parameterisation*** Develop mathematical parameterisation of cold regions processes for small to medium scales
- ***Theme 3 Prediction*** Evaluate and demonstrate improved hydrological and atmospheric prediction at regional and smaller scales in the cold regions of Canada
- *Ultimately* – contribute to multiscale assessment of coupled climate system, weather and water resources in cold regions

IP3
Research Basins





Marmot Creek Research Basin

- Kananaskis Valley, Alberta 1450-2886 m.a.s.l.
- Alpine Ridge
- Alpine Bowl
- Subalpine
- Montane
- Clearcut
- Meadow
- +600 mm precipitation
- 70% snowfall
- ~50% runoff from snow

Hay Meadow

- Chinook snow sublimation, energy balance and melt studies,
- Open environment snowmelt and evaporation
- Soil moisture, precipitation, modelling
- Wind flow in clearing
- Typical of cleared valley floor in Kananaskis

Vista View Clearcut

- Forest 'regrowth'
- High Elevation snow melt, energy balance and evaporation studies
- Soil moisture
- Cabin Creek modelling station

Lodgepole Pine Forests

- North Slope 26º
- Level 0º
- South Slope 25º
- East Slope 18º
- Snowmelt
- Canopy effects
- Frozen soils
- Runoff
- Chemistry
- Energy balance
- Interception
- Modelling



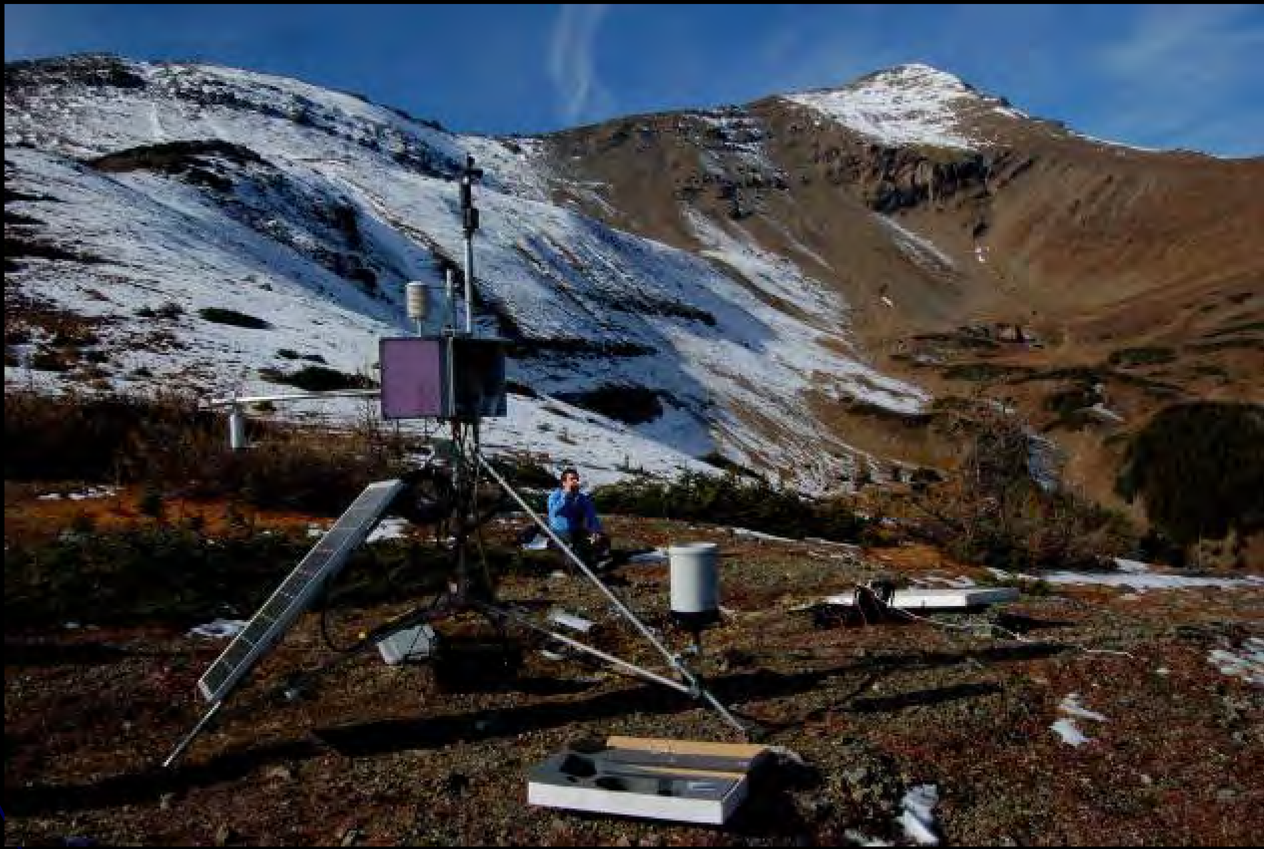

Upper Clearing & Upper Forest

- Mid elevation modelling sites
- Small clearing
- Fir and spruce forest
- Precipitation, energy balance, soil moisture, snowmelt, evaporation
- Assess clearing impact on snow accumulation and interception

New forest tower setup this winter

Fisera Ridge

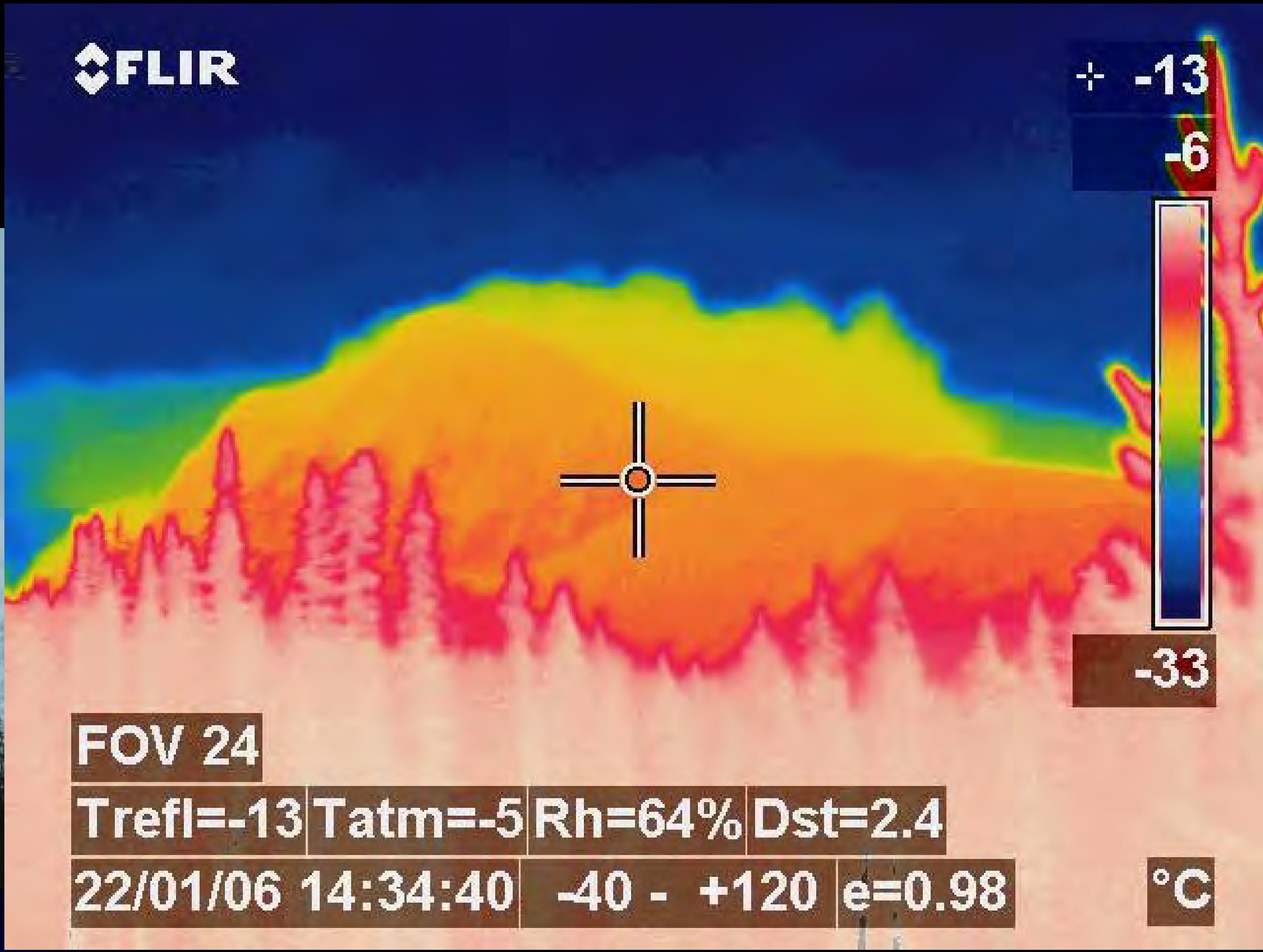
- Treeline transition
- Upper basin snow cirque
- Blowing snow
- Modelling



