GAMMA REMOTE SENSING

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Obtaining Time-Series of Snow Water Equivalent in Alpine Snow by Ground-based Differential Interferometry at 1 to 40 GHz at Davos-Laret

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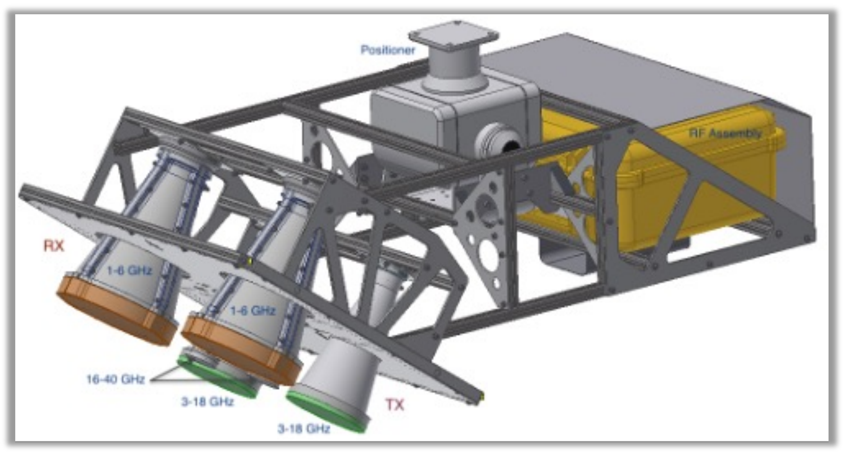
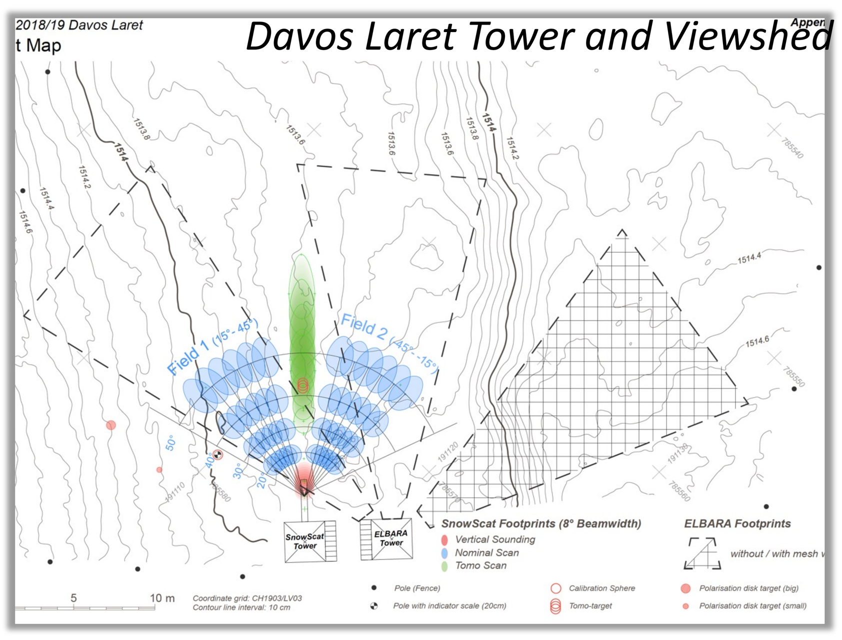
Introduction

- Snow water equivalent (SWE) is an essential climate variable due to its importance for regional and global water resource. For mapping of SWE from local to global scales, remote sensing techniques are the only efficient method.
- Substantial efforts on SWE retrieval have focused on using radar backscatter at different frequencies and polarizations. These studies have met with mixed success because the models do not capture the dynamics of the snowpack.
- *Gamma Remote Sensing AG* developed the **ground-based** WBSCAT 1-40 GHZ Polarimetric Scatterometer for the European Space Agency (ESA) to support mission development and microwave studies of a wide range of ground covers including snow and ice.
- This investigation describes the potential to recover SWE from interferometric processing of data acquired by WBSCAT while operating during the 2019-2020 winter season in Davos-Laret in Switzerland.
- It is known that dry snow has relatively low attenuation at frequencies < 10 GHz and acts as a dielectric layer above the ground if the ice structures of different scales (grains, grain-clusters, ice crusts and snow layers) within the snowpack are of significantly smaller scale than the wavelength. An almost linear relation of SWE to microwave propagation delay has been proposed and demonstrated [Guneriussen 2001, Leinss 2015].
- Given that there is little change in the configuration of scatterers in the time interval between radar measurements and that the snowpack remains dry, then interferometric phase measurements can potentially be used to track changes in SWE.



