Validation of SAR Remote Sensing Data on Wet Snow With In-Situ Measured Liquid Water Contents in the Alpine Snowpack

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Introduction

Snow significantly contributes to timing and intensity of mountain surface runoff. The buffering effect stored annual precipitation in snow covers at high altitudinal sites can be beneficial if meltwater supports discharge in rivers during the summer.

First meltwater flush at the beginning of snowmelt also poses risks of flooding or **short-term release of stored contaminants** (e.g. radionuclides).

Remote sensing provides accurate inputs to hydrological models concerning the spatial and temporal variability of snow. In particular, the analysis **of Synthetic Aperture Radar (SAR)** data on wet snow helps to predict snowmelt processes and melt water runoff initiation.

A better understanding of snowmelt processes should help to predict and prevent floods and to ensure a constant water quality by avoiding the distribution of contaminants.

Methods

SAR Remote Sensing Data

Wet snow maps are derived with a **novel multi-temporal approach that exploits the high temporal resolution provided by the Sentinel-1 mission.**

The method identifies wet snow on the ground by considering both the current value of the coefficient of backscattering and its temporal evolution (Fig. 1). SAR data are addressed to **understand** about the **transport of radionuclides in snow** and their **release to melt water**.

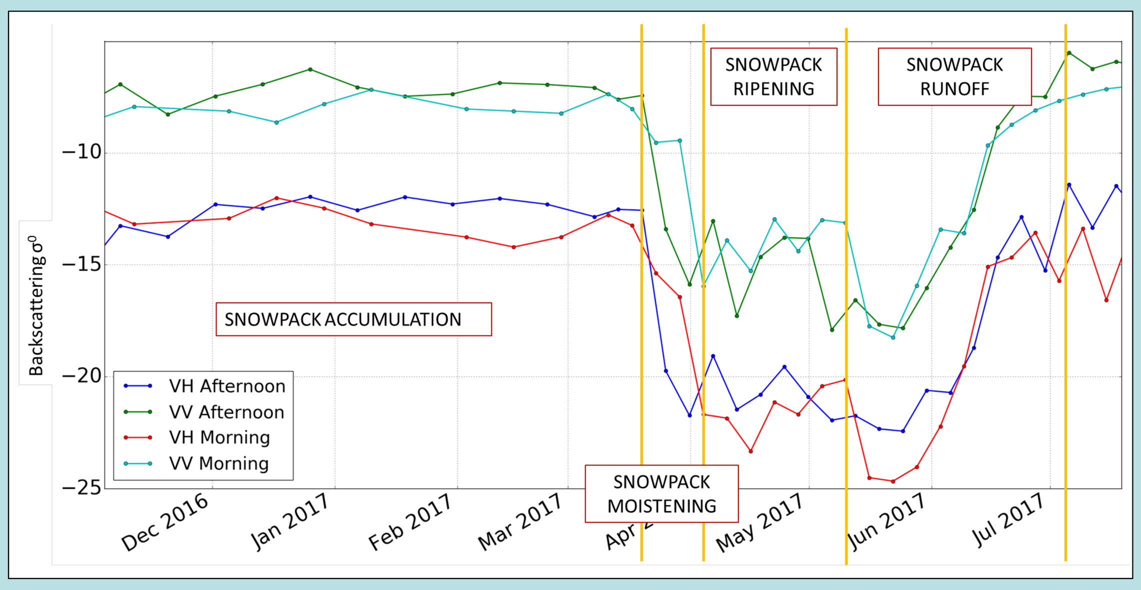

Fig. 1: Backscattering derived from Sentinel-1 over the Zugspitze station. Four phases are identified, which match with snowpack states identifiable also from the ground station measurement of snow water equivalent (SWE) and liquid water content (LWC).

In-Situ Liquid Water Contents of the Snowpack

Snow water equivalent (SWE) and liquid water contents (LWC) of the snowpack are recorded in-situ at Zugspitzplatt (2420 m a.s.l., Fig. 2), Mt. Zugspitze, Germany, using a combination of **snow scale and snow pack analyser.**

The latter measures the volumetric contents of ice and water in different snow heights using complex impedance along flat ribbon sensors with at least two frequencies (Fig. 3). **SWE and LWC will be used to validate the satellite data.**

Fig. 2: Meteorological station at Zugspitzplatt (2420 m a.s.l.), equipped with an ultrasound snow height sensor, snow pack analyser and a snow scale.

