Remote Sensing of Snow

Jakob Steiner

Date: 7 April 2022

overview

Importance of snow

Crucial variables of snow

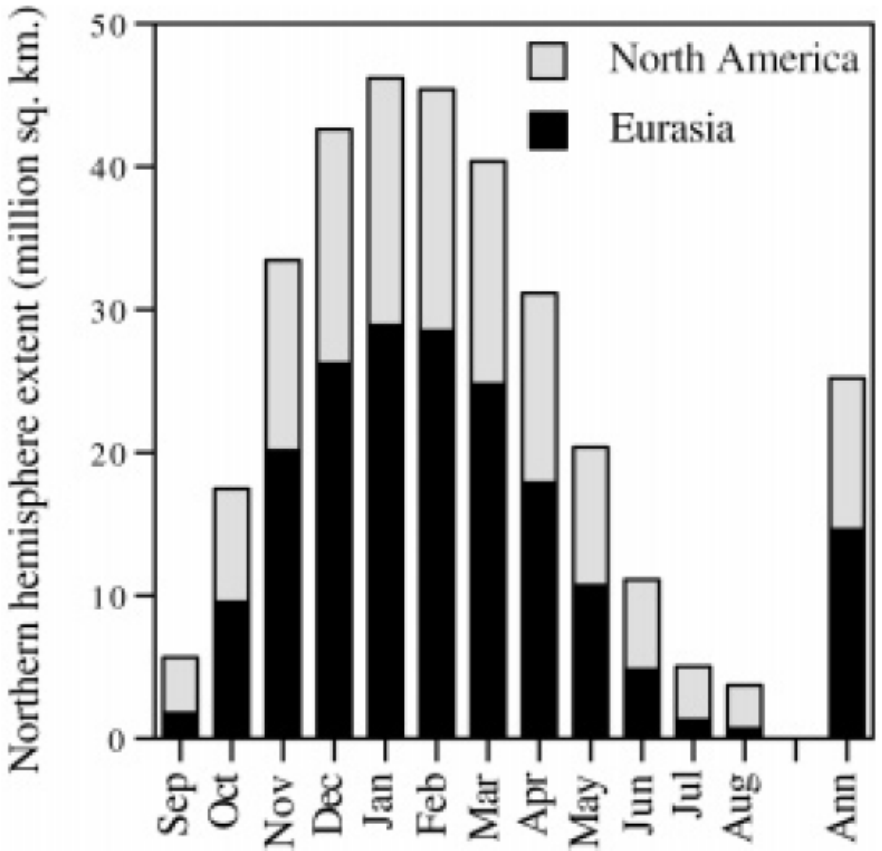
Remote sensing of snow

- Variables
- Active vs Passive sensors

What remote sensing can’t see (yet)

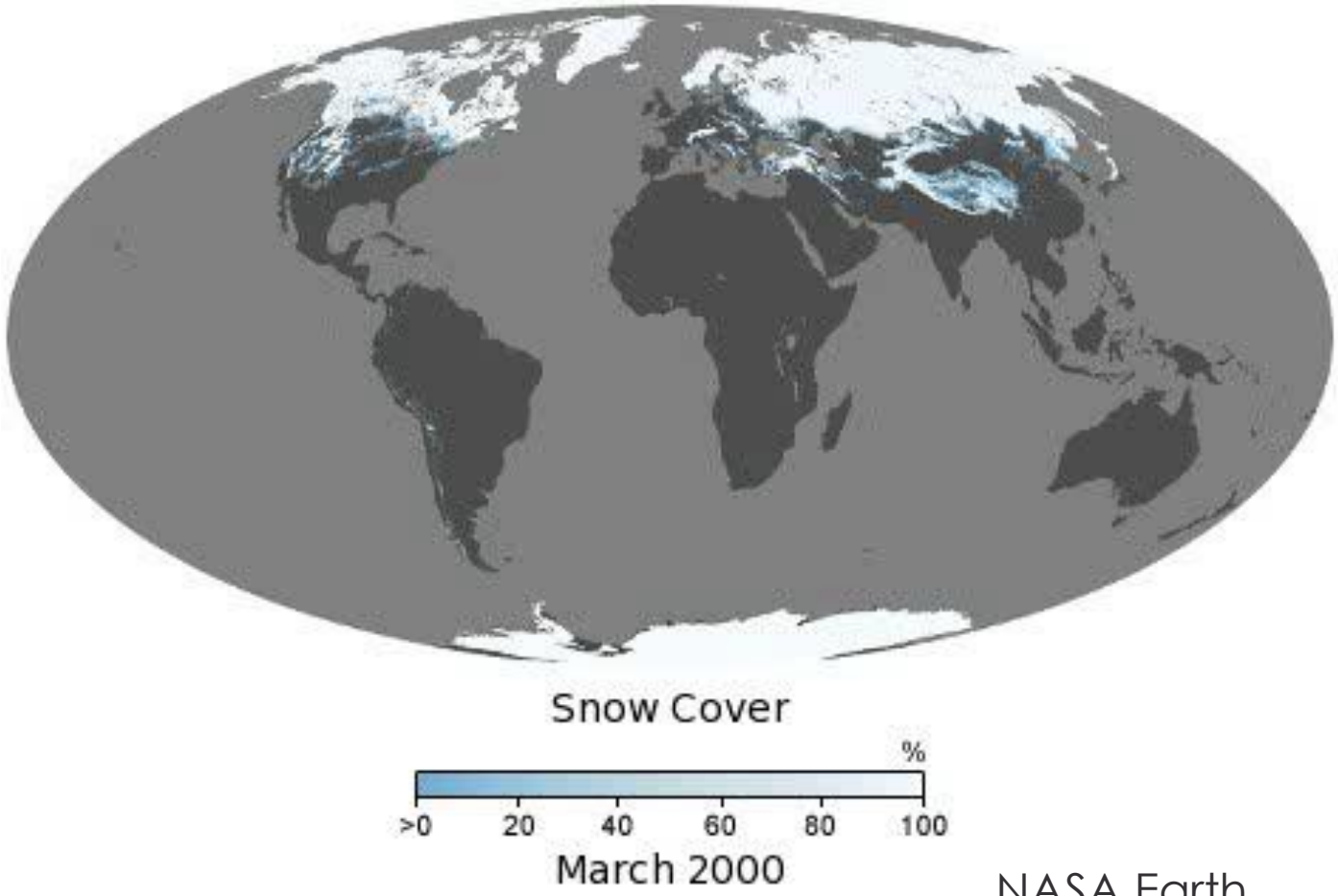
Global snow cover

Mean monthly SE (1972-1999)



Robinson and Frei, 2000

Global snow cover



NASA Earth Observatory

does it ever snow in Lahore?

DAWN, 2011

https://www.dawn.com/news/609813/snow-day-in-lahore

why does snow matter?

why does snow matter?

Hydrology

Climate
- albedo affects energy balance

Avalanches

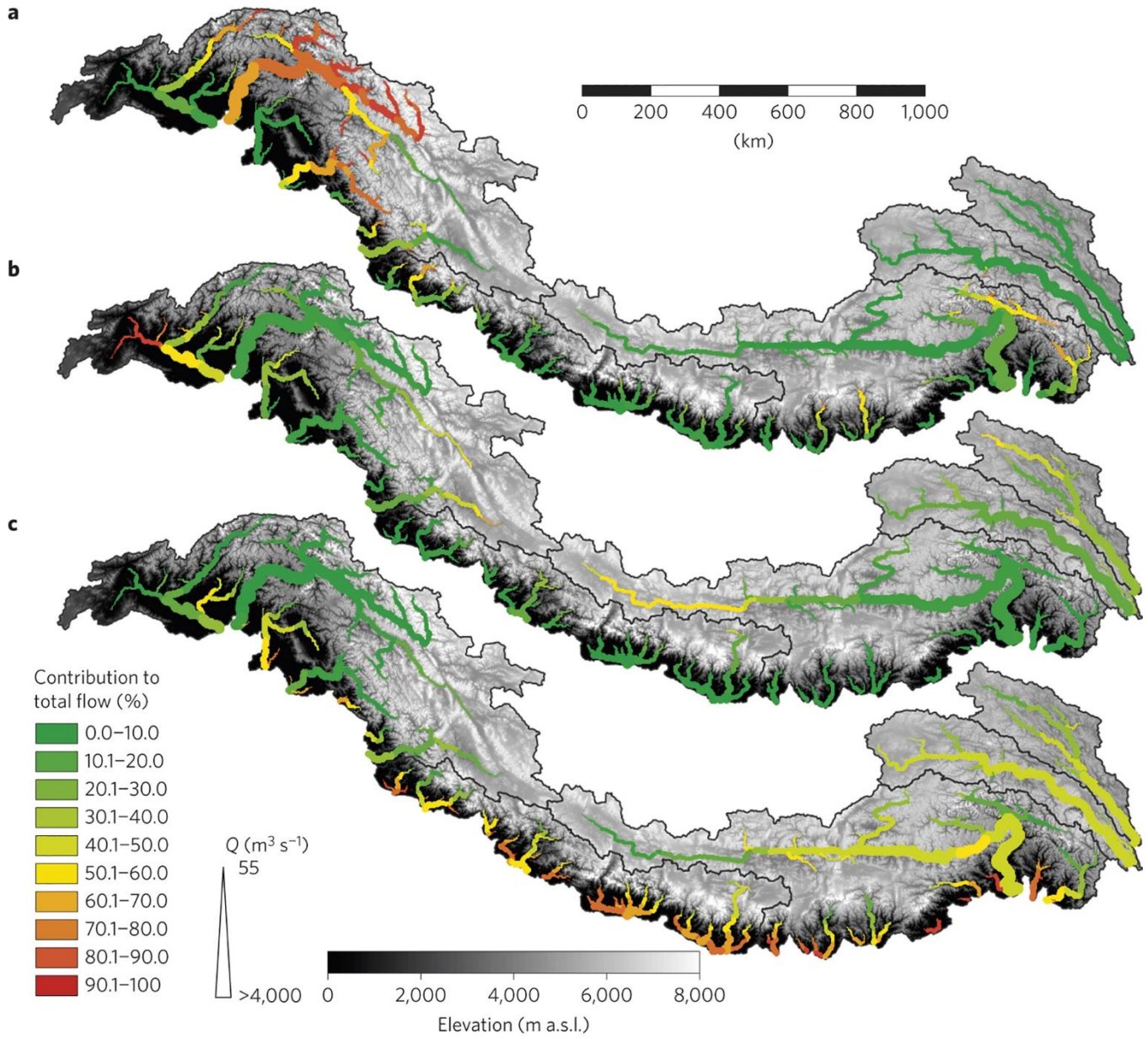
Saturation of soils from melt

snow melt in discharge

(a) glacier melt

(b) snow melt

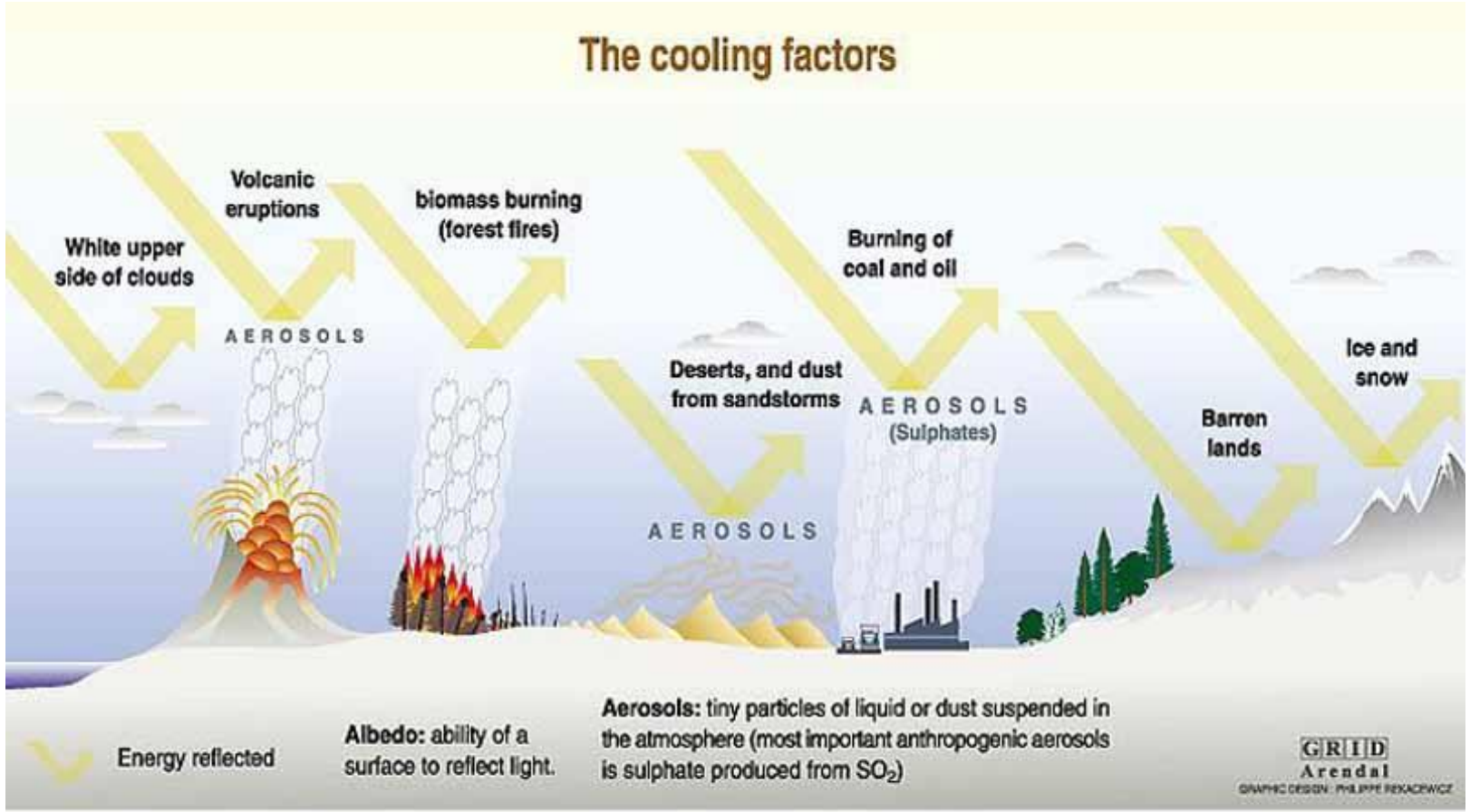
(c) rainfall



Lutz et al. 2014

albedo effect

- Fresh snow results in ~90% of radiation to be reflected
- Feedback loop: less snow -> warmer earth -> even less snow

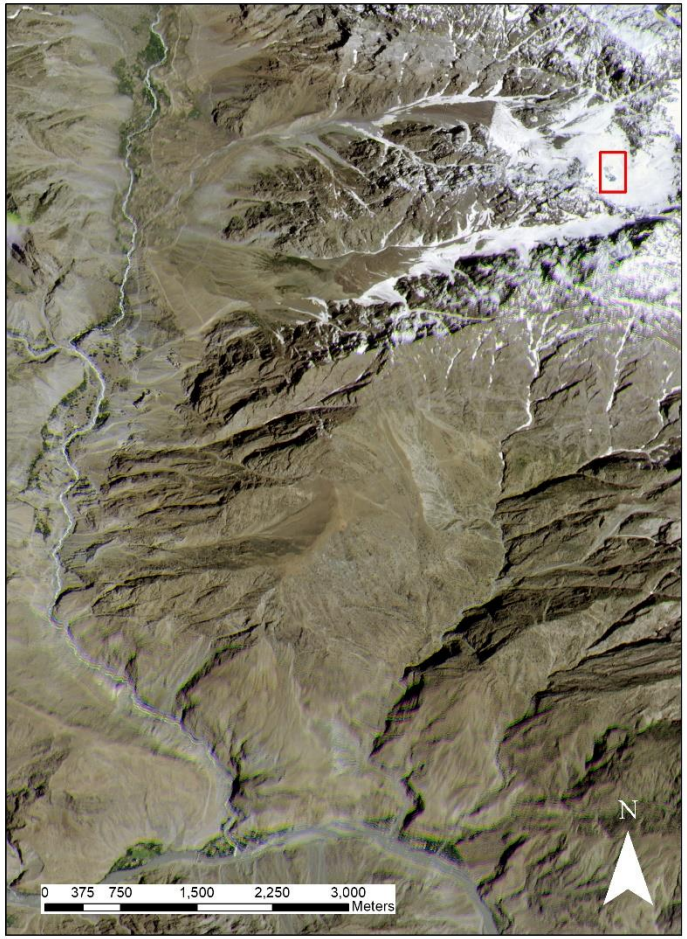


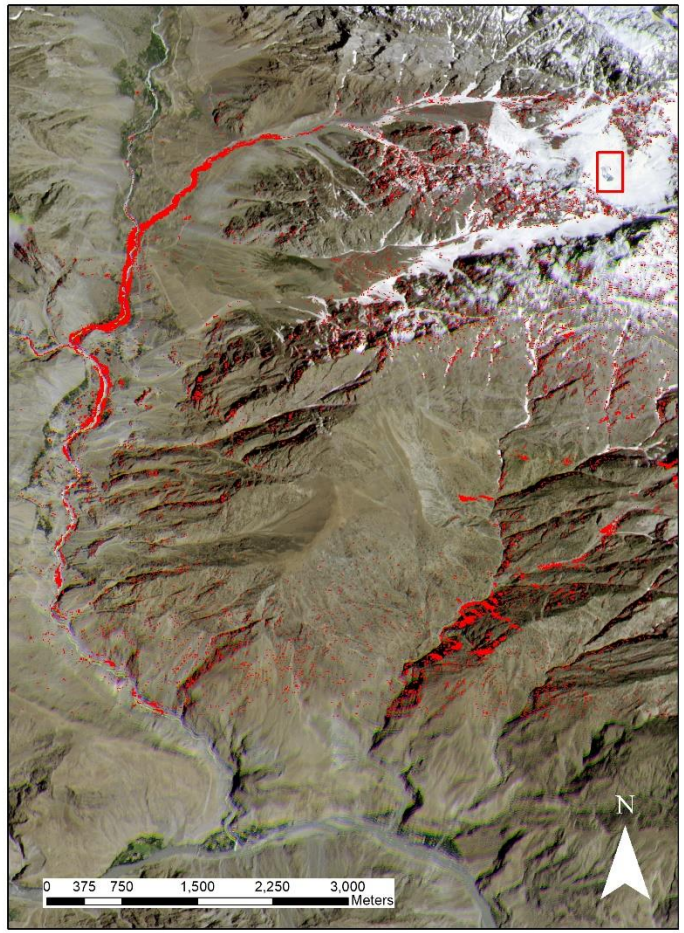
Sources: Radiative forcing of climate change, the 1994 report of the scientific assessment working group of IPCC, summary for policymakers, WMO, UNEP; L.D. Danny Harvey, Climate and global environmental change, Prentice Hall, pearson Education, Harlow, United Kingdom, 2000.

