Snow Dynamics and Model Parameterisation in Alpine, Arctic, and Forested Basins

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and collaborators
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and Centre for Hydrology Researchers
Tom Brown, Chris DeBeer, Pablo Dornes, Chad Ellis, Warren Helgason, Edgar Herrera, Nicholas Kinar, Jimmy MacDonald, Matt MacDonald, Chris Marsh, Michael Solohub

Study Elements

- Processes
  - Snow accumulation, structure and observation
  - Radiation effects on snowmelt under vegetation
  - Turbulent transfer to snow
- Parameterisations
  - Blowing snow over complex terrain
  - Sub-canopy snowmelt
  - SCA Depletion,
- Prediction
  - Wind modelling over complex terrain
  - Level of spatial complexity necessary in models
  - Regionalisation of CLASS parameters
  - Snow modelling contribution to MESH

Also see talks by Essery, Brown, Herrera, Pietroniro, Link

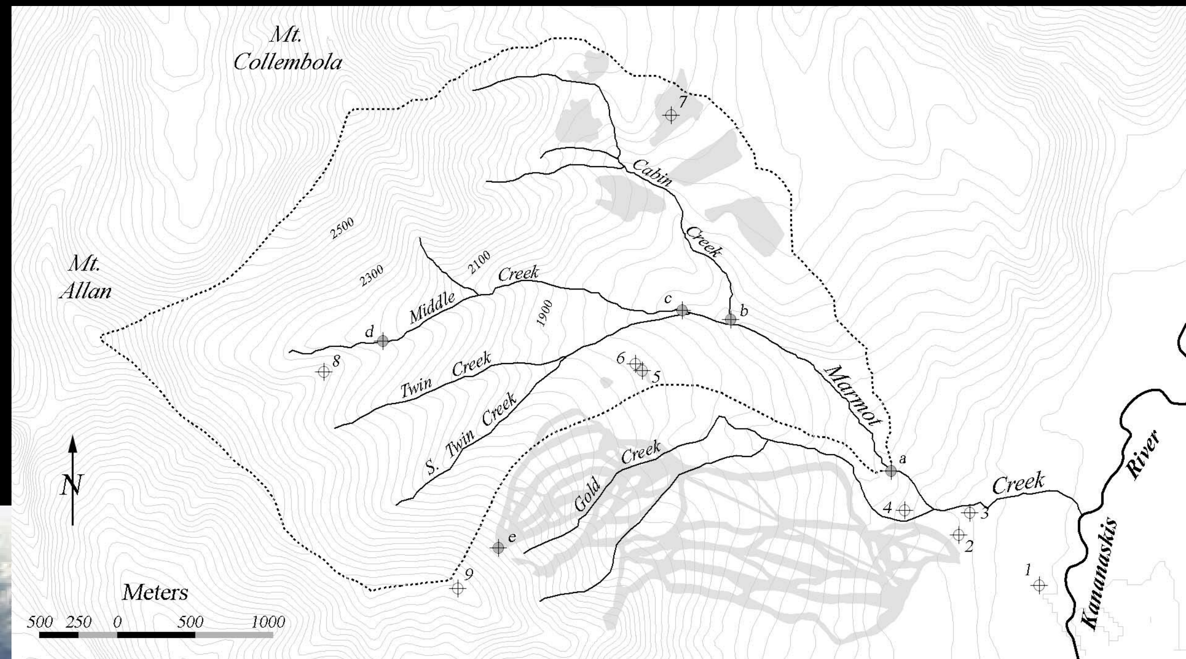
Marmot Creek

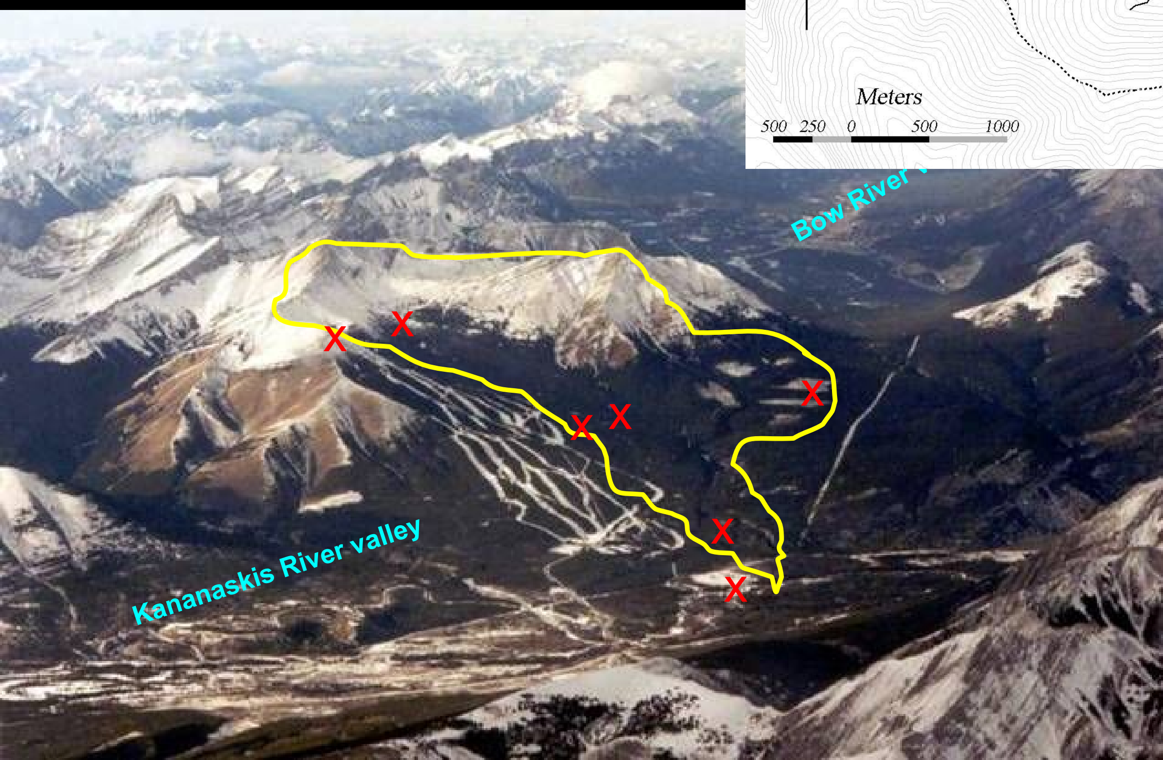
Wolf Creek

Marmot Creek, Alberta
-montane, subalpine forest
-alpine tundra
-steep alpine topography
-eastern slopes climate
-10 meteorological stations
-WSC streamflow gauge
-3 U of S streamflow gauges

Wolf Creek, Yukon
-boreal forest
-shrub and sparse tundra
-sub-arctic to arctic climate
-4 meteorological stations
-Snow pillow
-4 Yukon Environment streamflow gauges

Marmot Creek Research Basin

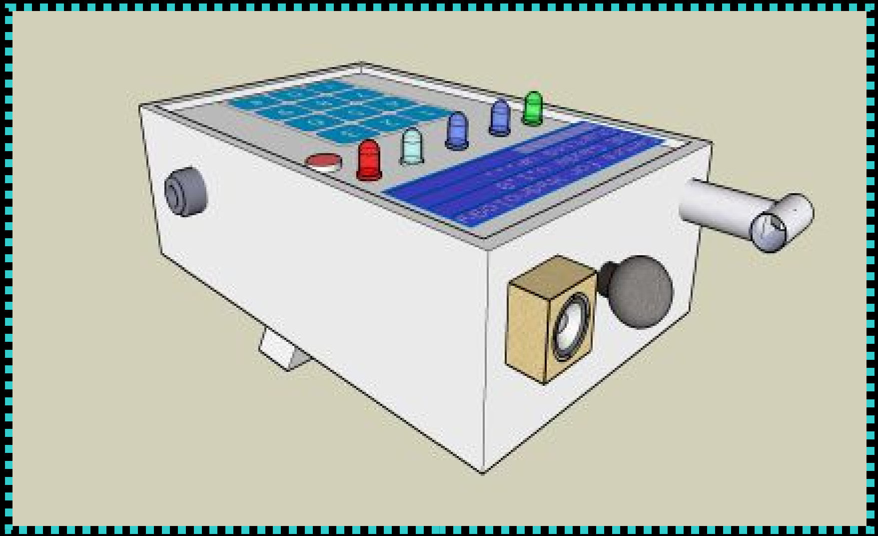




Snow Observations

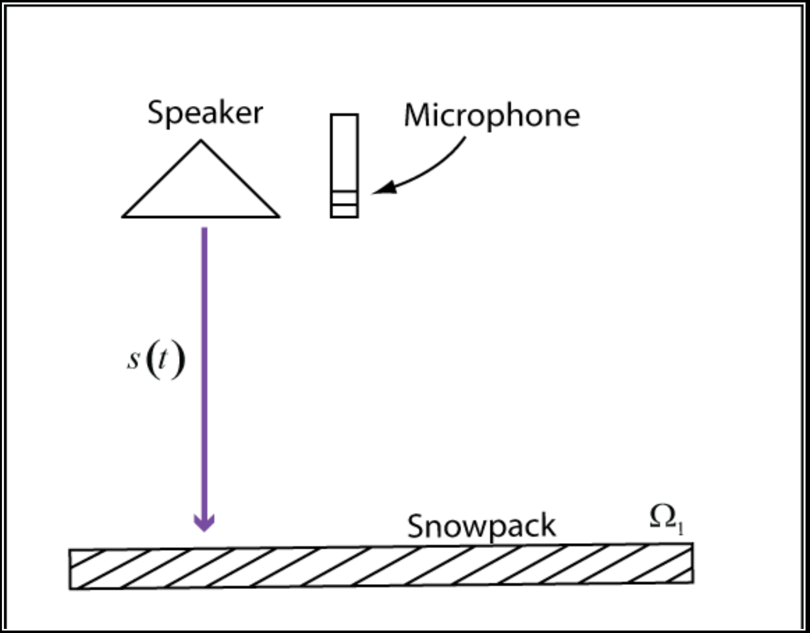
- Acoustic observation of SWE and Density
- LiDAR Determination of Mountain Snow Depth

Innovative Snow Measurements: Acoustics

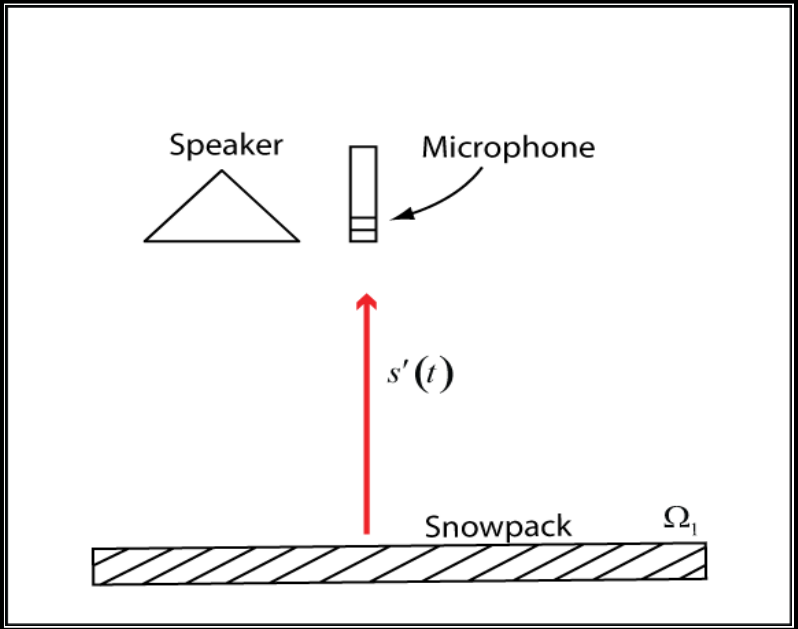


- Surface observations of Snow Water Equivalent (SWE) generally involve invasive devices that modify the snowpack
- Snow surveying is time-consuming, expensive, and prone to human error
- The equipment used has not evolved significantly for almost one century
- A sound wave can be used to determine depth and density of snow

