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# *Interactive comment on* "Utilisation of CryoSat-2 SAR altimeter in operational ice charting" *by* E. Rinne and M. Similä

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We thank the reviewer 1 for the work he/she has put into the comments. We find the comments positive and very helpful pointing out the shortcomings of our article. We plan to revise the paper to address the two main issues raised by the reviewer, as well as to include most of the minor suggestions made by the author. Detailed response to the reviewers comments is below. Reviewers comments are in italic immediately followed by our response.

**General comments:**

*The study investigate the feasibility of classifying sea ice types for ice charting in the Arctic using radar altimeter waveform characteristics when synthetic aperture radar*



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*data is not available. The authors have developed an automatic classification that is based on 4 parameters of CryoSat-2 near real-time data, however a training data set based on Russian ice charts is necessary to adapt the classification scheme for the seasonal cycle of the waveform characteristics. The classified sea ice types are open water, thin first year, first year and multi-year sea ice with mixed classification results in the study area. Open water, multi-year and first year ice seem to be reliably classified, though a notable ambiguity between deformed first year and multi-year sea ice remains. The target rate of thin first year ice in spring is rather poor.*

*The authors have set their primary goal at the application of radar altimeter data for operational services though the classification of sea ice surface types directly from radar waveforms though is also of interest in the field of climate research. It is not discussed if and how the classification scheme can be employed for the entire Arctic. It must be said though that the need of a training set for that region and the not very distinct differences in the waveform characteristics between different ice classes would make this task probably quite difficult. However most of the current CryoSat-2 based ice thickness processors employ a binary (first year or multi-year) classification scheme of ice from an external passive microwave dataset and surface type information of more classes and higher spatial resolution would be helpful. The study would therefore have a much broader impact if the authors would discuss a potential use of waveform-based sea ice type classification beyond ice charting. The choice of a manually classified ice charts as a benchmark for a waveform-based classification is an interesting and novel approach which seems to have more potential than has been exploited here.*

This is an encouraging comment from the reviewer. True, due to different densities of FYI and MYI, as well as the need to modulate the Warren snow climatology, some kind of ice classification scheme is required for the ice thickness processing – namely the conversion of freeboard to thickness.

The idea to use our approach as reviewer suggests has crossed our mind. However, we chose to leave it out from the manuscript for two main reasons:



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1. We decided to limit the scope of the manuscript to operational applications only to keep it focused.

2. As our approach requires the operational ice charts, we envisage that the best result might be obtained just by using the operational ice charts as the MY mask. This, actually, would be easy enough to implement in any CS2 thickness processor given that the Arctic wide ice charts are available. For gridded thickness products, we think that this simple solution would be good enough and we plan to propose that in the revised manuscript as a possible future study.

The reason 1 still stands and we do not intend to change the focus into a FYI/MYI detection study. Such a study was made by Marta Zygmuntowska in her thesis, and the results were not too promising. Heavily deformed FYI was often classified as MYI, which would be a problem for climate applications but not for operational use because most users will want to avoid heavily deformed FYI just like they want to avoid MYI.

Having said that, our study does prove that the CS2 waveform contains information about the sea ice type and that information could be utilised in the sea ice thickness processing. We still need auxilliary data, namely the ice charts, but especially products like the UCL NRT thickness product would most likely benefit from a MYI estimate derived from the waveform itself and few past ice charts using our methodology.

We will include text on the possible applications to the revised manuscript and suggest a follow up study where FYI/MYI classification will be derived using our methodology and applied in the CS2 SIT processing. Then we plan to actually do the work during 2016 as part of the EU funded H2020 / SPICES project.

*Though the manuscript is well-structured, I found it particular difficult to follow the method section containing the automatic classification scheme. Some key elements, such as a basic description of the k-NN classifier or how the distances of the feature vectors are actually used are missing. Some terms as distance metric or ties are just mentioned without further explanation or later reference in the manuscript. This all* *make it quite unclear what is actually done here. There are more examples in the detailed comments, but the authors should consider rewriting the method section and target an audience that not is not necessarily familiar with automatic classifications.*

This is a fair comment from the reviewer. The clarity of the method section for the classifier does not meet the standards of the TC. We have chosen to re-write the section before publication in the TC. The revision, at the time of writing these comments, has already been largely done.

