Aerosols in seasonal snow

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Introduction

What drives snowmelt?

Absorption of solar energy is the primary driver of snowmelt in mid-latitude mountains.

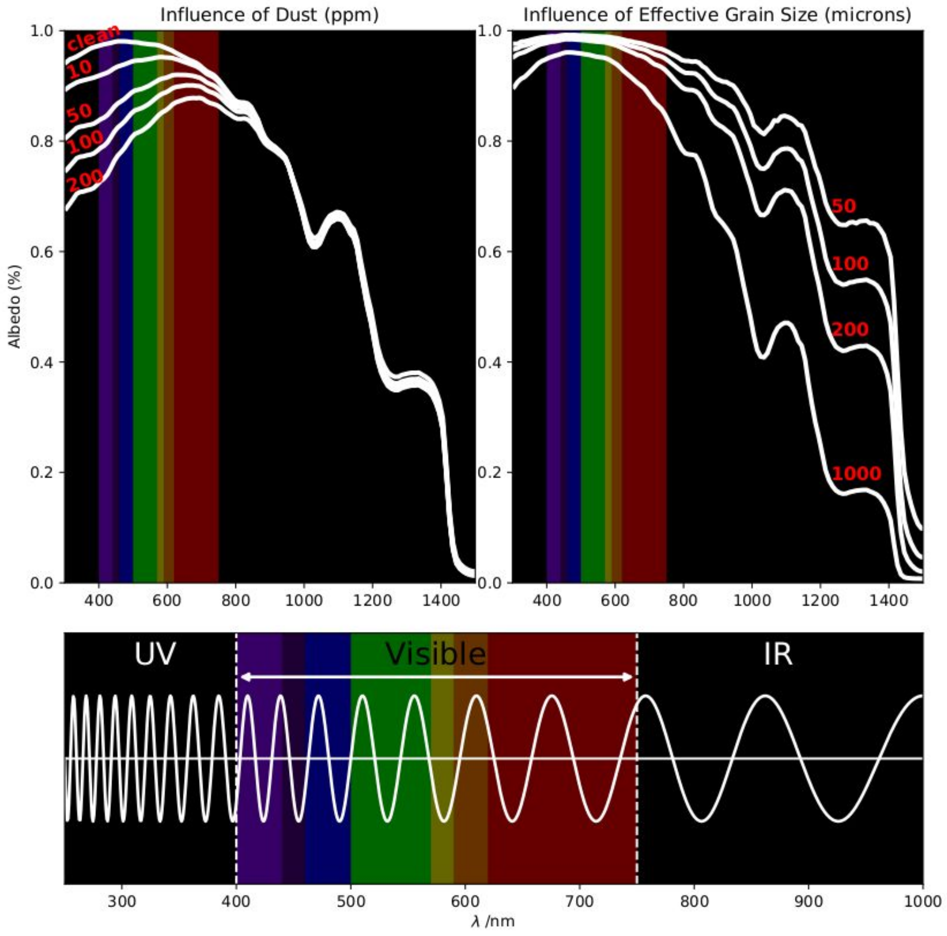
What drives the absorption of solar energy?

Albedo: reflectivity of a surface.

Fresh snow has BB albedo near 0.9, reflects 90% of solar energy.

VIS albedo decays due to LAI (dust, BC).
IR albedo decays due to snow grain growth.

POSITIVE FEEDBACK LOOP



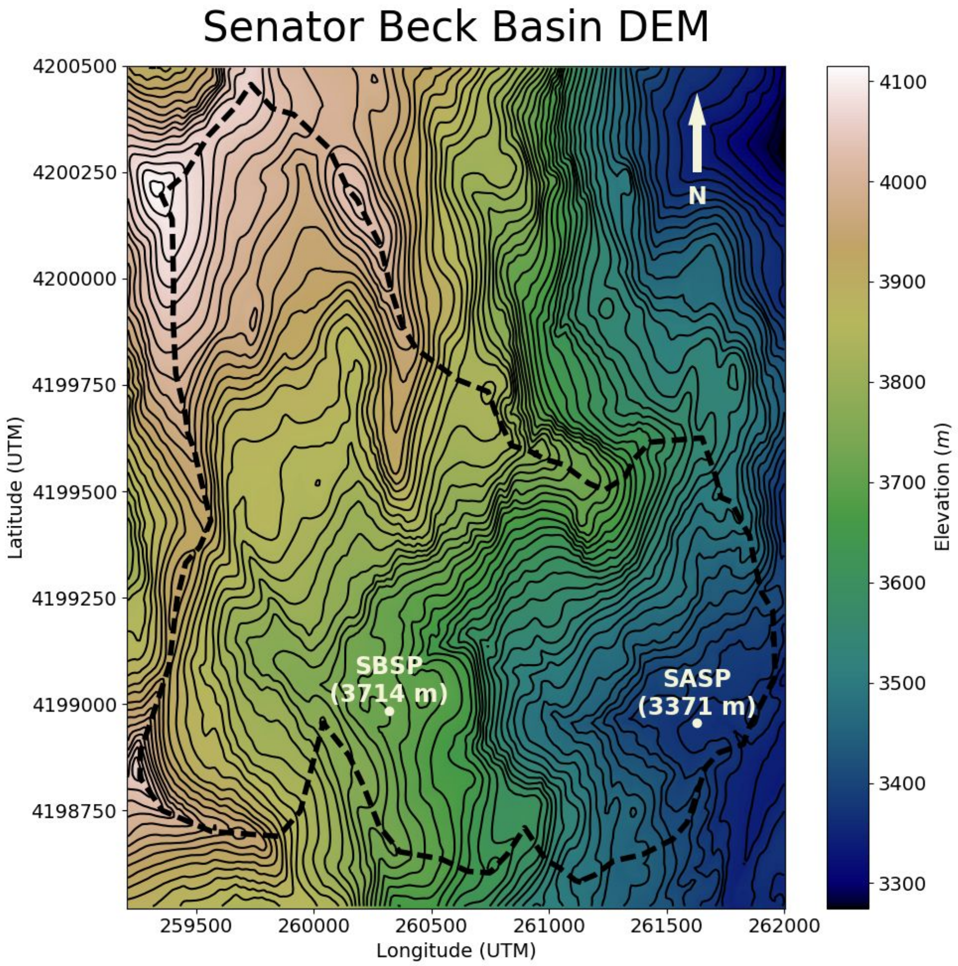
Not accounting for the effect dust has on albedo, therefore net solar may be a source of snowmelt model error (specifically timing of snowmelt)..

