

General comment

This study analyses the potential of radar altimetry to detect the seasonal freeze and melt events as well as the ice thickness on the Ob River, Russia. The study employs the backscatter (σ^0) signal from Jason-2 and Jason-3 missions, as well as in situ observations from several gauging stations.

While the idea behind the study is clear and definitely shows a good potential of the radar altimetry backscatter to monitor river ice, the presentation of the methods and results lacks structure and scientific rigour. The quality of figures and captions is in my opinion poor. I also recommend to concise the paper by focusing on fewer aspects and removing redundant parts. I also insist on a professional English proofreading to simplify and smooth the style and improve the clarity. Please check the terminology: reflect vs scatter, bias vs difference vs delay, algorithm vs method vs approach, etc. Please also check the comparatives: you very often use “higher”, “more”, “less”, etc. without mentioning what do you compare it with.

Please find my comments below. There are both specific and more general ones, but I found it easier to comment the parts at their place.

Introduction:

In my opinion too long and needs concision. Think about subsections and narrow down your story from general introduction to your specific objectives. For example: The importance of river ice monitoring → remote sensing observations so far → altimetry principles and observations of fresh ice (1-phenology, 2-ice thickness) → Jason mission → knowledge gap → your objectives.

49-50: I think you show with your own study that the word “excellent” is a little bit of a stretch.

51: please specify: you mean here the temporal resolution and not the frequency of the EM wave, correct?

61: “Active sensors operating in the microwave region are weather independent and provide higher spatial resolution” – higher than what? What about high- and medium-resolution optical sensors? Please include a sentence or two for the consistency.

63: to my knowledge, “largely” is an exaggeration for such studies.

75: please explain what means “water state and regime”?

74-79: there are repetitions, please compact

81, 82: what are the “materials”?

83: please specify “reflected” or “scattered”?

84-101: I propose not to go deep into the SAR studies, as they are not very relevant to your study. Instead, formulate briefly the main principles of the altimetry, how the data are collected, what are the data obtained (backscatter, waveform, what else?)

You can also combine some of the information with the paragraph 54-79.

97: Higher than what?

98-99: is the penetration depth important here considering that the typical ice thickness < 2 m? Would C-band have insufficient penetration? I would focus on the properties of Jason mission later when you describe it for your study.

103: you haven't mentioned before, that the altimetry missions are accompanied by radiometers

103-112: is it only about resolution or the different nature of measurements plays a role too?

113-117: is it already a description of the method you are using?

118-132: this reads rather specific and too long. Please consider revising, shortening or moving to the Methods section

132-142: this part is a presentation of your own results and should not appear in the Introduction

143-156: this is a place for your objectives, please state them instead of listing the sections

151: please introduce and explain what is a virtual station before

2. Regional setup

There is not even one reference to all the information you provide for your study area. Please provide them.

Please work on the study area figure. Make it colorful. There is no way to understand where is the study area on the globe, especially in black and white version. Is it topography or is it an optical imagery? The scale of the globe is too coarse and of the zoom-in is too fine. The zoom-in area lacks geographical coordinates and the tracks are strangely projected. The circles (gauging stations) are invisible. Please think about the reader who has no idea about your research.

173: please show these cities on the map.

175-205: If this is part of your results, please move it to the corresponding section. You also introduce your in situ data only later.

195-199: please show and explain the trends, I do not see any.

Figure 2: please improve the quality of the figure. Is that mean on figure a)? why only three stations of five are used?

3.1 Altimetry

Please provide more information on the data selection: tracks, cycles, virtual stations, repeat overpass etc.

231-233: please provide more information on how did you extracted the data via portal (programs used, codes?) and how did you use Landsat images for the selection. Is it a manual / visual selection? What exactly are the track numbers in relation to cycle and pass numbers?

3.2 Optical imagery

235-243: I do not think you need to describe the optical imagery in a separate data section. The first purpose you already mentioned in the previous section. The second purpose is not represented later in the paper substantial enough. You can describe the images in place.

I think the radiometric measurements deserve to be described in a separate subsection.

Please explain what do you refer to as an altimetric measurement, i.e. you talk about a precise selection over the river channel but at the same time mention multiple times that the signal is contaminated by the surrounding land. I encountered later the 400 m band oscillation – please refer to it early enough.