Alpine Ridgetop

- Centennial Ridge 2475 m
- High elevation modelling reference
- Blowing snow
- Snowmelt
- Evaporation
- Energy Balance
- Soil moisture

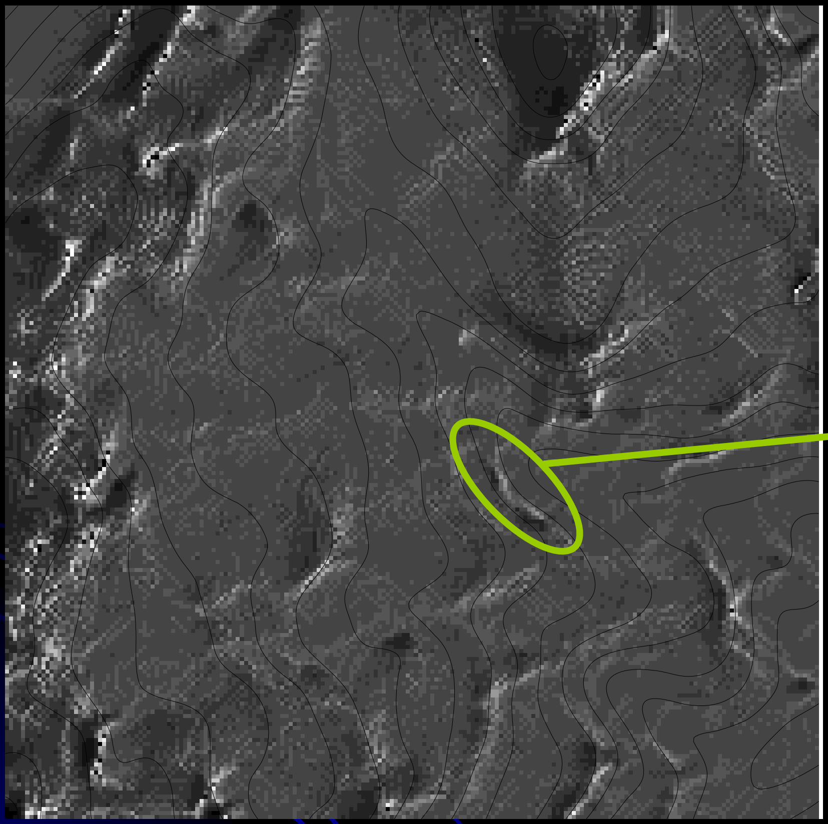
Alpine Blowing Snow: Flow Separation



Sublimation of Blowing Snow

- Increases with fetch
- Requires unsaturated atmosphere
- Possibly important at alpine ridgetops, where flow separation results in ‘plume’ of blowing snow
- Limits alpine snow redistribution distance

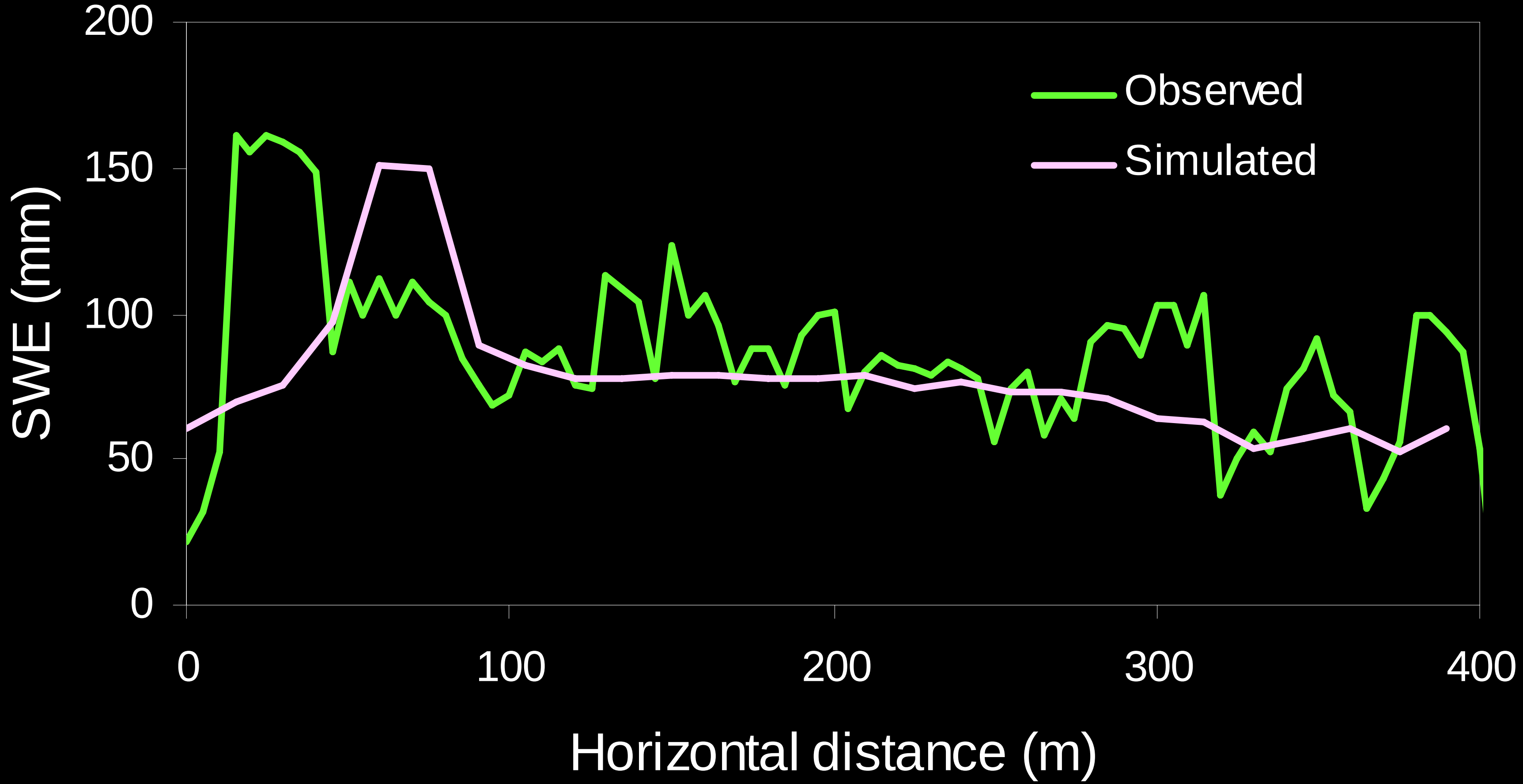
Simulation of Hillslope Snowdrift



3 km

Distributed Blowing Snow Model - Essery, Li & Pomeroy 1999 *Hydrological Processes*

