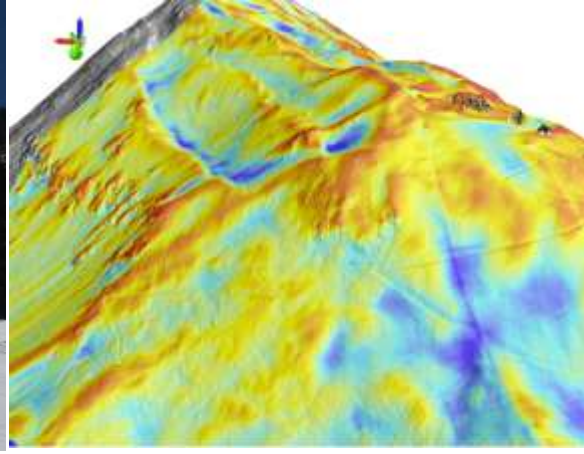




# Snow depth mapping applying Unmanned Aerial Systems UAS – Closing the gap between field measurements and low spatial resolution satellite data

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# Motivation

- **Snow depth** (HS) and **Snow Water Equivalent** (SWE) are key parameters for numerous applications:
  - Hydropower
  - Snow avalanche forecasting
  - Flood forecasting
  - Technical snow as base for ski tourism
  - Alpine ecology (Flora and Fauna)

- Poorly accessible, steep and dangerous **alpine terrain**
- Fast **changing** snowpack
- **Validation** of HS and SWE products is difficult, usually only **point measurements** available but are they representative?

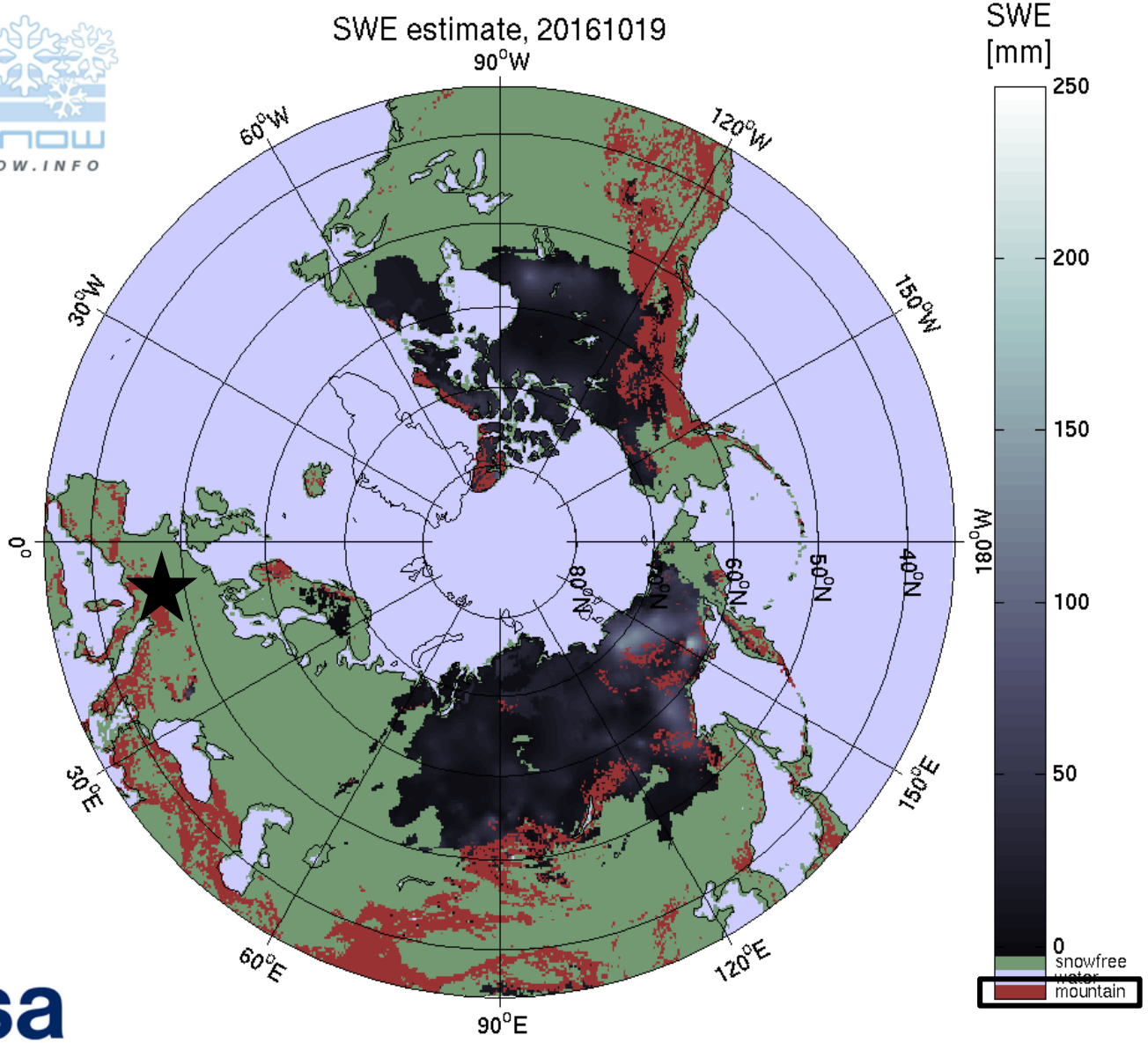


# How much snow do we have at Bräma?

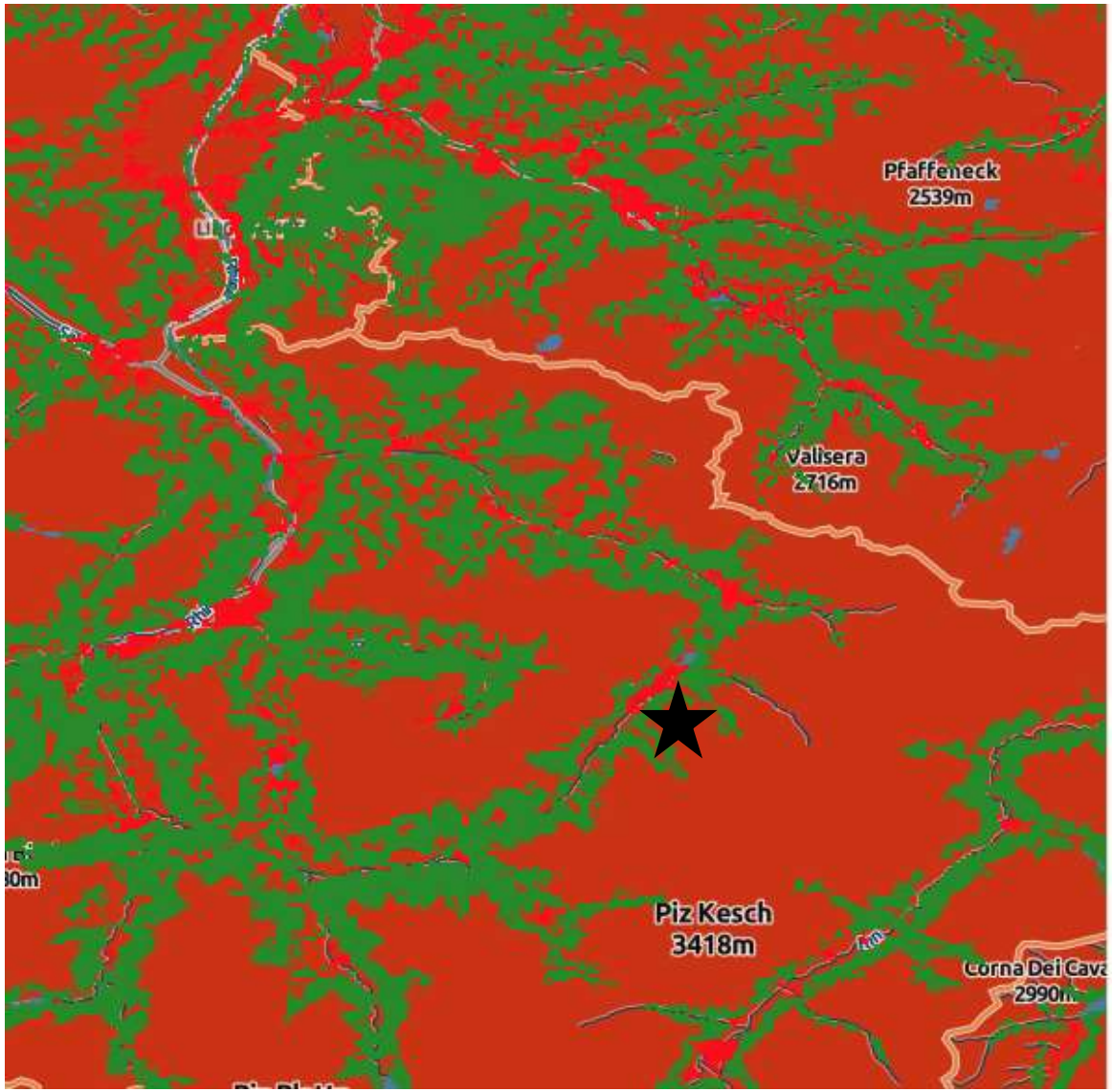
- Brämabüel,, Davos, GR, Switzerland, 19 April 2016 peak of winter
- 2500 m a.s.l., wind, technical snow, high variety in exposition



