The IP3 Research Network: Enhancing Understanding of Water Resources in Canada's Cold Regions

John Pomeroy & the IP3 Network

www.usask.ca/ip3

IP3
Improved Processes & Parameterisation for Prediction in Cold Regions

International Polar Year 2007-2008

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

IP3...

Improved Processes & Parameterisation for Prediction in Cold Regions

- ...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, France, Germany, Italy

- …runs from 2006-2010

Why IP3?

- Need to forecast changing flow regime of streams and rivers in the Western Cordillera and North
- Increasing consumptive use of Rocky Mountain water in Prairie Provinces
- Uncertainty in design for resource (oil & gas, diamond, etc) development and restoration activities in small to medium size, headwater ‘ungauged’ basins
- Opportunity to improve cold regions snow, ice, frost, soil and water processes in models to reduce predictive uncertainty in:

    Atmospheric impacts on snow, ice and water resources

    Simulation of land-cryosphere-atmosphere interaction

    Cycling and storage of water, snow and ice

    Prediction of future climate change

IP3 Network Investigators

Sean Carey, Carleton University
Richard Essery, Edinburgh University
Raoul Granger, Environment Canada
Masaki Hayashi, University of Calgary
Rick Janowicz, Yukon Environment
Philip Marsh, University of Saskatchewan
Scott Munro, University of Toronto
Alain Pietroniro, University of Saskatchewan
John Pomeroy (PI), University of Saskatchewan
William Quinton, Wilfrid Laurier University
Ken Snelgrove, Memorial University of Newfoundland
Ric Soulis, University of Waterloo
Chris Spence, University of Saskatchewan
Diana Verseghy, Environment Canada
(people in bold are on Scientific Committee)

IP3 Science Focus

- Snow – redistribution, accumulation, sublimation, radiative transfer and melt
- Forests – effect on radiative and turbulent transfer to snow and frozen ground
- Glaciers - interactions with the atmosphere
- Frozen ground – freezing, thaw, water transmission and storage
- Lakes/Ponds – advection, atmospheric fluxes, heat storage, flow in drainage systems

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

New IP3 Initiatives

- Advanced data management system
- Courses on CRHM and MESH given in Ontario, Manitoba, Alberta (Calgary, Edmonton, Red Deer), NWT
- Outreach meetings
- Science monograph
- Policy implications book

Network Completion

- HESS Special Issue on Cold Regions Hydrology
- No cost extension of IP3 to end of March 2011
  - Science Spending to cease by ~ August 2010
  - Special Prediction Effort to cease by Feb 2011
- Secretariat, Outreach and Information Management funded to end of March 2011

IP3 Legacy

- Canada a leader in the understanding of cold regions hydrology (snow, permafrost, ice, rivers)
- Development of network of research basins from Cordillera to Arctic
- Trained cold regions hydrologists and climatologists
- Cold regions hydrological models
- Mechanism for transfer of knowledge to users
- Coupled atmospheric-hydrological prediction models for Government of Canada and other users
- Informed public policy on mountain and northern water resources

IP3 Final Outputs

- Improved understanding of cold regions hydrological processes at multiple scales
- Unique observational archive of research basin data
- More effective incorporation of cold regions processes and parameterisations into hydrological and meteorological models at regional and smaller scales – CRHM, MESH
- Improved environmental predictive capability in cold regions in response to greater water resource demands:
  - Enhanced hydrological and atmospheric model performance at multiple spatial scales *and at scales requested by users*
  - Improved streamflow prediction in ungauged basins with less calibration of model parameters from gauged flows
  - Improved weather and climate prediction due to rigorous model development and testing

Policy Implications from IP3

- Loss of hydrological "stationarity" due to climate and land use change means traditional risk management analyses are inadequate for water resources management.
- Information for water policy, allocation, conservation and development is required that cannot be provided by analysis of observations alone.
- Improved information can be obtained from the results of coordinated observation and prediction systems that incorporate aspects of data assimilation, enhanced observations, improved model development and continuing process research to deal with evolving unknowns

Snow Regimes

Forest Snow – Open Snow

Shrub Growth?

1993

2008

Shrub Growth!