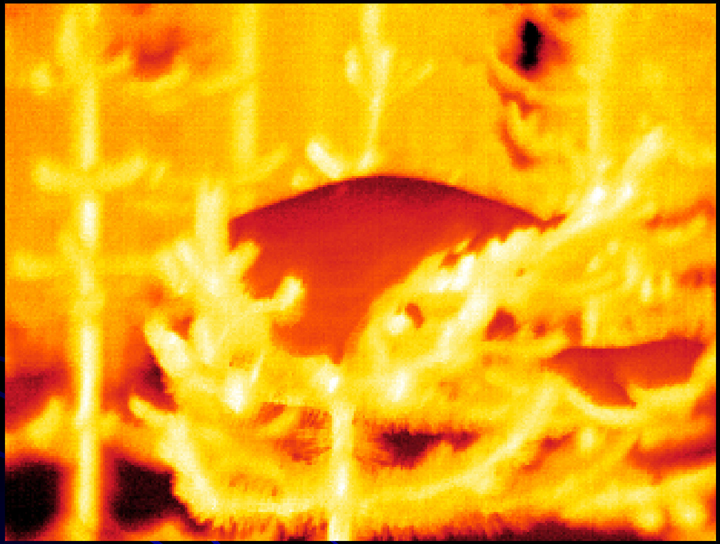
Mountain Drift Simulation



Snow Interception

- Leaf + stem area index (surface to collect snow)
- Air temperature (elasticity of branch, adhesion and cohesion of snow)
- Wind speed (particle trajectory, impact rate, branch bending, scouring)
- Unloading from warm and windy events

