Interactive comment on “About the consistency between Envisat and CryoSat-2 radar freeboard retrieval over Antarctic sea ice”
by S. Schwegmann et al.

We thank the reviewer for his/her comments. In general we find them positive and we plan to write a revised manuscript for publication in The Cryosphere. Detailed response to the comments can be found below.

Anonymous Referee #1

A comparison of the freeboard retrieval in Antarctic sea ice, between two different space-borne radar altimeter - the Envisat RA2 and Cryosat-2 SIRAL (in SAR and SARIn mode). The author attempt to show that during the overlapping period of 2011, results from the Envisat and CS-2 missions have a reasonable consistency. Thus, it is potentially feasible to construct a consistent time series of sea ice freeboard, thickness, and volume during the satellite radar altimetry and gain the knowledge of the Antarctic sea ice volume in recent two decades. However, as pointed out in the paper, due to different SSH (sea surface height) data used for the two products, I would argue that the current comparison are not valid, although they seem be compatible. Although they offer to use the DTU13 SSH products for both data in the future, I would rather them use DTU13 for this paper to assure a solid publication.

After careful consideration, we confess that the reviewers comment on the different MSSH is valid. We shall reprocess both CS-2 and RA-2 using DTU13 and use that for the final manuscript. At the time of writing this, the reprocessing for both datasets has already been done. Based on these results we will re-evaluate the occurrence and relative frequency of negative freeboards, therefore no detailed explanation to the reviewer questions can be given at this point.

Some general comments:

1. A comparison of the radar elevation and local sea level measured from both sensors would be a good addition to the comparison of the freeboard, at least one can know which one, the elevation from satellites or the local sea level estimation from models, accounts more in the biases/variations between the two datasets.

We have already looked at the mean and local SSH during the data processing. They showed that the largest differences occur in the western Weddell Sea and are in general small elsewhere. We can and shall easily include this in the revised manuscript.

2. Aside from the comparison with mean and modal value, the root mean squared difference (RMSD) is also a good indicator to interpret the differences/biases

between the two missions. And, a table listing the bias and the result of statistical testing in each sector/month would give a better and clear picture of the results.

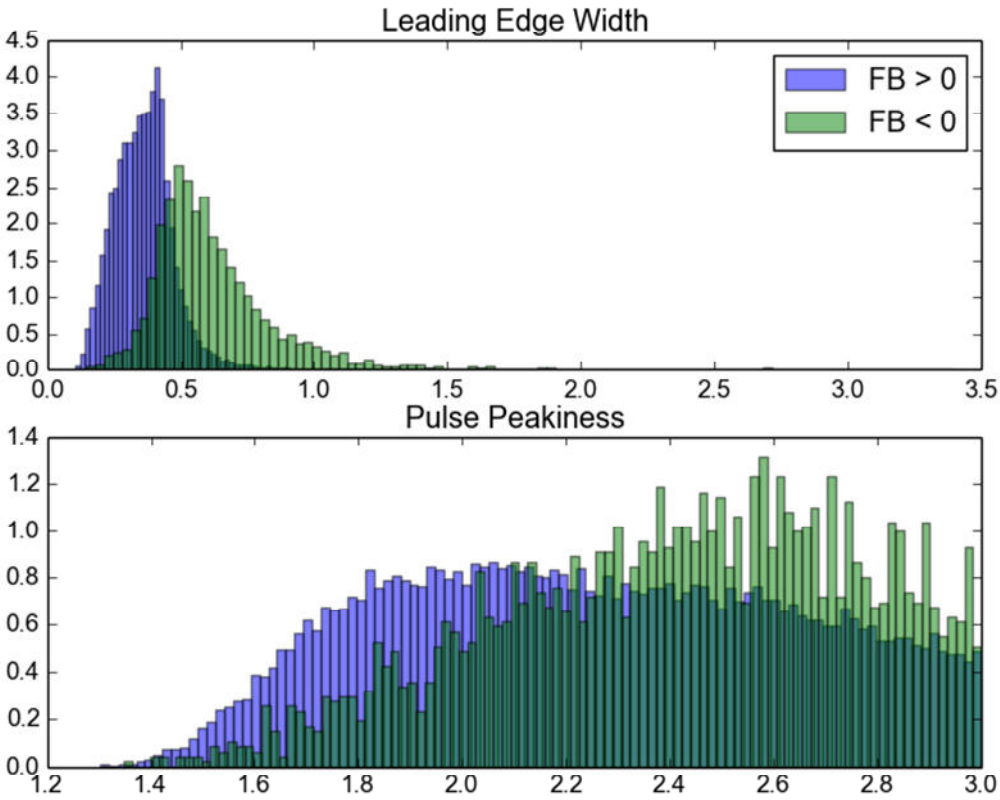
This is a fair comment as well and reasonably easy to include. We shall take the reviewers advice and do this in the revised manuscript.

3. The authors could also consider to introduce some in-situ or airborne altimetry data as a reference to assess that in each month/sector, which sensor would have a better performance.

This would be a good idea, if the purpose of the paper would be to study the accuracy of RA-2 and CS-2 retrievals. However, as clearly stated in the manuscript, our paper is on the consistency of RA-2 and CS-2. We do not assess the performance - only the differences. And thus we do not plan to include external validation data in this study. To keep the scope of this paper manageable, the validation of radar altimetry in the realm of southern seas will have to be left for another paper. As a general comment, this work is ongoing in the Sea Ice CCI Phase 2 round robin exercise and results are to be expected early next year.

4. For the footprints with negative freeboard, does the echo waveform pattern of negative radar freeboard-footprints significantly differ from that with positive radar freeboard?

