Experimental Studies on Dual Frequency InSAR Application for Snow Mass Monitoring

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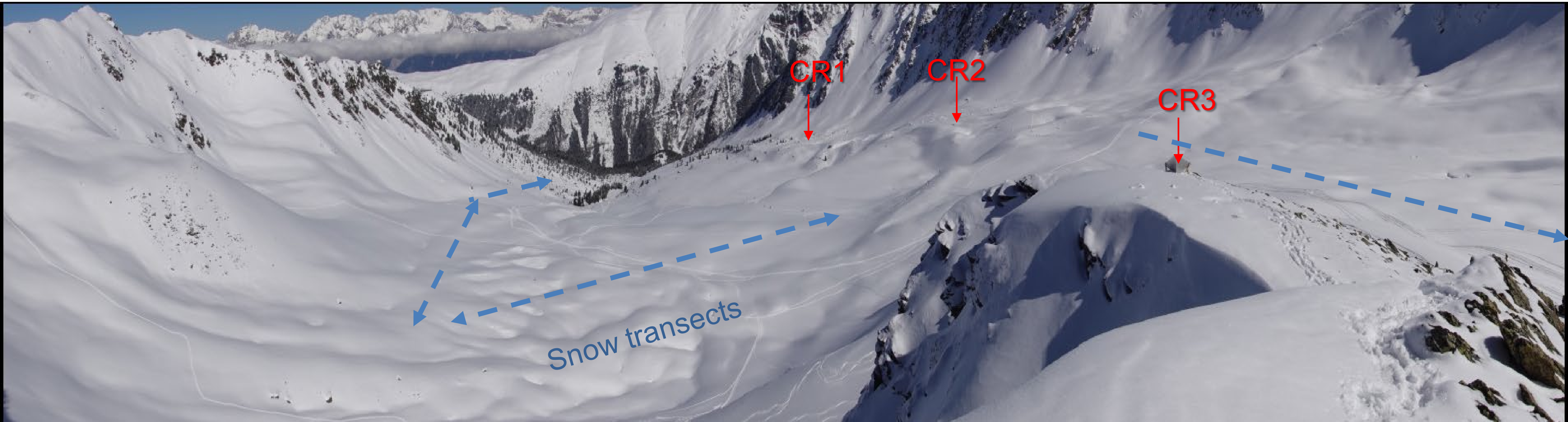
Field Campaign Wörgetal, Kühtai, March 2021

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).