Method



Speaker
Microphone
$s(t)$
Snowpack
Ω_1



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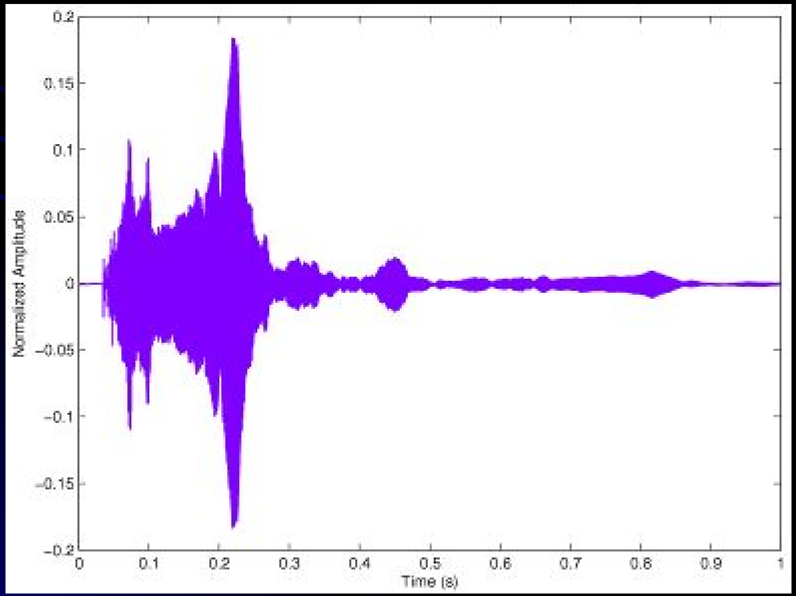
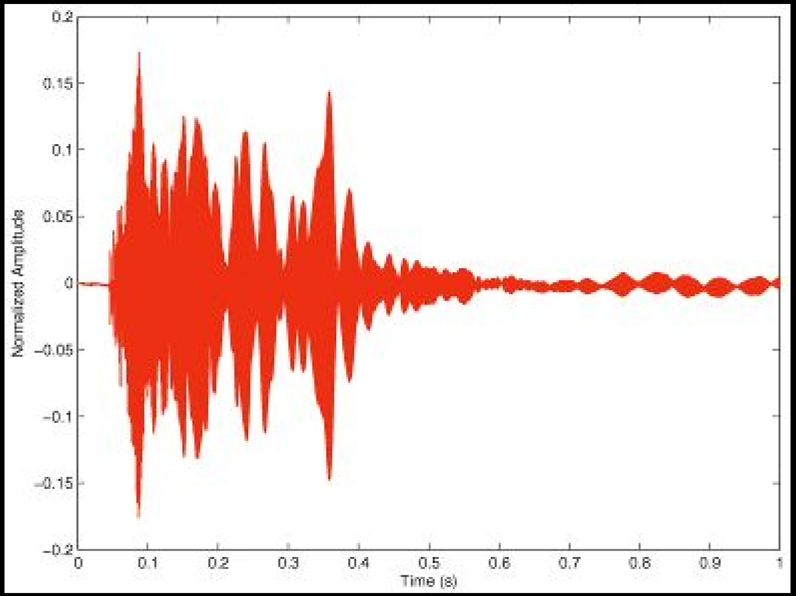


Normalized Amplitude
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)



Normalized Amplitude
0.2
0.15
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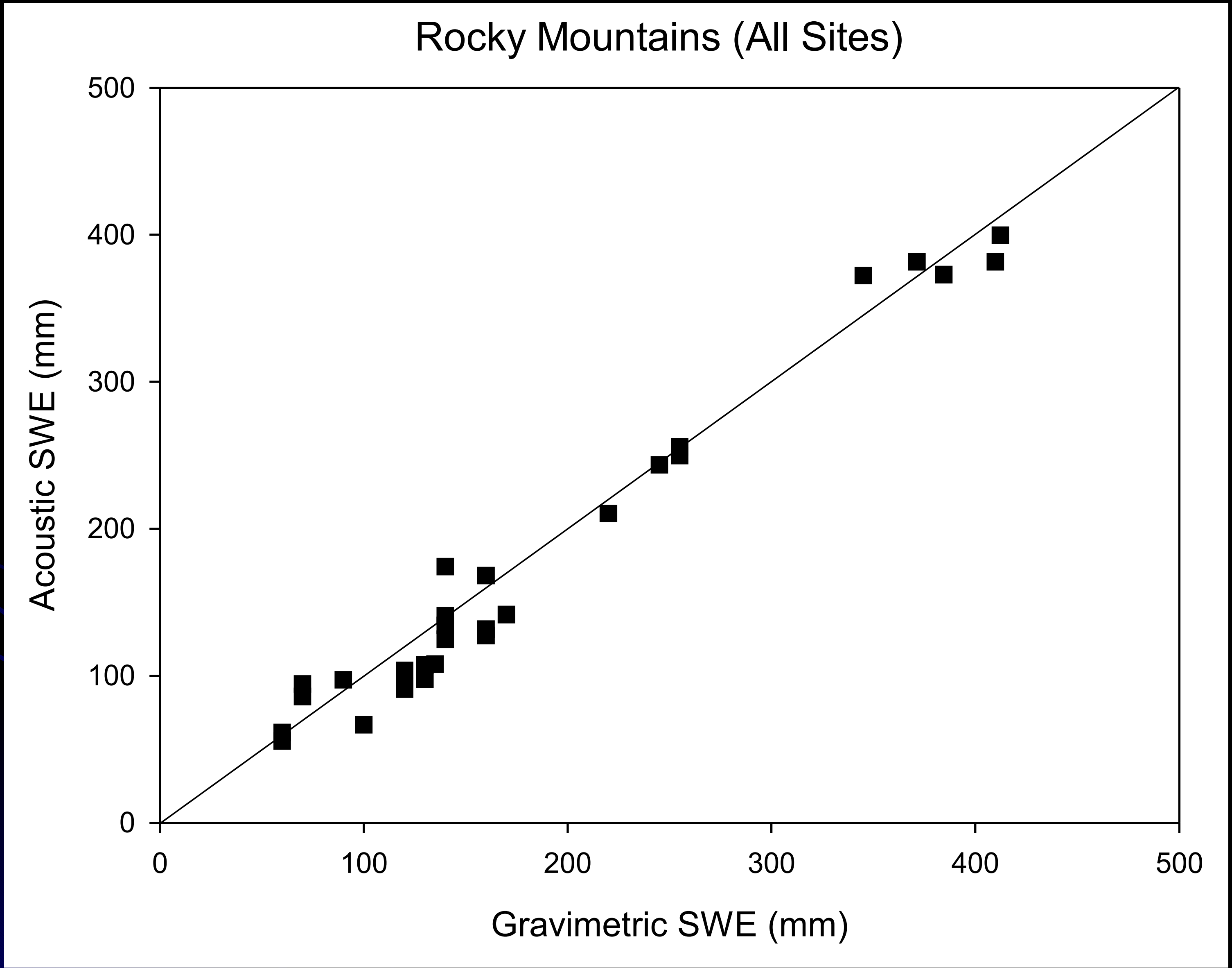
−0.05
−0.1
−0.15
−0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)