Goal: Show snowmelt models improve when we account for the effects of dust.

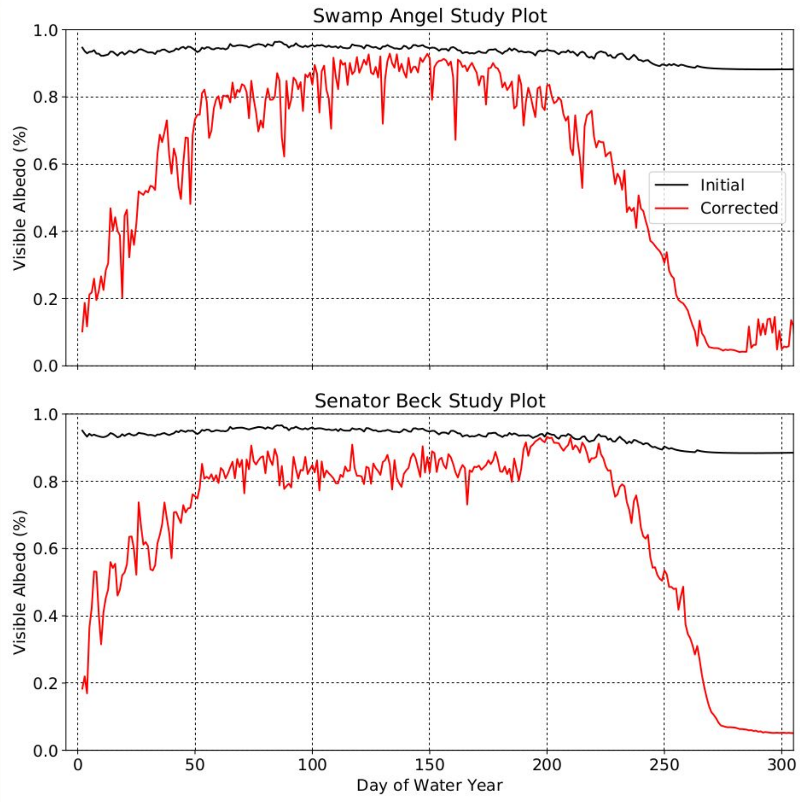
Run physically-based and spatially-distributed snowmelt model (iSnobal) over basin for entire snow season.

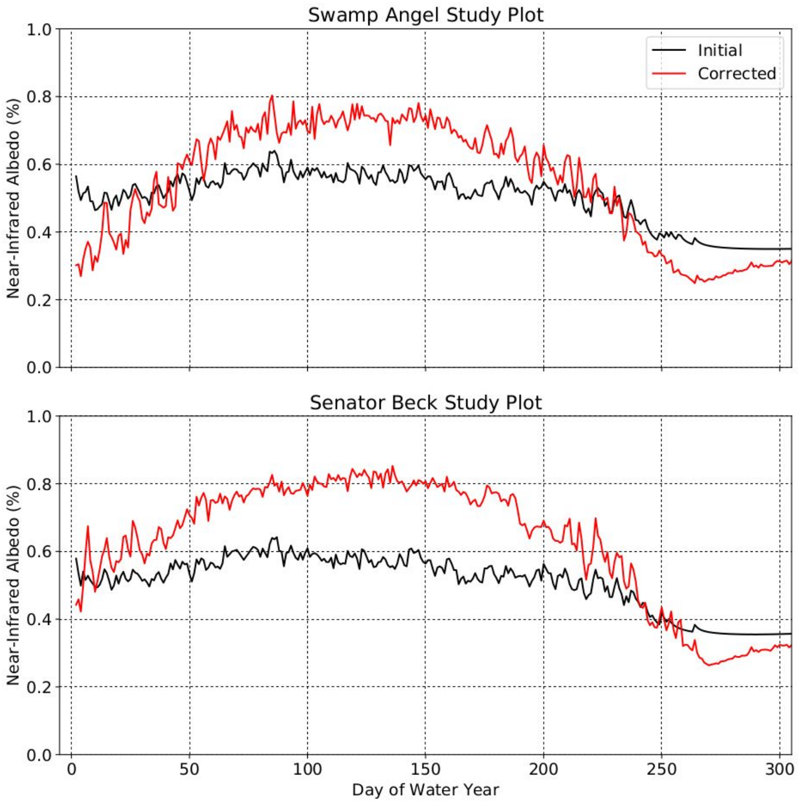
Basin: Senator Beck Basin (dust dominated).

Data from towers used to force snowmelt model.



