

Interactive comment on “Waveform analysis of airborne synthetic aperture radar altimeter over Arctic sea ice” by M. Zygmuntowska et al.

M. Zygmuntowska et al.

marta.zygmuntowska@nersc.no

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We would like to thank the second reviewer for the comments and suggestions which helped to improve the quality of our manuscript. Below we will address each concern in a point by point answer. Corrections of single words and typos are not mentioned here but all considered in the revised manuscript.

COMMENT: I feel that the paper could benefit from pointing a bit more towards the achievements and the role the results could play for future sea ice thickness retrieval in the Arctic.

ANSWER: The possibility to distinguish between different ice types and open water allows to improve the freeboard retrievals and the conversion into sea ice thickness

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where surface type dependent values for the sea ice density and snow load can be used. Today this can and is done by using large scale sea ice classification retrievals based on scatterometer or passive microwave retrievals. Our method has the benefit of not being dependent on other instruments and providing synchronous information about the surface type. The method has further the potential to improve the freeboard retrieval by developing a more accurate, surface dependent re-trackers. This could be done by using different fitting procedures to the waveforms depending on surface type. More studies however are needed to test this hypothesis. We added some information in the last paragraph of the discussion to point out the role our results could play for future sea ice thickness retrieval in the Arctic.

COMMENT: It would have been nice to see some numbers in the abstract. The same kind of applies to the conclusions.

ANSWER: We added some numbers in the abstract and conclusion to provide more detailed information.

COMMENT: In general, in the part here you give different levels of information for the different sensors: You talk about large-scale coverage for ICESat but don't give spatial resolution; you talk about coverage for ERS1/2 and Envisat and a relatively coarse resolution; you even give a footprint size for Cryosat. My suggestion would be that you provide the same level of information for all the 4 main sensors we are talking about here. If you don't want to write it in the text then you might want to use a table.

ANSWER: It is indeed correct that a different level of information is provided for CryoSat, IceSat and ERS. As the ASIRAS waveforms used in this study are comparable to CryoSat waveforms most informations is given about CryoSat. The coarse resolution of ERS and sparse temporal coverage of IceSat is mainly given for showing the improvement coming from CryoSat. The paragraph however has been revised accordingly to clarify this issue.

COMMENT: The CryoSat part for sure requires citation of the paper by Laxon et al.,

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2013, Geophys. Res. Lett. ANSWER: We added the reference for Laxon et al., 2013, Geophys. Res. Lett. , which has been published during the submission process.

COMMENT: P1218, first paragraph: It would help the understanding of the paper if you could illustrate the statements of this paragraph with a figure.

ANSWER: We understand the concern of the reviewer but believe that it is behind the scope of the paper to add more technical details about conventional altimeters. This is only mentioned to make clear that there is a substantial difference in the measuring technique and therefore in the waveform shape. It is not an essential information to understand our approach and results, therefore we suggest that citation of the appropriate papers will be sufficient for describing these technical information.

COMMENT: P1219: The long paragraph this page would surely benefit from such structuring. One way to do this could be to use a table into which you put the technical details of the ASIRAS instrument. You provide an along-track but no across-track resolution. I guess the spatial resolution is altitude independent? From Line 14 onwards you talk about supporting independent data of the same measurement campaigns. I can imagine that this can be stated a bit more clear in a separate paragraph. Line 17: Is "aircraft validation" the right term to use here? Line 19: The EM-bird measures the total ice+snow thickness. Line 21: a precise → an excellent

ANSWER: The paragraph has been restructured considering the suggestions. We divided it in two paragraphs, one dealing with the technical issues and the second with the validation and supporting data sets. We further added more detailed information about the ASIRAS sampling and footprint in the first paragraph as some information was misleading. ASIRAS operates with an antenna beam pattern of 10 degrees along track and 2.5 degrees across track. The footprint size depends on flight altitude but can be considered to be around 10mx50m at a flight altitude of 300m. Synthetic aperture radar technique is used to increase the resolution along track what results in a sampling frequency of 3 m.

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COMMENT: P1220: Here you refer to Figure 3. Are these theoretical values or are these results from the ASIRAS measurements?

ANSWER: These are values from ASIRAS. This information has been included in the caption of the figure to clarify this point.

COMMENT: Neither PP nor TeS are indicated in Figure 3. Would it be possible to mark them there as well?

ANSWER: We fully agree with the referee that it would be useful to have all 5 parameters included in the figure. The Pulse Peakiness which is missing in the figure is the ratio of the maximum power to the accumulated echo. The formula is given but we did not find a way to illustrate this in the plot. The same accounts for the Trailing Edge Slope.

COMMENT: P1221: L1-L8: I wonder whether it wouldn't make sense to give a few more details since at least to me it is not clear why the KS test is sensitive to differences in location and shape of the distribution function.

