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The Cryosphere Discussions
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# *Interactive comment on* "Seasonal variations of the backscattering coefficient measured by radar altimeters over the Antarctica Ice Sheet" *by* Fifi I. Adodo et al.

**Anonymous Referee #1**

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In this study, Adodo et al. observe seasonal variations in radar backscatter over the Antarctic Ice Sheet using three different radar frequencies. The authors define regions over Antarctica where backscattered power is found to peak in the summer for the S band, winter for the Ka band, and in both summer and winter for the intermediate Ku band. The authors perform a sensitivity study to help understand the effects of surface snow density, snow temperature, and snow grain size on backscattered power from each radar band. This study, in particular the delineation of these summer and winter 'peak zones', as referred to by the authors, represents a worthwhile addition to the literature. However, in my opinion some of the reasoning the authors provide in the discussion section to relate these seasonal variations to physical processes is lacking



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in places, and I would appreciate if they could respond to the following comments.

Specific Comments:

Section 1

P1 L8: I would suggest rephrasing to “radar wave interaction with the snow. . .” instead of “radar wave penetration. . .”.

P1 L27: I feel the phrase “More or less corrected” is quite vague here: corrections for atmosphere/ionosphere and slope errors are well established in the literature and minimise these errors with good accuracy – radar wave penetration is the main outstanding problem listed.

P1 L30: I have some concerns with the 2012 Greenland melt event being used as an example here. This is a positive elevation bias (not negative as the authors discuss in the preceding sentence) caused by a resetting of the radar scattering horizon due to an anomalous surface melt event. This is a process without equivalent in Antarctica, and one that has also been corrected for in the literature when measuring surface elevation change with radar altimetry (Nilsson et al., 2016, McMillan et al., 2016). In my opinion the authors should clarify this here, or include more examples on the effects of radar penetration on time series of elevation in Antarctica from radar altimetry in order to better establish the problem they are addressing.

P1 L41: The authors fail to mention the work of Davis and Ferguson here (Davis and Ferguson, 2004), however I feel this is a significant contribution to the literature which the authors should include.

P2 L46: The authors should cite Ridley and Partington 1988 here.

P2 L50: I think it would be helpful for the reader to know the wavelength of each radar band in addition to the frequency, either here on in Section 2.1.

P1 L55: The manuscript states later on that the orbit of AltiKa has recently been shifted,





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so I would suggest amending this sentence to reflect this.

Section 2

P2 L79: The authors describe the radar waveform, but the concept has already been introduced in the previous section. I would suggest formally defining the waveform where it is first mentioned as opposed to here, as it is a key concept needed for the paper.

P3 L87: The authors should rephrase this sentence to make it more clear that the ICE-2 retracker is used to obtain backscattering coefficients for the Ku and S bands.

Do the authors consider ascending and descending tracks separately? A previous study has shown radar backscatter has an anisotropic dependence resulting from the interaction between the radar polarization direction and wind induced features of the firn (Armitage et al., 2013).

Figure 1: Can the authors please include a map to indicate where this location is in relation to the continent, and along the orbit tracks of the 3 bands.

P3 L105: Do the authors place any controls on poorly constrained fits due to e.g. poor match between observed and modelled seasonal peaks?

In addition, can the authors please provide more information on how the amplitude and phase are gridded. Do they use the mean? If so, are there grid cells which have a high variance? How many coefficients, on average, are binned into a 5 km grid cell for each radar band? What data coverage does this provide in more challenging regions such as the margins and the Peninsula?

P4 L151: Can the authors please comment on the validity of applying this firn density profile obtained at one location to the rest of the Antarctic ice sheet – how sensitive are the results to this assumption?

Section 3

P5 L168: Which day/month of the year do these peaks correspond to? More information can be provided to the reader here.

Figure 2: It would be useful to plot elevation contours (or an inset elevation map) if elevation is used to delineate backscatter patterns in the text. It would also be helpful for the authors to indicate the locations of regions they refer to in the text (e.g. Wilkes Land, Dronning Maud Land).

Would it also be possible for the authors to mark out the summer and winter peak zones they define in the text? Finally, I would also suggest using a different colour scale, the differences between pale yellow-green-blue are quite hard to make out.

P5 L177: Do these percentages refer to the observed area, or the entire Antarctic ice sheet? This applies to any percentage stated in this way.

P5 L178: Do the percentages in brackets also refer to the area of these summer and winter zones for each band? As written it is not clear to me, I would suggest rephrasing this.

Figure 4: I would suggest using a different colour scale which is preferably divergent to make the figure clearer.

P6 L187: How are the uncertainties in backscatter coefficient derived here? They appear to be quite large to me.

