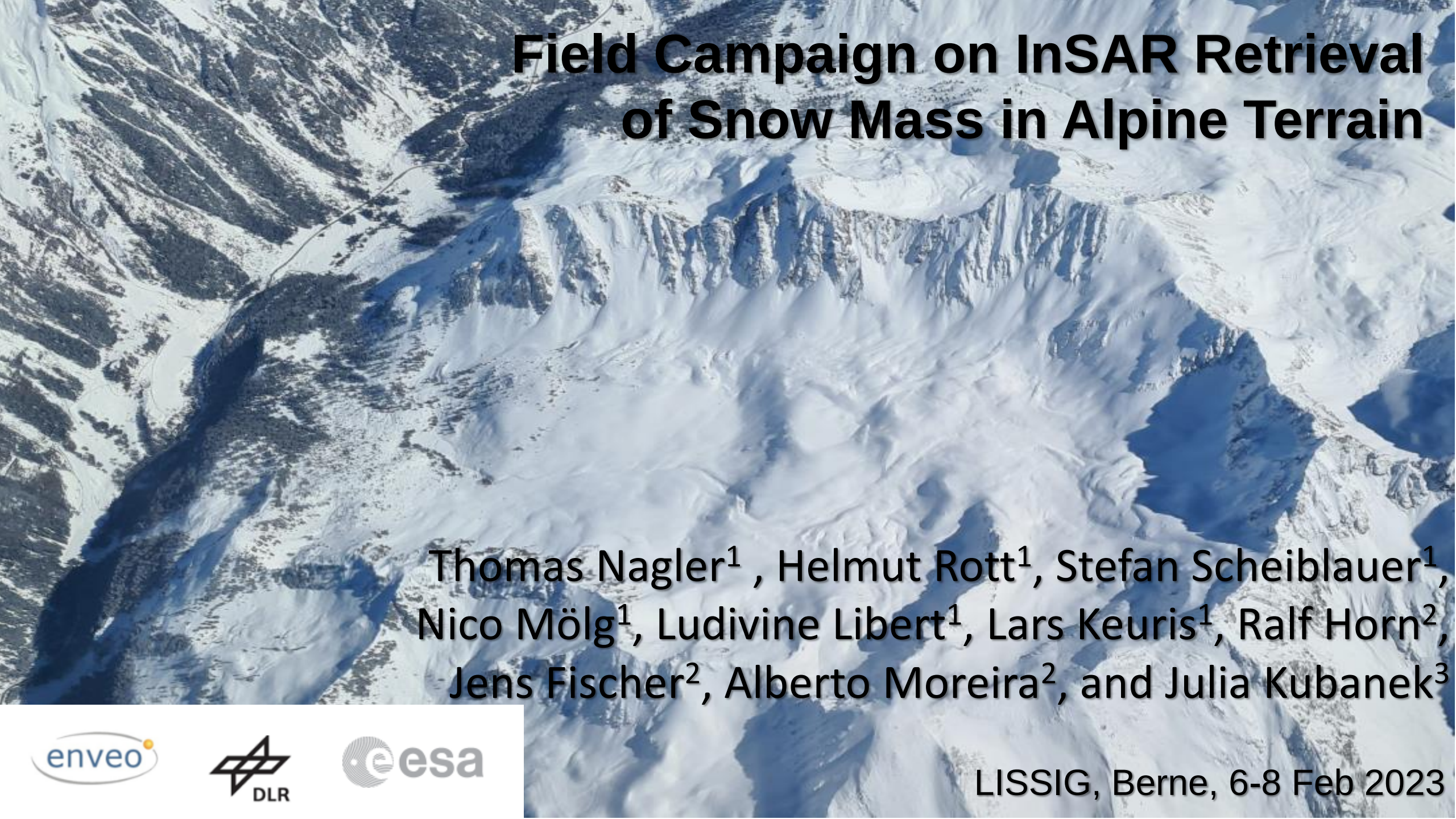

# Field Campaign on InSAR Retrieval of Snow Mass in Alpine Terrain

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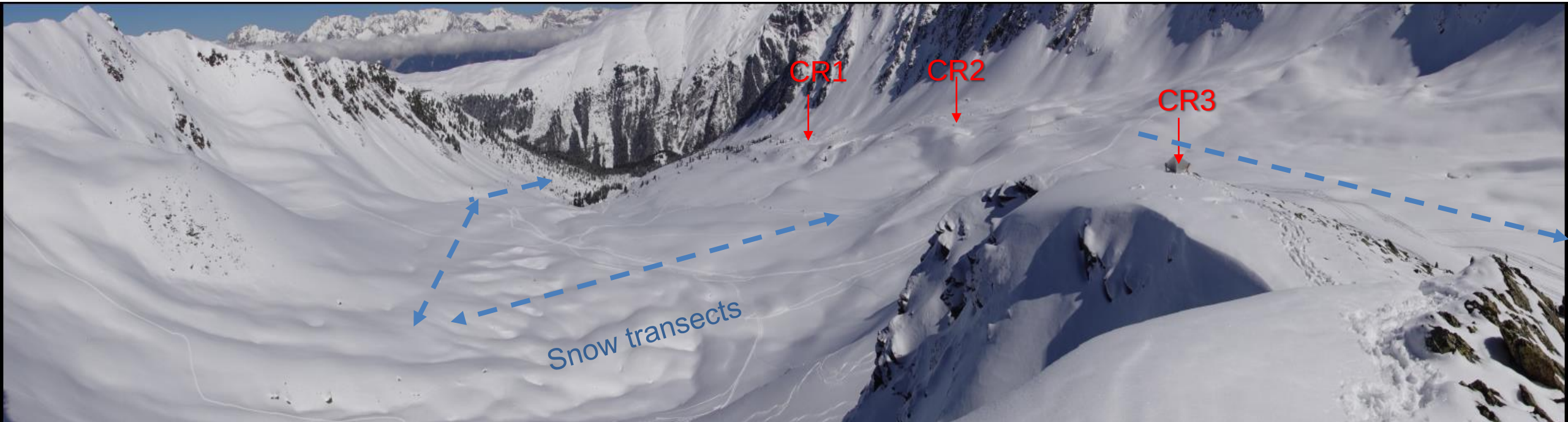
LISSIG, Berne, 6-8 Feb 2023

# Field Campaign Wörgetal, Kühtai, March 2021

**OBJECTIVES:**

- Testing and evaluating methods for snow mass (SWE) retrievals in Alpine environment with focus on the repeat-pass interferometric SAR (RP-InSAR) approach.
- Proof of concept for applying geostationary SAR systems for InSAR SWE retrieval, specifically addressing the feasibility of the HydroTerra mission (geostationary C-band SAR) that was proposed to ESA in response to the Call for Earth Explorer 10  Mission Ideas.
- Assessing the performance of polar orbiting L-band InSAR for SWE retrievals, in support of preparations for the mission ROSE-L (Radar Observation System for Europe at L-band).