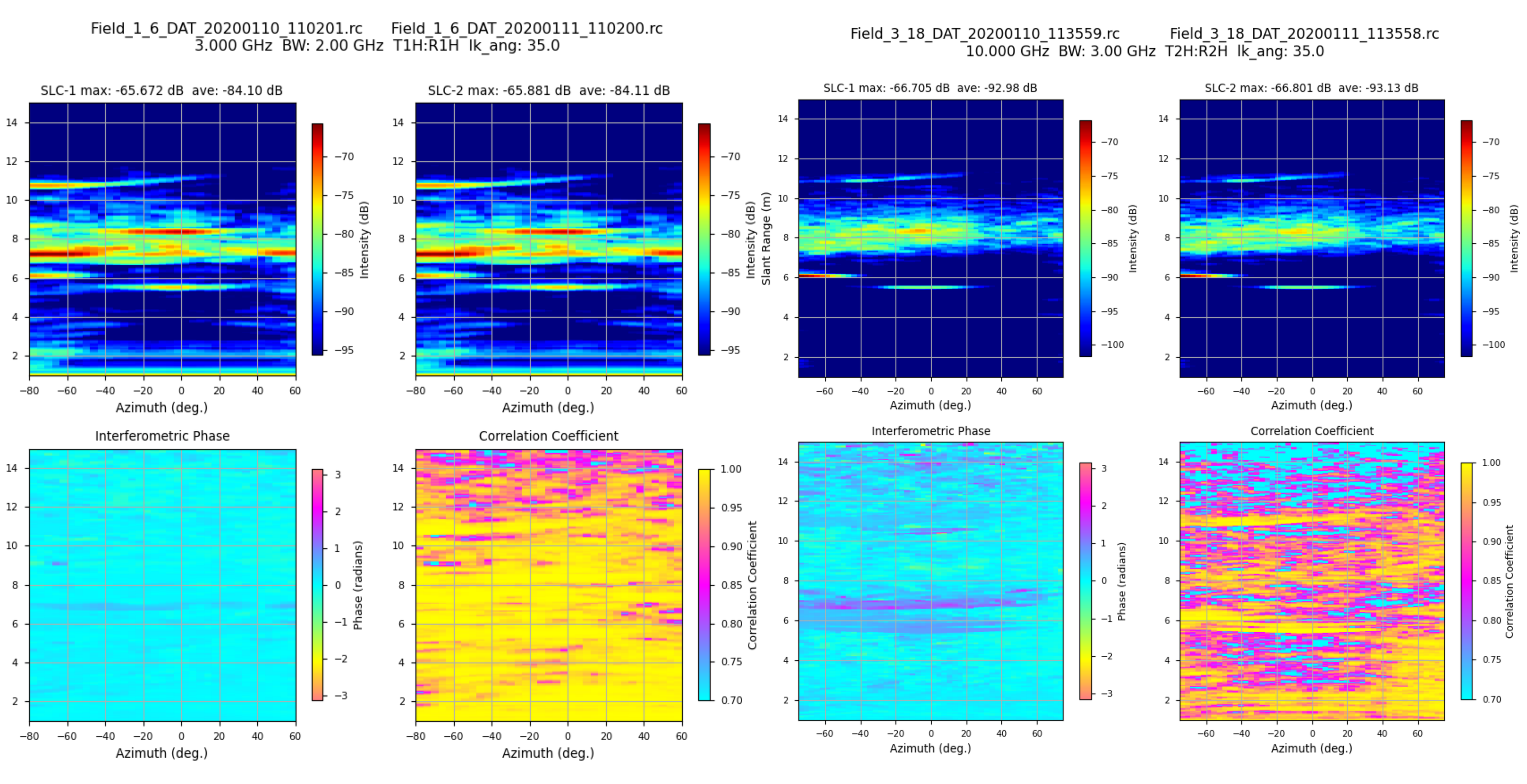
WBSCAT Scatterometer 1-6, 3-18, 16-40 GHz