Acoustic Snow Sounder

Tests of Acoustic Sounder - 2008

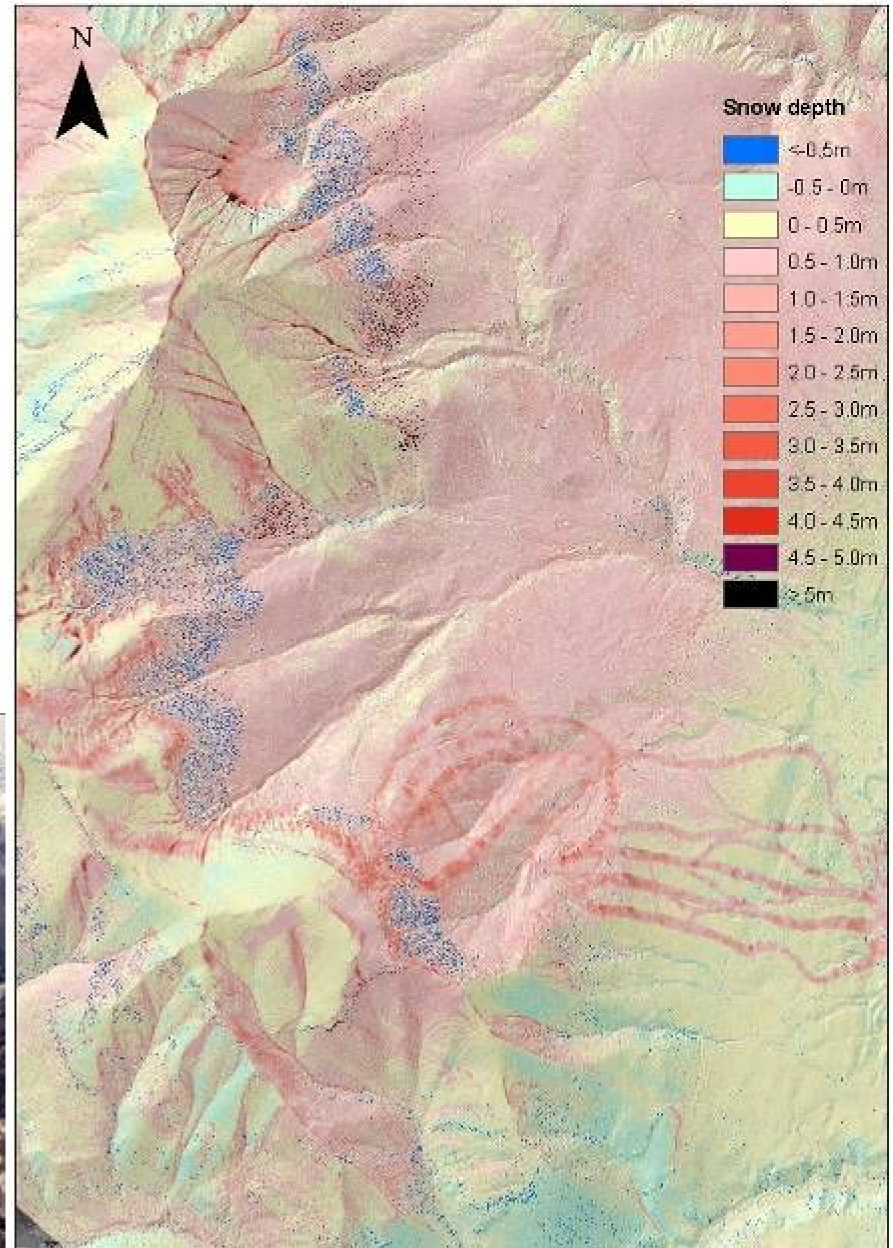


LiDAR Snow Depth

LiDAR flights in
Aug 2007, March 2008

Differencing of images after correction

Field surveys being used to evaluate



Blowing Snow Redistribution

Blowing Snow in Mountains

Inter-basin water transfer

Transport of snow to deep drifts

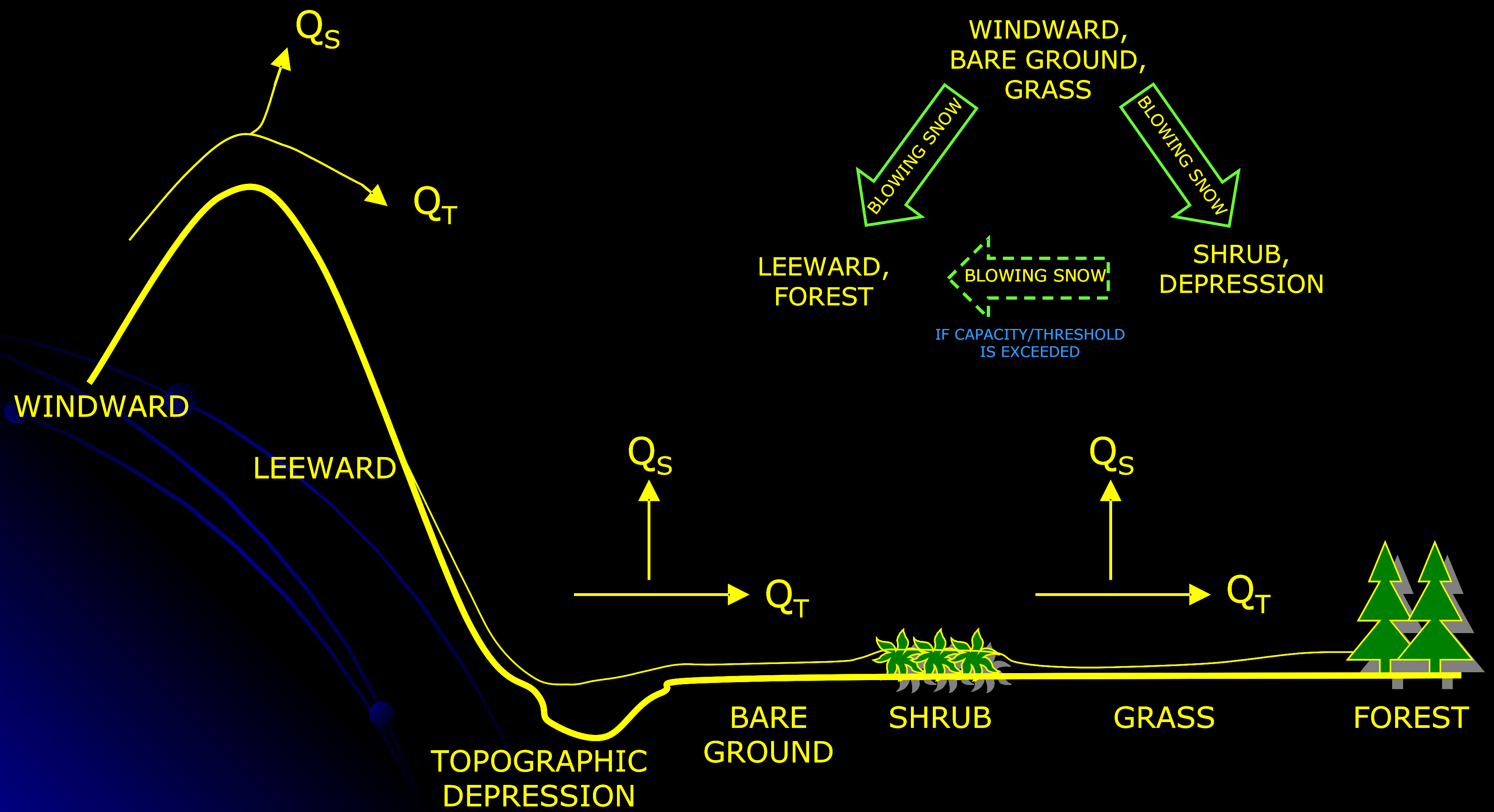
Supports glaciers, late lying snowfields, contributing areas

Water supply to sub-alpine forests

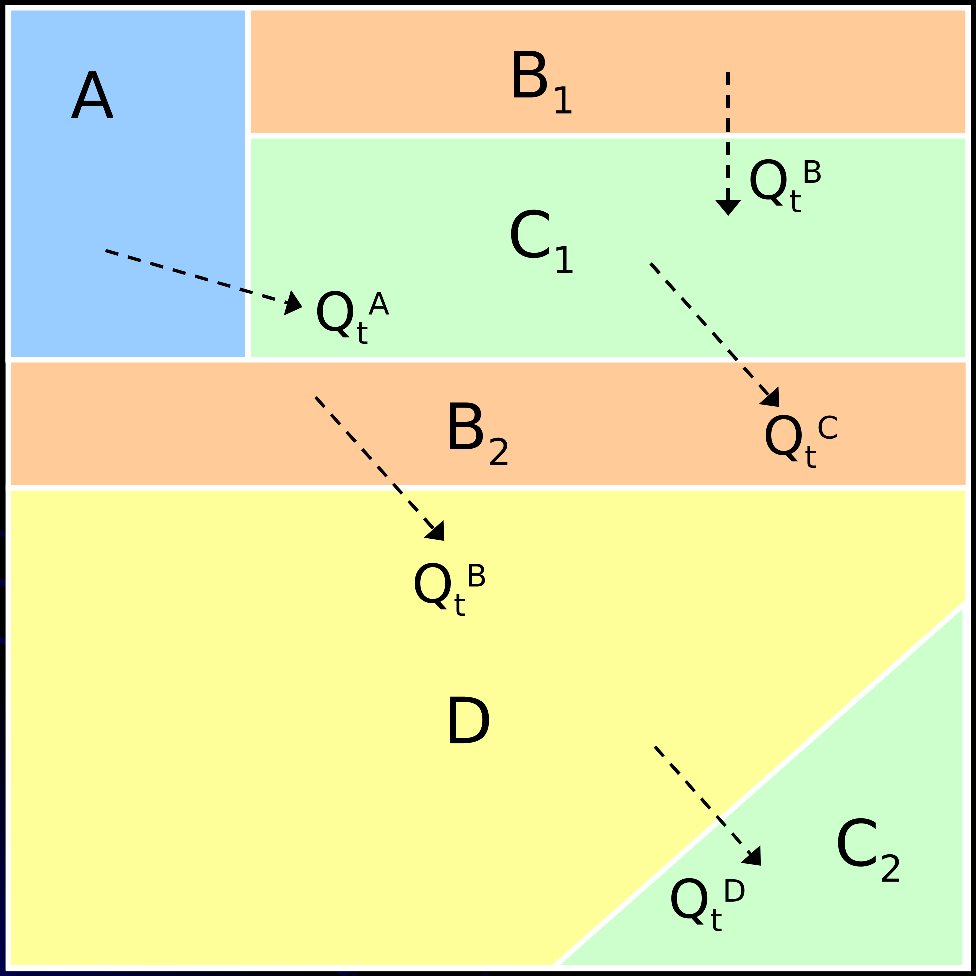
Melt controls summer streamflow

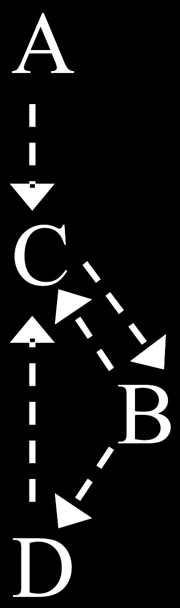
Snow Redistribution in Mountains

Inter-landscape unit and inter-grid square snow redistribution – blowing snow model



Parameterised Snow Redistribution amongst Landscape Units



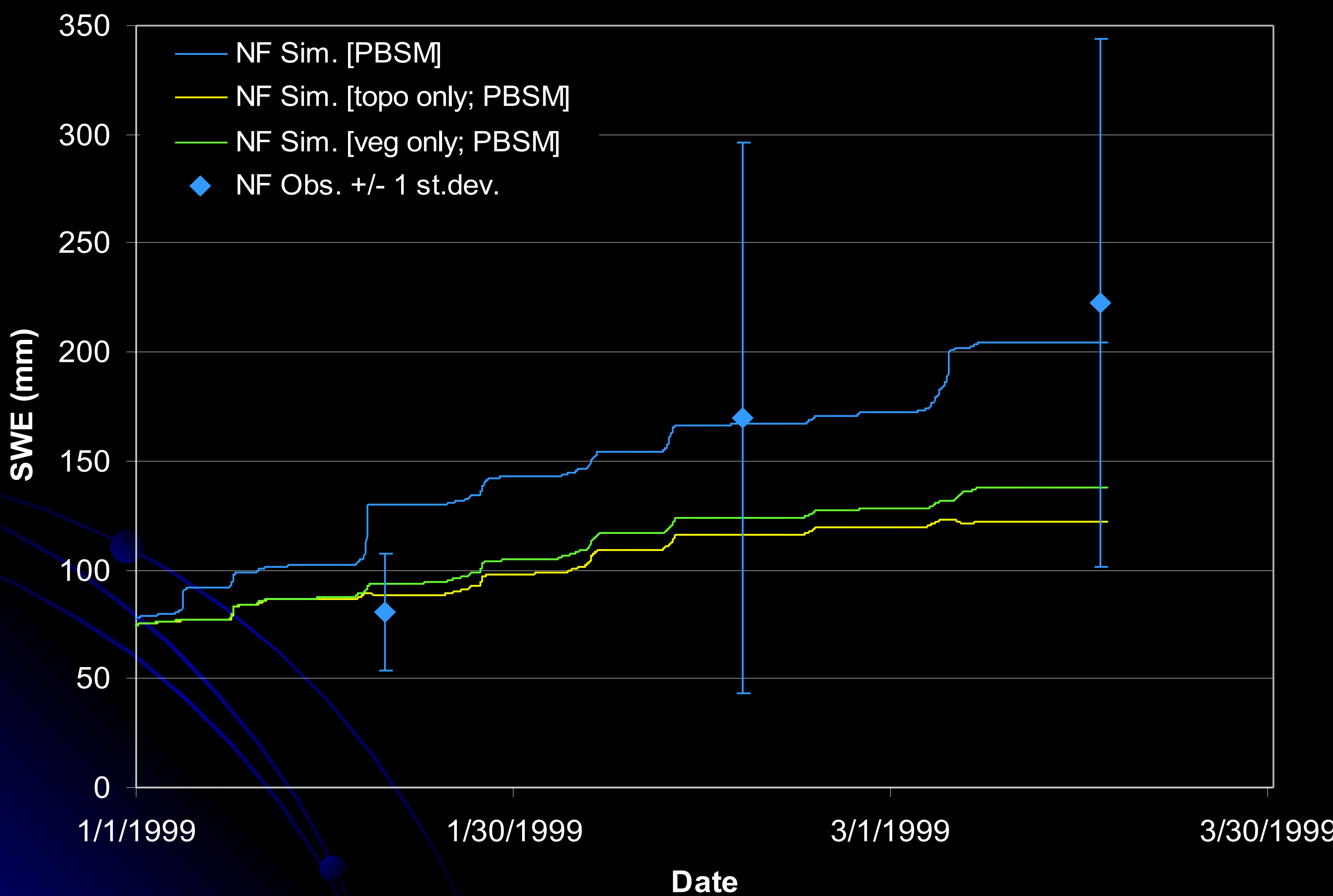


- Prairie Blowing Snow Model
- initial tests driven by distributed observations
- Testing parameterization of wind flow model