Clean snow run vs Dirty snow run





Run from 2008 to 2017 water years

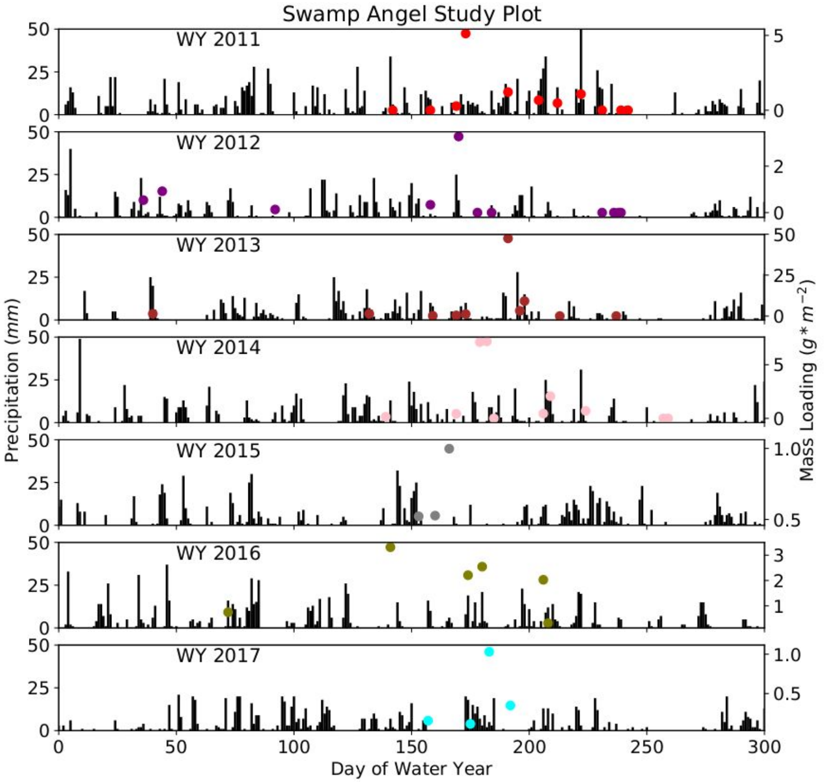
Video of heavy dust year (2012) and light dust year (2017). Spring dust events...

Compare clean and dirty snow model results to actual snow pits.

Consider...

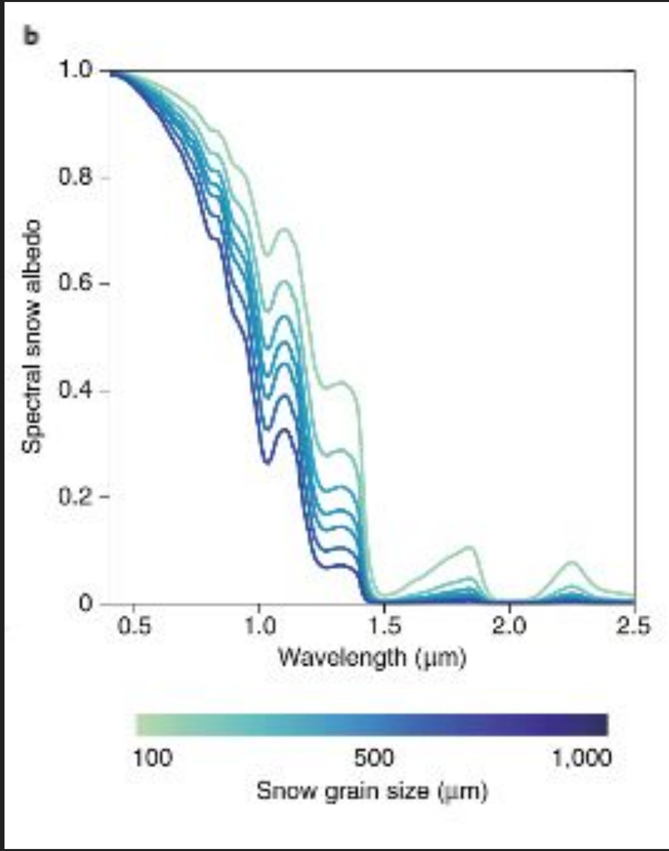
How does snowmelt timing differ between clean snow and dirty snow?

How could modeling errors in snowmelt timing and magnitude hinder water resource management?



Aerosol effects on grain size

- Direct impact of LAPs: surface darkening ➡ grain growth
  - This type of metamorphism is called **melt-freeze metamorphism**
- Low spectral albedo of larger grains:
  - Incoming solar radiation is **scattered deeper** into the pack, increasing the chances of radiation absorption along that path
  - Causes a **positive feedback**, especially when coupled with darkening snow



