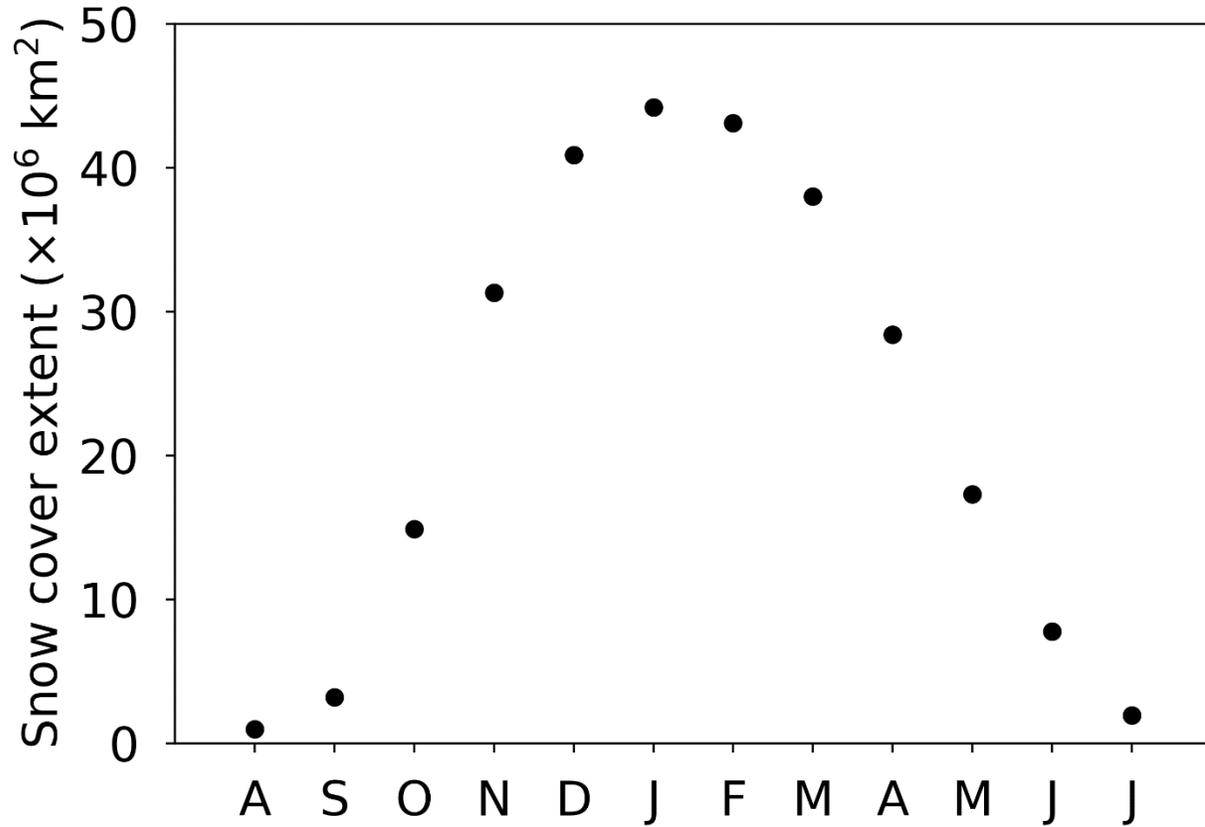
An aerial photograph of a vast, snow-covered tundra landscape. The terrain is characterized by rolling hills and a network of thin, winding paths or streams. The snow is a uniform white, with subtle shadows and highlights that define the contours of the land. In the upper center, a small, dark stream flows through a valley. The overall scene is serene and desolate, typical of a high-latitude environment.

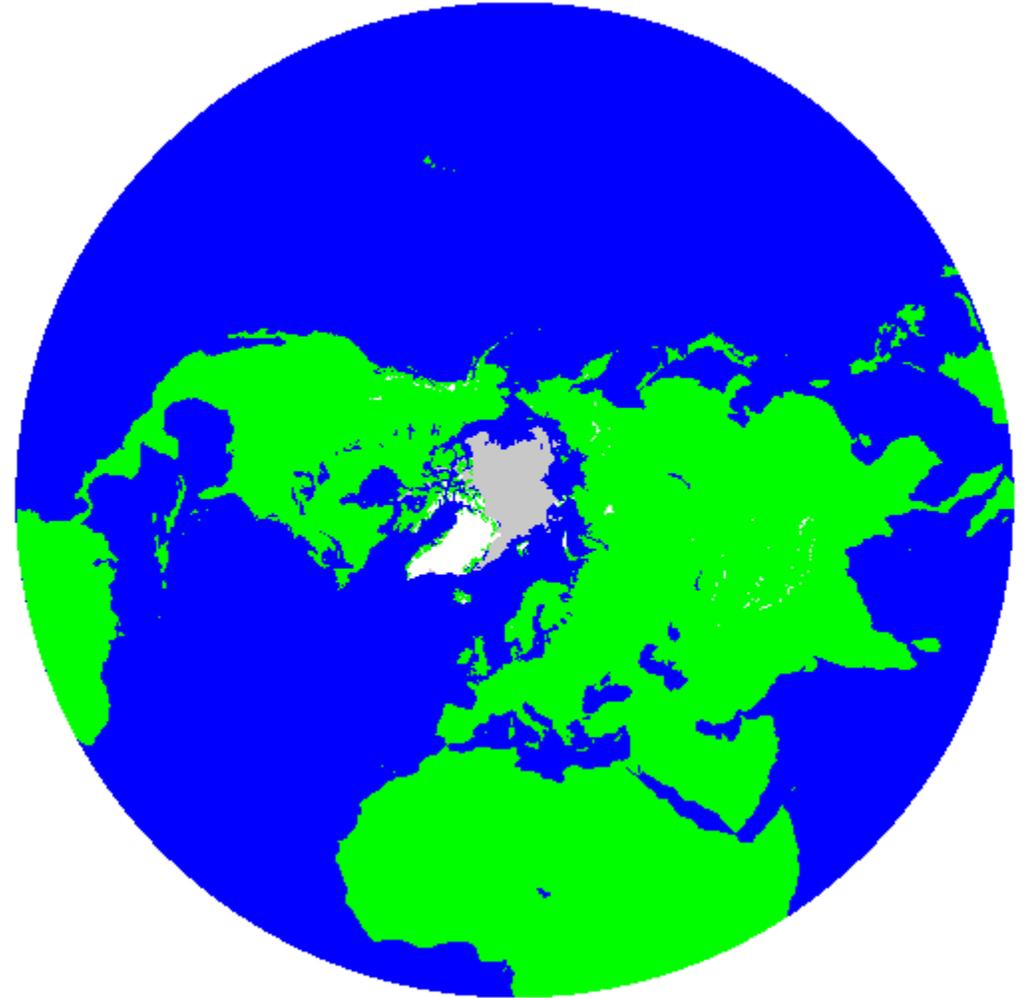
Why tundra snow is upside down in models, and why it matters

Richard Essery
School of GeoSciences
University of Edinburgh

Northern Hemisphere seasonal snow cover



- area > 40×10^6 km² and mass > 3×10^{15} kg at annual peak
- highly variable in space and time
- highly sensitive to weather and climate change



