

Sensitivity of Marmot Creek Snow Hydrology to Future Climate Change and Forest Disturbance

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How Might Marmot Creek Change?

► Forest disturbance

- Pine Beetle
- Salvage Logging
- Clear-cutting
- Burning

► Climate Warming

- Warming in forest
- Warming in alpine



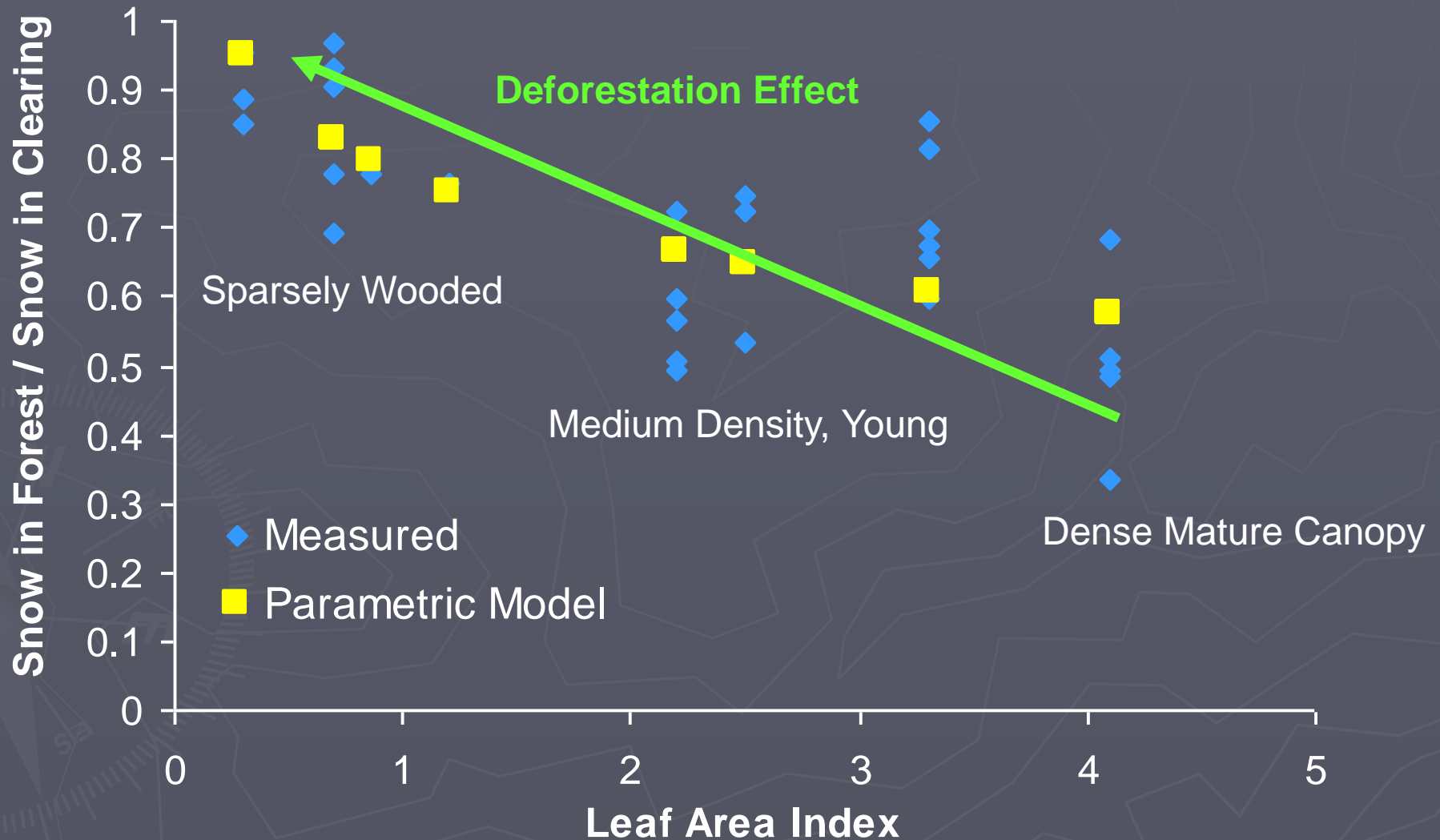
CRHM Modules

- ▶ **Prairie Blowing Snow Model (PBSM; Pomeroy & Li, 2000)**
 - Blowing snow transport
 - ▶ Saltation + suspension
 - Blowing snow sublimation
 - ▶ $f(\text{particle size, radiation, turbulent \& latent heat exchange, vapour density})$
 - Vegetation partitions wind shear stress on snow surface
 - ▶ $f(\text{stalk characteristics, drag coefficients})$
- ▶ **Snobal (Marks et al., 1998, 1999)**
 - Snowpack melt and sublimation/condensation
 - Two layers
- ▶ **Canopy module (Ellis et al., 2010)**
 - Canopy radiation adjustment (Pomeroy et al., 2009)
 - Snow interception, unloading, throughfall (Hedstrom & Pomeroy, 1998)
 - Intercepted snow sublimation (Pomeroy et al., 1998)
 - Enhanced longwave irradiance to surface from the canopy

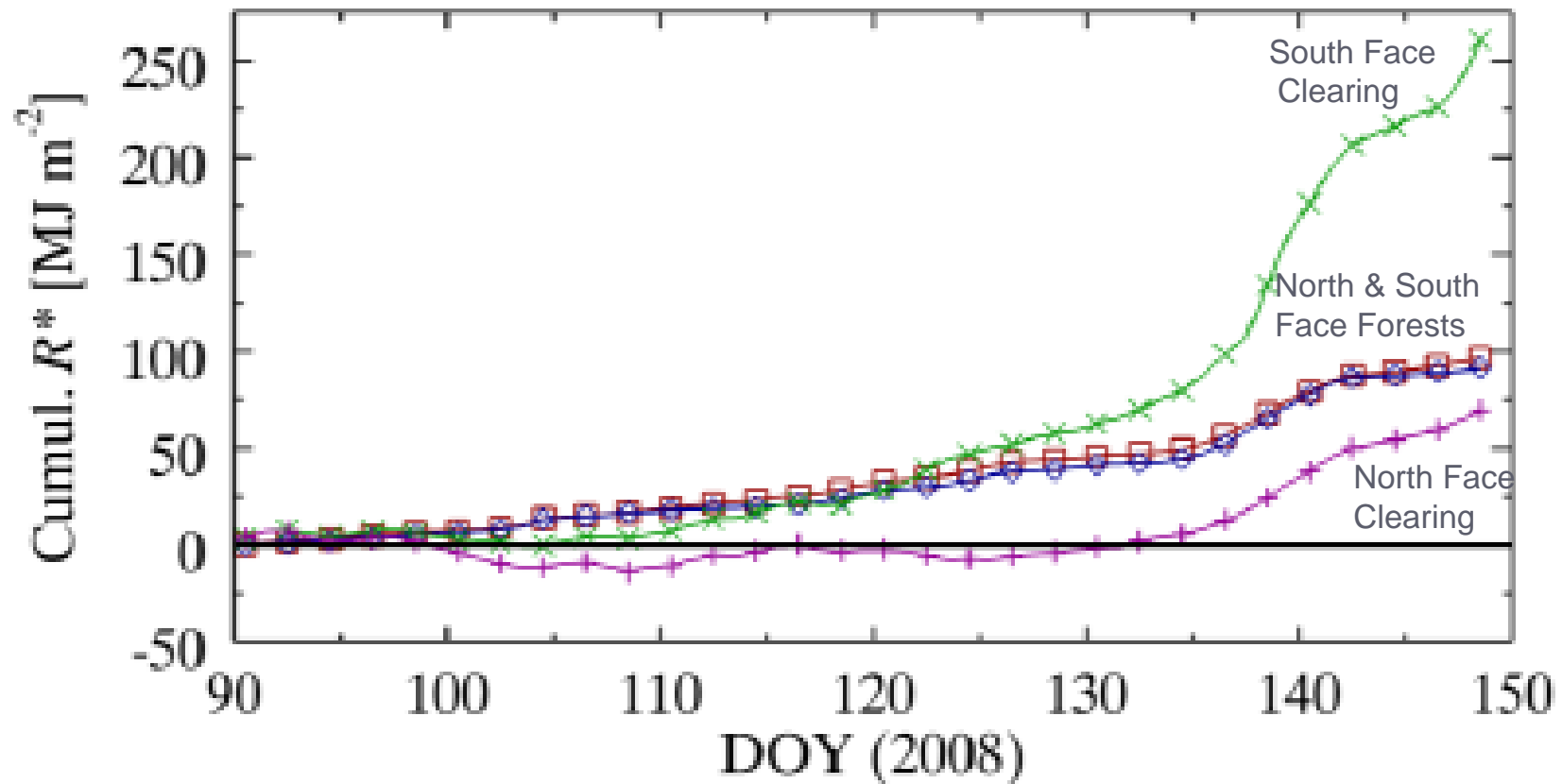
Snow Interception Studies



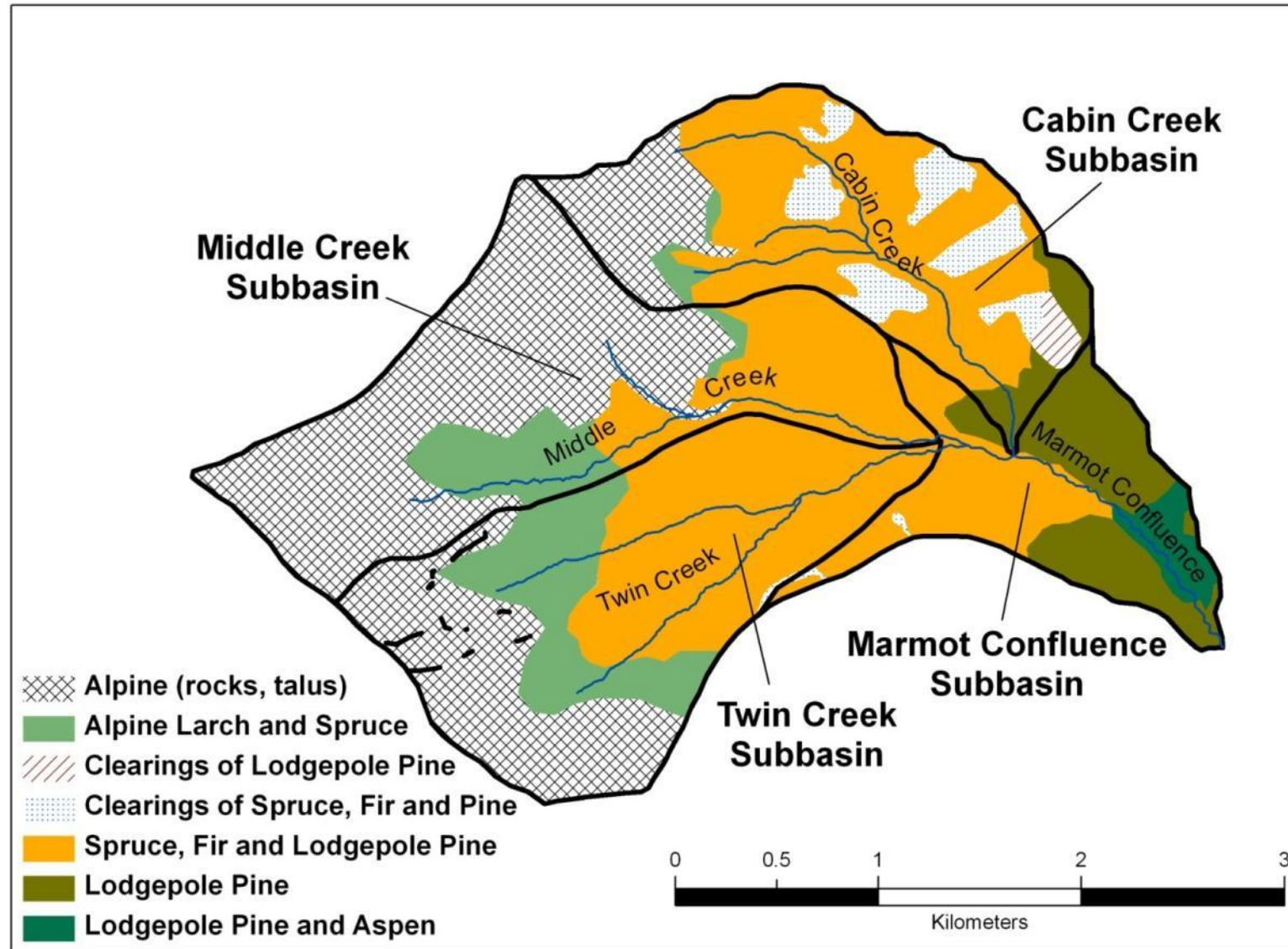
Effect of Forest Removal on Snow Accumulation