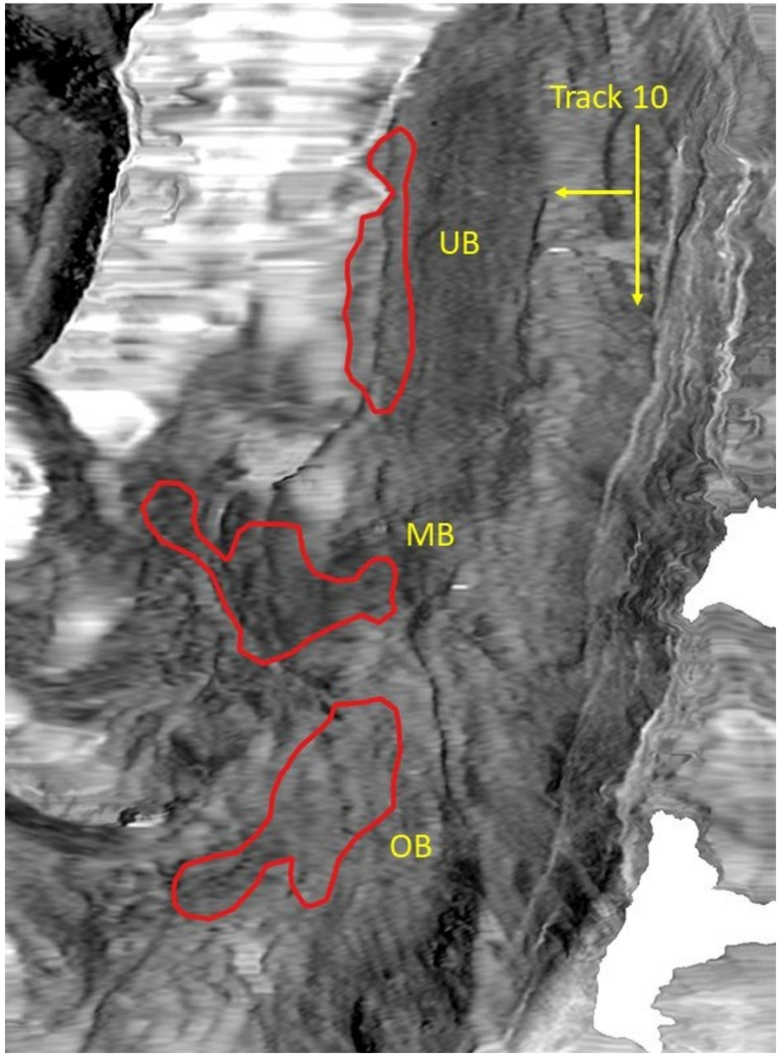


Airborne and In-situ Measurements

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

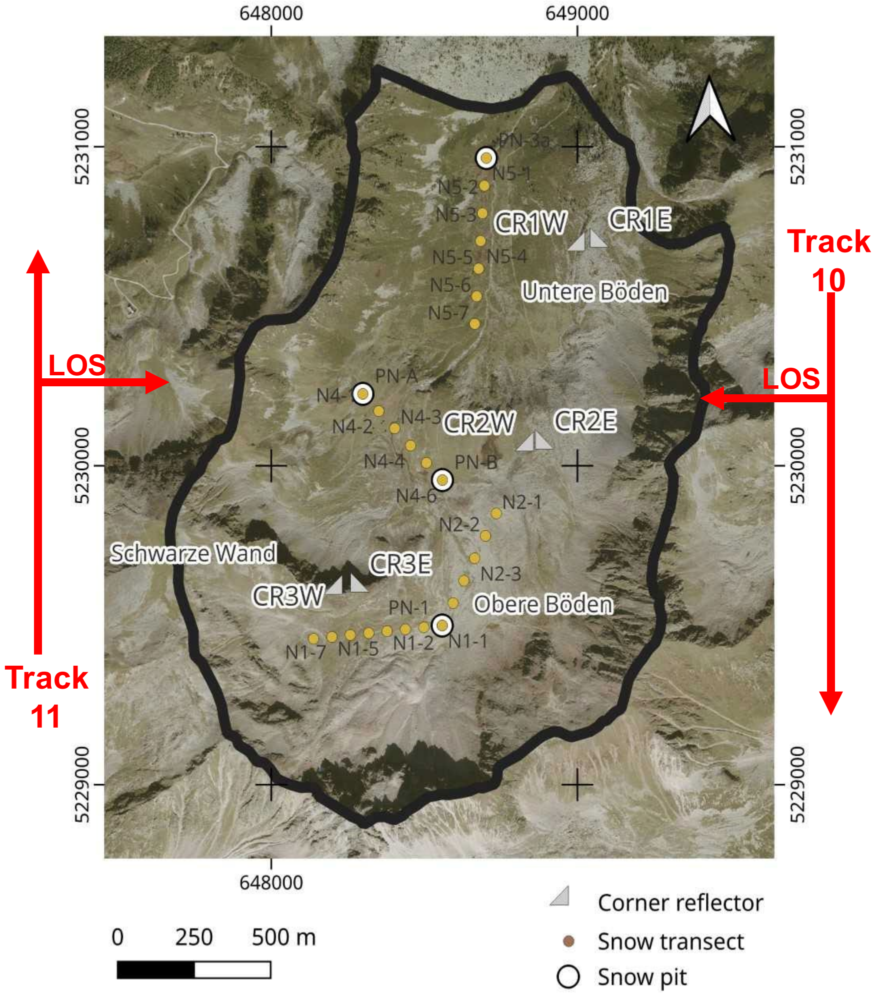
F-SAR, geocoded σ°VV image

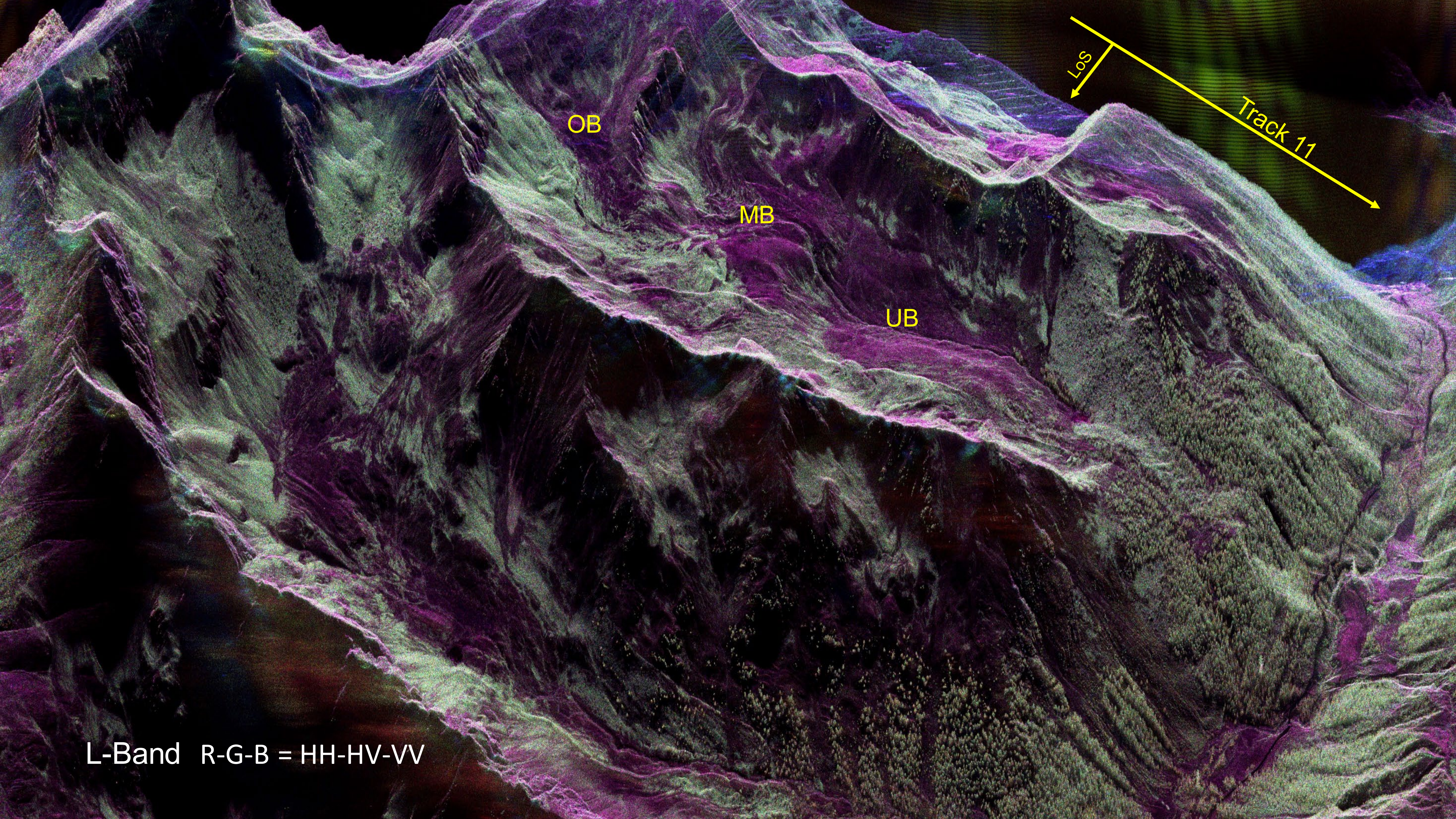
OB, MB, UB - Sites of field measurements and areas for SWE retrieval validation



Test site Wörgetal

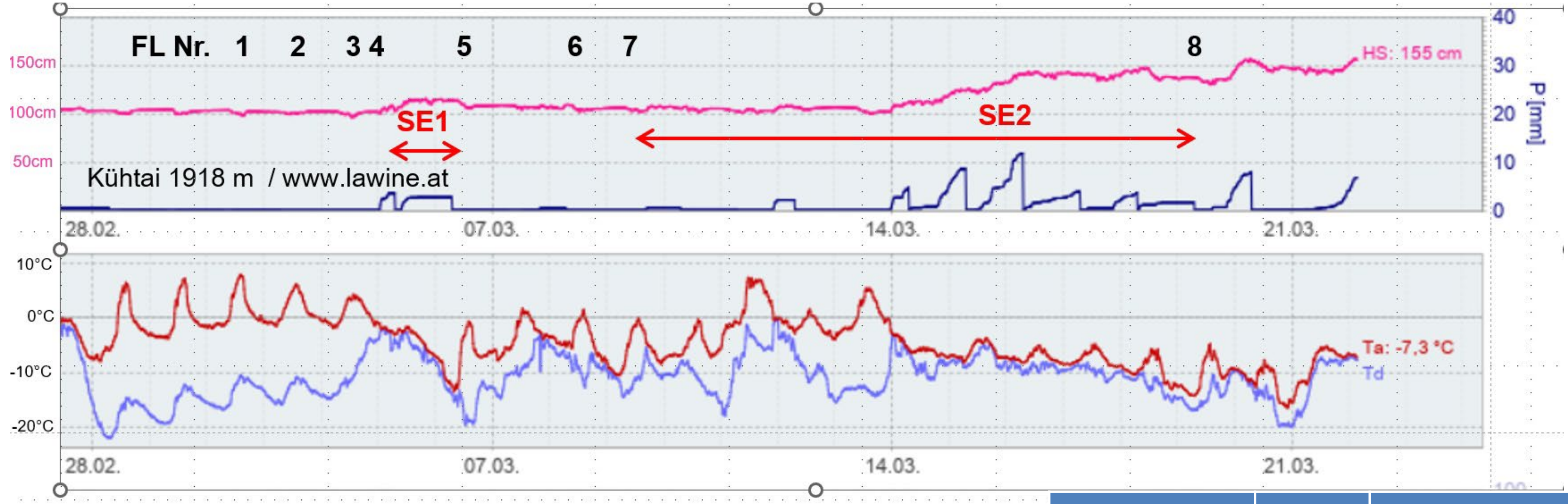
Location of snow pits & corner reflectors

