ESA SNOWLAB PROJECT: 4 YEARS OF WIDE BAND SCATTEROMETER MEASUREMENTS OF SEASONAL SNOW

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ABSTRACT

The aim of the ESA SnowLab project is to provide a comprehensive multi-frequency, multi-polarisation, multi-temporal dataset of active microwave measurements over snow-covered grounds to investigate the relationship between effective snow- and ground parameters and the resultant signals detected by microwave radar. An important part for the development of microwave models is the microstructural characterisation. This characterisation can only be done by repeated measurements by SnowMicroPen and more completely, but also much more expensive, by X-ray micro-tomography. Within this project we complemented the microwave measurements of Alpine snow in Switzerland with extensive effective snow- and ground parameters and meteorological data. Microwave backscatter measurements were conducted using the 9 – 18 GHz ESA SnowScat instrument and since December 2018 the recently built ESA WBScat instrument. WBScat allows to extend the spectral coverage to 1 – 40 GHz.

Index Terms— snow, scatterometer, time series, European Space Agency, ESA.

1. INTRODUCTION

In order to collect a comprehensive multi-frequency, multi-polarisation, multi-temporal dataset of active microwave measurements over snow-covered grounds a multi year campaign was setup in two different Alpine environments in Switzerland.

During the first winter season (2015/2016) of the ESA SnowLab campaign, situated at the test site “Gerstenegg” in the central Alps in Switzerland, the tomographic hardware and the automated data acquisition of multi-temporal, polarimetric, high-resolution tomographic profiles was tested and consolidated. The measurement setup and first results were presented in [1]. An important task in the first part of the project was to develop and code a Tomographic Analysis Tool.

In the winter seasons 2016/2017 and 2017/2018, the ESA SnowLab campaign was then carried out at the newly established SLF snow test site “Laret”, Davos, Switzerland [2]. In-situ measurements were carried out during the SnowScat campaigns. It was possible two acquire two complete sets of multi-frequency and -polarisation data at 8h interval covering the full snow season from onset of snow until complete melt. Extensive in-situ measurements with more than 30 snow profiles only in 2017/18 (snow pit profiles—with snow density per 3cm, temperature per 10cm, specific surface area (SSA) per 3cm, and snow water equivalent—or SnowMicroPen (SMP) profiles) were taken. In addition, two full micro-CT-based profiles of correlation lengths and snow density were also performed. Furthermore the test site was equipped with a weather station collecting all relevant meteorological parameters. With the availability of the wide band (1 – 40 GHz) scatterometer WBScat, the campaign was extended until 2018/19. The aim of the extension is to gather first experiences with WBScat and perform an intercomparison with SnowScat.

Near realtime (NRT) processing of the acquired data and remote connection were used to detect irregularities or special conditions early on. At all sites a local area network was established that connected the scatterometers, local network cameras and a network attached storage to the Internet. A web based monitoring platform provides current camera images and measurements, and instrument and meteorological information.

2. SCATTEROMETERS

2.1. ESA SnowScat

SnowScat (Fig. 1) was developed and built within the ESA ESTEC project KuScat contract No. 42000 20716/07/NL/EL [3,4]. It is a continuous-wave steppedfrequency radar covering the frequency range from 9 to 18 GHz. The instrument is fully polarimetric and coherent. Within ESA ESTEC contract No. 200020716/07/NL/EL CCN3 the instrument was enhanced by a levelling sensor to measure the absolute levelling of the antenna. Furthermore, a rail (linear scanner) was designed and implemented that allows measuring at precise displacement steps so that tomographic acquisitions can be made.

Figure 1: SnowScat is mounted on the tomographic rail that allows a displacement along the rail of about 2.5m. In addition a Quickset pan- tilt-positioner allows to rotate to dedicated angles in elevation and azimuth.

2.2 ESA WBScat

WBScat (Fig. 3) is a new terrestrial microwave scatterometer supporting polarimetric observations over the 1–40 GHz frequency range [5]. WBScat acquires fully polarimetric data in practically all-weather situations and temperatures, -40 to +50°C. A Vector Network Analyzer (Keysight FieldFox N9951A) covering frequencies up to 44 GHz is used for the signal generation and coherent measurements of the backscattered signal. An external calibration network with Short, Open, Load, Thru (SOLT) standards is used to calibrate the VNA and accurately measure the broad-band, low-noise amplifiers used in the receiver and transmitter. Three pairs of quad-ridge horn antennas cover the bands 1-6, 2-18, and 10-40 GHz.