GRID Arendal

avalanches

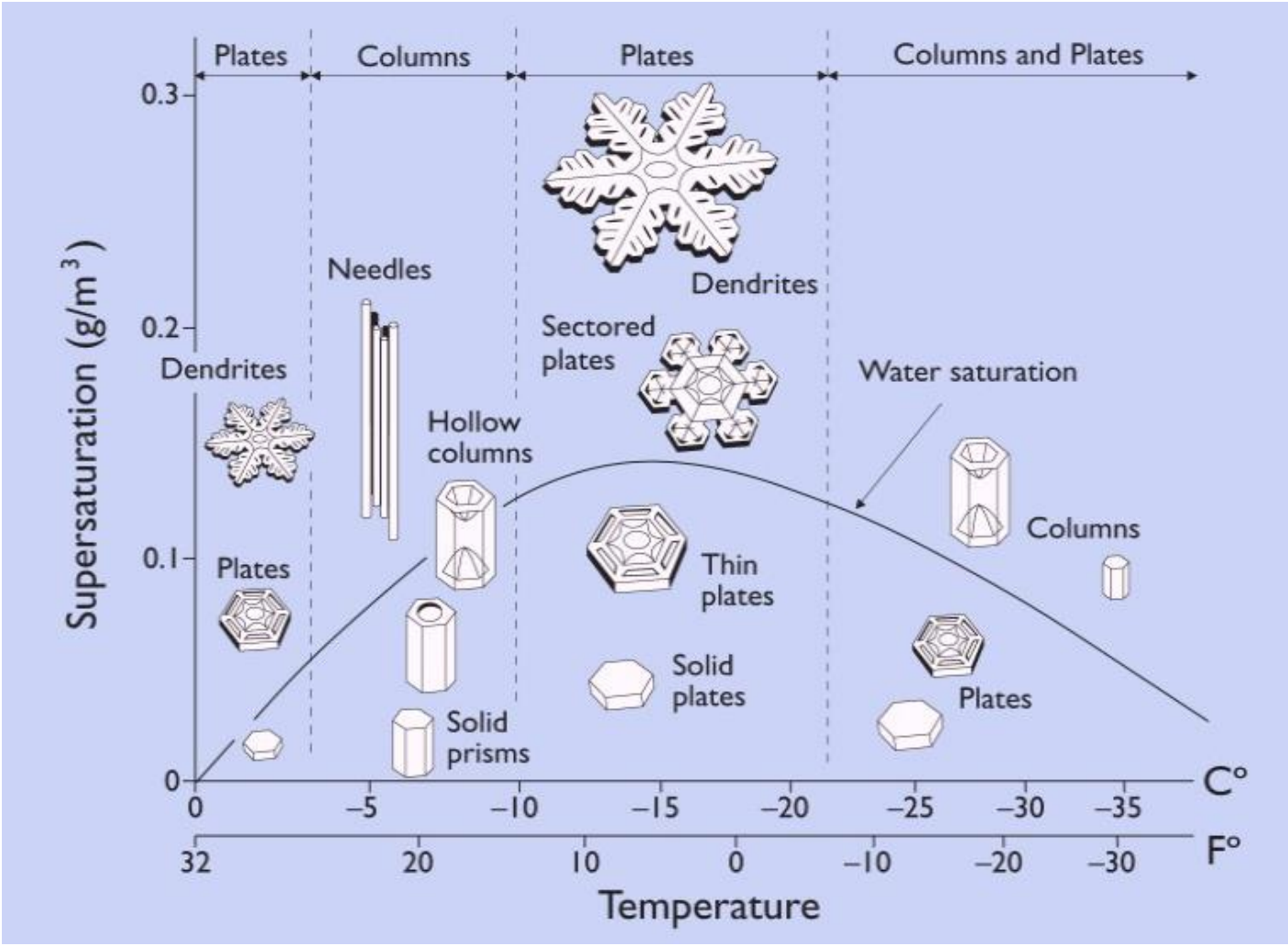
debris flows after soil saturation





Darmander debris flow (maps: Jakob Steiner)

what is snow?


Plates
Columns
Plates
Columns and Plates
0.3
0.2
0.1
0
Supersaturation (g/m³)
Needles
Dendrites
Dendrites
Sectored plates
Water saturation
Hollow columns
Thin plates
Columns
Plates
Solid plates
Plates
Solid prisms
C°
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Temperature

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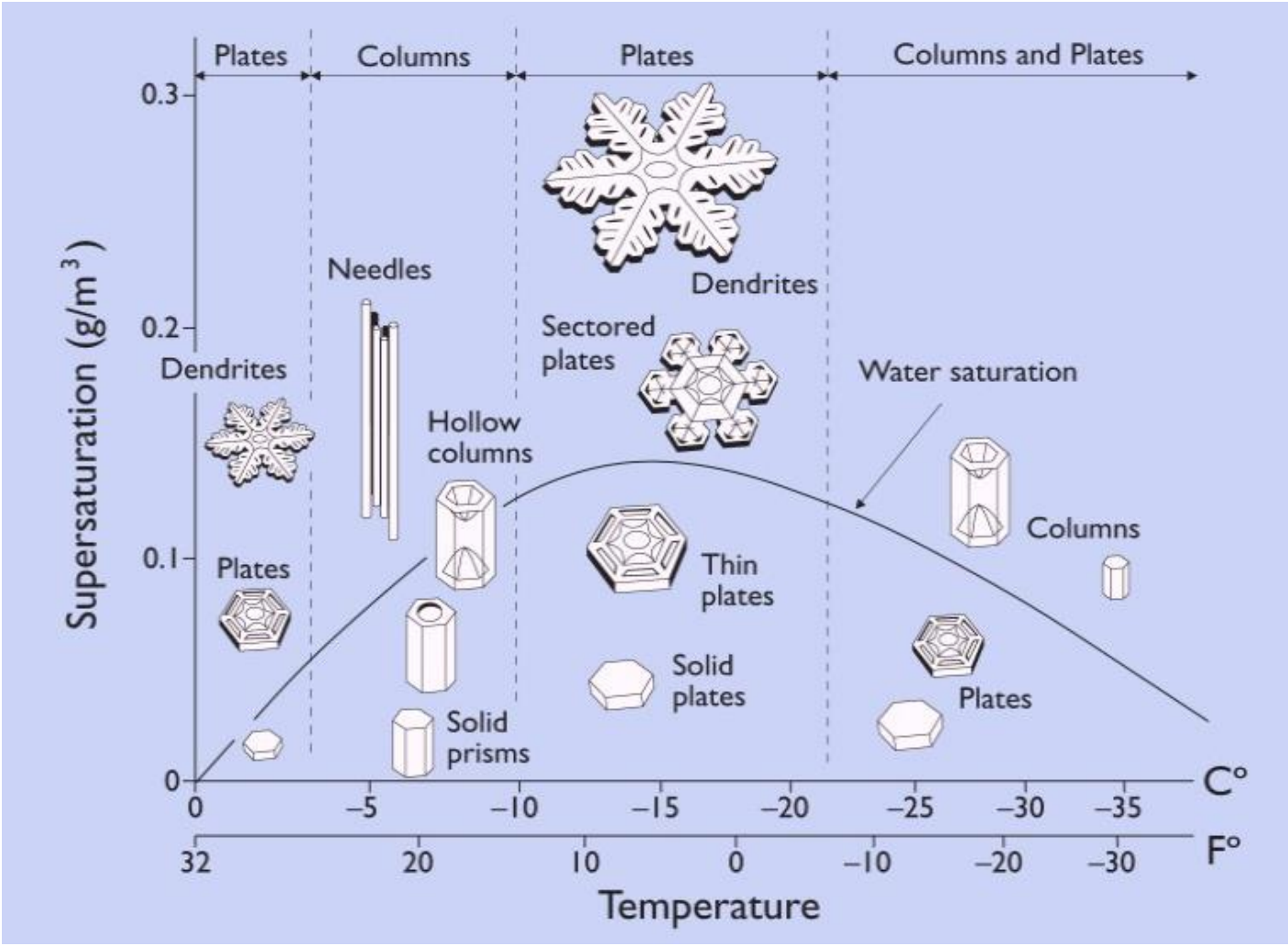
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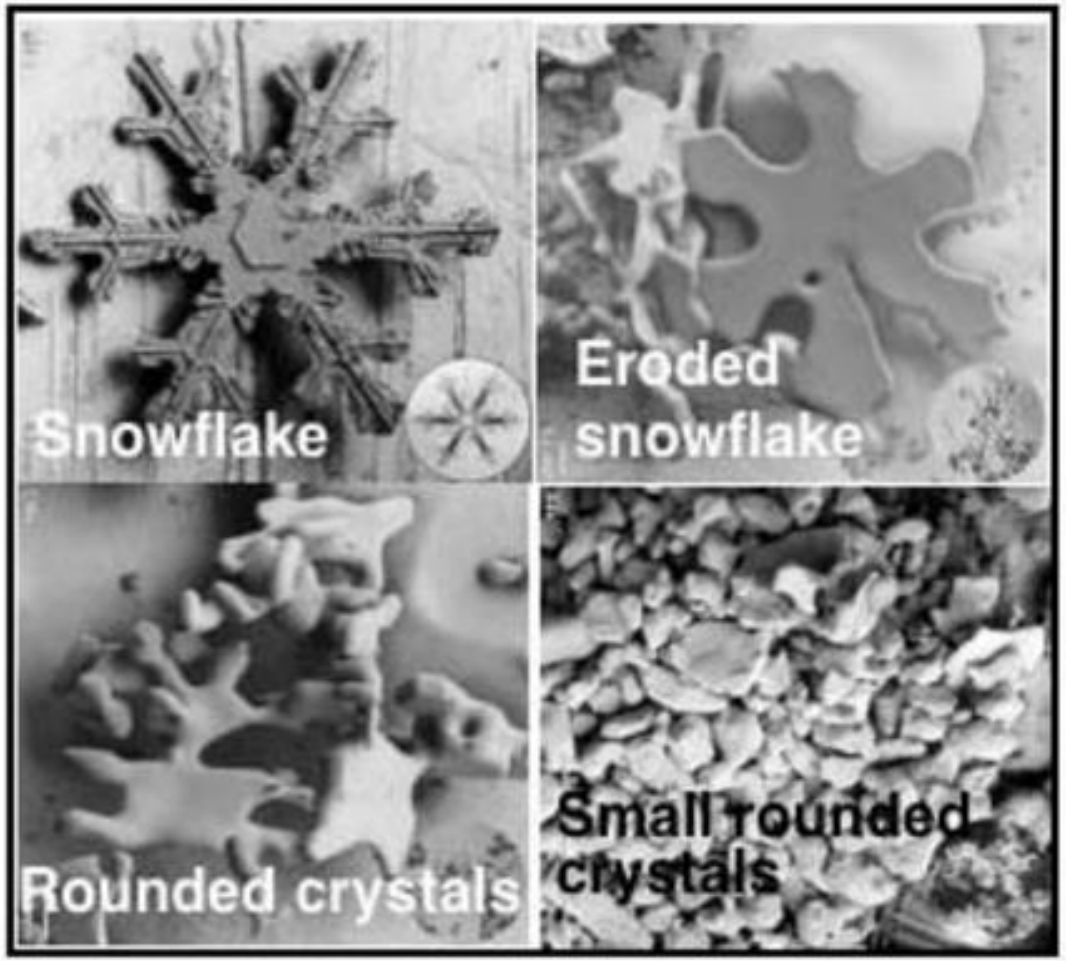
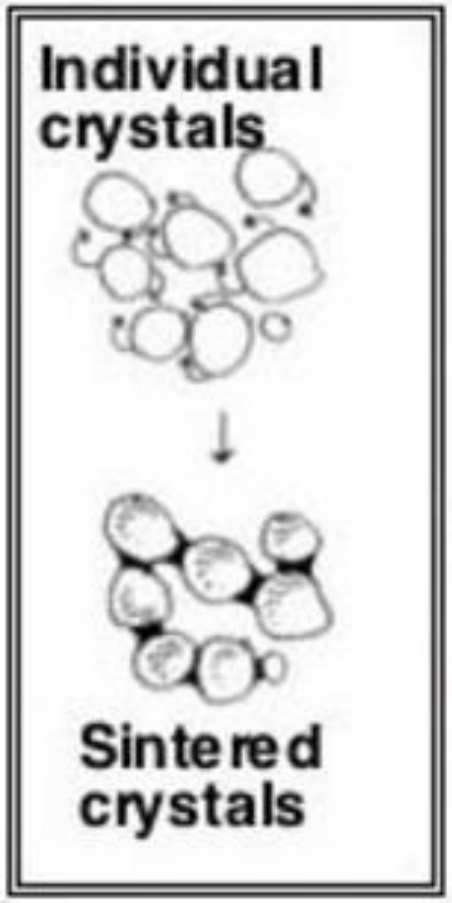

Snowflake
Eroded snowflake
Rounded crystals
Small rounded crystals


Individual crystals
Sintered crystals

variables of snow

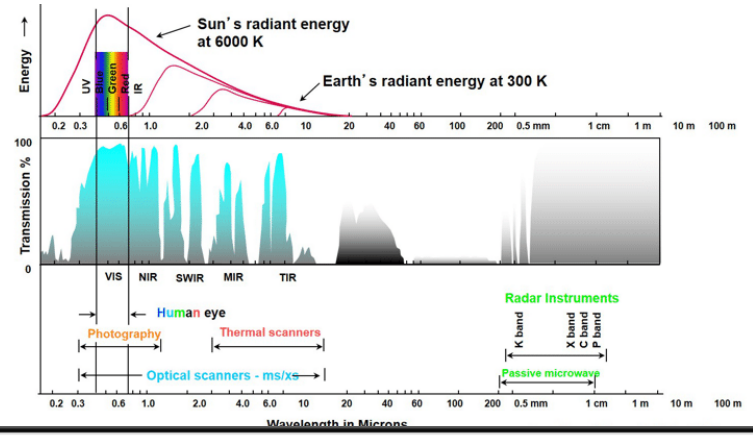
Property	Fresh snow	Settled snow
Snow cover extent or fraction (m^2 or %)	-	-
Depth (m)	-	-
Density (kg m^{-3})	20-150	250-550
Snow water equivalent (m w.e.)	-	-
Grain size (µm)	variable	variable
Albedo (-)	0.8-0.9	0.4-0.6
Thermal conductivity (W m^{-1} $°C^{-1}$)	0.03-0.06	0.1-0.7

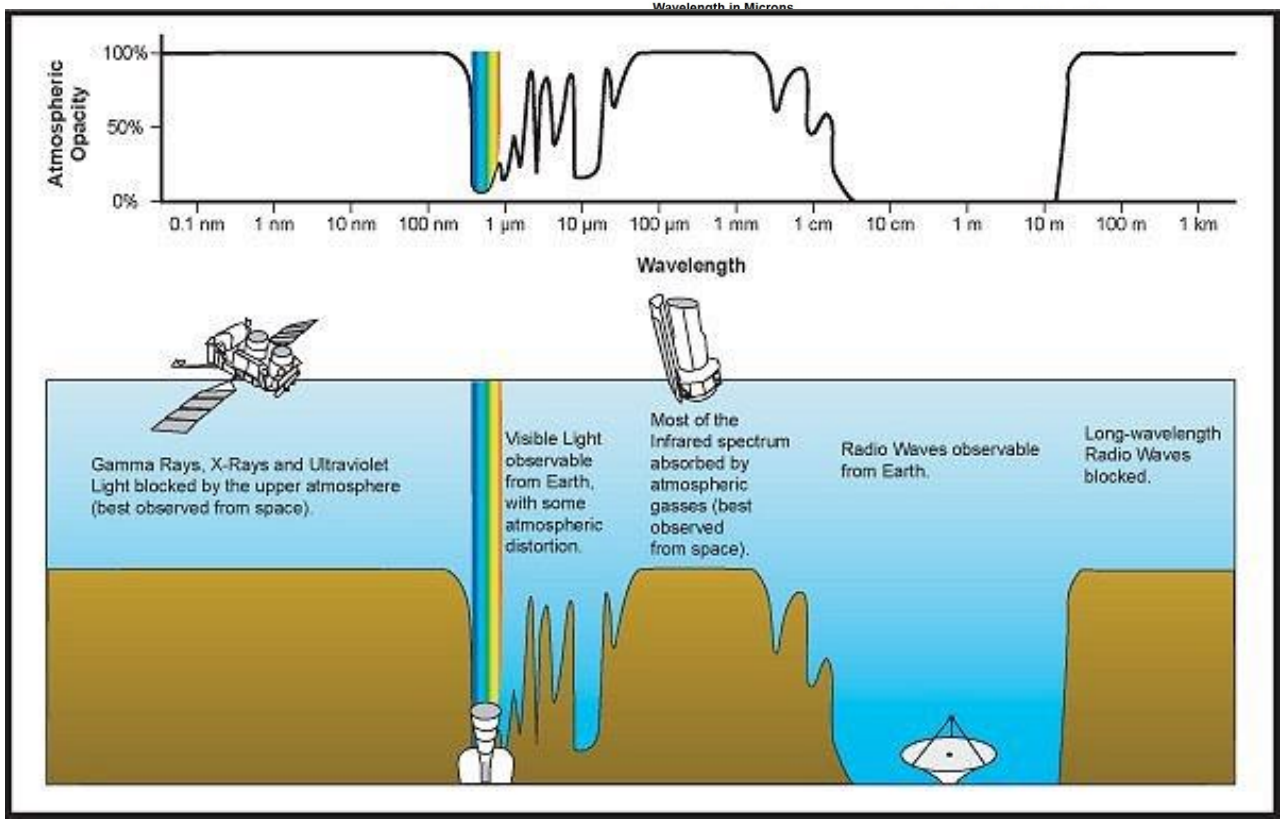
Remote sensing

Exploiting wavelengths

… of satellites

… of the earth surface





Active vs Passive Sensors

Passive sensors: record reflected or emitted electromagnetic signal

- visible light (reflected, optical imagery, daytime)
- microwave (emitted, AMSR, day and night)

Active sensors: send energy pulses and measure their return

- LIDAR (visible, SW)
- Radar (microwave)

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snow properties from optical imagery