Net Radiation to Forests: Slope Effects

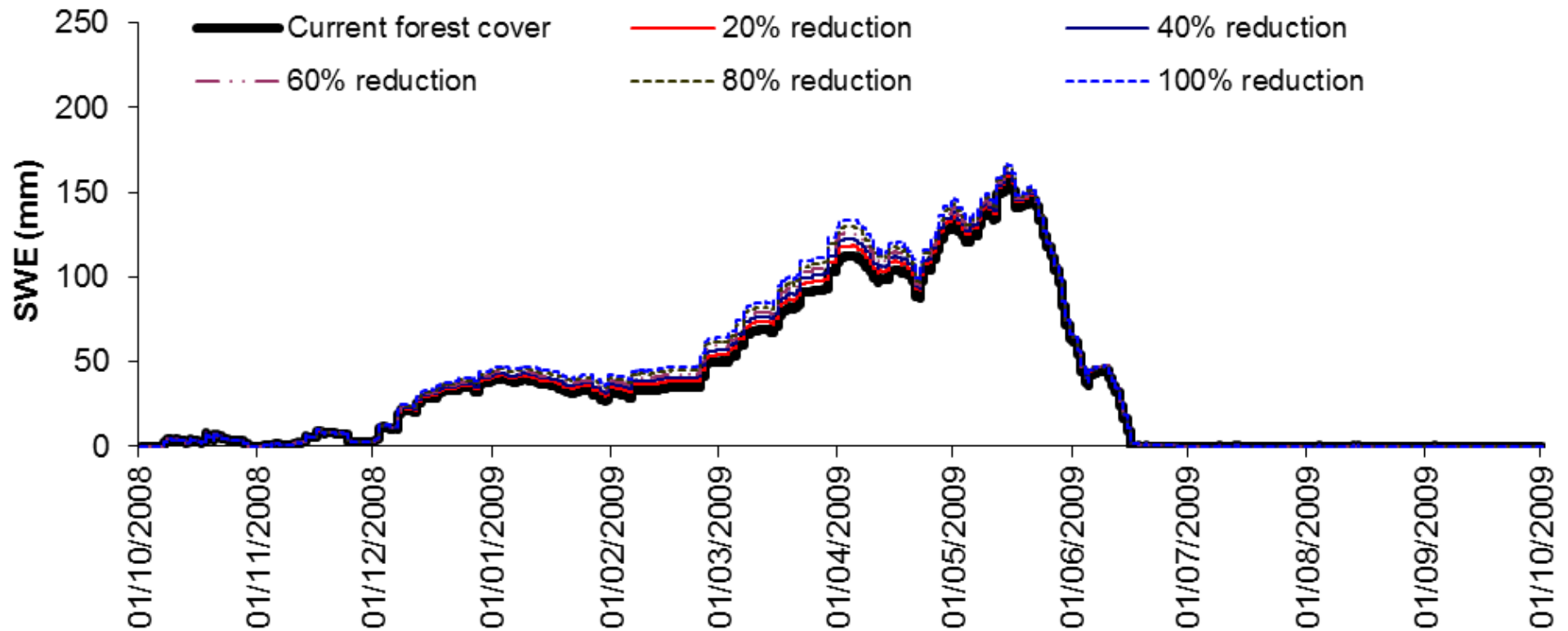


Forest Disturbance Scenarios



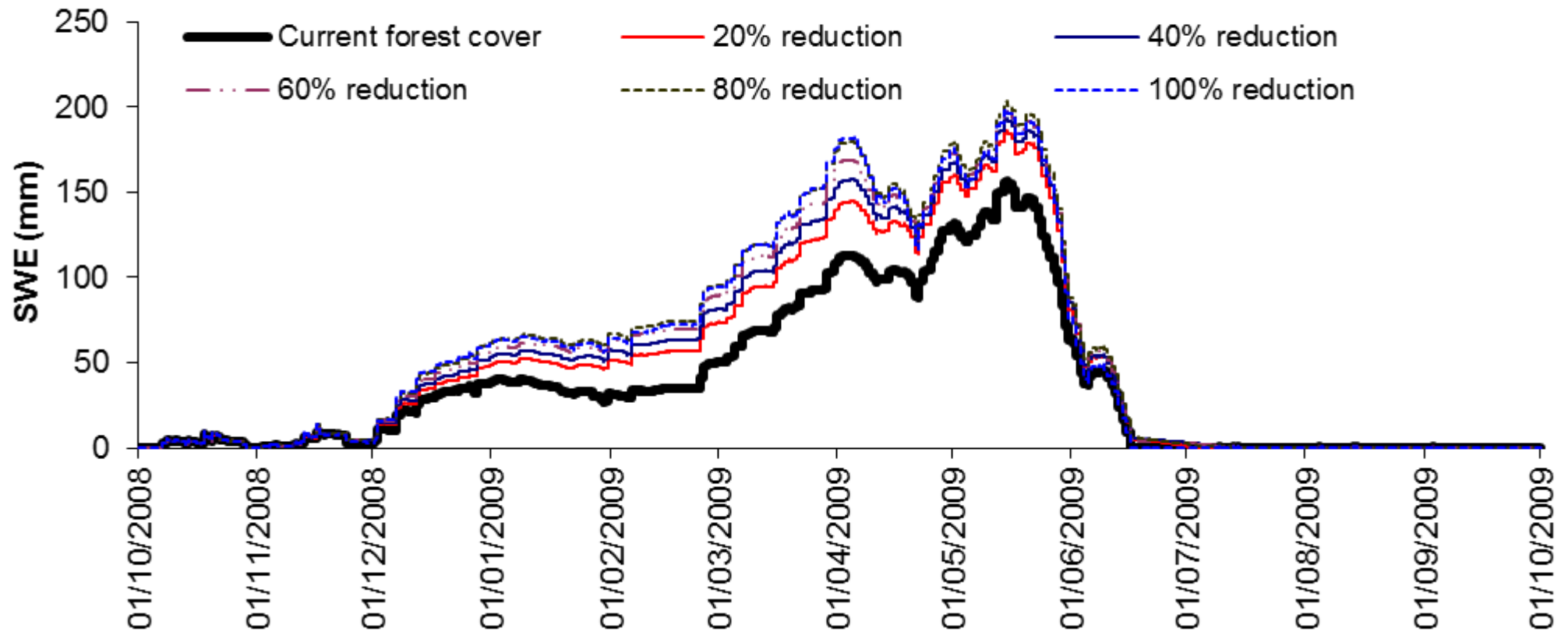
Pine Beetle Impact on Snow Regime

pine beetle; salvage logging



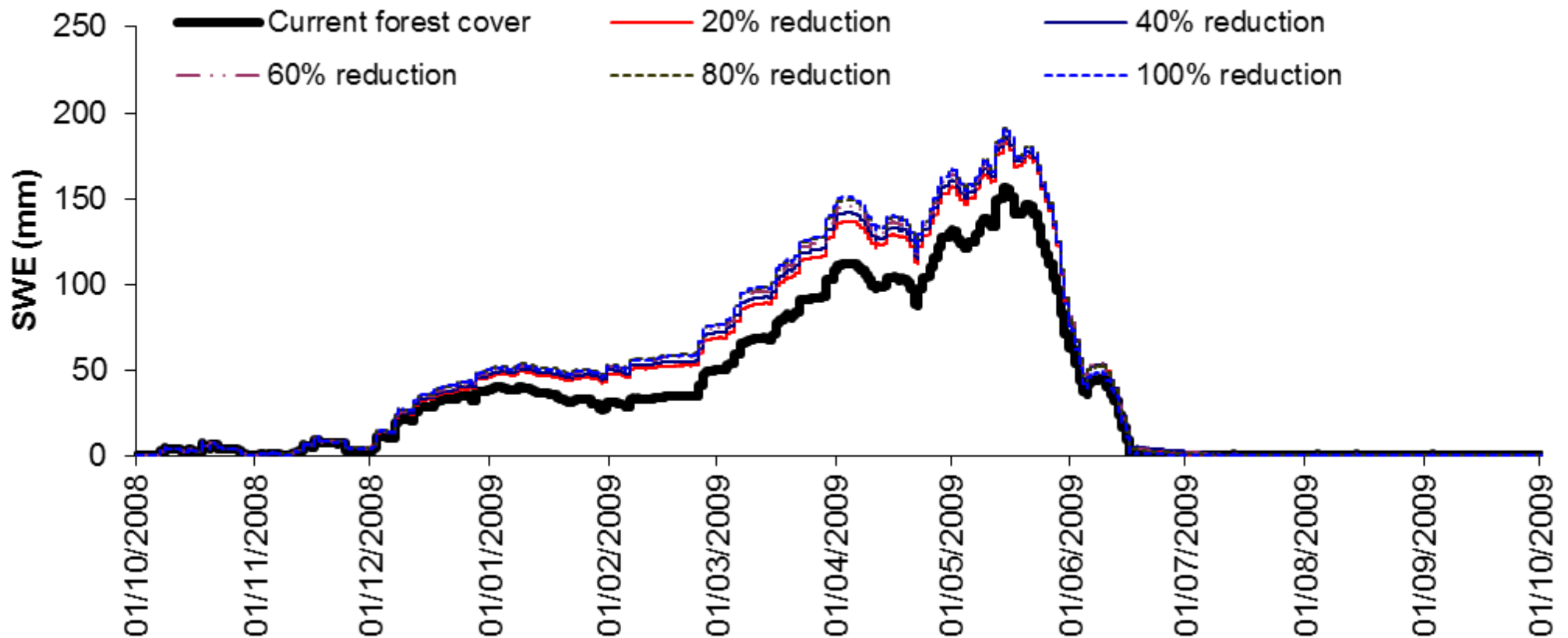
Fire Impact on Snow Regime

fire with salvage logging