Figure 3: WBScat is mounted on the tomographic rail that allows a displacement along the rail of about 2.5m. In addition a Quickset pan- tilt-positioner allows to rotate to dedicated angles in elevation and azimuth. The yellow box hosts the VNA and controller electronics. At the bottom the 3 pairs of send and receive antennas are visible.

3. CAMPAIGN SETUP AT LARET

3.1 Test Site

The test site for the winter 2016/2017, 2017/2018 and the ongoing 2018/2019 campaign is located close to the village Laret on the municipal territory of Davos/GR. The test site is a CryoNet station “Davos Laret” that belongs to the GCW CryoNet cluster “Davos”. The elevation is 1514 m a.s.l. A more detailed description of the site and the permanent sensors can be found in [2, 6]. A map view with the detailed topography is shown in Fig. 4.

Although, no long-term weather and snow data is available for this site, observations show that, in general, snow depth is larger than in Davos Dorf. The snow situation during the 2017/18 campaign was above-average and the maximum recorded snow-depth was 183 cm on 22. January 2018.

Figure 2: Test site "Laret" in winter 2017. The left tower hosts the radiometers: ELBARA (L-band) and Mora (X-band). The taller tower to the right hosts the rail for SnowScat and WBScat. Direction of the photograph is towards north-east.

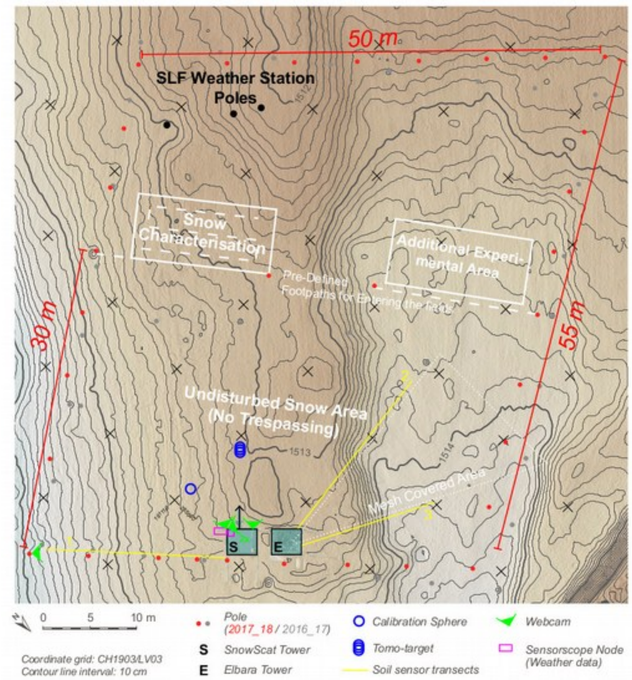

Figure 4: Detailed map view of the test-site Laret. The high-resolution topography was reconstructed using UAV Structure-from-motion photogrammetry recorded on 30.11.2016.

3.2 Snow Characterisation

In addition to the weather station [2] snow information was gathered manually on a weekly basis and after larger snowfall events. The internal structure of the snow-pack was sampled with semi-destructive methods such as Snow-Micro-Pen (SMP) measurements (~2x/week) or destructive profiling with manually dug snow pit profiles (~1x/week) [7]. A detailed analysis of the micro-structure was done twice with micro-computed tomography (Micro-CT) in the SLF Laboratory.

4. ACQUIRED DATA

Table 1 shows the total numbers of SnowScat data acquisitions of the different measurement modes and winters. While in the first winter the data acquisition was interrupted for a few days due to a failure of SnowScat, no gaps are present in the acquisitions in the two following winters.

The temporal behavior of the backscattering coefficient σ^0 for "Field 1" at 50° incidence angle during winter 2017/18 is shown in Fig. 5. The occasional melt events can well be distinguished by the drop in σ^0. In late March the wet snow refreezes resulting in a growing crust that is reflected by a strong increase of the backscatter signal. Fig. 6 shows the daily tomogram of 22 Jan 2018. The refrozen crusty snow at the lower meter of the snowpack can clearly be distinguished from the fresh dry snow on top.

Table 1: List of acquired SnowScat Data.