2001

2008

Snow Accumulation Variability

Blowing Snow in Complex Terrain

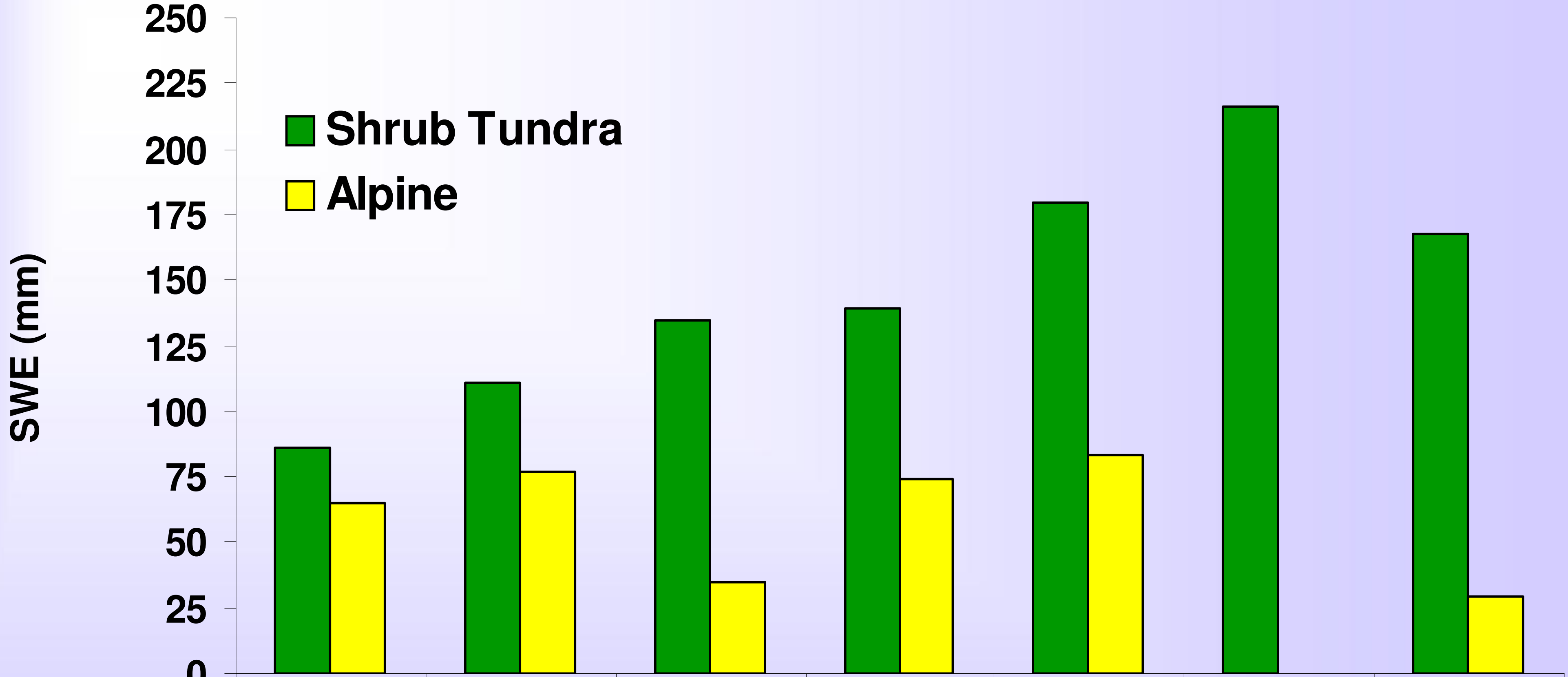
Inter-basin water transfer

Transport of snow to drifts

Supports glaciers, late lying snowfields, hydrological contributing areas

Blowing Snow Entering Basin

Shrub Tundra Accumulation Becoming Higher than Sparse Tundra

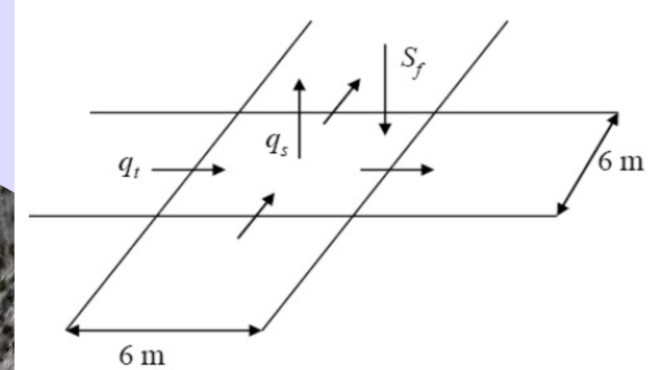


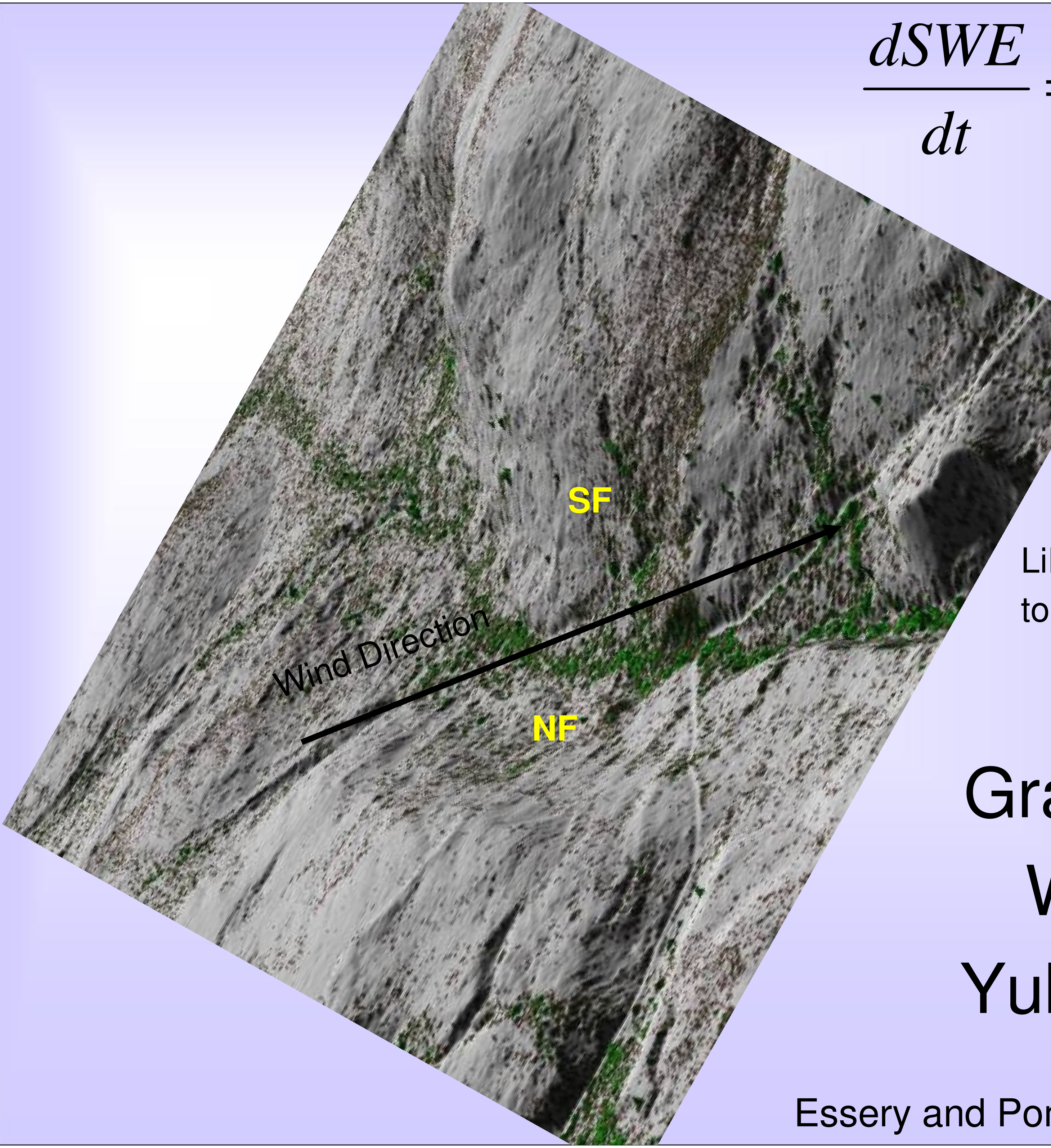
	1994	1995	1996	1998	1999	2000	2001
Shrub Tundra	87	111	134	139	179	216	168
Alpine	65	77	35	74	83		29

Note that shrub tundra at this site is 50 cm taller now than in 1994

Pomeroy et al., 2006 *Hydr Proc*

$$\frac{dSWE}{dt} = X_S - \nabla \cdot T - E_S$$





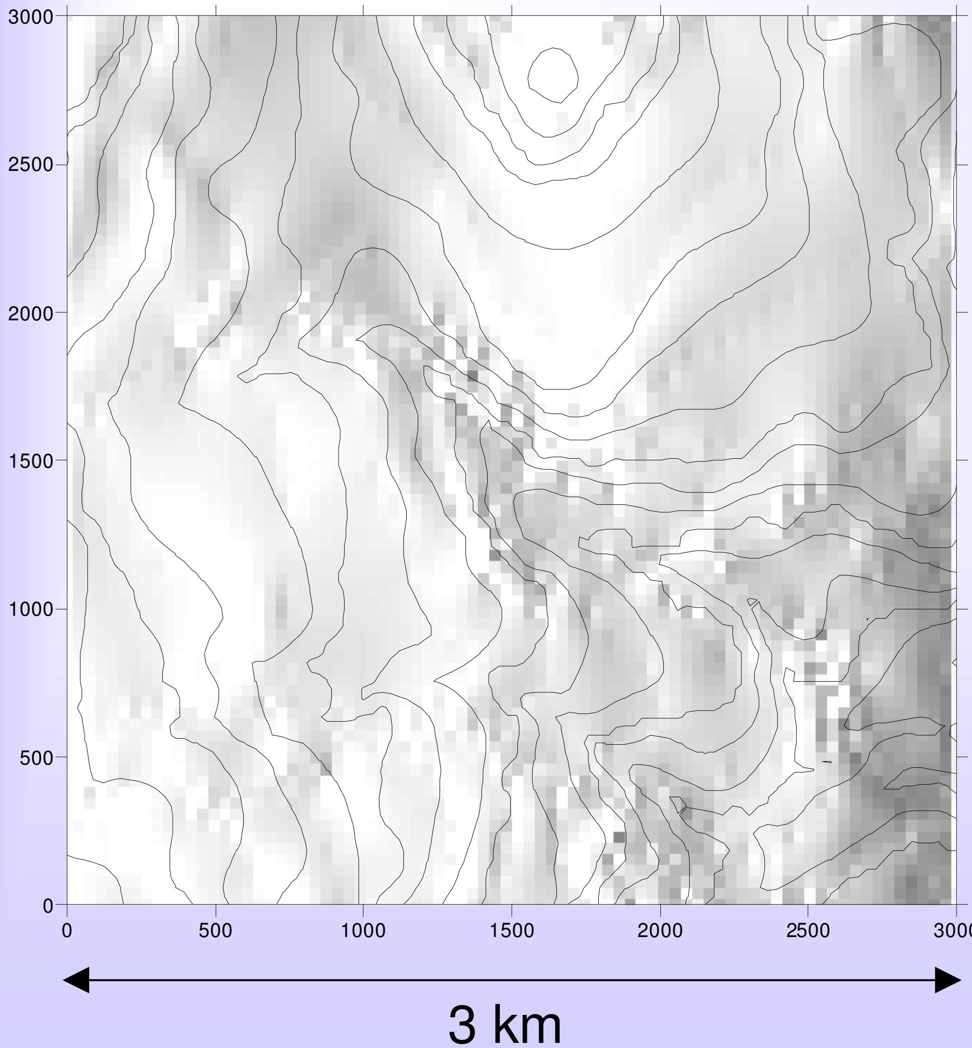
LiDAR used to develop topography and vegetation DEM