Skiles et al. 2018

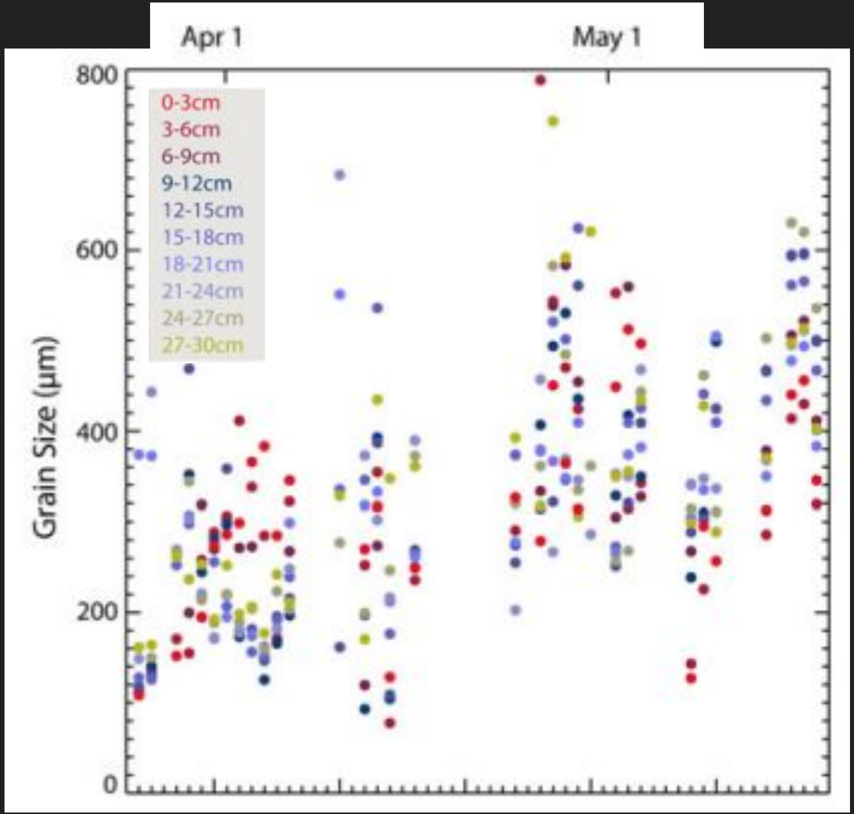
Aerosol effects on grain size

Grain growth pattern:

- First 2.5 weeks: slow growth (10μm d−1)
- Next 2.5 weeks: fast grain growth (17μm d−1)
- Final 2 weeks: slowing grain growth (1μm d−1)

Interpretation:

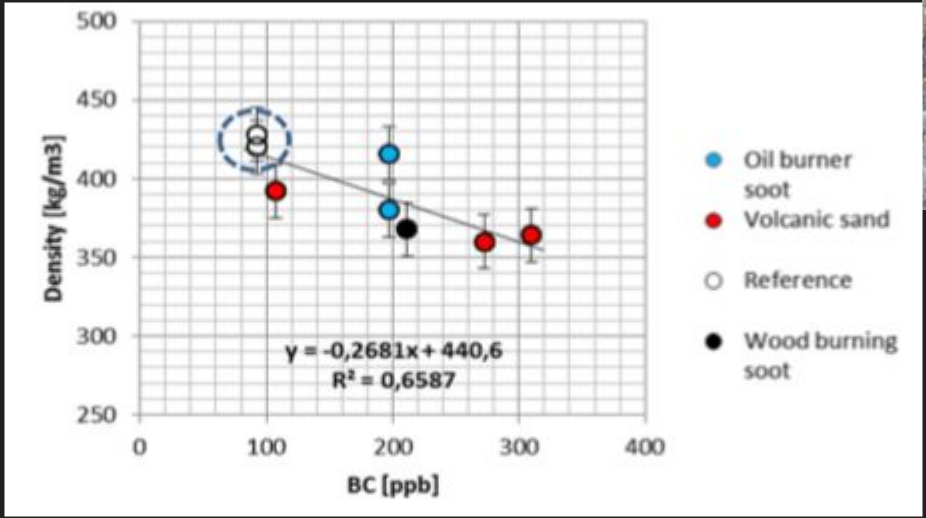
- First 2.5 weeks: clean snow
- Next 2.5 weeks: dust deposition
- Final 2 weeks: shift in control of snow metamorphism to liquid water

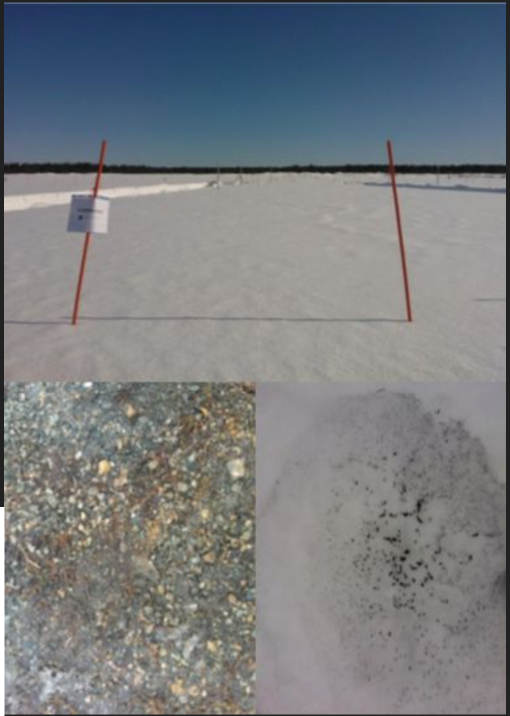


Skiles and Painter 2016

Aerosols and density / water retention

- Absorbing impurities cause melt, evaporation, sublimation, resulting in air pockets
- BC affects adhesion between liquid water and snow grains
- **BC results in larger snow grains, lowering water retention**





Meinander et al., 2014

Aerosols and insulation

- Volcanic ash accelerated snowmelt; however, once the layer of ash reached the critical thickness (15 mm), it delayed snowmelt by nearly 3 days.