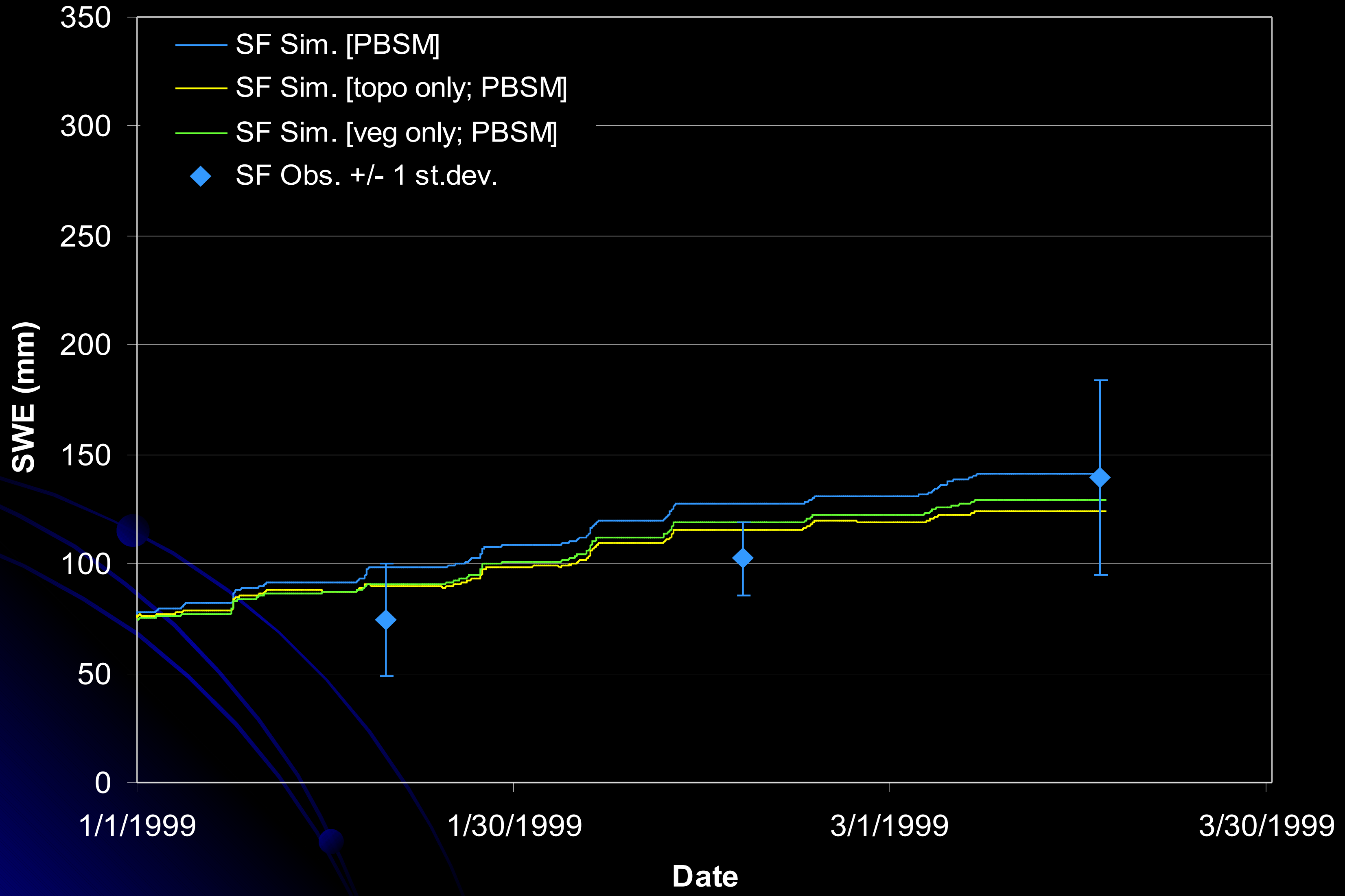
Granger Basin, Wolf Creek

LiDAR used to develop topography and vegetation DEM

Results – Wolf Creek, South Face

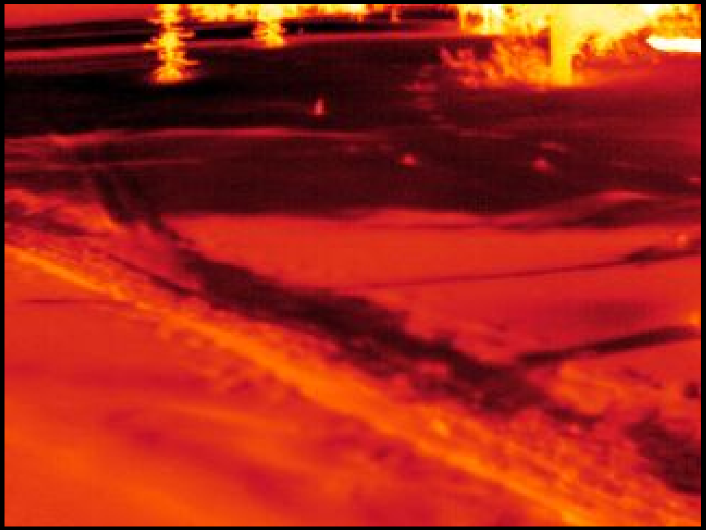


Results – Wolf Creek, North Face



Snowmelt

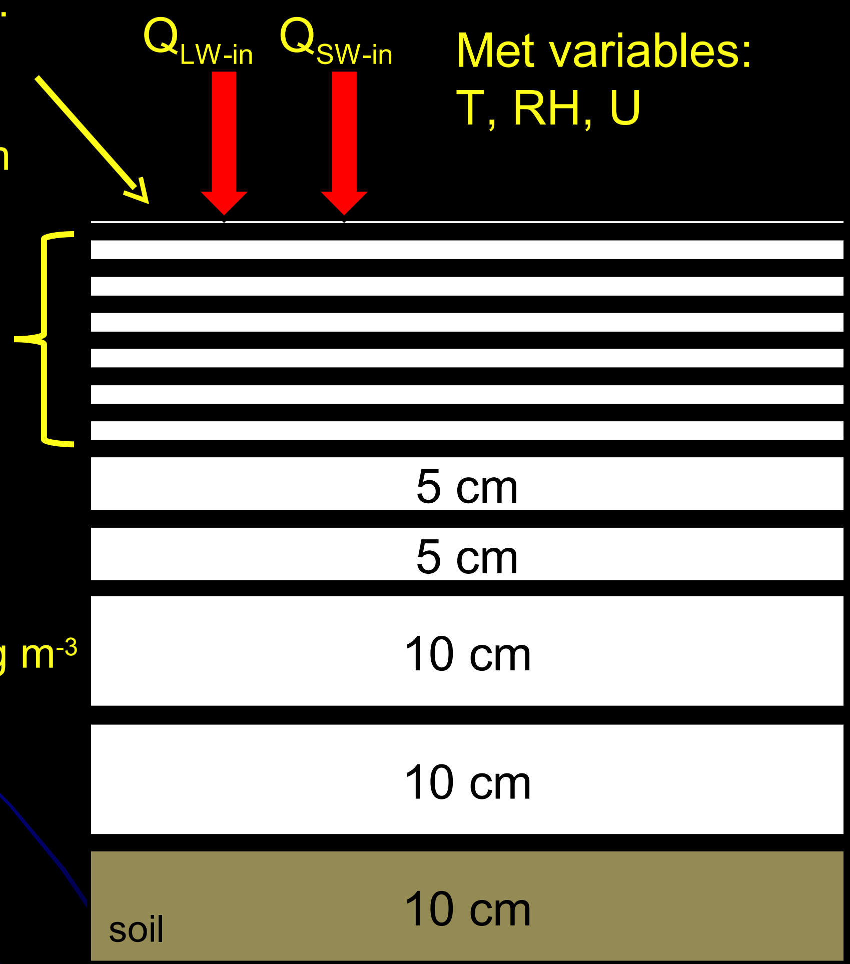
- Incoming solar and thermal radiation
- Warm air masses
- Energy storage
- Terrain and vegetation effects



Snow Energetics Analysis

Surface properties:
- 5 mm layer
- albedo = 0.92
- $z_{0m} = 1.0 \times 10^{-3}$ m

Met variables:
T, RH, U



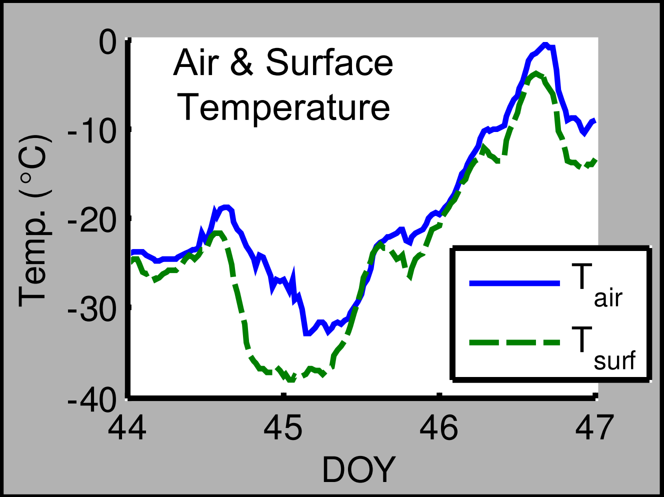
Snow layer properties:
- density: 250 – 400 kg m^{-3}
- initial temp.

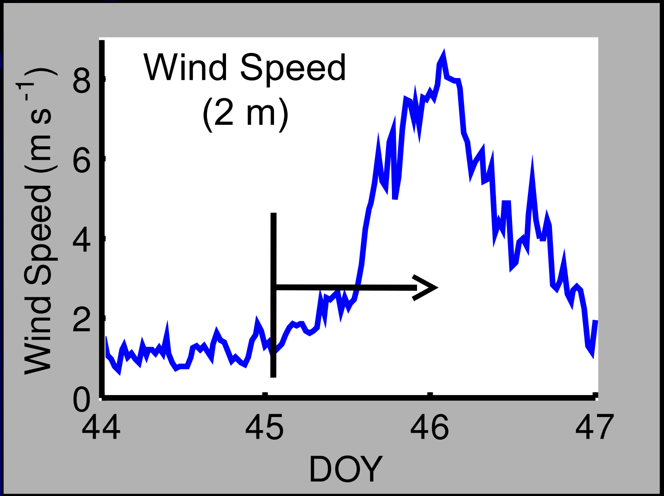
Model Output:
- Q_H
- Q_E
- Q_G
- $T_{surface}$
- T_{layer}
- dU/dt

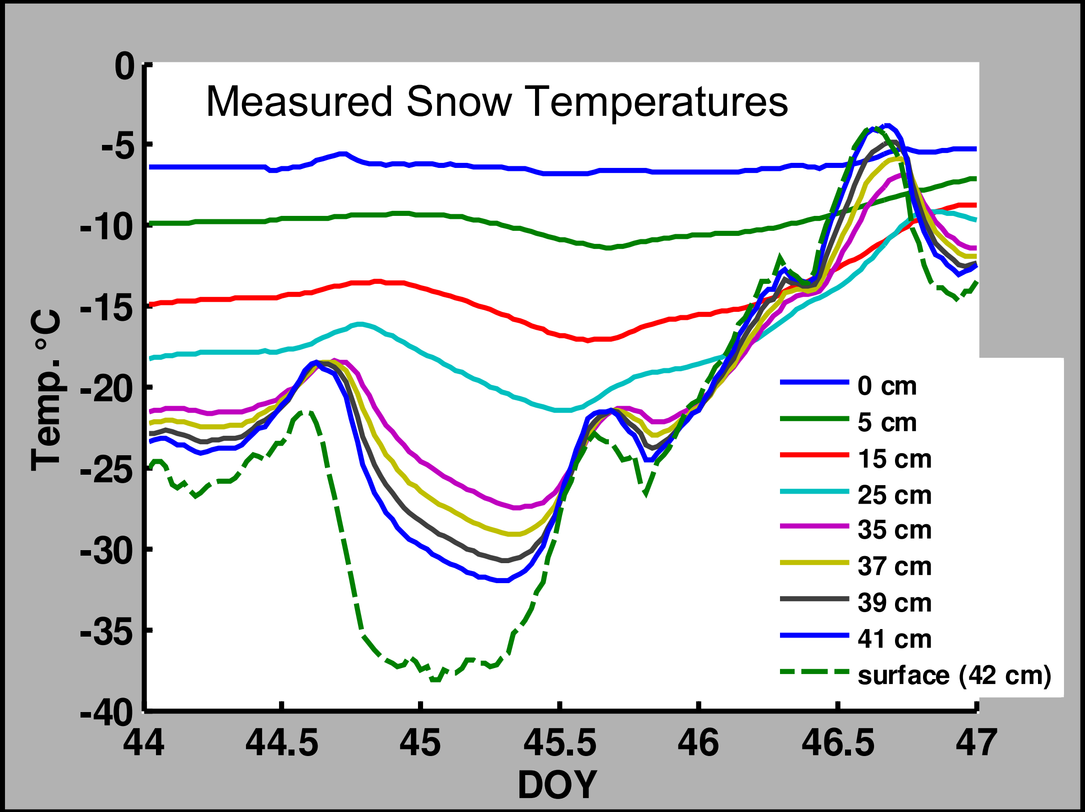
Modelled for Cold Level Site with 2 Eddy Flux Systems and Temp. & Radiation Obs.