Granger Basin, Wolf Creek, Yukon Territory

Essery and Pomeroy, in preparation

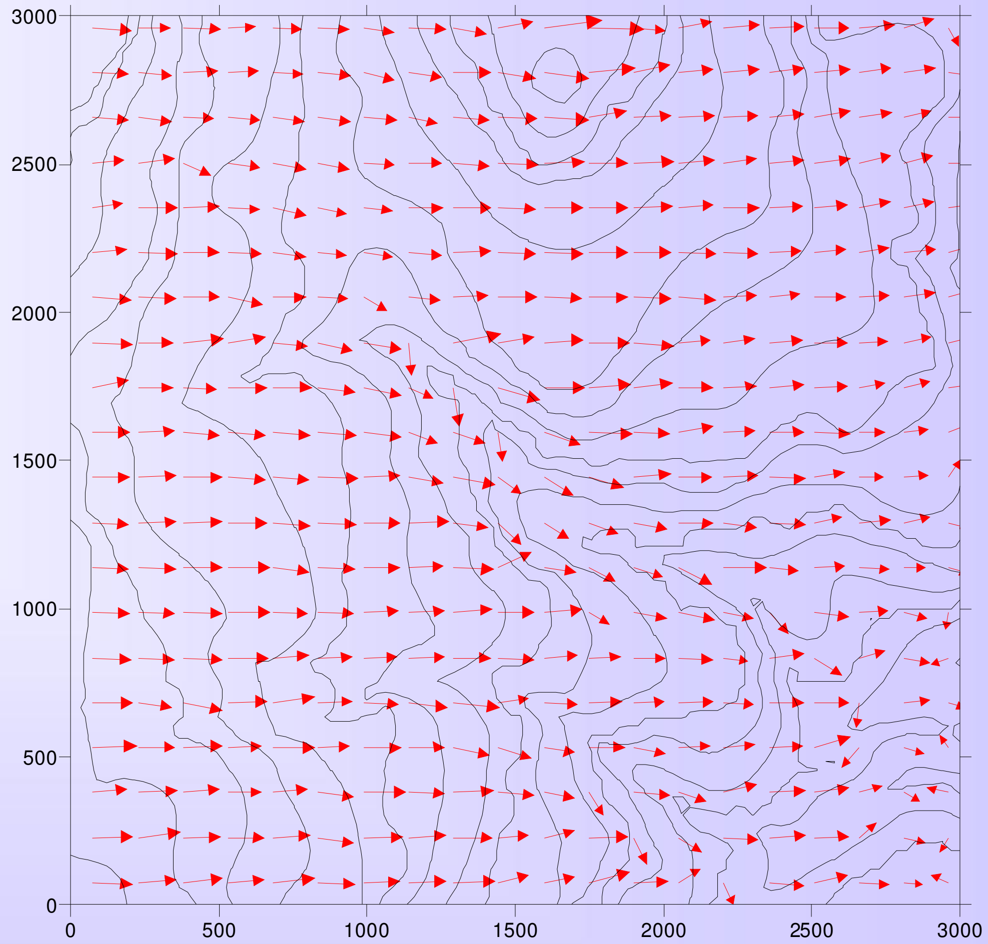
Computer simulation of wind flow over mountains

