Review of Manuscript 2024-EGUSphere-2024-2077: Sentinel-1 cross-polarization ratio as a proxy for surface mass balance across east Antarctic ice rises

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Overview

This study develops an empirical relationship between Surface Mass Balance (SMB) and the cross-polarisation ratio (σ_{HV}/σ_{HV}) of Sentinel-1 SAR data derived from a comparison to in situ snow data acquired from Antarctica. The relationship has been shown to demonstrate clear accumulation patterns across the three ice rises studied. On the windward side, high SMB and cross-polarisation ratio is associated with low density snow and smaller grains, whilst the opposite is true on the leeward side. A key part of the data processing is correcting for the satellite incidence angle which the study computes using a linear regression between SMB and at sampled locations and cross-polarisation ratio. Mapping these patterns shows that this ratio may be used as a proxy for SMB across Antarctica and therefore has potential to help map SMB in areas with few in situ measurements. Because of the potential application of this method, I believe the study should be published subject to the revisions below.

General Comments

My general comments can be split into three points:

- I am unsure about how the incidence angle correction has been implemented. Sentinel-1 has an incidence angle file associated with it, which I assume you use (although this is not stated). What is the result if you apply a standard approach such as conversion to γ^0 or σ^0 (divide by $\sin\theta$) (e.g. Small 2011). As I understand it, the regression coefficients used in Eq. 2 are derived from a regression between the cross-polarization ratio and angle. But you say this is calculated at each sampling point, so it's not clear what data is being used. Rewriting some of the text in Section 3.3 will probably help to clarify these points.
- Much of the results section discusses results as if there is a clear pattern between e.g. SMB and cross-polarisation ration. Whilst I can see there is a relationship, to me the pattern is variable and not consistent, implying there is more complex physics at play. Downplaying some of the results and emphasising the variable due to e.g. snowfall variations, local climate might help with this.
- The text is a bit colloquial in places. Phrases such as 'want to' and 'coming from' and 'steady' are used which do not describe some of the underlying processes being discusses e.g. quantifying wind speeds, describing the travel orientation of winds. Editing the text throughout will help

here.

Technical Corrections (References to page numbers (P) line (L) numbers in preprint)

Abstract

P1L3: 'large spatial coverage and and ability to penetrate the snowpack'

P1L15: You probably want to add that the proxy should be combined with physical models.

Introduction

P1L19: 'large uncertainties': how large are the uncertainties? Maybe quote mass balance for year e.g. 2023 + uncertainty?

P2L6-7: This sentence repeats what you've just said 'as in-situ measurements are sparse'. Suggest remove?

P2L13: Also different densities of dry snow, wet snow, firn and ice.

P2L26: Is this because the increase in travel time due to snow thickness increases is larger for the co-polarised image (i.e. σ_{VH} becomes larger than σ_{VV}? I think this should be stated clearly.

P2l29: 'ground that ice not ice'?

P2L33: Remove 'want'

P2L35: 'driving the cross-polarization ratio variability, which relates to volume scattering from the snowpack.'

P3L7: Change 'synthetic' to 'theoretical'

Data and study area

P3L17: Not keen on 'island-like topography'; maybe 'a protruding bedrock bump' or something similar?

P3L25: ', this allows for'

P3L26: 'crevassing which creates a strong surface scattering response, the backscatter signal from the undisturbed snowpack will dominate.'

P3L26: Can you comment on the accuracy of ERA5 for interpolating? How well does it match AWS1 data? Also state pixel size.

P4L15: I would include the tracks on Fig.1 if you can.

P4L18-19: State that the dating using ice cores is described below.

P4L19: Same GPR system as before? If not, please describe it briefly.

P4L26: Can you briefly explain of SSA was calculated given that it is included in Eq. 1 below?

P6L1: I would include the locations of these samples in Fig. 1.

P6L4-6: Remove repitition (e.g. Sentinel-1). How well distributed were the images across the year? E.e did you have images in particular seasons? Could you also state why you average across 6 years -

my assumption is to remove noise, but snow conditions might change quite significantly from year to year.

P6L9: Just to be absolutely clear, I read 'the logarithmic ratio between' as the ratio between σ_{HV} and σ_{VV} in dB?

Data and study area

P6L24: 'to what degree'

P7L3: Is the space between isochrones only related to snow accumulation? What about firn, ice or even ice lenses (maybe not an issue here given the low melt rates)?

P8L14-19: Combine with paragraph above.

P8L11: I would suggest clearly stating that the linear regression is between cross-polarization ratio and incidence angle (taken from the Sentinel-1 data set).

P8L16: Not sure this makes sense to me 'obscuring the incidence angle correction'

P9L6-8: Not sure I understand how the AWS2 data was extended by 20 years? What does it mean by 'looping'?

P9L9-P10L2: This section isn't clear to me e.g. how the AWS data was extended.

P10L6: Which panel are you referring to? Also, visually Fig, 4d and e don't align well together, yet you state in the text they do?

Results

P10L25: 'measured SMB' - important to emphasis what is measured and what is modelled.

P11L1-12: The patterns described in this section are a little vague and I struggle to follow some of it. For example, you state that SMB and cross-polarisation is higher on the windward side, lower on the windward side, but visually this does not match the graphs, they are very variable. Fig. 6A is most clear, so I think you can make the case for this pattern here, but for C and E I would instead on the variability of the pattern. It's still okay to state the broad pattern, but I would refrain from saying it is 1clear'.

P11L2: Could you label where the windward side is on the profiles should be for clarity?

P13L4: Again, best to annotate windward and leeward side throughout on you figures.

P14L7-13: Similar to above, the patterns are not totally clear. I would suggest being more cautious in your description.

Discussion

P16L1-2: This doesn't explain the reason why grain sizes are high on the leeward side & low on the windward side? I would think high SMB would mean higher density due to greater snow compaction? I am possibly misinterpreting things.

P17L33: 'Antarctic'

P18L3-4: What are those 'right circumstances'?

Figures

Figure 2: I find it a little confusing to have a distance profile on top then time series below, can you make 2 separate figures?

Figure 3: What do the dots represent? Average HV/HH for each pixel?

References

Small, D. (2011), 'Flattening gamma: Radiometric terrain correction for sar imagery', *IEEE Transactions on Geoscience and Remote Sensing* **49**(8), 3081–3093.