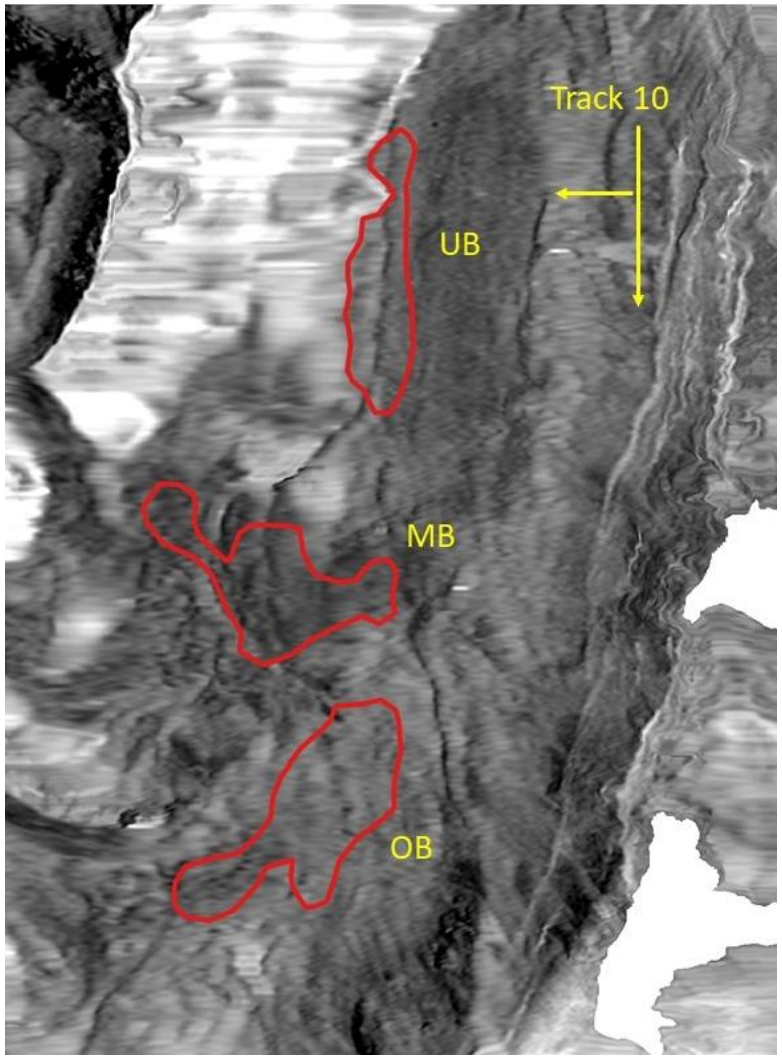


# Airborne and In-situ Measurements


| DLR F-SAR C+L | C-band | L-band |
|---|---|---|
| Center frequency | 5300 MHz | 1325 MHz |
| Signal bandwidth | 384 MHz | 150 MHz |
| Azimuth resolution | 0.50 m | 0.60 m |
| Range resolution | 0.50 m | 1.30 m |
| Pixel size | 0.2 m x 0.3 m | 0.4 m x 0.6 m |