Davos Laret Tower and Viewshed

Data Acquisition

- WBSCAT was located at the Davos-Laret CryoNet Station (LAR) at 1514 meters altitude and operated in cooperation with the WSL Institute for Snow and Avalanche Research SLF in Davos [Wiesmann 2019] during two seasons 2018-2019 and 2019-2020.
- WBSCAT is based on a vector network analyzer (VNA) using internal standards to calibrate the instrument. The instrument worked reliably during these seasons producing time-series of radar scattering coefficient σ_0, interferometric phase, and coherence. WBSCAT was mounted on a 2.5-meter rail, inclined 45 degrees from horizontal, located on a static tower, 8-meters above the ground surface.
- Regions on the ground were repeatedly measured every 8 hours covering the frequency range from 1 to 40 GHz.
- Multi-look interferograms and correlation maps were produced for each adjacent 8-hour interferometric pair.
- A 7x7 rectangular region near the antenna boresight was used to estimate the phase and correlation in the time-series.
- The differential interferometric phase time-series are unwrapped by summing phase differences, see (Leinss 2015) for details, using interferometric phases with coherence above a set threshold.



(a) Interferometric 3 GHz image pair with 2 GHz bandwidth, HH-polarization, incidence angle $\theta = 35°$, 2020-01-10 11:02 and 2020-01-11 11:02.

(b) Interferometric 10 GHz image pair with 3 GHz bandwidth, HH-polarization, incidence angle $\theta = 35°$, 2020-01-10 11:36 and 2020-01-11 11:36 .

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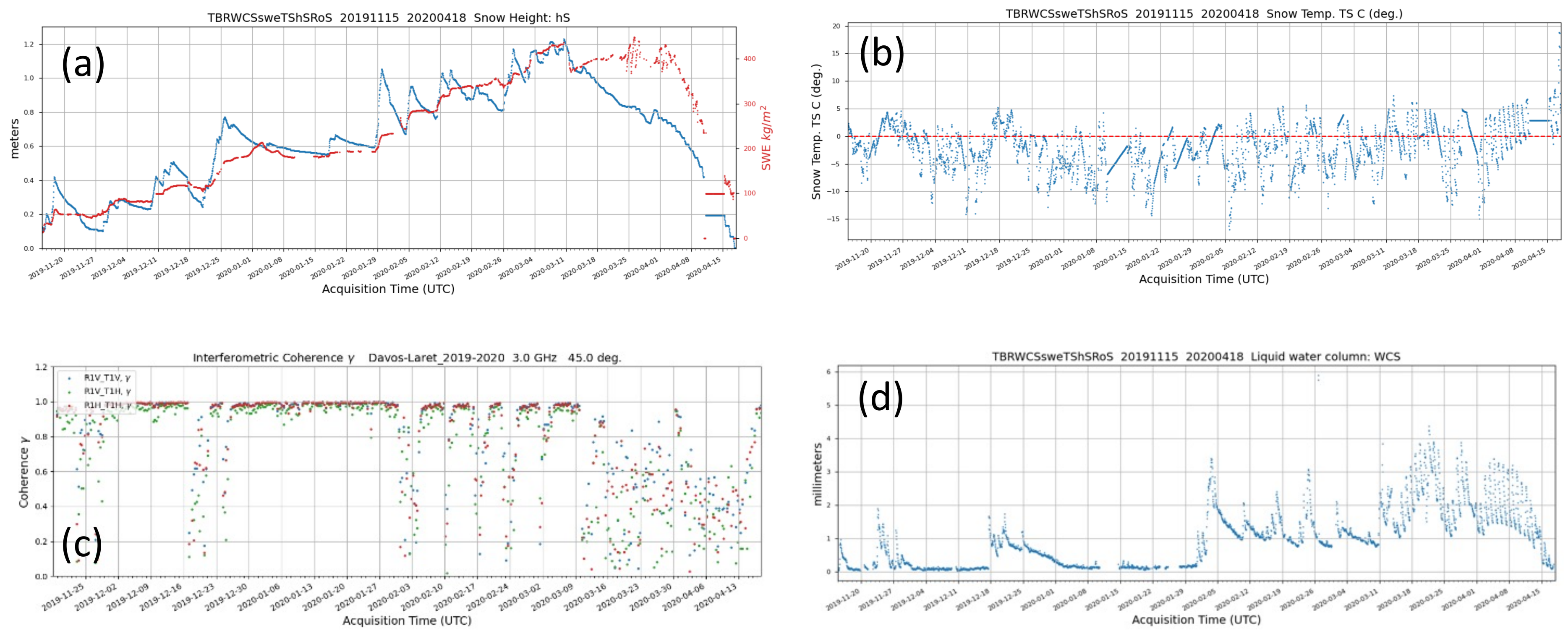
2019-2020 Snow Measurements



