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High-resolution snow parameter/structure retrieval from tower-based radar time series of seasonal snow obtained with the ESA SnowScat and the ESA Wideband Scatterometer in SAR tomographic profiling mode

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Seasonal alpine snow is subject to fluctuating meteorological conditions with diurnal temperature cycles around the freezing point and a mix of snow and rain. Throughout the season, fresh snow accumulations repeatedly contribute to the snowpack whereas older layers beneath contain snow at various stages of the metamorphosis often including melting and refreezing periods. The increasing complexity of the snowpack throughout the snow season affects the interaction of radar signals with the snowpack and underlying ground.

Numerous radar/SAR missions, operating at different frequencies, aim to retrieve snow parameters such as snow mass, snow water equivalent, and snow cover extent. These include missions like CRISTAL, TSMM, ROSE-L, and NISAR, each utilizing specific frequency bands to study the temporal variations in snow properties. Understanding the vertical structure of seasonal snow and its interaction with radar signals at various microwave frequencies from L- to Ka-band is therefore essential.

In our study, we investigated tower-mounted rail-based tomographic SAR measurements obtained within the ESA SnowLab project in Davos Laret, Switzerland. The SAR tomography technique provides non-destructive measurements of the vertical structure of the snowpack by means of vertical profiles of radar backscatter, co-polar phase differences, and interferometric phase differences. The measurements were taken with the ESA SnowScat and the ESA Wide-Band Scatterometer, covering a wide range of frequency bands. Additional data on snow characteristics and meteorology complemented the radar measurements. We present time series of SAR tomographic profiles over entire snow seasons at different frequency bands (1-6 GHz, 12-18 GHz, and 28-40 GHz) with reference snow characterizations obtained from snow pits and SnowMicroPen measurements. Detailed analyses include depth-resolved co-polar phase differences, anisotropy, and differential interferometric phase, revealing insights into changes in snow properties over time.

The high-resolution SAR tomographic profiles offer valuable information on microwave interactions with seasonal alpine snow. Analysis of vertical radar backscatter profiles indicates relative changes in location and intensity within the snowpack, correlating with factors like melting and refreezing cycles, snow accumulation, and liquid water content.

We find that distinctive features of seasonal snow, such as melt-freeze crusts, varying penetration depths, and anisotropy can be tracked over time using a SAR tomography approach. To exploit this information for snow mass and structure retrieval, further research tailored to specific spaceborne SAR mission objectives is required. The ESA SnowLab time series of SAR tomographic profiles is a rich dataset covering a broad spectrum of frequencies and providing an opportunity to advance the understanding of scattering mechanisms in alpine snow for various spaceborne SAR missions. The comprehensive coverage includes frequency bands relevant to existing and future mission concepts.