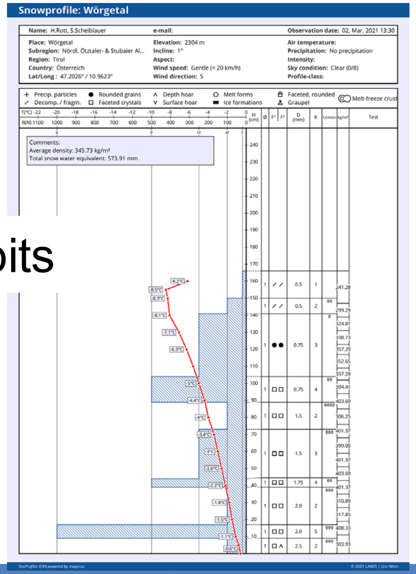




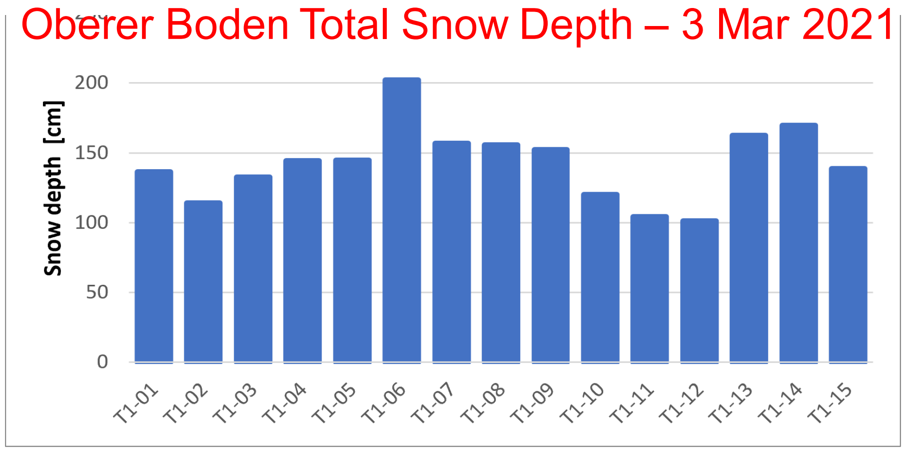
OB
MB
UB
LoS
Track 11
L-Band R-G-B = HH-HV-VV

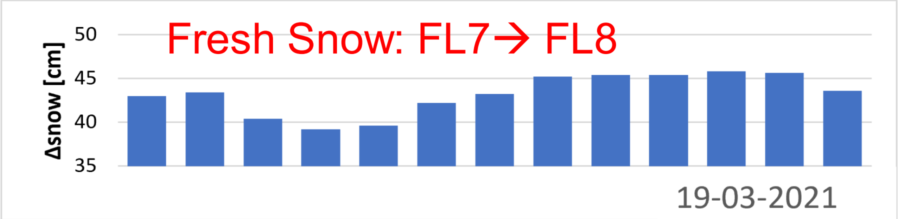
Field Measurements and F-SAR Flights





snow pits





Date	FSAR	Field Activity
18/23.2.2021	--	Exploration of test area, location for CR, snow pits, transects
1.3.2021	--	Setup of CR
2.3.2021	FL1	Check of CR, and completion, snow measurements
3.3.2021	FL2	CR check, snow measurements
4.3.2021	FL3+4	CR check, snow measurements
6.3.2021	FL5	CR check, snow measurements
8.3.2021	FL6	-
9.3.2021	FL7	CR check, snow measurements
13.3.2021	--	Geodetic GPS measurements of CR
19.3.2021	FL8	CR check, snow measurements
30.3.2021		Cleaning of Test area

Snow Event SE1
~10 cm fresh snow

Snow Event SE2
30-50 cm fresh snow

SWE Retrieval by means of Repeat-pass SAR Interferometry

enveo

Basic Approach:

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

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

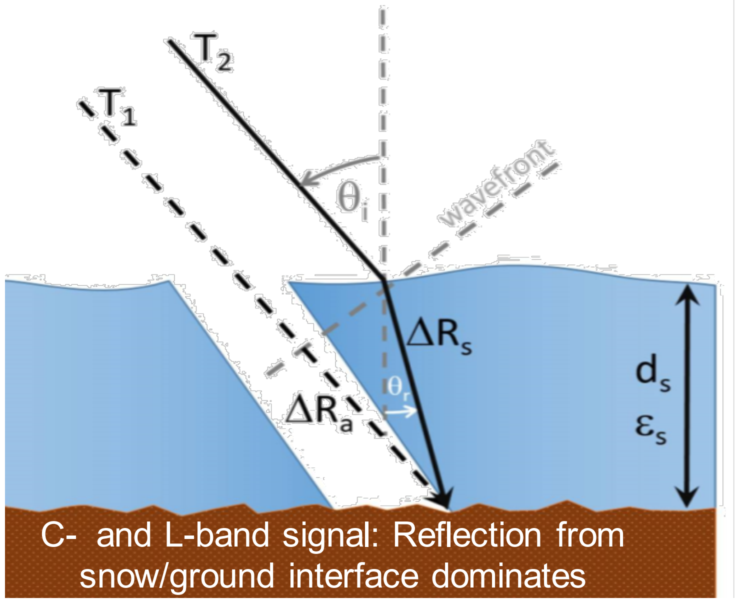
- The interferometric phase delay in dry snow is related to snow depth and density (for backscatter dominated by signal of snow/ground interface)

$$\Delta SWE = \rho_s\, \Delta d_s \qquad \epsilon'(\rho_s) = 1 + 1.60\,\rho_s + 1.86\,\rho_s^3 \;\; [g\; cm^{-3}]$$

$$\Delta\phi_{snow} = -\frac{4\pi}{\lambda}\Delta d_s\, \cos\alpha\left(\cos\theta_i - \sqrt{\varepsilon - \sin\theta_i^2}\right)$$

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

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

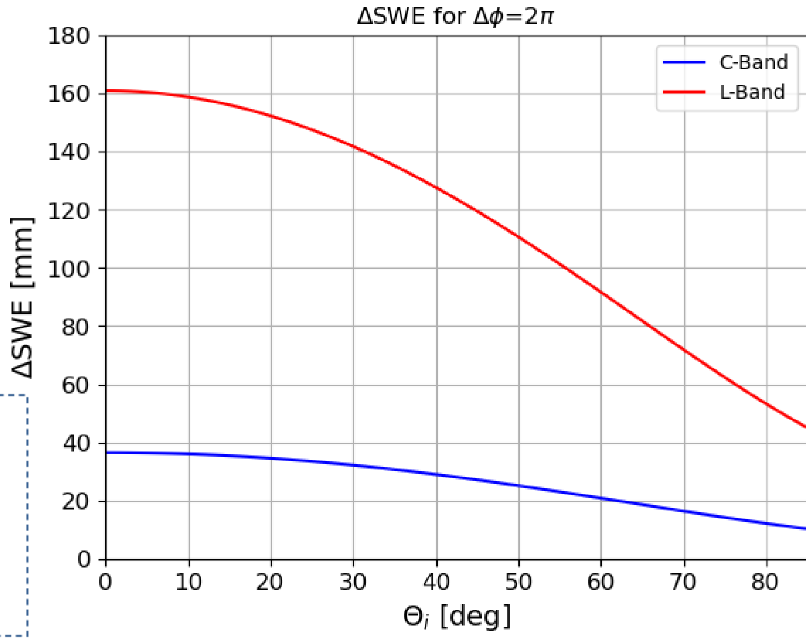


Critical issues:

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

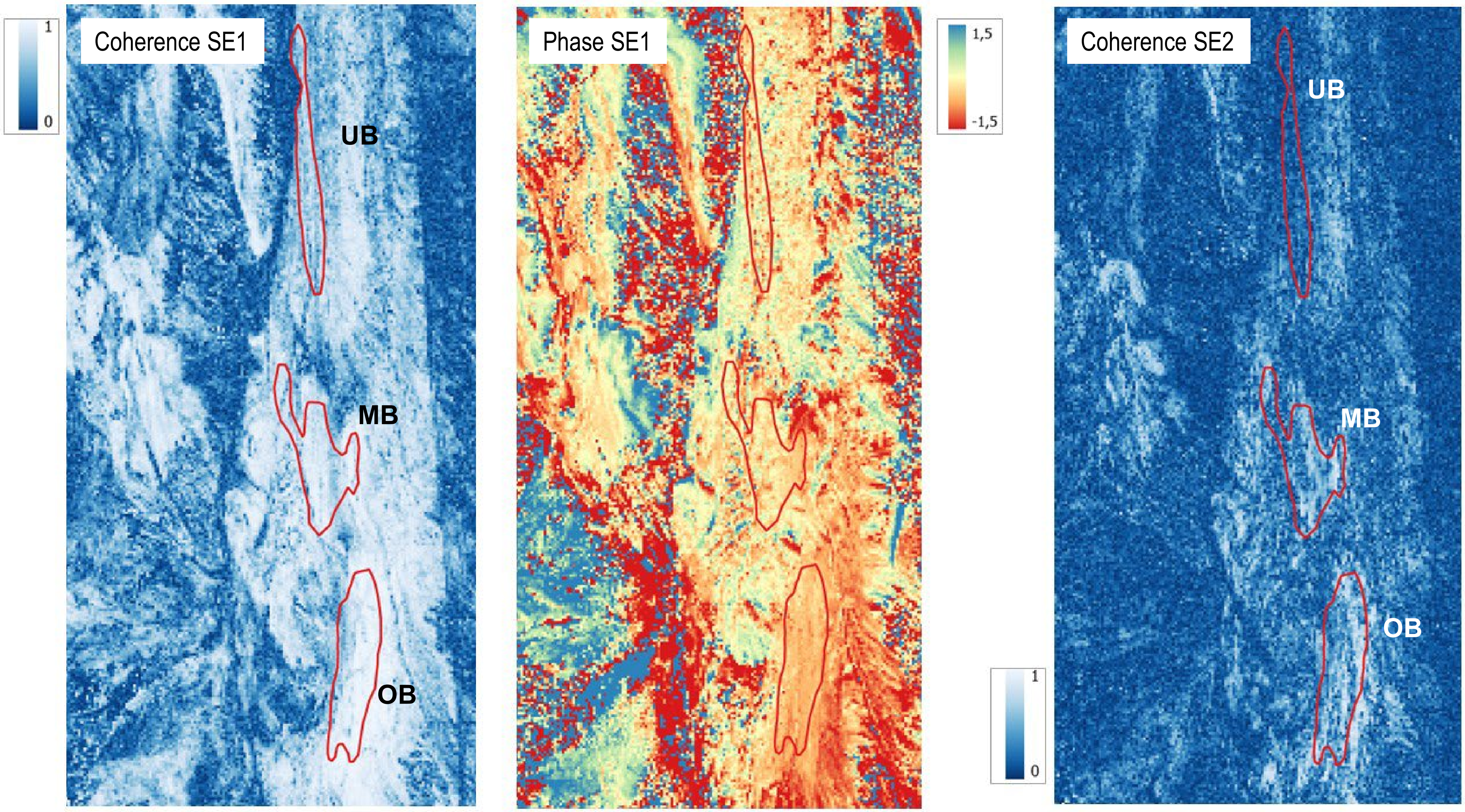
SWE ↔ SD for Δϕ=2π at θ=40°:

	SWE	SD (150 kg m^{-3})
L-Band:	131mm	0.87 m
C-Band:	29mm	0.19 m



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

Coherence and Phase Images C-band



SE1

Suitable coherence and phase signal

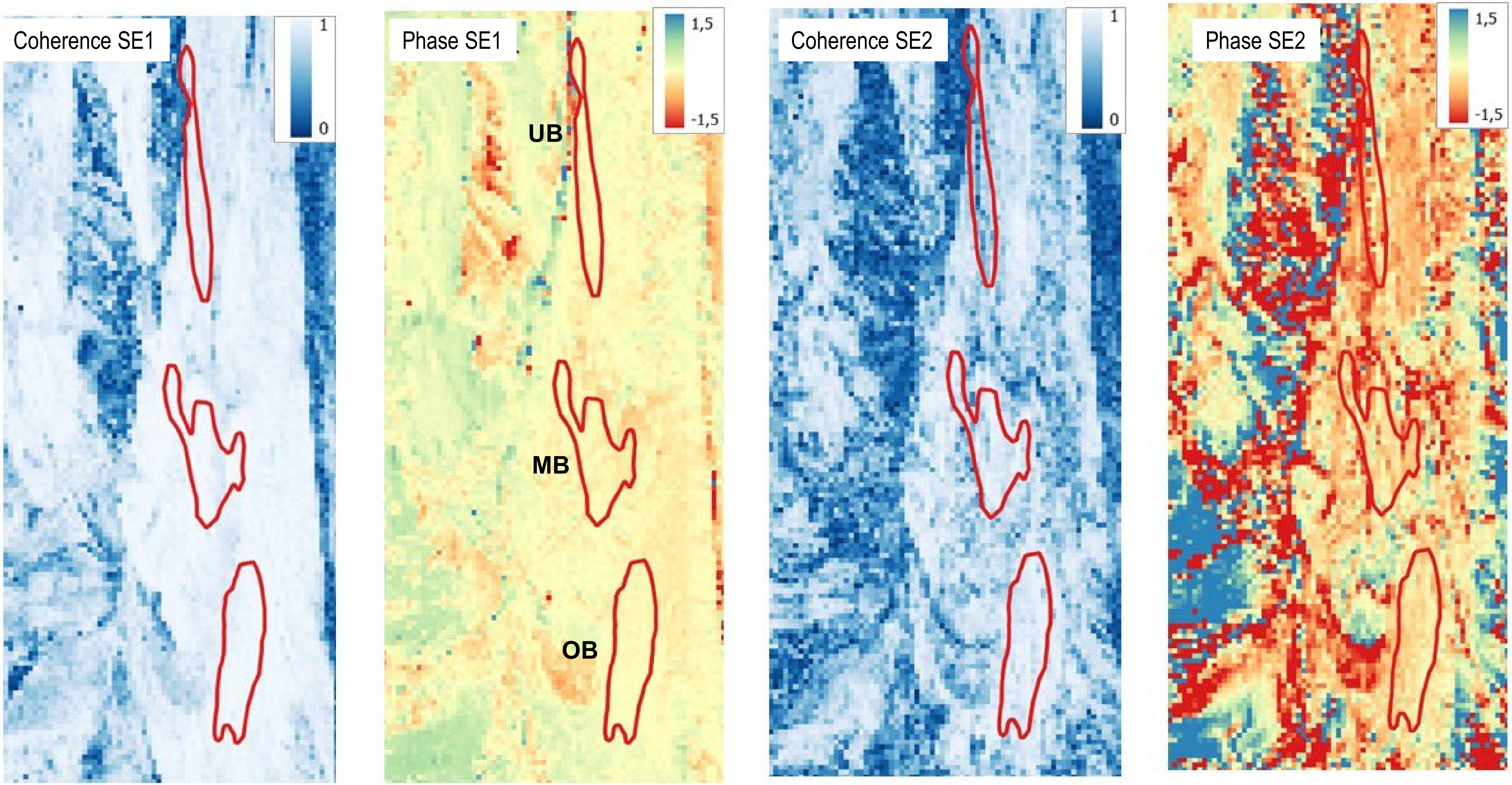
SE2

C-band constraints

- SWE amount exceeds 2 π ambiguity
- Temporal decorrelation

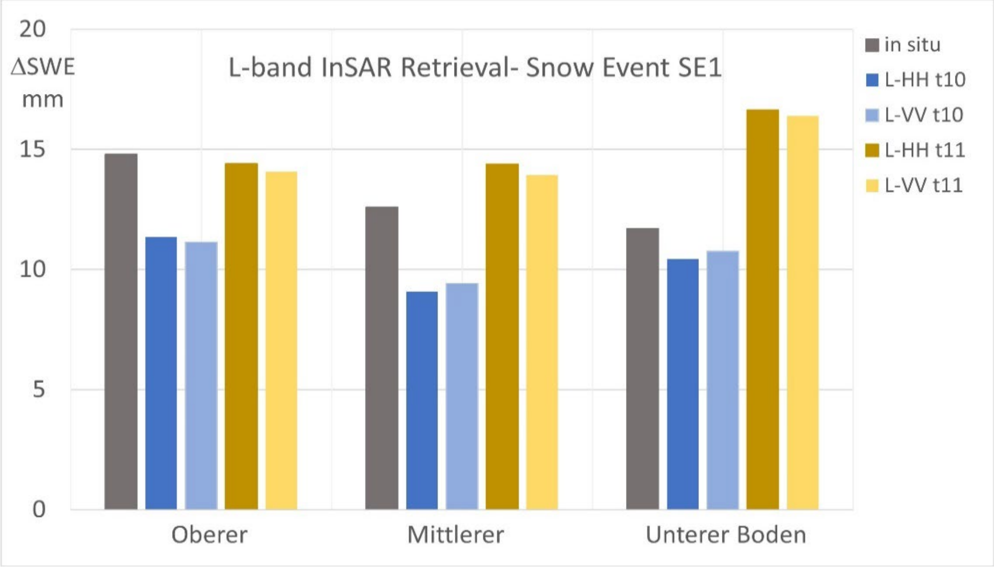
Track 10 – VV Radar Imaging Geometry

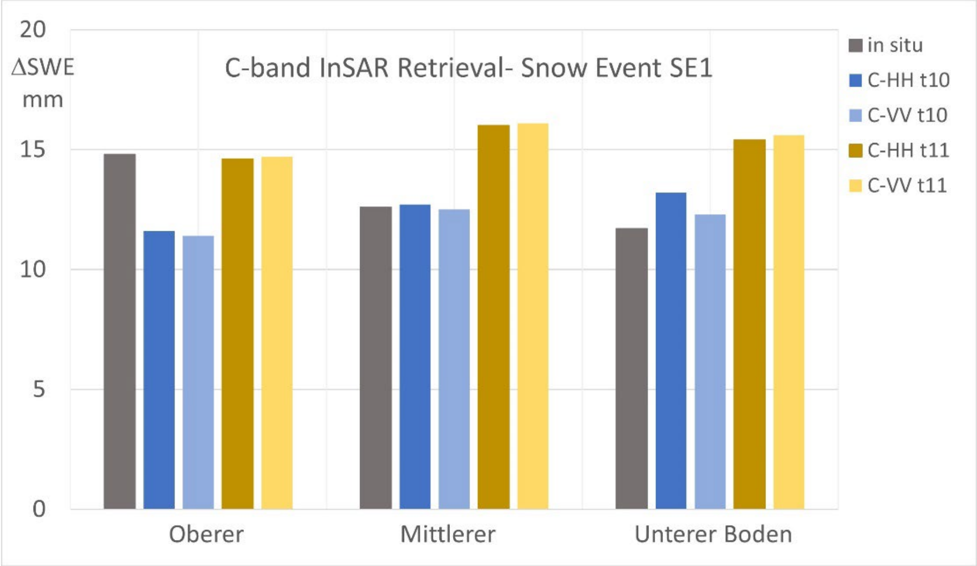
Coherence and Phase Images L-band

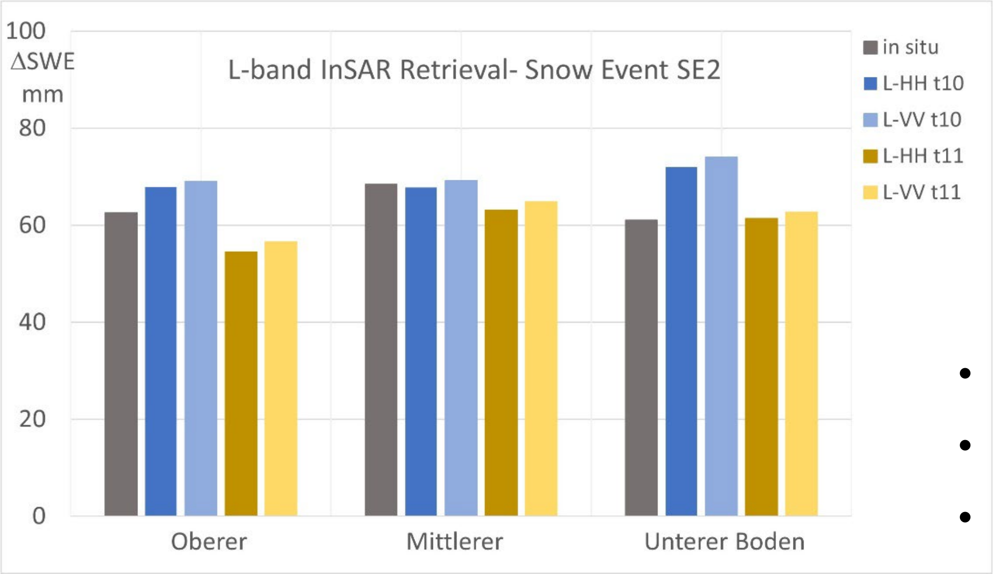


Track 10 – Radar Imaging Geometry – VV Polarisation

SWE Retrieval Performance – Comparison with Field Measurements