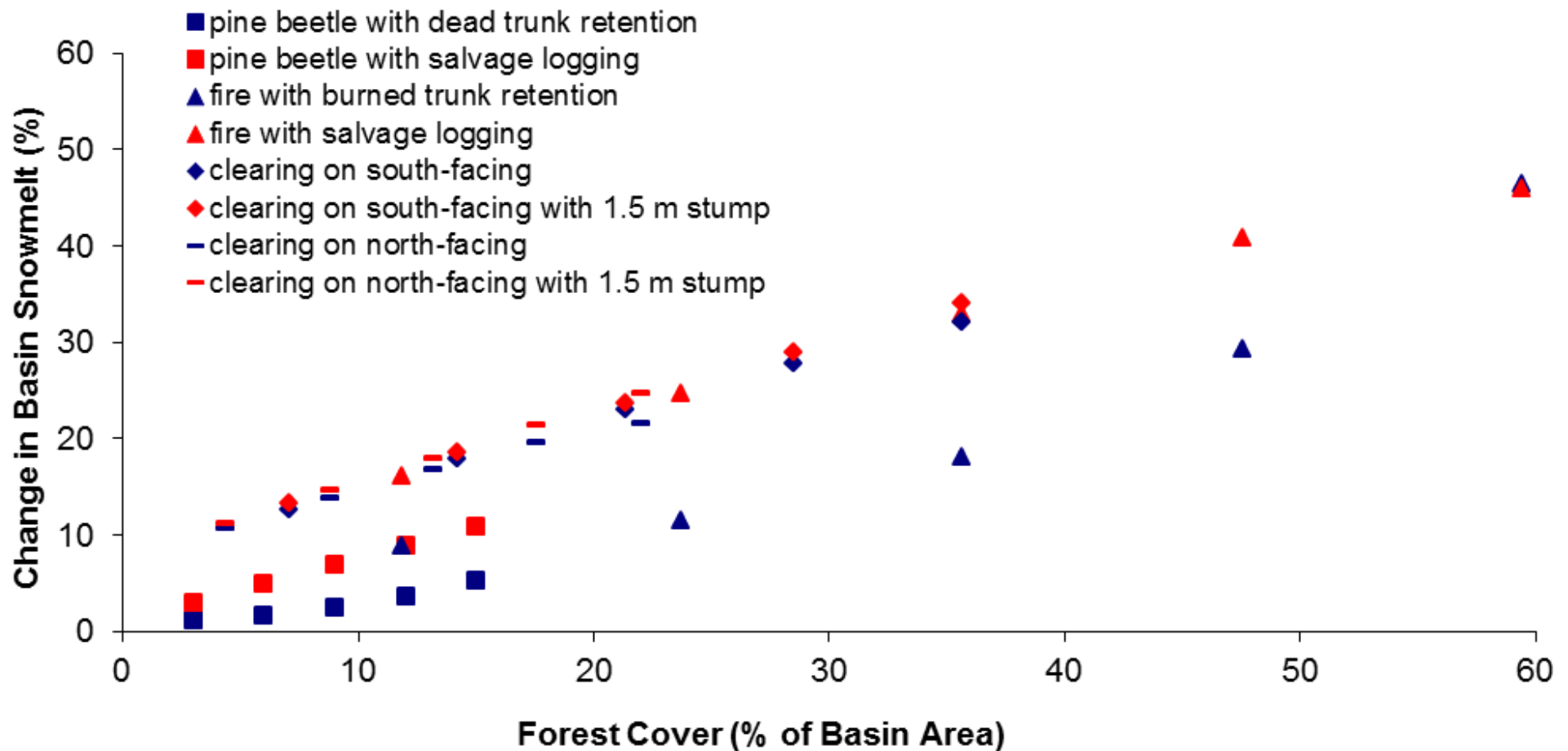


Clear-cutting Impact on Snow Regime

log only north-facing forest cover



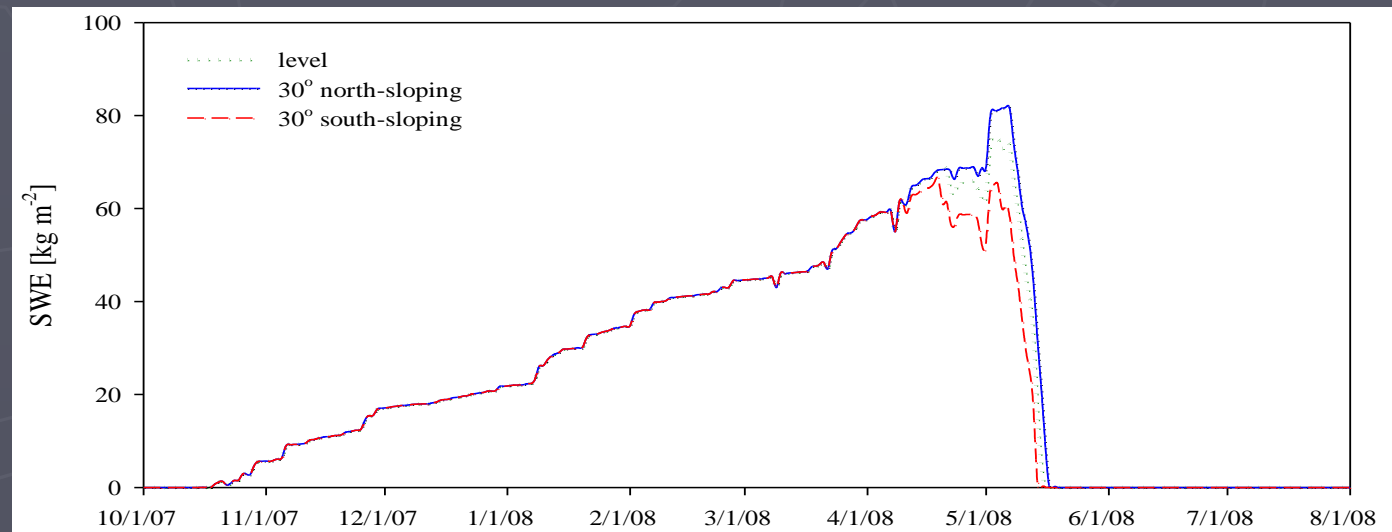
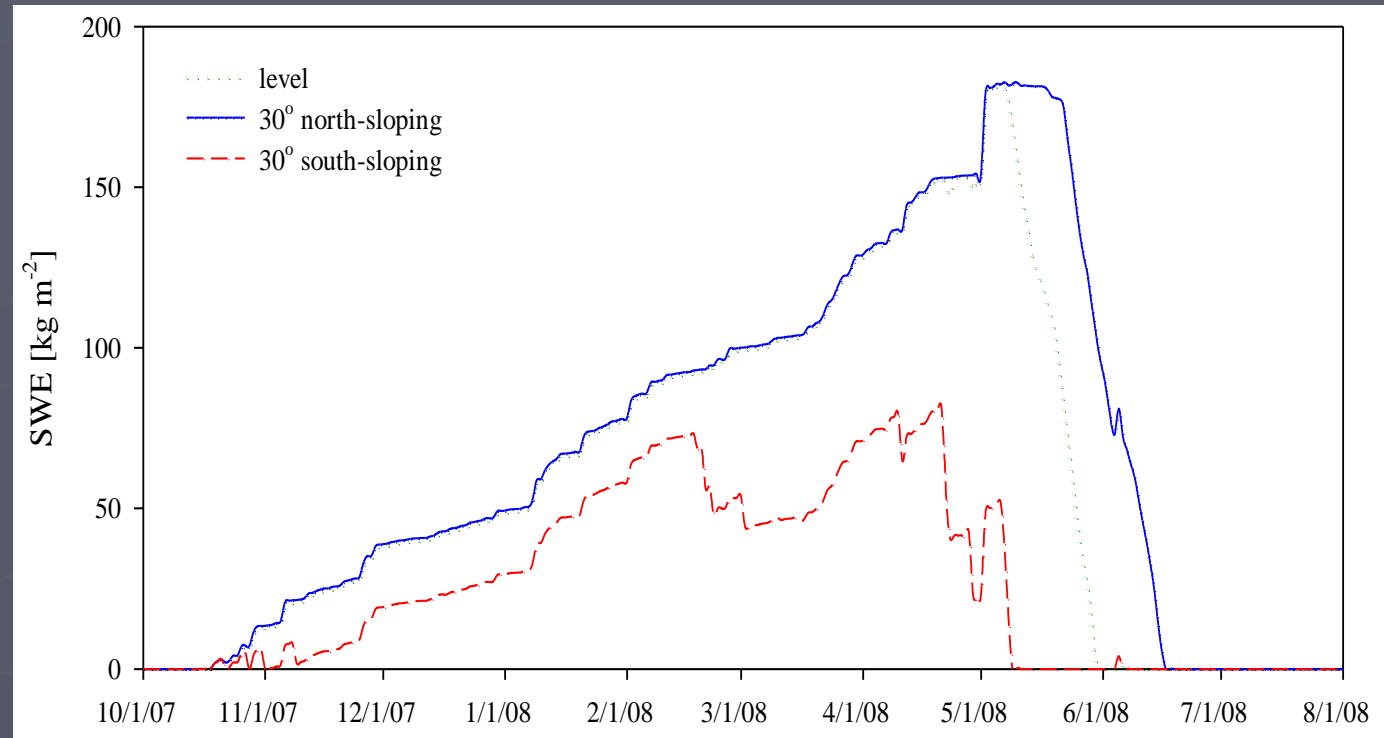
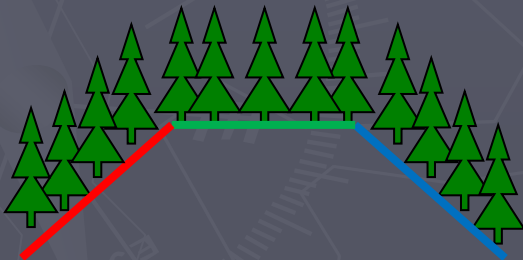
Forest Cover Disturbance Impact on Snowmelt Quantity