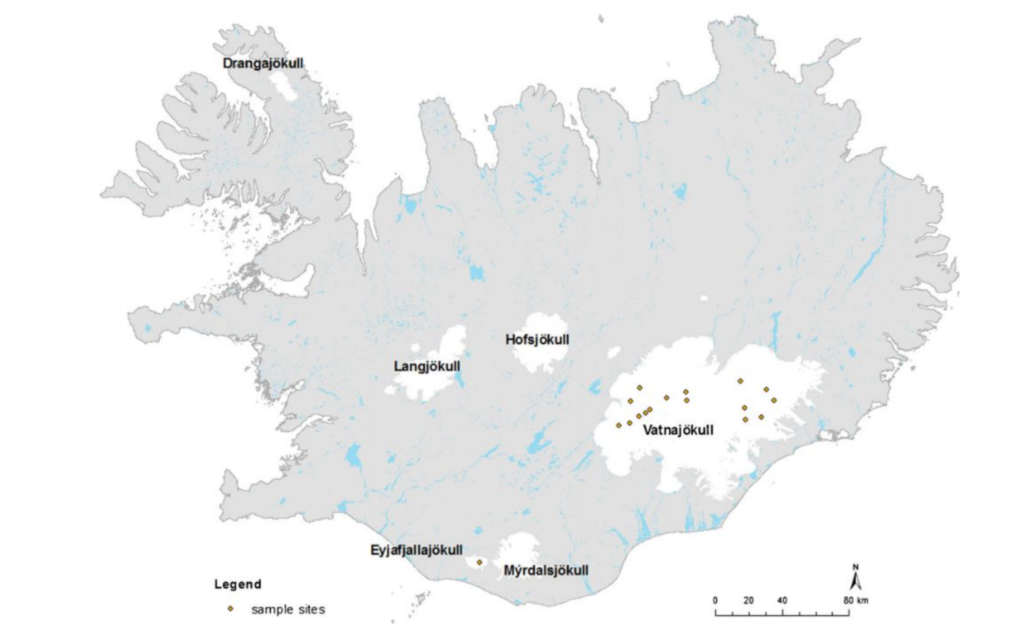


Fig. 1 Iceland with glacier outlines and sample sites on Vatnajökull and Eyjafjallajökull (base map by Landmælingar Íslands, 1993)

(Dragosics et al. 2016)

Penetration of solar radiation into pure and Mars-dust contaminated snow

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A B S T R A C T

Rock and soil surface layers absorb and reflect incoming solar radiation immediately at the surface. Ices on the other hand, whilst opaque in the infrared, are partially transparent in the visible spectral range. These properties are responsible for the "solid-state greenhouse effect" (SSGE), which may play an important role in the energy balance of icy surfaces in the Solar System. To model the SSGE, we need to know not only thermal properties but also optical properties such as the albedo and the absorption scale length of the ice. We have investigated the absorption scale length, also known as e-folding scale, of snow/dust mixtures within the scope of a project directed at investigating the behaviour of the martian polar caps. After measuring the e-folding scale of recrystallized snow we can now also relate the dust content of contaminated snow to the penetration depth of sunlight into the mixture. Equally important, however, is our observation that light penetration through the mixture is dramatically affected by small-scale inhomogeneities.