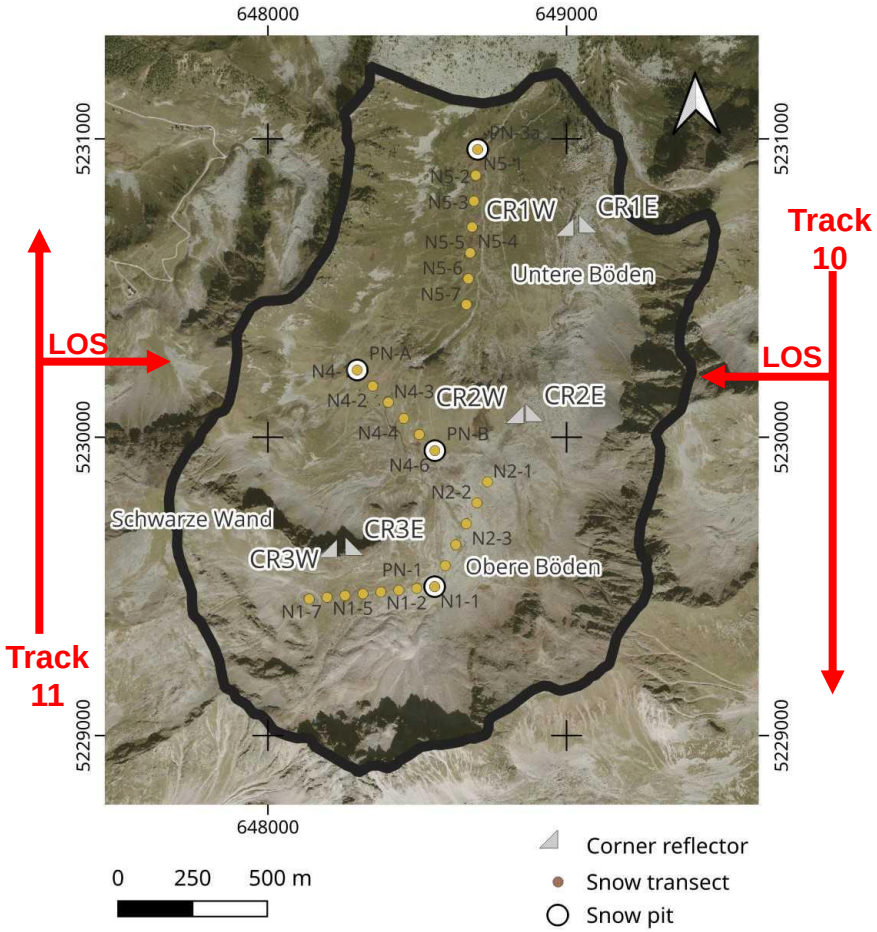
F-SAR, geocoded σ°VV image

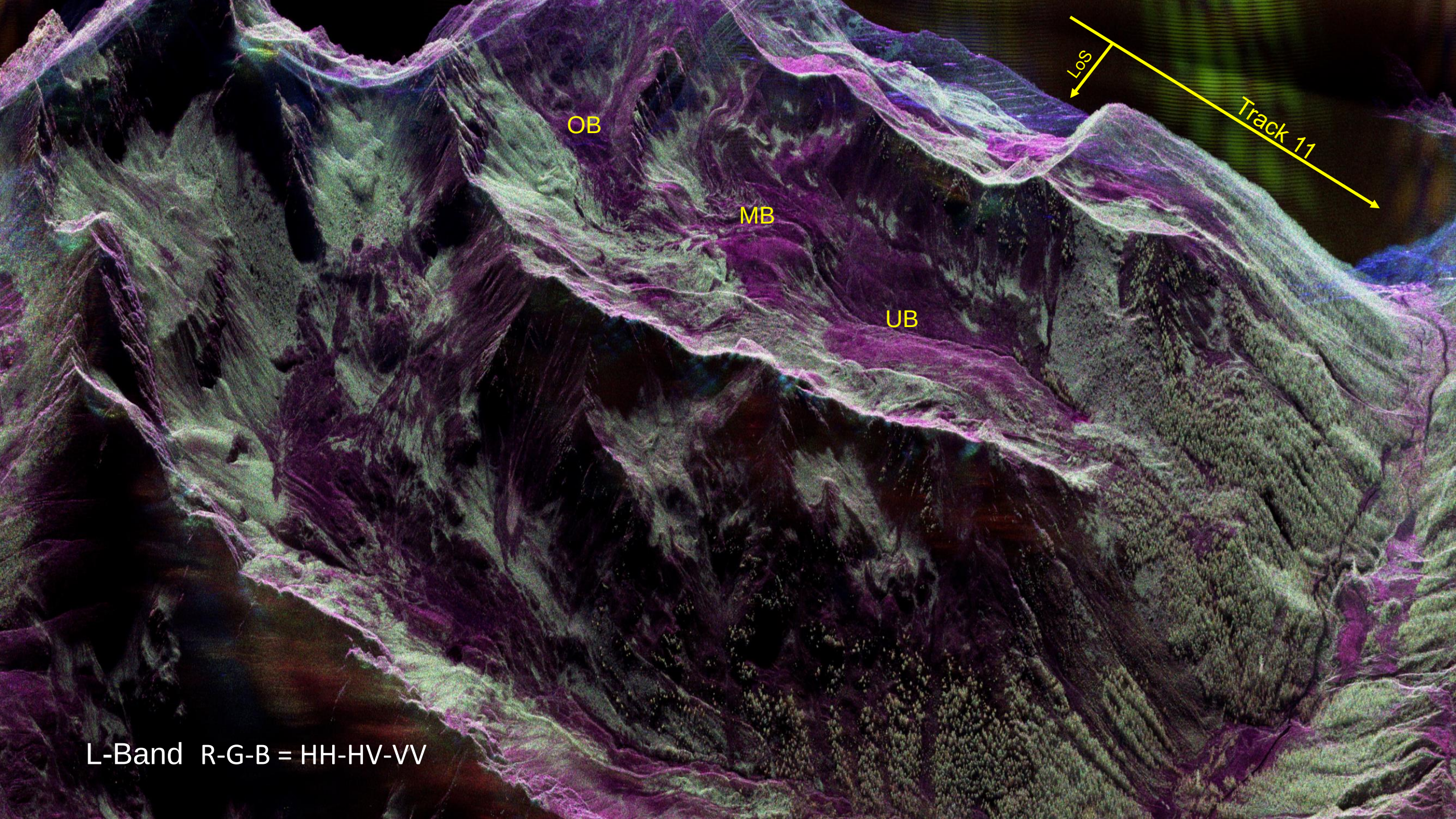
OB, MB, UB - Sites of field measurements and areas for retrieval validation