First complete energy balance measurement for snow

Sample event - Feb 13-15, 2007

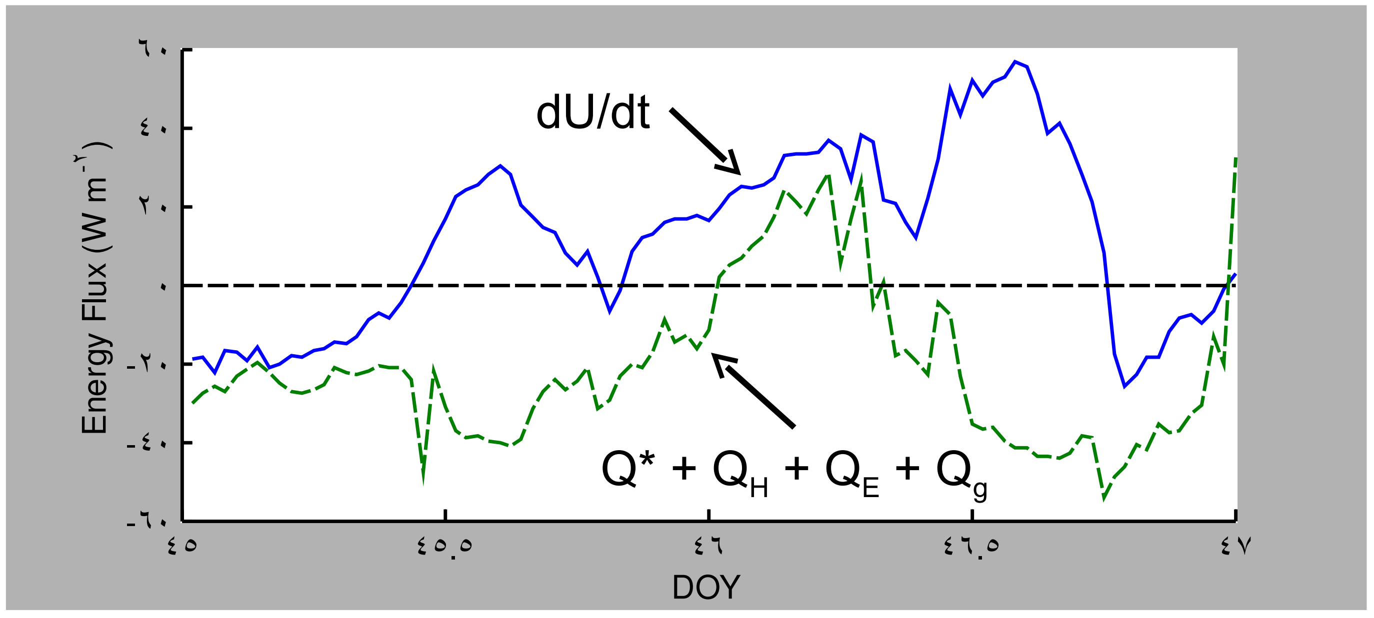


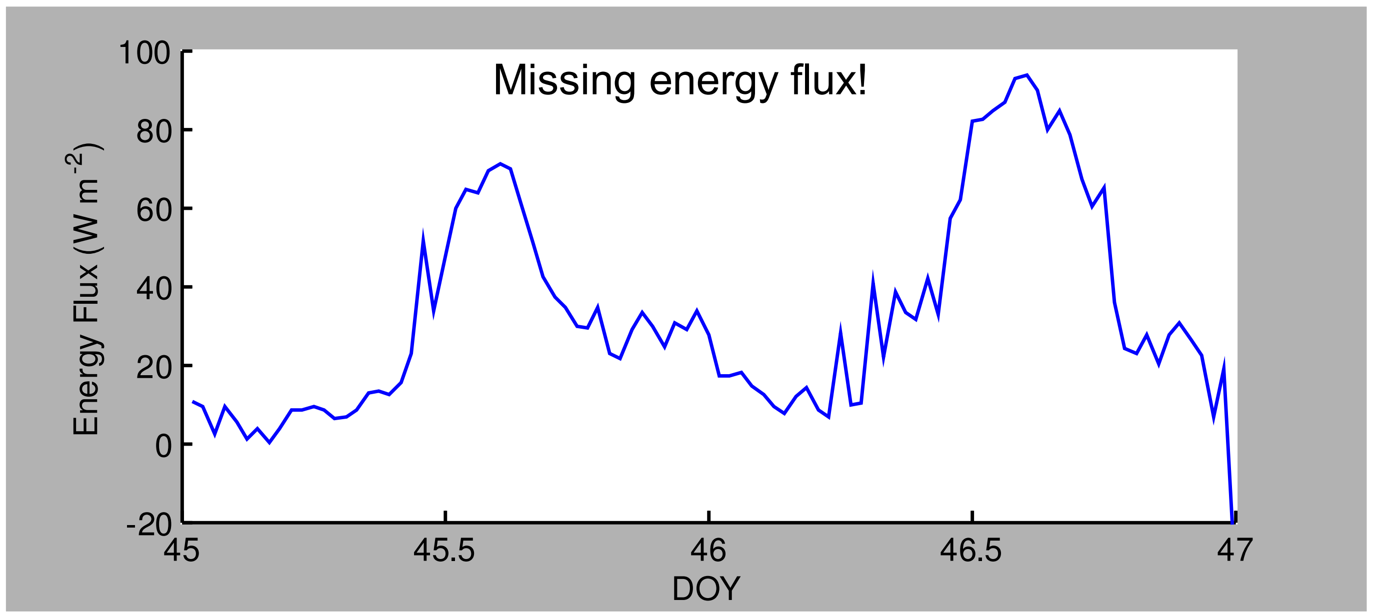




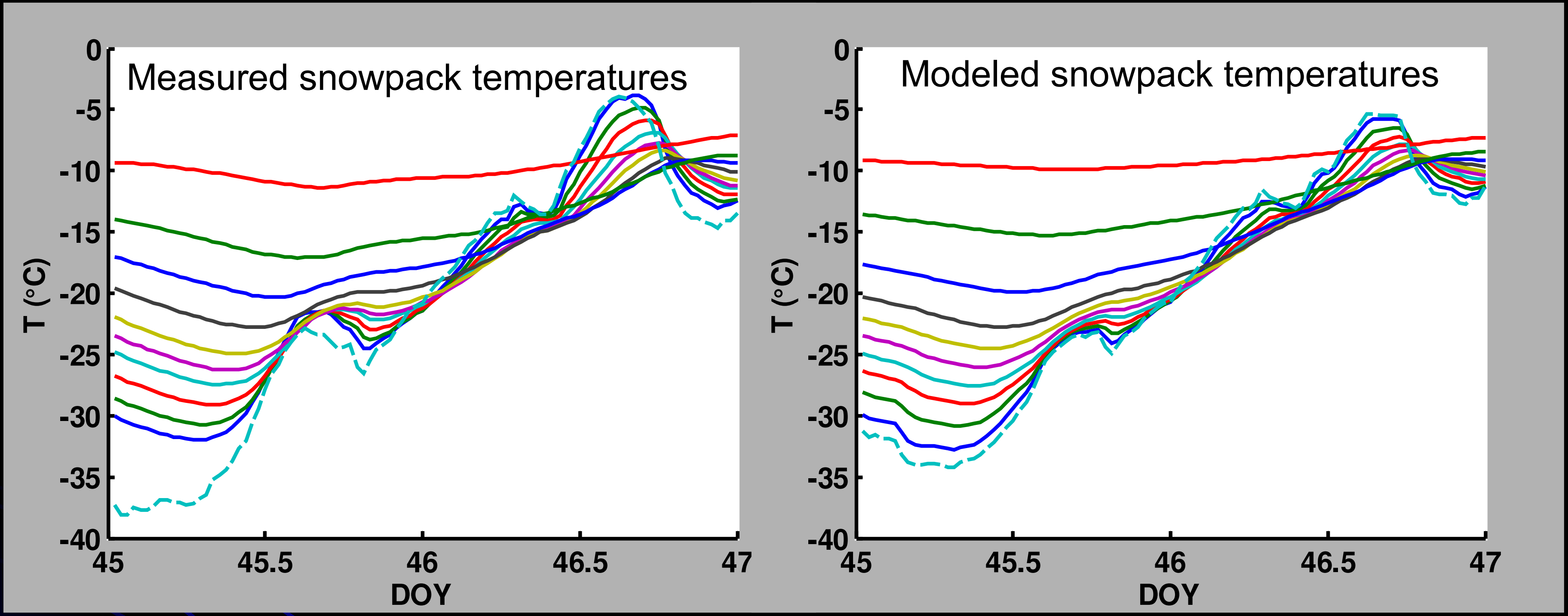
Will discuss well developed turbulence conditions only

Energy Balance Closure (or lack thereof)





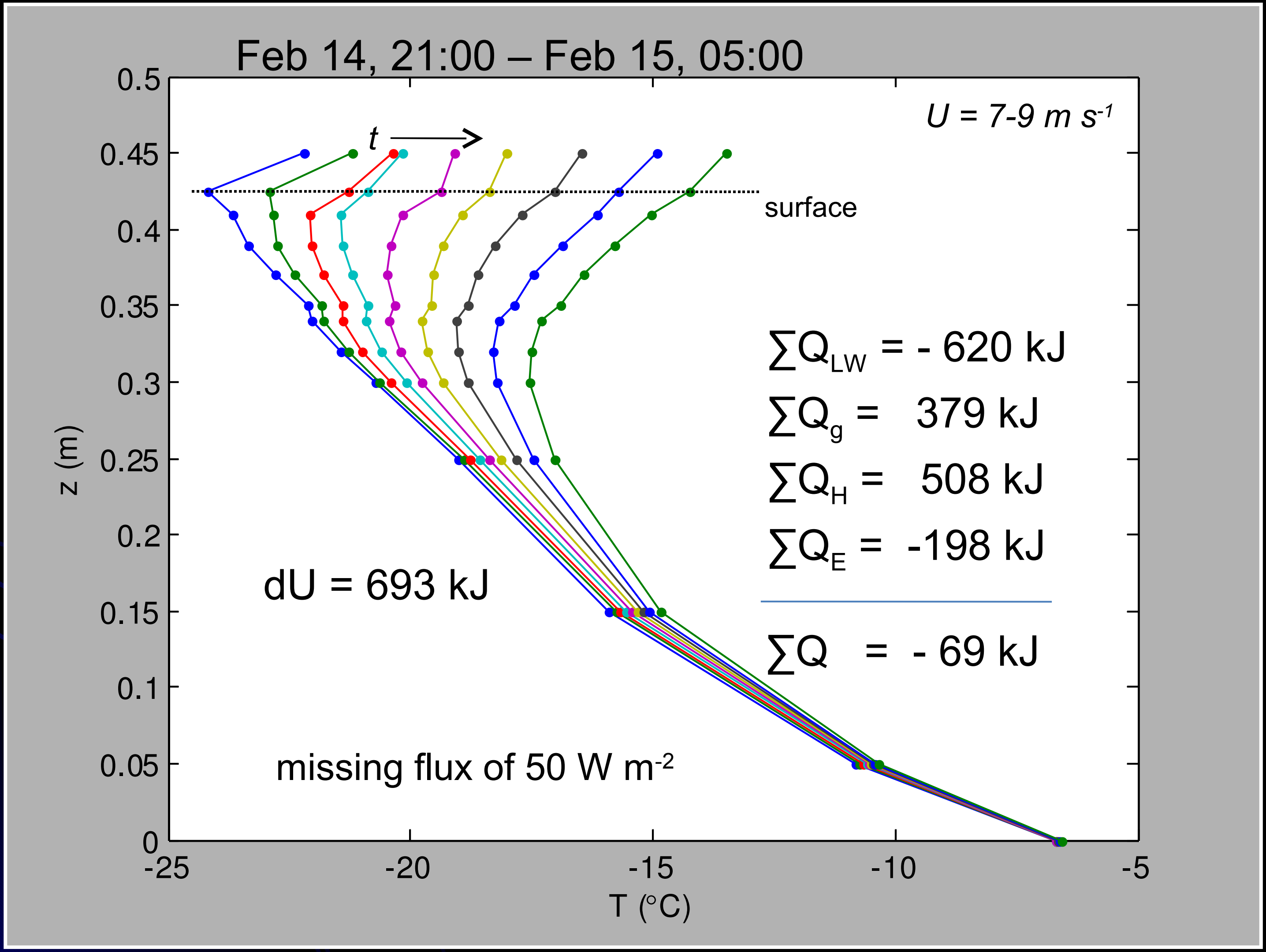
Prediction of snowpack temperature with fictitious parameters



