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The Cryosphere Discussions

Interactive comment on "Simulated Ka- and Ku-band radar altimeter scattering horizon on snow-covered Arctic sea ice" *by* Rasmus T. Tonboe et al.

Anonymous Referee #2

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General comments:

The objective of this paper is to evaluate the capability of Ka/Ku bi-fréquency altimeters to measure the snow depth (SD) over sea-ice using a simulator. The authors tackle a particularly complex subject: what is the impact of the type of snow (salinity, density, temperature, grain size, etc.) on the performance of the measurements. The simulator is powered by measurements of terrain and its outputs are confronted with airborne measurements.

This type of work is indispensable to improve the quality of the measurements of the sea ice thickness (SIT) by satellite, and to prepare for the the Copernicus project of

the CRISTAL dual-frequency altimetry satellite, one of the first missions of which is to monitor the physics and dynamics of the sea ice.

As such, this work and the data used must be disseminated and made public.

Nevertheless, the results presented are in contradiction with several results already published and the arguments are not sufficiently convincing. Indeed, although this is not explicitly stated, this study seems to conclude that the Ku-frequency almost no penetrate the snow, no matter what are the snow caracteristics (see Figure 6).

In fact, most of the paper focuses on the _differential_ of snow penetration between Ka and Ku. Penetrations in the snow of each individual frequency is not analyzed. However, the conclusions are largely based on the measurement of the ice freeboard (FB) by means of the Ku frequency alone, a measure which appears only in this section 6 without being justified beforehand.

Figure 6 in the same section is therefore difficult to interpret. For example, it is not clear how the Ku nor the green differential curve have been obtained. For SD=0 we observe an ice freeboard of 0.2m and a Ku freeboard of 0m while it does not may have a problem of penetration in the absence of snow: these 2 measures should be equal.

This section 6 is far from insignificant because it leads to surprising conclusions, repeated in conclusion, including in particular the fact that the measurement of the SIT is little impacted by the method of obtaining the snow depth. This assertion is in contradiction with equation (1) of equilibrium which shows that the snow depth is involved in the process for about 30% of the measurement of the SIT (the density of snow being about 1/3 of that of water and the values of FB and SD being of the same order of magnitude).

Also the model implicitly assumes that the alitimeter is in LRM mode, while all Ku altimeters currently in flight are in SAR mode. The SAR mode has a much smaller footprint than the LRM mode. It is therefore less sensitive to surface roughness and

especially one cannot make the hypothesis of a retracking at 50% of the waveform (in SAR mode the retracker is between 85% to 95%).

This does not call into question the study presented because the comparison of Ka/Ku penetrations is a primordial subject that deserves to be studied whatever the the altimeter mode. But it is important to mention it. And with this perspective we would like to see more precisely what are the backscatter of each of these 2 individual frequencies according to the surfaces and interfaces considered (air/snow retrodiffusion, snow/ice and volume in snow).

Finally, this multilayer model seems to consider only one layer for snow, whereas we generally consider at least 2 layers for snow over sea ice, with a hard and dense superciel layer and a deepest layer of very metamorphosed grains of consequent dimensions (of the order of centimeters). This point should also be discussed.

I would therefore recommend to the authors to deepen the presentation of the measures carried out, and especially the model deployed and the conclusions that it brings on each of the frequencies, quite to reduce the part 6 on the results expected by altimetry.

Detailed comments:

P1 L27: I do not agree with the following sentence: "... the impact of using a snow climatology versus the actual snow depth is relatively small on the measured freeboard" that must be more clearly demonstrated (see general comments and other comments bellow).

P2 L45: "The radar scattering horizon or track point is conceptualized as the scattering surface depth detected by the radar re- tracker algorithm and the floe buoyancy" : this study should not depend on the buoyancy but only on the penetration. P2 L51: The following sentence is true only for the heuristic retrackers, not for the retrackers based on physical models: "The re-tracker algorithm can be tuned so that the radar scattering

horizon coincides with the snow/sea ice interface." P2 L54: What do you mean by : "leading to preferential sampling of the thinner ice types " ? P2 L61: when speaking of "penetration correction" do you include the speed propagation reduction into the snow ?

P6 L142: You say that the "surface roughness is assumed to not influence the scattering horizon variability in our model simulations" while the surface as a strong impact on the altimetric waveforms. Does that mean that the model do not reflect the altimetric behavior? Please comment.

P7 Fig 3: Please specify that depth=0.0 corresponds to the bottom, not to the surface! (if I dont mistake)

P9 L206: You say that "The track point is found at half of the maximum waveform power point in time". It is a true mean for LRM altimetry but physical retrackers show that this value varies according to the roughness and the specularity of the surface. For SAR altimetry the mean value is much higher. P9 L210: What do you mean by "the total backscatter is dominated by surface/interface scattering"? The interface is between the surfaces? Or it is another surface? Do you mean that the volum scattering is negligeable? In such a case it must be said/shown explicitely. P9 L213: In the sentence "This assumption is believed to be more realistic than other sea ice surface scattering" please specify which other sea ice surface scattering you are thinking off.

P10 L241: "the track point is computed as a point in time located midway between the noise floor and the maximum return signal power received by the radar." This is pertinent only for LRM altimetry.

P11 Table1: Only one layer for the snow. Is it realistic? Please comment.

P12 L297: Typo: "Ku- and Ku-"

P14 L338: "The snow climatology is used to 1) compensate for the effect of the snow cover on the ice floe buoyancy, and 2) to compute radar propagation in the snow." For

point 2) I suppose that you mean "compute radar slow down speed propagation in the snow" ?

P15 L345: "We do not show the actual ice thickness, but it is proportional to the freeboard." As shown by your equation (1) the SIT depends also on the snow load. So please could you precise the SIT used in the Fig 6. P15 L352: "The green line in Figure 6 shows the combined effect of snow on the track point and the floe buoyancy." Which track point? Ka? Ku? Until this section 6 only the ka-ku difference has been considered. P15 L357: "The effect of snow depth on the Ku- and Ka- track point is linear up to snow depths of $\sim$ 50 cm (Figure 6)." Fig 6 does not show the Ka measurement. P15 L360: "The correction" for the track point is on average 0.35 times the snow depth". Which track point? Ka? Ku? P15 L368: typo "SYI"

P16 Fig 6: "Red circles is the Ku-band radar track point as a function of snow depth and density" : The Ku FB has not been introduced beforhand, how do you obtain it? "The combined effect of both Ka- and Ku-band track point and buoyancy is the green line freeboard": how it is computed ? How do you get a nul Ku-FB for a ice-FB, without snow, of 20cm? Thus it is clearly not a problem of snow penetration!

P17 L389: "the snow climatology results in a small impact on the derived sea ice thickness": this sentence is clearly in contradiction with equation (1). See general comments. P17 L393: "The small impact of the snow on the measured freeboard is the reason why the sea ice thickness can be derived using radar altimeters even without actual snow information." If the first part of this sentence could be true, the second one is clearly false. Even if we can not measure precisely the FB, the SD does have nevertheless a strong impact on the resulting SIT! It is easy to demonstrate using equation (1) and various SD datasets. P17 L405: "Our simulations demonstrate that the direct Ka- and Ku-band track point difference sensitivity is about 0.033 times the snow": it is not (yet) a demonstration but still an assumption based on a model. Please mitigate.

P18 L421: "This implies that the measured freeboard is nearly independent of snow depth." Using Ka? Ku? Both? Please be more precise or mitigate. P18 L424: "the impact of actual snow depth is small in the sea ice thickness estimate": equ (1) shows that the SD may not be negligeable at all.

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