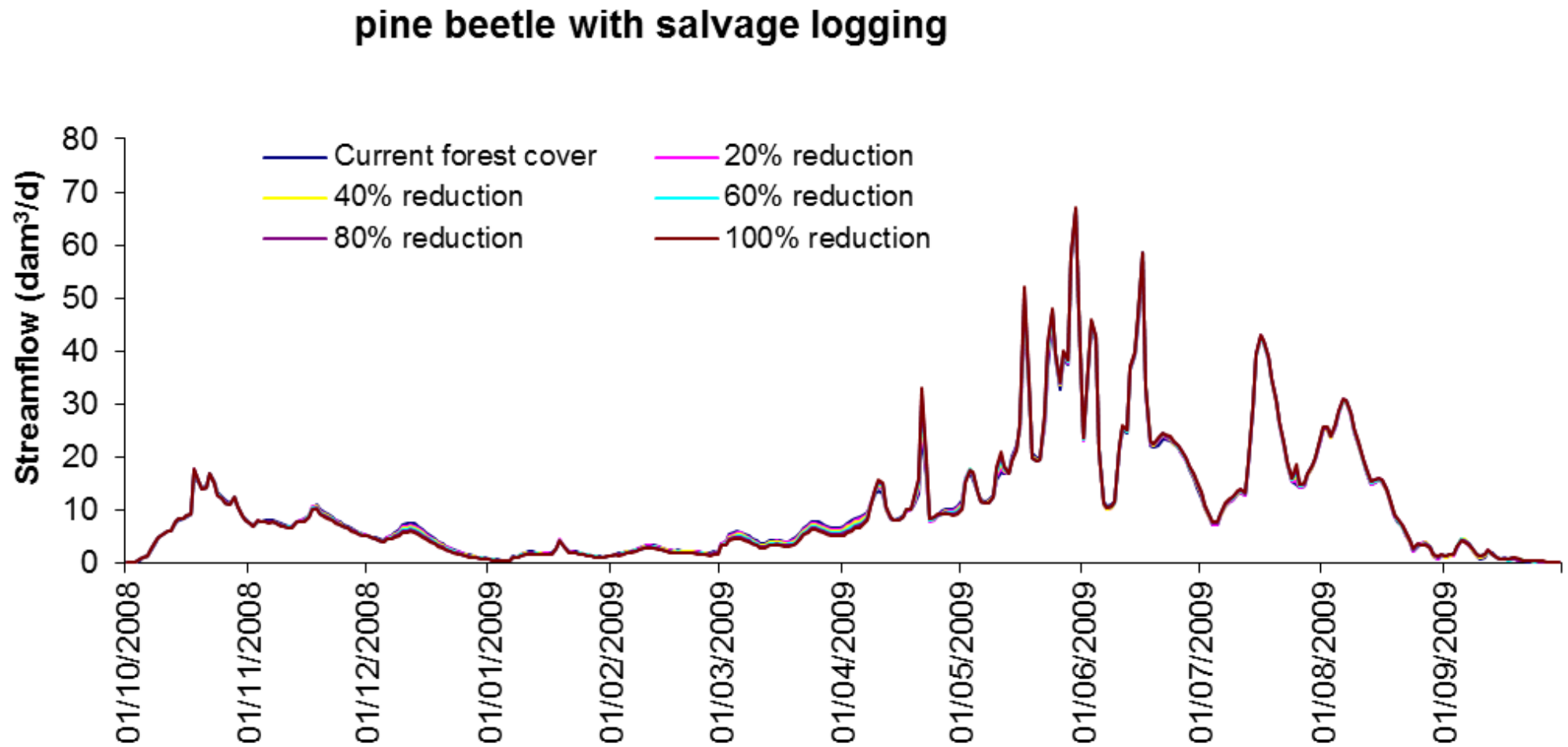
Forest Snow Regime on Slopes



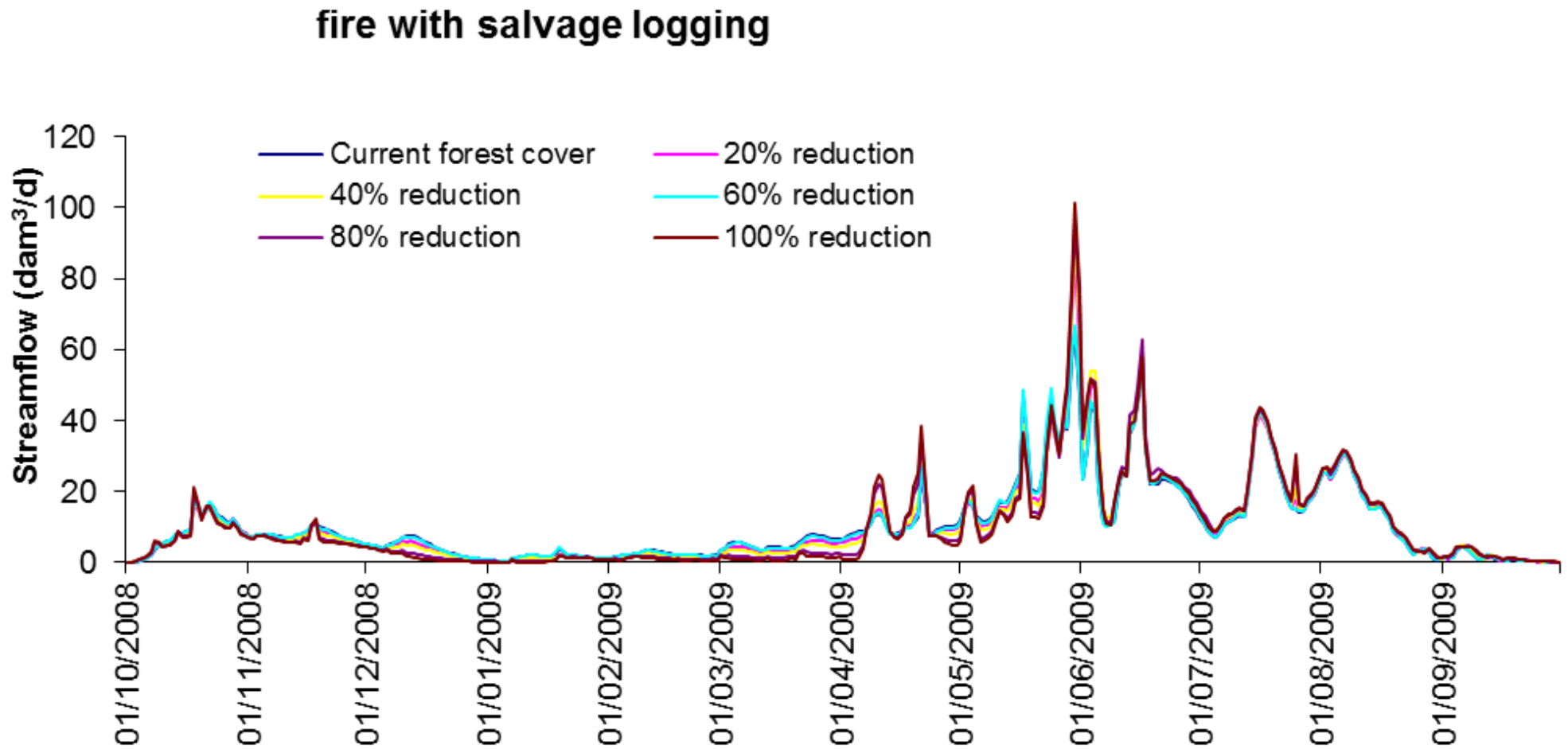
Open slopes highly sensitive to irradiation difference, forests are not