Data from National Snow and Ice Data Center

Snow models

hydrology models

empirical modelling with limited data requirements

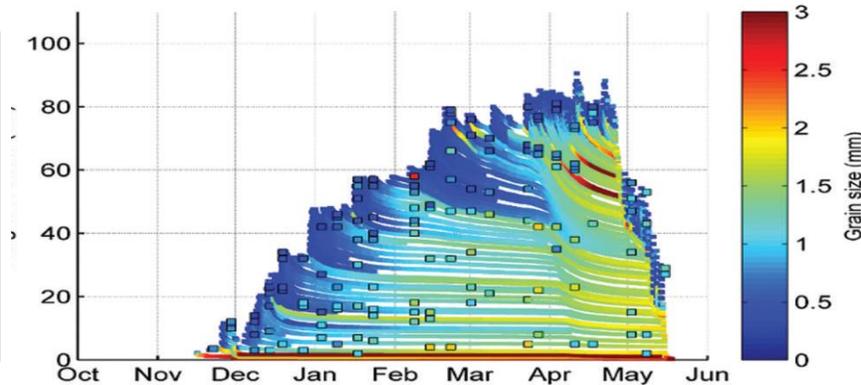
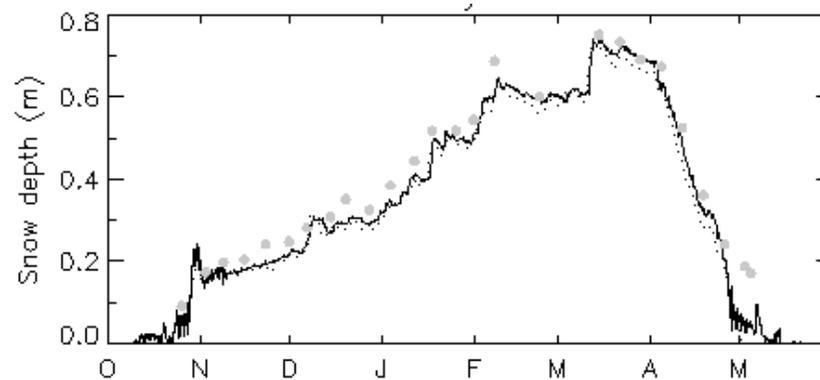
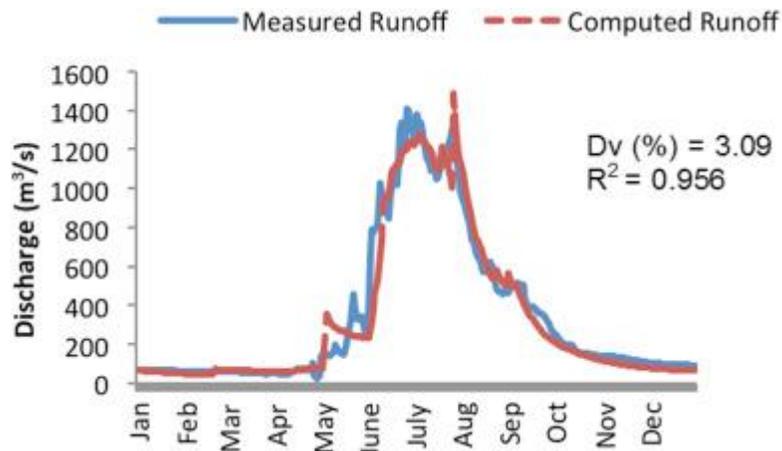
weather / climate models