This is an interesting question and something that demands effort. Once again, to answer this in detail would be a study of its own including a modelling part on the snow pack properties and surface roughness. In order to answer the reviewers comment we quickly looked at the distribution of RA-2 waveform characteristics, namely the Leading edge width and Pulse Peakiness (for definitions see Ridout, A. and Ivanova, N.: Sea Ice Climate Change Initiative Phase 1, Algorithm Theoretical Basis Document (ATBDv0) issue 1.1, ESA Document, Doc Ref: SICCI-ATBDv0-07-12, ESA, available at: http://esa-cci.nersc.no/?q=webfm_send/160). The distributions for the 10 first days of September 2011(admittedly a random timespan) are plotted below:



Looking at the figure, we can say that for RA-2, yes the waveforms of negative and positive freeboards differ. It seems that the leading edge width is larger for negative FB than for positive. This is quite possibly due to the thicker snow cover, contributing to an early rise of the waveform over noise level. The difference in pulse peakiness is more subtle - possibly the PP values < 2 are less common for the negative freeboards than for positive freeboards. This is most likely due to heavily deformed ice (resulting in off-nadir returns and smaller PP) is less likely to have negative freeboard than less deformed.
As the waveforms, at least for RA-2, are different for, we cannot rule out that one of the two different filtering schemes of RA-2 and CS-2, is more prone to filter out good measurements of negative freeboard. This is very unlikely though, but we shall discuss this in the revised manuscript. We believe a more likely candidate for the negative freeboard is the ssh interpolation and the density of leads along track.

Specific Comments

Page6, Line 12: As both the CS-2 SAR and SARIn L1b data used, is there any significant different in retracking and freeboard retrieval between these two modes? Which data is really used for the freeboard retrieval?

The retracking algorithm of CryoSat-2 data does not differ between the SAR and SARin mode. SARin waveforms may have a higher noise level, but this is accounted for in the revised data product. In the original submission higher noise level of SARin data might have resulted in higher freeboard for some cases.

Page 7, Line 21 and Page 9, Line 5: It can be seen that radar freeboard with extreme values (<-0.3m & >2m for CS-2, and <-1m & >2m) are discarded. I hope you can provide some reasoning or citations why these values are selected. What is the reason that the CS-2 did not retrieved much negative freeboard on the inner ice pack? Should it be the result of the higher random error associated with the Envisat freeboard?

The choice of these thresholds is based on our experience of the uncertainty range of the orbit data from the two satellites. The analysis of the relative amount of negative freeboard for both mission needs to be revisited after the reprocessing with the common mean sea surface and thus results will be reported in the revised manuscript.

Page 9, the “Results” section: As presented by the manuscript, the Envisat and CS-2 sea ice freeboard are well consistent with each other, as there are only a very low overall bias. However, as the performance of Envisat and CS-2 differs in different time and location, can the authors recommend which one might be better in each of the specified sea sector and/or specified month?

A SAR altimeter of smaller footprint size with less potential for mixing of surface types is definitely preferable over an LRM altimeter. Though at an Envisat like orbit inclination there would be a better coverage for all sea-ice covered areas in the southern hemisphere. The upcoming Sentinel-3 mission will be such a best case for Antarctic sea ice.

Page9, line17-21, negative freeboard is discussed, but it is not shown anywhere in figure 2.

This will be made more clearly visible in the revised manuscript

Page12, line 5-6, why Envisat has more negative freeboard than CS-2?

Besides the expected higher uncertainty of LRM waveforms, we will investigate the influence of different handling of sea surface height estimation in the two products. As discussed above, the amount of negative freeboard might change and results will be reported and discussed in the revised document.

Page14 Line 17: The CS-2 freeboard near the Antarctic coast is mostly higher than that of the Envisat in almost all sectors and in all months. The author explained this

as the higher error in the SARIn mode. However, it seems this is mostly a bias between the SARIn and Envisat. Also, could this be caused by the higher error or bias in the Envisat when measuring the coastal, fast ice, not by the CS-2 SARIn mode?

At this point we can only speculate about the nature of this observed bias, especially when comparing SAR/SARin (CryoSat-2) and LRM (Envisat) waveforms. It might be true that waveforms of SAR and LRM altimeters show different sensitivities towards certain ice surfaces. One way to verify this would to extent this analysis to the Arctic, but this is beyond the scope of this study.

Page14, line25-29 about footprint size effect, please also see this paper for the Antarctic. Xie, H., A. Tekeli, S. Ackley, D. Yi, and J. Zwally, 2013. Sea ice thickness estimations from ICESat Altimetry over the Bellingshausen and Amundsen Seas, 2003-2009, Journal of Geophysical Research, doi: 10.1002/jgrc.20179;

Reference will be included in the revised manuscript

Page 23: Table 2, I am not sure how the authors handled the situation when snow depth is lower than the pre-set penetration depth (be 5cm or 15cm), this could be the cause of the negative SIV? And, I am not sure if the SIV does include the snow volume.

In case the snow depth is lower than the assumed penetration depth, we assume full penetration of the main backscatter horizon, which is identical to setting the penetration depth to the snow depth.

SIV in our study does not include snow volume.

Page 24: Fig.1, what is the measurement/unit of the “Echo power” represented in the plots? It could be DB? Also, the plots could be wide, as the leading edge is extremely steep and it is hard to see if the retracking points are located at the 40% threshold.

The unit is dB. We will improve the information content of the figures and captions in revised document.

Figure 4, 5, 6. font size of the words are too small to see.

This is true and, with pleasure, we can conclude our responses with a promise that we shall include the font size in the revised manuscript. We do agree that too small fonts are a pain.