Pine Beetle Impact on Streamflow

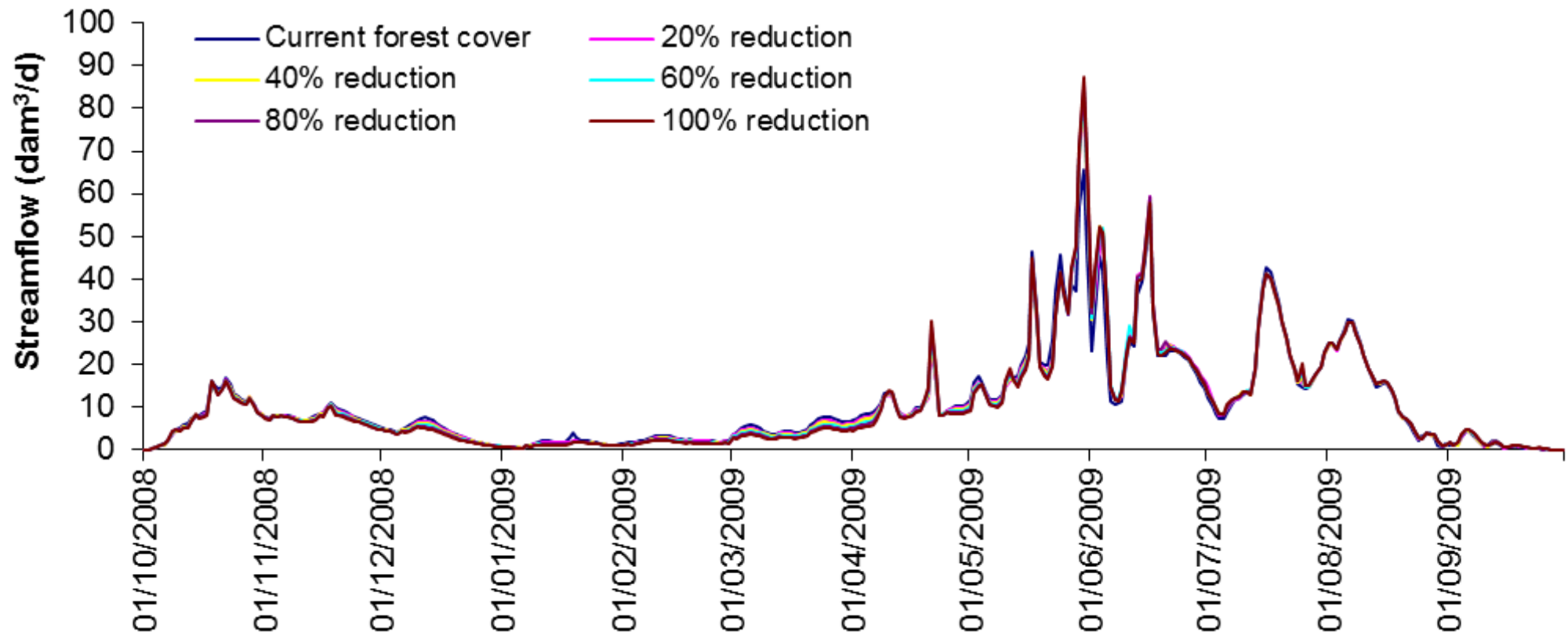


Fire Impact on Streamflow

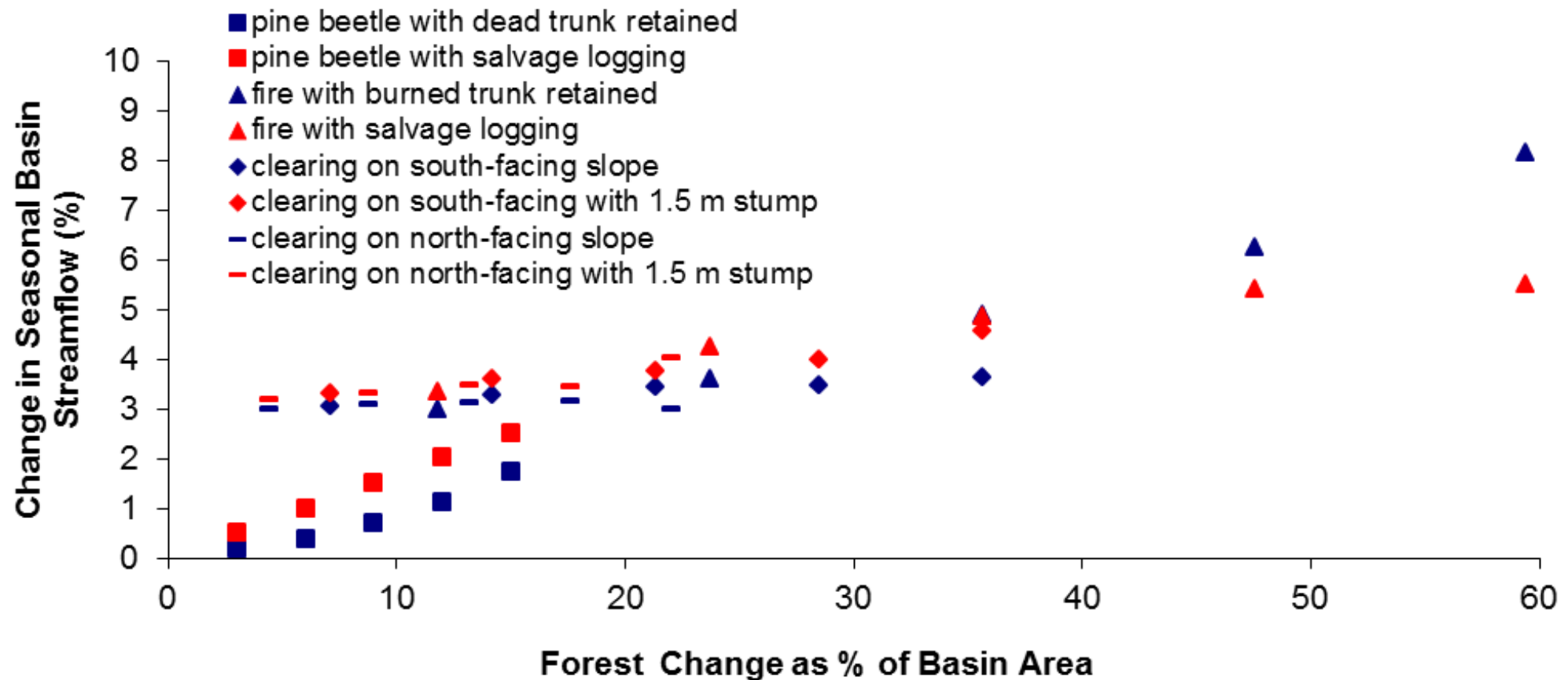


Clear-cutting Impact on Streamflow

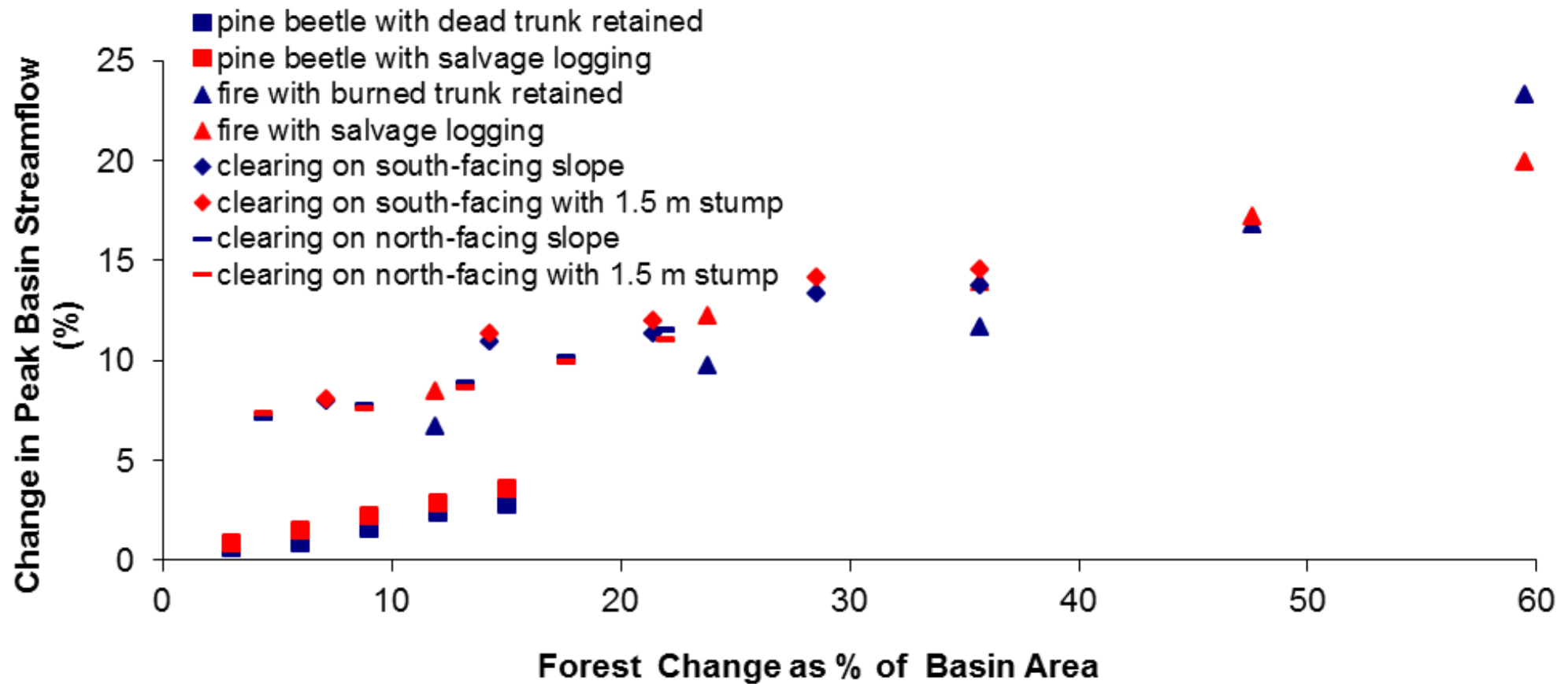
log only north facing slopes



Forest Cover Disturbance Impact on Seasonal Streamflow

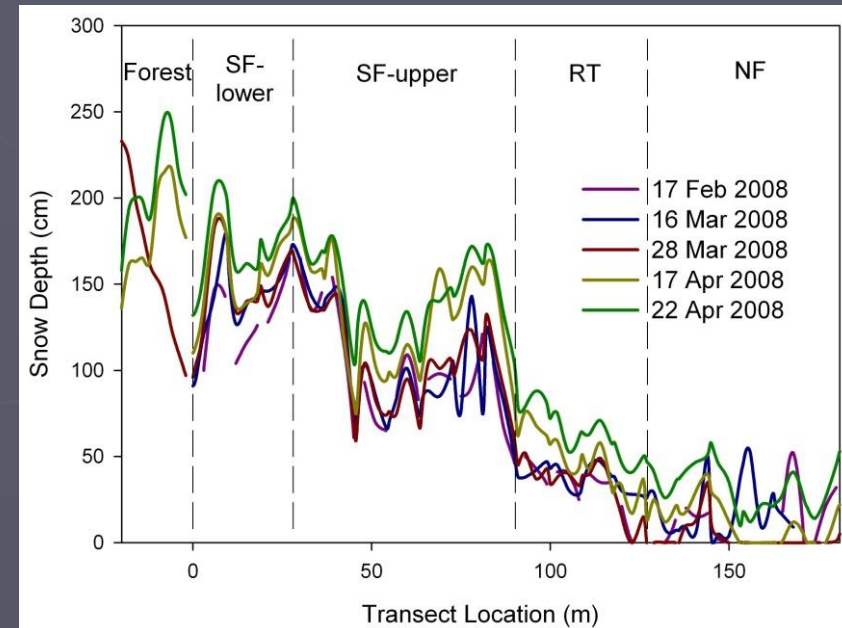
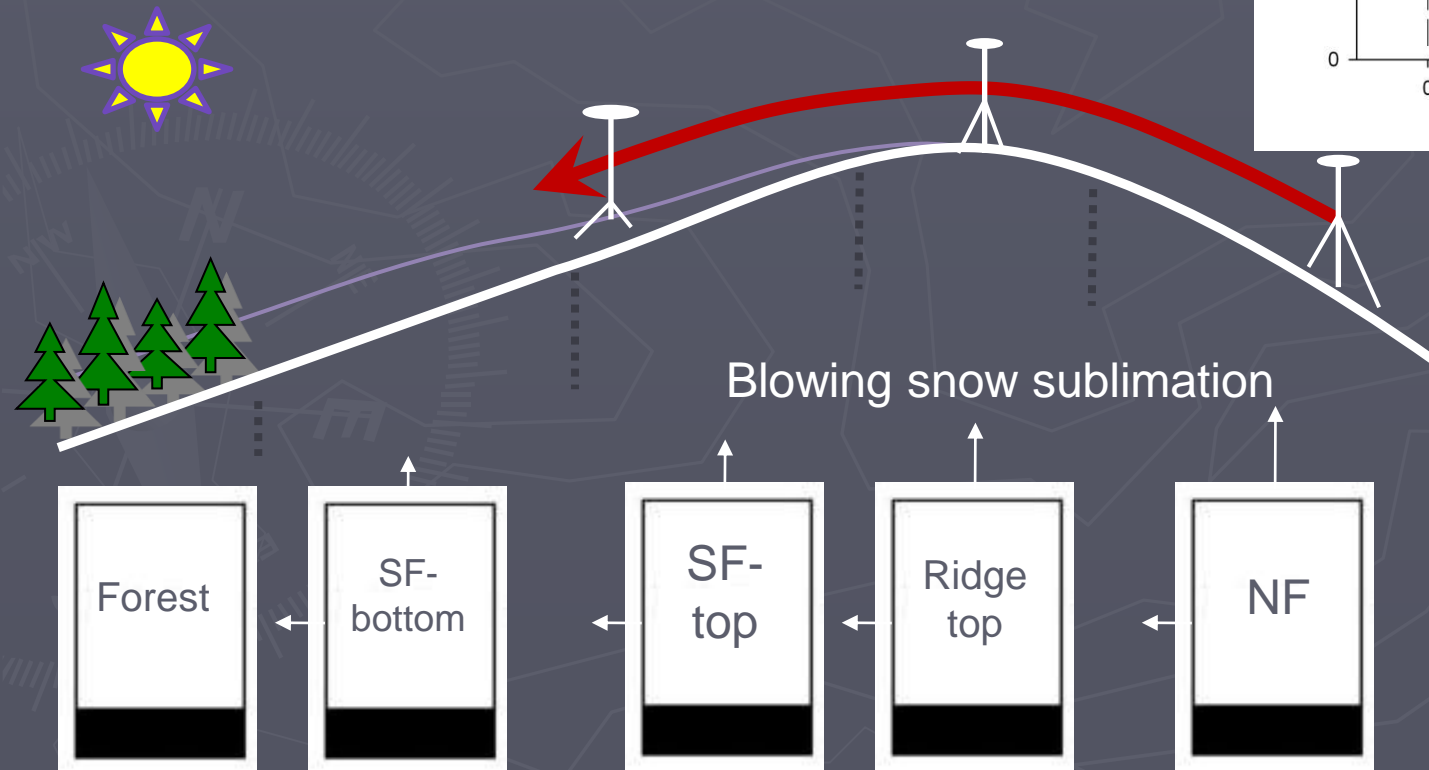