*It is therefore the two points of discussing the impact of their findings for the prospect of sea-ice thickness retrieval and a better method description that need to be addressed before publication. There are a few more detailed comments and suggestions below.*

We shall address the two points. In short, the method section will be rewritten and the short discussion on the potential use of out methodology in the sea ice thickness retrieval will be added.

**Minor comments / Suggestions:**

*The authors use lead identification to exclude leads from the classification scheme. Later they use the term "open water" for the diffuse echoes that originate from areas without ice and a obviously a significant wave height as can be seen by the large leading edge width. Since sometimes "open water" is also used as synonym for lead in ice-covered areas, I would suggest using the term "open ocean" instead of "open water" throughout the manuscript.*

This is a very good suggestion. We tried to use "lead" when we meant leads in ice covered waters, but it seems some ambiguity remained in our use of words. We shall revise the paper to use "open ocean" and "leads" consistently in the final paper.

*It would be helpful to show the parameters for the two test periods in the same plot (with the exception of thick FYI). That could be used as indication how the waveform properties differ between November and March and why each period needs its own*



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*training dataset. Just from looking at the two plots I do not see a substantial difference between the histograms.*

This is true. The differences are quite small to see, but still have effect on the classification. We will plot the two test periods in same plots to make the differences between distributions in November and March more apparent.

*P4121 L9 The (pulse-limited) across track footprint of CryoSat-2 is 1650m (CryoSat footprints, Document: SAR-CRY2-TEN-6331)*

We thank the reviewer for the number and the reference. These will surely be mentioned in the revised final version.

*P4121 L26 A resolution of 2 km is quite close to the size of the CryoSat-2 footprint (see previous comment), therefore there might be some spillover between adjacent grid cells. Will this influence the k-NN classifier?*

In short, no.

In order to determine the ice type we extracted grids from the AARI ice maps of size 2 km. From the point of view the classification the crucial range in the CS-2 footprint is the along-track range ( 380 m). To smooth the speckle induced noise inherent in the waveform statistics we applied a running mean filter of length five for the statistics like PP (spatially covered range 1900 m). This mean PP value was assigned to the CS-2 waveform in the middle of the window. These smoothed statistics were then classified. Thus, due to us averaging over several measurements in this classification scheme, the potential spillovers will not influence the outcome.

*P4123 L20 The definition of the pulse peakiness here is based on 128 range bins. The latest version of CryoSat-2 SAR data is oversampled to 256 bins. Is this not the case for the SAR NRT data?*

The data we use in this paper is a NRT version of what was the “baseline B” version of Cryosat data. Thus the definition stands here. We will revise the data description to



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mention that we are using baseline B with 128 bins but the current version indeed has 256 range bins.

*P4124 L12 Same question is previous comment: Do the authors use 128 range bins or the oversampled 256 bins?*

See previous – we do use 128 bin version of the data.

*P4125 L7ff The authors should add a short description of the basic concept of a k-NN classifier since it is a crucial part of this study*

As noted earlier we will reorganise the classification Section 3. In the revised version of this paper, the presentation of the basic concepts and properties of the k-NN classifier are described in more detail.

*P4126 L1ff The description in this part is difficult to follow.*

This is true, and this part will be re-written during the revision.

*P4126 L6 What does "Ties are broken at random" mean?*

It means that when there is a point (a measurement) with equal number of neighbors in two (or more) different classes, the classification for that point (or measurement) will be chosen in random from these classes.

*P4126 L13ff What are the actual limits for the scaling (the same as the x-axis in figures 3 4)? Why has this choice been made and not the [0,1] interval range? Does proper metric mean that all 4 parameters must /will have an equal weight?*

The full range interval [0,2] corresponds the PP value range [0,40], LEW range [0,8], SSD range [0,50] and finally TTP range [0,0.18]. By looking at Figs. 3 and 4, these ranges seem to contain most of the variation.

For the interval [0,2] and not [0,1], we did not really give much thought on choosing it. It was coded in the processor early on and then it stayed there. As stated in the text –



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[0,1] or any other interval could had been used.

“Proper metric” is here a function that satisfies the conditions of a metric function. That is, it is always positive, symmetric, the distance from point A to B is 0 if and only if A=B and the triangle inequality stands. This does not imply that all parameters must have equal weights, only that the distance function is a well behaving mathematical construction.