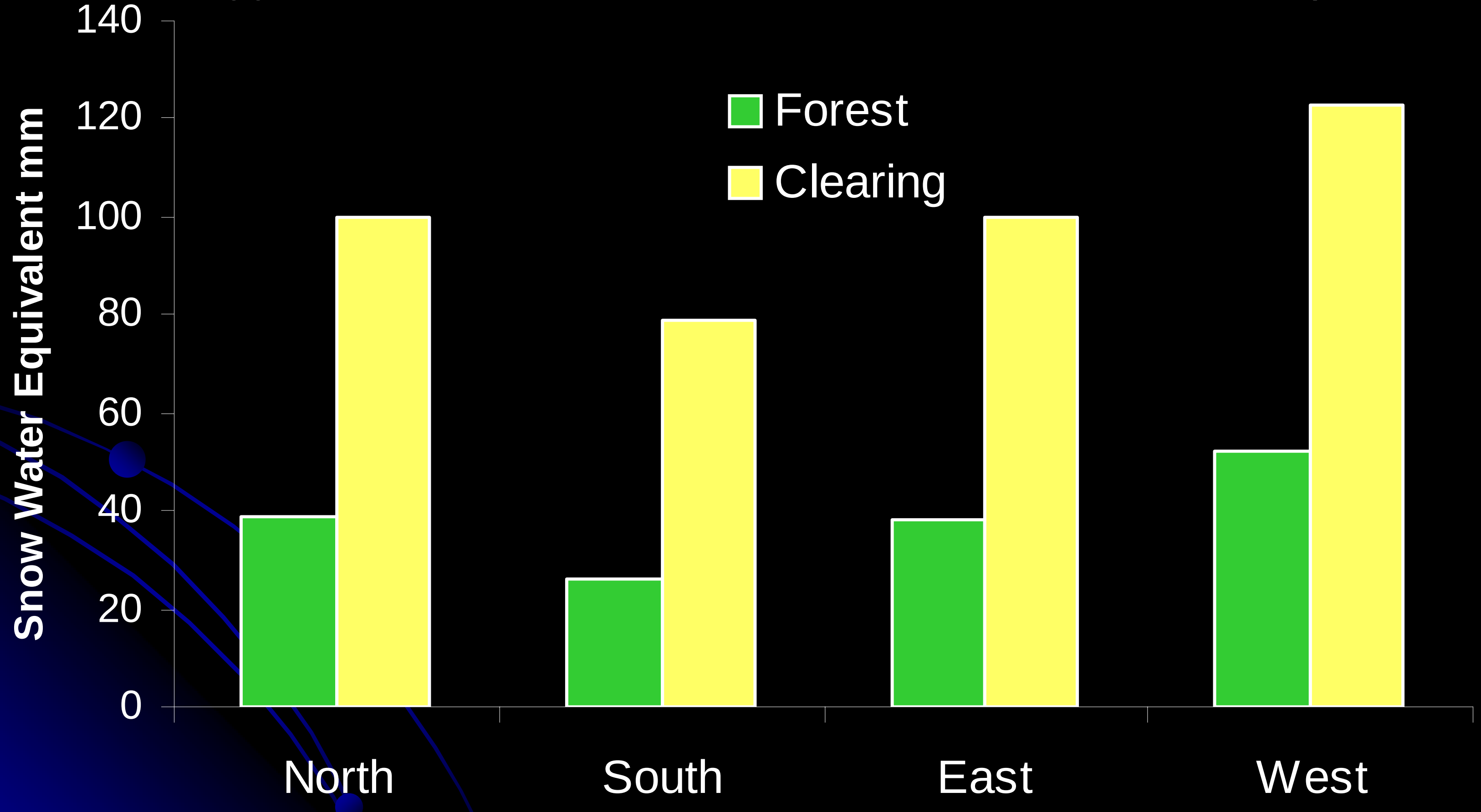
Intercepted Snow Sublimation



Pomeroy, Parviainen, Hedstrom, Gray 1998 *Hydrological Processes*

Forest Snow Interception Loss
Fir-Spruce Forest vs. Small Clearing

Suggests that 61% of snowfall was sublimated from intercepted snow

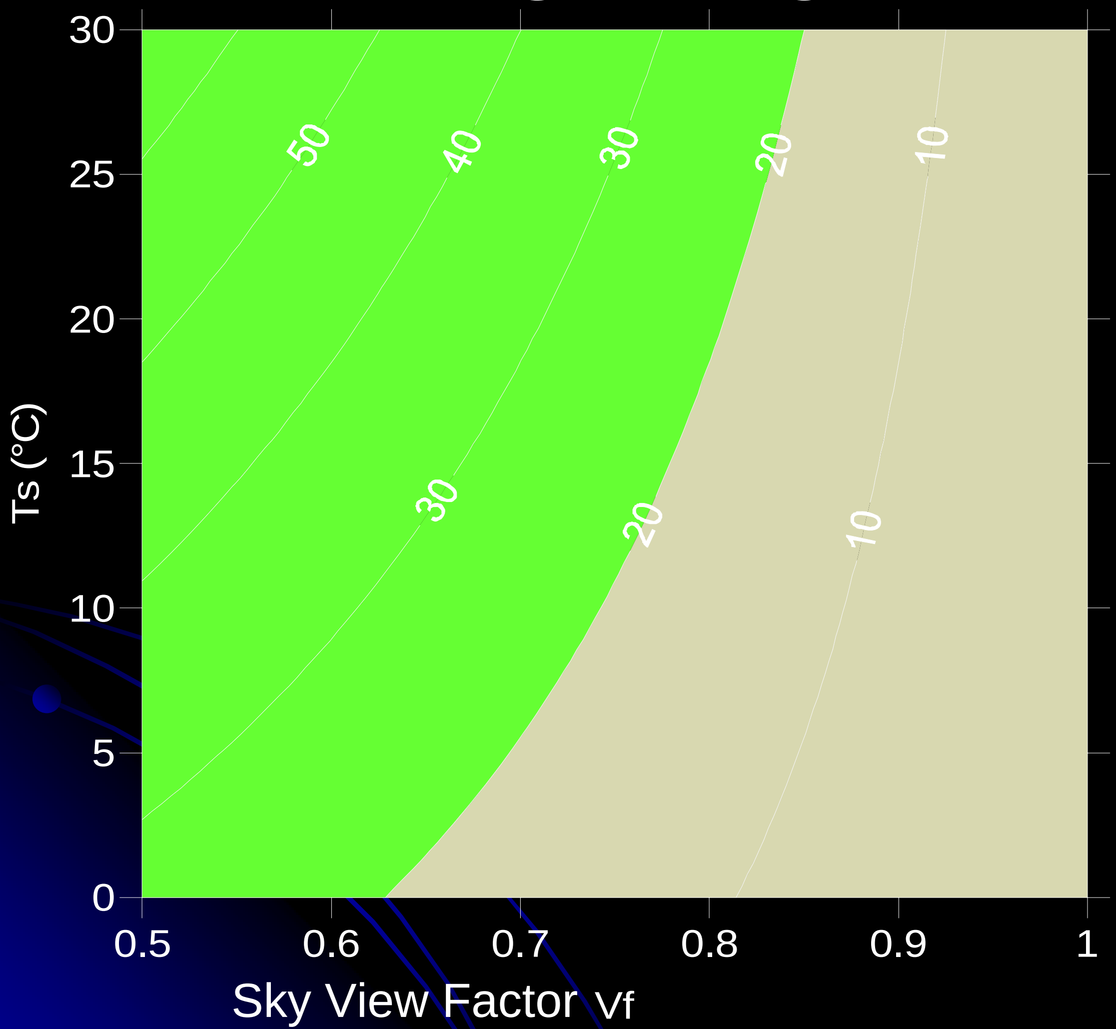


Marmot Creek, March 2006 Pomeroy, Essery, Rutter

Snowmelt

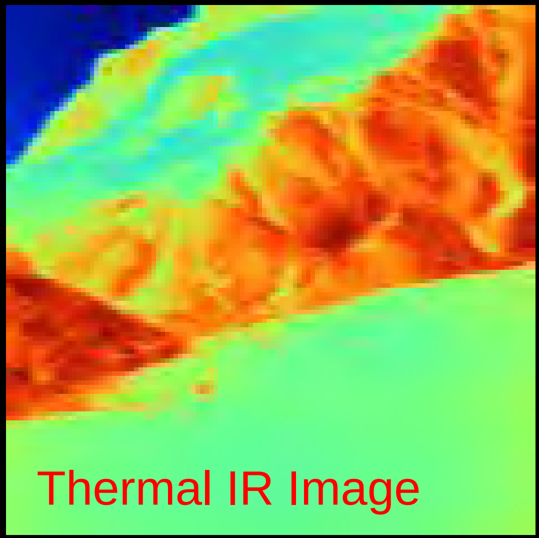
- Improved Methods to Estimate Short and Longwave Radiation
- Terrain Effects on Radiation
- Terrain Effects on Turbulent Transfer
- Forest Canopies – radiation effects
- Combined Forest Canopy and Slope Effects - radiation

Incoming Longwave in Mountains



Percent increase in longwave irradiance due to terrain emission due to sky view factor (V_f) and surface temperature (T_s).

