The Cryosphere Discussions

The Cryosphere Discuss., author comment AC1
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# Reply on RC1

Hans Lievens et al.

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Author comment on "Sentinel-1 snow depth retrieval at sub-kilometer resolution over the European Alps" by Hans Lievens et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-74-AC1, 2021

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We thank the reviewer for the detailed feedback on our manuscript. We will address all the comments in detail during the revision. However, there are number of comments, especially on the S-1 processing, on which we disagree and which we address here to stimulate the open discussion.

- Reviewer comment: "With all the processing done to the SAR imagery, it is impossible to assess the physical interactions of the SAR signal with the snowpack since the data has been smoothed multiple times and transformed radiometrically and geometrically. You have multi-looking (averaging 10x10 pixels), border noise removal, thermal noise removal, terrain correction and reprojection to the WGS84 projection. The multi-looking is especially concerning given the topographic complexity of the Alps. It is smoothing all the topographic information (which is crucial for snow retrievals) and emphasizing only the areas of significant snow (snow drifts) which is not representative of a 100m grid cell in the Alps. Then you add incidence angle correction using a DEM (30m) that is of lower resolution than the pixel spacing (10m) of the original image. A DEM with similar resolution should be used but also, the topographic information has already been altered from the multi-looking which is not representative of the local topography. Then there's temporal averaging (Eq.2) which alters the signal even further. Finally, outliers are replaced by a 12-day average to smooth the data once more."

Author response: We strongly argue for the opposite: Useful snow information can only be obtained if the processing of the S-1 data is adequate, and our processing is conforming the state-of-the-art. There are several steps involved in the S-1 data processing, but none of these steps involves 'smoothing':

- Border noise removal and thermal noise removal are very basic and standard procedures that are recommended by any literature source or handbook, and for any application that uses S-1 backscatter data.
- The data is corrected radiometrically for the local incidence angle impact, similar to the way gamma0 is calculated. This appropriately reduces the impact of the local incidence angle and therefore will better reveal the relationship between backscatter and snow depth. Note this is a rescaling rather than a smoothing operation.
- The data was geometrically corrected by range-Doppler terrain correction, which is also a standard processing step, especially in terrain with complex topography, that improves the geo-location of the radar measurements.
- We believe there is a misinterpretation of Eq. 2. This equation explains the bias-

correction of the backscatter data by the rescaling of the mean and standard deviation. This is again not a smoothing but a rescaling step. We moreover strongly recommend such rescaling for any application that aims at combining measurements from different relative orbits of S-1.
- In summary, we are strongly convinced the above-mentioned processing steps are fully conform with the state-of-the-art.

The reviewer also mentions that the multi-looking to 100 m is especially concerning. We are surprised by this statement. The multi-looking effectively reduces the pixel spacing of the backscatter measurements from 10 m in the original S-1 data (which is below the ~20-m spatial resolution) to 100 m in the multi-looked data. The result is thus similar as if one would have an instrument that measures backscatter at a native pixel size of 100 m, but with reduced noise (e.g., speckle).

- If the 100-m scale is problematic to retrieve snow depth according to the reviewer, what is then the take on novel satellite mission concepts, such as dual-Ku band SAR, that propose resolutions up to 500 m?
- The multi-looking is not only applied to reduce speckle noise, but also to keep the computation time for the processing and the data storage feasible. Our intention is to perform a consistent processing also at the larger scale, including other mountain regions and the full S-1 archive. Such processing would no longer be feasible using the high-performance computer that we have access to at a further reduced pixel spacing.

- Reviewer comment: "The errors obtained from the SAR retrievals (Figure 11) are most of the time larger than the precision of the reference data which is the model simulations. It is very difficult to determine that the correlations are statistically significant in this case and also looking at Figure 10, most of the comparison points are grouped around 0 which tends to falsely boost the correlation."

Author response: Figure 11 does not show the accuracy of the model simulations, but the accuracy of the S-1 retrievals with respect to the in situ snow depth measurements. We did not show the validation of the model simulations in this study, in order to focus on the validation of the S-1 retrievals. Furthermore, the model simulations of OSHD are including the assimilation of in situ measurements, and can therefore not be independently validated using these same measurements. We are surprised that the reviewer questions the statistical significance of the time series correlations shown in Figure 11, which are mostly higher than 0.8 for sites reaching snow depths above 1 m. We agree that the inclusion of zero snow depths can slightly increase the correlations. Therefore, Figure 5 shows time series correlations (against model simulations) both with and without the exclusion of zero snow depths. Even though more data are clustered around low snow depths in Figure 10, the density plots clearly demonstrate the overall agreement between the S-1 retrievals and the in situ measurements also for the high snow depths, especially for the coarser 300 m and 1 km retrievals.