ΔSWE retrievals based on Track 10 & 11

Mean values for 3 RoI's vs. in-situ measurements

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

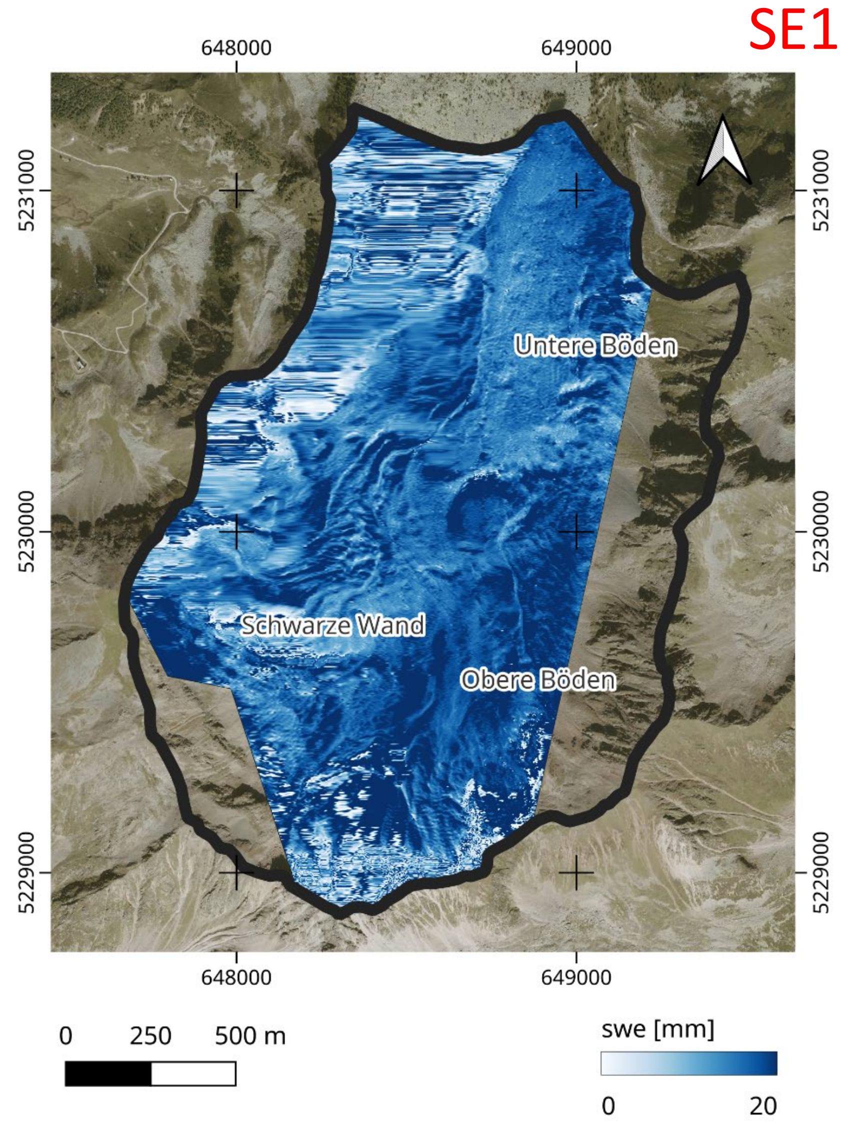
SE1 L-band: $\Delta SWE_{ret} - \Delta SWE_{obs}$ = 1.2 mm

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

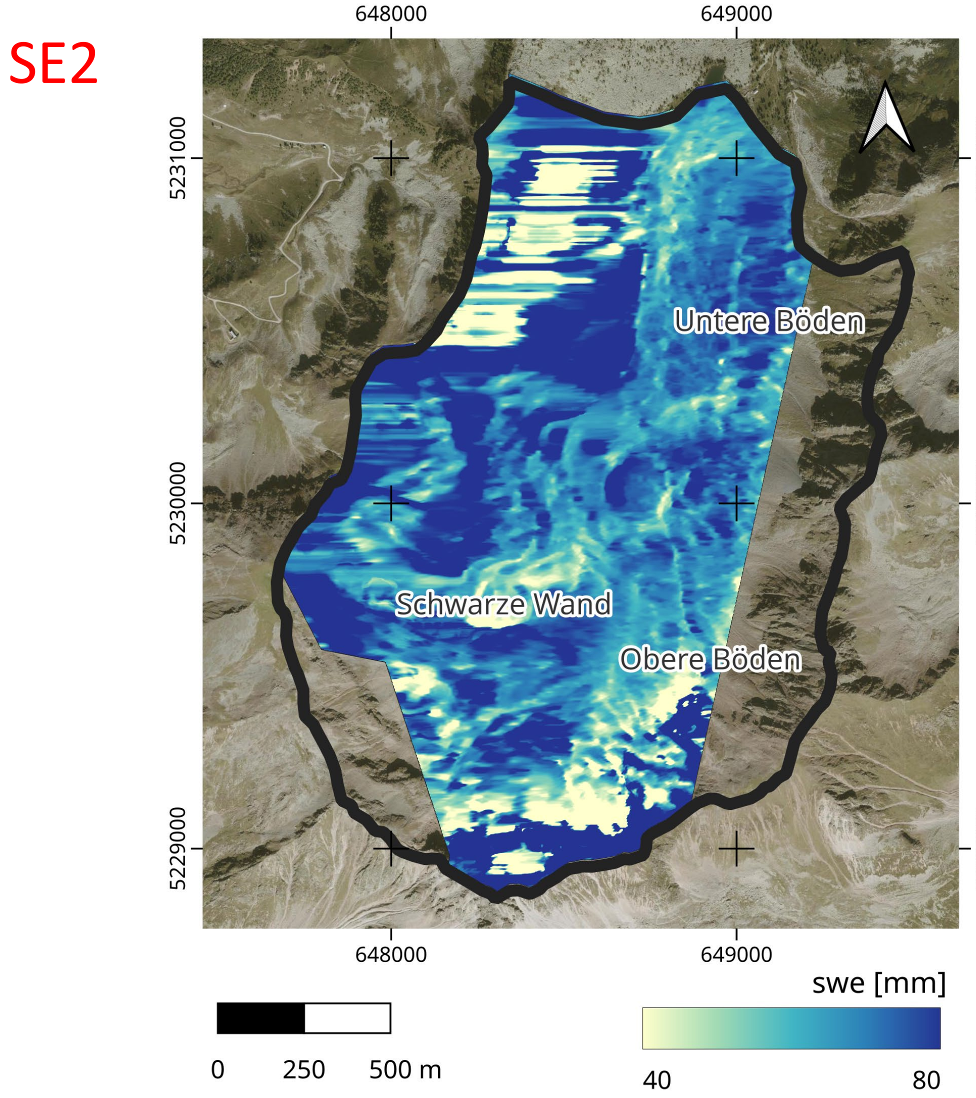
- High agreement between average retrieved and in situ ΔSWE
- No systematic differences between HH and VV–based retrievals
- Some difference between Track 10 & Track 11 retrieval, most likely related to uncertainty of the reference phase (corner reflector)