Air temperature is 0°C and the clear sky emissivity is 0.65

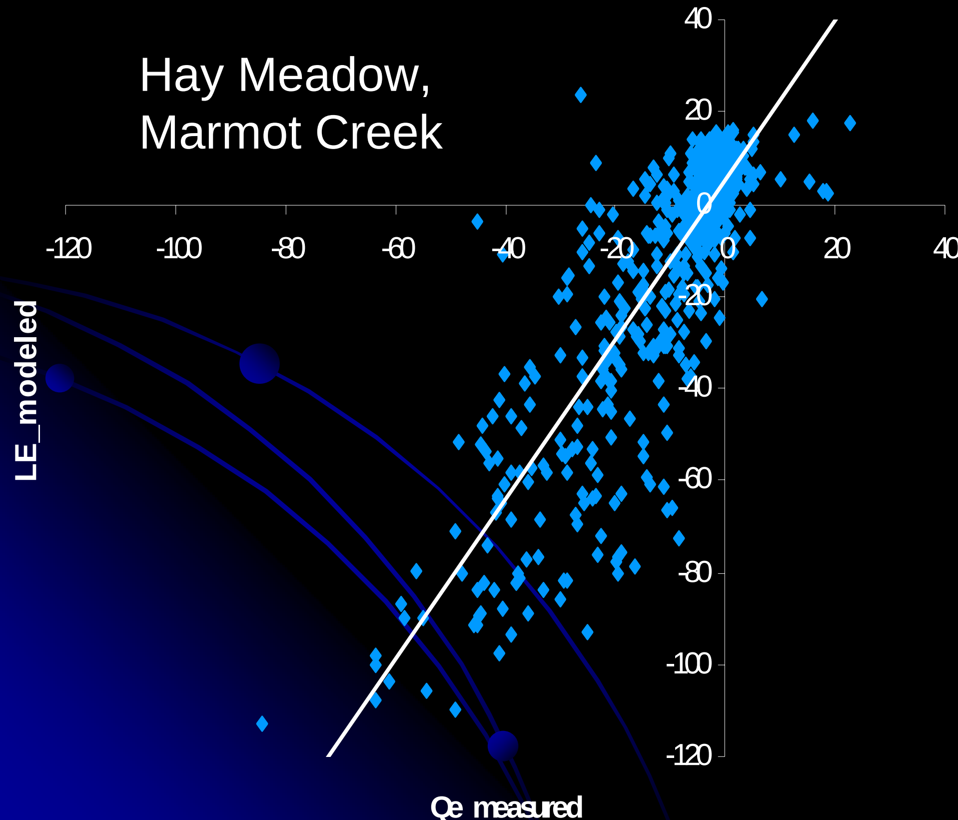


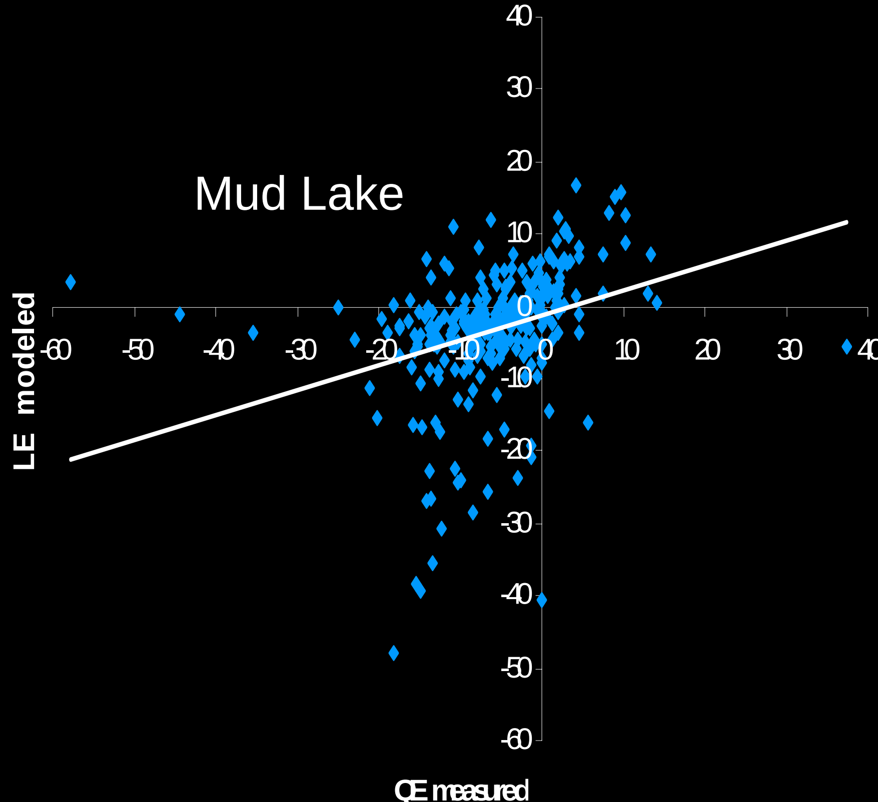
Sicart et al. 2006 *Hydrological Processes*

Sublimation from Mountain Snowpacks – Measurements and Typical Model

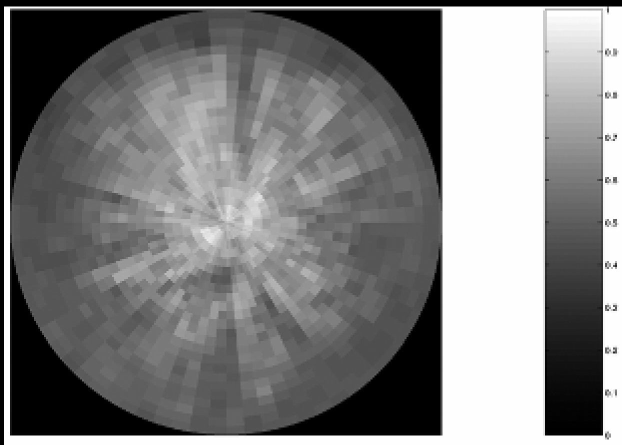
Mountain snow is aerodynamically rougher than other snows

No evidence of large evaporation rates during chinook events

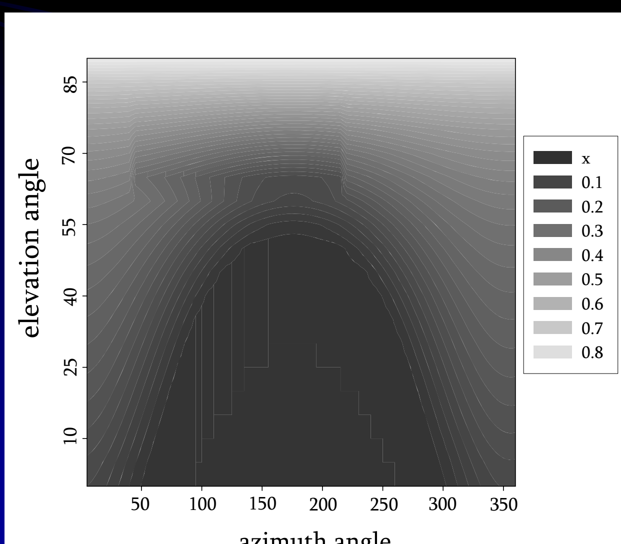




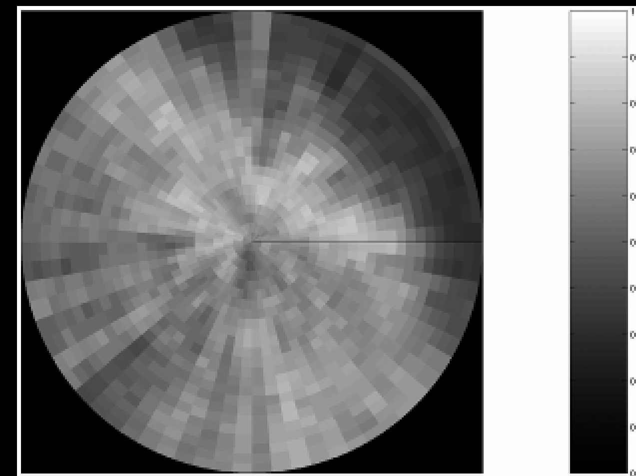
Solar Transmission through Sloping Forest Canopies



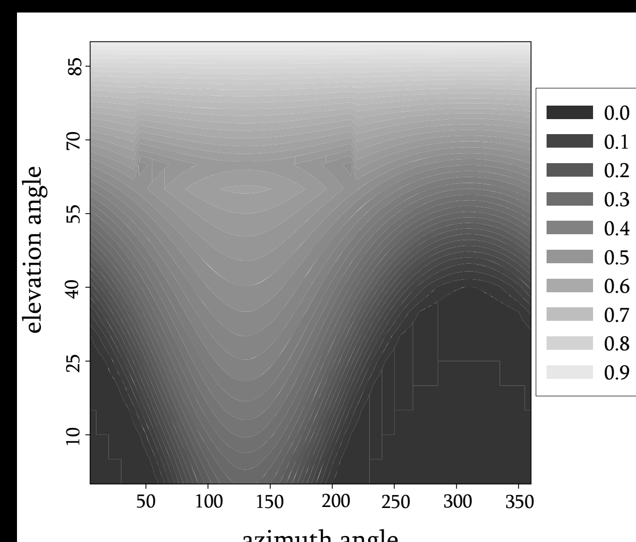
North Face Forest



τ a function of
LAI,
Foliage inclination
Crown coverage
Slope,
Aspect,
Solar azimuth,
Solar elevation