simple energy balance modelling

radiative transfer models

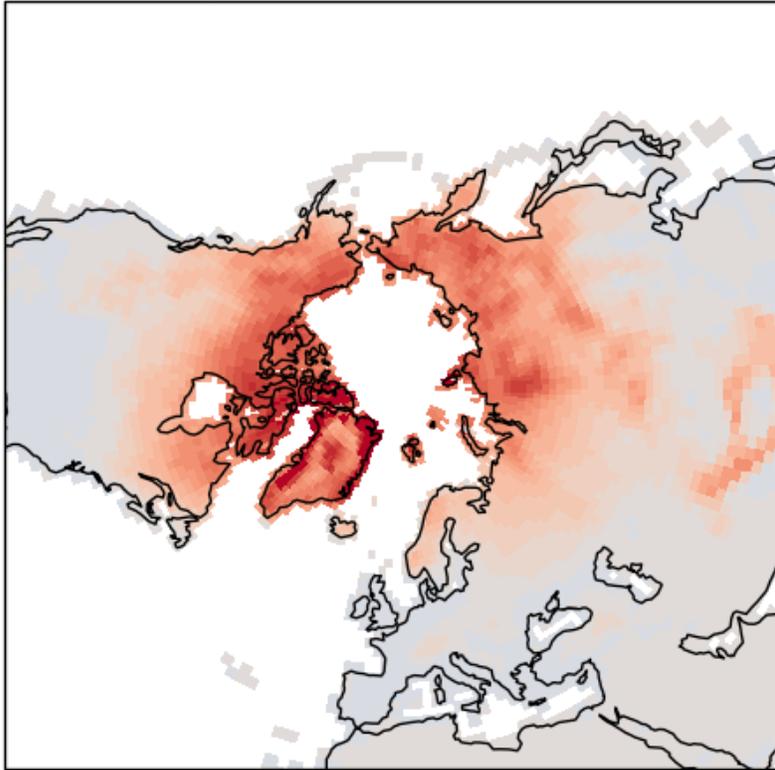
snow physics models

high vertical resolution and many processes

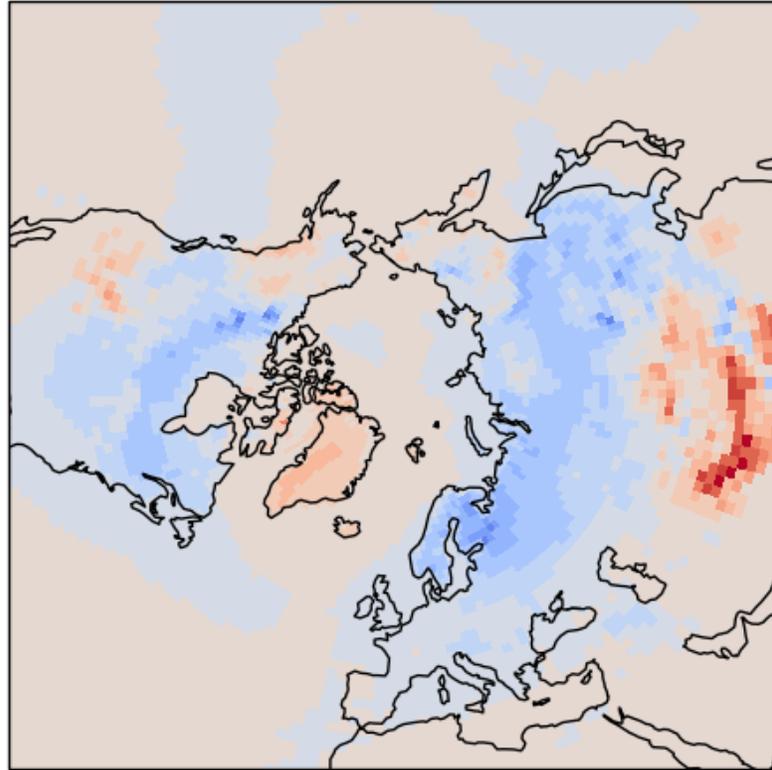


Snow insulation

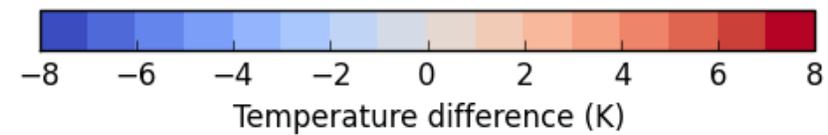
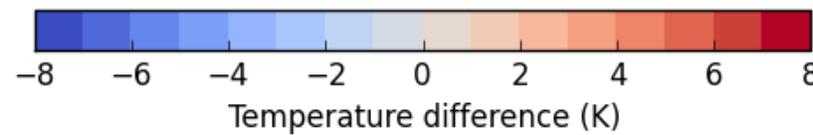
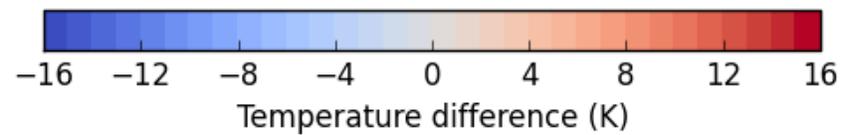
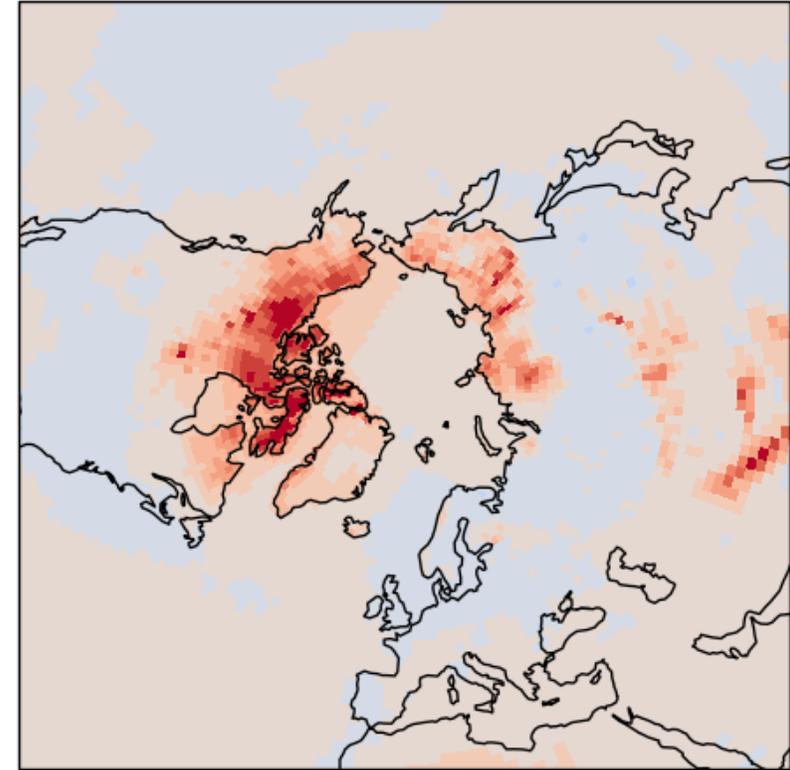
Annual mean top level soil temperature
Multi-layer snow minus GA6.0/GL6.0



