Comments to the paper:
Characterization of Ice Features in the Southwest Greenland Ablation Zone Using Multi-Modal SAR Data

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The paper presents an investigation based on airborne multi-frequency, polarimetric, interferometric and tomographic SAR data to characterize ice features detected in the ablation zone of the Greenland Ice Sheet. Additional data and results from other studies are used to support the analysis, including ALOS-2 data, P-band sounder measurements, Sentinel-2 optical data, lidar derived topographic data from NASA's IceBridge initiative and in-situ data of ice temperature.

The work focuses on radar-bright and radar-dark features which are more evident with increasing wavelength (i.e at L- and P-band), suggesting a link with subsurface features (weathering crust) and dynamics occurring at the study area.

General comments:

The paper has a clear structure and is easy to read. The analysis is presented in a clear way with an approach that tries to link the different aspects (polarimetry, interferometry, tomography) coherently.

There is potential to get additional insights by expanding the analysis to investigate for instance the dependency of PolSAR and InSAR signatures of the bright and dark features on the imaging geometry. In addition, the use of C-band data would also provide another piece of useful information.

The analysis is supported by a modelling effort which is able to explain the behavior of the PolInSAR coherence at L- and P-band, even though some assumptions, like the presence of specific layers not detectable in the sounder data and in the tomograms, are difficult to justify from a physical point of view.

Overall, the study presents new interesting elements for the interpretation of SAR data of land ice. The interpretation of the shallow subsurface scattering component with the presence of a weathering crust looks reasonable and it is supported by other studies. From a SAR modelling perspective, it suggests a possible source of scattering (to my knowledge) not yet considered in literature, which adds to the previously proposed sastrugi, oriented crevasse fields, volume scattering from air inclusions embedded into ice layers and icy inclusions embedded into firn.

Specific comments:

Eq. 7 :

Except the volumetric decorrelation, the other terms contributing to the InSAR coherence are not introduced/defined in the text.

Line 180 :

I suggest substituting the term ‘subsurface ice elements’ with ‘subsurface scatterers’ or ‘subsurface scattering sources’.

Section 4.1

Here the authors start with the analysis of the PolSAR data which include X-, L- and P-band. As shown in Parrella et al. 2021 (JSTARS), this dataset includes also C-band acquisitions. It would be interesting to see also this data to have a more complete understanding of how the investigated radar-dark/bright features behave with frequency. InSAR and TomoSAR data should be available at C-band as well. Did the authors look at them?

Line 238:

I believe the authors here refer to Table 1 (instead of Table 2) when discussing about spatial resolution of P- and L-band data.

Table 4:

Here the authors report a summary of the value found with the polarimetric analysis at different frequencies.

My first point is that polarimetric signatures (including H and alpha angle) are typically influenced by the variation of incidence angle along the range direction. As both dark and bright features seem to be spread along the entire range direction in the SAR images, did the author assess whether the interval of observed H and alpha values is related to variation of incidence angle? Or are those values randomly occurring at different incidence angles? In general, it would be interesting to carry out an analysis of the polarimetric signatures with respect to the incidence angle for both bright and dark features. This might provide additional insights about the type of scattering mechanisms occurring in the two feature types, and support further the results of the InSAR and TomoSAR analysis.

My second point concerns the values observed at X-band for both H and alpha. At shorter wavelengths, I would expect overall higher values w.r.t. L- and P-band. I am a bit surprised to see that for radar-bright features, the lowest value of H and alpha is lower at X-band (0.2 and 0 degrees) than L- (0.5 and 20 deg) and P-band (0.6 and 30 degrees). Interestingly, the figures obtained for the radar-dark features are much more in line with the expected behavior. Do the authors have an interpretation of this phenomenon?

Table 5:

Also here, it would be interesting to know for which incidence angle are the estimated phase center height range representative, and if the authors observed any trend with the incidence angle.

Line 258-261:

I think that the limited penetration over the radar-dark features could also be related to the lack of effective scatterers deeper into the ice and not necessarily to a real shallow penetration (related to absorption). This is maybe an option to consider here.

Section 4.2.2, Line 284

Please replace ‘albedo’ with ‘snow albedo’

Section 4.3.1

It is clear that the authors focus on P-band for the tomographic analysis since this provides an ‘enhanced’ sensitivity to subsurface scattering and deeper penetration. Anyway, it would be interesting to show and discuss also L-band tomograms and consistent with Section 4.4, where the InSAR modelling addresses both P and L-band measurements.

Line 376-378

‘The general drop of coherence with increasing…. is typical for two scattering components with a certain vertical distance.’ Please add a reference.

Figure 8 and 9

I miss here a brief discussion about the values of surface-to-volume ratio obtained to fit the data. Are they reasonable/explainable across polarizations (HH vs HV) and frequencies (L vs P)? The information reported in the appendix is explaining in more details the modelling approach and the obtained results, but it is not discussing them.

Please, also provide bigger images.

Section 5.1 and 5.2

In my opinion, these 2 paragraphs could be removed since they mostly summarize the findings of the analysis carried out in the previous sections.

Figures

Please expand Figures 1, 3, 5 to full page width and with better resolution. In some cases, it is difficult to observe the features and patterns discussed in the text (e.g. in Fig. 5).