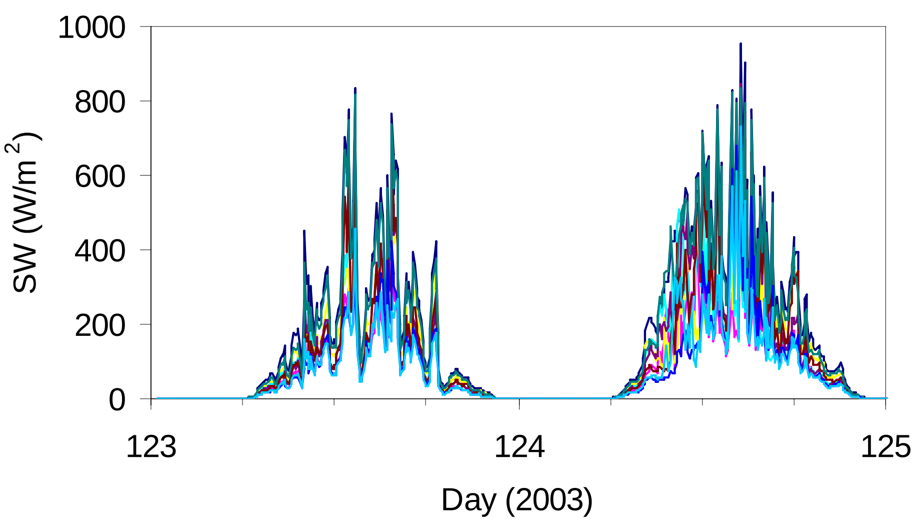
South Face Forest

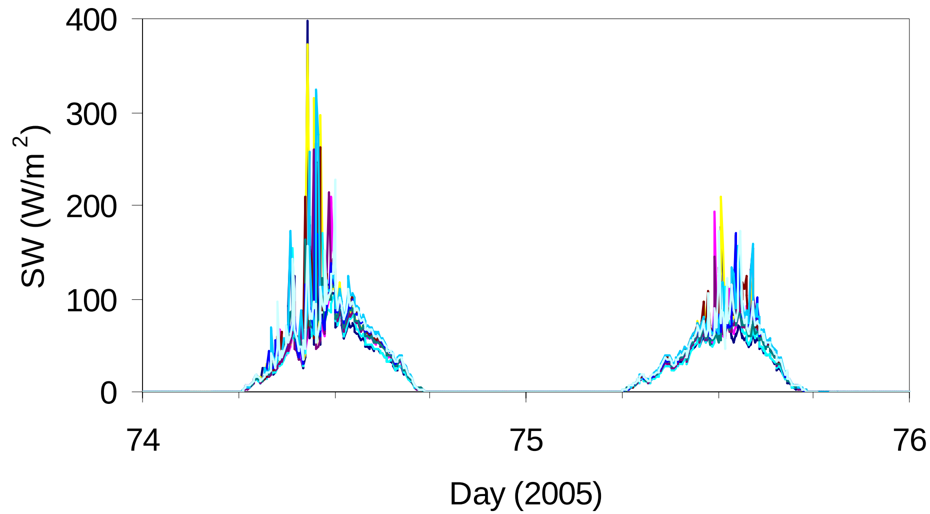


Solar Radiation to Snow beneath Shrubs and Trees

Tall Shrubs

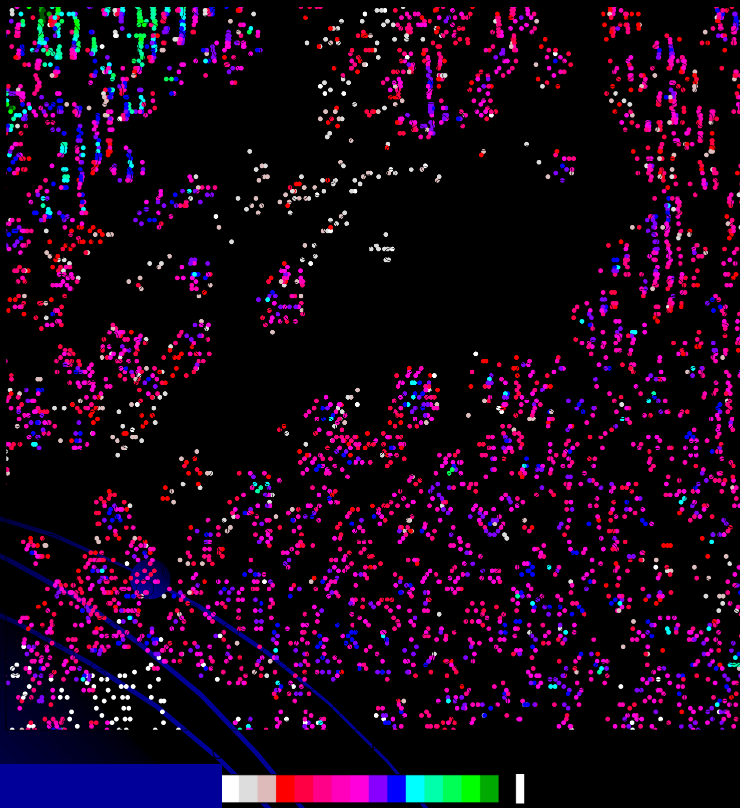
Marmot Creek level forest



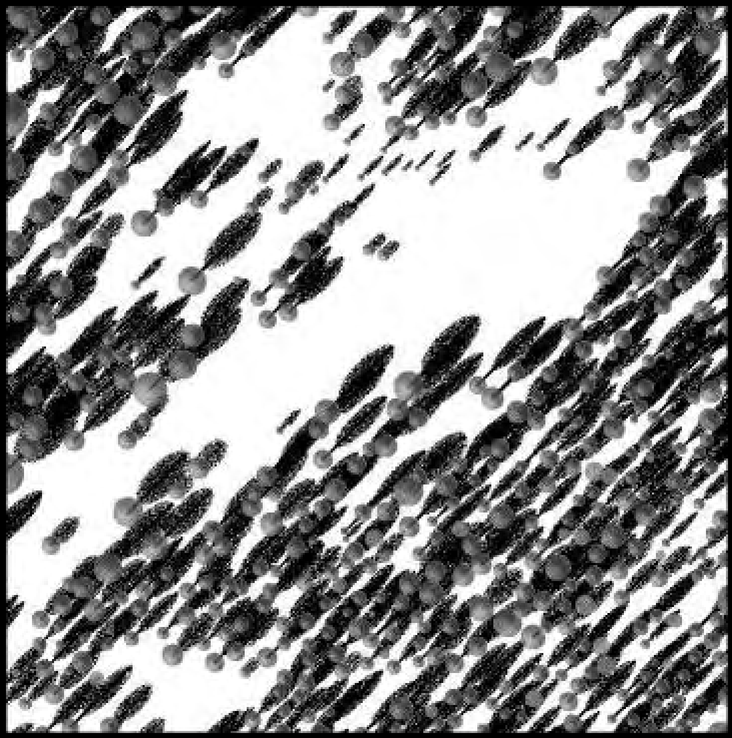


Fine Scale Modelling of Sub-alpine Solar Radiation

LIDAR and canopy delineation



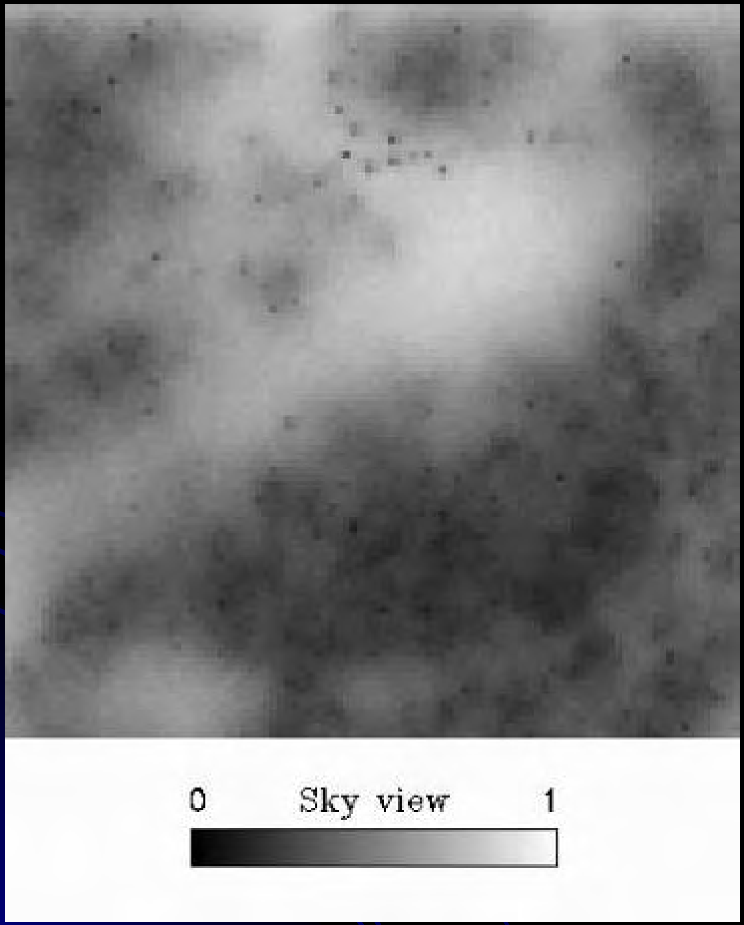
Tree Shadow Simulation



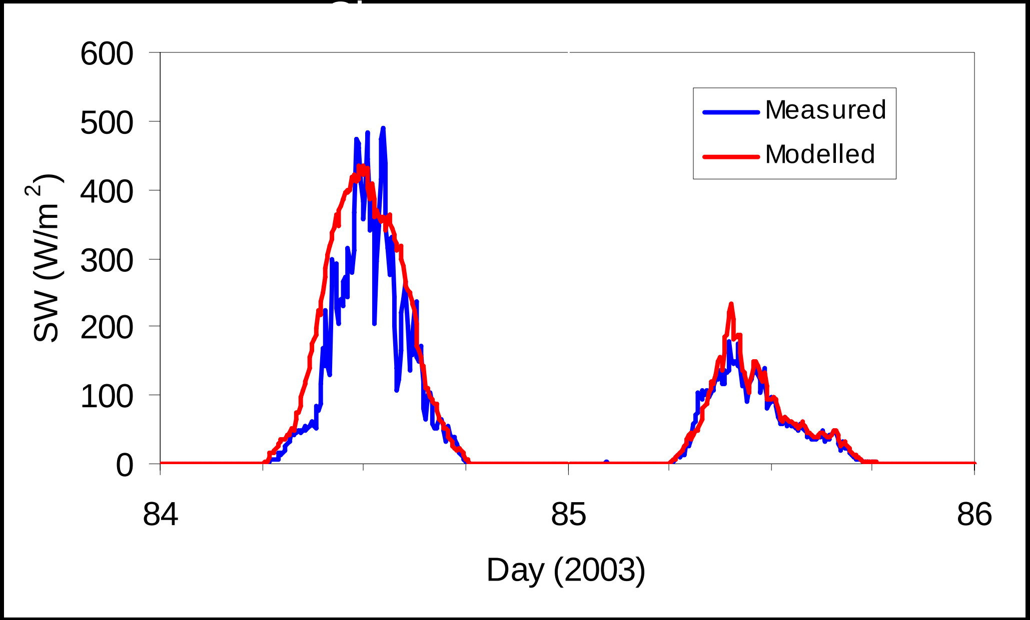
Essery et al. (2007). In preparation for *Journal of Hydrometeorology.*