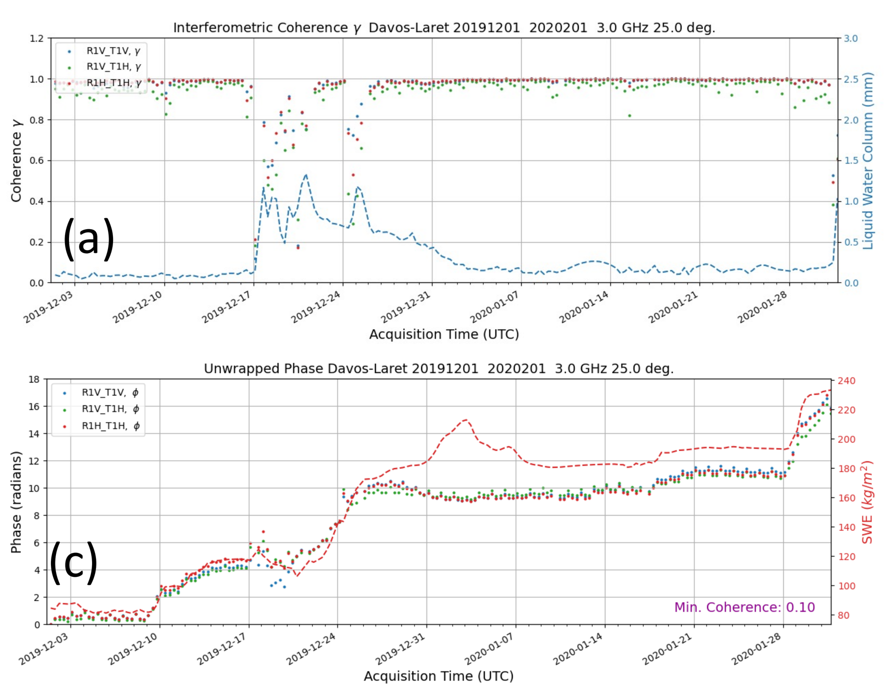
(a) Comparison of measured snow height (blue) and the SWE (red) from the weather station for the entire winter measured with VV, VH, and HH polarization, 45 deg. look angle