Forest Cover Disturbance Impact on Peak Streamflow



Blowing Snow: Fisera Ridge

- Flow over ridgetop and into forest

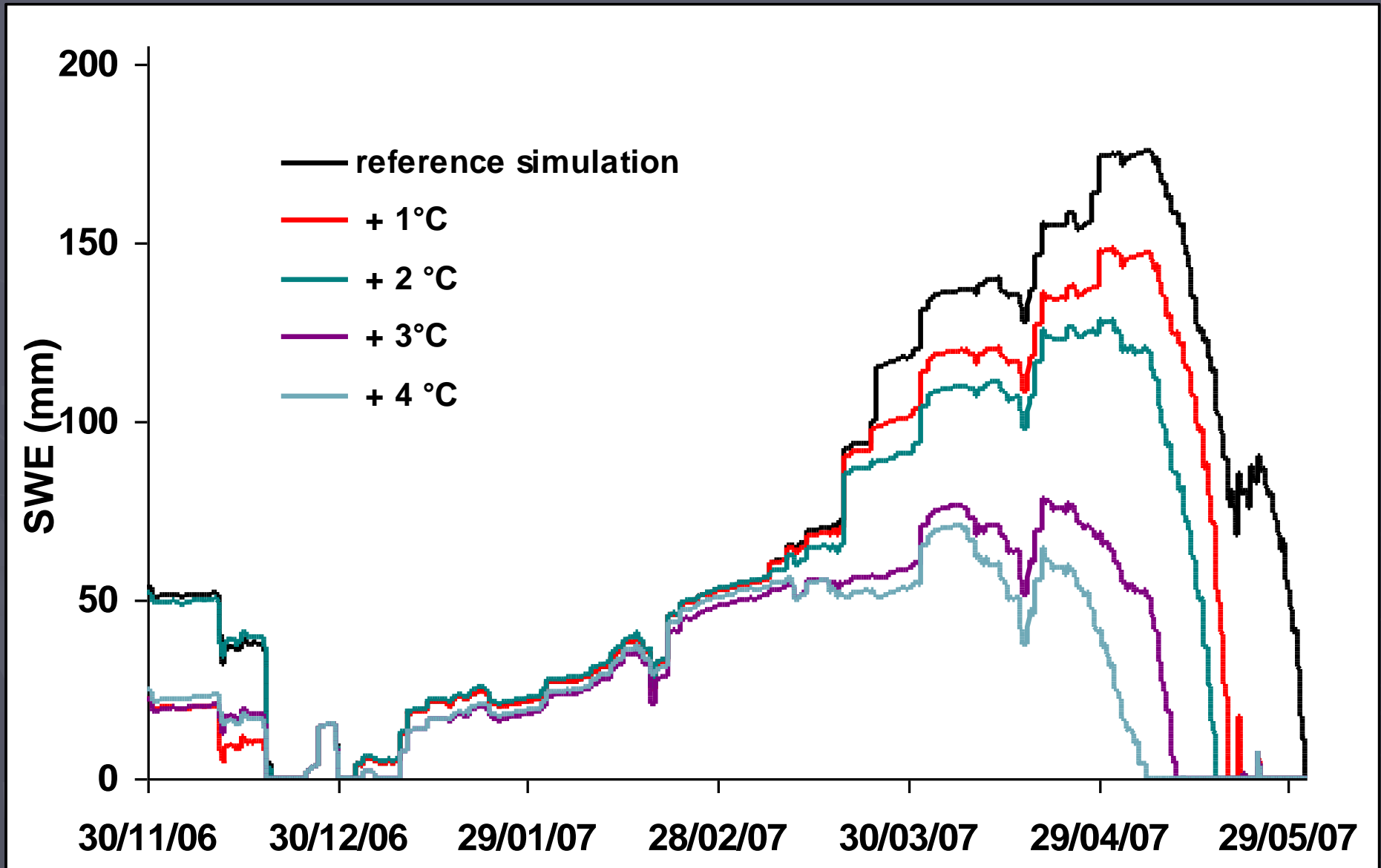


Alpine Hydrological Model

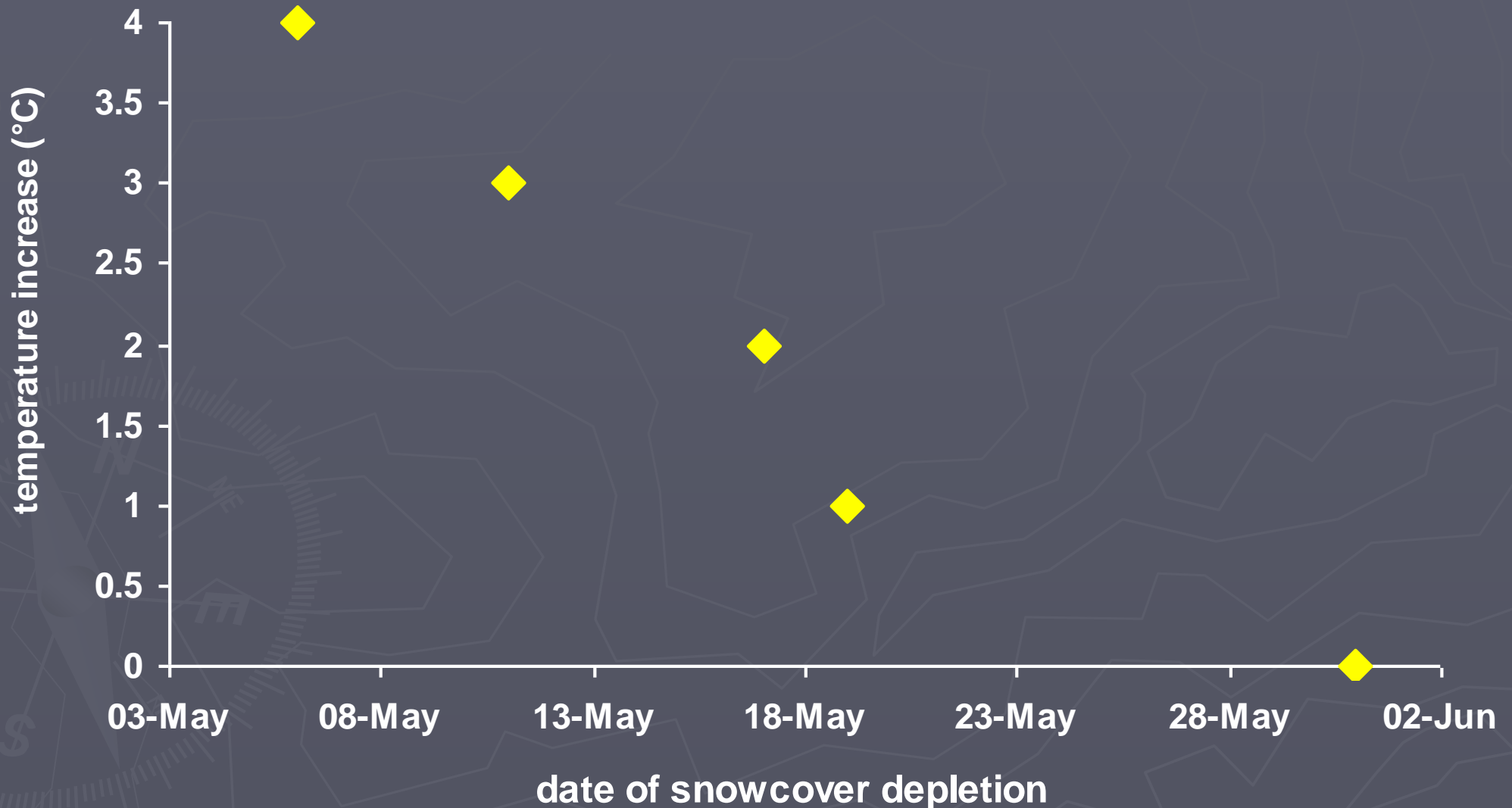
derived from Cold Regions Hydrological Model

- ▶ Model components
 - Snow wind redistribution, interception and melt
 - Actual evapotranspiration,
 - frozen soil infiltration,
 - unfrozen infiltration,
 - soil moisture balance,
 - routing
- ▶ Ability to perturb the model via temperature changes
 - Affects precipitation phase
 - Affects hydrological processes

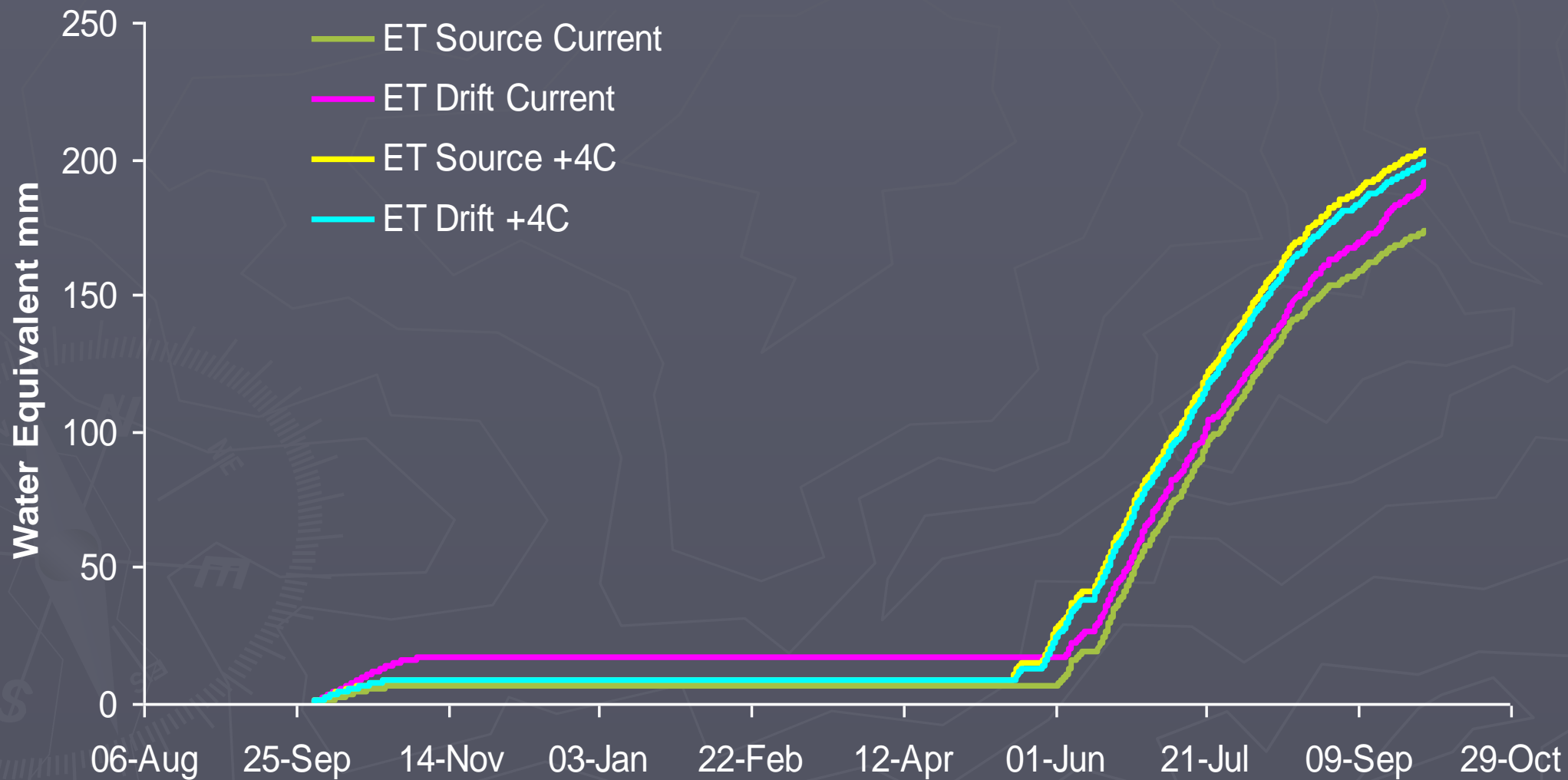
Winter Warming Impact on Alpine Ridge Snow Accumulation



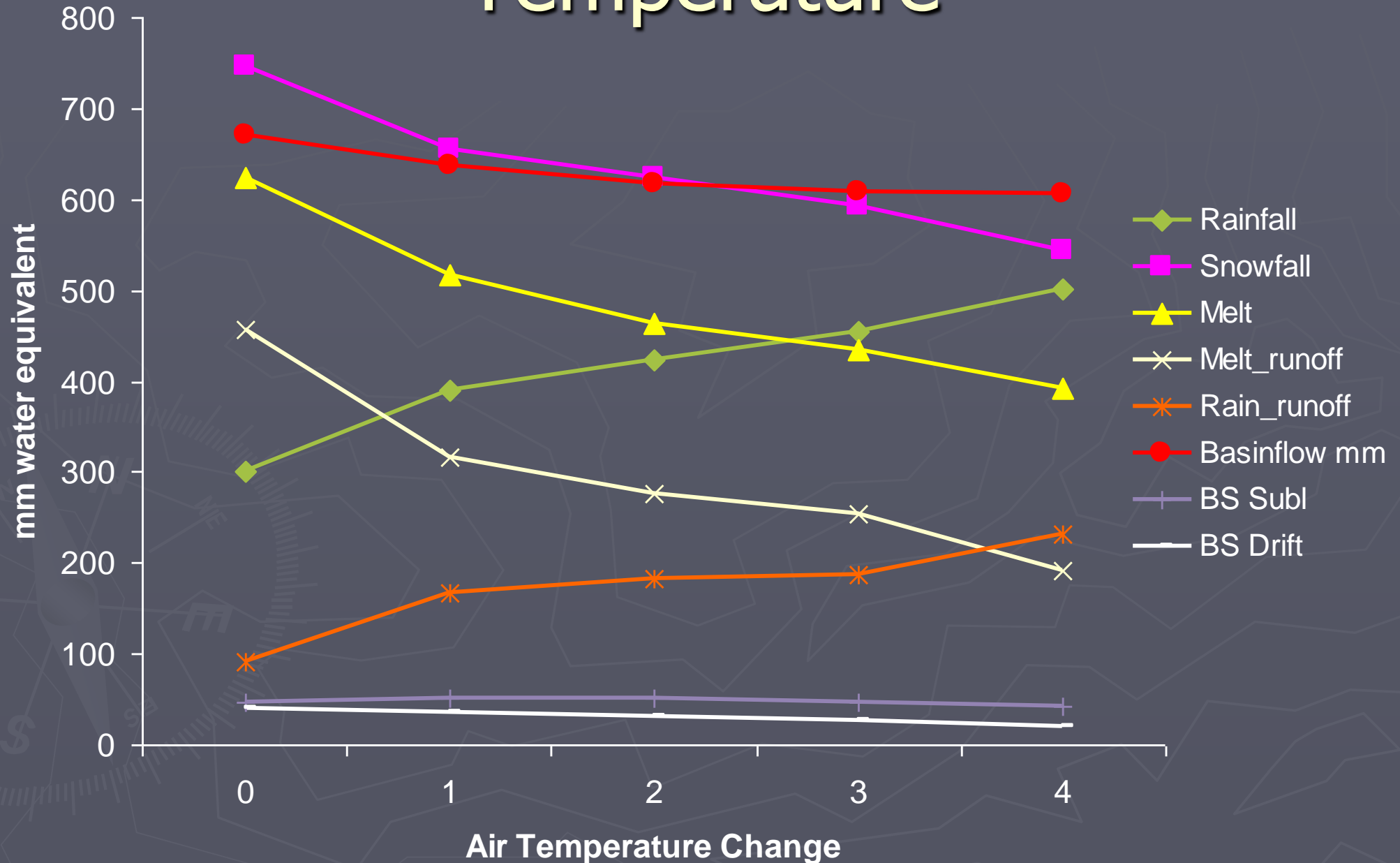
Impact of Winter Warming on Date of Snowpack Depletion