Windspeed



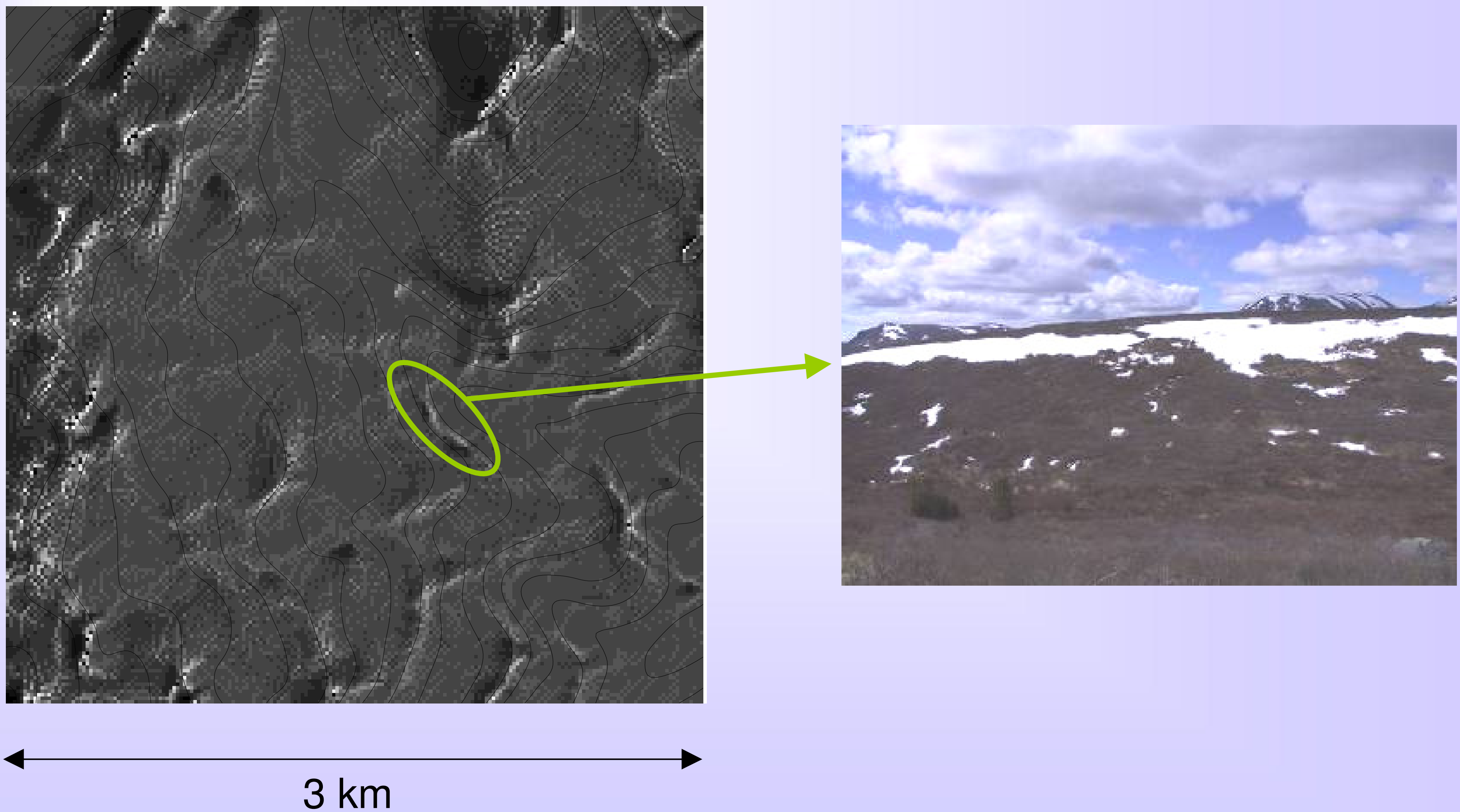
3 km

Direction



Granger Basin, Wolf Creek, Yukon

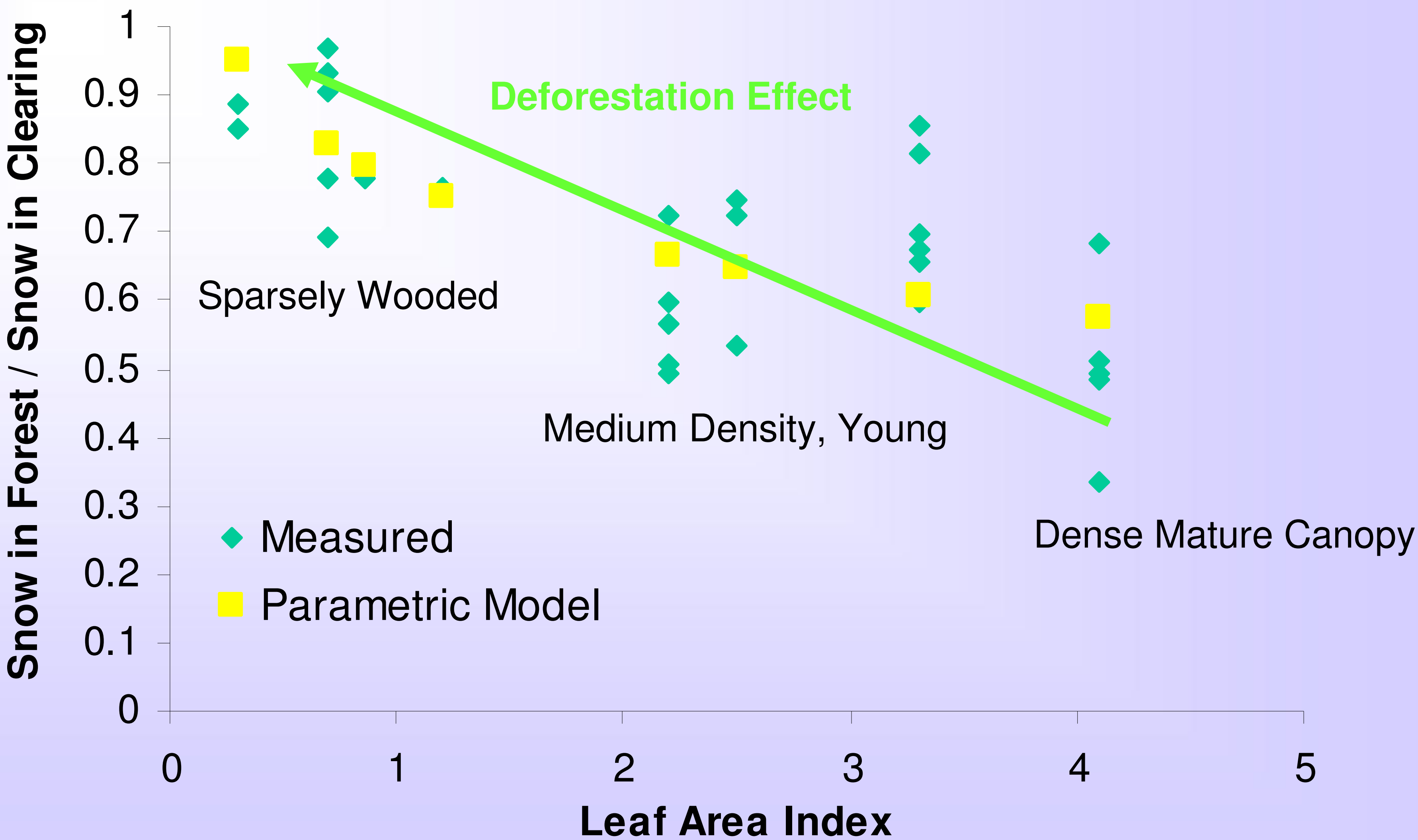
Simulation of Hillslope Snowdrift



Intercepted Snow

- Snow intercepted for weeks to months in cold regions forests
- Low albedo, high net radiation, high turbulent transfer result in enhanced sublimation loss
- Accumulation = Snowfall – Interception + Unloading + Drip or
- Accumulation = Snowfall - Sublimation

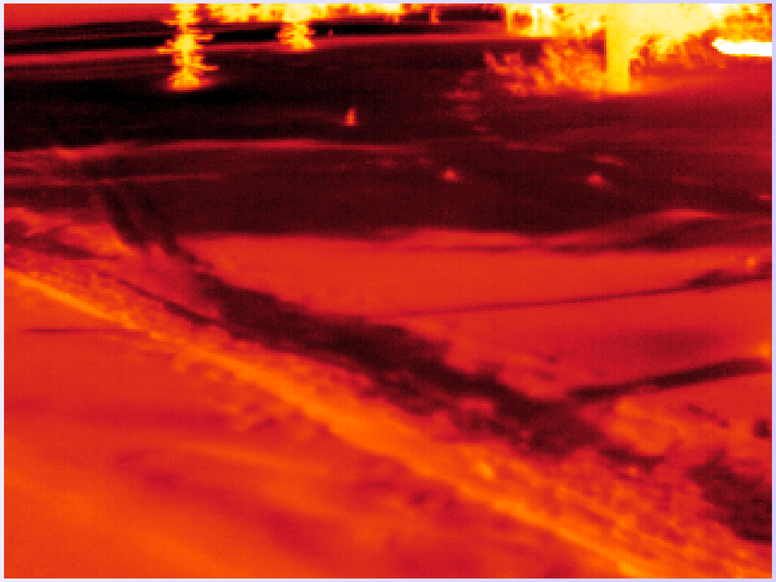
Effect of Forest Removal on Snow Accumulation