SWE Maps based on Track 10

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

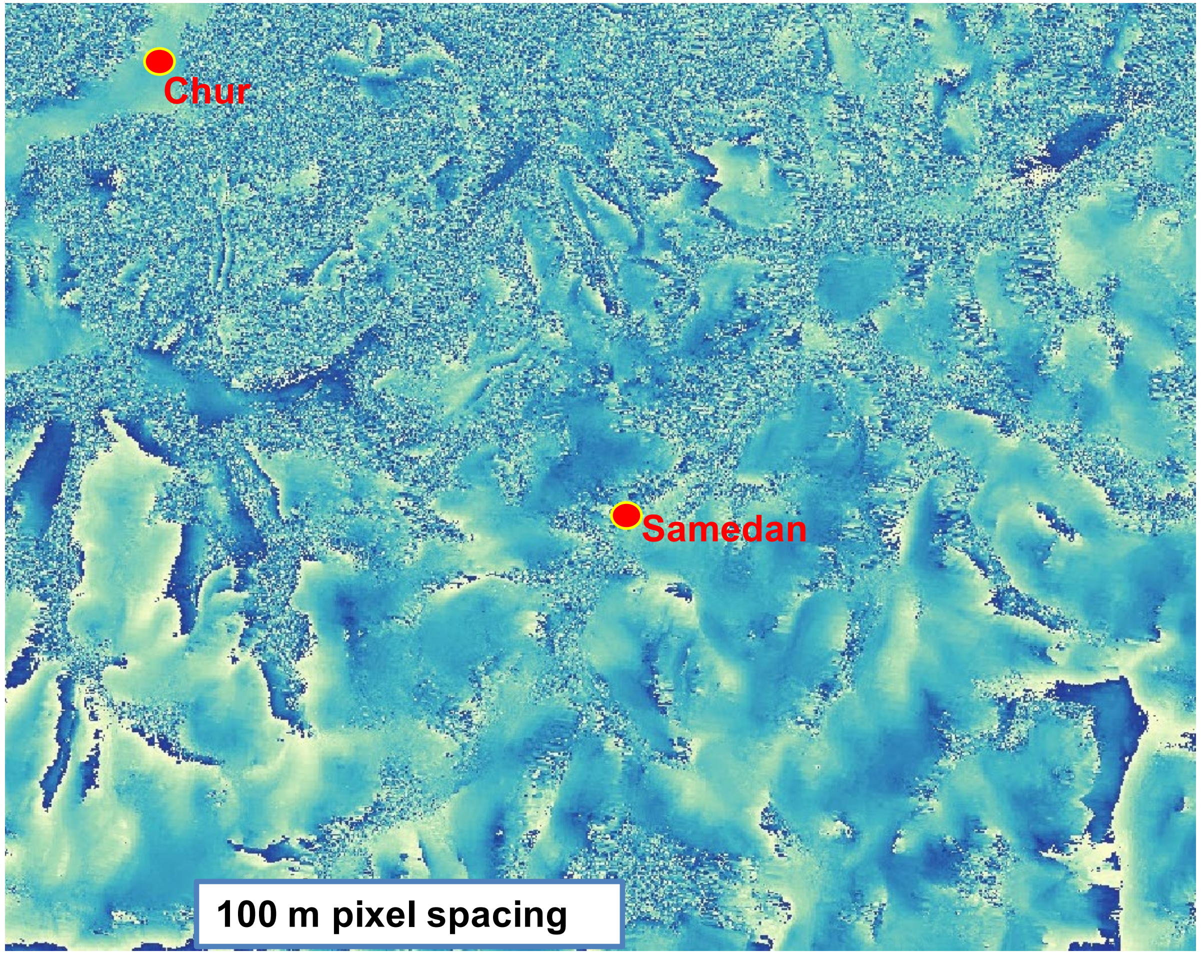


Map of snow accumulated during the period 14 to 18 March 2021, derived from ***L-band VV InSAR*** data