Spectrometers

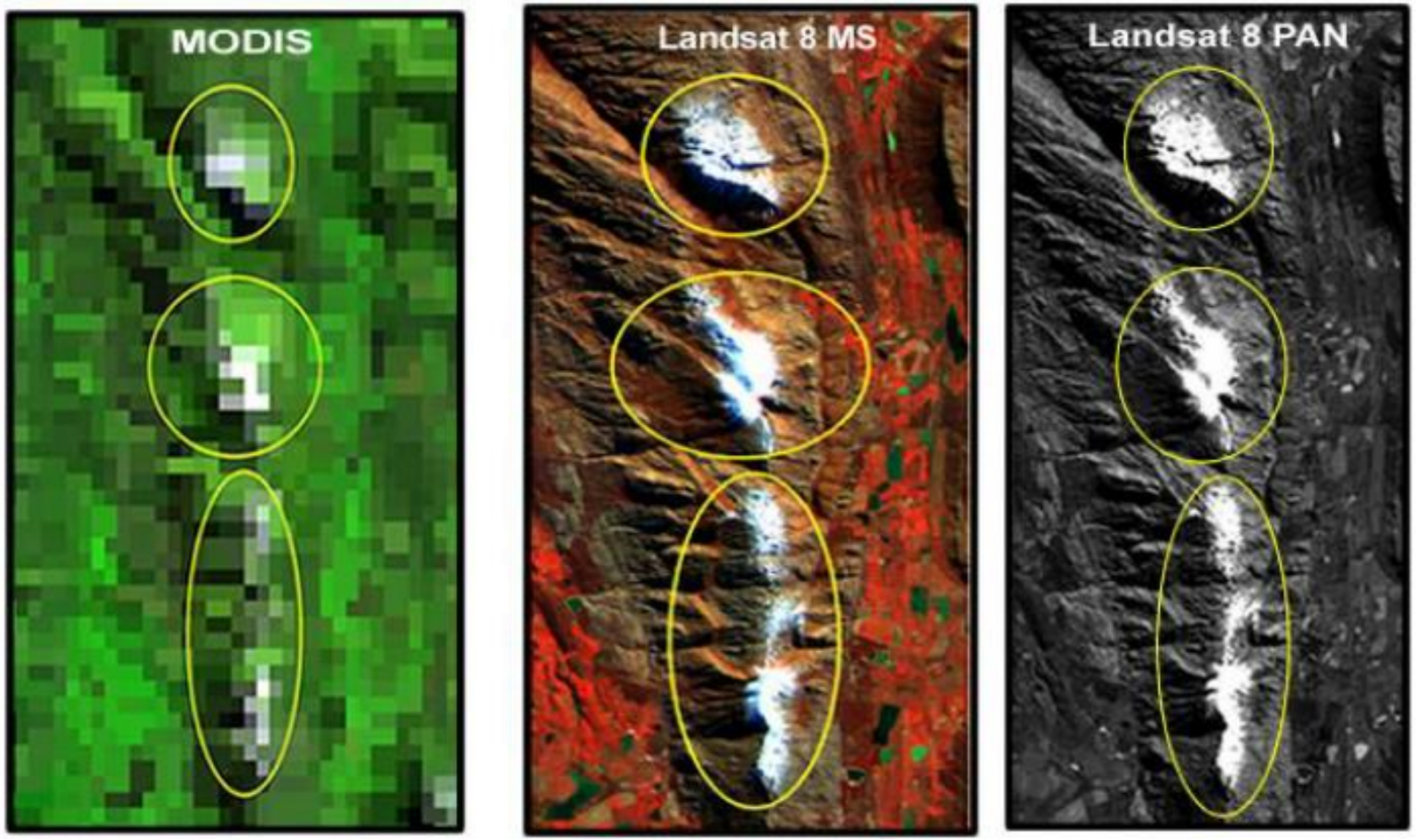
- Snow covered area/duration
- Snow grain size
- albedo/darkening (LAPs)

Cameras

- Repeat photogrammetry to produce snow depth

Resolution

- Spatial (0.5 – 5000 m)
- Temporal (revisit time, daily to bi-weekly)
- Spectral (number of bands, one to ~ten)
- Radiometric (variation in brightness)



Sibandze et al. (2014)

Temporal Resolution

Landsat:

+ Spatial accuracy

- Long revisit time

- Impact of clouds

MODIS

- Spatially coarse

+ independent of clouds

+ near daily revisit

Satellite(s)—Instrument(s)	Operational since/until	Revisit Time	Spatial Resolution	Swath Width
Landsat MSS/TM/ETM+/OLI	1972/Today	16–18 days	30–100 m	185 km
Terra, Aqua-MODIS	2000/Today	Twice per day	250–1000 m	2330 km
TIROS/NOAA/Metop AVHRR	1978/Today	At least daily	1100 m	2400 km
Envisat/AATSR	2002/2012	2–3 days	1000 m	500 km
Envisat/MERIS	2002/2012	2–3 days	300 m	1150 km
ERS-2/ATSR-2	1995/2011	2–3 days	1000 m	512 km
Sentinel 2	to be launched in 2015	3–5 days	10–60 m	290 km
Sentinel 3-OLCI/SLSTR	to be launched in 2015	1–2 days	300–500 m	1270 km
Suomi-NPP-VIIRS	2011/Today	Daily	375–750 m	3040 km

Sources: [33–41].

Andreas et al. (2014)

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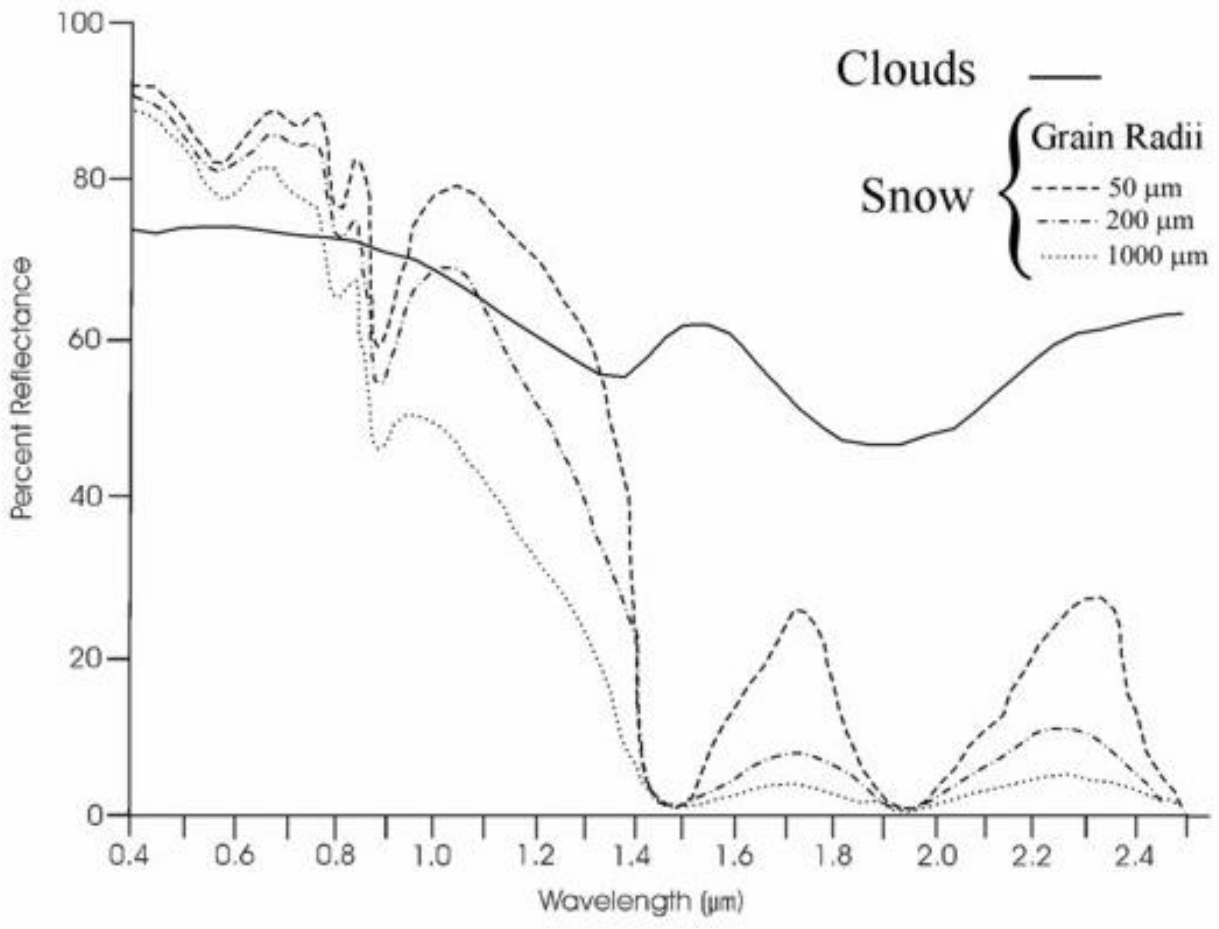
Spectral signature of snow

Reflectance in different parts of the electromagnetic spectrum

Snow is generally highly reflective as ice is transparent resulting in scattering

- For short wavelength absorption is controlled by light absorbing particles (LAPs)
- For longer wavelengths ice is absorptive and reflectance is controlled by grain size (radius, specific surface area)

http://snow.engin.umich.edu/



Reflectance vs albedo

Reflected waves are picked up in a directional manner by eyes (case 7)/satellites (case 8)

Albedo is the hemispherical budget of reflected waves (case 9)

Incoming/**Reflected**	**Directional**	**Conical**	**Hemispherical**
Hemispherical	Hemispherical-directional Case 7	Hemispherical-conical Case 8	Bihemispherical Case 9

Milton et al. (2007)

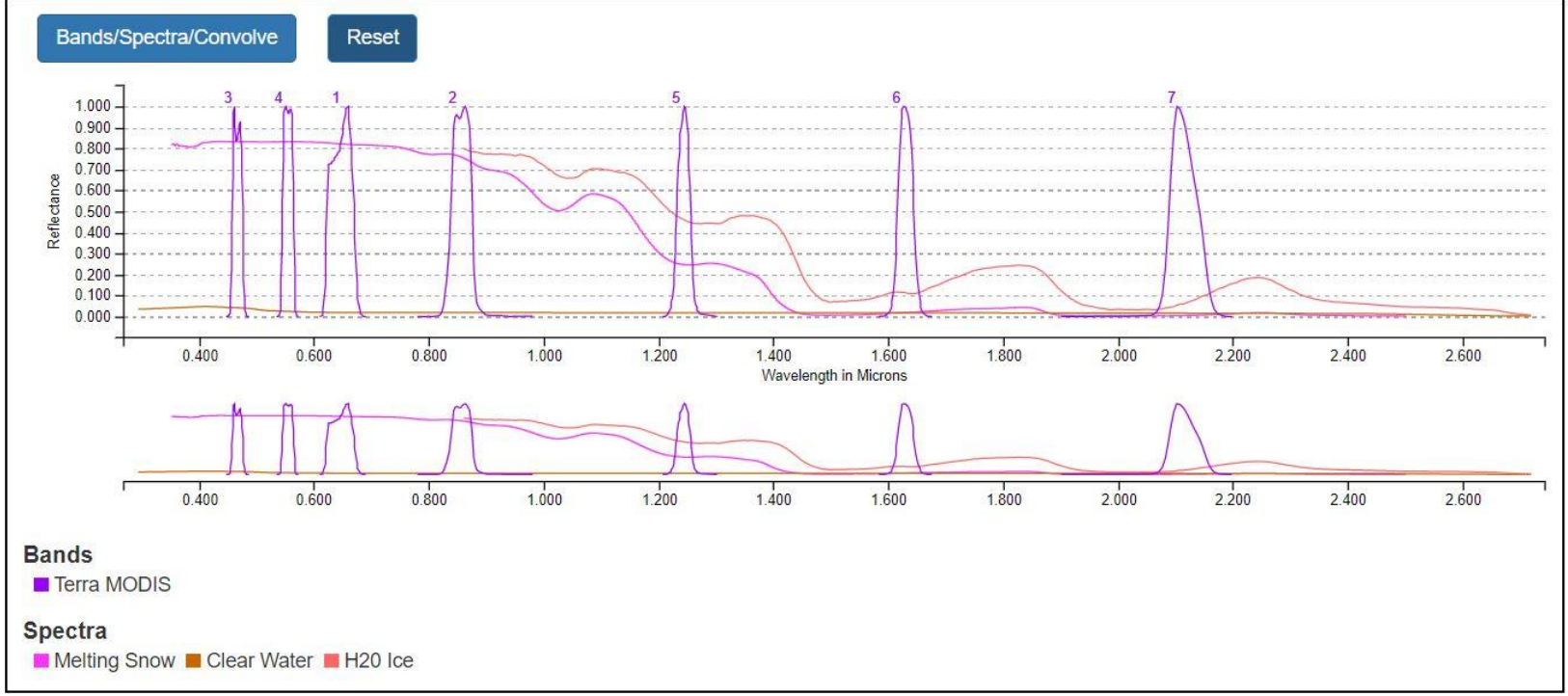
Multispectral bands

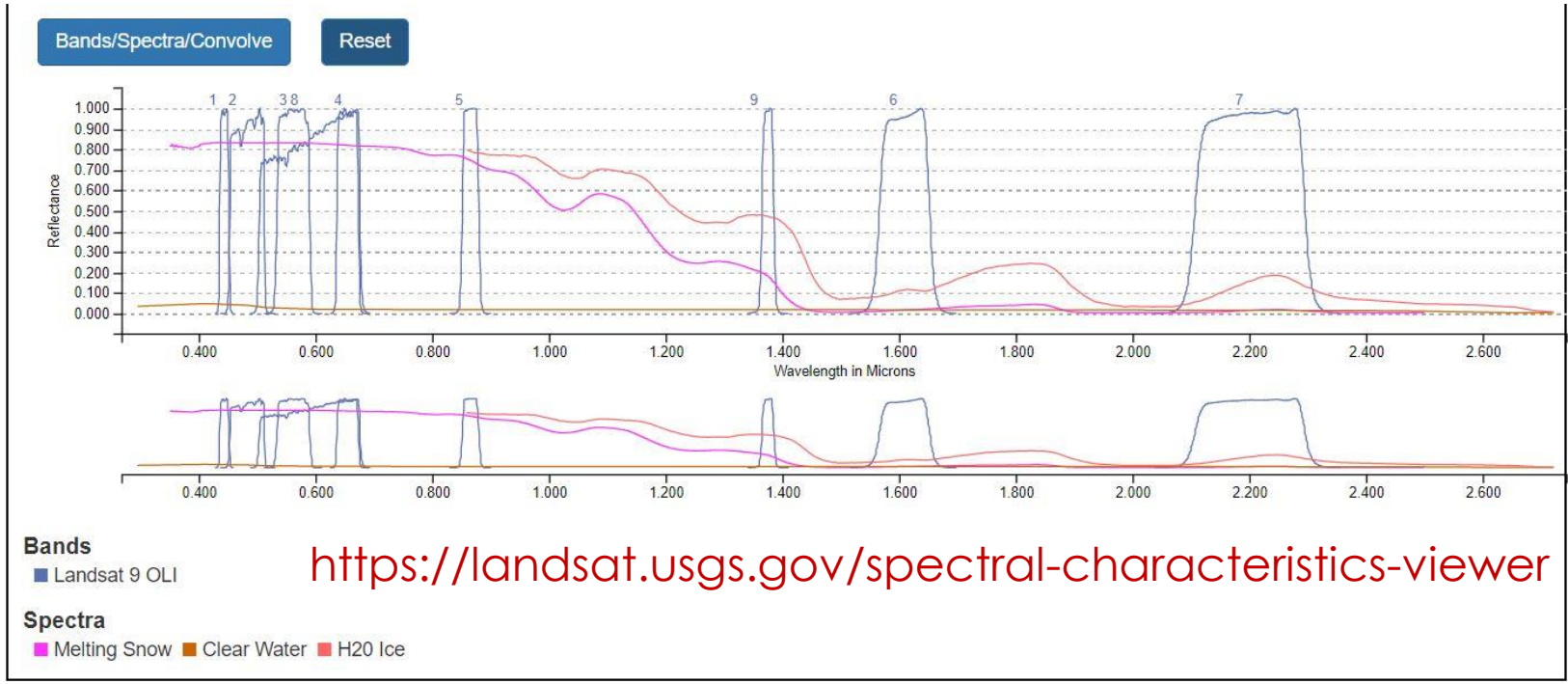
$$NDSI = \frac{VIS - SWIR}{VIS + SWIR}$$

MODIS: b 4 / b 6

Landsat: b 3 / b 6

NDSI > 0.4 → snow





https://landsat.usgs.gov/spectral-characteristics-viewer

snow covered area

NDSI (normalized differential snow index, binary)

- computationally efficient
- long practice and equivalent to other such indices (NDVI, NDWI etc)
- but…

Challenges …

- Resolution becomes an issue:
  - MODIS 500 m
  - Landsat 30/90 m
- Fractional snow cover increasingly important for hydrology, permafrost and ecology

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snow covered area

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- computational
- long practice c
- but…

fSCA (fractional sn

- uses all bands to

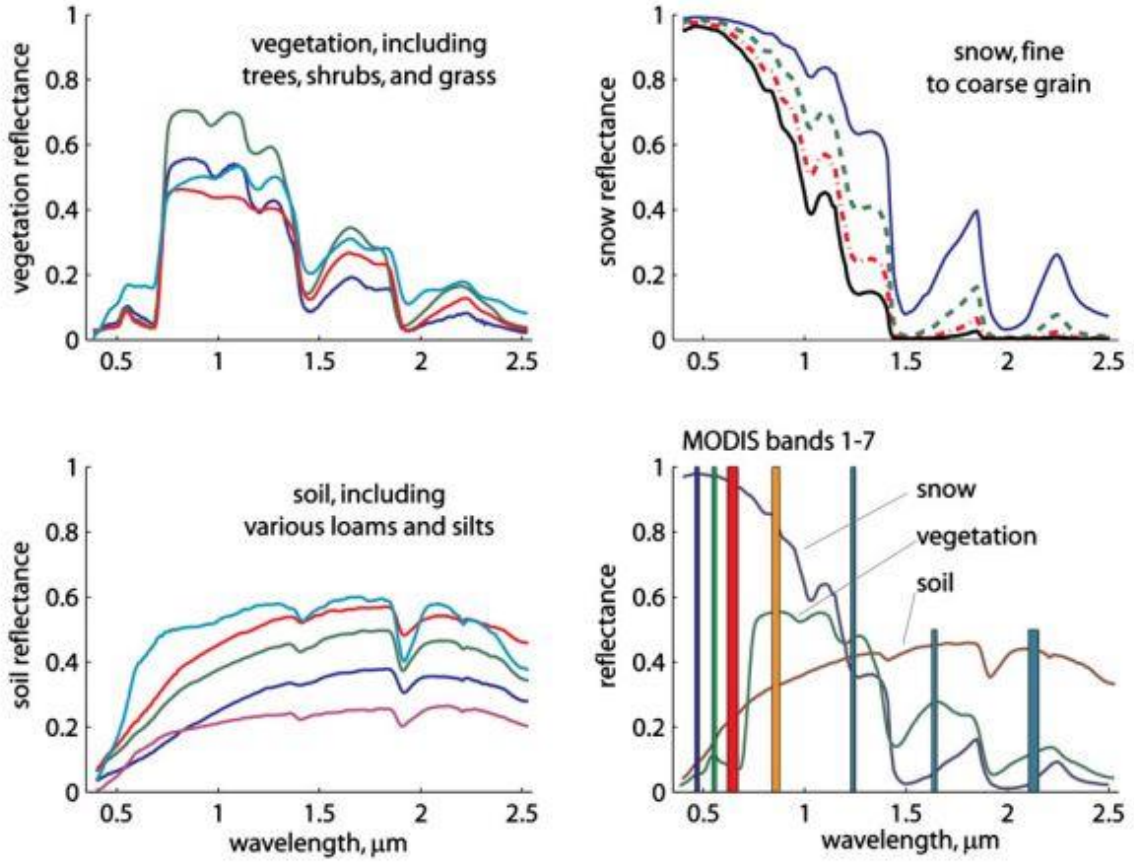


Fig. 1. Spectral reflectance of snow, vegetation, and soils. The vegetation and soils data are from laboratory or field measurements. The snow reflectance values are generated from a radiative transfer model. In the lower right graph, the MODIS land bands are shown, along with one sample spectrum each from vegetation, snow, and soil.