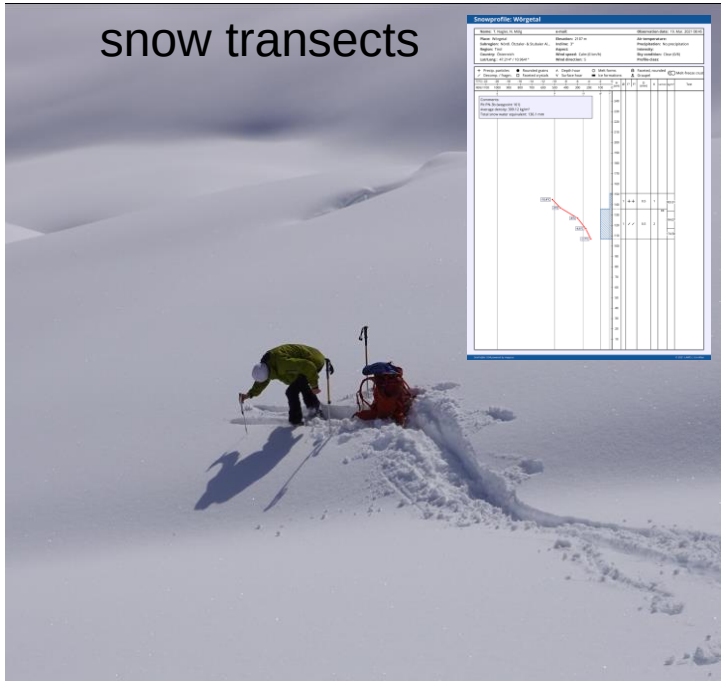

Test site Wörgetal

Location of snow pits & corner reflectors

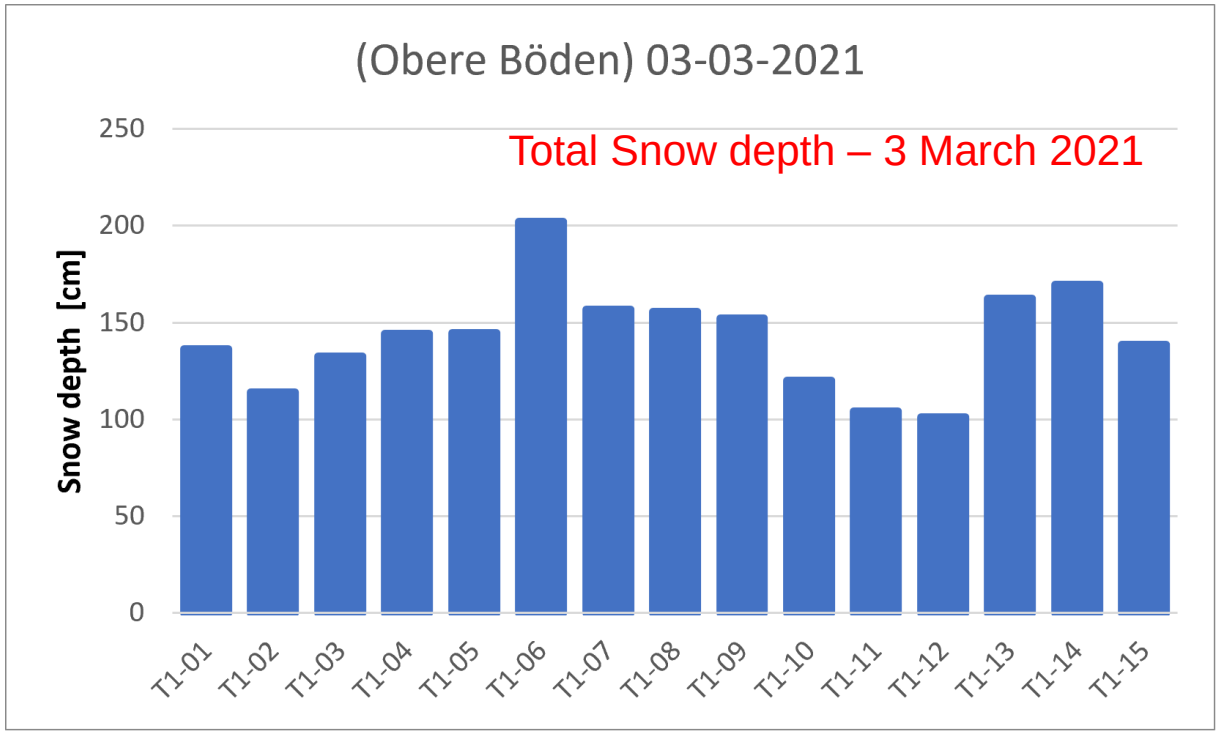


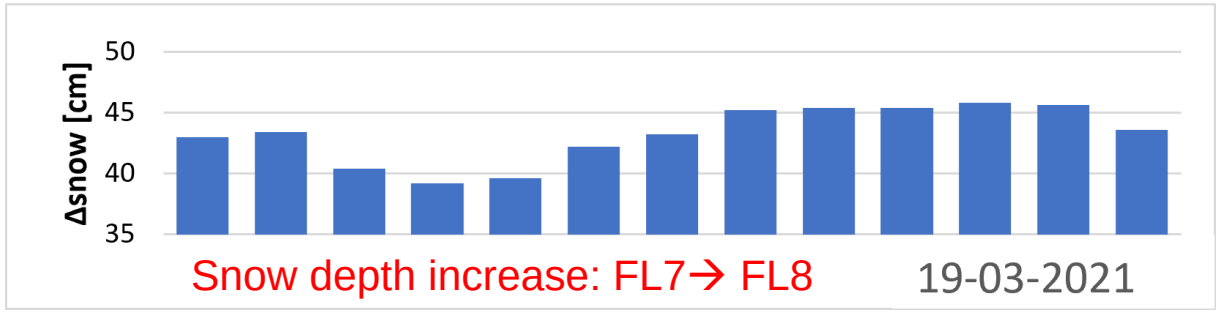

LoS
Track 11
OB
MB
UB
L-Band R-G-B = HH-HV-VV

# Field Measurements

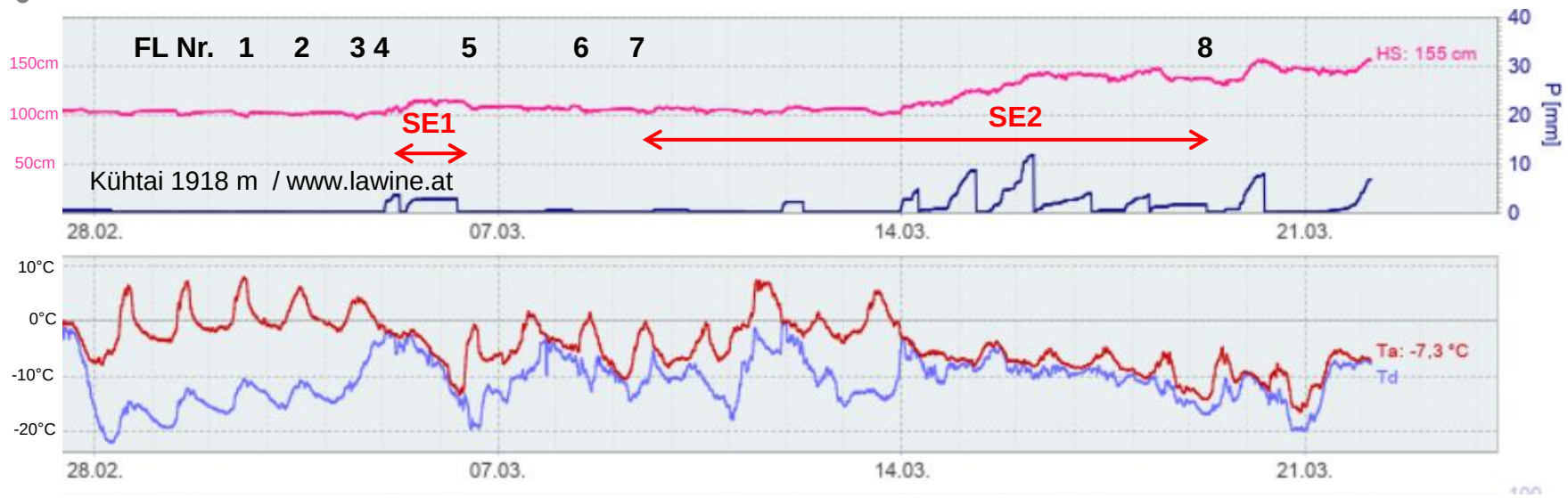







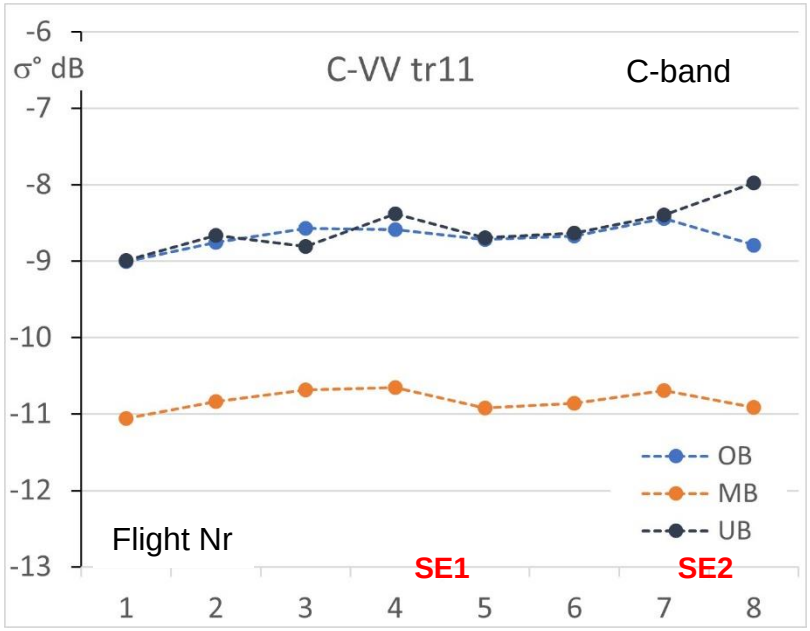



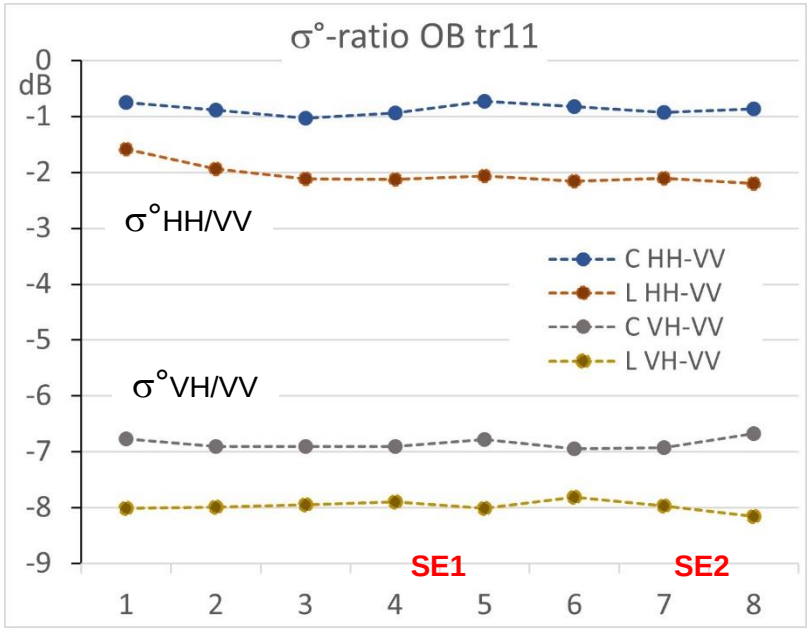
# Snow Accumulation and Backscatter Signatures




Accumulation of snowfall events

| RoI | Event | ΔSD [cm] | std. dev [cm] | ΔSWE [mm] |
|---|---|---|---|---|
| OB | SE1 | 15.6 | 2.1 | 14.8 |
| MB | SE1 | 13.3 | 2.4 | 12.6 |
| UB | SE1 | 12.3 | 1.1 | 11.7 |
| OB | SE2 | 43.2 | 2.3 | 62.6 |
| MB | SE2 | 47.2 | 6.2 | 68.4 |
| UB | SE2 | 42.1 | 6.2 | 61.0 |




C- & L-band σ° & pol-ratios:

⇐ No response to snowfall events

# SWE Retrieval by means of Repeat-pass SAR Interferometry

**Basic Approach:**

- Differential processing of repeat-pass InSAR data to obtain $\Delta\phi_{snow}(t_2\text{-}t_1)$