3.3 In situ data

254-255: please clarify what is measured daily and what is measured 3-6 times per month.

256: do they drill a new hole every time for a new measurement?

How do you credit the data from gauging stations? Are they publicly available?

4. Methods

4.1 This does not look like methods to me. You describe the environmental processes and the response of altimetric backscatter on them. Create a separate (sub-)section and provide references to all the processes you describe. Exclude your own results and move them to the Results section.

I might disagree that the presence of ice increases the specularity. The ice-water interface should be rough, shouldn't it?

Mention the difference between the nadir-looking altimeter and side-looking SAR instruments (i.e. low and high backscatter from rough and smooth surfaces).

Figure 3: This figure would be more informative if you show a mean backscatter with the range of values across all the stations for one typical year. Then you would guide the reader through the seasonal evolution of backscatter and attribute the backscatter change to environmental processes. Adding the in situ dates of freeze up and melt begin/end onto figure would help. The plot in its current version does not add any value in my opinion.

304-305: I am not sure that wet snow leads to an increase of the backscatter. To my understanding, wet snow attenuates the signal stronger than the dry snow. Please provide a proof.

312-313: the sentence is not clear.

314-315: I do not agree that the waves are increasing with the water level. Should depend on the wind?

319: Provide more specific title for the section

Was this algorithm ever applied already or it is brand new?

320: referring to an example figure as described above would help to follow.

320: not sure about the word "annual" in this context

320: how do you define a peak?

321-322: "In the case of a multi-peaky recession limb, this peak should be of order of spring and summer peaks". Why? What is spring and summer peaks?

322: what is recession limb?

322: "If the selection of peak is not straight forward..." – how does the algorithm select a peak?

324: Explain why and how do use the dTb and add dTb on the figure described above.

326: why exactly t-1, t+2? Why 2K? Can you refer to previous studies or explain this choice?

Please provide a conceptual scheme for the automated algorithm.

351-360: if you do not use this approach in the end, I do not see a reason to include it in the paper. Or “guided over river ice by the main waveform peak” means that you use this information? Please clarify.

You never refer to the Fig. 5b. The information on a) and b) seems to me redundant. Is a) just one example? Why did you choose only two virtual stations on b)? Why not to include all gauging stations? Improve the quality of the figures, avoid work-in-progress axis titles and legend entries.

388: how did you create a virtual station? Did you use the same stations for the dates of ice freeze-up and ice break extraction?

390: what is “ice thickness relations”?

391: by “extrapolated” you mean “applied”?

391: what is “other “main set””? the rest 40 stations?

393: 2) not clear what do you correlate with what

395: the scheme needs to explain better what are you doing. What do white and grey color mean? What are the grey outlined circles?

Results:

Maybe it would make sense to make subsections and give them titles. It is not easy to understand when the topic is suddenly changing. For example, **algorithm evaluation**, **interannual variability**, **spatial variability**, etc...

400-403: this paragraph seems redundant to what you already described in the Methods.

5.1 Ice phenology

Please start with an accurate description of your results.

405-408: this seems to me a repetition of your methods section, at the same time rather a hypothesis of what you think is captured by the altimetric measurements.

407: would open river water always appear rougher than the young ice? Even if the flow is calm and there is no wind?

408: decrease compared to open water?

411: I think “bias” is not correct term for what you describe since bias has a direction. Difference would do better?

411: “accuracy for Jason” – not for the altimeter but for your algorithm, for the date extraction?

411: how many retrievals are there? 8 stations by 12 years? 48 stations?

413: what is close to zero and if it is not exact how did you end up with 56%?

417: less accurate than what?

491: what results and what do you refer to here?

424: better than what? Do you mean the algorithm or manual approach?

426-428: what means "least" here and what do 54% and 67% refer to?

430: what do you mean by outliers? Please explain. Is it possible to adapt the algorithm? What about radiometric measurements? Do they not help? Can the manual peak extraction be affected if the person knows in advance the true date of freeze up and melt from the in situ measurements?

433: melting **and freezing** before 10 April and after 10 June? How did you define these dates?