DJF screen level temperature
Multi-layer snow minus GA6.0/GL6.0

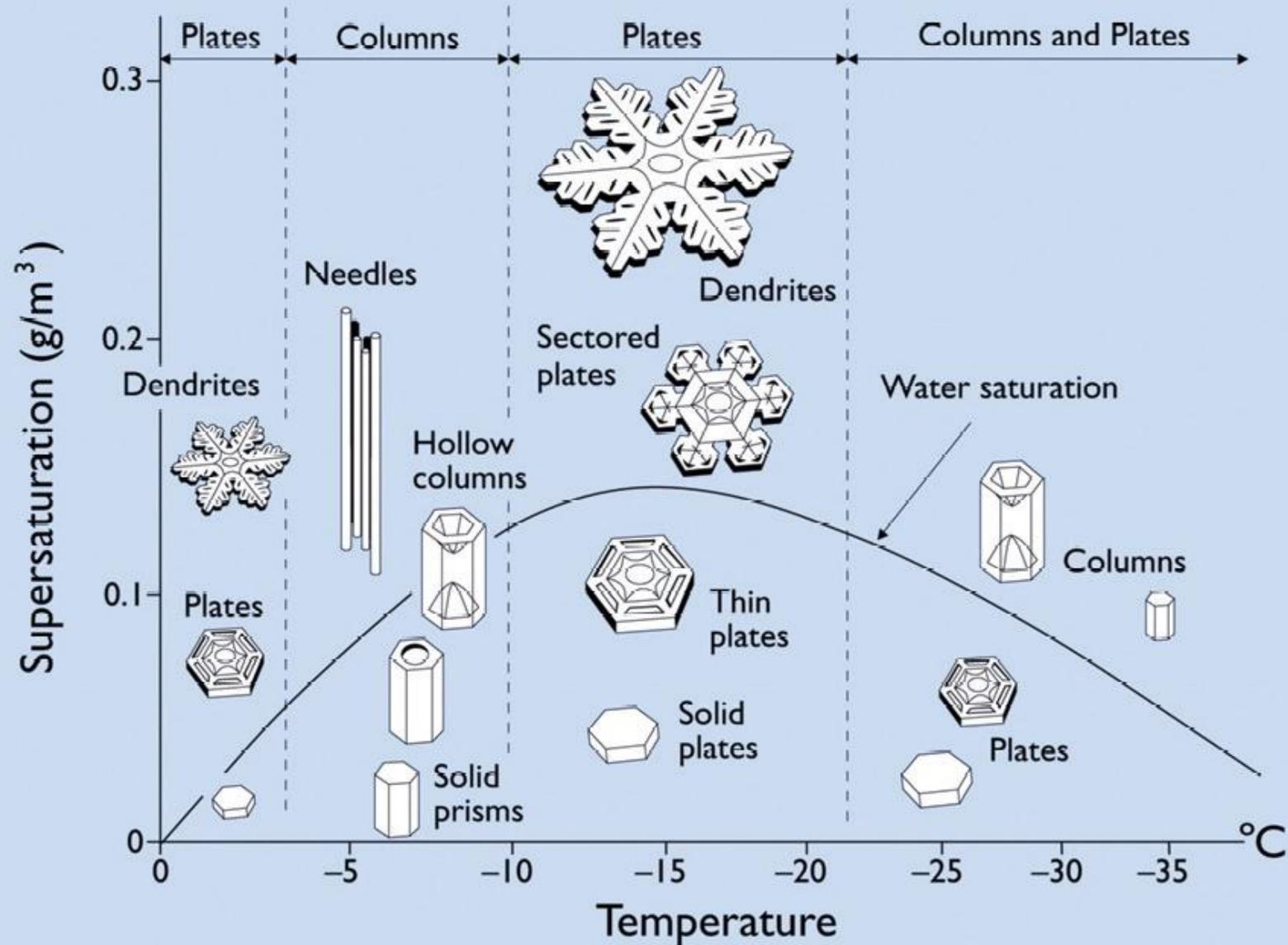


MAM screen level temperature
Multi-layer snow minus GA6.0/GL6.0



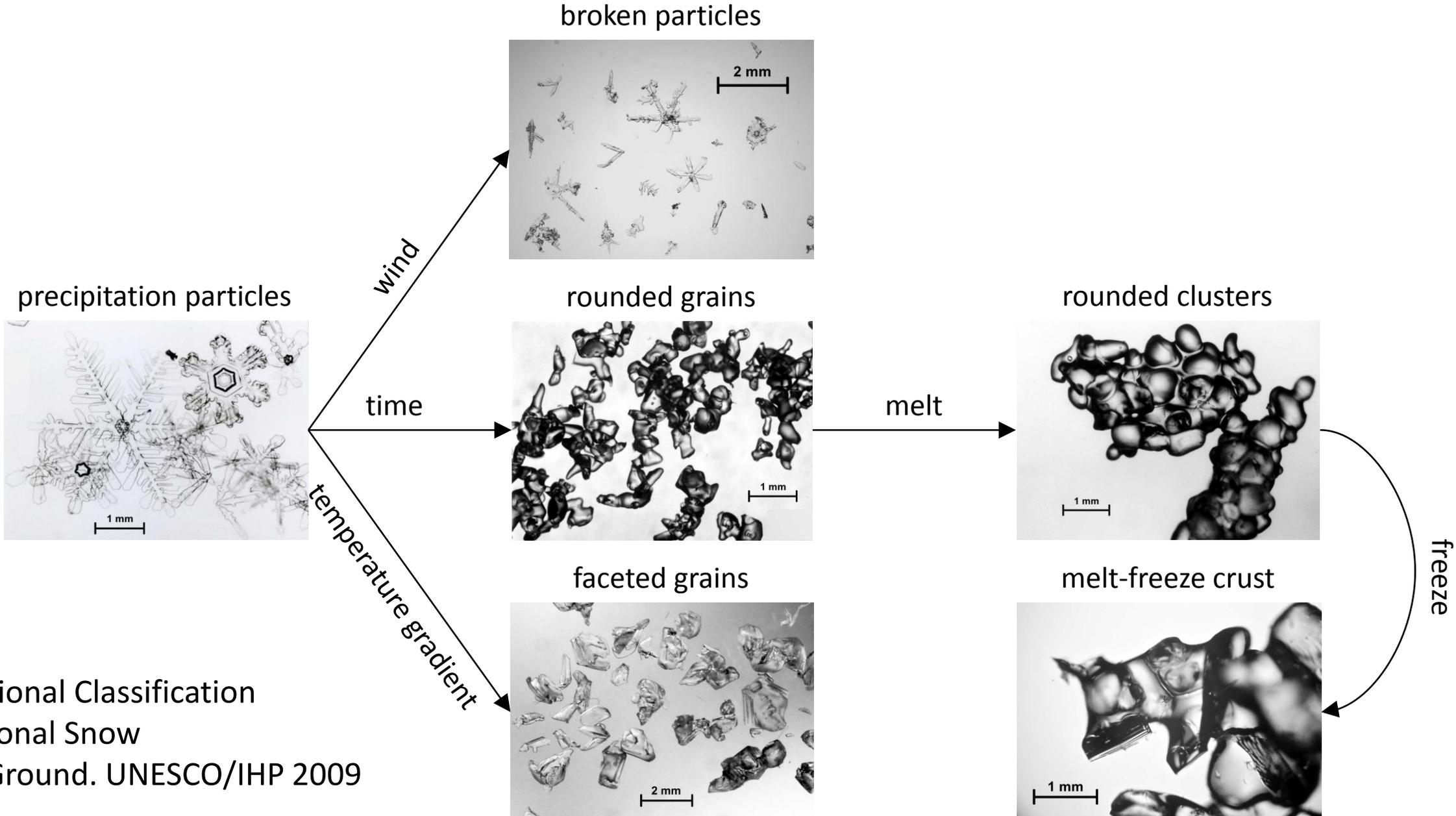
Walters et al. (2017), *Geosci. Model Dev. Discuss.*

Snow grain growth



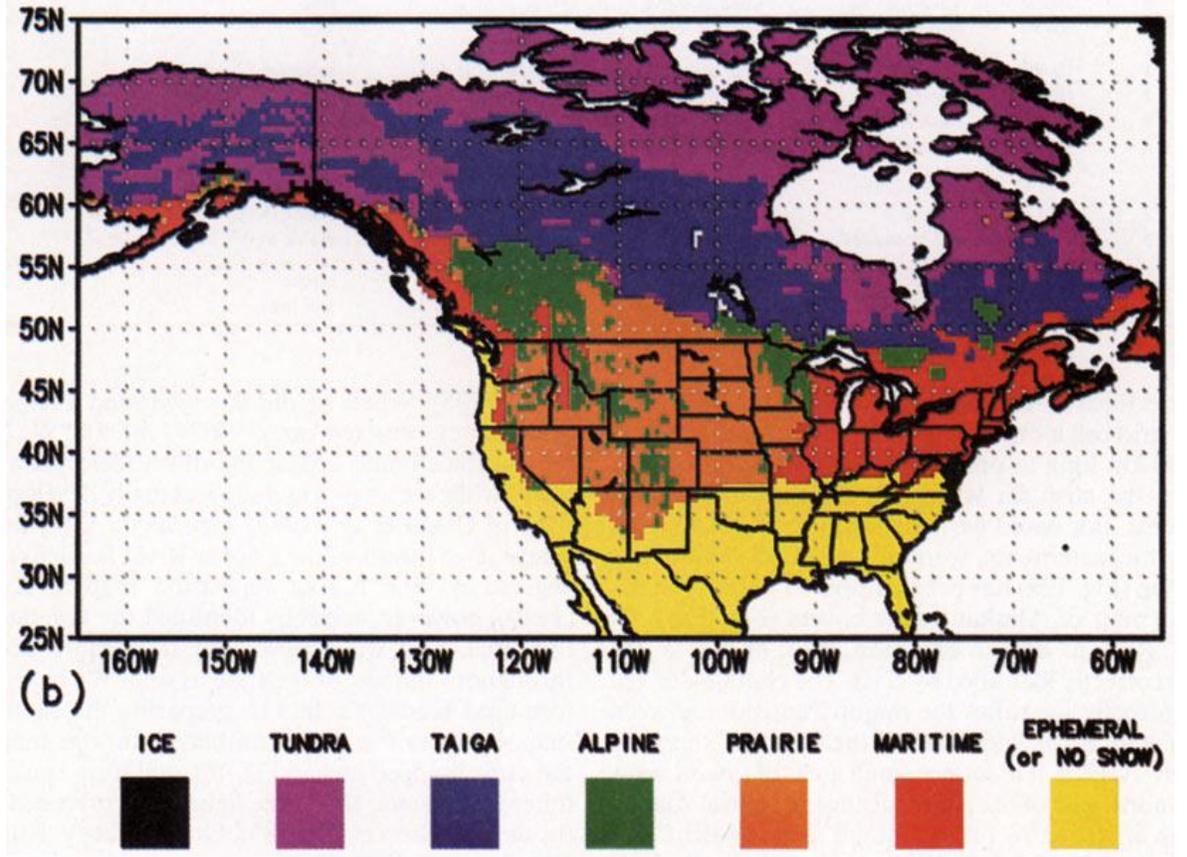
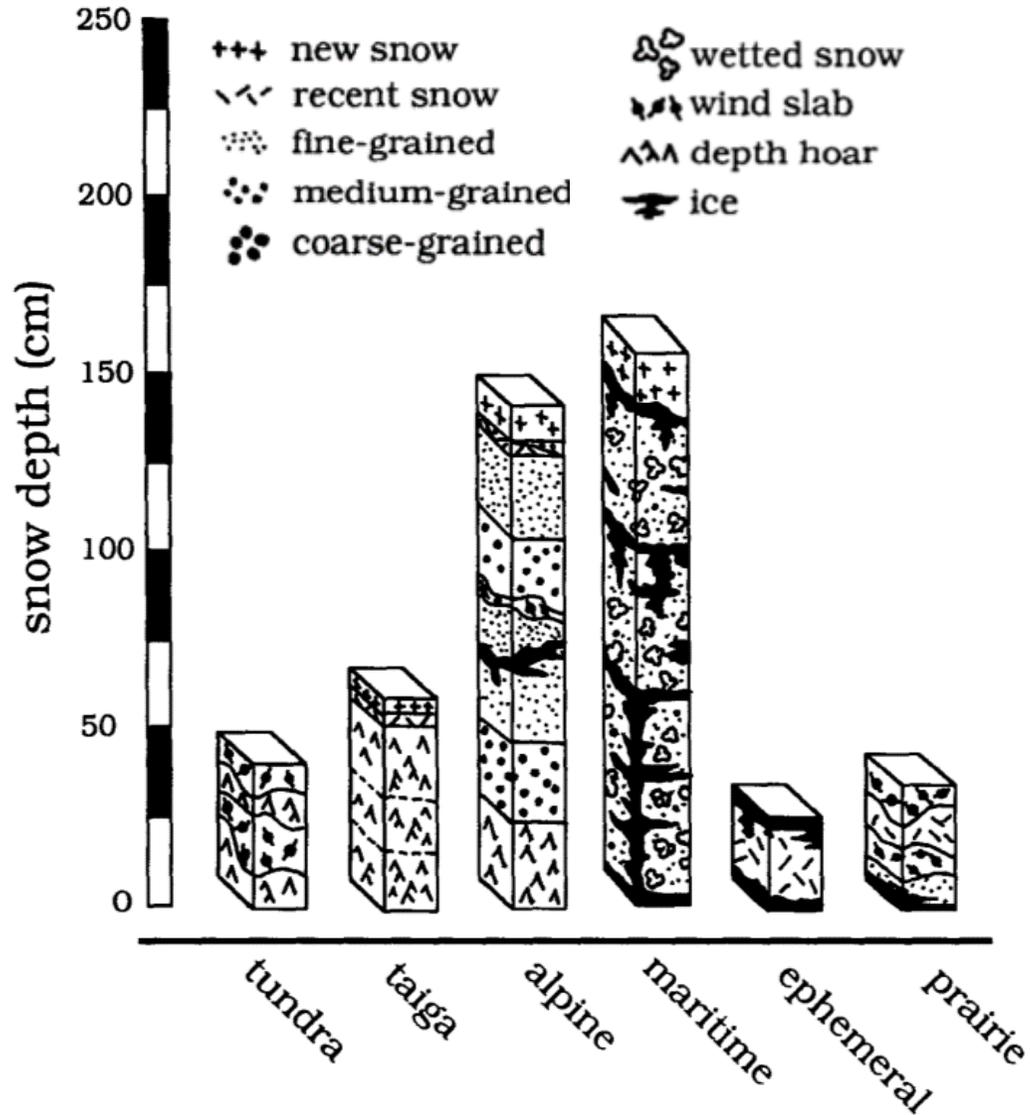
Libbrecht (2005). The physics of snow crystals. *Rep. Prog. Phys.*, **68**, 855–895