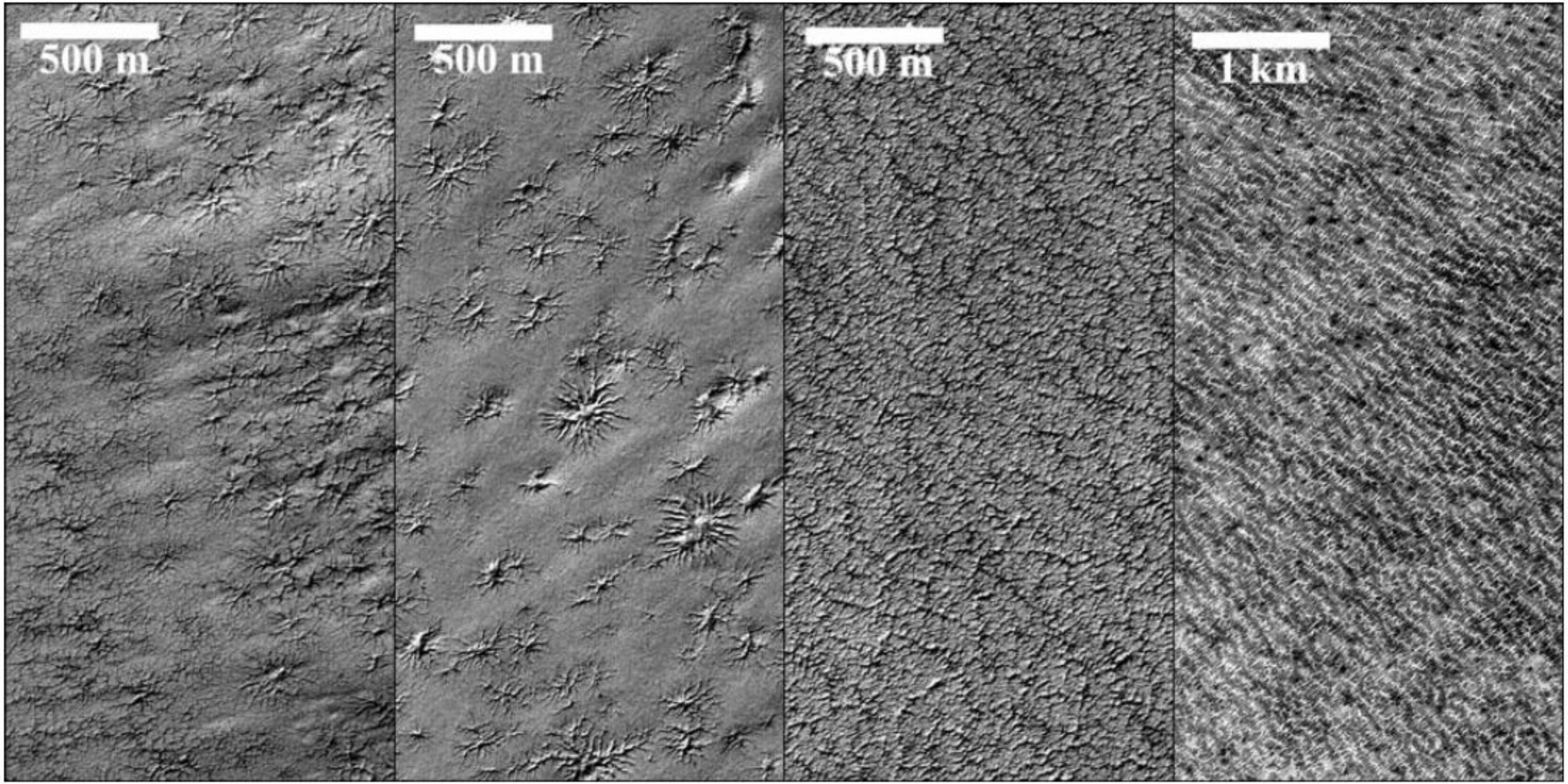


Figure 1. Examples of terrain which we have mapped as "spiders." Both well-separated spiders (left two panels) and merged spiders (right two panels) were considered. The MOC narrow angle images are, from left to right, M11/02573 (87°S, 260°W, L_s = 285°); M11/02368 (87°S, 233°W, L_s = 284°); M11/03283 (87°S, 261°W, L_s = 288°); and M09/00851 (87°S, 269°W, L_s = 237°).

(Piqueux et al. 2003)

Aerosols in Maritime Snow

- BC concentrations:
  - Snow accumulation: homogeneous distribution
  - Snow melt: more spatial variability
  - Sublimation: reduces snowpack by nearly 10 mm in maritime regions
  - Rapid snowmelt: decrease in BC

(Sturm et al. 1995)

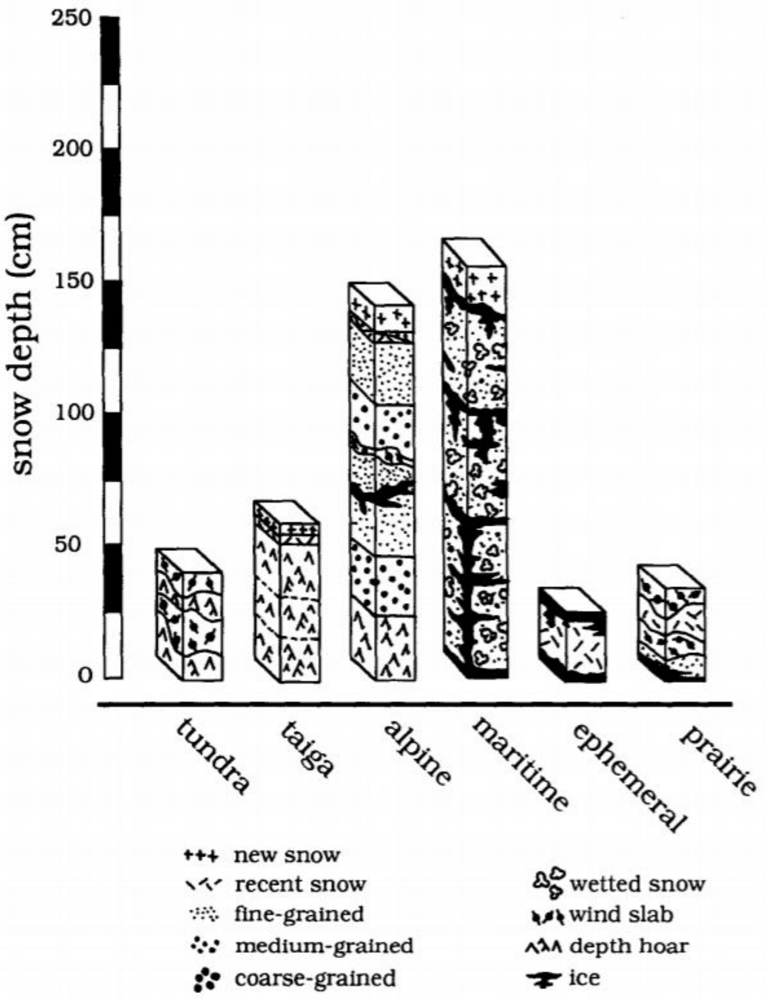


FIG. 2. The basic stratigraphic and textural attributes of each class of snow cover as they would appear in middle to late winter. Symbols follow Colbeck et al. 1992.