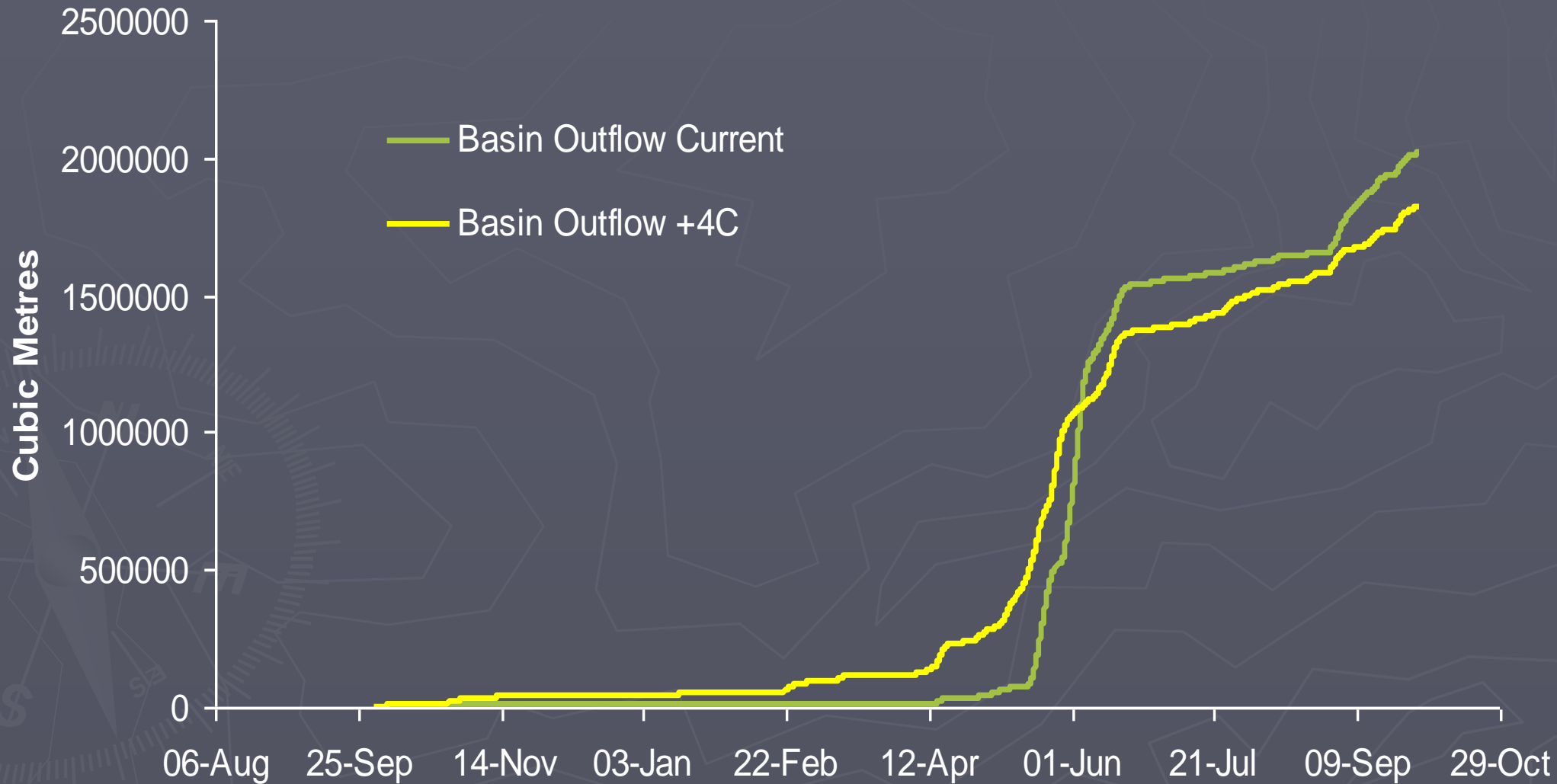
Change in Actual Evapotranspiration



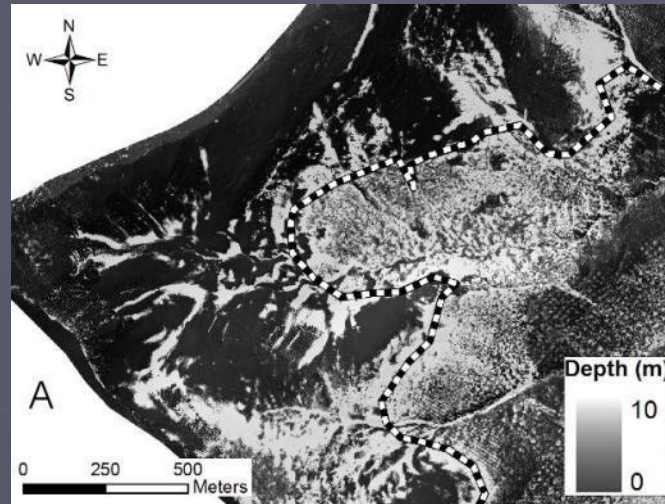
Hydrology Change with Temperature



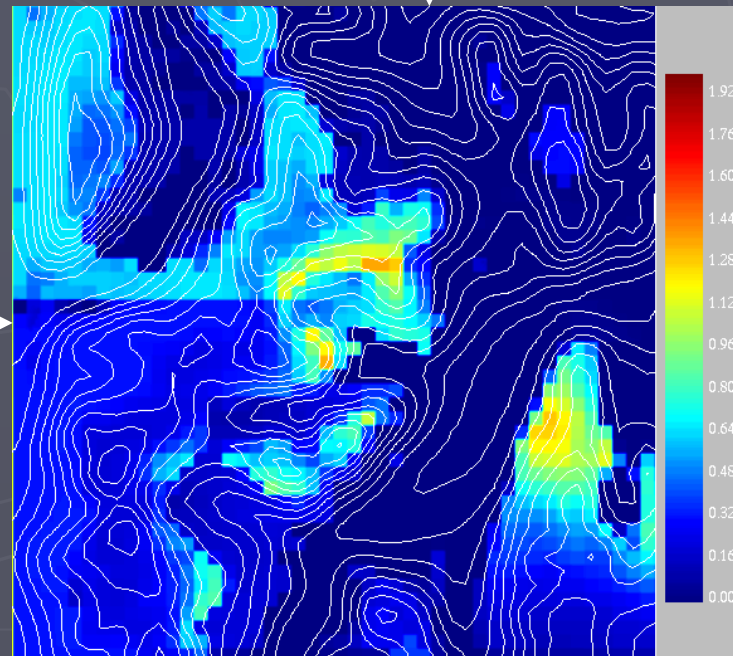
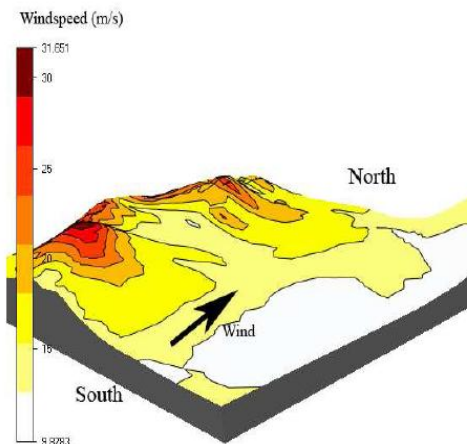
Change in Alpine Basin Discharge



Next Steps: Integrated Observing & Predicting Systems



Current high altitude observation network in Canada is inadequate, need a network of stations, remote sensing, modelling, data assimilation in order to predict our cold regions water resources adequately.



Canadian Rockies Hydrological Observatory

Initially the Upper Bow River Basin.

- 10 high altitude hydrometeorological stations – research basins
- 5 high altitude stream gauge stations – research basins
- Portable detailed measurement system
- Data management, information assimilation and water modelling system
- Glacier hydrology, treeline ecology, climate modelling, snow physics

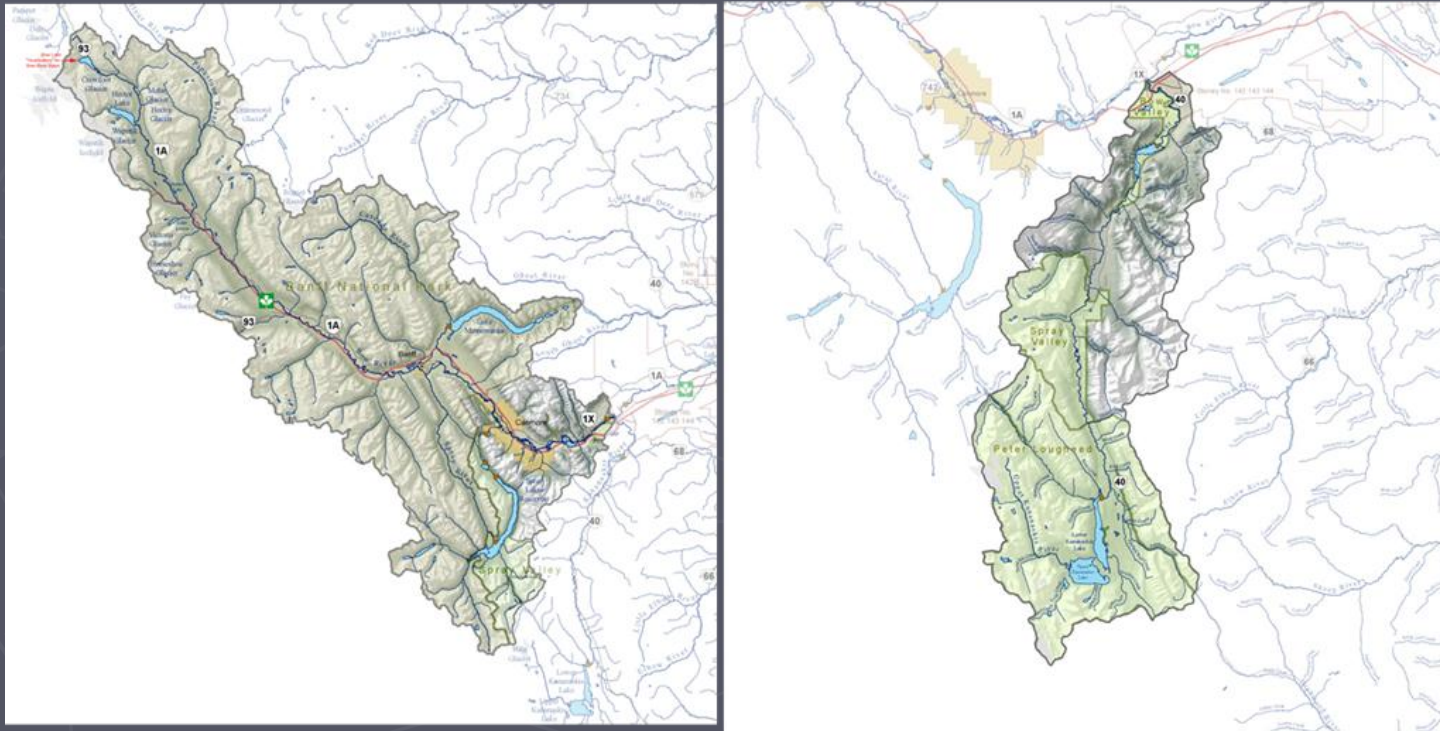


Figure 1 Upper Bow River Basin – showing segments above Kananaskis and the Kananaskis River.