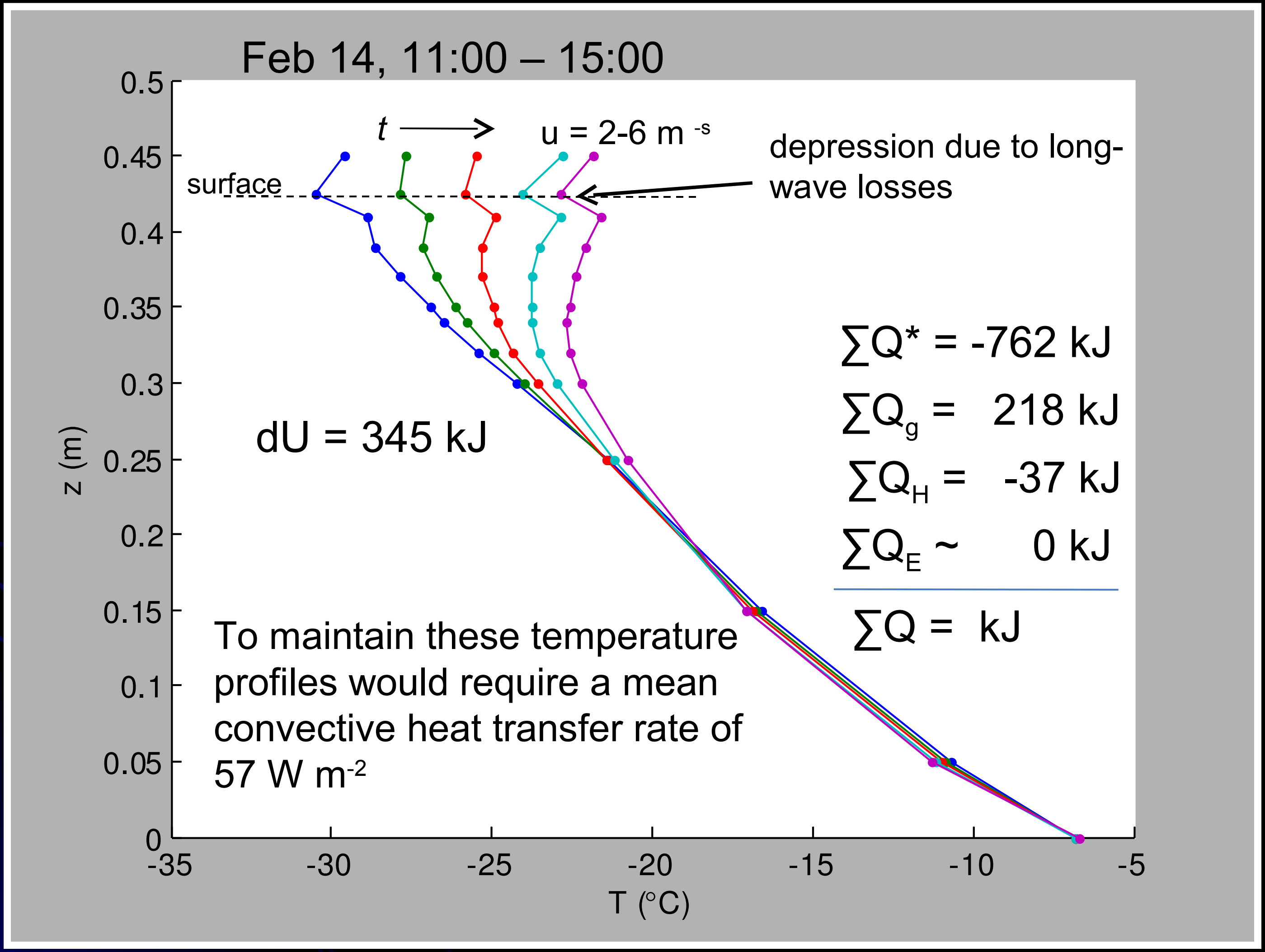
SNTHERM can accurately predict internal energy changes over the 3-day period if given fictitious surface roughness parameterisations (z_o orders of magnitude too large)

- Predicted sensible heat fluxes are much larger than measured (200% larger!)
- Predicted radiation peak losses are less than measured (lower surface temperature during these periods)

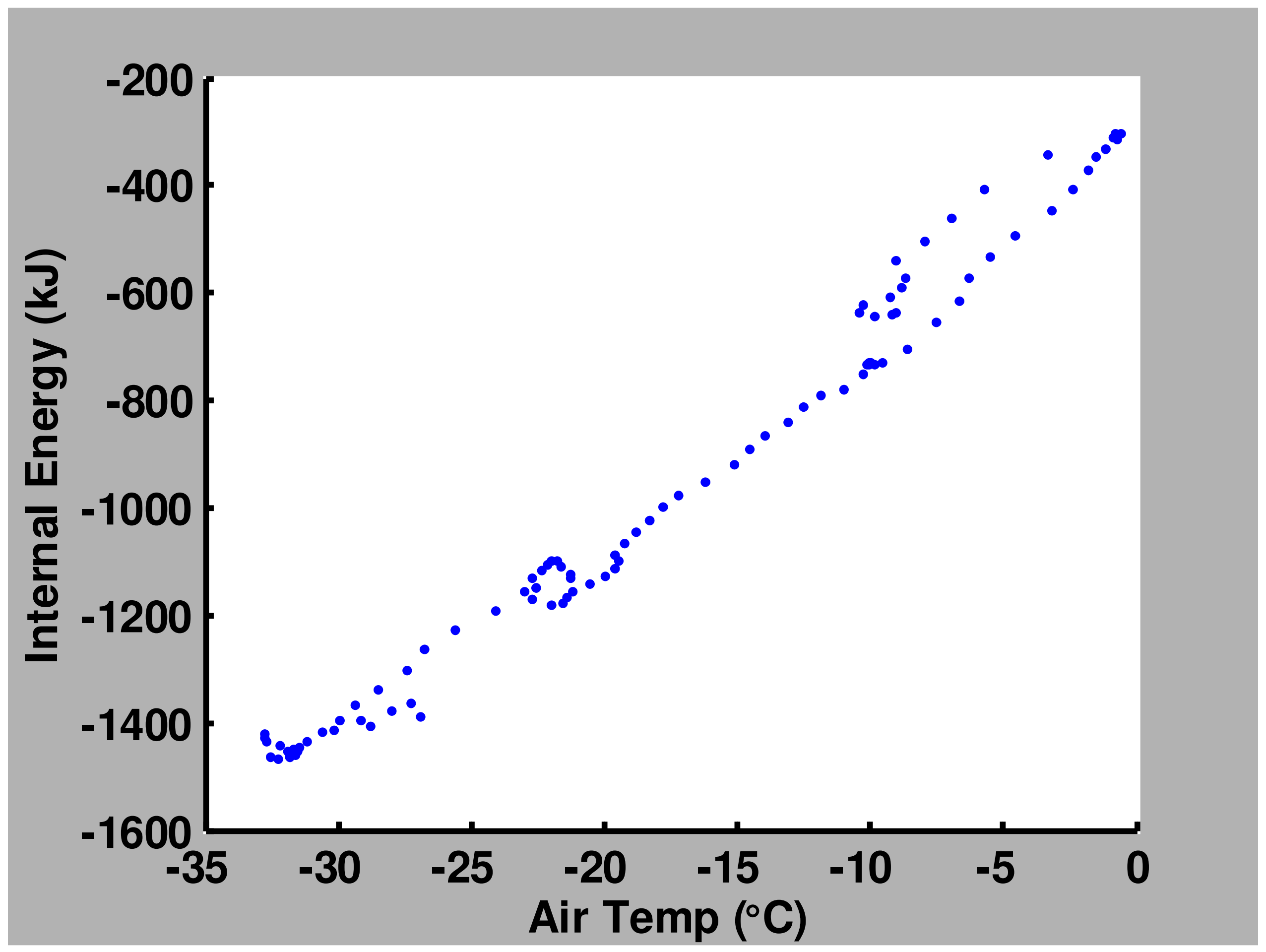
Measured snow temperature profiles: evening



Measured snow temperature profiles: mid-day, clear skies:



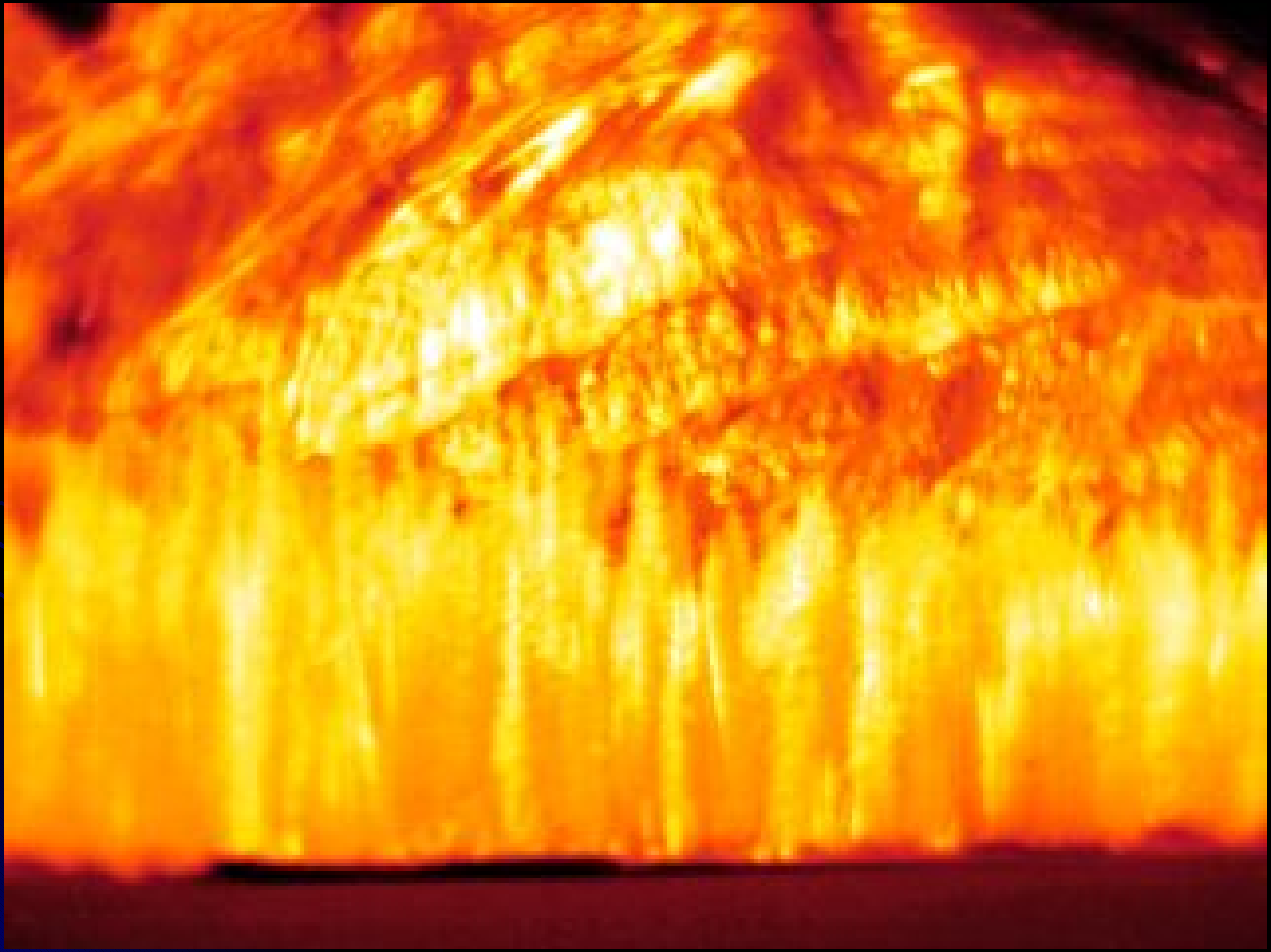
Internal energy of upper 10 cm of snowpack is strongly linked with air temperature