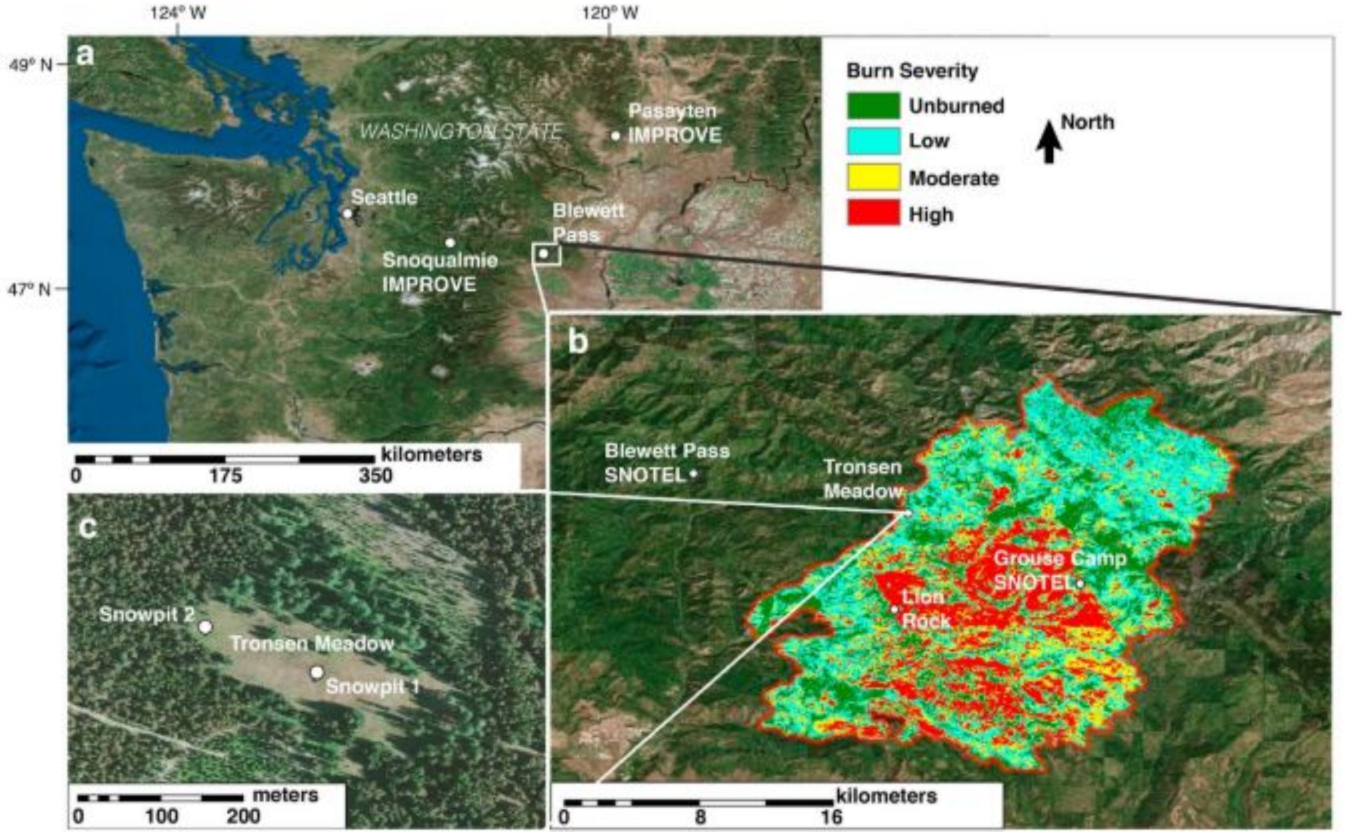


Figure 1. Map of the study area. (a) Location in Washington State, USA, of the Blewett Pass study area and Snoqualmie and Pasayten IMPROVE sites. (b) Burn severity map of the Table Mountain fire during 2012, and location of the Tronsen Meadow and Lion Rock study areas and the Blewett Pass and Grouse Camp SNOTEL sites. Burn severity is detailed in *Liu et al.* [2011]. (c) Snowpit locations within Tronsen Meadow.

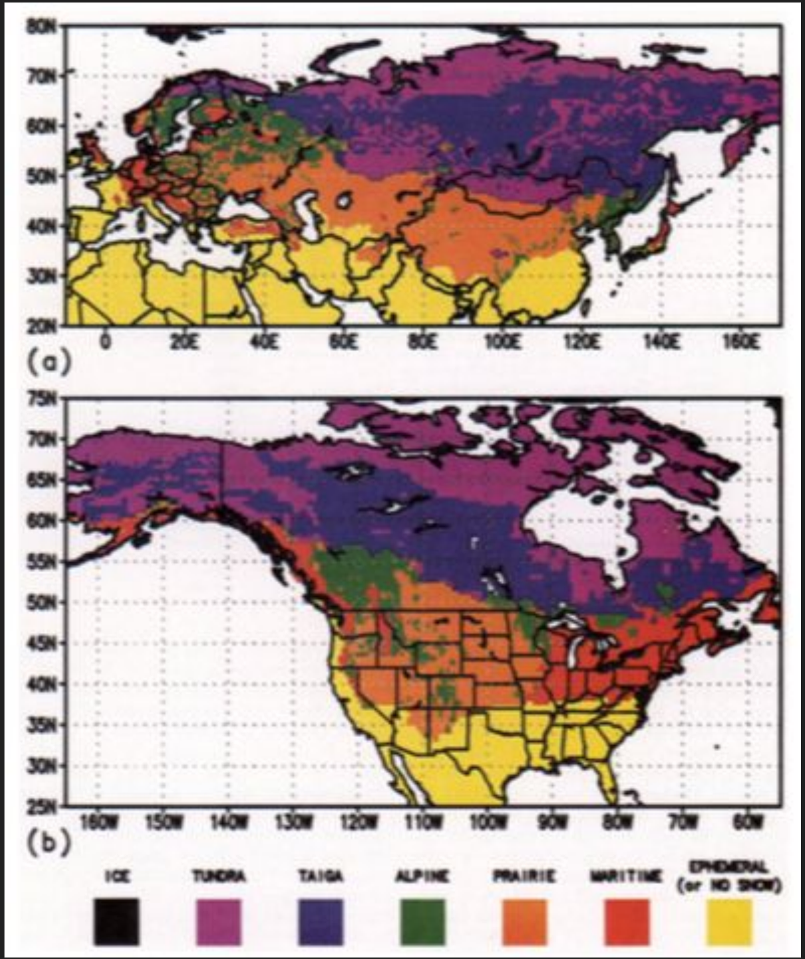
(Delaney et al. 2015)

Aerosols in alpine snow

- Snowpack depth: 70-250cm
- Low wind speeds
- High temperatures

Many mid-latitude sites, and largely seasonal snowcover

- Mid latitudinal snowpack melting is intensified due to LAPs being at the surface during the summer when solar irradiance is greatest