Primitive Snow Observations



Sami in Lapland

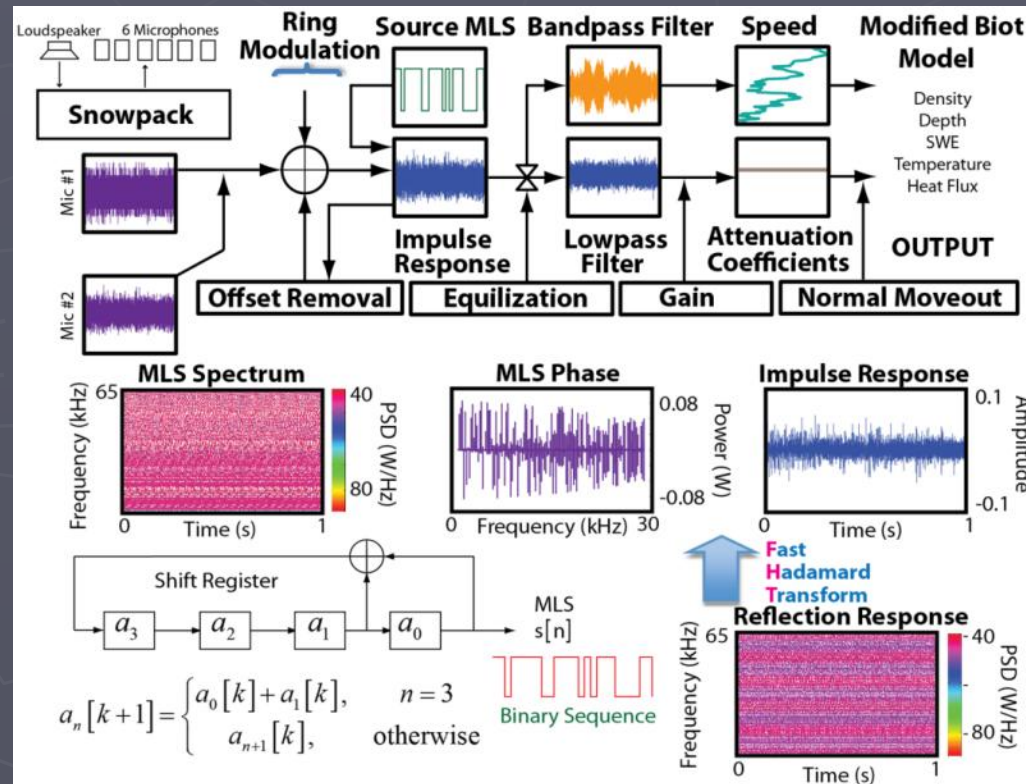
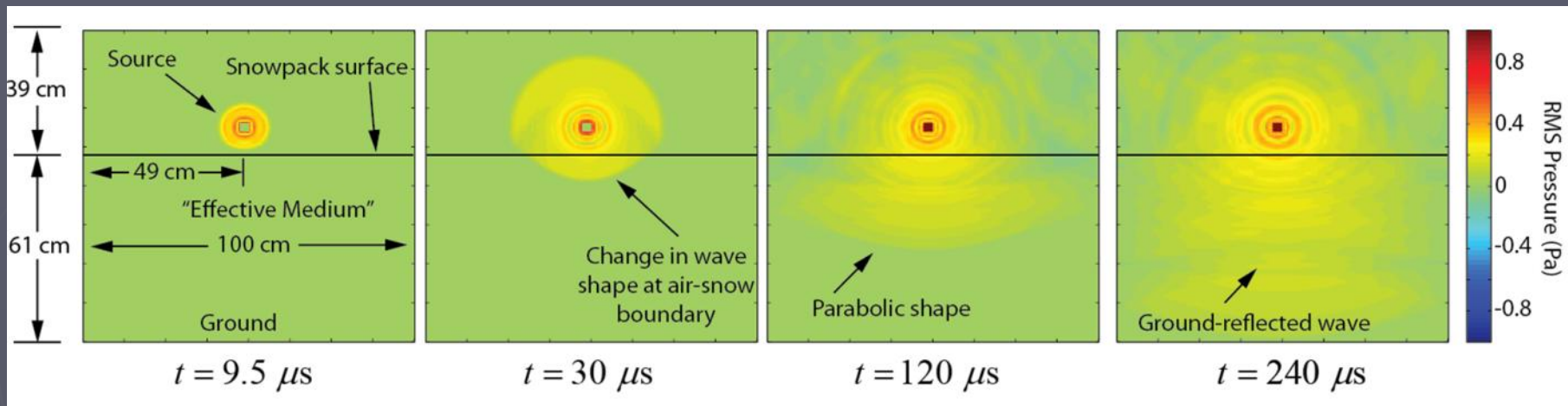


Pomeroy & Guan in Alberta



Scottish Snow Surveyor

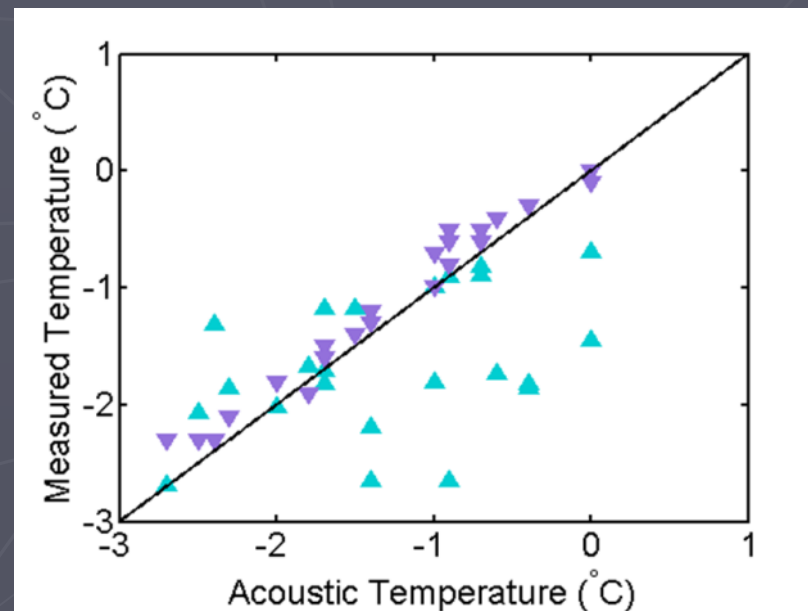
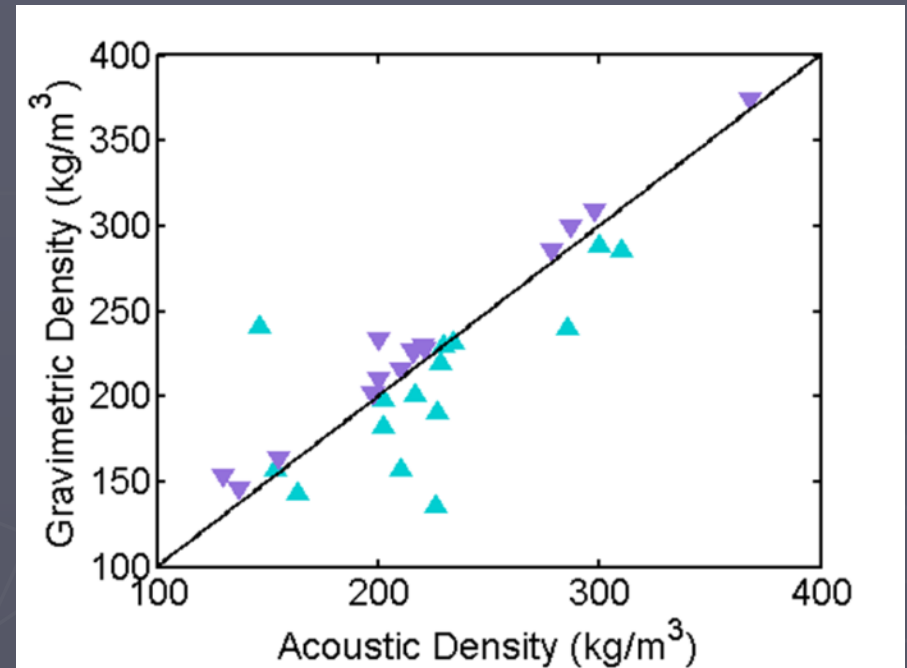
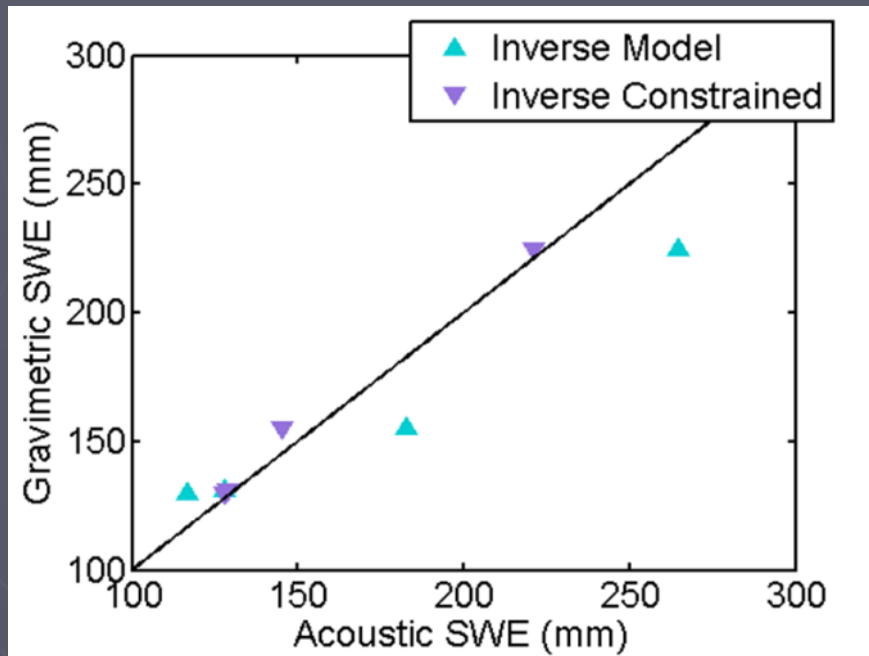
Acoustic Snow Measurement



Acoustic Gauge Testing



Acoustic Results and Testing



Improved Snow Measurements



INARCH

INARCH: International Network for Alpine Research Catchment Hydrology

Canada – Marmot Creek, Peyto Glacier Alberta and Wolf Creek,
Yukon;

Germany – Zugspitze; Switzerland – Dischma;

Spain – Izas, Pyrenees; USA – Reynolds Creek, Idaho.

Chile - Andes, China – Tibet



Conclusions

- ▶ Relationships between snow and vegetation are strongly influenced by atmospheric energy and mass inputs which in turn are controlled by weather and topography
 - If windblown: less forest => less snow
 - No wind transport: less forest => more snow
 - South facing, level: less forest => faster snowmelt
 - North facing: less forest => slower snowmelt
- ▶ Modelled impacts of forest cover reduction in Marmot Creek resulted in small to moderate increases in streamflow despite much greater increases in snow accumulation.
 - Pine beetle infestation had a small effect on snowmelt quantities and insignificant effect on streamflow due to the small and relatively dry area of the basin covered with lodgepole pine.
 - Fire and logging were much more effective than pine beetle in changing the hydrology due to the higher elevations and larger area affected.
- ▶ Further warming and loss of snow and ice are likely to further reduce streamflow and exacerbate high variability in water supply
- ▶ Warming will increase importance of rainfall-runoff mechanisms and require new water management approaches in downstream populated regions.
- ▶ Improvement and expansion of observations and modelling outside of Marmot Creek is essential.