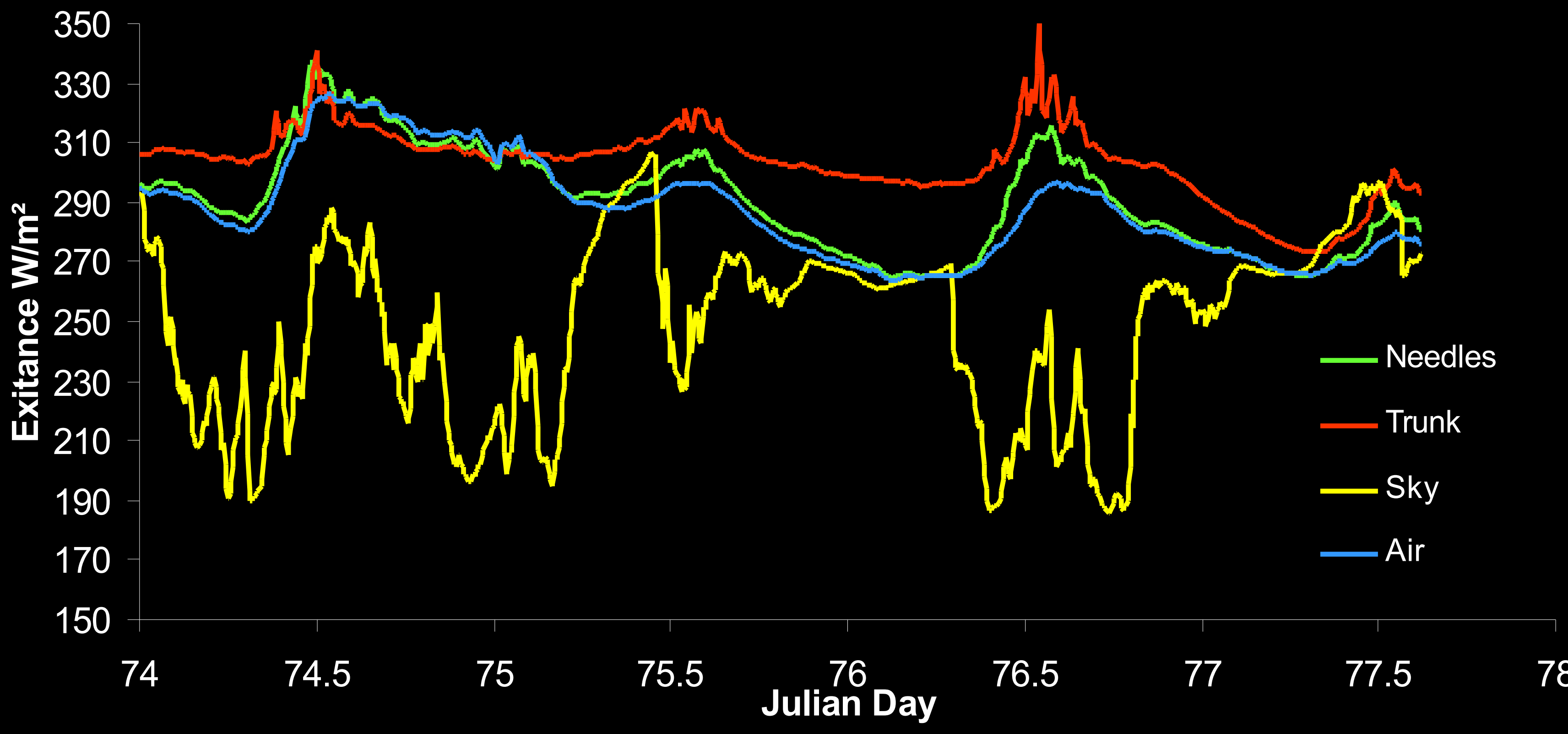
Mechanisms for heat transfer

- Snow is a rough, permeable surface
  - increased surface area for heat and mass transfer ($400\ cm^2\ g^{-1} \rightarrow 12\ m^2$ surface area if $0.001\ m \times 1m^2$ exposed)
  - pressure gradients induced across roughness elements (pore velocities 2 – 30 mm s^{-1} at 1 cm depth)
  - slip velocity at the snow surface
- Surface temperature depression establishes a local gradient
  - *laminar forced convection* is possible (30 – 90 W m^{-2})

Hot Trees – Thermal Radiation



Thermal Radiation from Pine

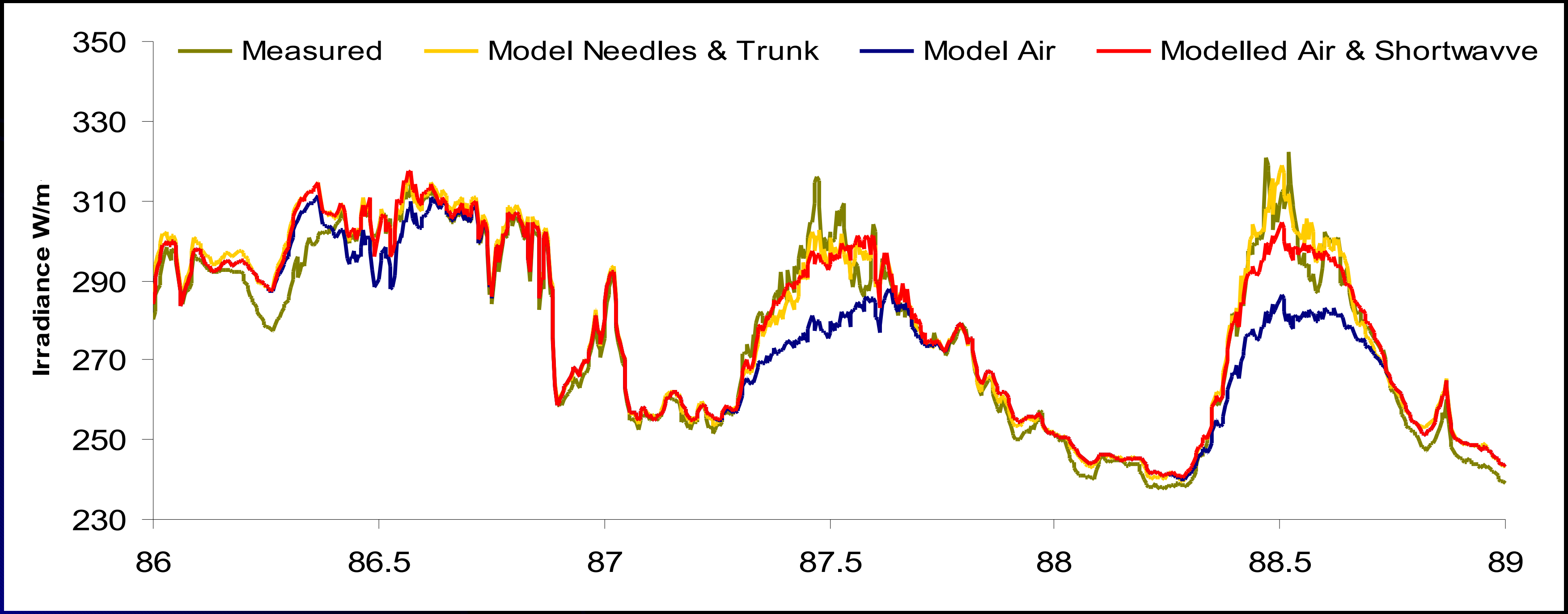


Forest temperatures enhanced above air temperature by extinction of solar radiation
Thermal radiation from forests greatly enhances melt compared to open environments

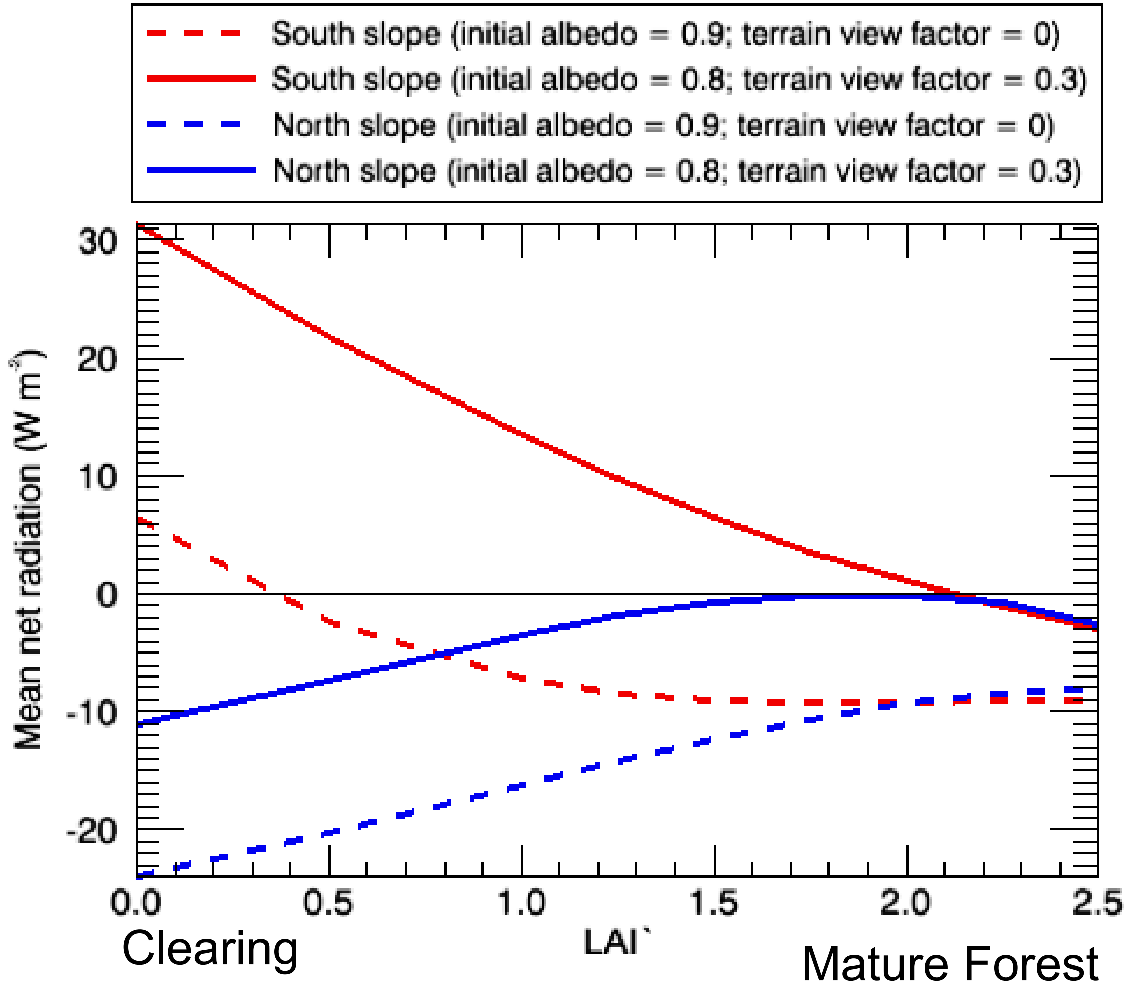
Estimating Canopy Contribution to Downward Longwave