# Globsnow: http://http://www.globsnow.info



# Cryoland: http://www.cryoland.eu




Common to all CryoLand Products

- Sea mask
- Lake mask
- River Mask
- Cloud mask
- Bare Ground, free of snow
- Glacier mask
- Forest mask
- Dense forest mask
- Urban mask
- Mountains
- Polar Night
- Outside Area / Data Error

No Data (Base Layer is visible)

daily_FSC_PanEuropean_Optical

daily_FSC_PanEuropean_Optical_Uncertainty

daily_MODIS_RGB651_PanEuropean

daily_SWE_PanEuropean_Microwave

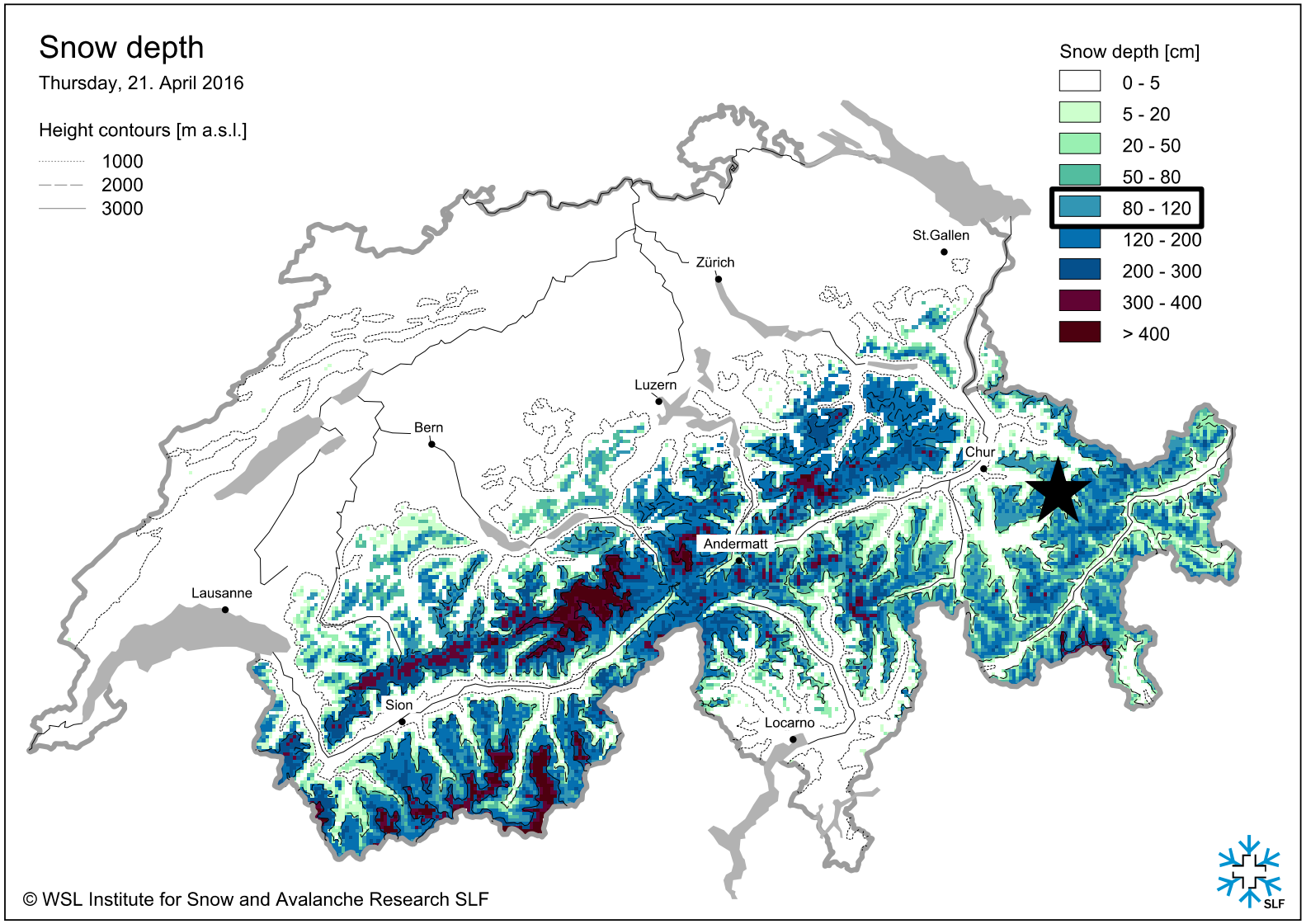
- Snow Water Equivalent 0 mm w.e.
- Snow Water Equivalent 1-50 mm w.e.
- Snow Water Equivalent 51-100 mm w.e.
- Snow Water Equivalent 101-150 mm w.e.
- Snow Water Equivalent 151-200 mm w.e.
- Snow Water Equivalent 201-250 mm w.e.
- Snow Water Equivalent 251-300 mm w.e.
- Snow Water Equivalent 301-350 mm w.e.
- Snow Water Equivalent 351-400 mm w.e.