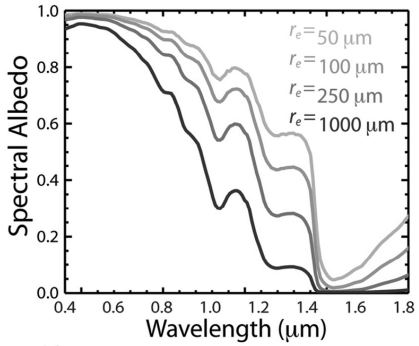
Painter et al., 2009

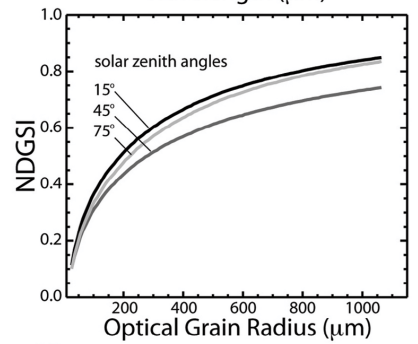
snow grain size

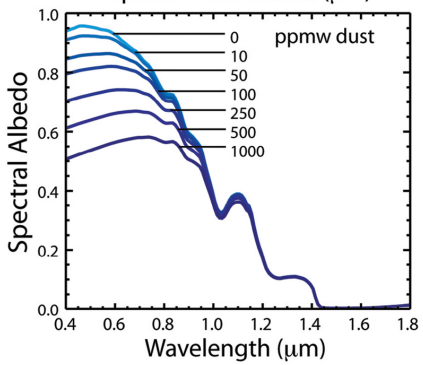
NDGSI (normalized differential grain size index)

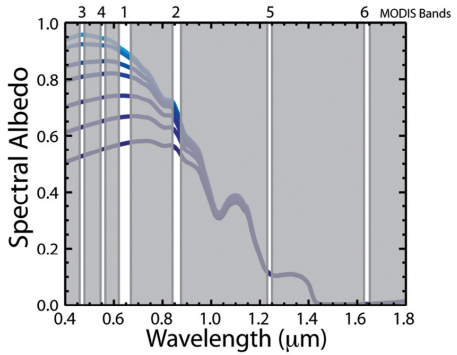
$$\text{NDGSI} = \frac{NIR - SWIR}{NIR + SWIR}$$

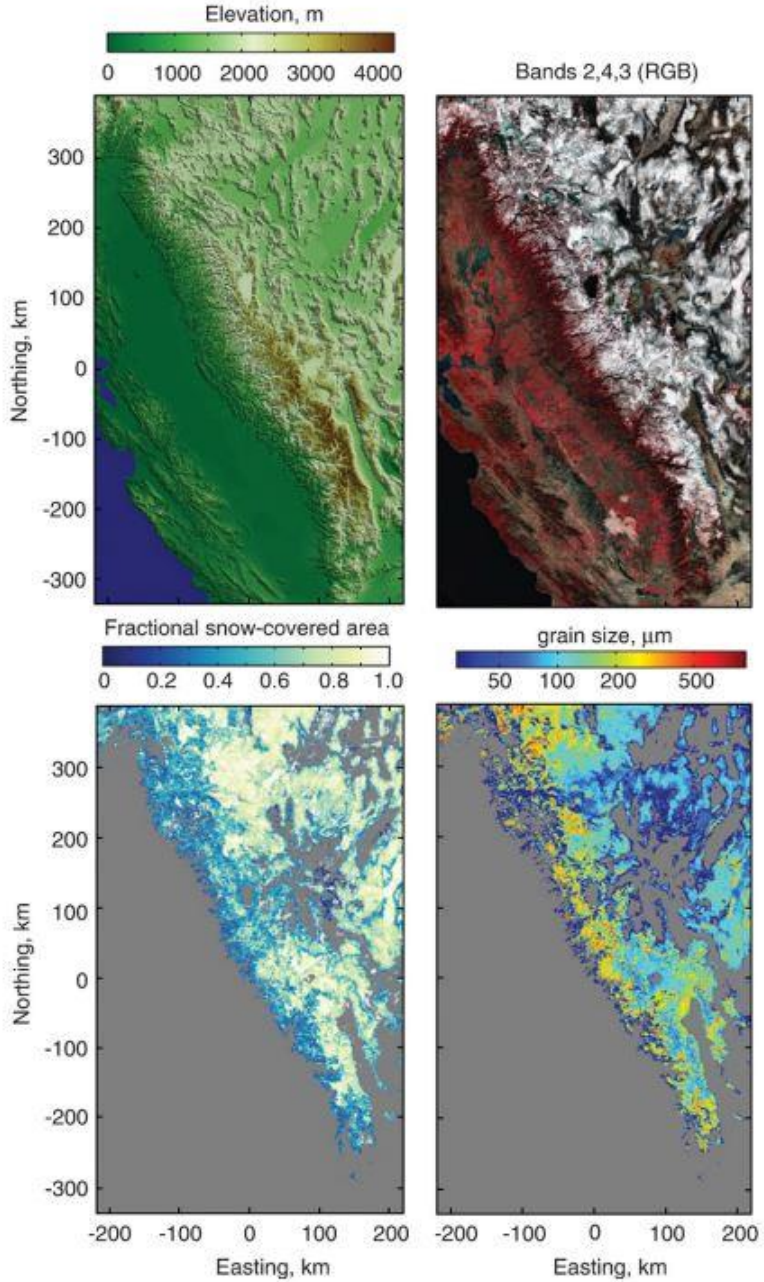
MODIS: b 2 / b 5







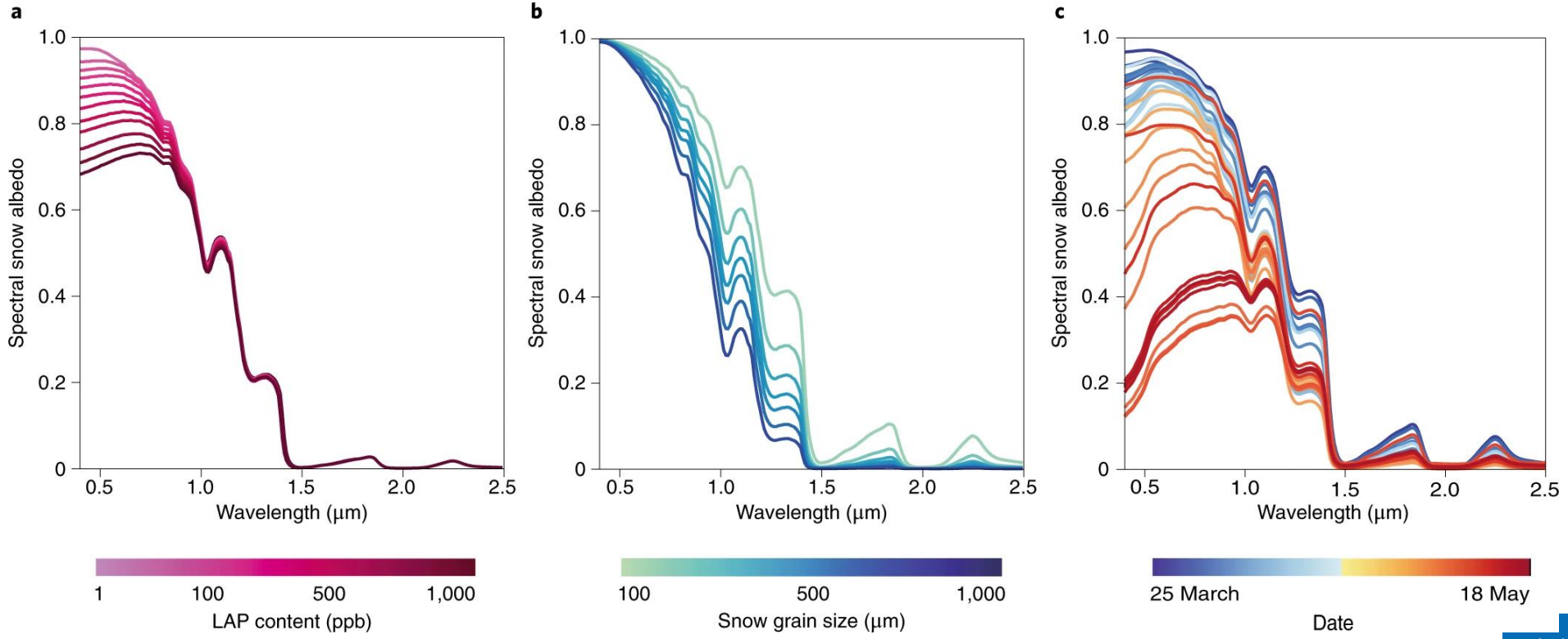




Painter, 2009

From grain size to albedo reduction

- Compute a theoretical spectral curve based on observed grain size
- Retrieve the actual snow spectra
- Calculate the difference to assess the impact of LAPs (light absorbing particles)



Skiles et al., 2018

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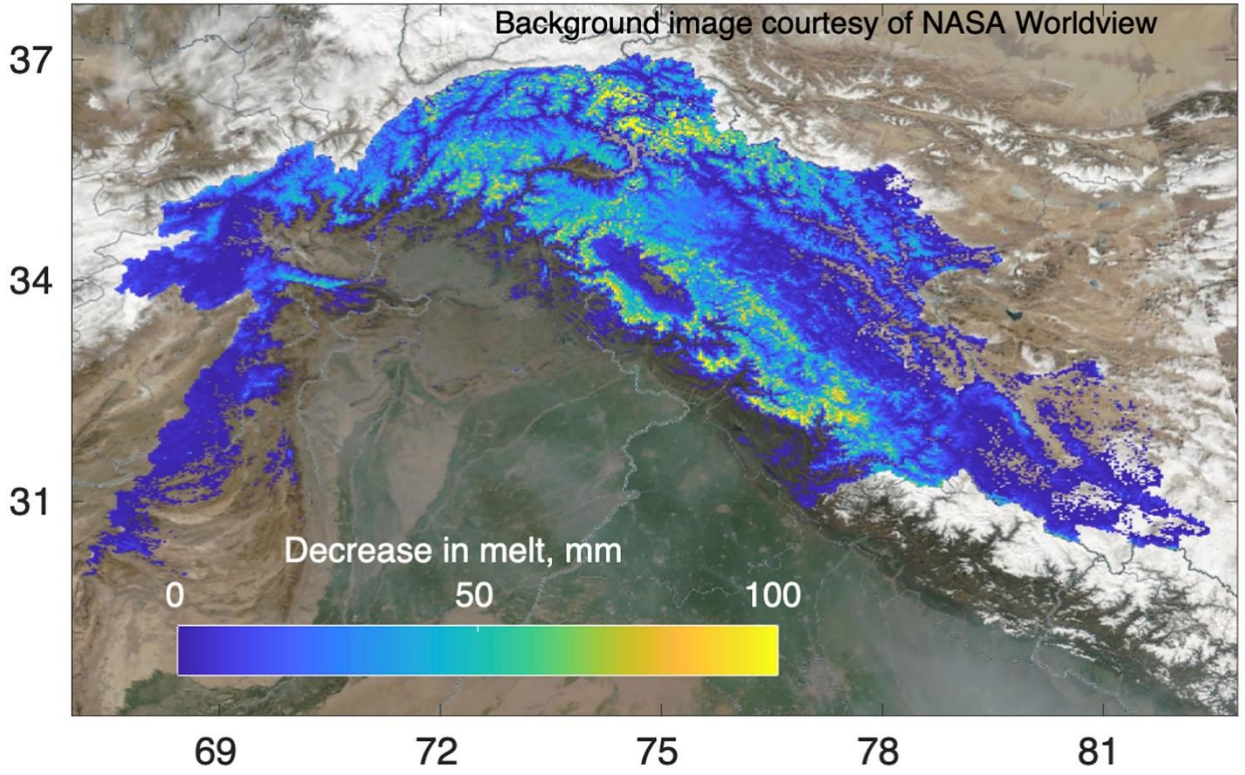


- combine LAPs with actual irradiance to calculate increased/decreased melt
- application for impact of lockdown measures (reduction in LAPs)

Bair et al., 2021

snow properties from optical imagery

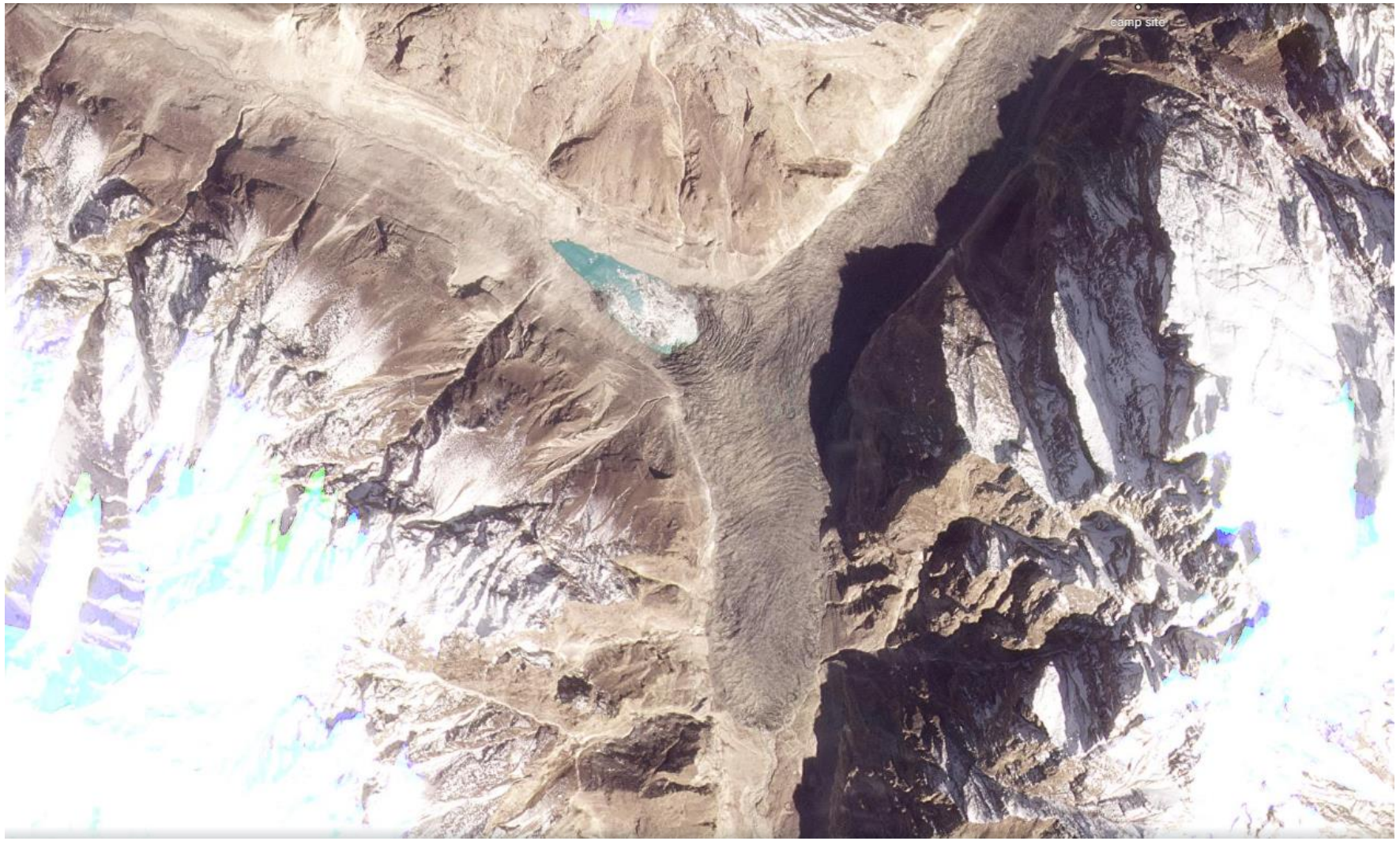
Spectrometers

- Snow covered area/duration
- Snow grain size
- albedo/darkening (LAPs)