Stand Scale Modelling of Solar Radiation

Simulated skyview

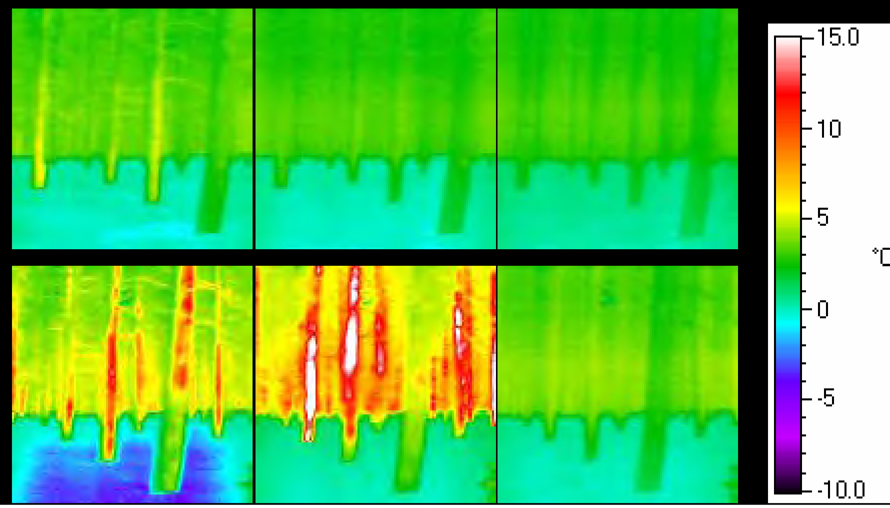


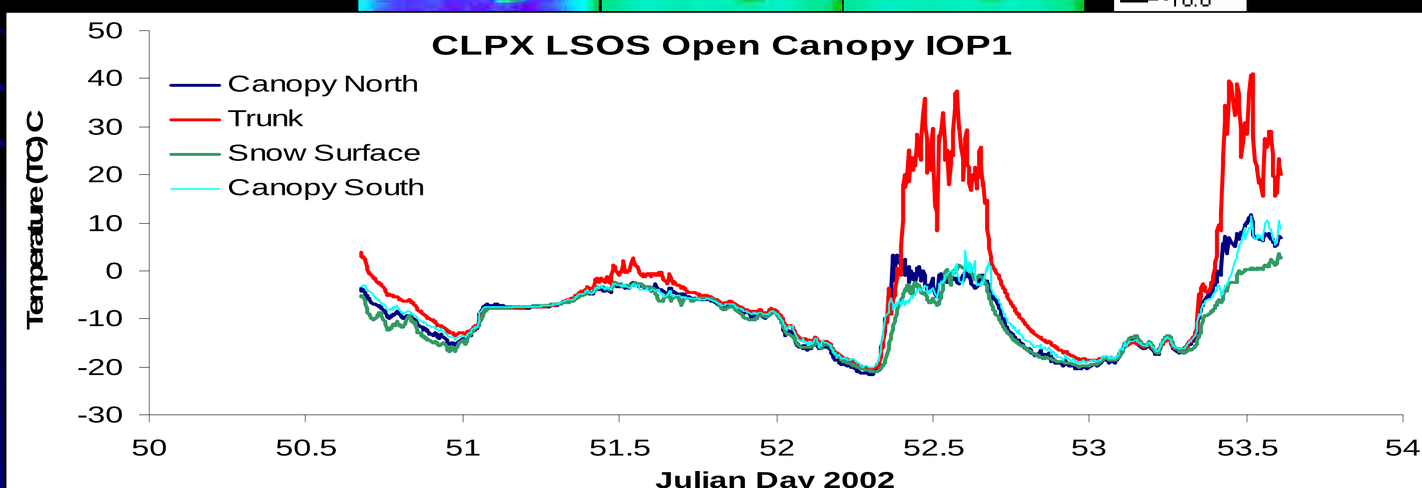
Simulated skyview



Essery et al. (2007). In preparation for *Journal of Hydrometeorology.*

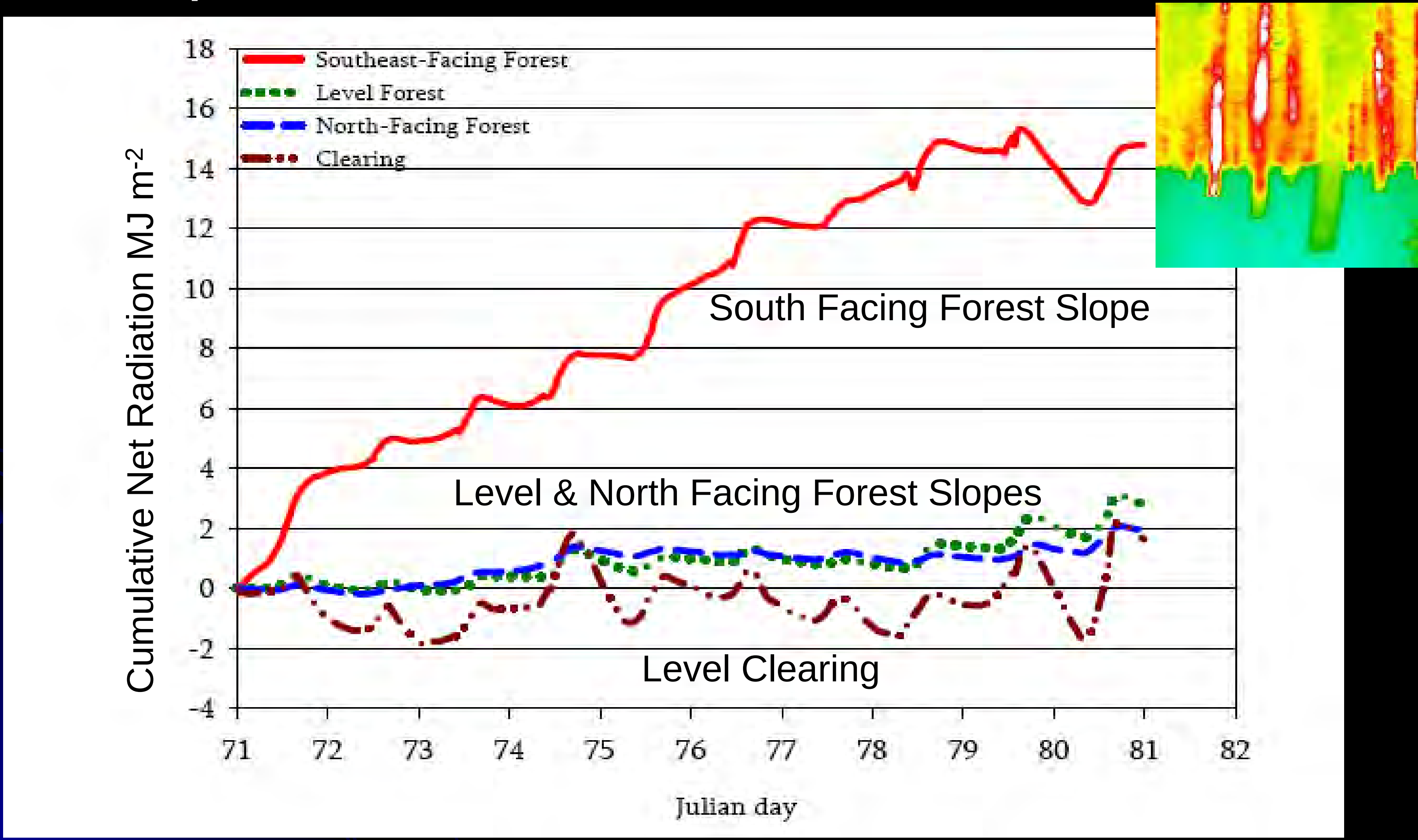
Hot Canopy and Trunks Increase Forest Longwave Radiation





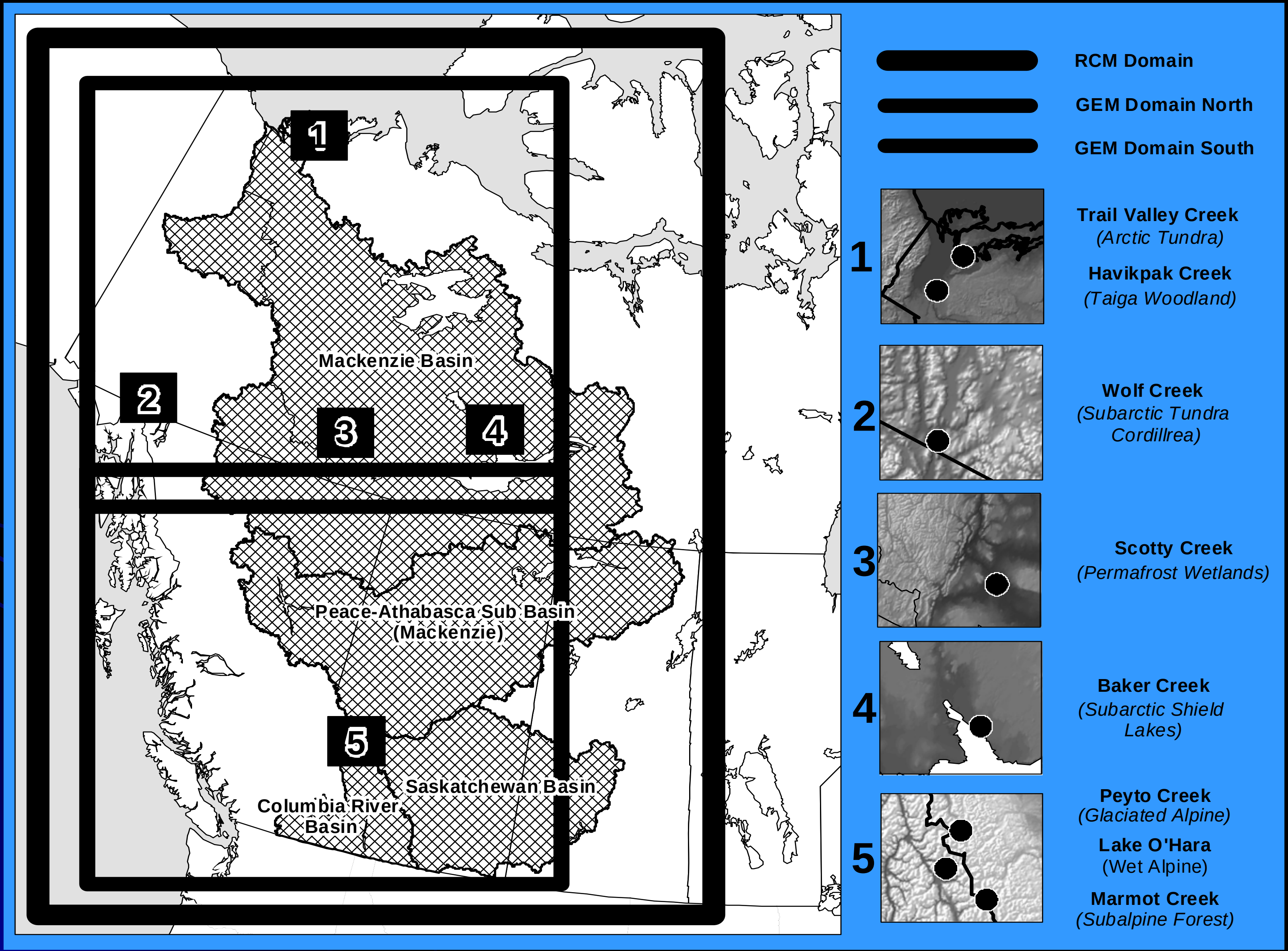
Rowlands, Pomeroy, Hardy, Marks, Link, Essery 2002 *Proc. Eastern Snow Conference*

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



Ellis, Pomeroy, Essery, Link submission to *Canadian Journal of Forest Research*

Mountain Prediction



Conclusions

- Rocky Mountain hydrology is changing due to climate and land use change, 12% reduction in the South Saskatchewan River natural flow since 1912, snowmelt change possible cause.
- Climate change to 2070 will reduce flows by another 8.5% however there is great uncertainty in this value!
- Glacier contribution to flow is small, even in ‘classic’ glacier basins
  - 0.6% of Bow River at Calgary
  - 2.4% of North Saskatchewan River at Edmonton
- Forest snow interception losses large in Rockies, forest cover reduction *may cause streamflow increase*
- Blowing snow redistribution – vegetation and temperature sensitive
- Snowmelt enhanced under south facing forests,
- Major research initiative underway to develop a predictive system for mountain hydrology and link this to climate and weather prediction models

Thank You!

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- -Canada Foundation for Innovation
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