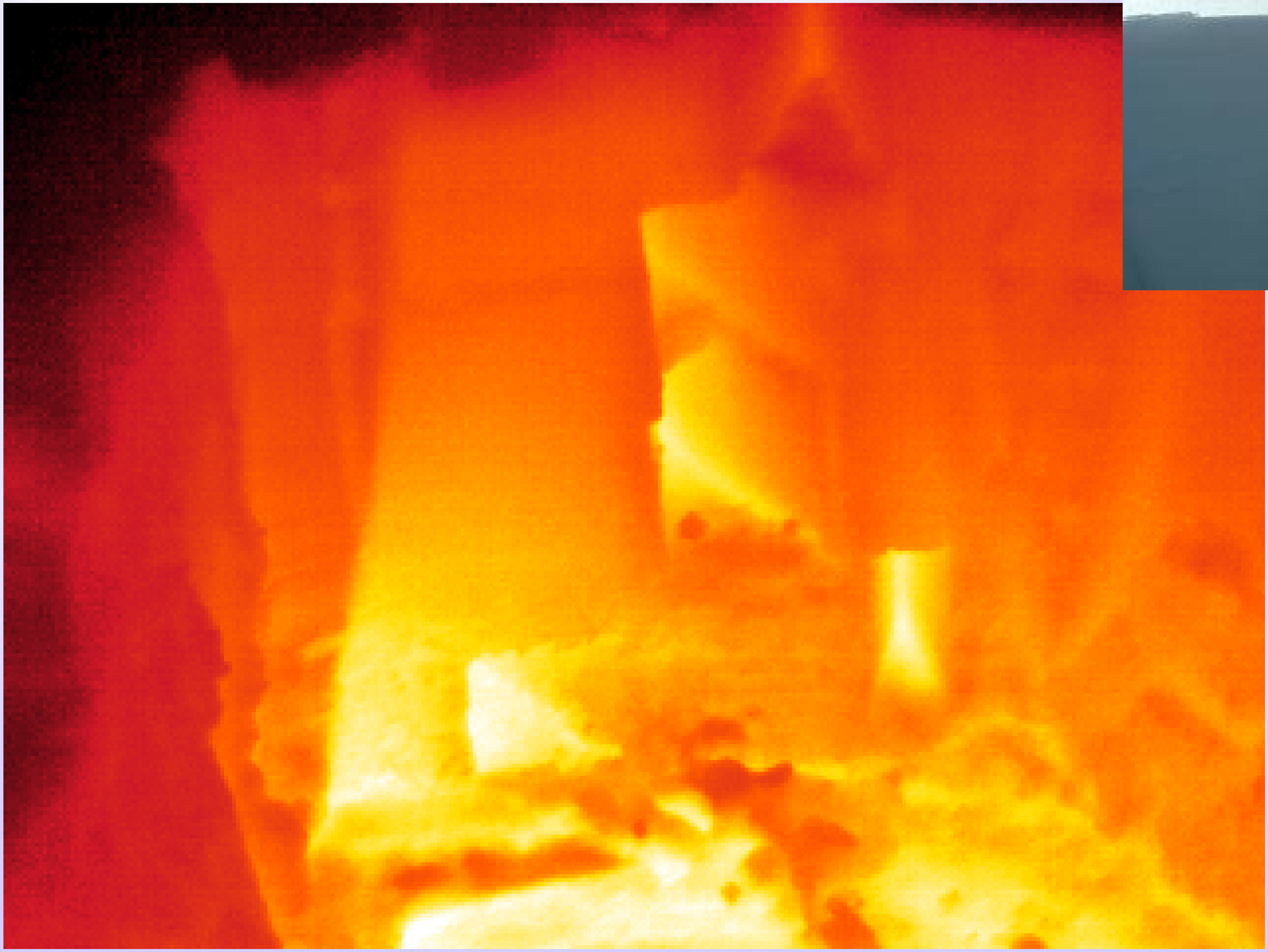
Pomeroy et al., 2002 *Hydr Proc*

Snowmelt

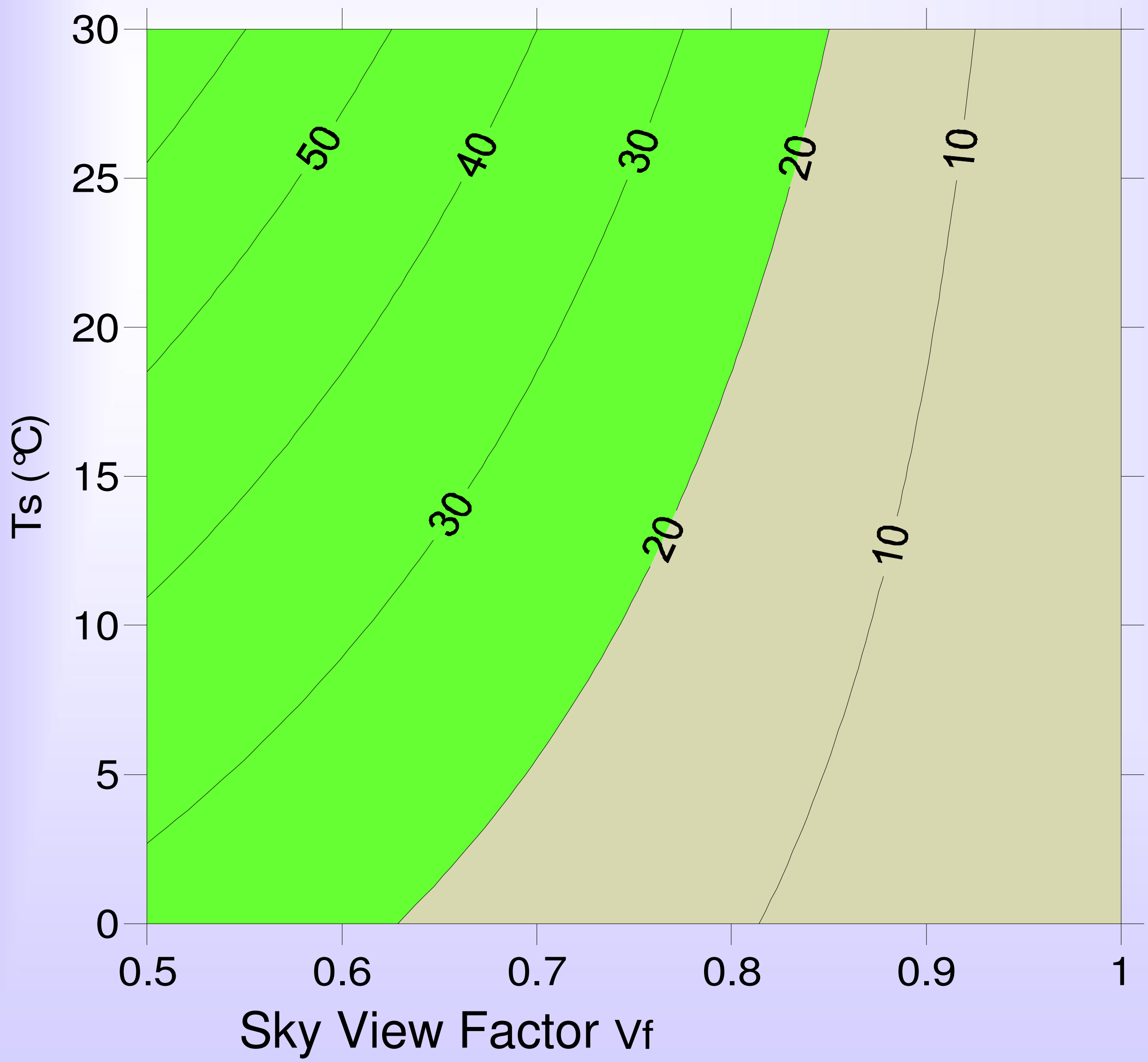
- Incoming solar and thermal radiation
- Warm air masses
- Energy storage
- Terrain and vegetation effects



Snow Energetics

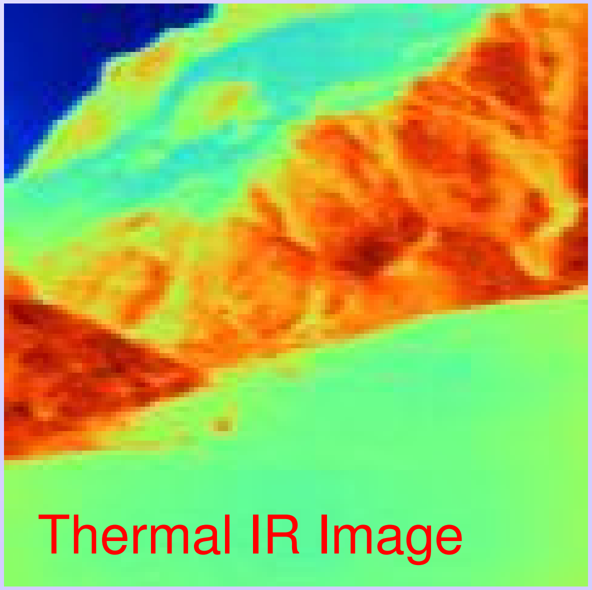


Incoming Longwave in Arctic Mountains



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℃ and the clear sky emissivity is 0.65