Cameras

- Repeat photogrammetry
- Stereo photogrammetry

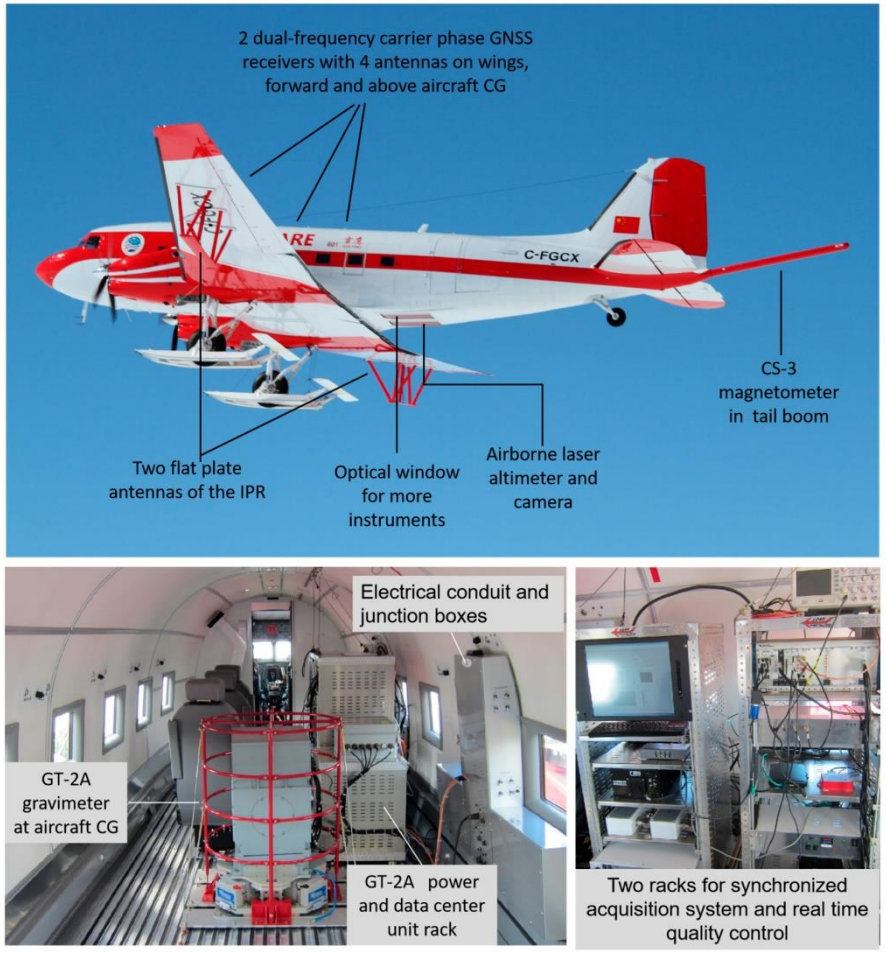
new suite of commercial satellites



- satellite data is virtually accessible to anyone with ~10h time lag

Shisper, March 2022

Mapping from planes or UAVs

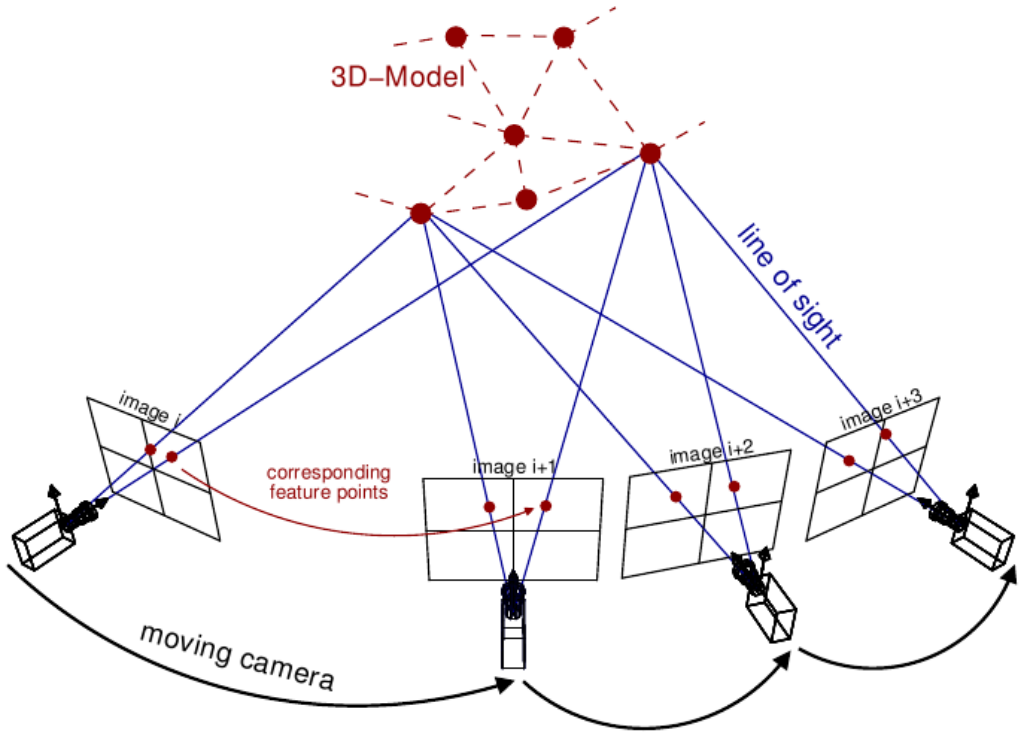


Cui et al., 2020

Tiggelen et al., 2022

structure from motion

- use simple oblique imagery to create 3D models
- wide range of applications and software
- generally done from handheld and UAV imagery



Riel et al., 2016

structure from motion

- surface roughness

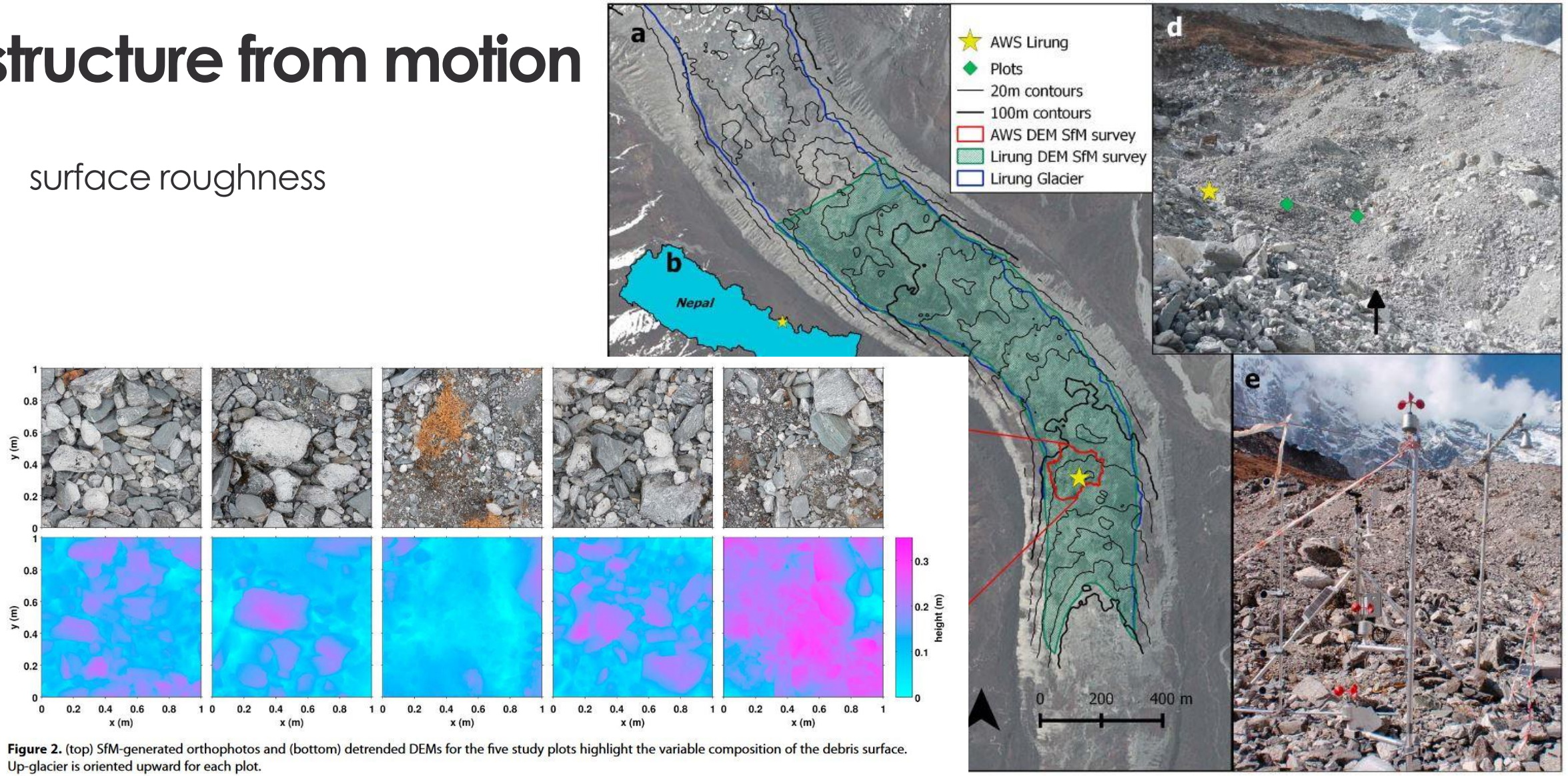


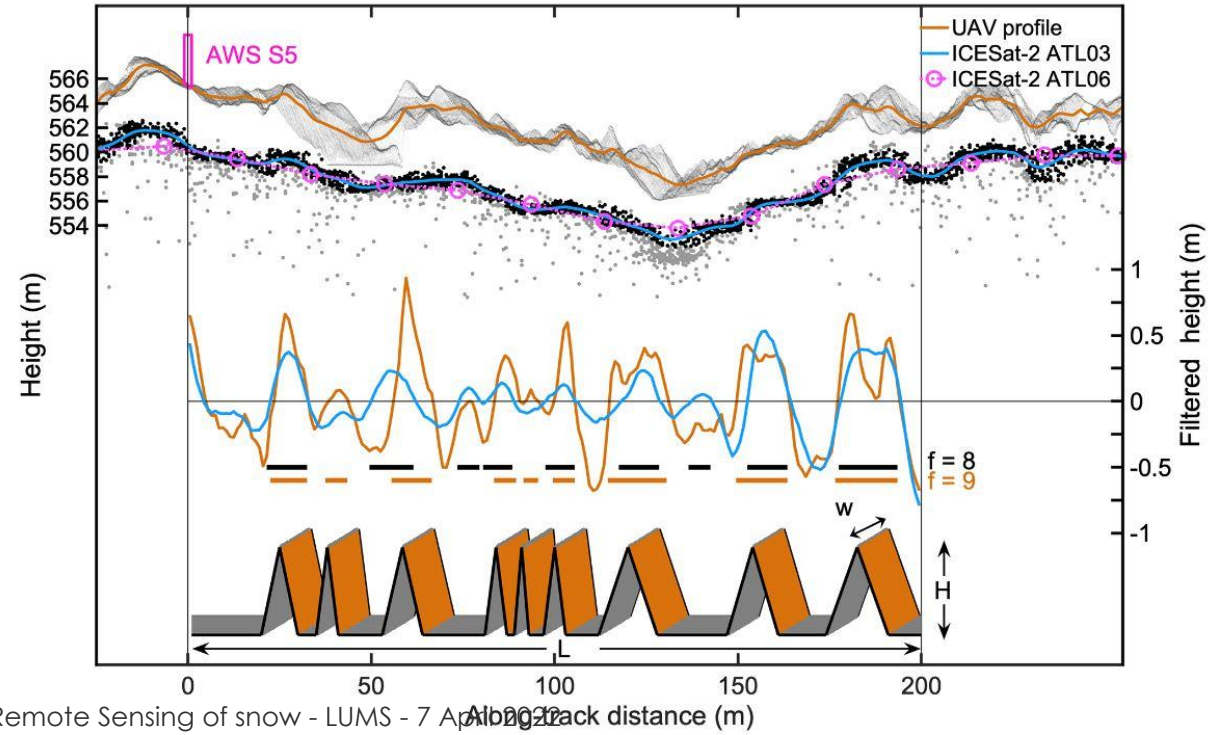
Figure 2. (top) SfM-generated orthophotos and (bottom) detrended DEMs for the five study plots highlight the variable composition of the debris surface. Up-glacier is oriented upward for each plot.

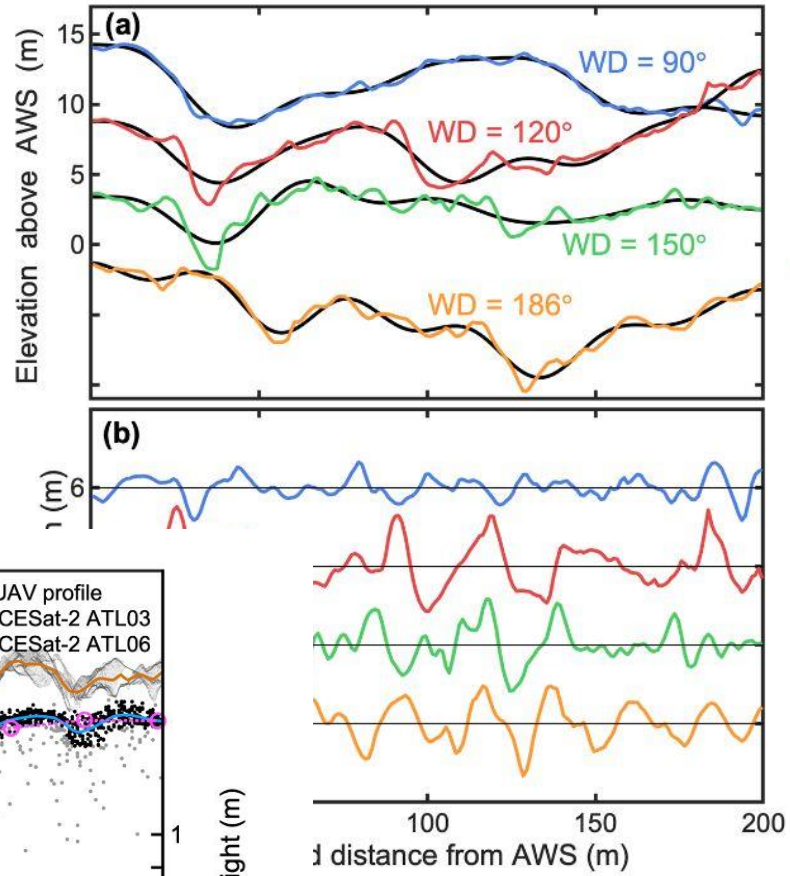
Miles et al., 2017

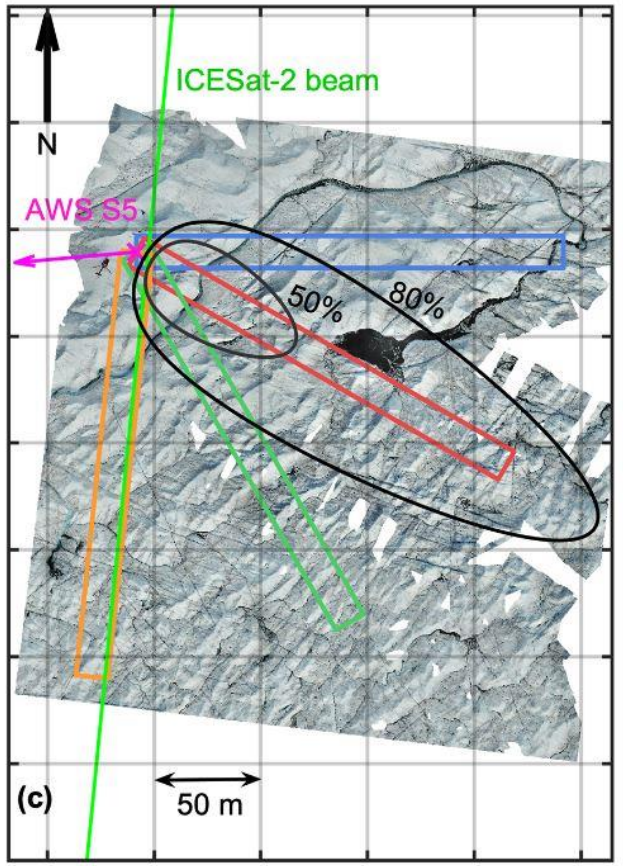
structure from motion

- surface roughness

- combined with RS laser (IceSat)