daily_FSC_Alps_Optical

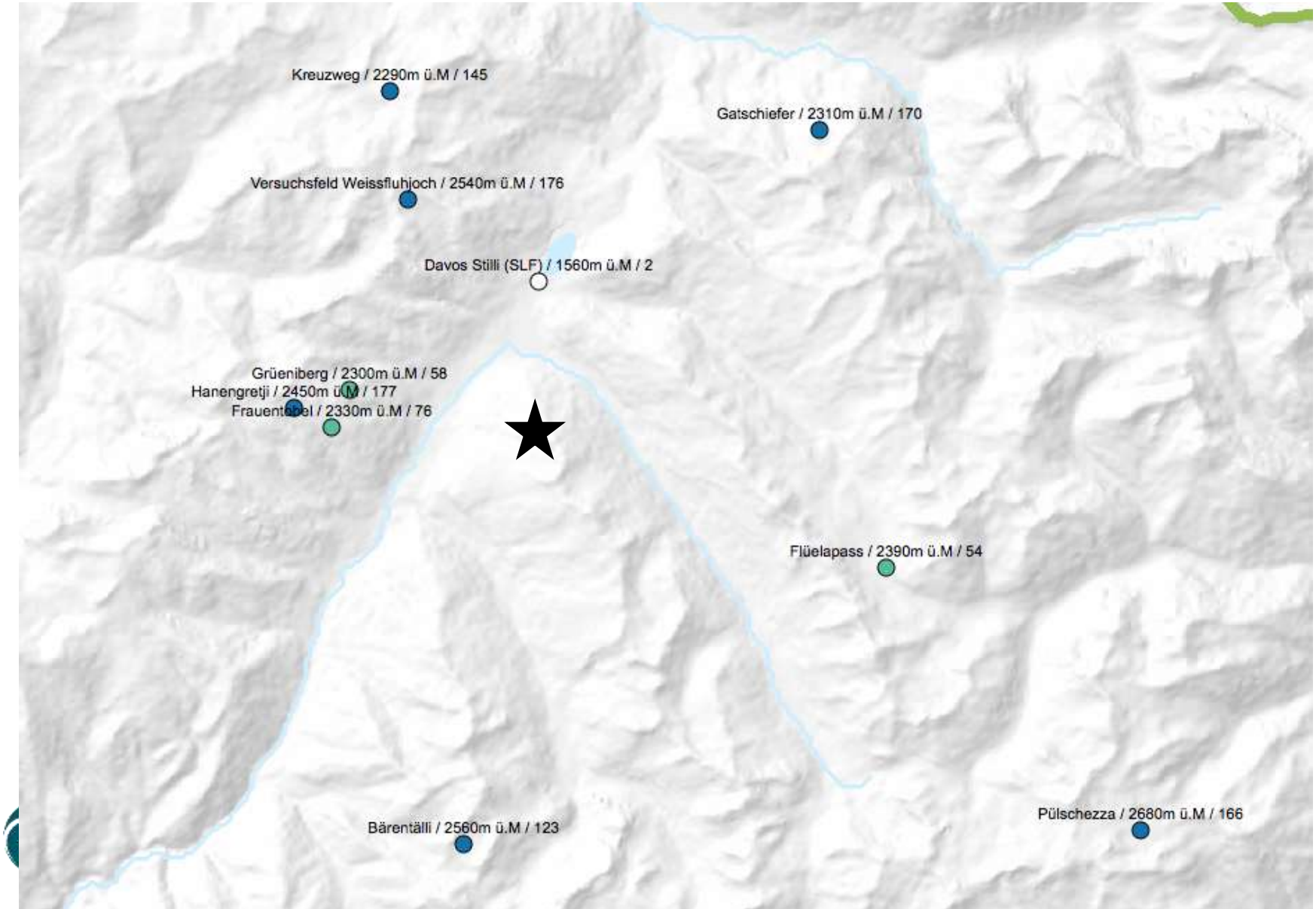
multitemp_SCAW_Alps_Radar

- Radar shadow / layover / foreshortening
- Dry Snow or Bare Ground, no Wet Snow mapping
- Wet Snow

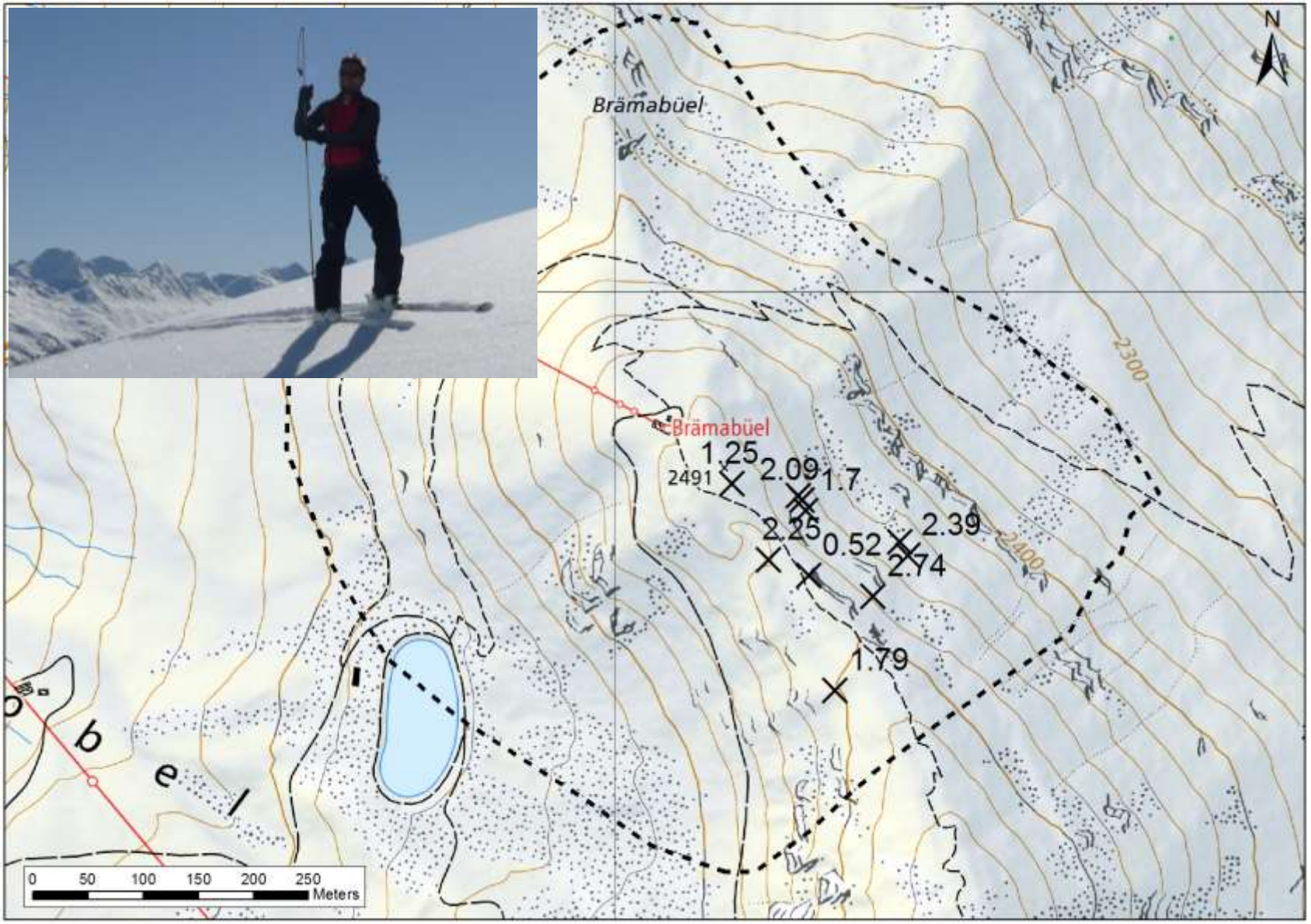
# Schneehöhenkarte SLF:
# http://www.slf.ch/schneeinfo/schneekarten/hstop/index_DE



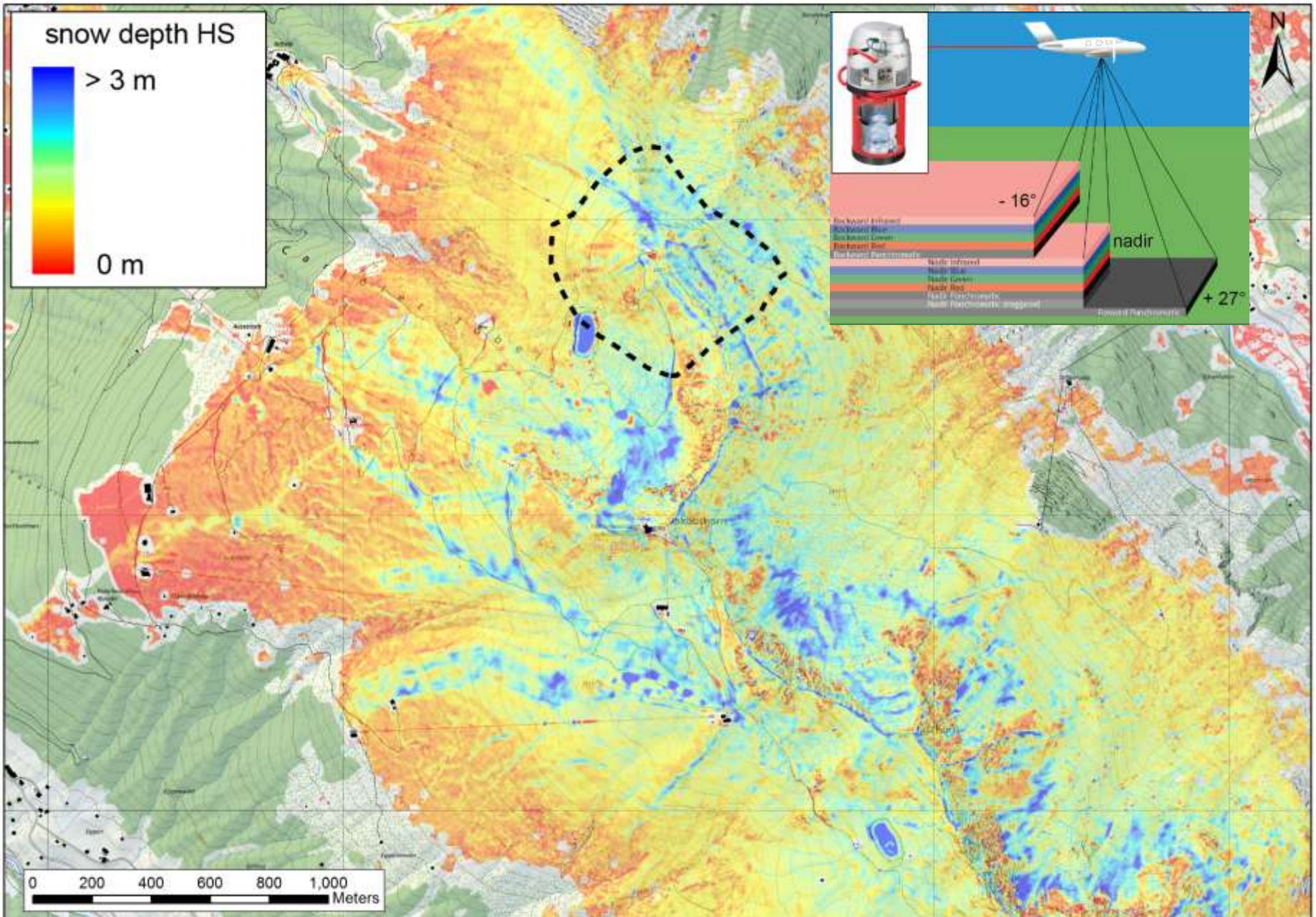
# Neighboring station data at similar elevation:
# 54 – 177 cm, mean = 125 cm