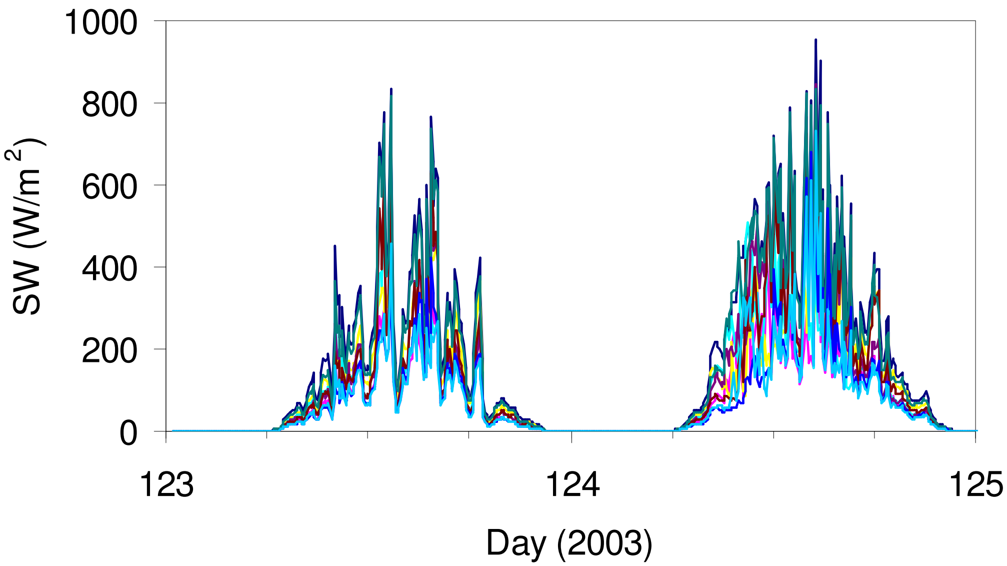


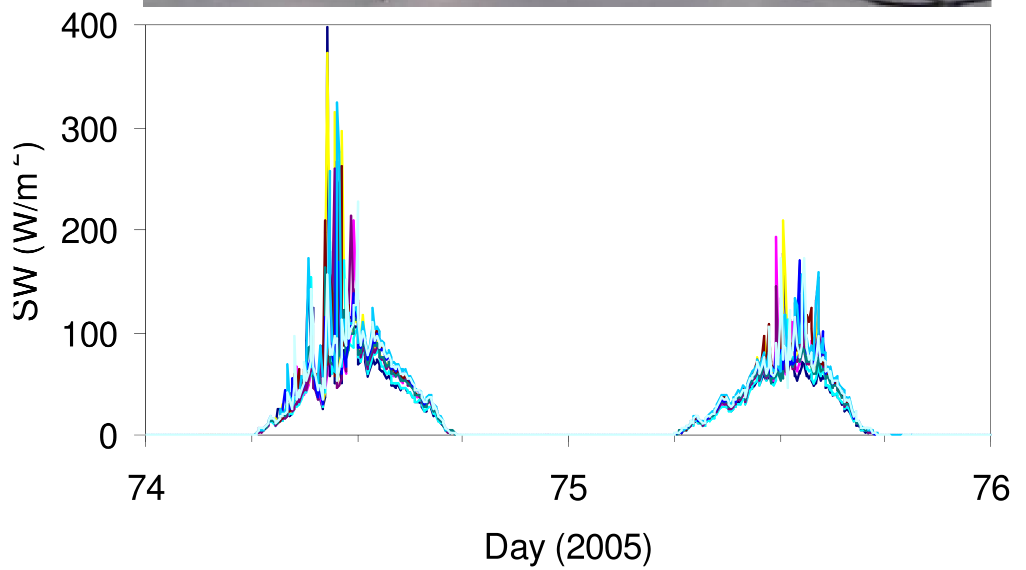
Sicart et al. 2006 *Hyd Proc*

Solar radiation to snow beneath shrubs and trees

Wolf Creek shrubs

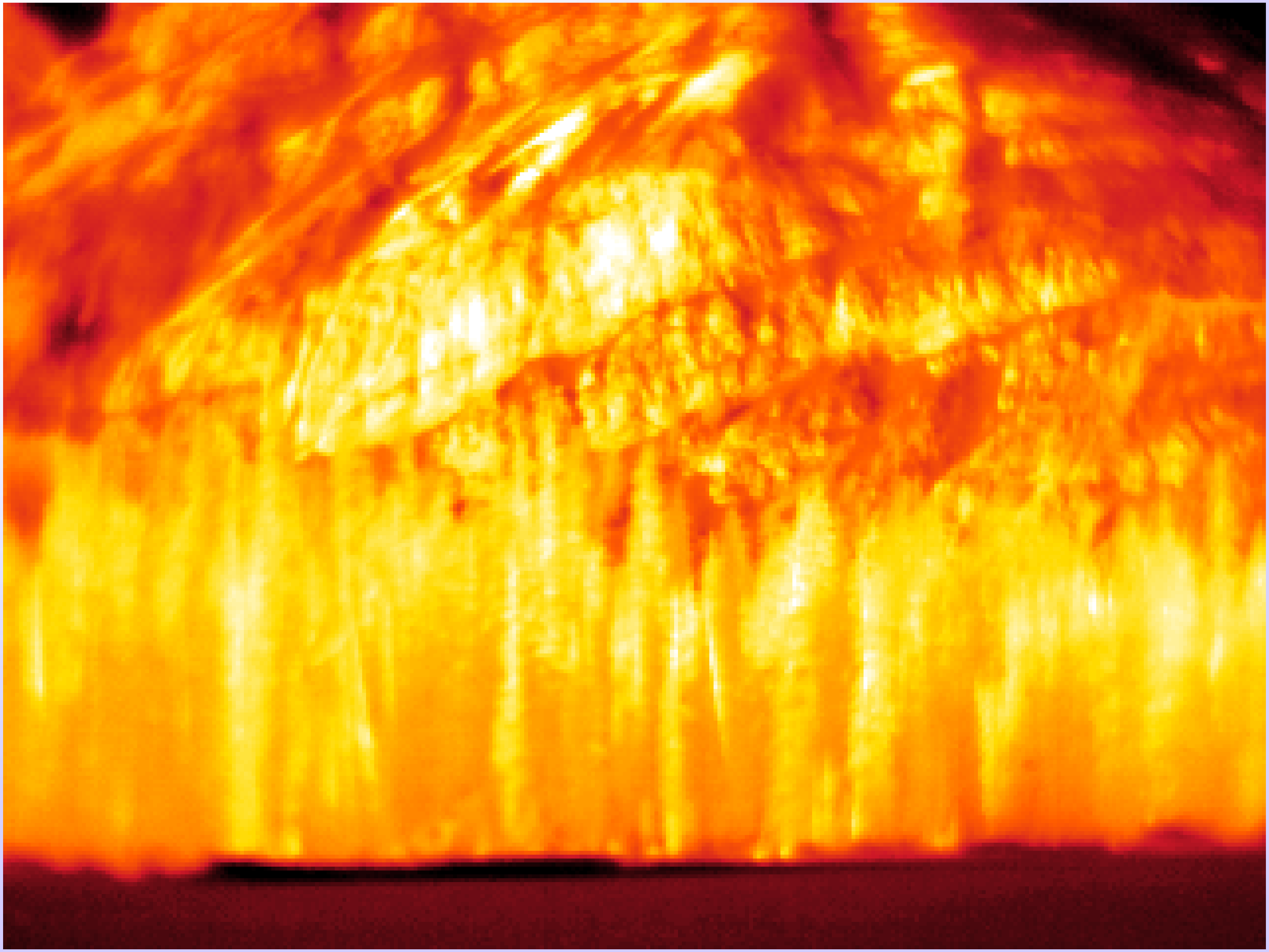
Marmot Creek level forest



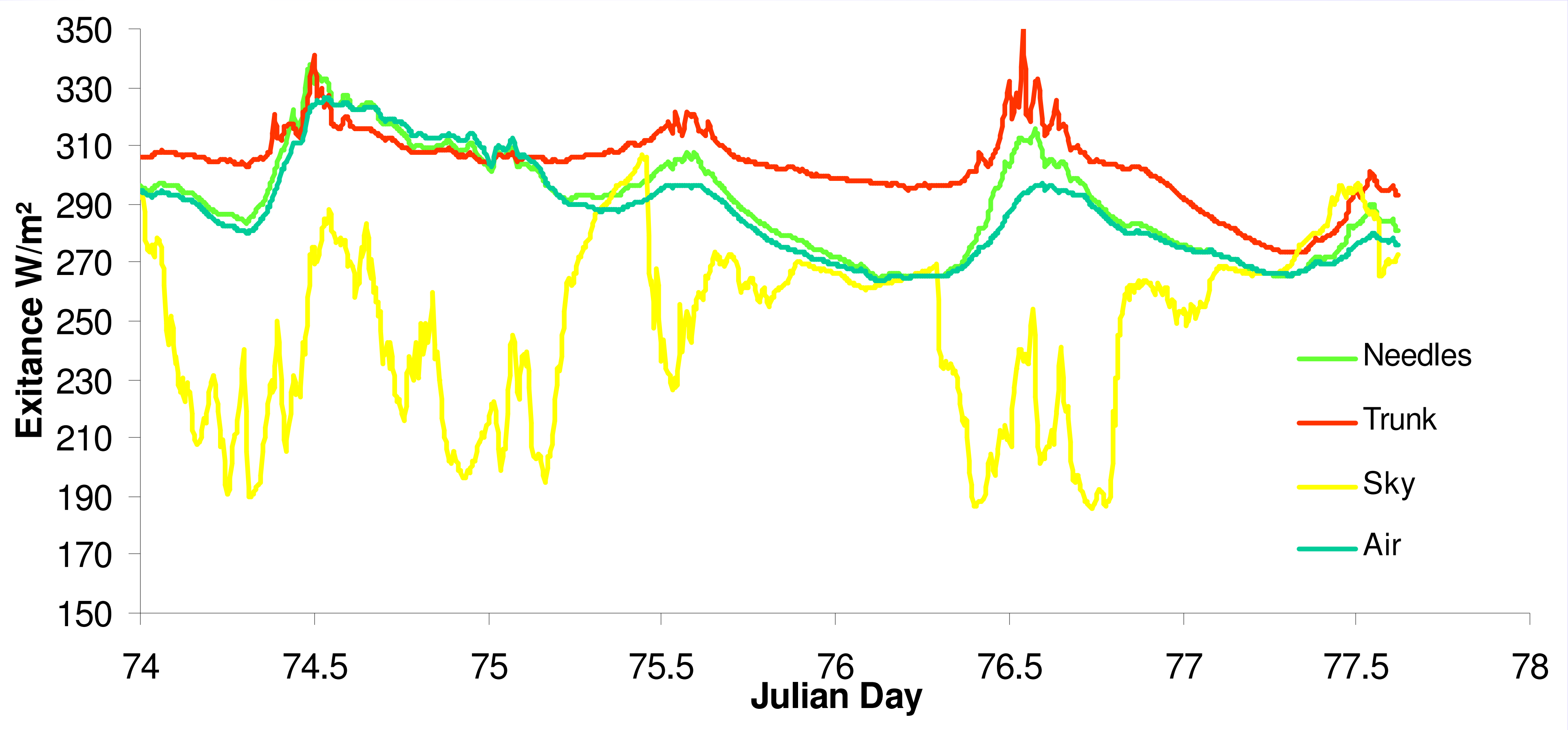


Pomeroy et al., *J Hydrometeorol*, 2008

Hot Trees

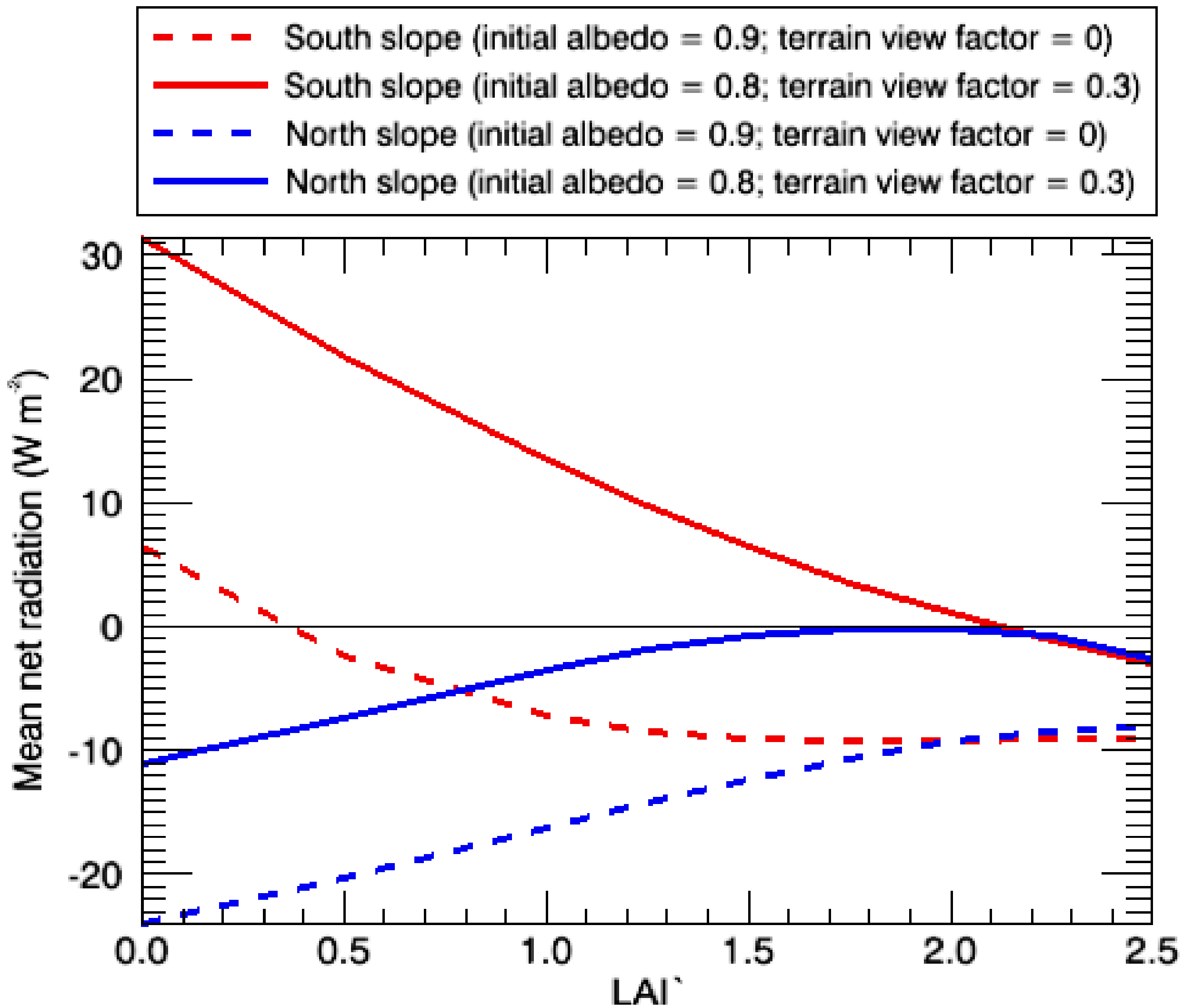


Longwave Exitance Pine Stand



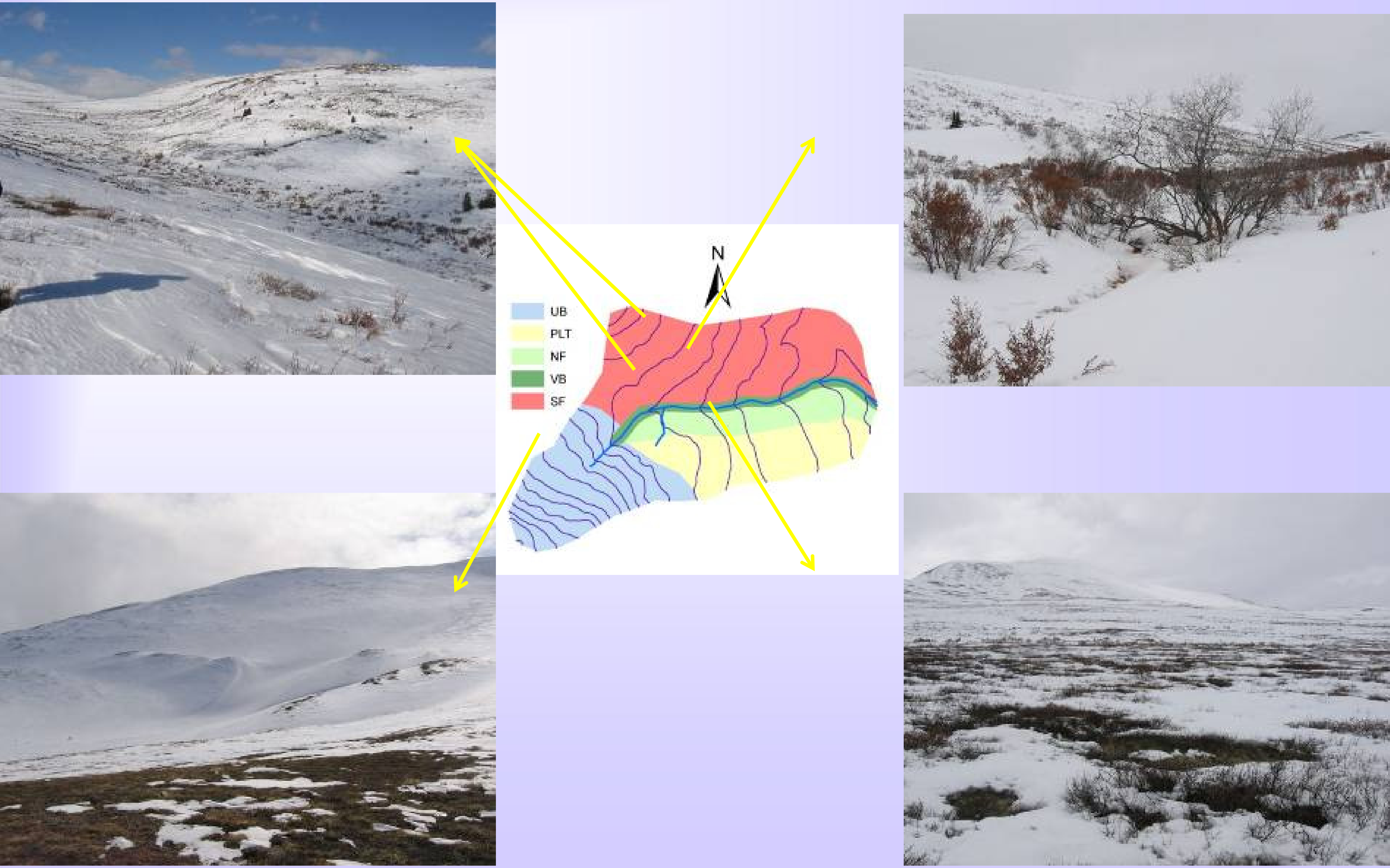
Pomeroy et al., *J Hydromet*. 2009

Slope and Forest Density Effect on Net Radiation for Snowmelt



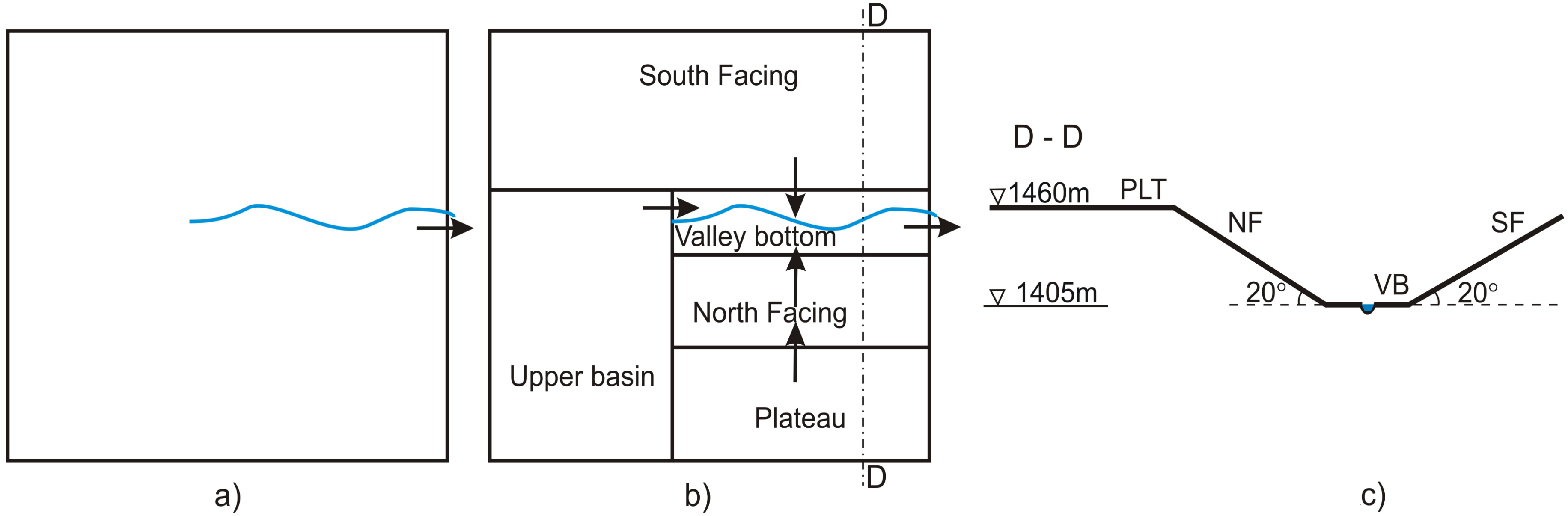