$$\Delta\phi = \Delta\phi_{flat} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{snow}$$

- The interferometric phase delay in dry snow is related to snow depth and density (for backscatter dominated by signal of snow/ground interface)

$$\Delta SWE = \rho_s \, \Delta d_s$$

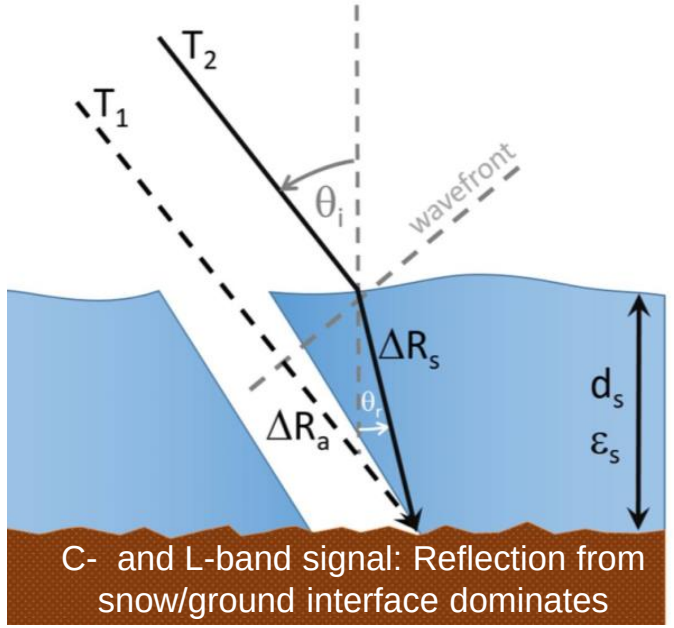
$$\Delta\phi_{snow} = -\frac{4\pi}{\lambda} \Delta d_s \left( cos\theta_i - \sqrt{\varepsilon - sin\theta_i^2} \right) \qquad \epsilon' = 1 + 1.60\,\rho_s + 1.86\,\rho_s^3 \;\; [g\ cm^{-3}]$$

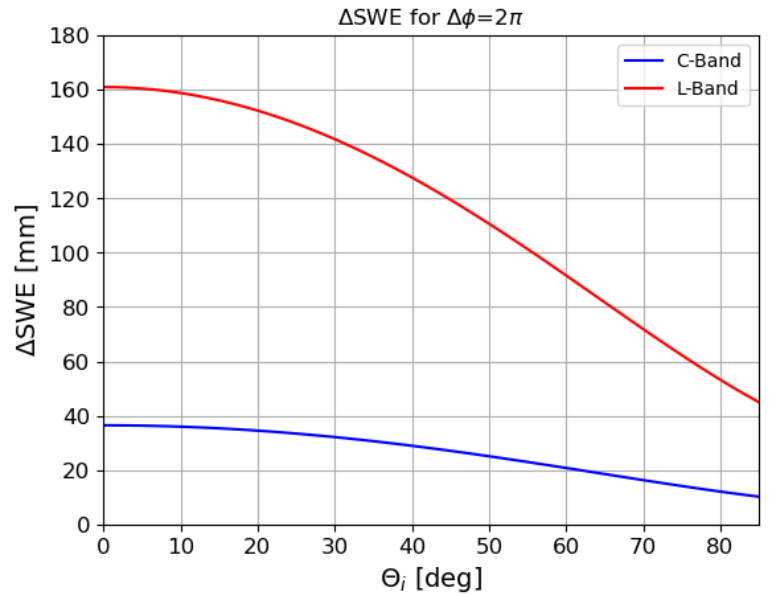
- Linear approximation for $\theta_i \leq 40°$: $\Delta\phi_{snow} = -\frac{2\pi}{\lambda} \frac{1.6}{cos\theta_i} \Delta SWE$

- For obtaining $\Delta\phi_{snow}$ from $\Delta\phi$ a reference phase (sites with zero or known ΔSWE) is needed: $\Delta\phi_{snow} = \Delta\phi - \Delta\phi_{ref}$