Tiggelen et al., 2022

SfM for snow depth

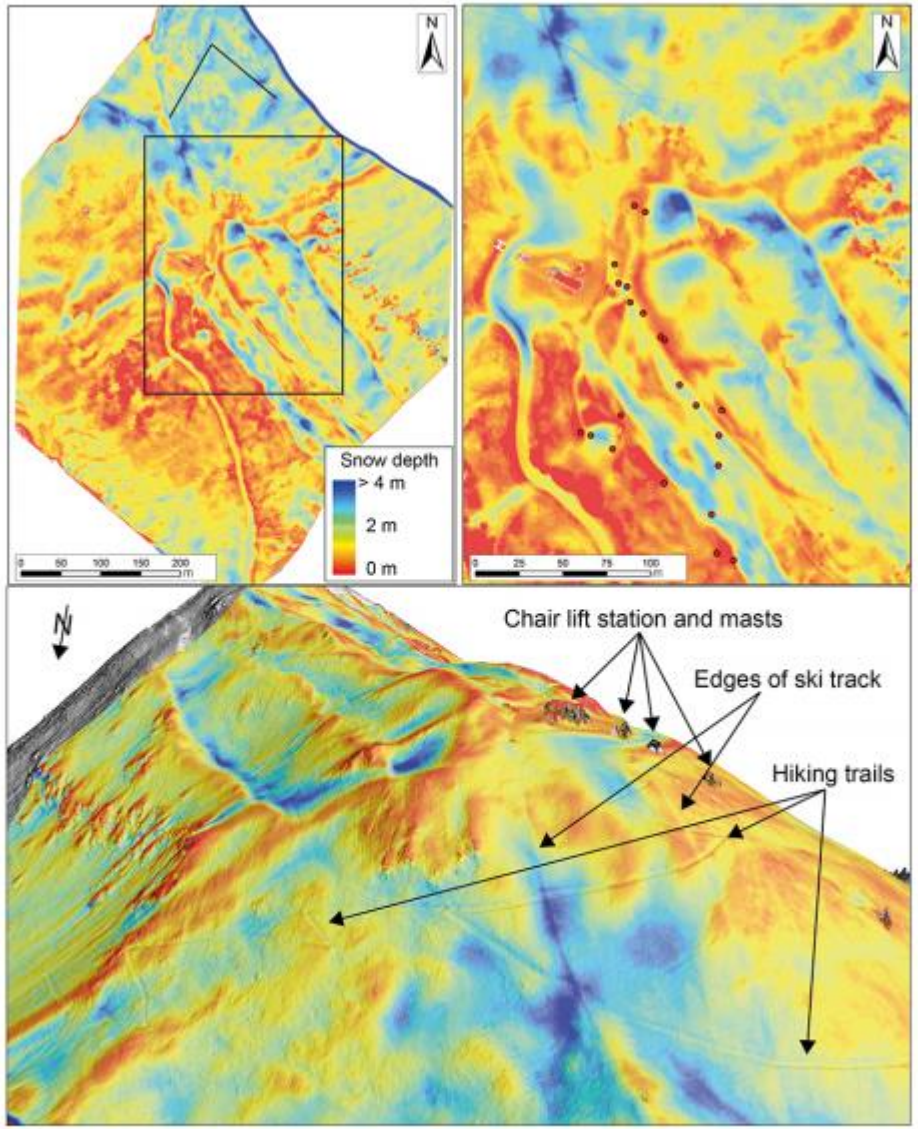


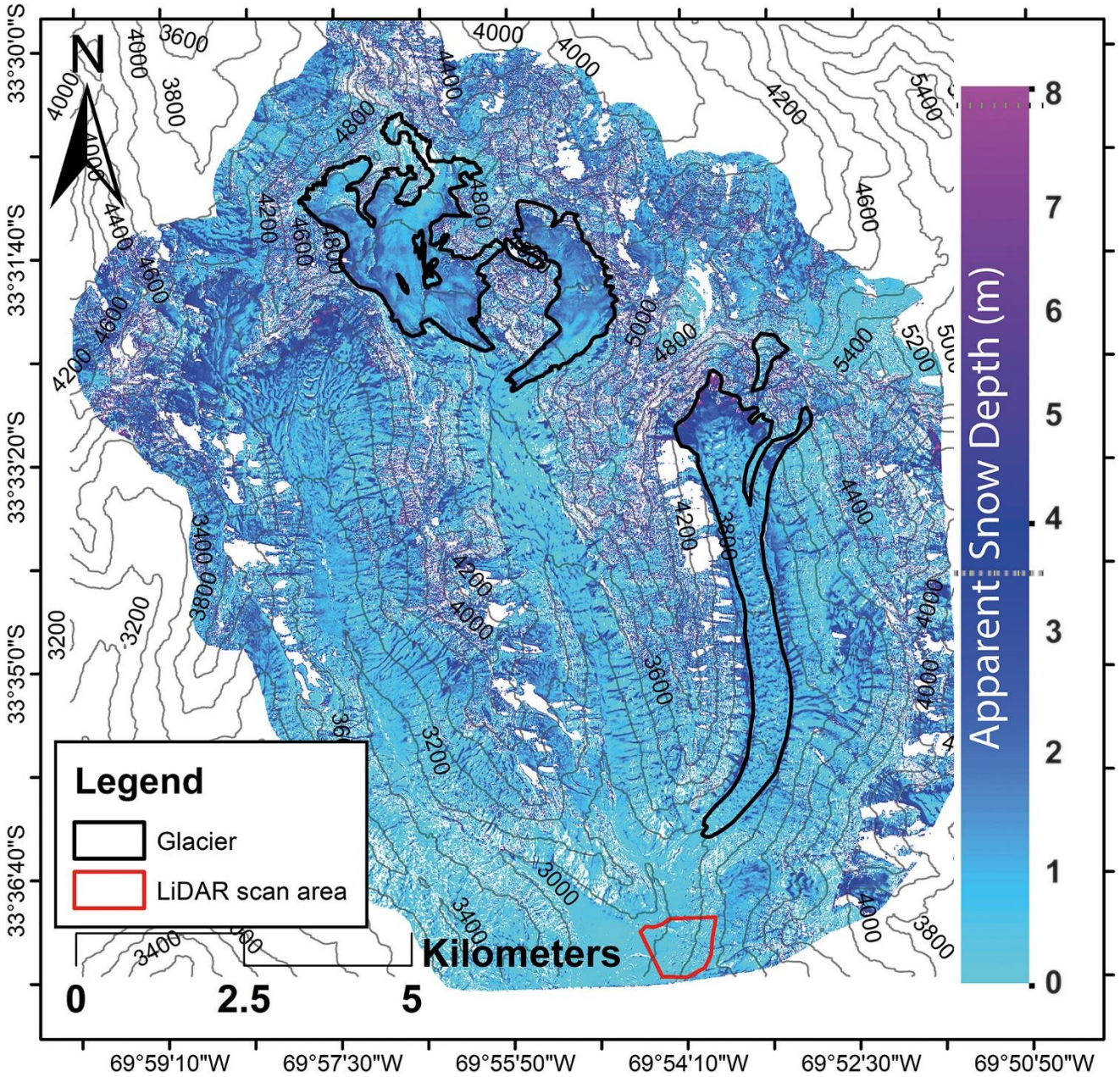
Figure 6. Overall HS map of the Brämabühl test site (top left panel) and close-up of the central part (top right panel). The locations of the reference plots are displayed as red circles. 3-D view of the HS draped over the hillshade of the snow-free DSM facing from north to south (bottom panel).

Buehler et al, 2016 (TC)

Tri-Stereo photogrammetry

- high resolution optical imagery (Pleiades, CubeSats, SPOT etc)

- generally commercial



Shaw et al, 2020

Active vs Passive Sensors

Passive sensors: record reflected or emitted electromagnetic signal

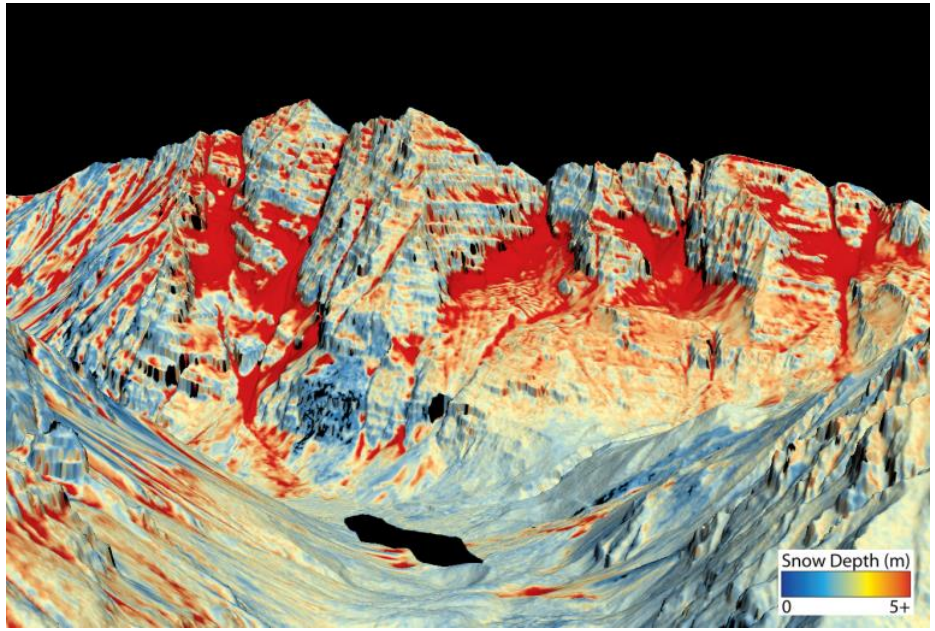
- visible light (reflected, optical imagery, daytime)
- microwave (emitted, AMSR, day and night)

Active sensors: send energy pulses and measure their return

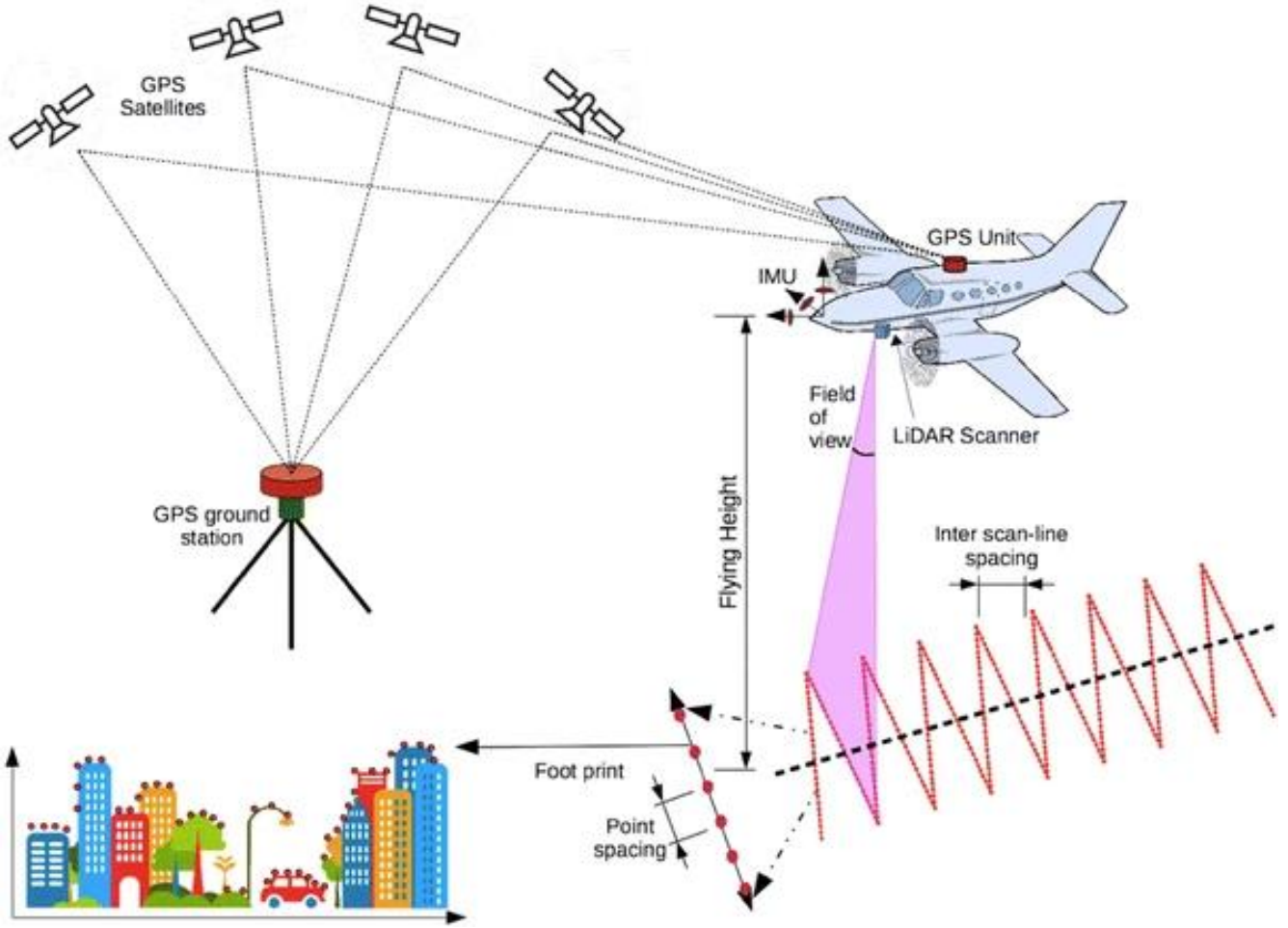
- LIDAR (visible, SW)
- Radar (microwave)

LIDAR (light detection and ranging, active)

- Emitted laser, tracking the time/distance between sensor and surface
- application on planes and UAVs



NASA ASO



Lohani and Ghosh, 2017

Satellite microwave

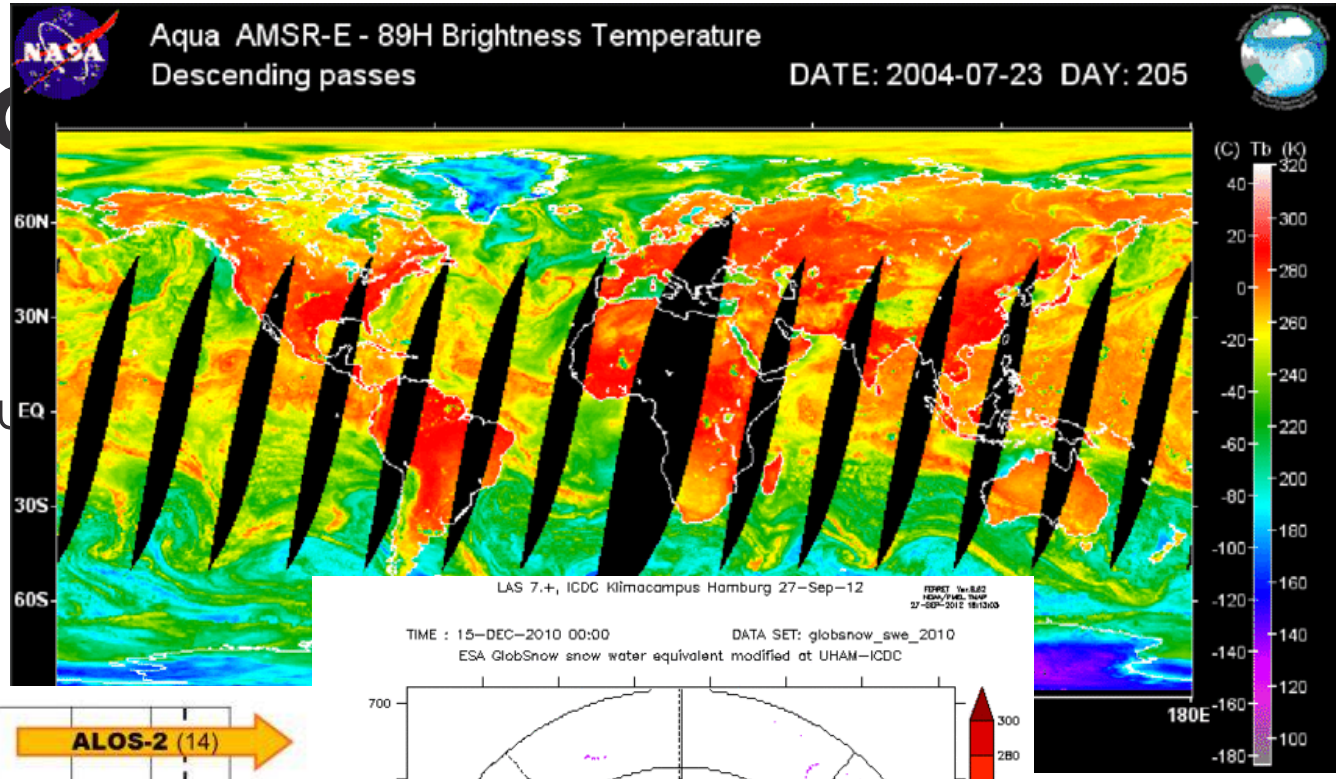
Passive:

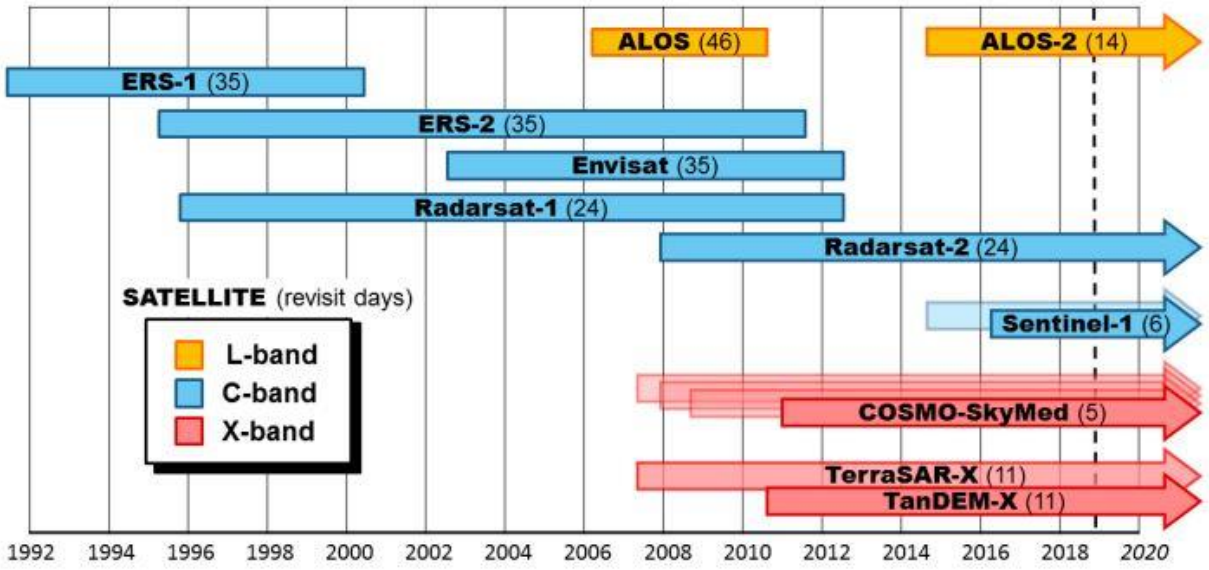
AMSR/SMMR: wide swath, near daily data bu

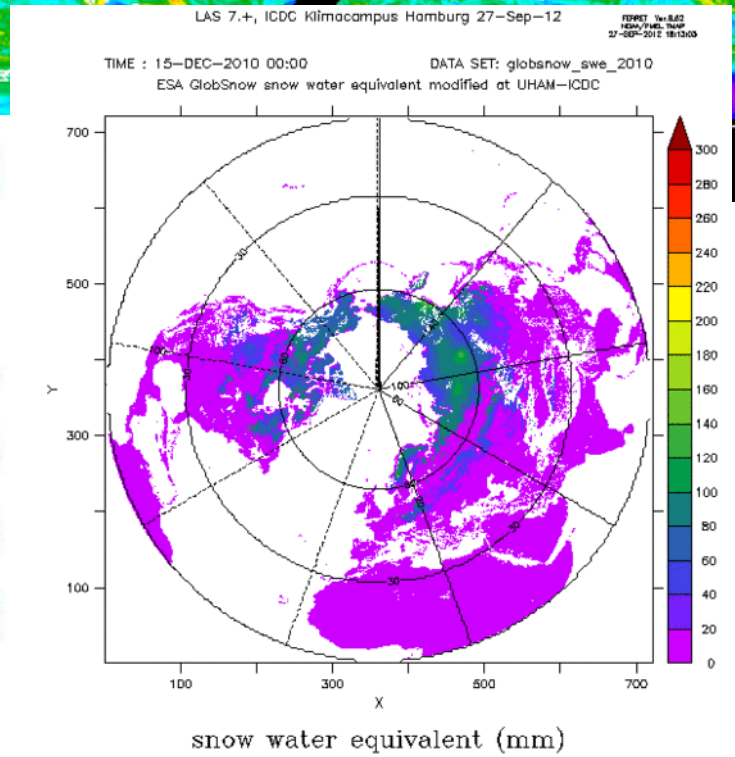
- crucial is emissivity ε
- $\varepsilon = 1$ for perfect black body
- $\varepsilon = 0.7$ to 0.9 for dry snow

Active

Radar







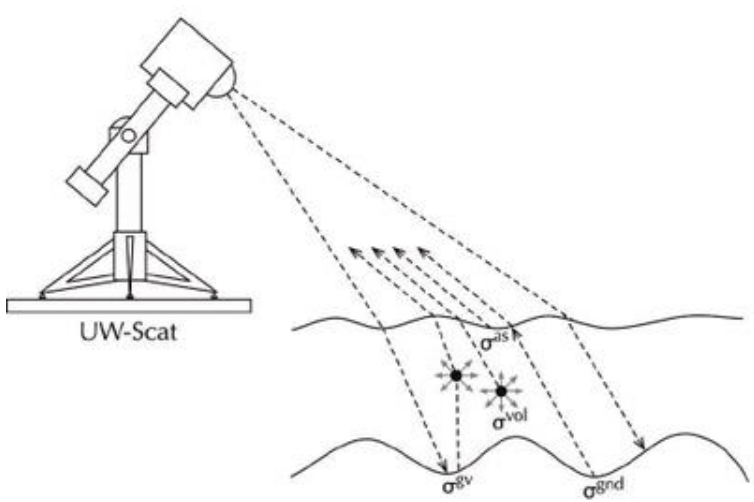
snow water equivalent (mm)