Snow grain metamorphosis



International Classification
for Seasonal Snow
on the Ground. UNESCO/IHP 2009

Snow stratigraphy

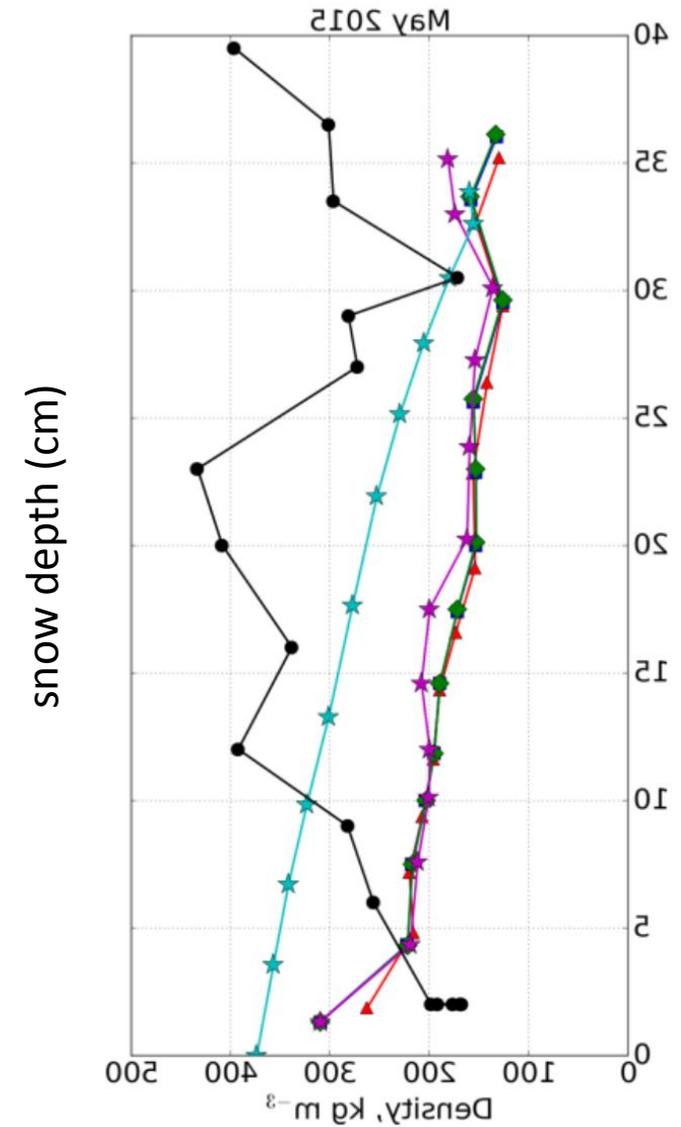


Sturm et al. (1995), *J. Clim.*, **8**
Seasonal snow cover classification

Tundra snow stratigraphy



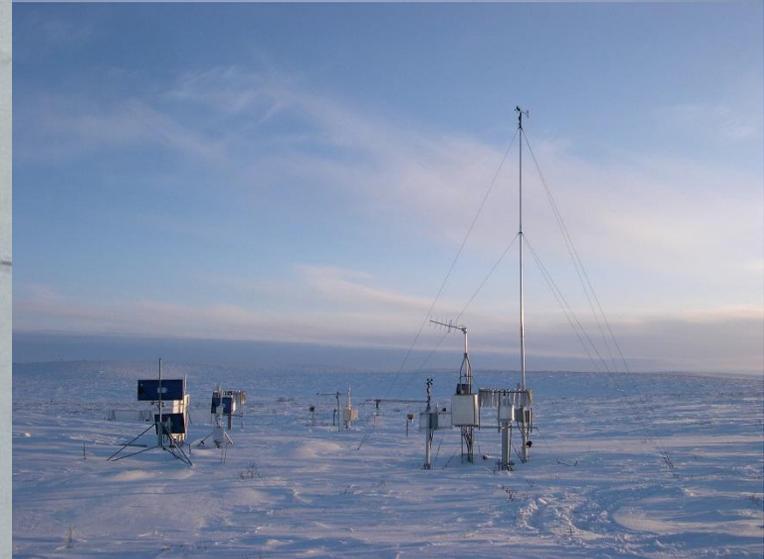
Domine et al. (2016).
The Cryosphere, **10**, 2573–2588