***Critical issues:***

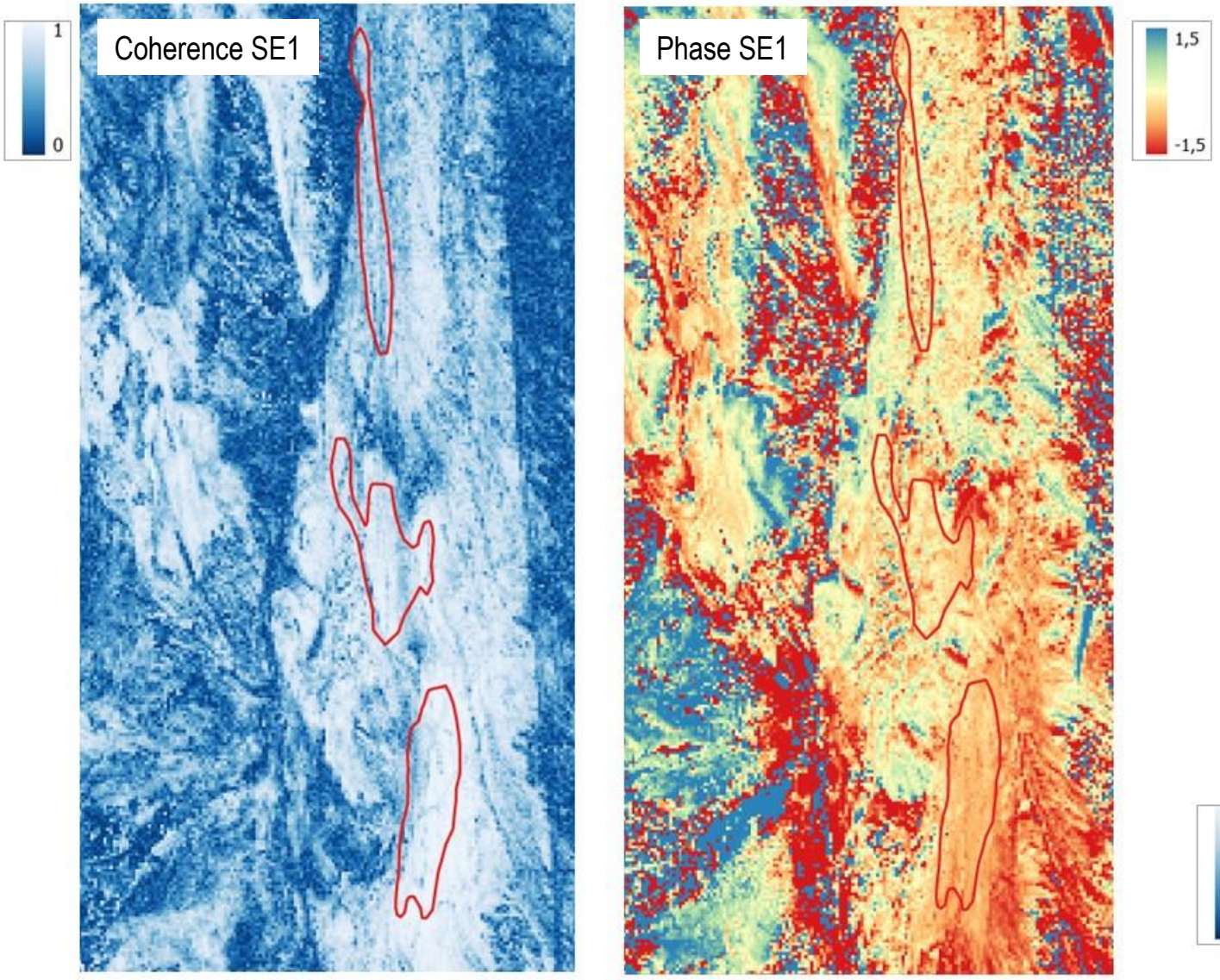
- Temporal decorrelation (related to snowfall, snow drift, ….)
- Reference phase at sites with zero or known ΔSWE *
- 2π phase ambiguity
- Correction for change in $\Delta\phi_{atm}$ *