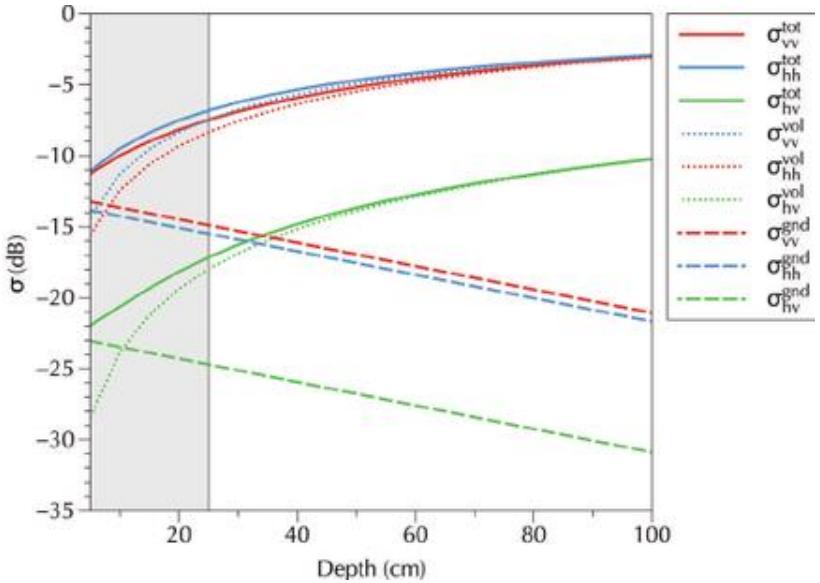
Radar

Snow Depth

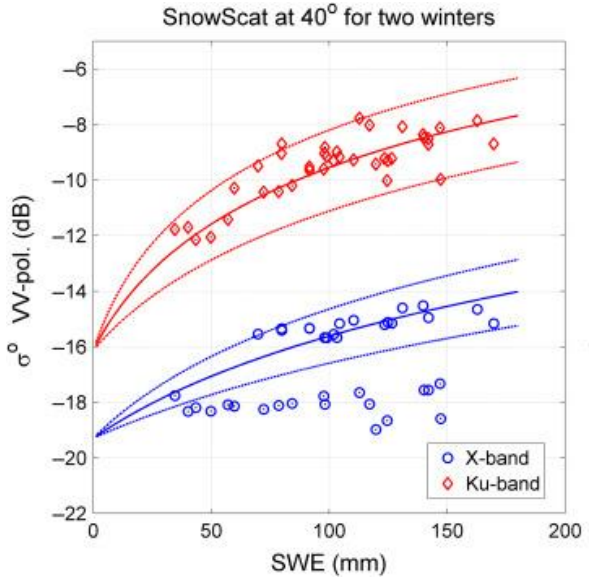
Snow Water Equivalent

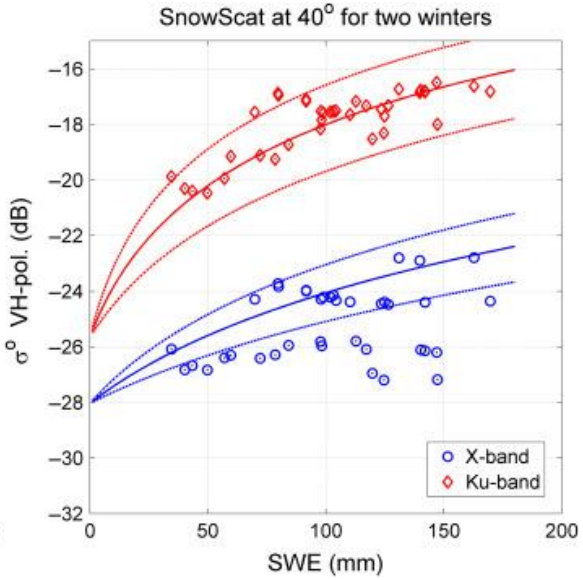
Grain Size (hoar etc)