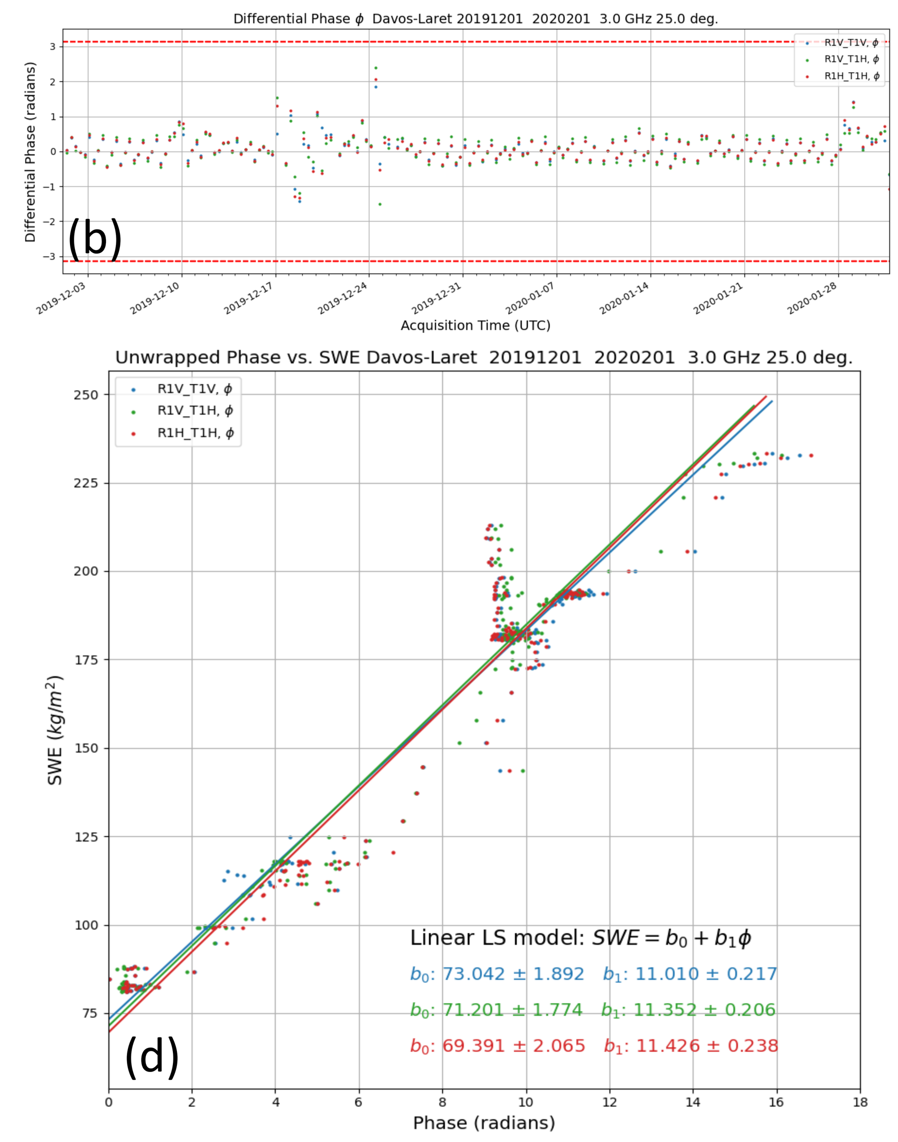
(b) Snow surface temperature C

(c) 8-hour interval interferometric coherence measured by WBSCAT at 3 GHz

(d) Snow liquid water column derived from L-Band close range radiometry (Naderpour 2022)

3 GHz Interferometric Time-Series (25-deg. Look Angle)





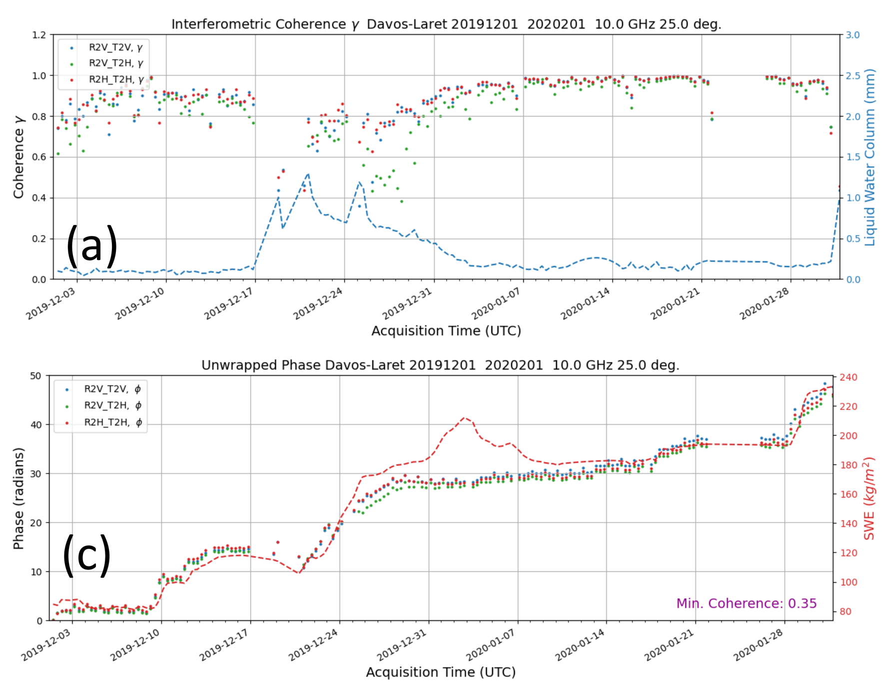
(a) 3-GHz 8-hour interferometric coherence time-series 20191201-20200201 with liquid water column height estimated from L-Band radiometry