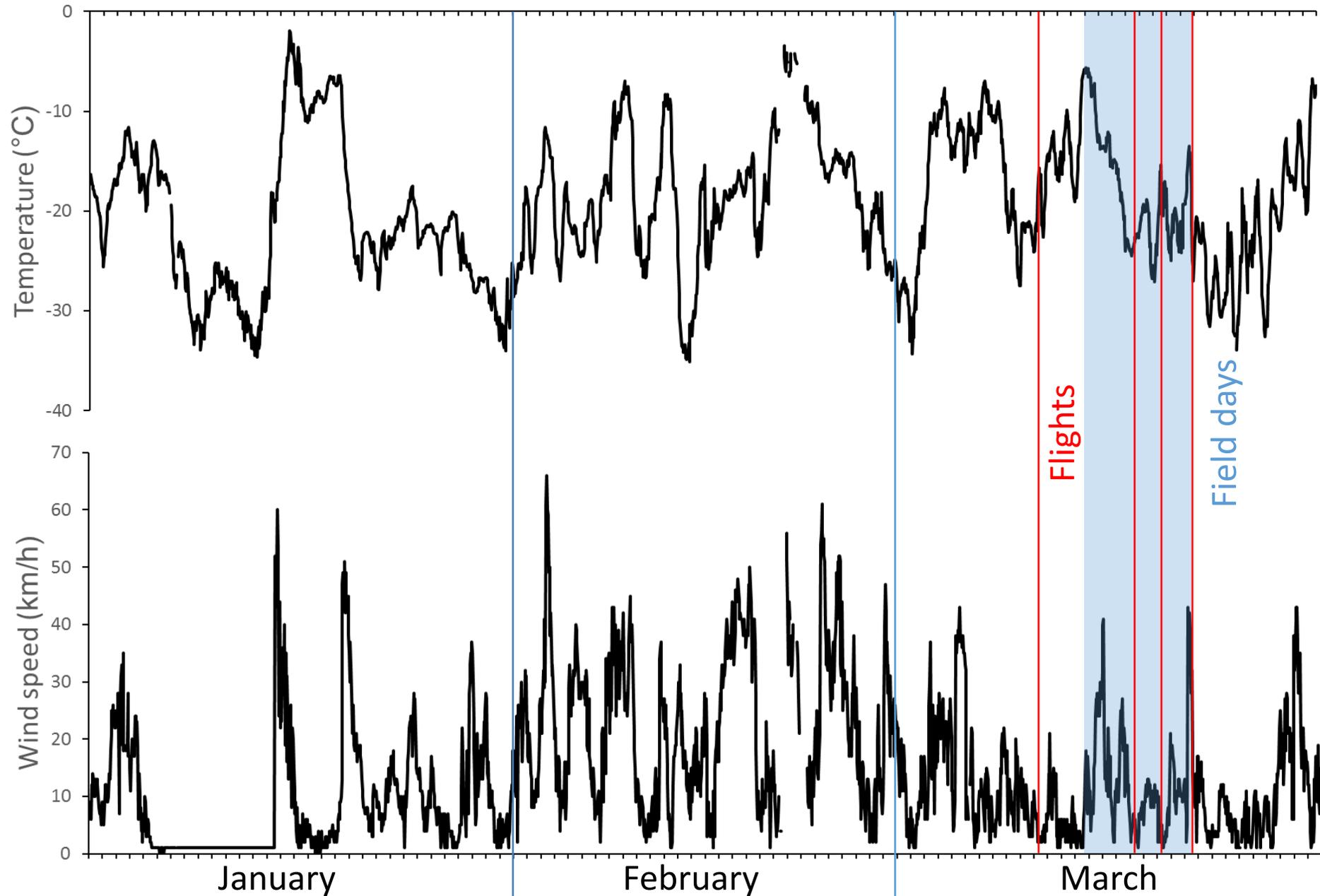
Barrere et al. (2017)
Geosci. Model Dev., **10**, 3461–3479

MACSSIMIZE ground campaign, 14-22 March 2018

Trail Valley Creek field camp, NWT, Canada



January - March weather at Trail Valley Creek



Manual measurement of snow properties

Density

- weigh known volume of snow

Temperature

- stem thermometer

Wetness

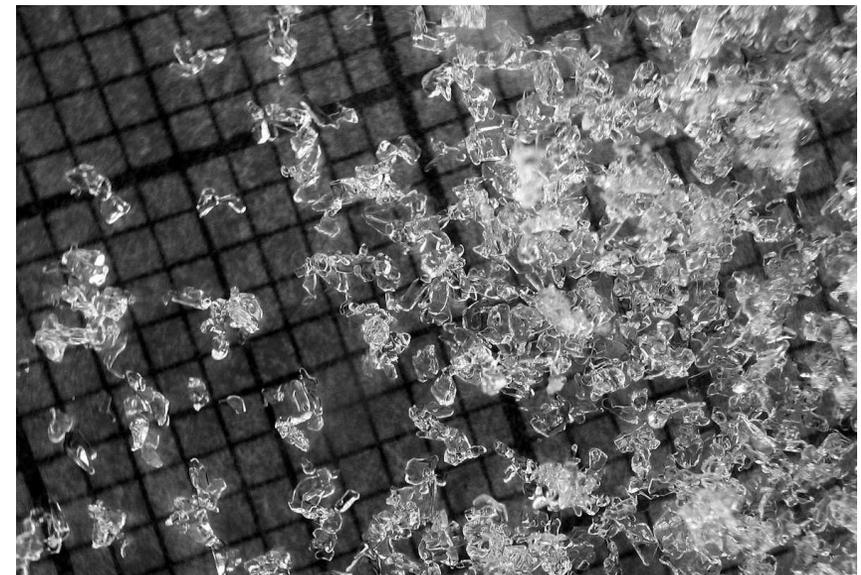
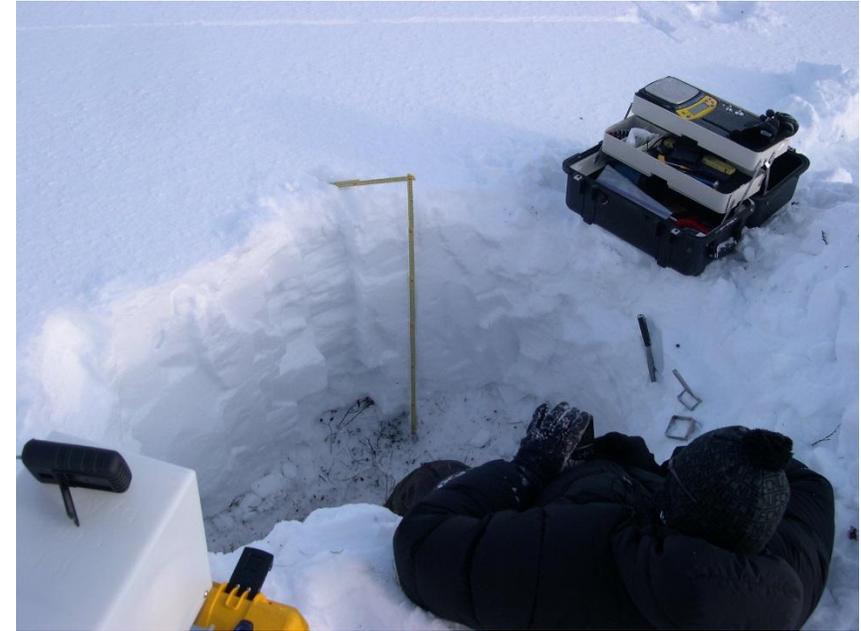
- snowball test