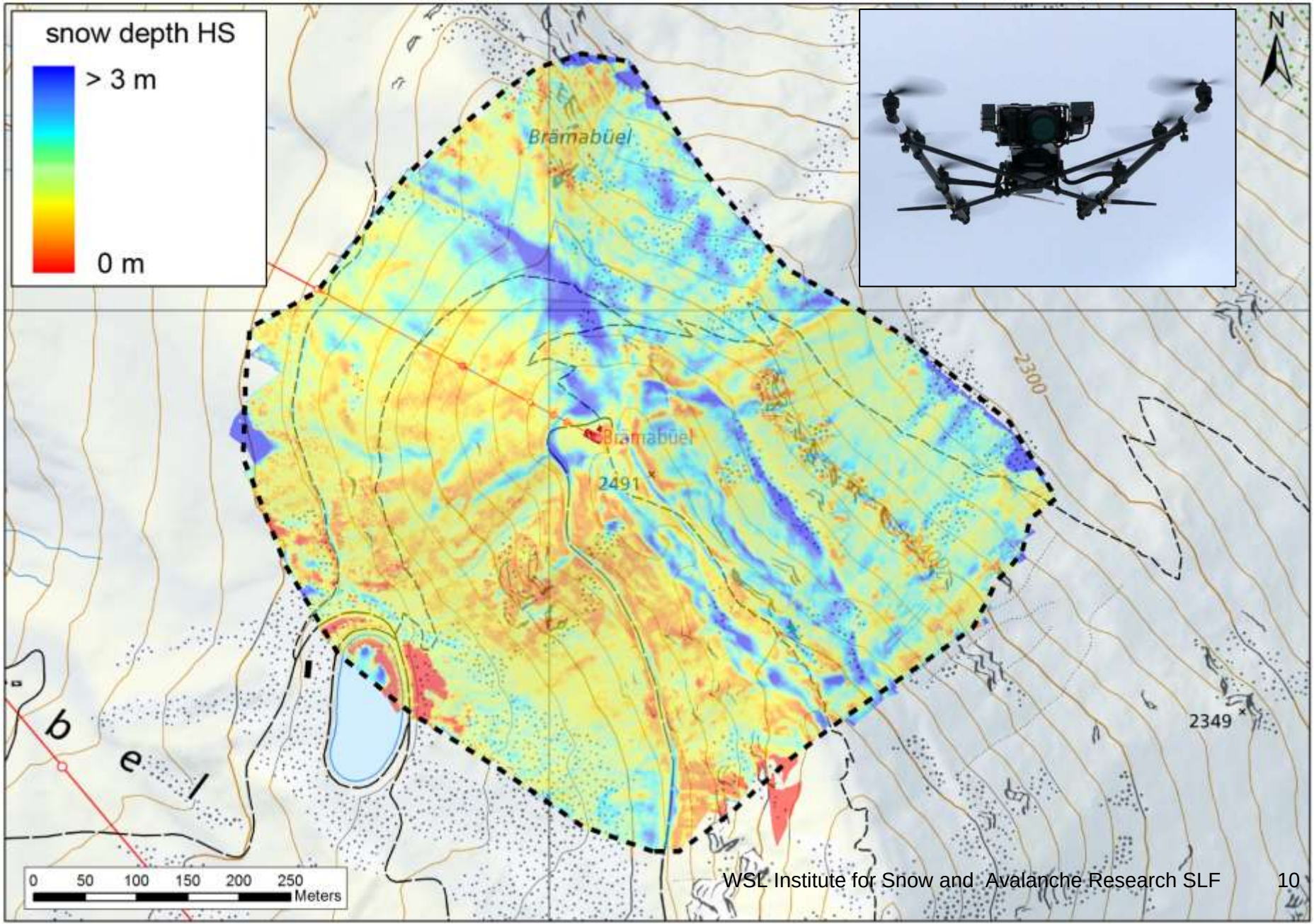
# Probing by hand: HS = 52 – 274 cm, mean = 196 cm



# Airplane based optical scanner data ADS: HS mean = 142 cm



# Unmanned Aerial System UAS data: HS mean = 137 cm



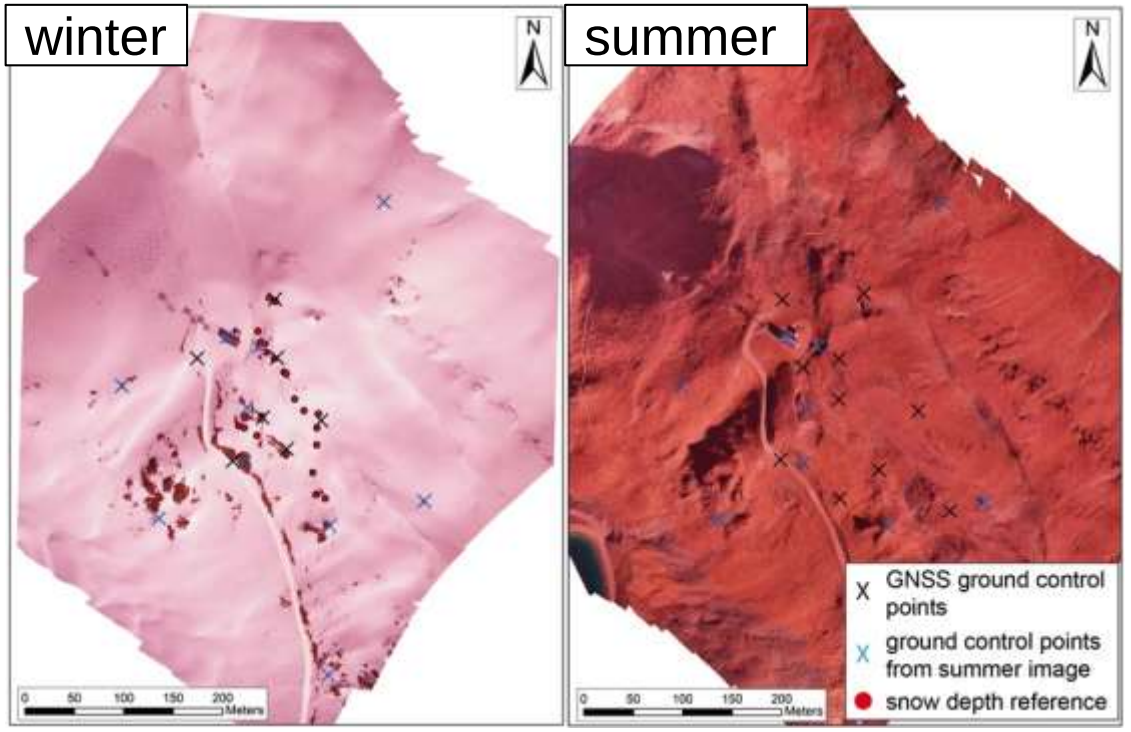
# Snow depth at a specific area?