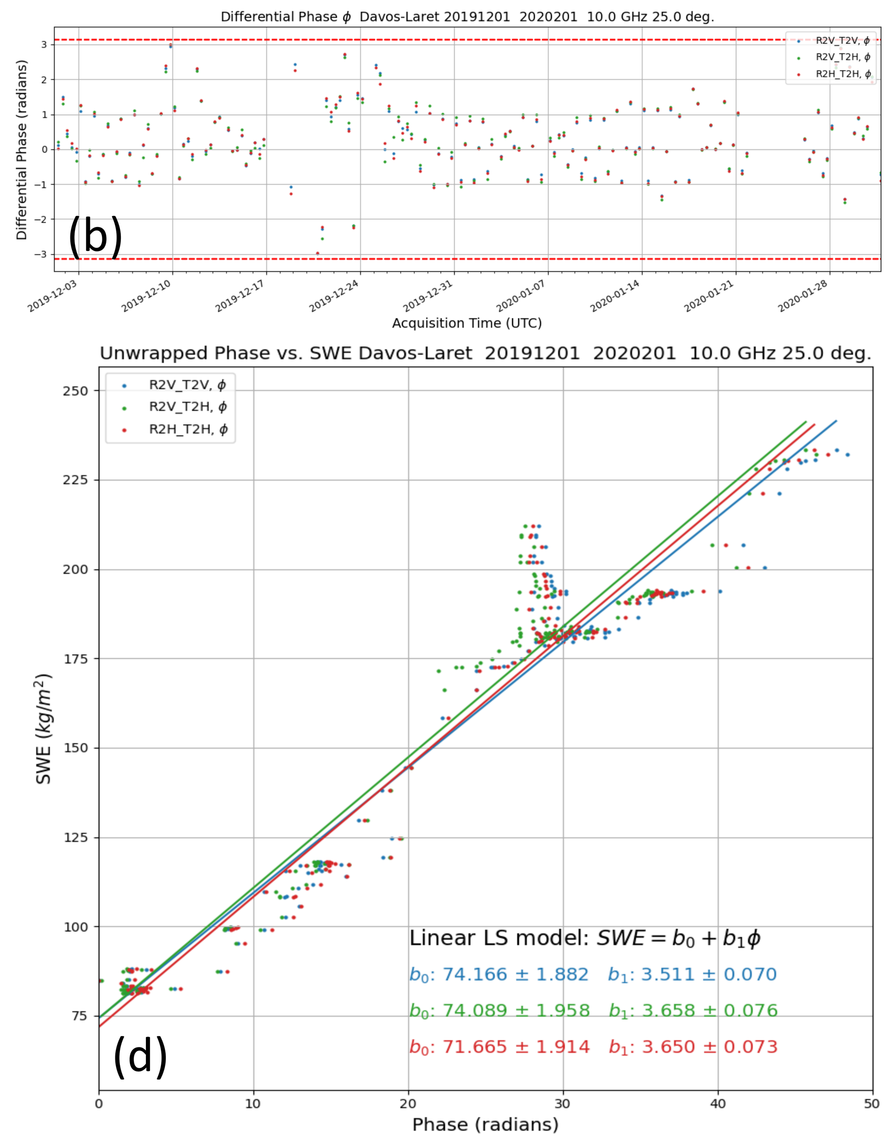
(b) 8-hour wrapped differential interferometric phase

(c) Unwrapped differential interferometric phase with measured SWE as a function of date. Unwrapping coherence threshold = 0.1

(d) Linear regression of unwrapped differential phase and SWE using orthogonal distance regression (ODR)

10-GHz Interferometric Time-Series (25-deg. Look Angle)





(a) 10-GHz 8-hour interferometric coherence time-series 20191201-20200201 with liquid water column height estimated from L-Band radiometry

(b) 8-hour wrapped differential interferometric phase

(c) Unwrapped differential interferometric phase with measured SWE as a function of date. Unwrapping coherence threshold = 0.35

(d) Linear regression of unwrapped differential phase and SWE using ODR

Discussion and Conclusions

(a) Decorrelation of the snowpack is strongly correlated with surface temperature and the integrated water column height, as determined from L-Band close-range radiometry. When the snow surface becomes wet, there is an immediate and significant drop in the interferometric coherence. After the temperature drops again below 0° C, the short-term correlation gradually rises as the liquid water refreezes.

(b) The X-band (10 GHz) coherence is more sensitive to the liquid water fraction than S-Band (3 GHz). Lower correlation at X-Band may be related to the larger fraction of direct scattering from the changing snowpack.

(c) Using short-time interferograms avoids wrapping of the interferometric phase, leading to direct phase unwrapping by summing the incremental differential phases.

(d) This approach does not mitigate phase unwrapping errors due loss of interferometric coherence from liquid water in the snowpack due to melting.

(e) The ratio of the regression slopes matches the ratio of the frequencies, and this suggests that the backscatter is primarily from the ground/snow interface. Furthermore, the S-band phase time-series can be used to support unwrapping of the X-band data.

(f) WBSCAT has collected a broad-band interferometric data set at Laret that can be used to study SWE retrieval algorithms and evaluate their robustness with respect to frequency, sampling interval, and resolution.

References

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