**MONITORING OF ALPINE SNOW CONDITIONS USING C-BAND SAR**

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## INTRODUCTION

Aperture synthesis in radar imaging has allowed the acquisition of high-resolution earth observation data. This data is commonly referred to as synthetic aperture radar (SAR) imagery [1]. Many SAR systems operate in the C-band to take advantage of its significant sensitivity to one of the most abundant molecules on Earth: water. It has proven to be an indispensable way of monitoring processes taking place within the cryosphere, e.g. iceberg monitoring, wet snow extent or snow property mapping.

Recent radar satellite missions as well as in-situ snow profile measurements offer a valuable basis for investigating the relationship of both high-resolution SAR backscatter and snow parameter data. Profound relations shall be determined by correlating snow parameters such as snow height, grain size and snow wetness with backscatter. This backscatter can be transformed to different representations, where the most suitable ones need to be identified to finally be able to derive maps indicating snow conditions.

## INTERACTIONS OF MICROWAVES WITH MULTI-LAYERED SNOW PACKS

The fundamental background of all models describing the interaction of electromagnetic (EM) waves with media is based on the radiative transfer theory, which is very complex in the presence of a dense medium as it is the case for an aged snow pack (cf. Fig. 1).

Yet, assumptions in terms of the composition of the snow pack or the propagation characteristics of the radiation allow to derive certain snow parameters. This has been shown in past studies, e.g. an estimation of grain size, snow density and snow depth using the polarimetric properties of SIR-C's X/C-band sensor [2] or mapping extents of a wet snow pack with the aid of change detection [3].

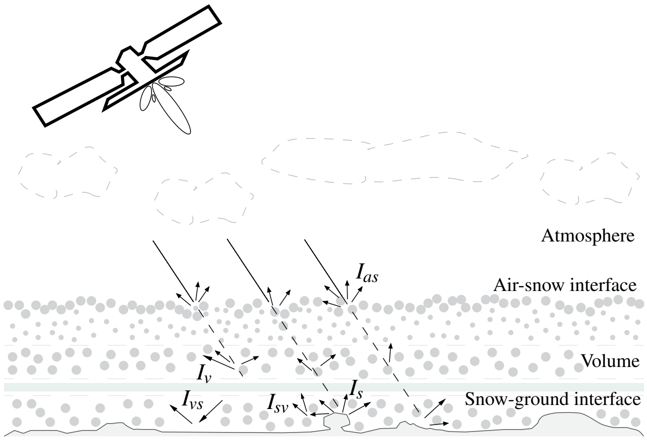


**Figure 1:** Interaction of radiation with a multi-layered snow pack.

## EXPERIMENTS

A comparison of C-band SAR backscatter data from ESA's Sentinel-1 satellites with snow profile measurements offered by the *Lawinenwarndienst Tirol* was proceeded for the timespan summer 2015 to autumn 2017. The geographical scope was limited to an alpine area being 100 $\times$ 100 km wide and covering the North and South Tyrolean alps.

A plausible correlation of the data sets mentioned above demands to adjust the backscatter data, which is strongly influenced by the observation geometry in steep terrain or, in other words, the variability of the incidence angle. Since a snow profile measurement was rarely performed at the same location, the dependency of backscatter on incidence angles has to be eliminated. To do so, various methods, both model based and data-driven, have been presented.

One method belonging to the former category is radiometric terrain flattening, which simulates the local illuminated area based on a Digital Elevation Model (DEM) and utilises it during radiometric normalisation. If many observations at different incidence angles are available, linear regression can be used to normalise backscatter to a certain reference incidence angle. In addition, a novel data-driven normalisation technique relying on the percentiles derived for each orbit was introduced in this study. Well-known quantities such as backscattering differences originating from change detection or polarisation ratios were also created to support an extensive comparison with snow data.

## RESULTS AND DISCUSSION

As a measure of predictability, the Pearson correlation coefficient was chosen to compare a subset of snow parameters with the aforementioned backscatter representations. Normalised backscatter by means of linear regression and VH polarisation appeared as the best setup. Results were enhanced by spatio-temporal filtering of backscatter data leading to a partial increase in correlation by nearly 0.2. The most meaningful, consistent correlation of -0.64 was found with respect to maximum snow wetness when doing change detection, which approves presented methodologies to map wet snow [3]. When computing such differences, normalised and not-normalised backscatter perform equally well, since steady effects like the dependency on incidence angles cancel out. Snow height was characterised by the highest positive correlation (0.67), but its significance is questionable, because dry snow is likely a transparent medium for C-band radiation. On the other hand, an aged snow pack containing larger grains can alter the radiation and its state of polarisation to a larger extent being visible in cross-polarisation ratios at the end of the snow melt season.

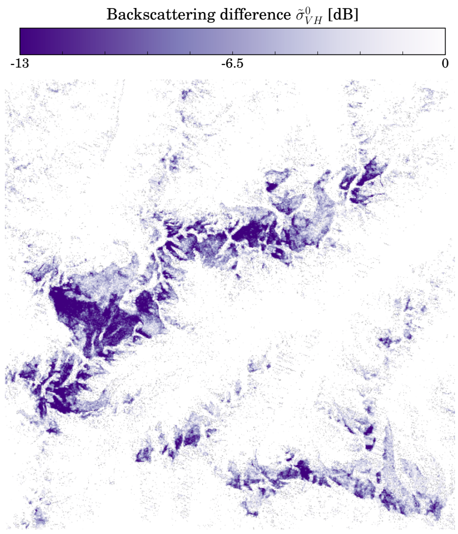


**Figure 2:** Backscattering differences indicating wet snow (Equi7 grid system).

## CONCLUSION

This study has shown, that snow wetness is indeed the most promising quantity to be derived from single-frequency, cross-polarised C-band SAR backscatter data. Fortunately it is not necessary to put effort in normalisation, since the difference formation eliminates terrain effects. Filtering both data sets by time (e.g., separating winter from snow melt season) could be interesting for further research, but more data would be needed to preserve significance. Useful information for run-off models and for determining fragile snow packs is offered by the herein presented wet and dry snow maps aiding in the prediction of avalanche risk assessment.

## REFERENCES

[1] Moreira, Alberto et al.:*"A tutorial on synthetic aperture radar"*. IEEE Geoscience and remote sensing magazine 1.1, p. 6-43, 2013

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[3] Nagler, T.; Rott H.: *"Retrieval of wet snow by means of multitemporal SAR data"*. IEEE Transactions on Geoscience and Remote Sensing 38.2, p. 754-765, 2000