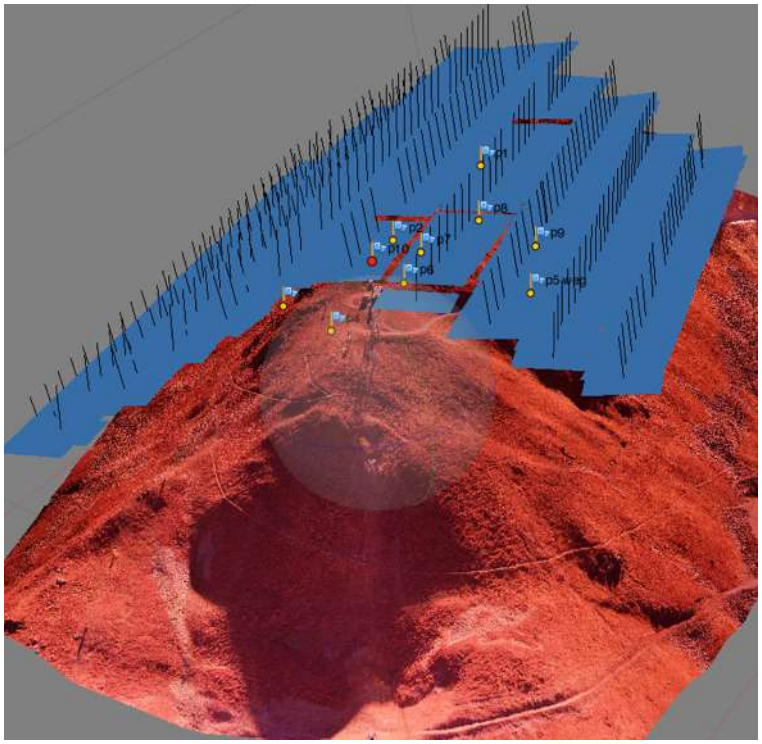
| | |
|---|---|
| **Globsnow** | No data |
| **Cryoland** | SWE = 300 mm -> HS = **100 cm** ($\delta$ = 300 kg/m$^3$) |
| **SLF HS map** | HS = **80 – 120 cm** |
| **AWS Stations** | HS = 49 – 182 cm, mean = **125 cm** |
| **Hand probing** | HS = 54 – 274 cm, mean **196 cm** |
| **ADS airplane** | HS = 0 – 600 cm, mean = **143 cm** |
| **UAS** | HS = 0 – 650 cm, mean = **137 cm** |

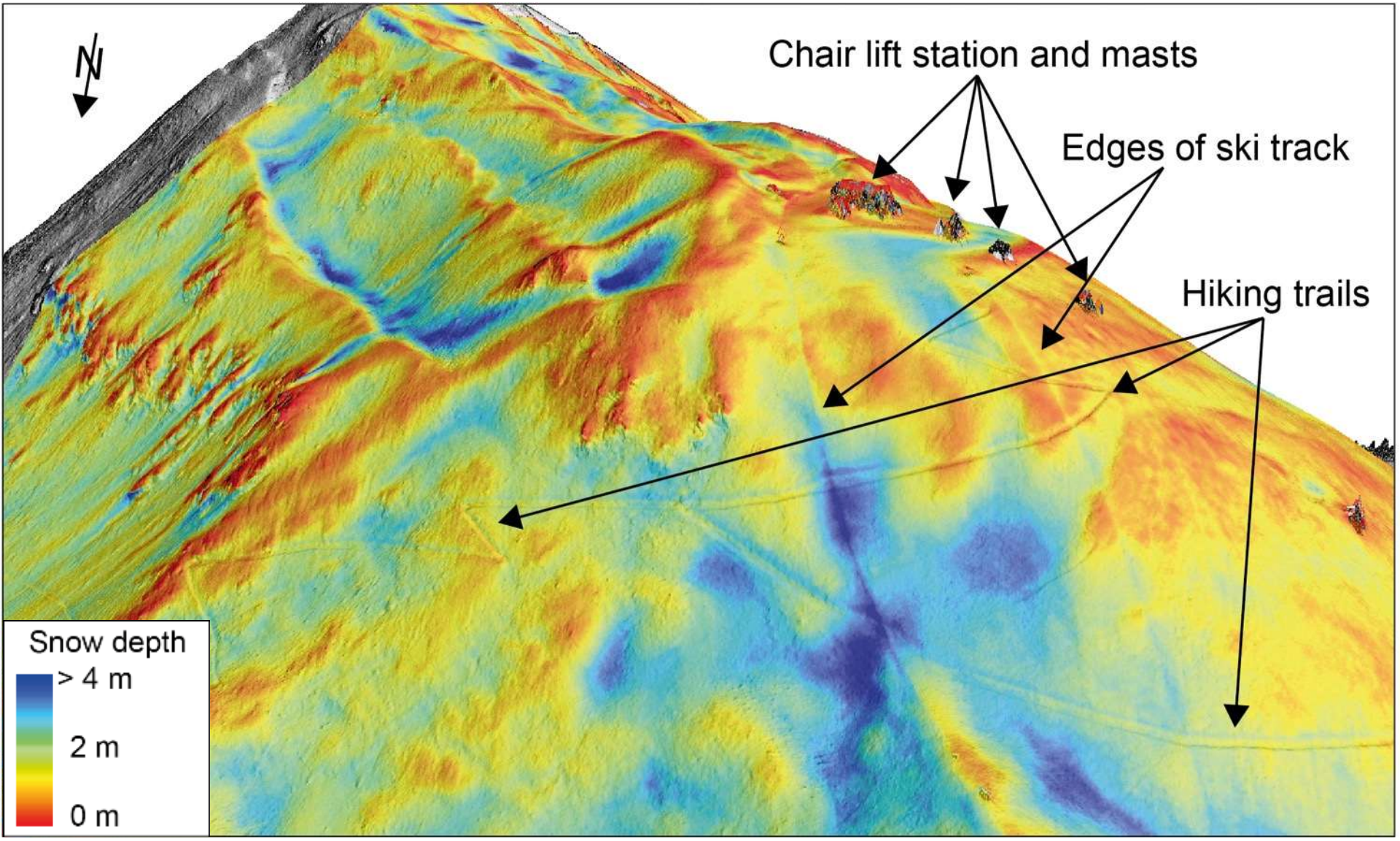
- Variation of **up to 100 %** in mean snow depth.
- We do not know if point samples are **representative** for an area
- Remote sensing based snow depth mapping enables an **accurate** and **spatial continuous** mapping of snow depth (HS)
- Coverage: UAS < 1km$^2$, airplane up to hundreds of km$^2$

# UAS based snow depth mapping

- 2300 – 2500 m a.s.l. mountain top: high wind speeds & artificial snow production / grooming, area: ~ 600 x 700 m
- 274 images @ 100 m above ground, 3 batteries
- Positioning accuracy <  10 cm with 10 reference points
- Flight time 15 minutes, reference points setting is time consuming!