Hardness

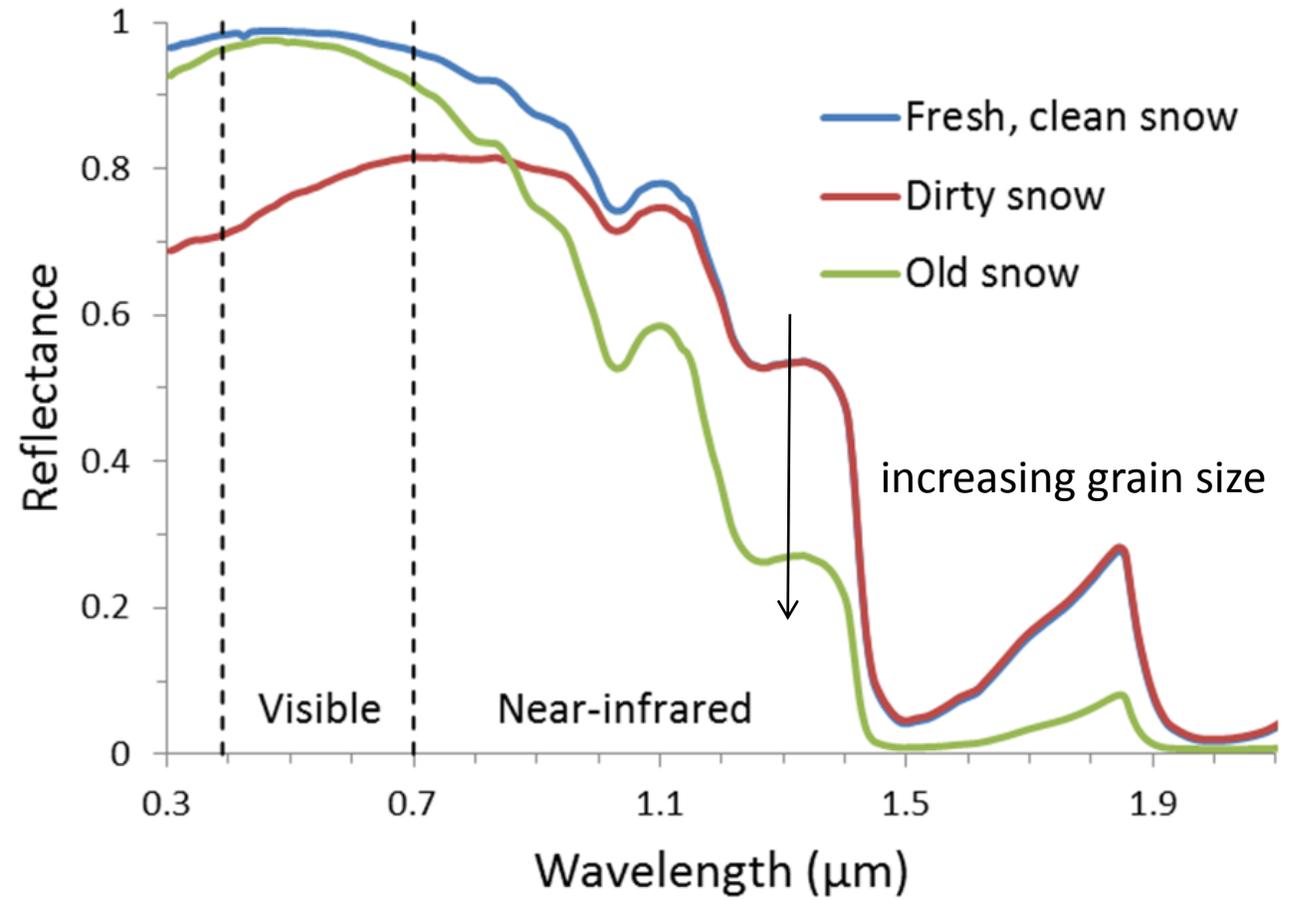
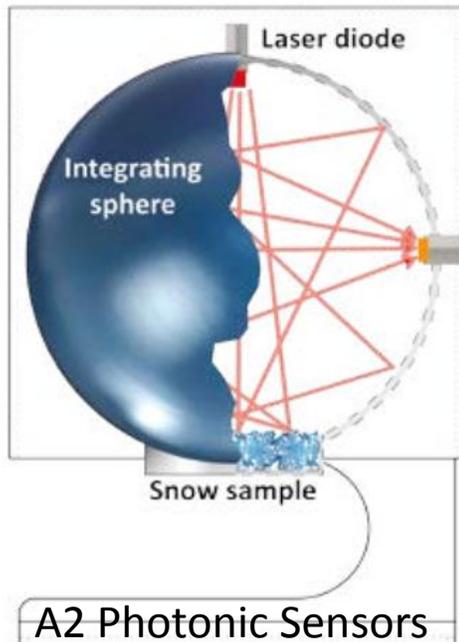
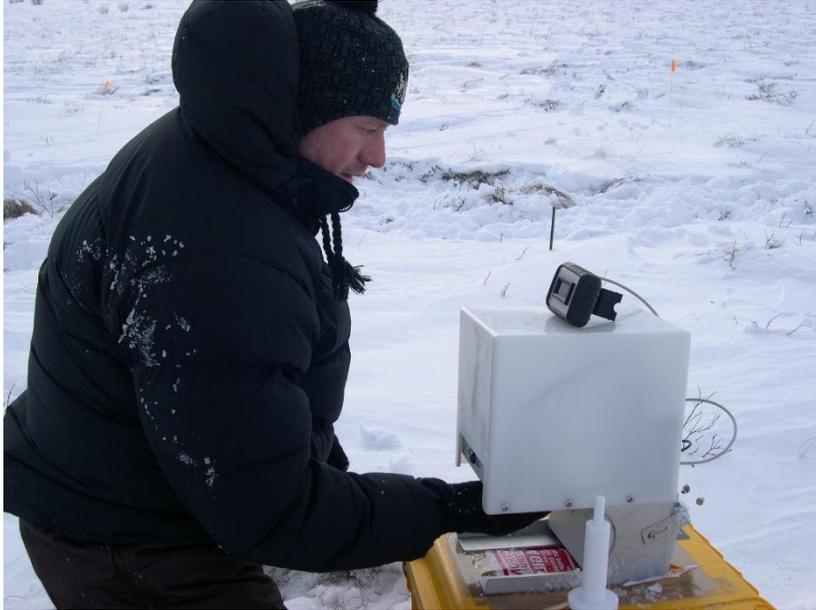
- penetration (fist / finger / pencil / knife)

Microstructure

- visual identification of grain type and size

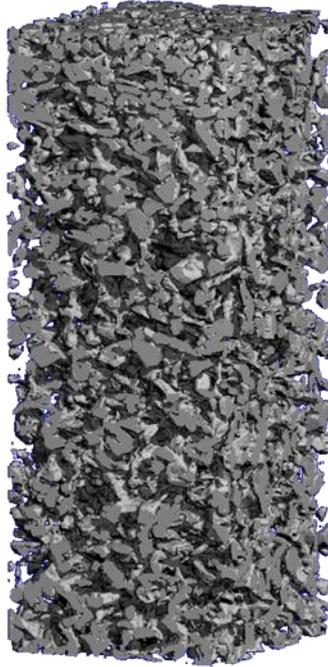


Optical grain size



Snow microstructure

Microtomography
(image from
Martin Proksch)



micropenetrometer

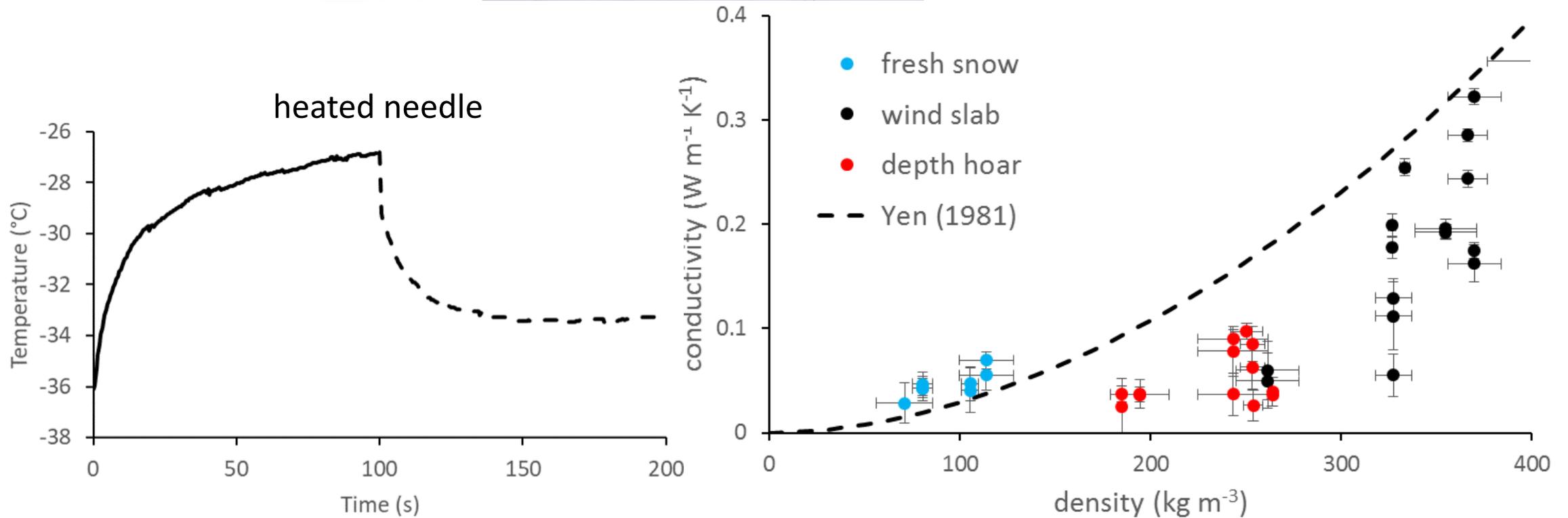
- p_{ex} – exponential correlation length from fit to autocorrelation function
- p_c – correlation length from derivative of autocorrelation function
- D_o – radius of monodisperse spheres with same optical properties
- D_q – radius of monodisperse spheres with same surface area–volume ratio
- D_m – average of greatest extension of grains