Fig. 3: In-situ measurement of snow water equivalents (snow scale) and liquid water contents of the snowpack in 10 cm, 30 cm and 50 cm height (snow pack analyser).

Preliminary Results

In a first attempt, the data measured in-situ at **Zugspitzplatt** during the snowfall **seasons 2014-2017** was compared with the remote sensing data retrieved **every 12 days**. The images cover the 11.4 km² large plateau, with a **spatial resolution of 20 m**. From the SAR imagery the end of the snowpack moistening phase, which coincides with a penetration of the wetting front below the insulation layer of the snowpack, and the start of the snowpack ripening phase are inferred with an uncertainty of ±3 d.

The determined timing derived from the Sentinel data was compared with in-situ measurements for the beginning of the water saturation of the basal snow layer and first meltwater runoff indicated by the decrease of SWE values and accordingly mass loss on the snow scale. The **time shift for first runoff estimated from the remote sensing data in comparison with observed first mass loss information on the snow scale** was **+7 days in May 2015**, **+6 days in May 2016** and **+10 days in May 2017** (Fig. 4). At first glance, the method provides promising results on the snowmelt phase and deserves further investigation.

End of snowpack moistening phase from S1 data — *End of snowpack ripening phase from S1 data*
Arrival of the downward penetrating melt water front in the basal snow layer (10 cm height) — *First melt water runoff at the snow base*

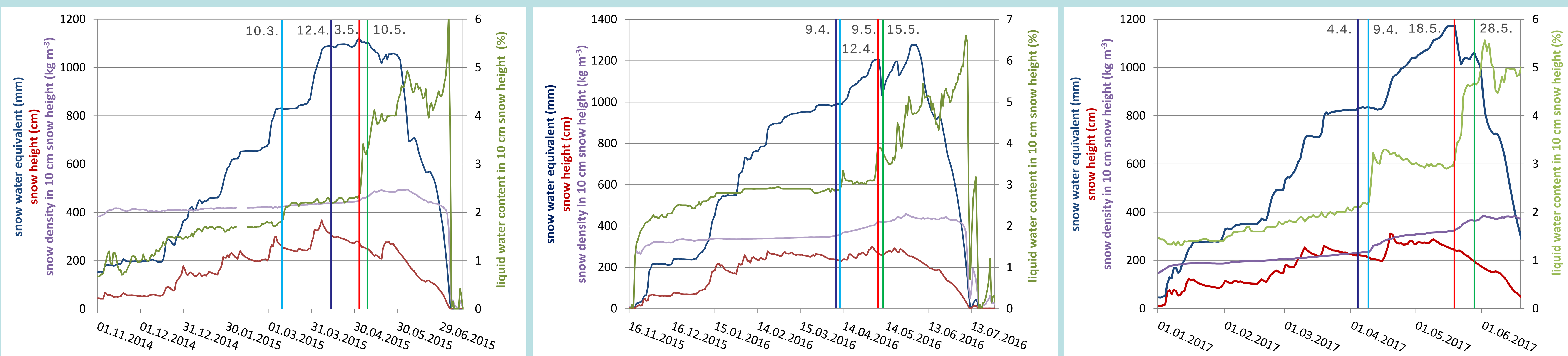

Fig. 4: Snow parameters measured in-situ at Zugspitzplatt during the snow accumulation periods 2014/2015, 2015/2016 and 2016/2017.
Dates for the beginning of meltwater saturation and runoff are inferred and compared to the marked timings for the ends of the moistening and ripening phase derived from the Sentinel-1 data.

Outlook

It is planned to use the information collected by the in-situ measurements in order to **better understand the electromagnetic mechanisms of SAR sensors in presence of different conditions of wet snow**. The SAR data will be used for the **alpine-wide extrapolation of releases of potential radionuclide contents of the snowpack**.

This will allow the **definition of a robust approach for SAR data able to retrieve snowpack status for large area and with 20 m resolution**. The investigations are envisaged to be implemented as an **application case study** in the **online data management platform Alpine Environmental Data Analysis Center** (AlpEnDAC, http://www.alpendac.eu).