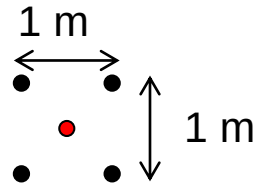


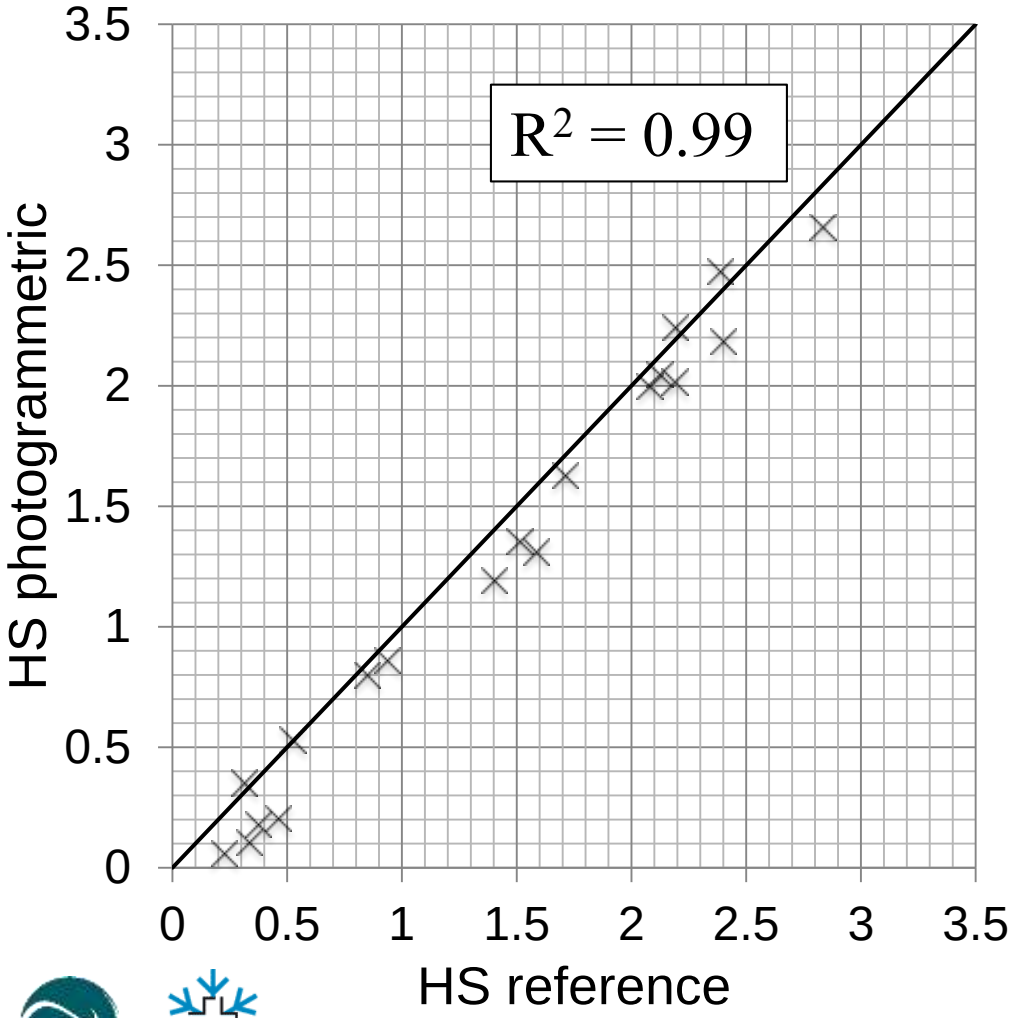



HS map: 10 cm resolution, input imagery 2 cm (Bühler et al. 2016 TC)

# Validation Brämabüel




- 22 reference plots with 5 probe measurements




- RMSE = 15 cm

- Small shift of 10 cm
- This can be explained by low grass and small bushes in the summer DSM

- Accurate mapping of HS variability



# What about homogenous snow surface?

Worst case: fresh snow and diffuse illumination

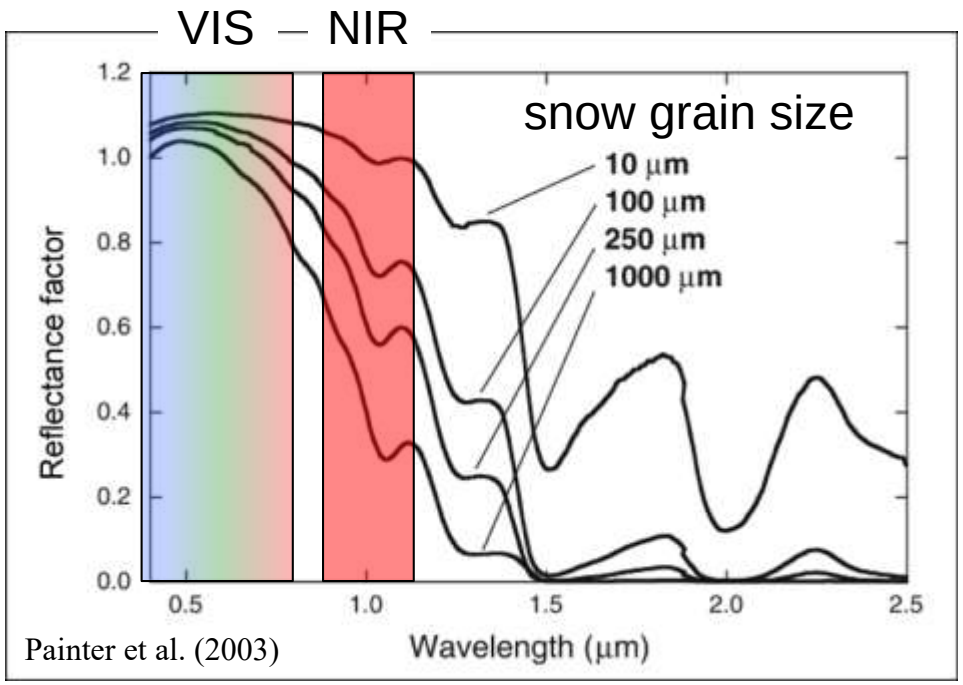


# Near Infrared NIR (0.7 – 1 µm)

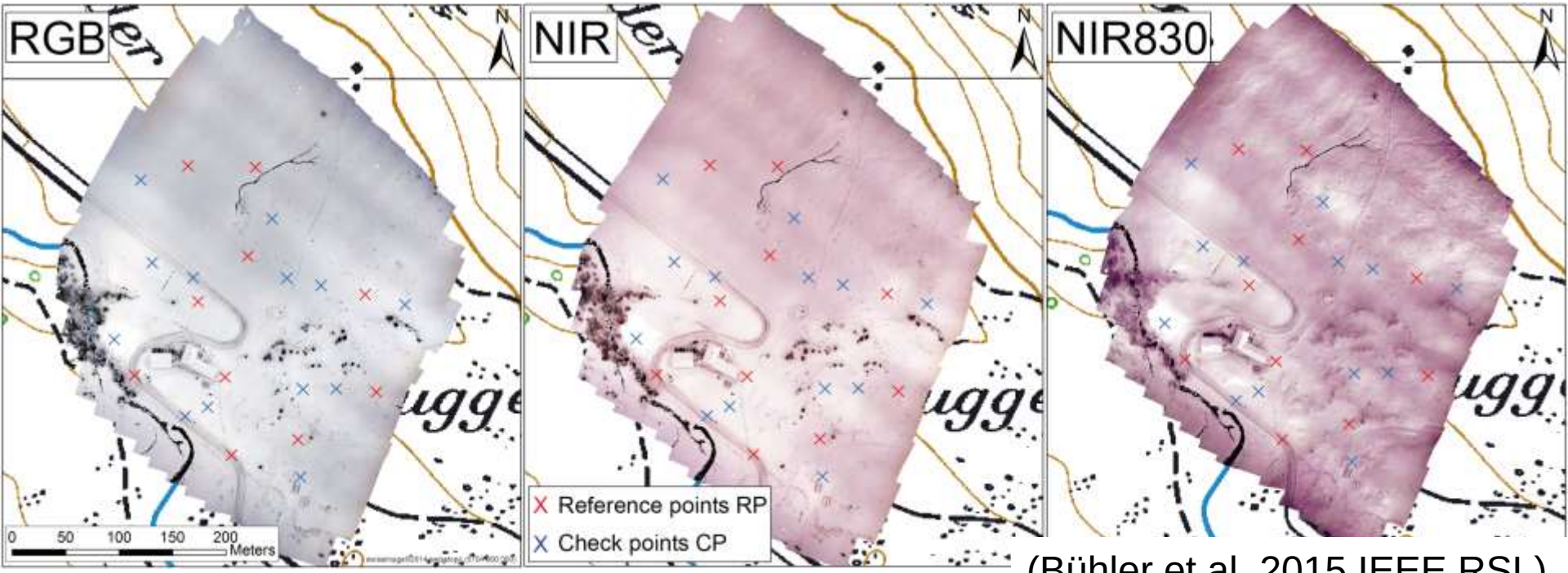
Sensitive to snow grain size, lower reflection on snow