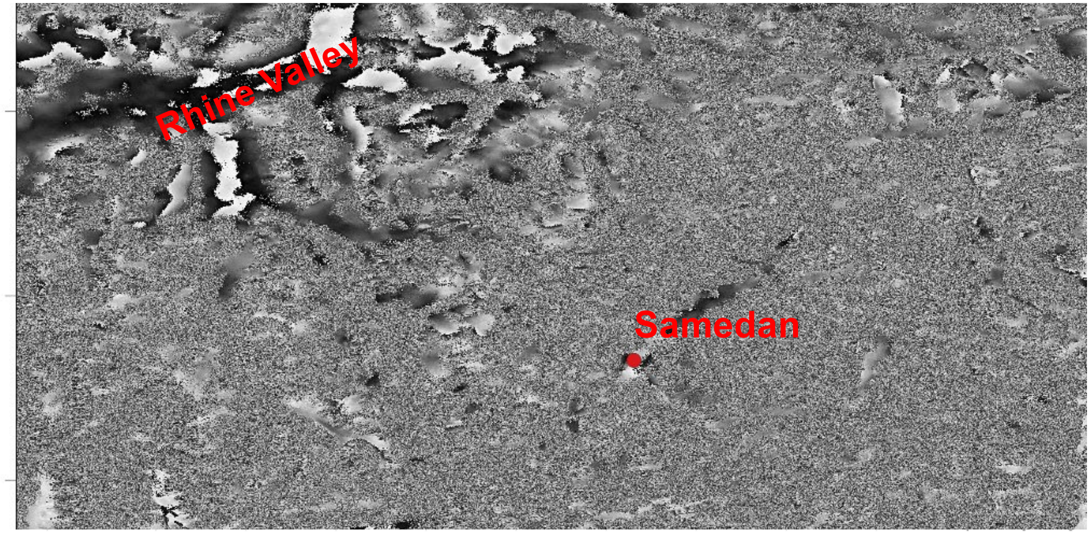


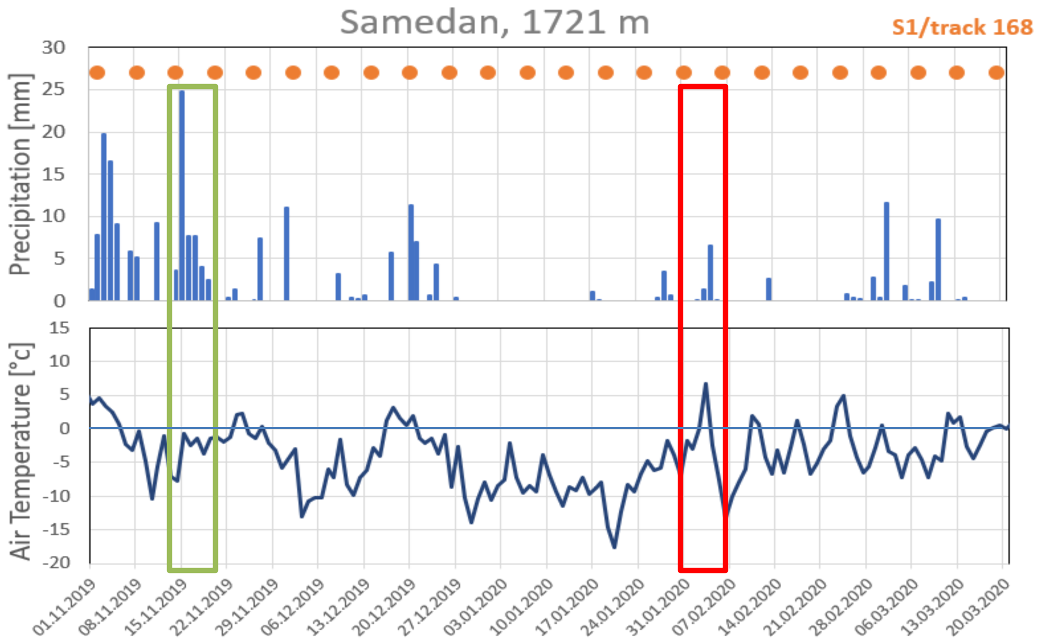
Sentinel-1 C-band InSAR Phase

31/1-6/02/2020 moderate snow fall mid winter



15-21/11/2019 significant snow fall early winter

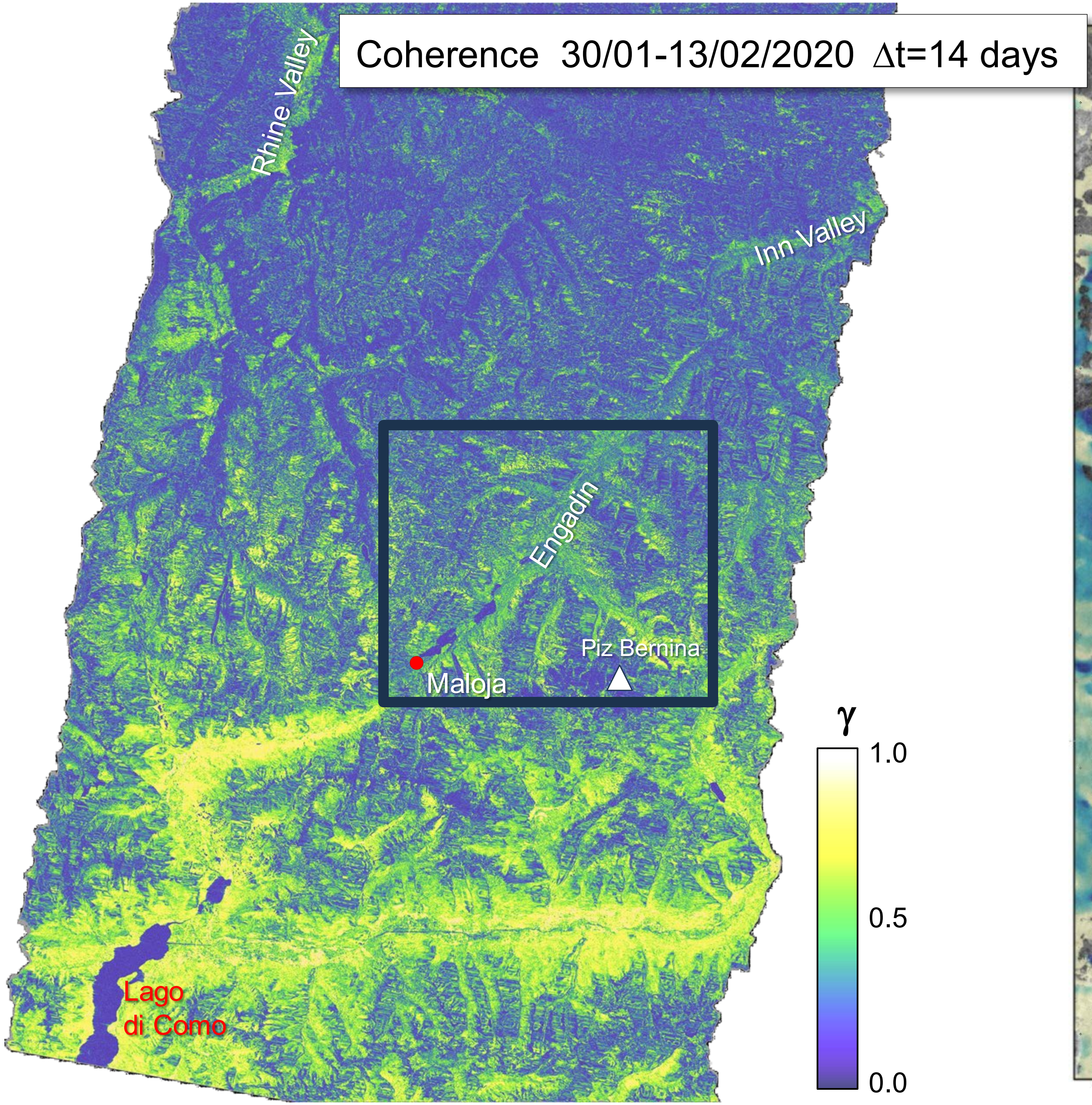


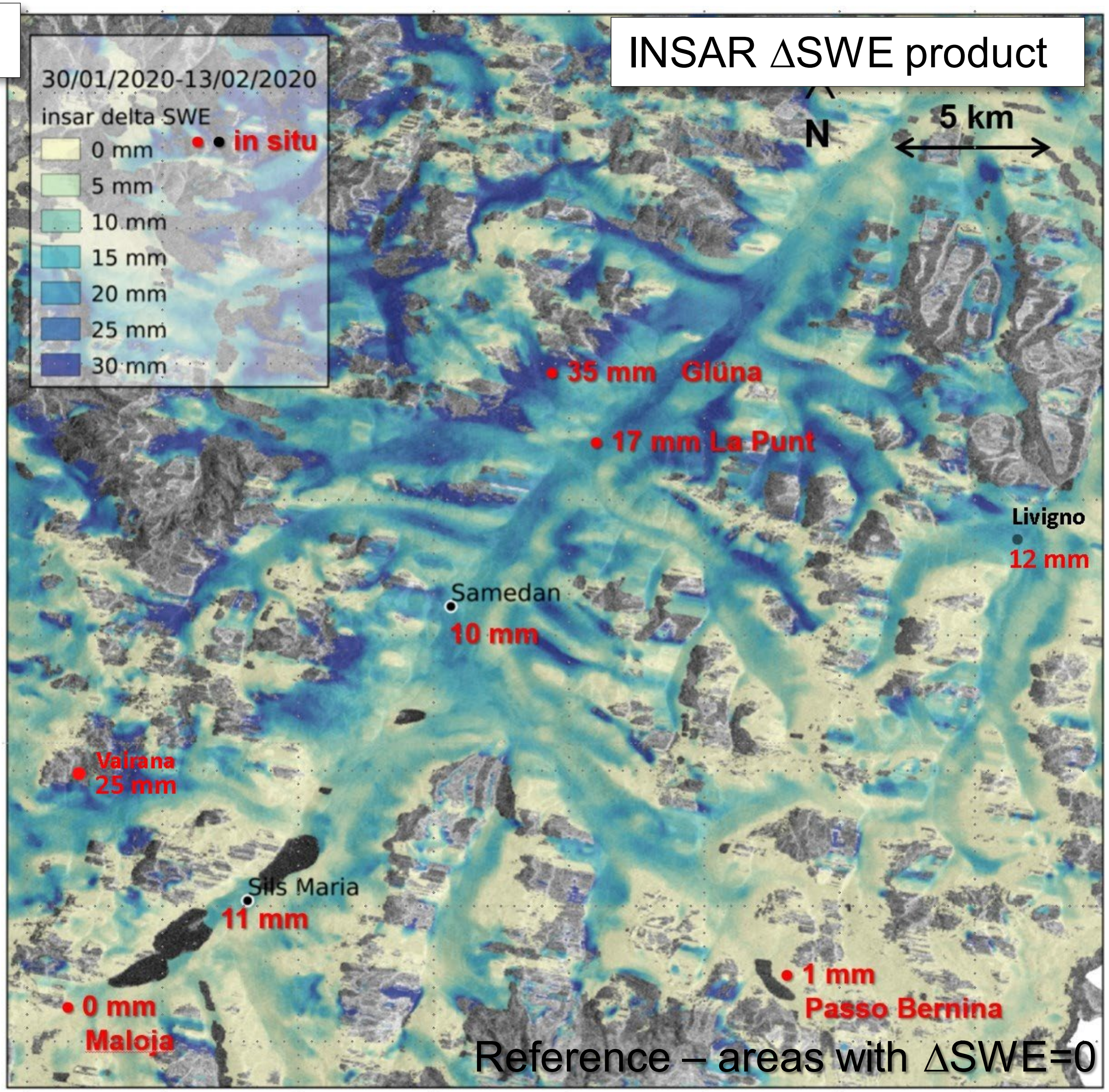


Critical issues:

- removal of atmospheric phase delays
- selection of reference points for ΔSWE retrieval

ALOS-2 PALSAR INSAR based SWE Product





Conclusions

- The Wörgetal campaign, based on L- and C-band airborne SAR data, confirms the high potential of the repeat-pass InSAR approach, for observing the mass of snow accumulating in Alpine terrain.
- The F-SAR L-band InSAR data show high coherence and good performance for SWE retrieval also for a high snow accumulation event.
- The F-SAR C-band InSAR data show good results for retrieving snow accumulation of moderate intensity but are not suitable for intense snowfall due to low coherence and 2π phase ambiguity
- VV-polarized RP-InSAR data show slightly higher coherence than HH-polarized data, but the differences in retrieved SWE are insignificant.
- The studies with C-band (Sentinel-1) and L-band (PALSAR) InSAR data of Engadin confirm the findings regarding general preference of L-band vs. C-band and emphasize the need for continuous repeat-pass acquisitions throughout the snow cover period.
- Critical issues for InSAR SWE retrieval in mountains are the selection of reliable reference points for phase / SWE calibration, reduced sensitivity in forests, and topography-related correction for atmospheric effects. The use of S1 ETAD for correcting atmospheric phase delays in mountain regions will be studied.