* Wörgetal-campaign: $\Delta\phi_{CR}$ *is* used as reference phase

# Coherence and Phase Images C-band



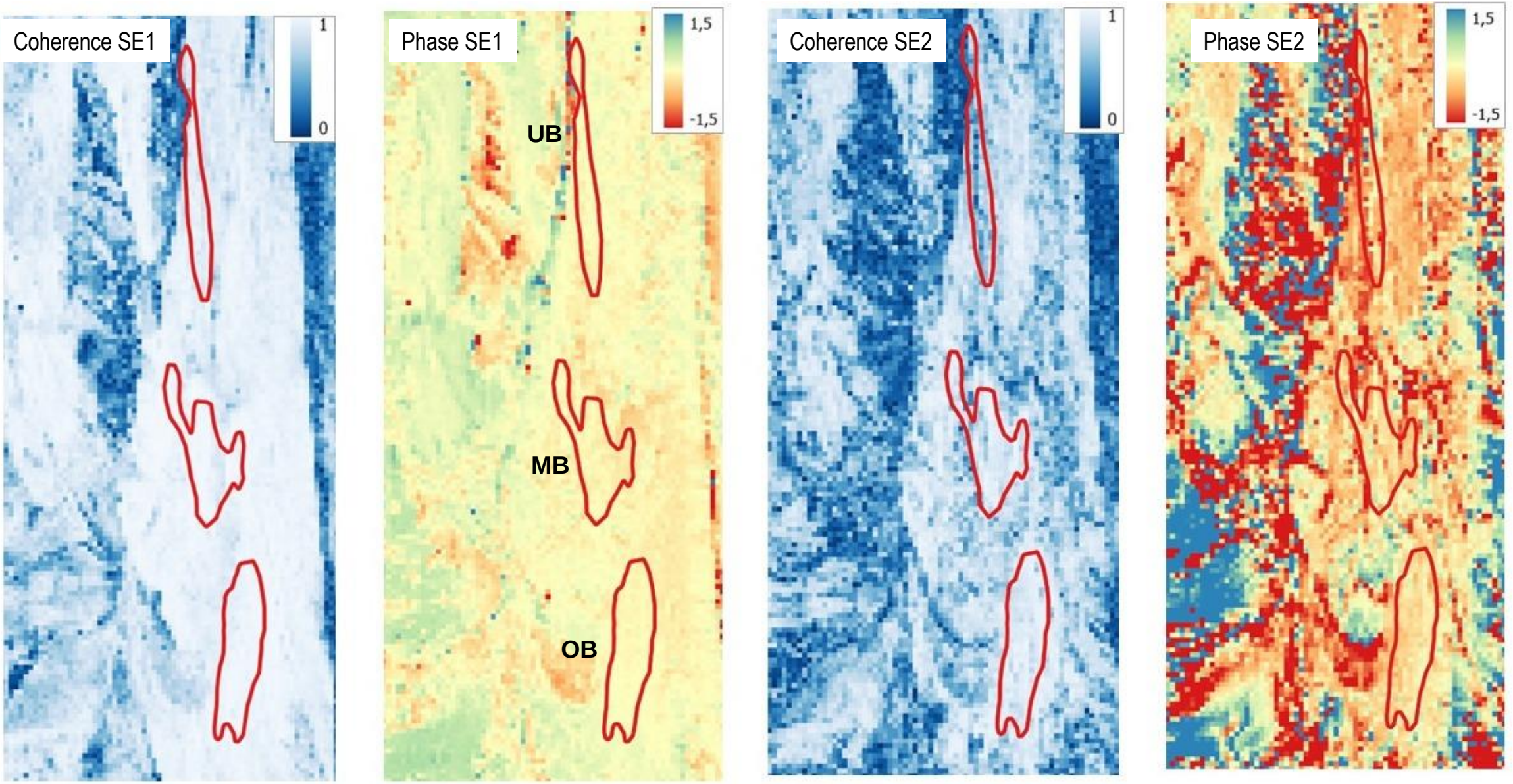

***SE2***

*C-band constraints*

- SWE amount exceeds 2 π ambiguity
- Temporal decorrelation

*Track 10, VV*

# Coherence and Phase Images L-band

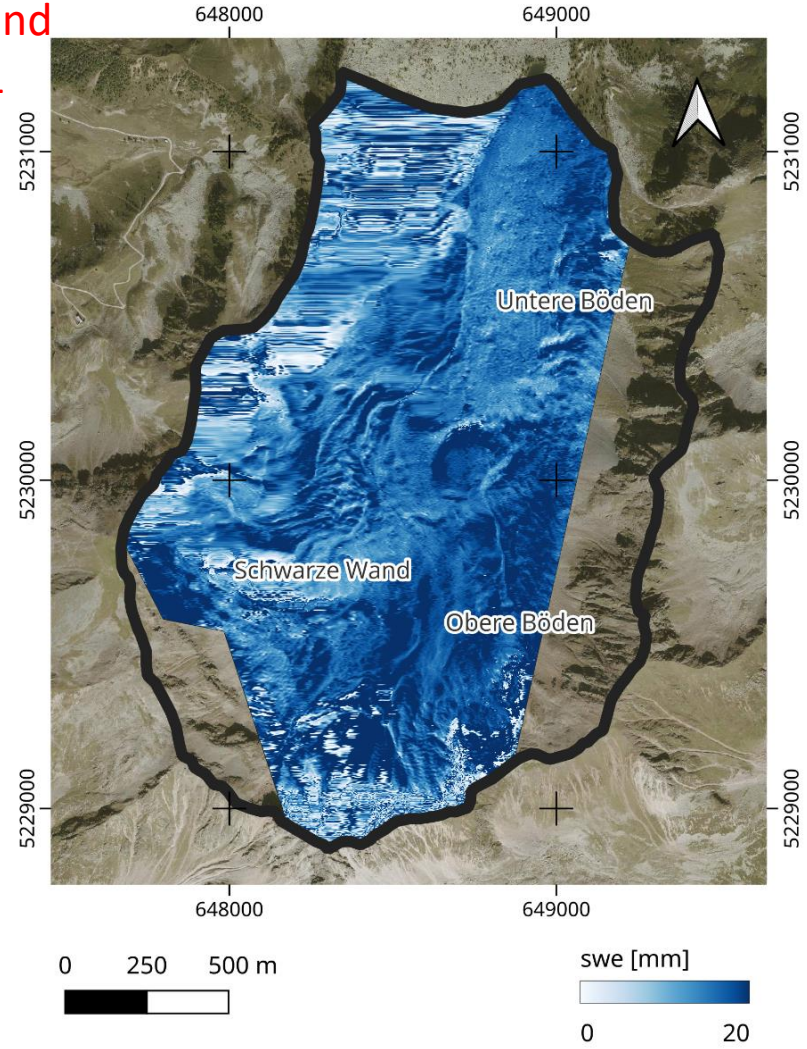



*Track 10 , VV*

# SWE Maps based on Track 10

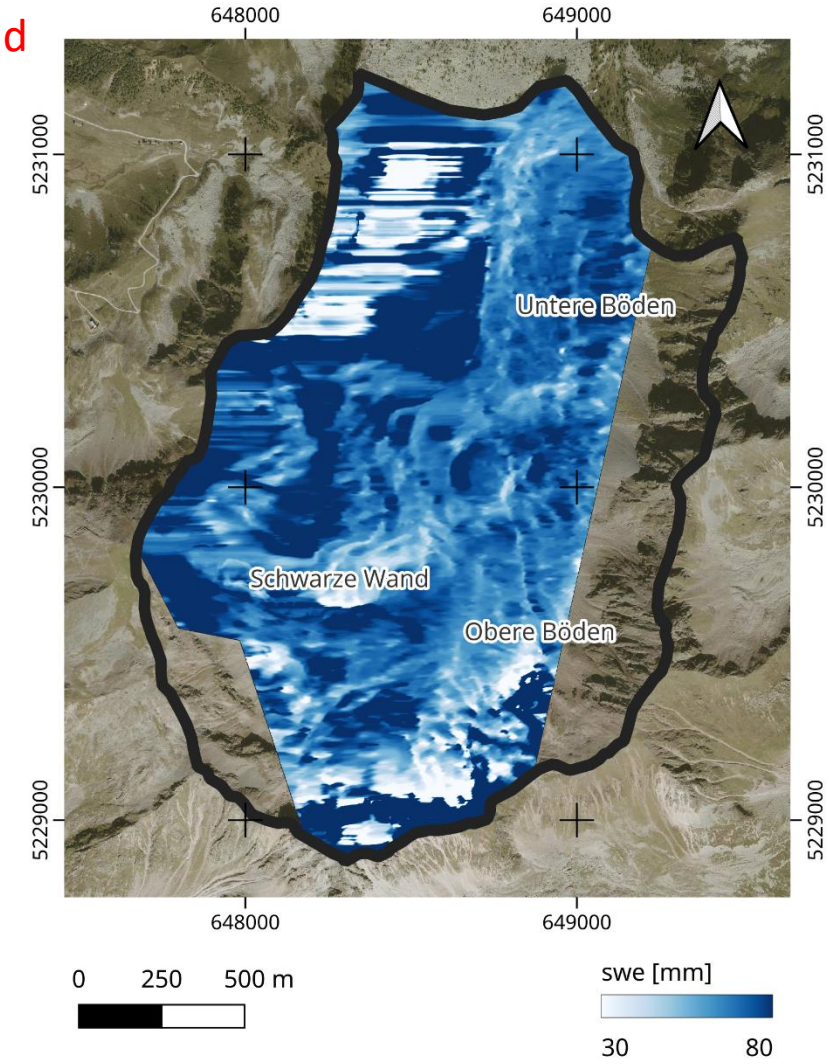
Map of snow accumulated on 5 March 2021, derived from ***C-band VV InSAR*** data