ANSWER: The KS-test makes no assumption about the distribution of the two data samples, but evaluates the distance between the empirical cumulative distribution function (cdf). The cdfs in turn are sensitive to differences in location and shape of the distribution function. The ks-test is not as widely used as other statistical test but it is still as standard procedure in many statistical tools and therefore well documented. We believe that it is behind the scope of our manuscript to describe the method in more detail.

COMMENT: P1222: L10/11: How valid is this assumption that the parameters are conditionally independent?

ANSWER: It is indeed a simplification to assume that the parameters are conditionally independent. Although the parameters are not fully independent, different waveform parameters are sensitive to different characteristics of the surface. The presented

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Bayesian method provides better results than other classification techniques, as e.g. a linear discriminant analysis (not shown in the manuscript). We therefore believe that the made simplification is justified.

COMMENT: P1222, L8: "e.g." Are these all parameters you have used? Maybe you can be more specific and give a table about which parameters you use in total and then direct the reader to a subset of these.

ANSWER: We revised the section accordingly and referred to 5 parameters because all of them were used in the analysis.

COMMENT: P1222, L9: I would add that you look for multiyear ice and first-year ice when you talk about the ice types.

ANSWER: This has been rephrased accordingly to clarify this point.

COMMENT: P1222, L17 ... Did you tell the reader how many single waveforms are used for the mean ones? How did you select at this stage what is first-year or multiyear ice? Did you use the classifiers?

ANSWER: The number of waveforms is given in table 1. To select the ice type, SAR images, visual pictures and available data description has been used as described in section 2.1.

COMMENT: P1223, Description and interpretation of Figure 5: I guess this section would benefit from starting with a more general description of what the figure shows before you step into the details. Maybe you then discuss the parameters in the order they appear in the figure? I would find it important to stress also, that using, e.g. PP one can perfectly well distinguish between multi year ice and leads.

ANSWER: In the beginning of the paragraph we added some short introduction what has been done in the analysis. The paragraph has also been revised for clarification. We added the information that one can very well distinguish between multi year ice and leads in paragraph 4.

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COMMENT: P1224, L1-2: Where can we see this statement? In Table 2? I guess so. Would you mind to tell which significance test you used and how you end up at the at this statement? How reasonable is it to average of a cumulative distribution which has long tails like the LeW for multi year ice????

ANSWER: We thank the reviewer for his question, as it helped to clarify this important issue.

In order to check if the average distributions are significantly different at a 5% level, KS-test was applied. This test was used for quantifying the distances between the cdfs presented in the table 2, and it also allows to perform the significant test. Analysis shows that for all 5 parameters we can reject the 0-hyphthesis that the two samples come from the same distribution at a significance level of 5 %.

In addition this result is confirmed by a Wilcoxon-Mann-Whitney-Test (but not mentioned in the manuscript). With that test we found that the medians are also significantly different at a significance level of 5 %.

At that we compared the average distributions for each class but not the averages of every distribution. Therefore when using KS-test the tails of the distribution are taking into account.

COMMENT: P1229, L7-9: I suggest to mention that this paper is about airborne radar altimeter data and not just about "signals". I would specify the sea ice types.

ANSWER: The concluding section has been revised accordingly.

COMMENT: P1235, caption Table 1: Were these Wide Swath Mode SAR images?

ANSWER: The Wide Swath image shows the area north od Alert. This information has been added to the caption.

COMMENT: P1237: Does the multiyear ice - first-year ice discrimination have to be separate from the lead - ice discrimination? What happens if we want to classify all

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three surface types at once.

ANSWER: Table shows that different parameters perform better for lead detection and the discrimination between first year ice and multi year ice. Combining both attempts results therefore in a lower classification rate of about 65 %, depending on method used. As stated by the reviewer himself it is further no problem to distinguish between leads and multi year ice. We therefore believe that the results as given in our manuscripts are sufficient and adding the combined result in the manuscript will not provide any practical information.

COMMENT: P1238: Figure 1: The annotation is cut at the left edge. The legend could be smaller. In the caption there is a typo: cases → Cases

ANSWER: It has been changed accordingly.

COMMENT: P1239: Figure 2: Is there a chance to know the size and location of the camera images? There is a typo in the caption: from the 1 May → from May 1.

ANSWER: The figure has been changed accordingly indicating now the position of the camera images on the SAR image.

COMMENT: L1240: Figure 3: Are LeW and TeW placed arbitrarily? Are these theoretical values or measured data? Please indicate so in the caption.

ANSWER: The waveform is a subset of the waveforms coming from first year ice as showed in Figure 4. LeW and TeW are not calculated but roughly placed for visualization. We believe that this is sufficient.

COMMENT: L1241: Figure 4, captions: The waveform → The waveforms ... andn type → types. What is a "power waveform"?

ANSWER: The waveform describes the power distribution, therefore it can be called power waveform. We rephrased this sloppy statement to be consistent in our jargon.

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Interactive comment on The Cryosphere Discuss., 7, 1215, 2013.

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