

Interactive comment on “Anisotropy of seasonal snow measured by polarimetric phase differences in radar time series” by S. Leinss et al.

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Dear Reviewer 2,

We thank for the careful examination of the manuscript and the comments. All comments have been carefully answered.

The answers are attached below.

We would like to point out, that an additional computer tomography dataset has been added to the paper. The updated figure is attached.

We hope that our answers satisfy the reviewers comments.

best regards, S. Leinss

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Answers to the comments of the reviewer: _____
Anonymous Referee #2

General comments: This paper describes the measurement of CPD and its relationship to snow's anisotropy and SWE/density. Multiple seasons of snow measurements were conducted and the measured data were compared to the model described in the paper. The measured anisotropy of snow showed a good agreement with the results obtained from the micro-CT scan of the snow pack.

General comments: _____ Comment: What is the transmit power used?

Answer: The transmit power is approximately 10 mW. However, the SnowScat Instrument is a "Stepped Frequency Continuous Wave" Radar, therefore a good SNR is achieved by an integration time of about 5 ms for each frequency. The transmit power is not relevant for the content of the paper. To give a reference for technical data, a reference where this specification (10 mW) can be found was added in section 3.1 (Microwave measurements). (See p. 9 in "SnowScat, X- to Ku-Band Scatterometer Development: D13 SnowScat User Manual" ESTEC/AO1-5311/06/NL/EL). This paper is available on request from Andreas Wiesmann, Gamma Remote Sensing. It should also be available on request by ESA.

Comment: What is the effect of surface roughness and features on the measured CPD? How is the effect being isolated from the anisotropic of snow?

Answer: The effect of a rough snow surface and also of rough layer boundaries within the snow pack is now more clearly discussed in the section "Generalization for scattering multilayer systems". An additional section discusses the effect of a rough underlying ground surface in "Contribution of a rough ground surface".

In the present work, scattering contributions from the snow surface and layers within the snow pack are shown to be small, as the snow water equivalent could be precisely determined using differential interferometry as shown in the paper "Snow Water

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Equivalent of Dry Snow Measured by Differential Interferometry" by Leinss et al in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (2015), vol. 8 no 8. The reference and argumentation has been added to the section "Microwave Measurements".

The effect of the underlying ground has already been discussed in section 4.7 "Effect of Underlying Ground". The time series data (Fig. 7 - 10) show, that during dry snow conditions, the CPD is very close to zero.

Specific comments: ————— Comment: p. 6071; line 1-3: Nadir-looking radars can also measure 2D anisotropy if there is a difference in crystal orientation along the xy-plane.

Answer: Of course, this is correct. But we do not see any reason which could cause any anisotropy in the xy-plane in a snow pack situated in flat terrain. As mentioned in the last paragraph of the section "Definition of structural anisotropy" "We restrict our model to flat terrain and do not consider shear stress or temperature gradients not parallel to gravity, which can both occur on steep terrain."

Comment: p. 6071; line 6: It appears the statement is a bit contradicting as the anisotropy is caused by the particle scattering

Answer: I disagree. In the present paper, snow is considered as an effective medium (see 1st paragraph of section "Relative permittivity as a function of anisotropic inclusions") which is transparent but which has a dielectric anisotropy. The dielectric anisotropy is caused by a different polarizability of the anisotropic ice grains and not by scattering effects.

Comment: p. 6080, line 10: Is it possible to show a raw radargram of the quad-pol data as well as the SLC radargram with reference to the geometry depicted in Figure 5? It is interesting to see the spatial variability of the raw radar signal.

Answer: Here I refer to Figure 3 in the paper "Snow Water Equivalent of Dry Snow

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Measured by Differential Interferometry" by Leinss et al in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (2015), vol. 8 no 8. The figure shows a time-averaged "radargram" with respect to the imaging geometry as shown in Fig. 5 our paper. Please note, that the SnowScat system is a side-looking radar therefore each range cell contains the integrated backscatter signal of the snow surface, snow volume and the underlying ground. I like to refer also to the conference paper "Snow Structure Evolution Measured by Ground Based Polarimetric Phase Differences" by S. Leinss; J. Lemmetyinen; A. Wiesmann; I. Hajnsek, (2014); in Proceedings of 10th European Conference on Synthetic Aperture Radar (EUSAR). In this proceeding paper, time-resolved radargrams are shown which indicate that the microwaves completely penetrate the snow volume as long as the snow is dry. In this paper, the delay difference between dry snow and wet snow at the onset of snow melt is proportional to the snow depth of 80 cm.

Comment: p.6086, line 21: Can the authors show a comparison between CPD_meas and CPD_model before optimization and after optimization, and the corresponding number of iterations and change in fitting parameters? Is the data in Figure 14 before or after optimization?

Answer: Equation (19) contains only one free parameters, the Anisotropy A. As written in section 4.2 "Estimation of the average anisotropy of snow", all other parameters (wavelength or frequency, snow depth, incidence angle, density) are known. The minimization of Eq. (24) is done by simply testing about 2000 anisotropy values between -1 and 1. The anisotropy value which minimizes Eq. (24) is defined as $A(\theta, f)$ and depends on incidence angle and frequency. To avoid confusion with iterative optimization algorithms, the term "iterative" has been removed from the caption of Fig. 11 and replaced by "minimization with respect to A". Figure 14 shows the standard deviation and mean difference between measured and modeled CPD values. The modeled CPD values are based on the average of the anisotropy values obtained by minimization. The standard deviation of the anisotropy $A(\theta, f)$ is shown in Fig. 12.

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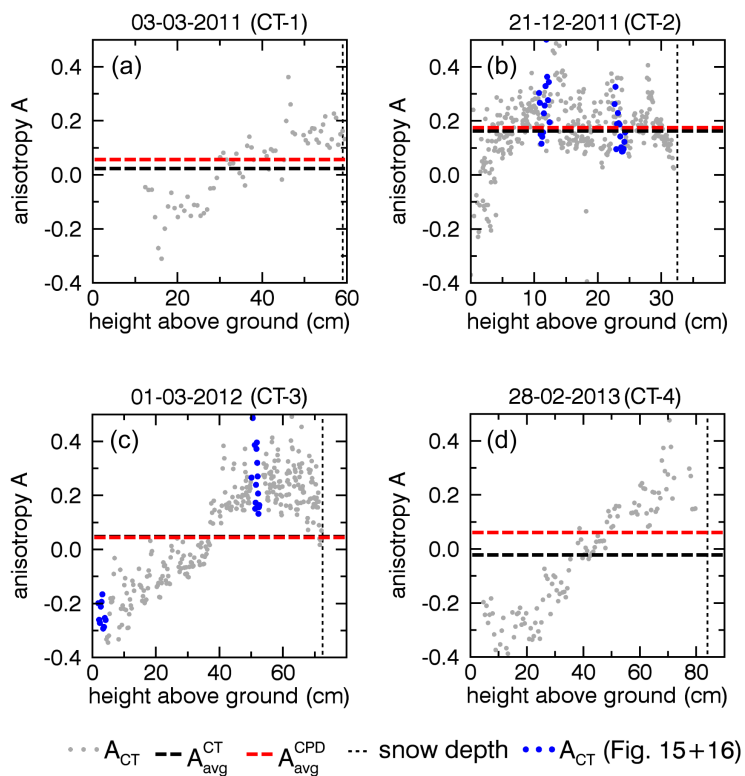


Fig. 1.

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