*P4126 L14 But how is the distance between feature vectors used in the classification scheme?*

Once again, the original manuscript seems to have been hard to follow. We plan to include following text in the revised manuscript:

“The distance function (the Euclidean distance) is applied to calculate the closeness of two feature vectors in feature space (in other words, measurements). This has nothing to do with the spatial distance of the measurements. Spatially two neighboring points in feature space may be hundreds of kilometers apart spatially.”

*P4127 L2 Suggestion: Describe TPP as late tail to peak power and KF1 as early tail to peak power since their definition is essentially the same and only the indices of the tail bins differ*

This is a good suggestion and we will implement it in the revision.

*P4127 L23 Move the last sentence to the next paragraph. It reads as if the LEW > 14 is used for the removal of leads*

Another good suggestion. Will comply.

*P4128 L12 Is there a reason to smooth the feature space and not the waveforms?*

The waveforms are subject to speckle as any SAR based measurement. This induces noise also in the statistics calculated from the power of these echoes. Hence the statistics are computed from noisy measurements and are noisy themselves. We have chosen to smooth the noisy statistics to get rid of the speckle. Smoothing the waveforms, that is, somehow combining (stacking) five subsequent waveforms, would most likely work just as well too.

*P4128 L20 The authors should add a description how the classification is done*

Which we will in the revised manuscript.

*P4129 L11ff If the classifier takes the next 3-5 neighbors of one waveform that these will be almost certainly the neighboring waveform on the same track. So that basically means that 1) even smoothed parameters are to variable to be classified as a the same class and 2) the correlation between waveform parameters breaks down again with a distance of 3 or more waveform to each side? It would be good if the author could relate the k value to the spatial scale on the ground.*

It seems we failed to explain our classification scheme clearly and we are sorry for that. It is apparent here that the reviewer has misunderstood the classification methodology. The k neighbors refer to the closest k feature vectors for the specific feature vector which we want to classify. The closeness is measured with the distance function (here the Euclidean metric). The distance in feature space has nothing to do with the geographical distance. Spatially the closest feature vectors may be close or far away from the specific feature vector. Similarly, the closest neighbors in feature space may be also far away from each other. When we discussed about the value of k we were pondering how many close neighbors in the feature space we should take into account when the class label is determined.

*P4130 L6ff Also the incidence angles between SAR images (oblige) and CryoSat-2 radar altimetry (nadir) are not compatible*

This is true, but we are not quite sure what the reviewer means by this. This would be a relevant comment if we would be comparing for example backscattering coefficients from the two instruments but we are not.



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*P4131 L6 Add "following" before "five days test set"*

Yes. We will.

*P4132 L26ff For the very thin ice it is crucial to define the term open water. Very thin ice close the ice edge might be classified as open water if swell generates surface roughness. Without the surface roughness very thin ice might still be a specular target that might be identified as a lead and thus be removed from the classification process.*

This is true. Ice can be easily erroneously classified as a lead and removed from the processing if it returns a specular echo, but we do not see this as a problem. The surface roughness from swell that will result in a false open ocean classification can potentially be a larger problem, but for the application of supporting navigation is not crucial – very thin ice poses very little danger to ships.

*Can the authors check whether there are a higher levels of lead detections in the areas which are labeled as thin ice?*

We do see higher levels of lead detections in the thin ice areas compared to areas with thicker ice. About 10

*Also in November the young FYI has a significant misclassification as MYI. Would this be in areas that were ice covered by the end of the melting season?*

The November missclassifications of FYI as MYI mostly occur in the high latitudes (>80) and are therefore in the vicinity of the perennial ice pack. However, they were not ice covered at the end of melt season. The MYI ice in the AARI charts for November 2013 has a striking resemblance to the ice minimum pattern of 2013. Our classification sees much more MYI ice south of the ice edge during the minimum.

*P4133 L24ff Based on their interaction with the ice service, would the authors think that NRT ice thickness information would be at least helpful for ice charting?*

We do think it would be. Especially if it would be available in near real time. A continuation study should be to study CS-2 measured thicknesses and freeboards to auxiliary information in scales meaningful for tactical ice navigation. Such work is ongoing in the EU funded SPICES H2020 project, and we do hope to publish the results during 2016.

*Table 1 2 Add a description of the rows and columns (columns: AARI classifications?)*

These will be added in the revised version.

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