Modified Sony NEX-7 camera

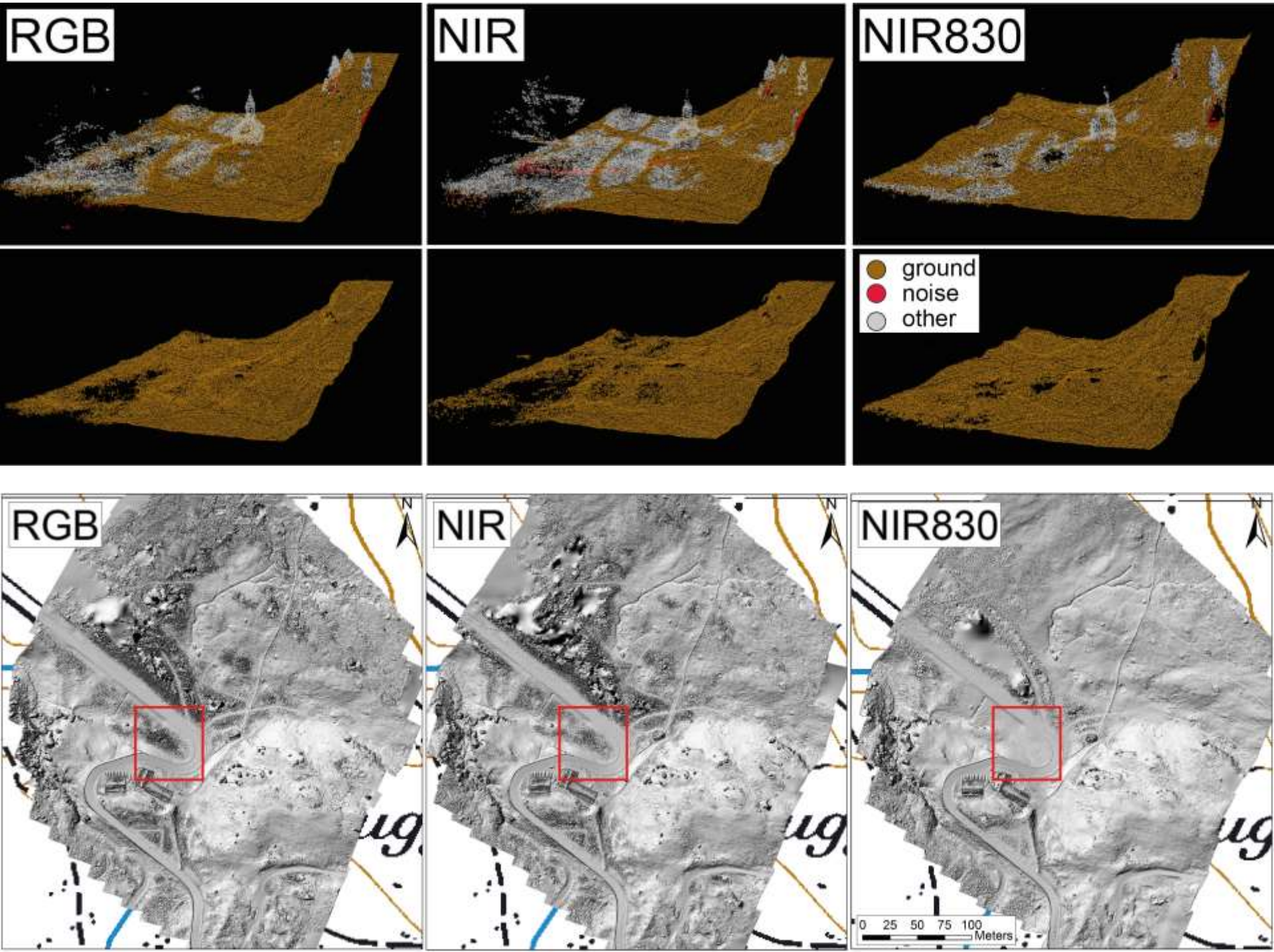
- RGB
- Mixed NIR & RGB
- Filter λ > 830 nm

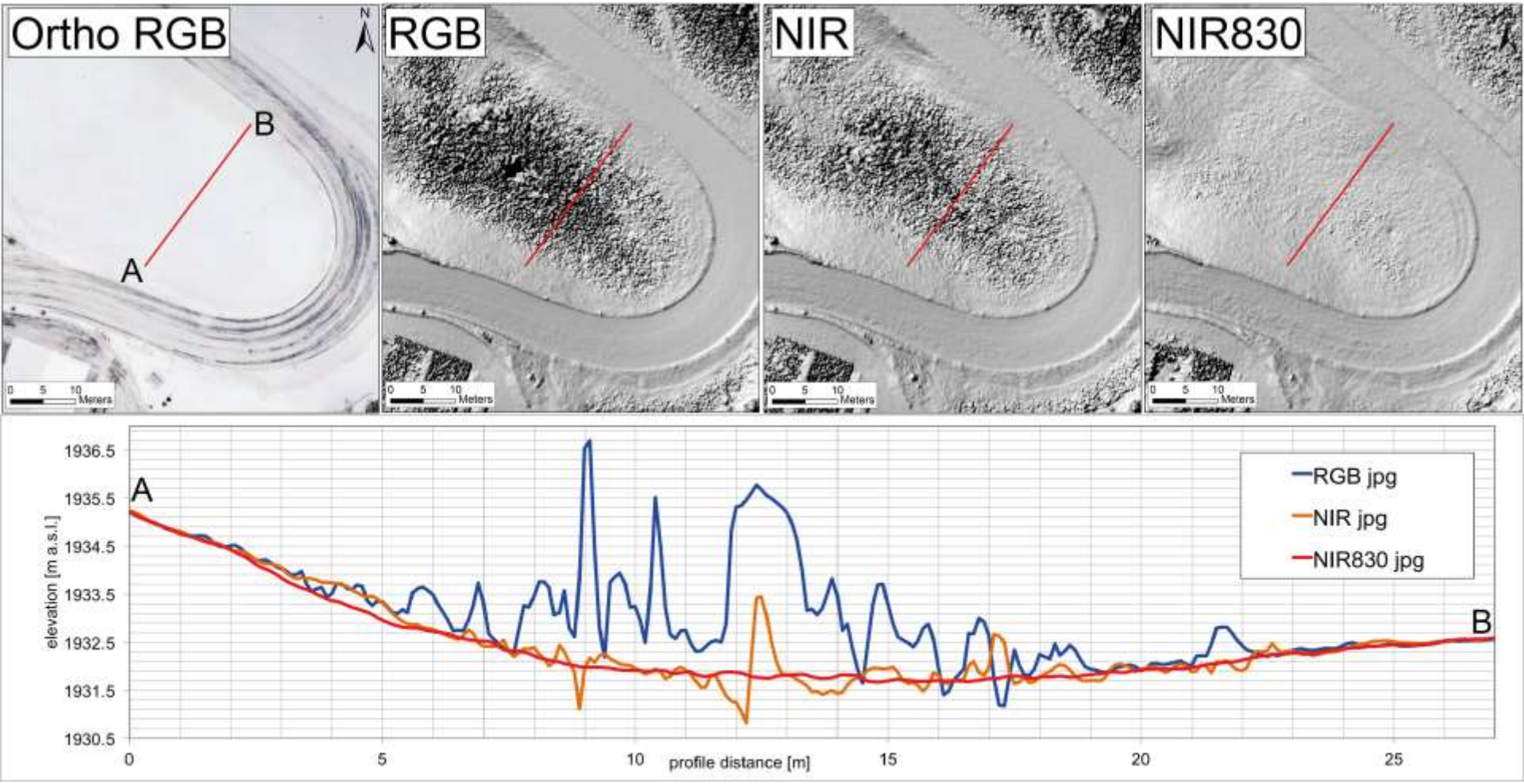


Painter et al. (2003)



(Bühler et al. 2015 IEEE RSL)