C-Bnd
SE1

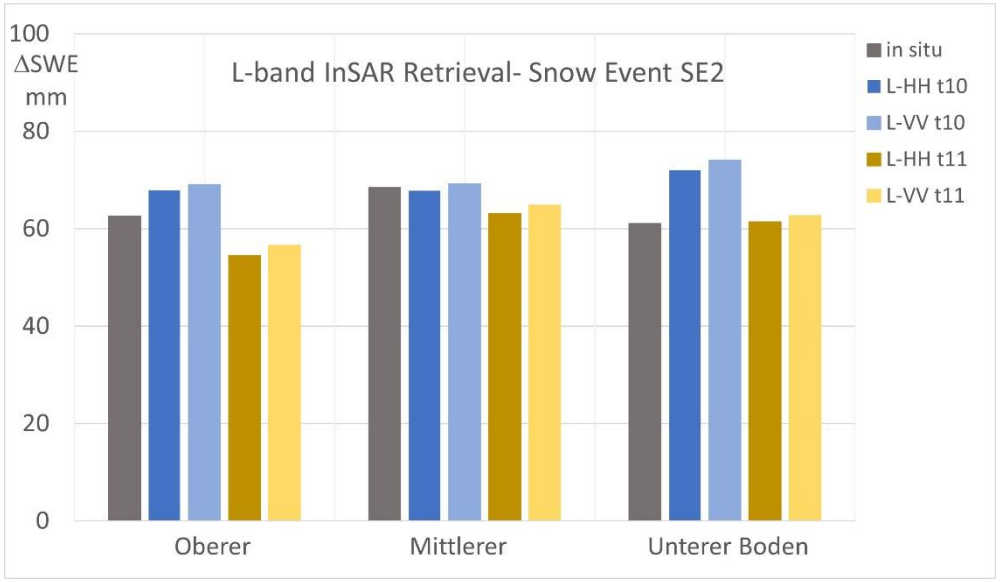



Map of snow accumulated during the period 14 to 18 March 2021, derived from ***L-band VV InSAR*** data

L-Bnd
SE2



# SWE Retrieval Performance – Comparison with Field Measurements



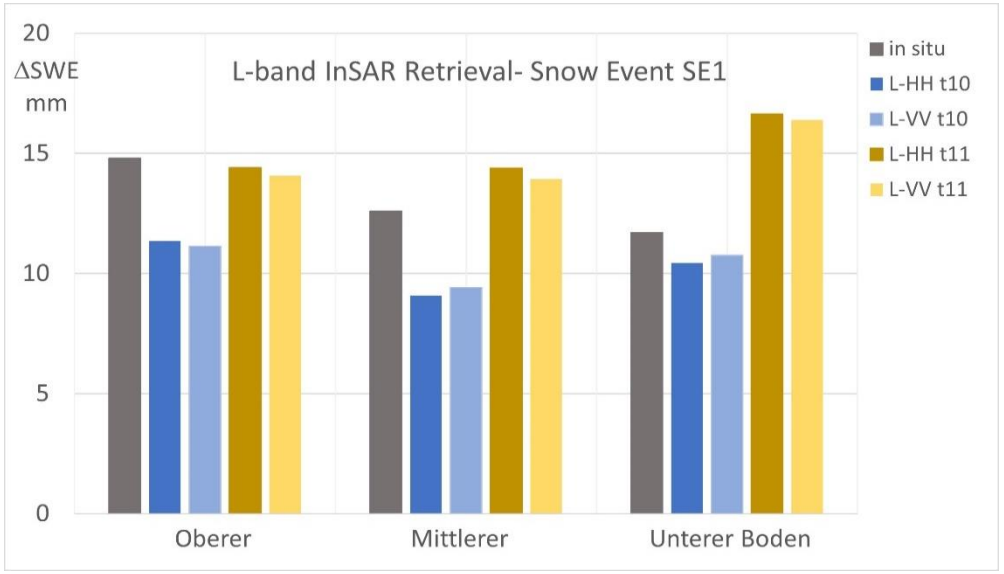

ΔSWE retrievals based on Track 10 & 11

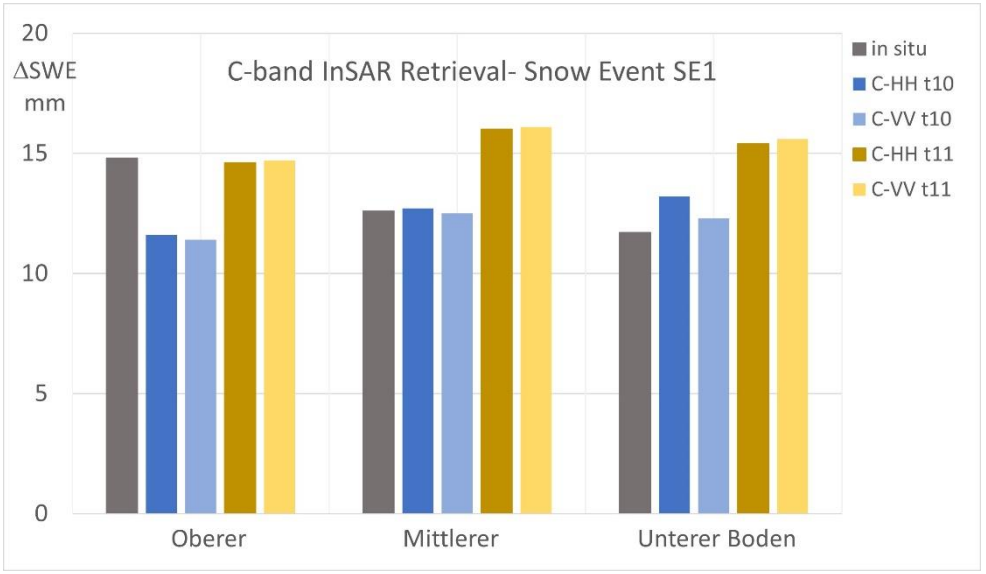
Mean values for RoI's, compared with in-situ measurements

**SE2** L-band: $\Delta SWE_{ret}$ - $\Delta SWE_{obs}$ = 1.6 mm ; RMSD = 6.5 mm

**SE1** L-band: $\Delta SWE_{ret}$ - $\Delta SWE_{obs}$ = 1.2 mm ; RMSD = 2.9 mm

**SE1** C-band: $\Delta SWE_{ret}$ - $\Delta SWE_{obs}$ = 0.2 mm ; RMSD = 2.5 mm



# Conclusions

- The Wörgetal campaign confirms the high potential of the repeat-pass InSAR approach, using L- and C-band data, for observing the mass of snow accumulating in Alpine terrain.
- Temporal decorrelation related to snowfall and the $2\pi$ phase ambiguity are limiting factors for continuous applications, depending on radar frequency.
- C-Band InSAR data show good results for retrieving snow accumulation of moderate intensity, but repeat-pass data decorrelate at snowfall events of higher intensity.
- The F-SAR L-band InSAR data show high coherence and good performance for SWE retrieval also for the high accumulation event.
- VV-polarized RP-InSAR data show slightly higher coherence than HH-polarized data, but the differences in retrieved SWE are insignificant.
- C- and L-band co- and cross-pol backscatter intensity of the Wörgetal data set does not show a response to the snow accumulation events.
- Feasibility studies on the application of geostationary interferometric SAR for SWE retrieval are in progress, based on simulated SAR data.