Sturm et al., 1995

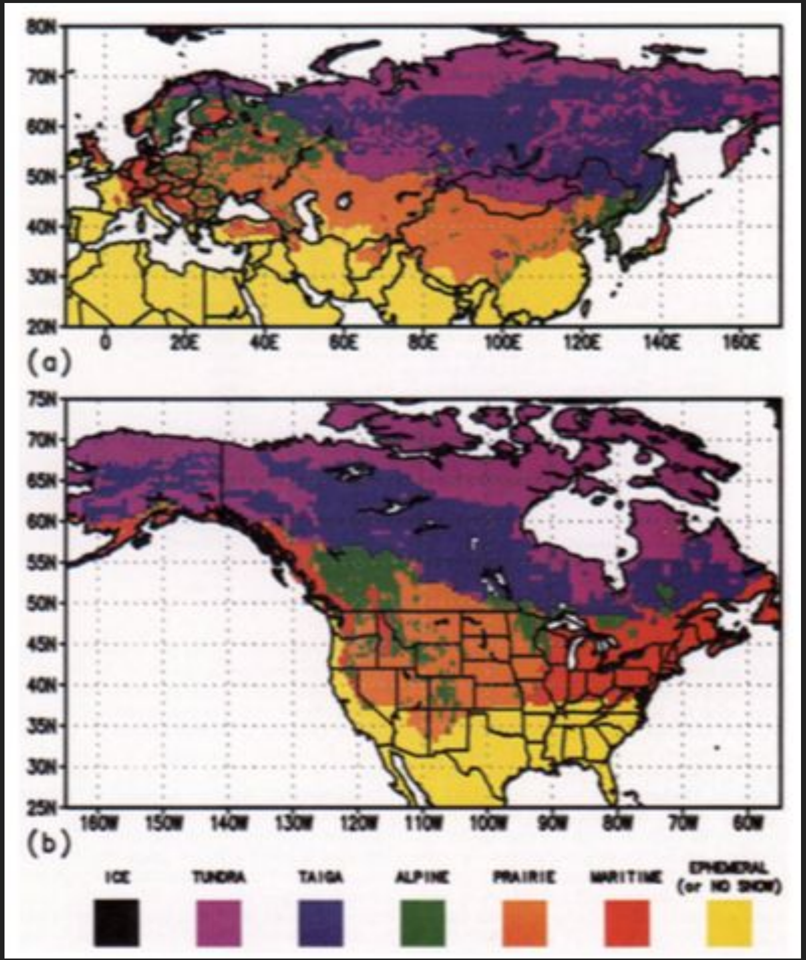
Aerosols in alpine snow

- These regions experience significant radiative forcing from dust and BC due to being close to dust sources
    - European mountains - Saharan dust
    - HMA - BC from industrial regions in Asia; dust from Middle East, northern Africa, Asia
    - Northern China - similar to HMA, but snow is annual, not perennial
    - North America (mid- to southern Rockies) - Colorado Plateau
- Advances melt by as much as a month

jpl.nasa.gov

Aerosols in tundra/taiga snow

- Shallow snowpack (depth: 10-120 cm)
- Low precipitation rates and cold temperatures (snow/ground interface temperatures below 0 degrees C)
- Low bulk density (0.26-0.38 g / cubic cm)
- Difference in wind speed (tundra: high, taiga: low)

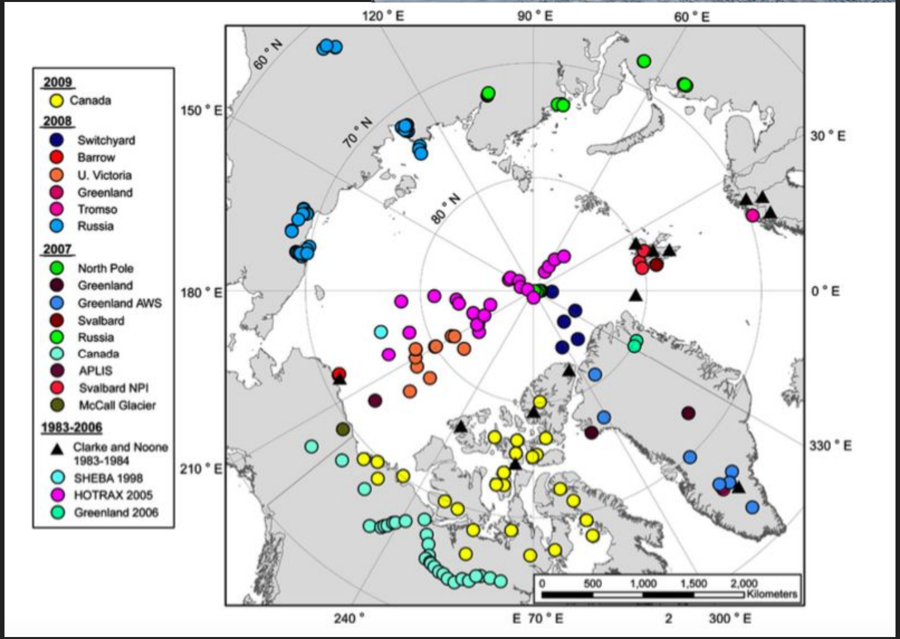


Sturm et al., 1995

Aerosols in tundra/taiga snow

- 1200 snow samples collected in Alaska, Canada, Greenland, Svalbard, Norway, Russia, Arctic Ocean 1998 and 2005-2009
- Impurities in snow are significant for surface energy budget
- Concentrations are highest in Russia, Scandinavia, and Svalbard
- Impurity concentrations are lower than 1983-84 study
- 20-50% of light absorption is non-black carbon

Doherty et al., 2010



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