RGB
NIR
NIR830
ground
noise
other
RGB
NIR
NIR830
N
0 25 50 75 100
Meters

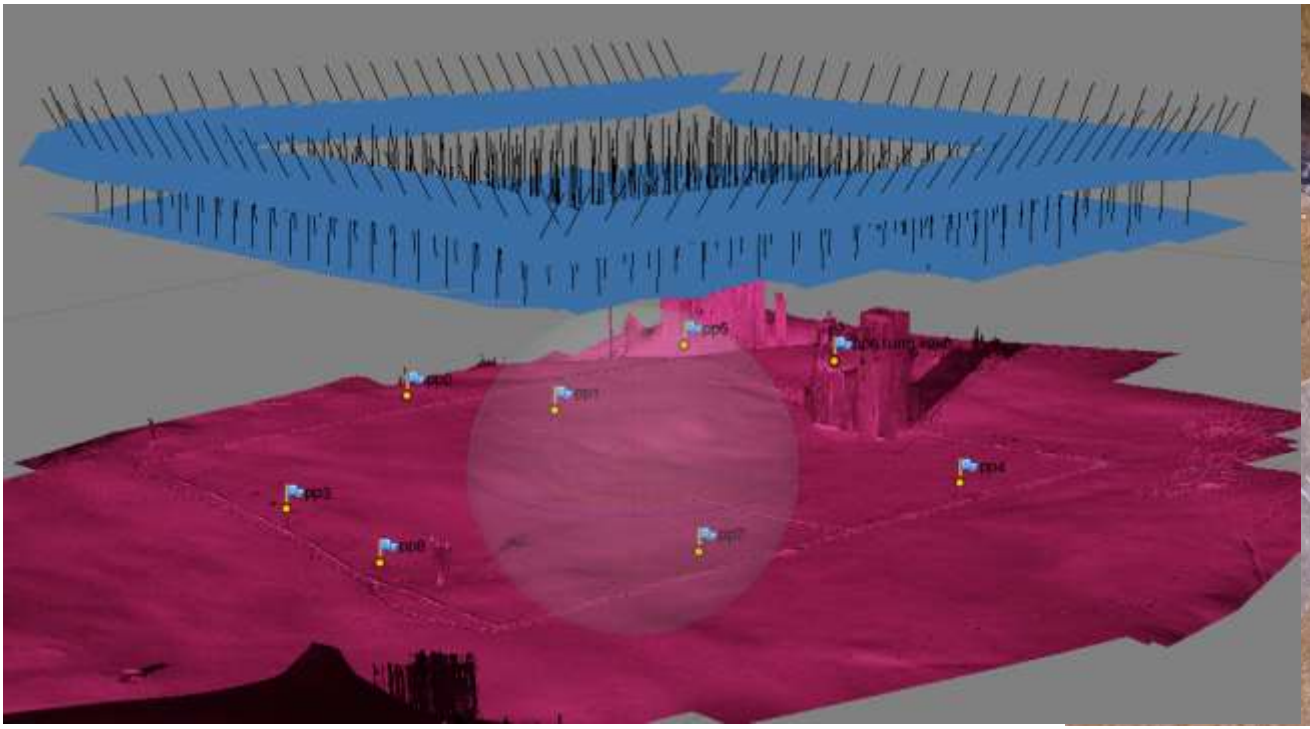



- Significantly better point matching with NIR
- Less outliers and noise
- Better results, higher accuracy

(Bühler et al. 2017 IJRS)

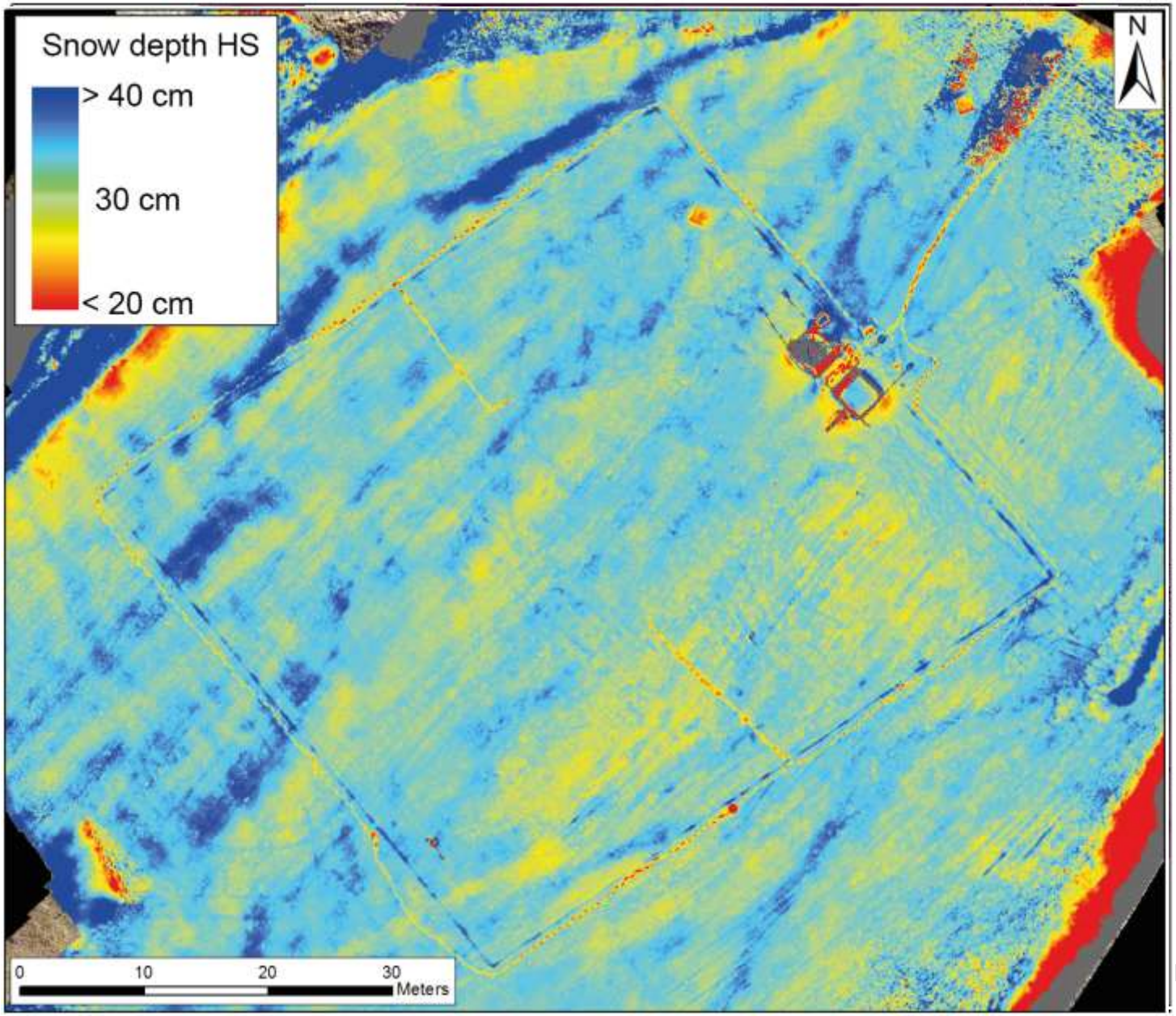
# ESA SnowLab Laret, Davos

- 15 m above ground, GSD = 3 mm, fixed ground control points
- Flight time 12 minutes, 3 batteries
- Result: 1 cm DSM, Oblique images to avoid doming effects
- Estimated z accuracy of ~1 cm





# SLF/GAMMA Test field Laret, Davos



# Conclusions

- Meaningful snow depth mapping is **not trivial**
- **Point measurements** might not be representative
- Unmanned Aerial Systems are able to accurately **map snow depth** and its **spatial distribution**
- Valuable **validation tool** for any snow depth / snow water equivalent products
- Successful **application** of UAS snow depth mapping at SLF test sites around Davos
- Legal limitations **limit** the area to ~1 $km^2$, technically much more would be possible, rapid and dynamic development

WSL SLF

# Recent relevant publications


Bühler, Y., M. Adams, A. Stoffel, and R. Boesch (2017): Photogrammetric reconstruction of homogenous snow surfaces in alpine terrain applying near infrared UAS imagery, *International Journal of Remote Sensing*, doi: 10.1080/01431161.2016.1275060.

Bühler, Y., M. Adams, R. Bösch and A. Stoffel (2016): Mapping snow depth in alpine terrain with unmanned aerial systems (UASs): potentials and limitations, *The Cryosphere, 10,* 1-14, doi:10.5194/tc-10-1-2016.

Bühler, Y., M. Marty, L. Egli, J. Veitinger, T. Jonas, P. Thee, and C. Ginzler (2015a): Snow depth mapping in high-alpine catchments using digital photogrammetry, *The Cryosphere*, *9*, 229-243.

Bühler, Y., L. Meier, and C. Ginzler (2015b): Potential of operational, high spatial resolution near infrared remote sensing instruments for snow surface type mapping, *Geoscience and Remote Sensing Letters, IEEE*, *12*(4), 821 – 825.

Bühler, Y., R. Bösch, A. Stoffel, and M. Adams (2015), Geodatenerfassung im hochalpinen Gelände mittels Drohnen, Geomatik Schweiz, 9/2015, 366 - 370.