Ellis et al, submitted

Landscape Heterogeneity



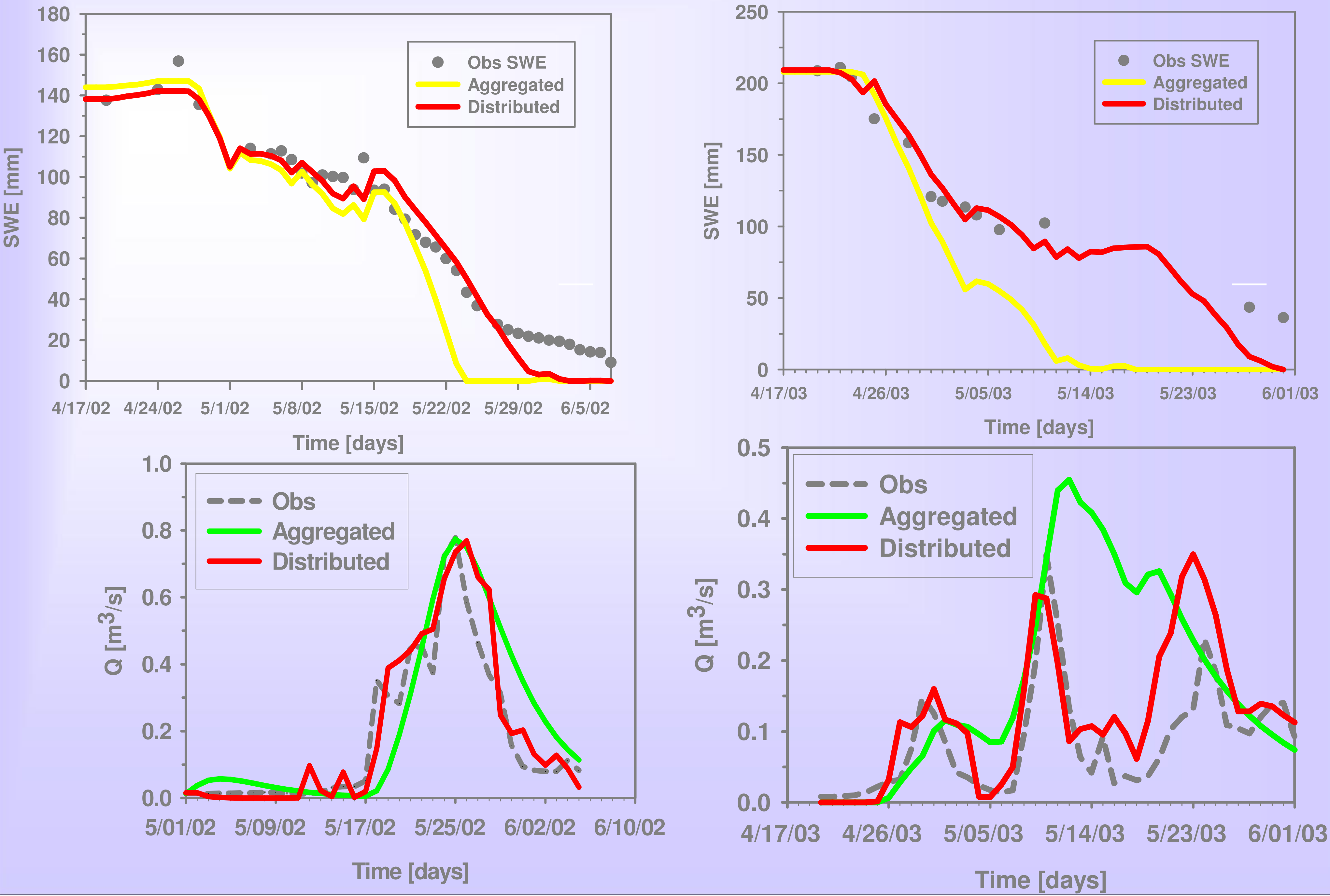
Modelling Approach

Aggregated vs. Distributed



Dornes et al., 2008 *Hydrol Proc.*

Snowmelt and Streamflow



Concluding Remarks

- Relationships between snow and vegetation are strongly influenced by atmospheric energy and mass inputs which in turn are controlled by weather and topography
  - Less forests => more snow (except if windblown)
  - More shrubs => more snow (if windblown)
  - Less forests => more rapid snowmelt on south facing, slower melt on north facing slopes
- Increasing shrub height and coverage and decreasing forest coverage in cold regions mountains with both tend to increase snow accumulation in some locations and will both tend to increase melt rate except on north facing slopes.
- Further questions
  - What snow regime is optimal for sustaining current vegetation communities?
  - What are stable snow-vegetation regimes for various climates and how do these respond to and modulate climate change impacts?
  - Can we develop integrated snow ecology – hydrology models to show how climate change, terrestrial ecosystem shifts and hydrology interact as a system?