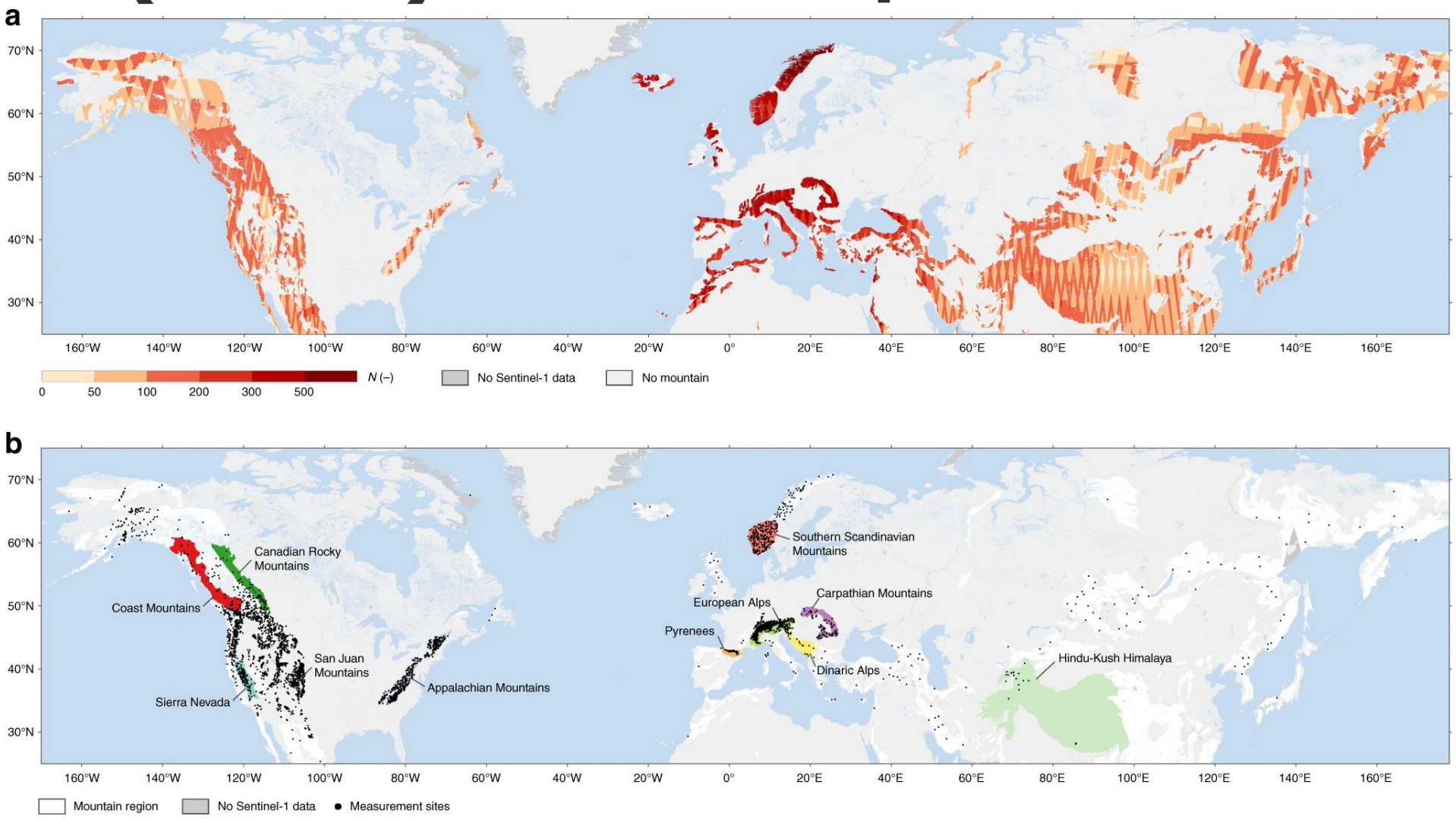
King et al., 2014





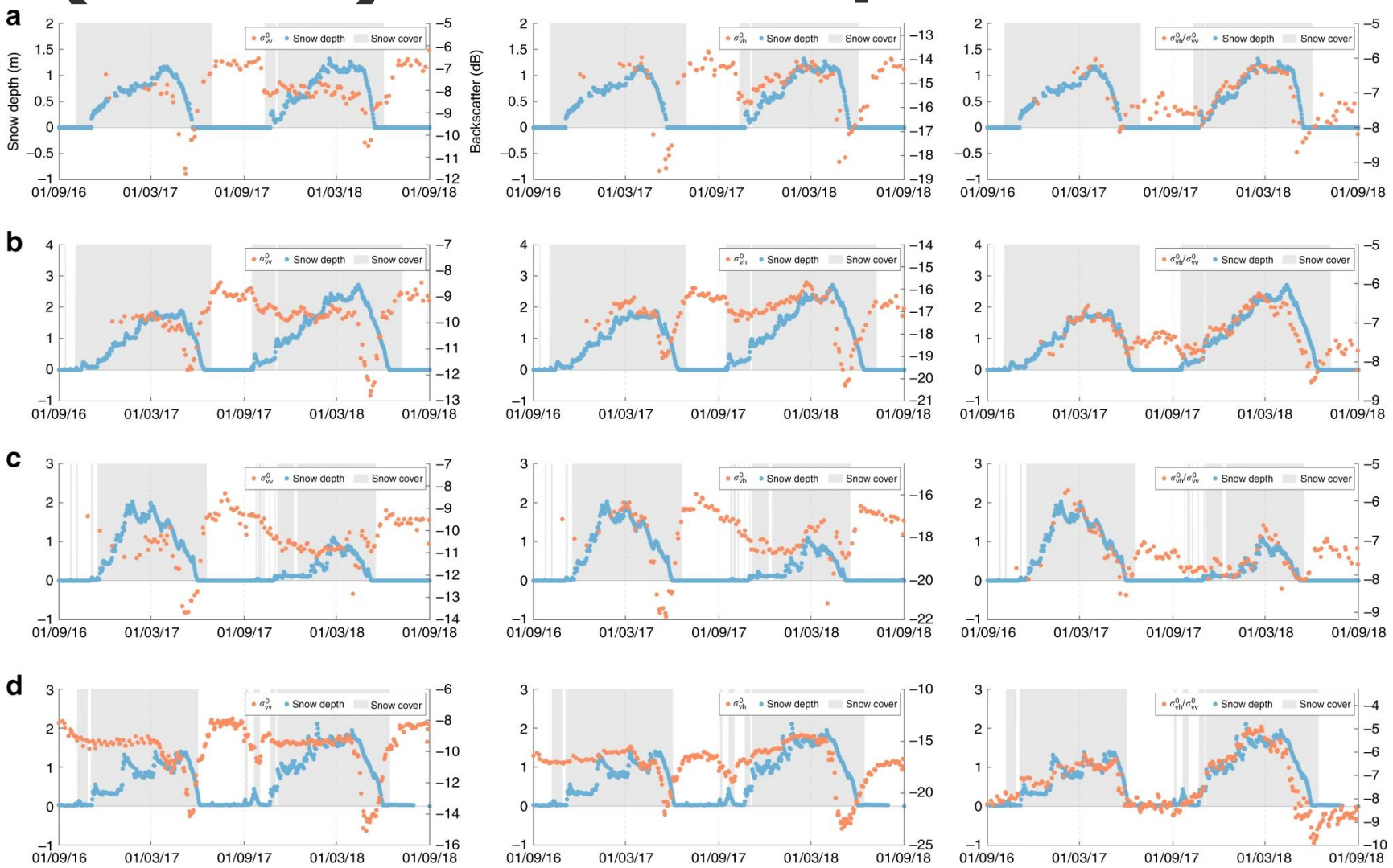
Rott et al., 2018

Radar (active) – Snow Depth



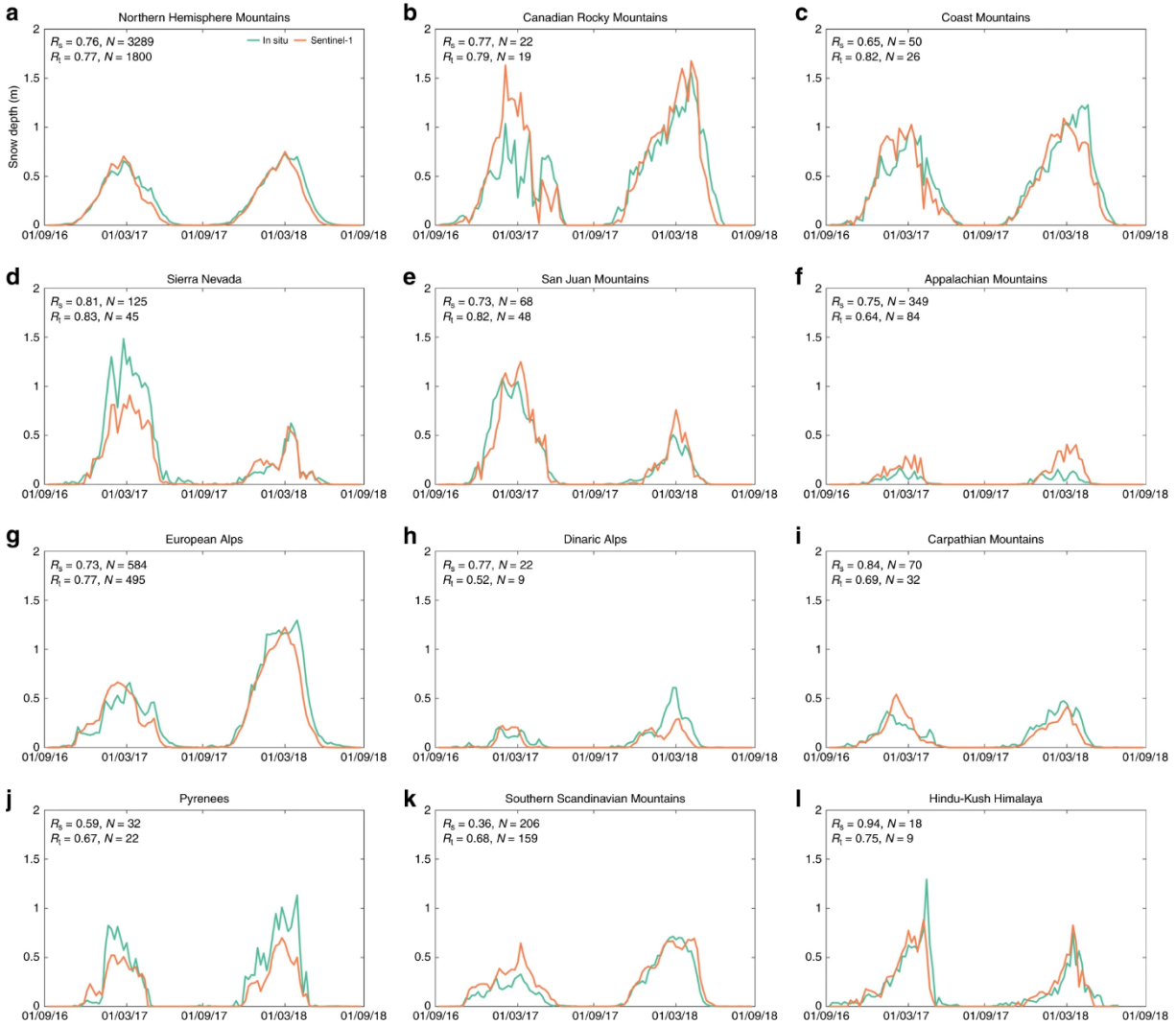
Lievens et al., 2018

Radar (active) – Snow Depth



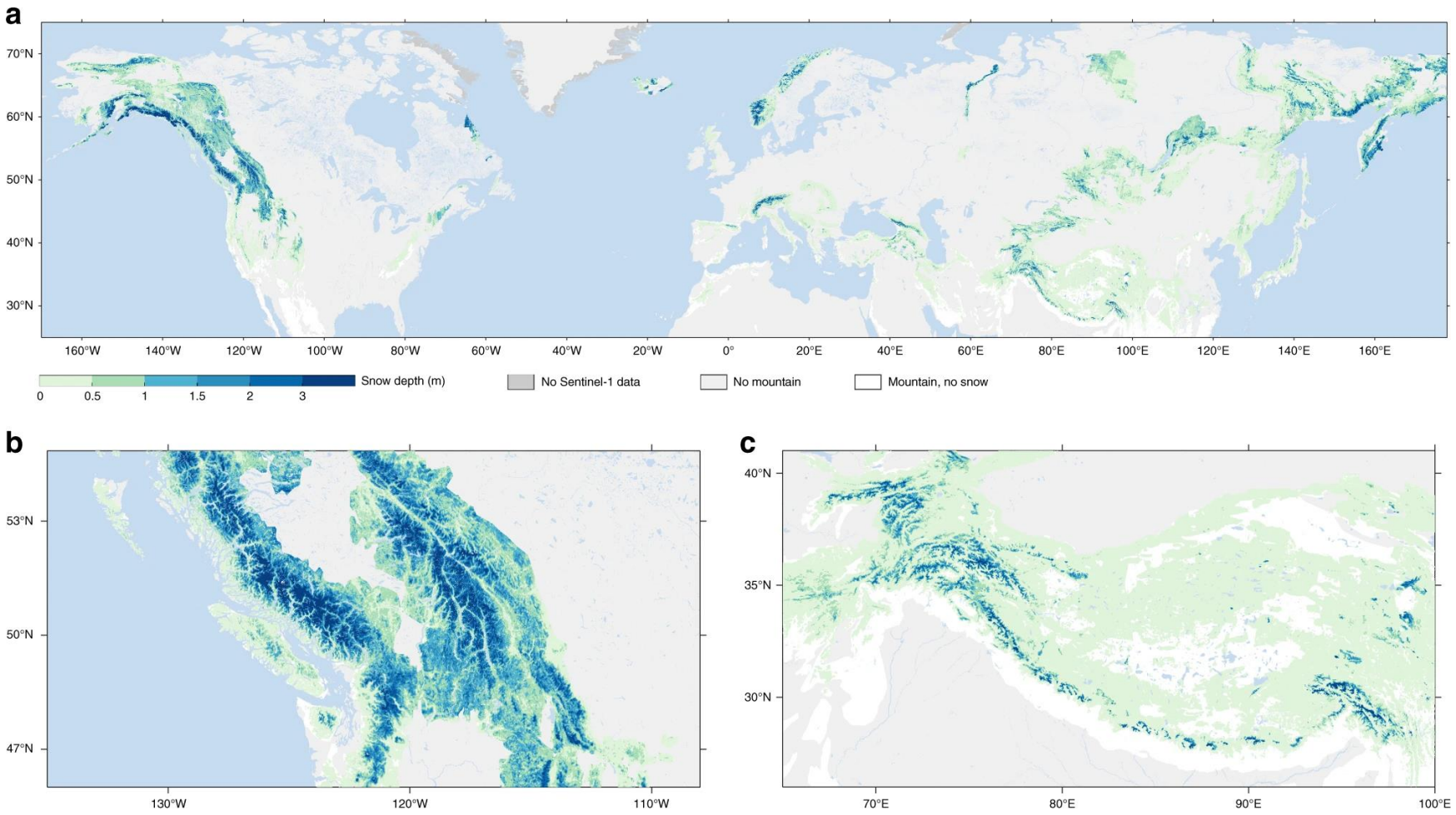
Lievens et al., 2018

Radar (active) – Snow Depth



Lievens et al., 2018

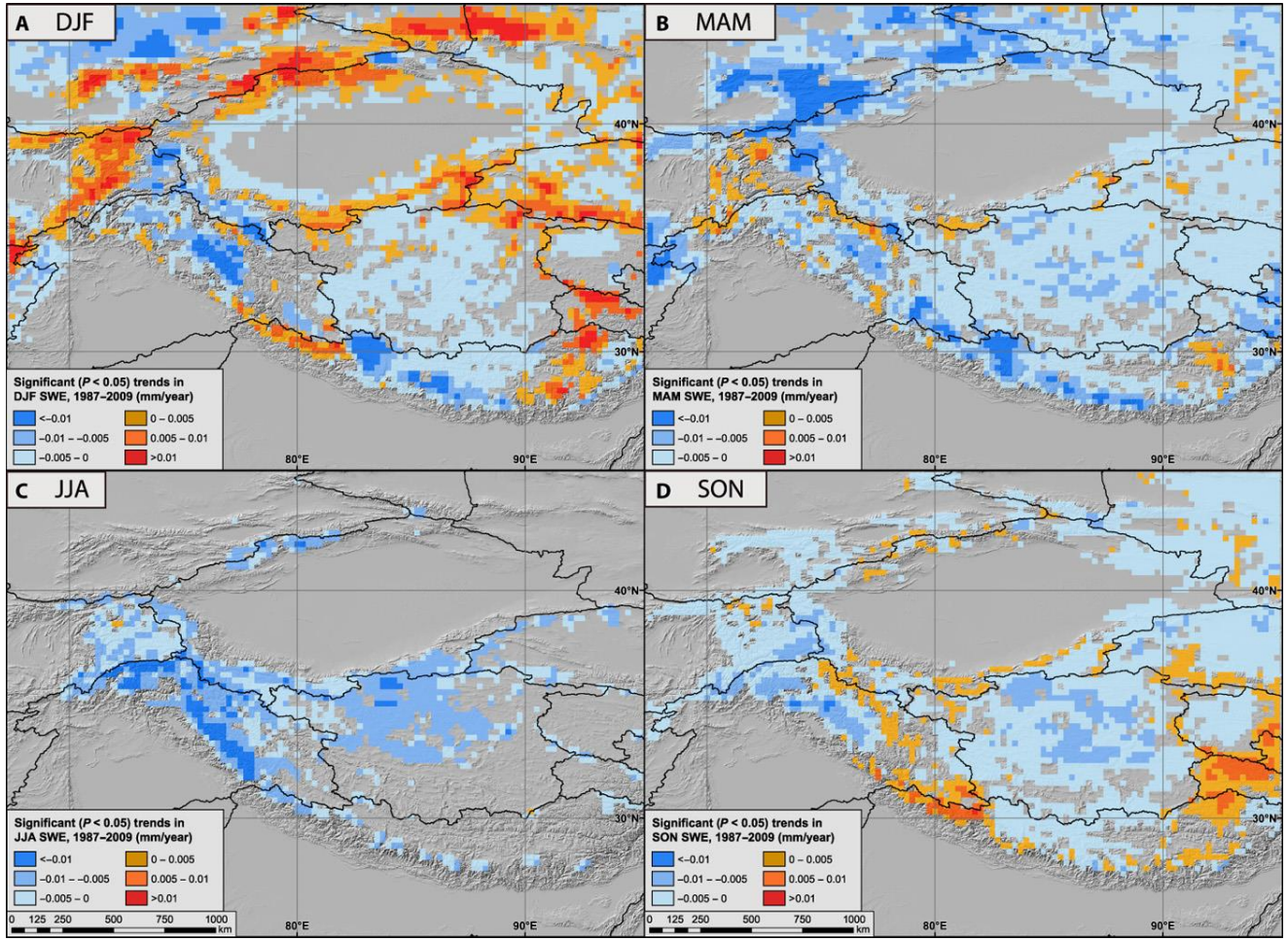
Radar (active) – Snow Depth



Lievens et al., 2018

Radar (passive) – Snow Water Equivalent

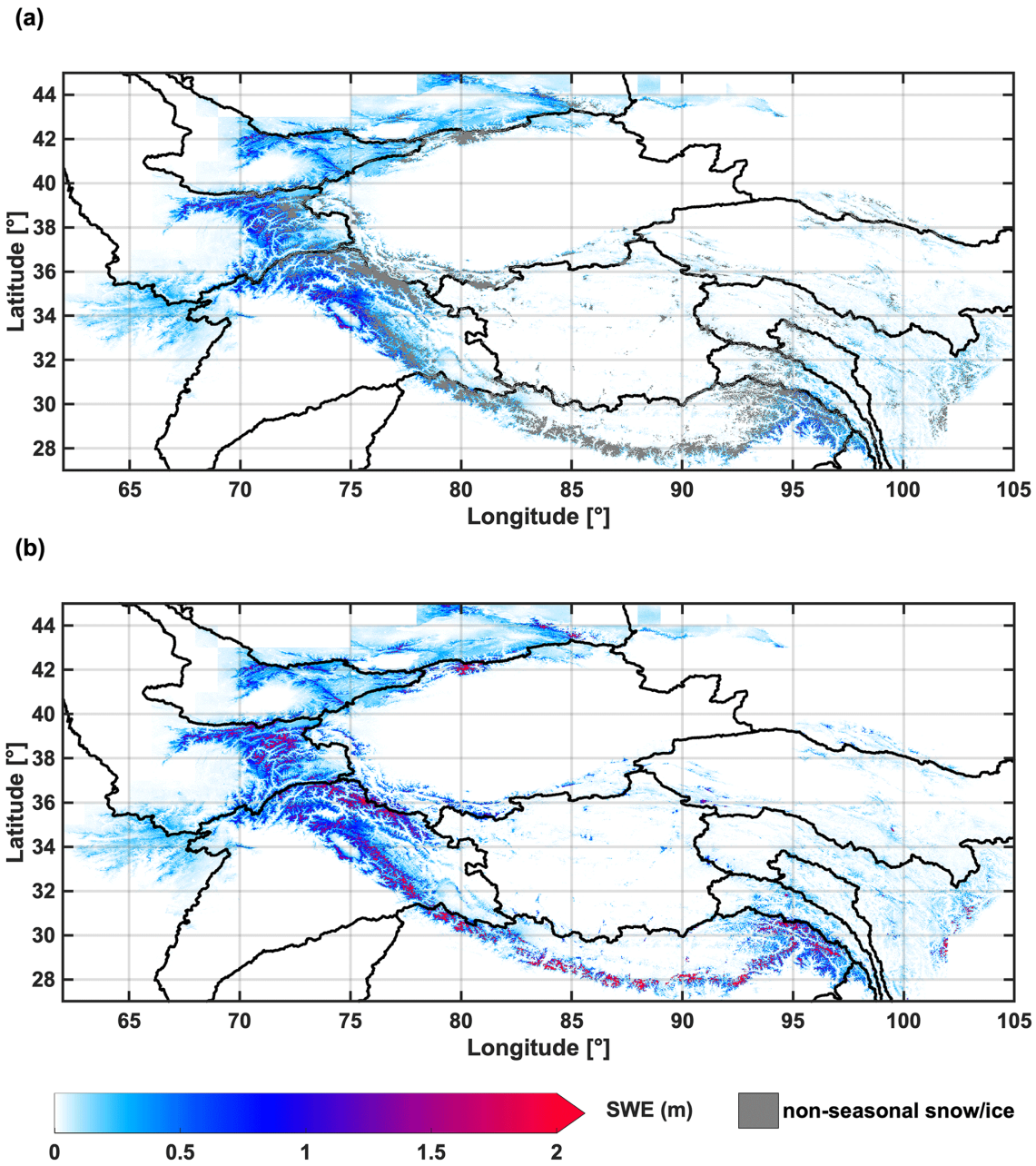
- SSMI (passive, 1979 – 2009)
- 27km resolution



Smith and Bookhagen et al., 2017

Modelled SWE

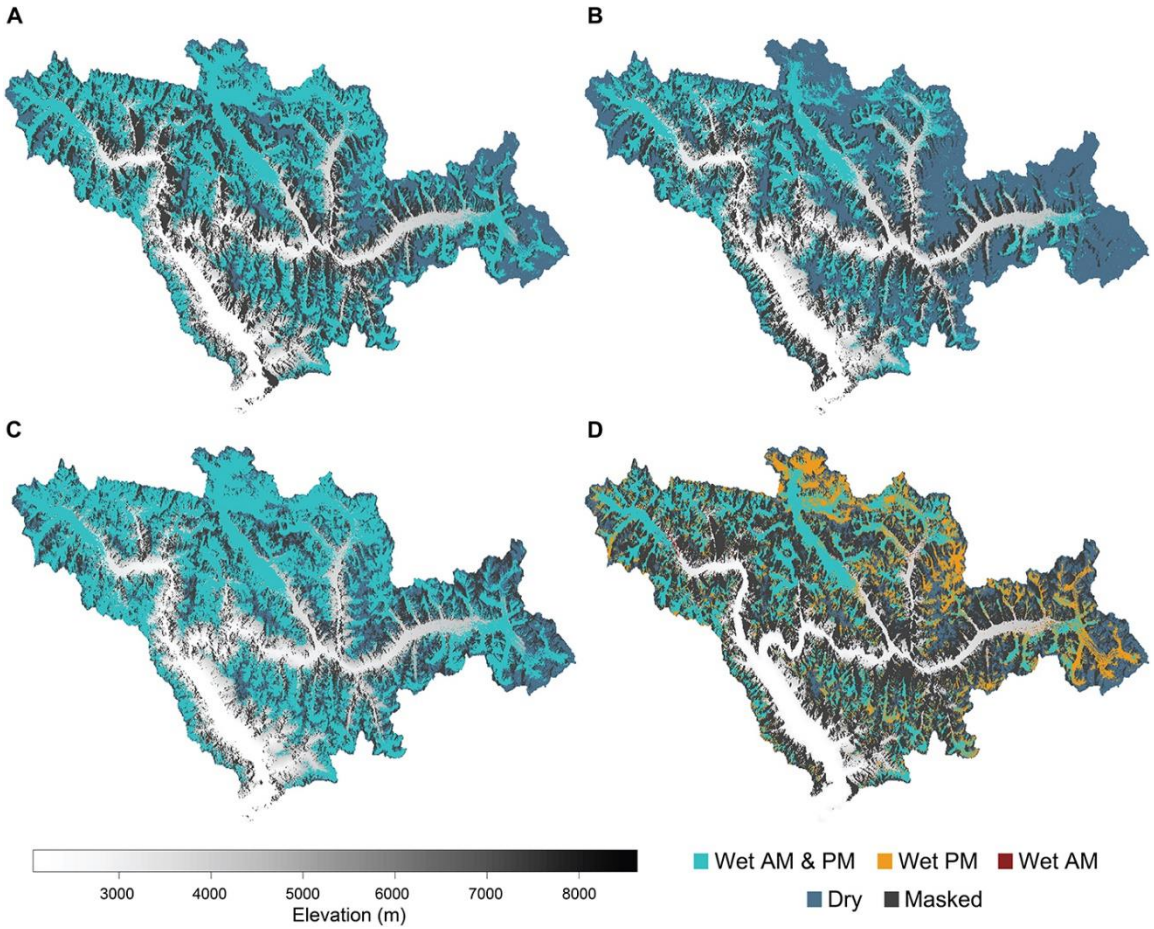
- Using fSCA
- Combine that with a simple model, based on climatic forcings
- 500 m resolution



Liu et al., 2021

What can't we see (or remains difficult)

- Melt …. getting there
- Sublimation
- Refreezing
- Snow redistribution (wind drift/erosion)



Lund et al., 2021

Refreezing

- 20% - 30% of snowmelt is refrozen in Central Himalaya
- ~15% of positive energy is needed to "remelt" frozen meltwater

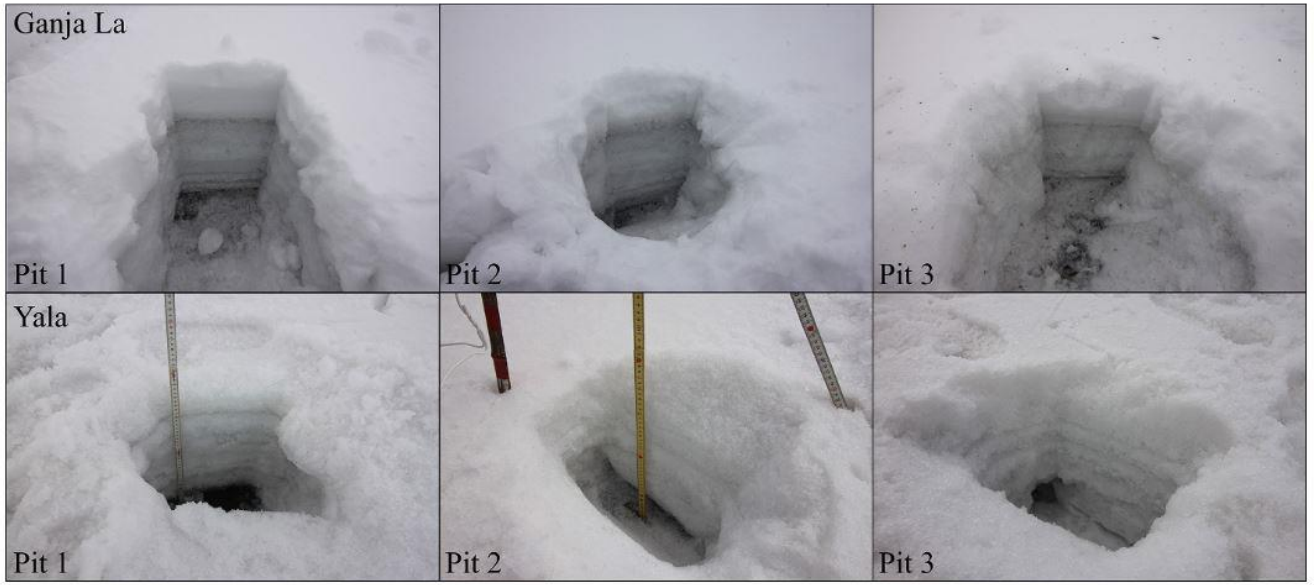


Fig. 8. Pictures of three snow pits at Ganja La on April 30th 2018 and Yala on April 25th 2018. The snow pits at Ganja La have a depth of 41–42 cm and contain four or five ice layers. The snow pits at Yala have a depth of 38–44 cm and contain five ice layers.

Stigter et al., 2018

Refreezing

- catchment scale research allows us to understand and model processes
- acts as point scale validation of remote sensing products

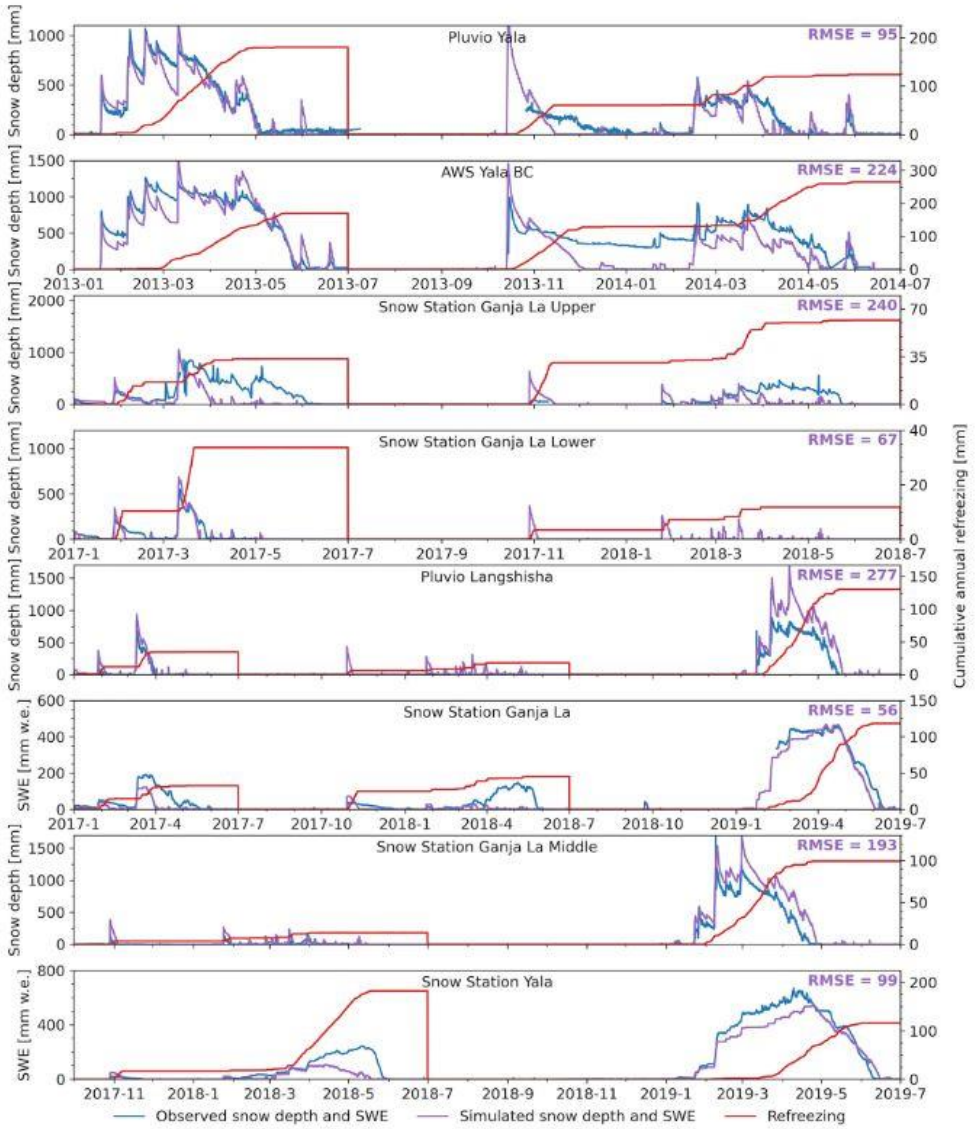


Fig. 6. Simulated and observed snow depth and SWE at stations for periods with measurements, including the simulated cumulative annual refreezing at the stations.

Veldhuisen et al., 2021

Measuring snow

Snow water equivalent
- snow pits
- snow pillows
- gamma-ray sensor

Measuring snow

Snow water equivalent


Thank you
Let's protect
the pulse.