$$p_{ex} < p_c < D_o = D_q < D_m$$

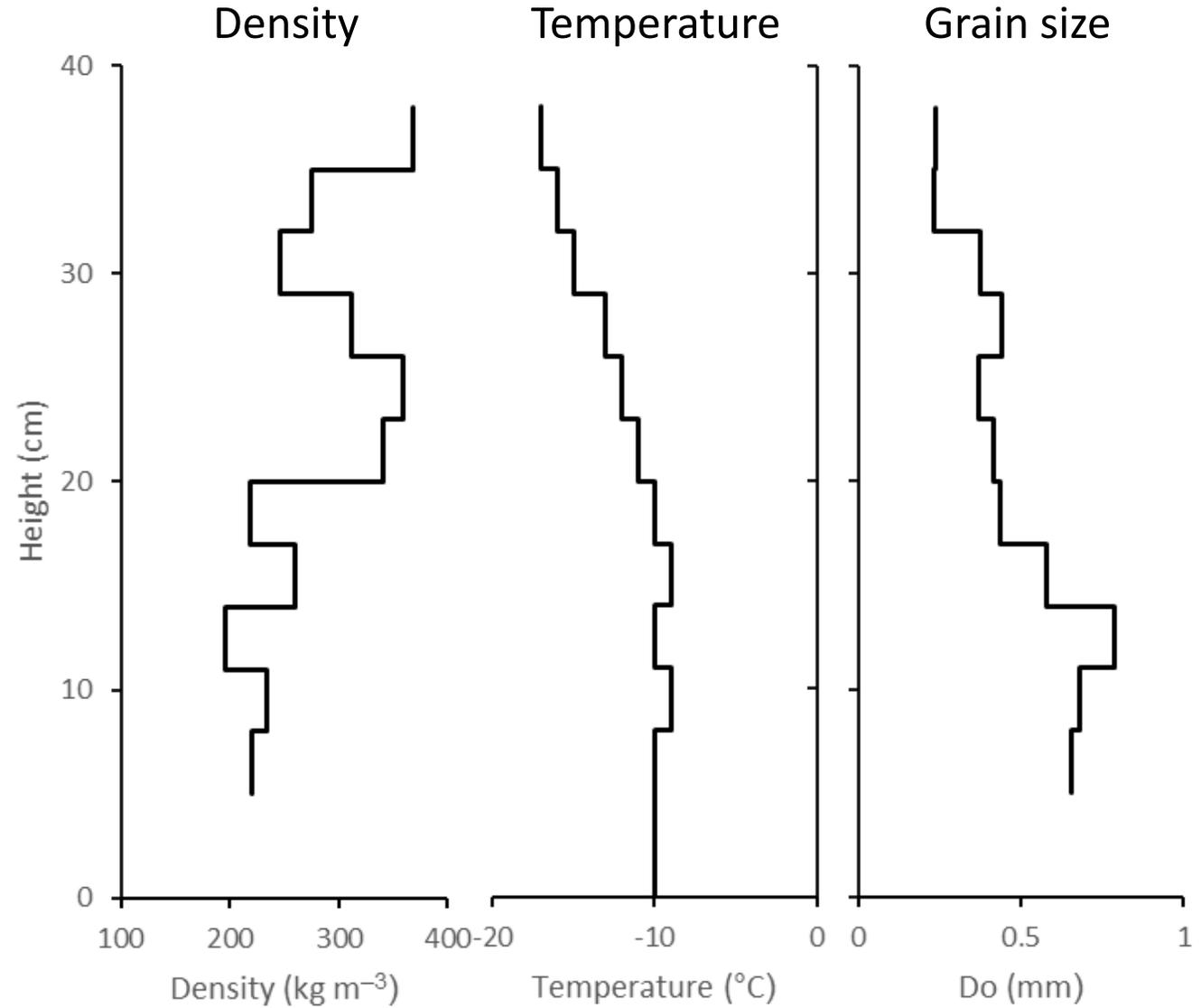
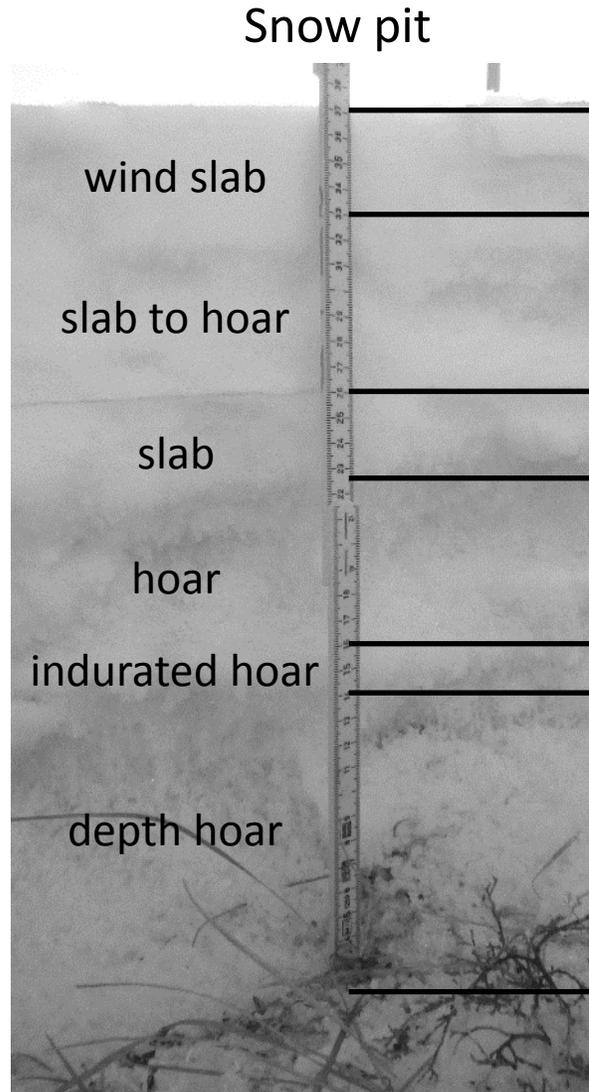
Thermal conductivity



Field data processed by Michael Lai
(NERC Research Experience Placement)



Snow profiles



Conclusions

Tundra snow has a characteristic structure of hard, small-grained wind slab over loose, large-grained depth hoar which:

- has important influences on microwave scattering (remote sensing) and thermal conduction (numerical weather prediction, climate modelling)
- is formed by processes not represented in snow models (although there may be compensating errors)
- can be characterised objectively in the field by instruments that are now becoming more widely available

Acknowledgments

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Facility for Atmospheric Airborne Measurements

Michael Lai, University of Reading

Field crew from Environment Canada and universities:
Edinburgh, Northumbria, Sherbrooke and Wilfrid Laurier

Thank you!

Arvids

Nick

Richard

Alex

Céline

Alain

Peter

Evan

Branden



Photo: Branden Walker