Air Temperature Model: all temperatures are air temperature, segregate by sky view V_f and emissivity ε

Air Temperature & Shortwave Extinction Model: common temperature at air temperature with shortwave extinction term B K^*_H that accounts for shortwave conversion to longwave



Slope and Forest Density Effect on Net Radiation for Snowmelt - Rockies

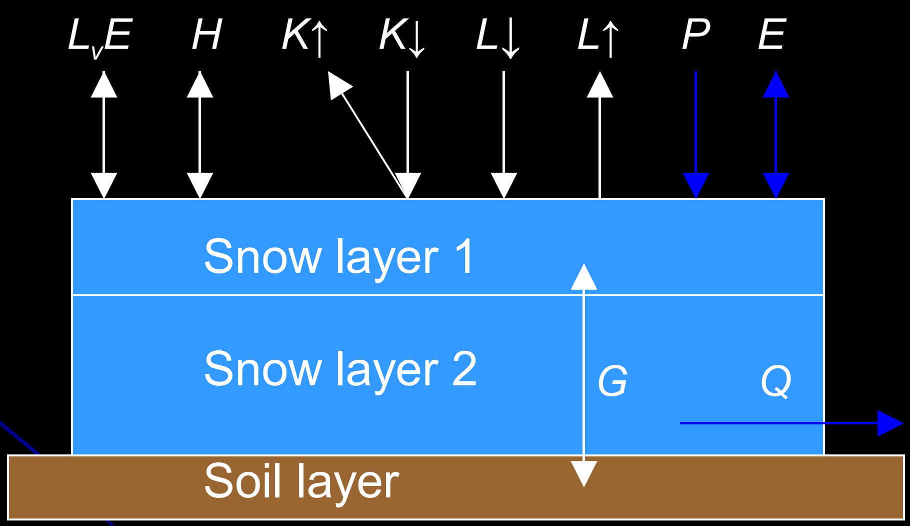


Net radiation = solar + thermal radiation

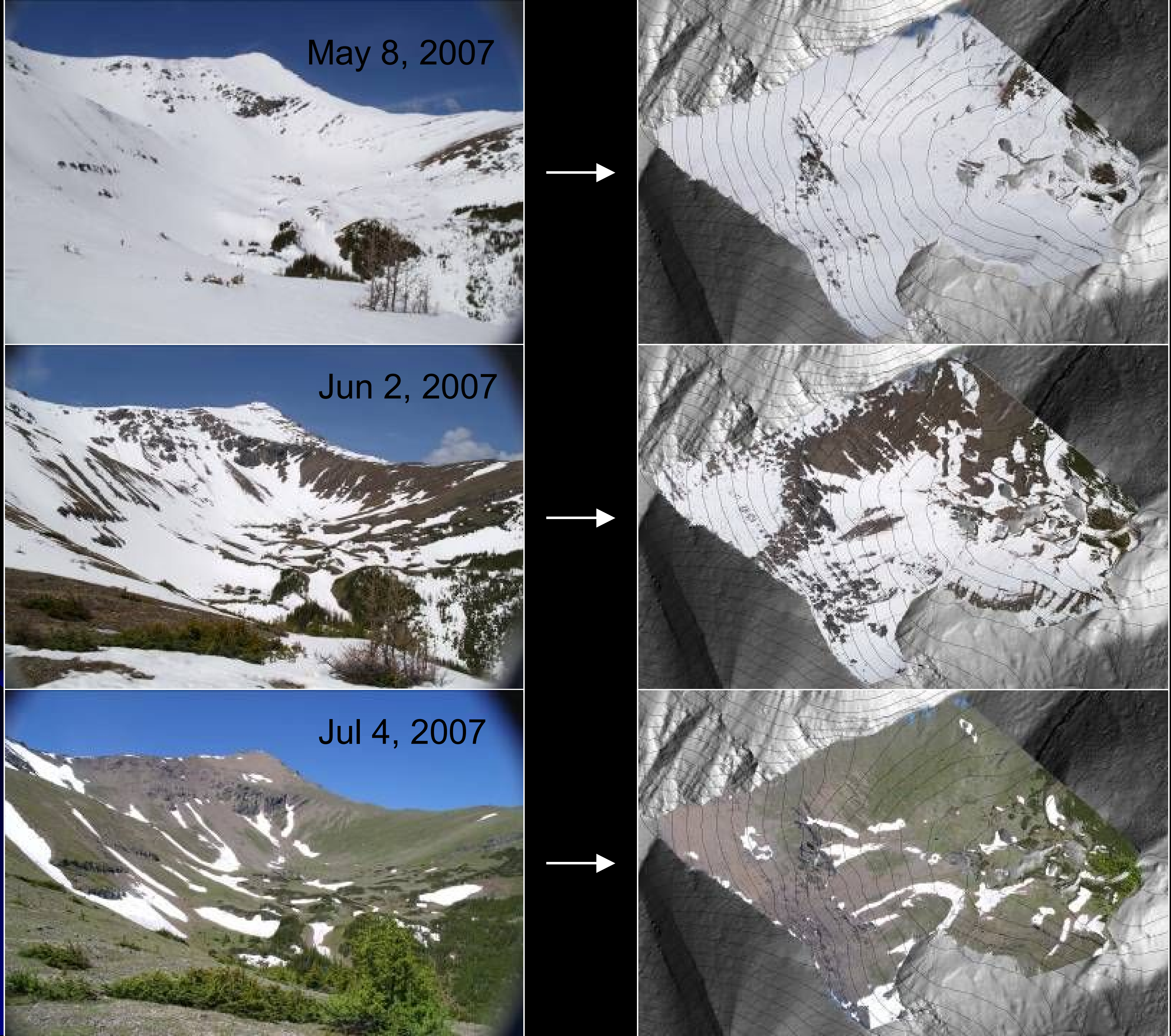
Ellis & Pomeroy

Alpine Snowmelt & Snow Covered Area Depletion Modeling

- Snowmelt rates modeled from observed meteorological data using the Cold Regions Hydrological Model (CRHM) platform
  - Snobal mass and energy balance routine after Marks et al. (1999)



- SCA estimated from observed SWE frequency distribution and accumulated melt



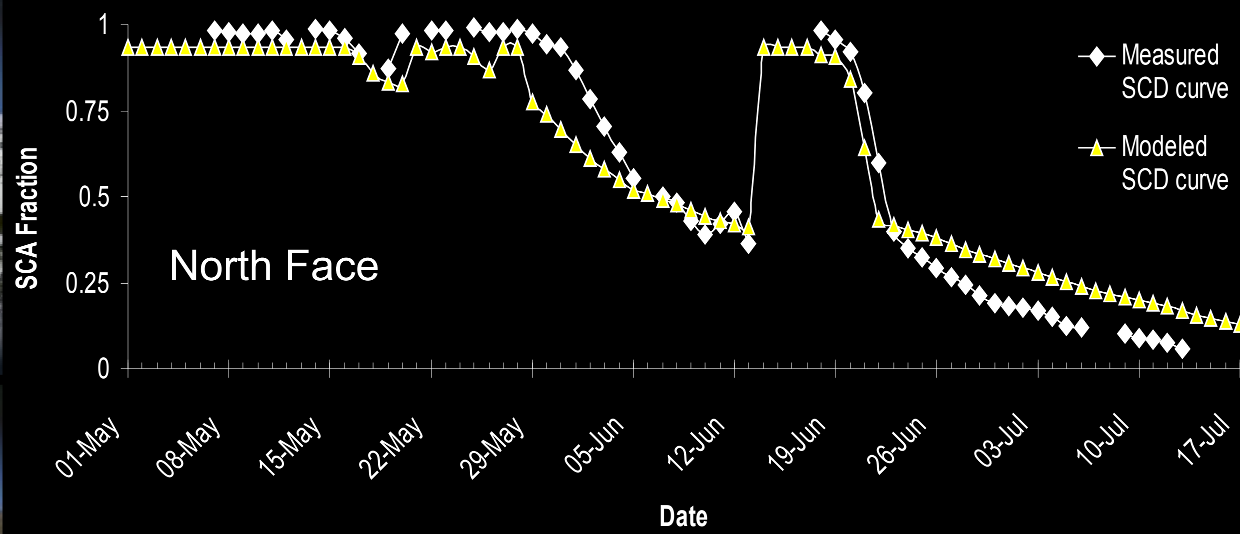
Cirque
SCA
fraction

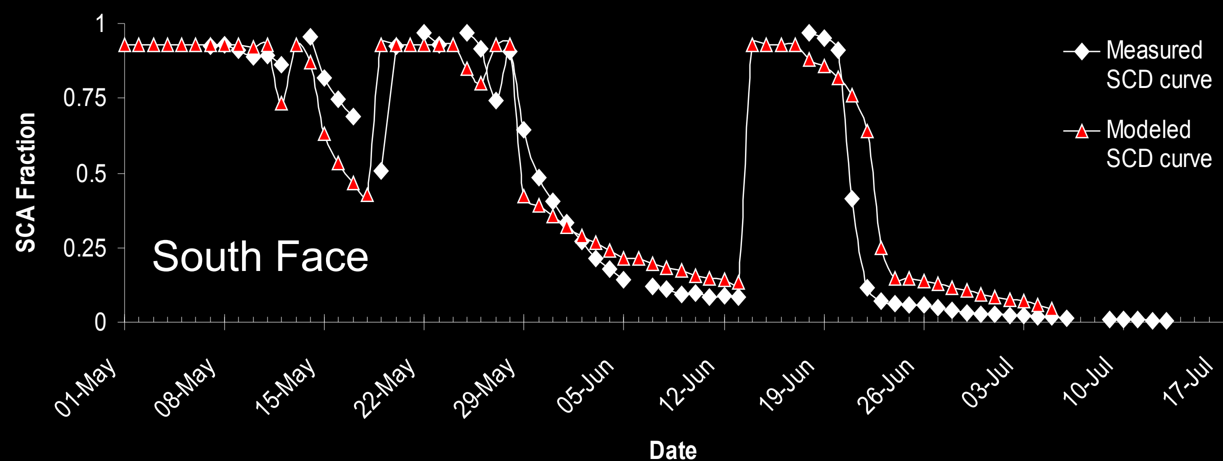
0.95

0.62

0.08

Snowcover Depletion in Alpine Basins





- Single snow cover depletion curve cannot be applied even for relatively ‘small’ scales in mountain terrain

Other Results

- Development of new physically based snow energetics and melt model suitable for hydrological and LSS models
- Analysis of snow unloading events from forest canopies
- PBSM applied/evaluated with windflow model on HRU basis to Trail Valley Creek – regional Arctic snow accumulation modelling
- Coupling of PBSM to Snobal for alpine snow accumulation and ablation analyses
- Shrub burial and emergence observations

Next Steps

- Basin seasonal SWE and snow properties observations using acoustic sensor
- Snow unloading algorithm
- Alpine blowing snow parameterisation for MESH, GEM, tested using LiDAR
- Snowmelt parameterisation for forested slopes
- Snow covered depletion model for alpine
- Revisions to snowmelt sensible heat estimation – non-turbulent contribution

Thanks