Season	*Scan*	*Total*	*Rate [Acq/Day]*
2015/16	*Sphere*	*837*	*6*
	Vertical	*250*	*3*
	Nominal	*834*	*6*
	Tomographic	*205*	*2-3*
2016/17	*Vertical*	*449*	*4*
	Nominal	*449*	*4*
	Tomographic	*115*	*1*
2017/18	*Vertical*	*620*	*4*
	Nominal	*620*	*4*
	Tomographic	*262 + 37 leftl.*	*1 (4)*
	2d Sphere	*20*	*1 per week*

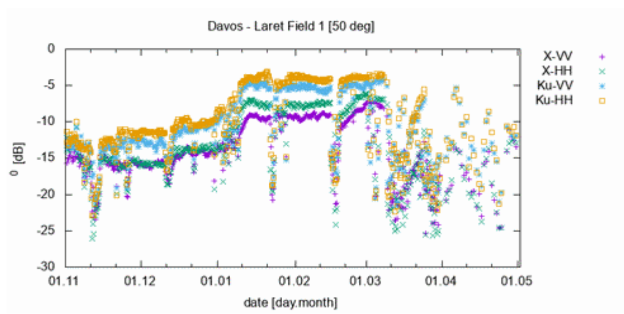

Figure 5: Example of time series of backscattering coefficient σ^0 obtained for Field 1 during the season 2017/2018.

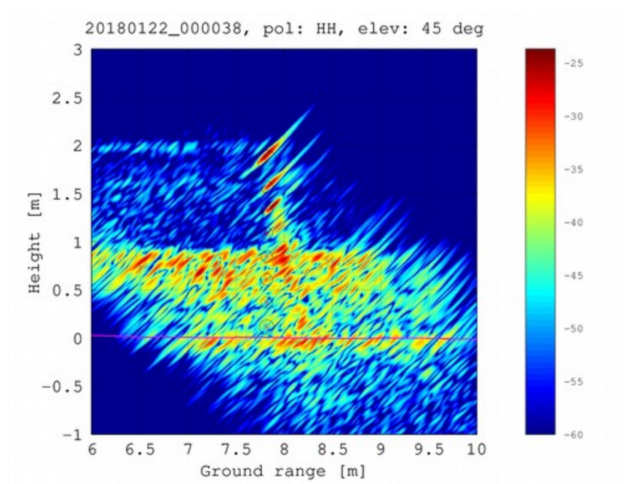

Figure 6: Maximum snow situation on 22.1.2018 with ~2m snow at the target location.

Fig. 7 shows the temporal evolution of the snow profiles derived from the vertical measurements. Different layers in the snowpack can be distinguished. During wet snow situations no information from inside the snowpack can be retrieved due to the strong absorption of wet snow.

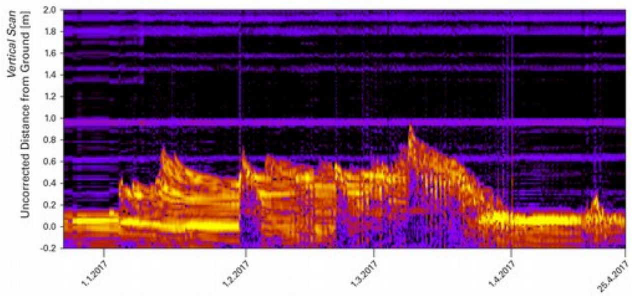

Figure 7: Result of all vertical scans taken during the campaign winter 2016/2017. Yellow means high backscatter intensity. The range distance is not yet corrected with respect to the snow pack.

5. CONCLUSIONS

The multi-year ESA SnowLab project has been carried out at the newly established CryoNet station Davos-Laret (Switzerland) since the end of 2016. Before, a one season campaign at Gerstenegg was conducted. In December 2018 WBScat became available, extending the spectral coverage further.

SnowLab provides a comprehensive multi-frequency, multi-polarisation, multi-temporal data set of active microwave measurements over snow-covered grounds in an Alpine snow regime. The main instrument in ESA SnowLab was ESA's SnowScat X- to Ku-band coherent tomographic scatterometer. The active microwave measurements are complemented by micro meteorological measurements and regular snow characterization using state-of-the-art sensors, in order to allow resolving the 3D snow microstructure necessary to investigate the origin of electromagnetic signatures associated with scattering effects. The resulting data set is needed to further investigate the relationship between effective snow-and ground parameters and their specific microwave backscatter, measured by radars. In addition to traditional backscatter signature measurements, SnowScat was used to acquired tomographic and vertical snowpack measurements. All three campaigns can be considered highly successful. More than 1800 signature scans were conducted and more than 500 tomographic profiles collected. Near real-time processing and data visualisation supported the monitoring and quality control of the running campaign. Following final data quality and documentation the campaign data will be made available to the science community following final data quality assessments, consolidation and documentation.

A first preliminary analysis of the active microwave data has been elaborated within the framework of the ESA SnowLab project. A detailed scientific analysis will be necessary and is planned to further exploit the data.

6. ACKNOWLEDGMENTS

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