P6 L195: Can the authors please expand on how they are deriving surface elevation, is it also from the ICE-2 retracker, and binned at the same 5 km grid used for the backscatter coefficients? Have these elevations been corrected for atmosphere/slope? In addition, how are the values of dhd$\sigma$ derived?

Figure 7: The units in the caption state dB not m/dB.

Section 4

P6 L217: "...resulting in a decreases of the radar wave in the volume...". Are the





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authors referring to a decrease of backscattered power? I suggest the use of more precise language in instances like this. Also decreases should be decrease.

P6 L220: It would be helpful to show this WP zone on Figure 4 to make clear to the reader.

P7 L222: Do the authors have any evidence to back up this assertion of volume echo variations being driven by temperature? I agree this is a reasonable conclusion to propose, however the authors do not offer enough evidence to convince that this is indeed the case. I would suggest that the sentence is reworded to make the authors argument clearer.

P7 L230-240: I am not sure I agree with the soil analogy – in my opinion it doesn't offer any clarity to the reader and isn't needed. Can the authors please expand on what they mean when they state the snow surface is sensed "as a volume scattering medium at the Ka band" – in reality there will always be a surface component of the radar echo controlled by incidence angle and topography on the footprint scale.

P7 L244: Do the authors mean to reference Fig. 8 here and not Fig. 3?

P7 L246: Do the authors have any evidence for a seasonal cycle of snow surface roughness?

P7 L249: The authors state here that the seasonal variability in surface roughness is poorly known, therefore I'm not sure they can argue that it controls the seasonal cycle in the S band (please see my previous comment).

P7 L250: I would suggest rephrasing point (iii) to make the argument the authors are trying to make clearer.

Figure 9: Should this figure have a colour scale? I would suggest a rework of this figure – it is not clear where the SP and WP zones are.

P7 L256: The authors argue here that the WP zone maximum is due to the volume





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echo, but matches regions of megadunes and wind-glazed surfaces. I would appreciate if the authors addressed the following regarding this statement: (i) the Antarctic megadunes have surface features and sloped terrain on length scales similar in size to the radar footprint – how can the authors distinguish between the effects of surface and volume here? (ii) I would expect more backscatter in the summer over wind glazed regions due to the presence of large ice crystals near the surface, should that cause a backscatter peak in the summer in these regions?

P7 L264-L266: Can the authors quantify this spatial coherence, or are they implying correlation from visual inspection? Are pixels with high seasonal wind speed amplitude correlated with the winter dates of high backscatter? I'm not sure I see the relationship looking at these plots, or from the average wind speed values.

Can the authors also please expand on the seasonal amplitude of the wind speed – how is this obtained?

P8 L268: As per my previous comment, I am not sure of this correlation at Ka band either.

Figure 10: Please can the authors explicitly state the time period used in the caption. I find the elevation contours very difficult to make out, also.

P8 L282: Isn't depth-hoar predominantly formed during the late spring and summer over these wind-glazed regions, according to Scambos et al., 2012?

P8 L288: Over which time period were these grain size vertical gradients obtained? Over winter periods only or a multi-year average?

Section 5

P9 L308: "may therefore be a consequence of the presence or not of the wind-glazed areas" – I'm not sure what the authors are communicating here, I would suggest rephrasing this to make it clearer.

Technical Comments:

Please find some technical comments below, but not all I have found are listed here. In my opinion the paper is in need of a thorough proof read, with a particular focus on grammar, sentence structure and the use of more precise language to increase readability.

Title: Should read "...over the Antarctic Ice Sheet."

P1 L13: Please rephrase this sentence to make this clearer.

P1 L18: Should be: "At Ku band, which is intermediate..." and "...the seasonal cycle in the first zone is dominated..."

P1 L20: Should read "...should be taken into account for the more precise..."

P2 L60: Please rephrase this sentence for readability.

P2 L65: Please rephrase this sentence for readability.

P2 L78: "The footprint has around 5 km radius" Âň– please rephrase.

P3 L81: "To ensure post-ENVISAT mission..." this is incomplete, please rephrase this sentence.

P4 L148: Should this heading have a section number?

P6 L218: Please rephrase this sentence for readability.

P7 L250: "...interdependent and linked..." is a tautology, please rephrase

P8 L294: "The radar altimeter remaining on the same tracks..." is referring to two different satellites here, I would suggest rephrasing.

P9 L314: Should read "...are the key to improving..."

References:





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Armitage, T.W.K. et al. (2014), Meteorological Origin of the Static Crossover Pattern Present in Low-Resolution-Mode CryoSat-2 Data Over Central Antarctica. IEEE Geoscience and Remote Sensing Letters. 11(7),pp.1295–1299.

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