Figure 7: please use the total number instead of norm pdf. Please mark the 90% cases on the graph. How do you explain

- Bimodality and bias towards earlier freeze up of the automatic algorithm for freeze up? Do I understand correctly that negative values correspond to the earlier date?
- Bias towards the later melt start for both automatic and manual approach?
- Poor results for the melt end for both approaches, especially for the manual approach?

436: as mentioned, this is generally not a bias.

437: why 11 stations? You mentioned 48 in the text. Why not to include all of them?

438: I thought that training set applies to ice thickness retrieval? Why do you need a training set for the ice dates?

439: how do you evaluate that? How do you define what is a good sensitivity? I think you need to find a rigid approach to evaluate your algorithm performance. Maybe you do not even need to go on with the automatic algorithm in describing multiyear variability and spatial variability? You can choose manual and show the results only for it as it is clearly better.

440: not the altimeter but your algorithm?

441: what do you mean by "noisy"? Noisier than what?

442: "Nevertheless, a clear coherence exists between the corresponding time series". Please clarify this sentence. What do you mean by coherence, what are the corresponding time series, and why is it clear. Not clear to me.

439-445. Please find more consistent and smooth way to describe your results, than by picking some years and saying that some events are noticeable.

Why on Fig. 9 you present the different events (melt start and melt end) AND different approaches (manual and automatic)? Please use the same approach for consistency.

446: why important?

447: Why Salekhard station is not included from the very beginning? "Adding" to where?

Describe this gradient, i.e. earlier freeze up at the northern stations? If you talk about trends, provide the parameters, i.e. days per degree (or km).

448: average what? Why "calculated"? Are you talking about the algorithm?

449-451: either show what you mean or remove. Very difficult to follow. What years, what half?

452: the same comment as before, please describe these gradients more detailed.

452-453: what do you mean by “gradient in the order of 20 days”? What is denominator of the gradient? Km?

454: the same here.

Figure 8: why do you use median for the altimetric data and mean for the gauging stations?

Please use legend to display the information in the caption, it is very difficult to follow.

458: does it mean 4 gauging stations average? Why 20 virtual stations? How did you decide which ones to include?

Figure 9: as already mentioned, make it consistent with the approaches. Comments for Fig. 8 applies here as well.

Figure 10: what is the x-axis? Please use more reader-friendly labels. Use figure titles in addition to a,b,c. Why do you show manual approach for a and b and the automatic one for c? Please be consistent. Please indicate stations on the red line. Use legend to explain the lines and shaded areas.

474: what do you mean by “different years”?

479-500: this whole section is a little hard to follow. How did you select the shown years? How certain you can be with the algorithm results? What about in situ data? I am not sure that the way of presenting those results as in Fig. 11 is optimal. Would it be possible to use mean values for the entire period of observations instead of only three years?

486-487: “This is shown clearly on a Sentinel-2 optical image...” I do not see anything clearly on the Sentinel image. Please use color version, and mark on the image what is what (land, ice, water, main channel, narrow channels, etc). The same comment applies to the Fig. 12b.

489: branches, not brunches

489-491: Please show the image. If there is a polynya until March, does it mean it is not freezing at all during some years?

492: “between the branches” – do you mean main and secondary branches?

494-496: “At the beginning of ice degradation local morphological controls only play a small role (Figure 11b). Their role amplifies during mechanical break-up, which is better captured by our automated algorithm (Figure 11c).”. How do Figures 11b and 11c illustrate both statements?

497: uncertainty in what?

497: higher than what?

500: please explain Fig. 12b in more details and support the statement.

5.2 Ice thickness

Would it make sense to show the Fig. 5b here? To support the equation 1?

501: what means different gauging stations? All of them? Some of them?

501-503: how do you come up with 9 runs? Please explain the approach more detailed. How to read Table 2? How did you sort rows in the Table 2? Why there are two Pitlar, two Gorki, and two Muzhi entries? Why did you decide to work with an individual relationship for each station and not with one universal relationship? How would Fig. 5b look if you include all the gauging stations? What do

the correlation coefficients and RMSE describe? The relationship between backscatter and ice thickness? Then RMSE should be not in m but m per dB? Why correlation coefficient and not coefficient of determination, especially considering that the relationship is not linear? Or R and RMSE describe the relationship between in situ and altimetry ice thicknesses?

509-510: How do I see on the Fig. 13 that those stations are northern? I'm confused here, I thought that the stations 138 and 161 are used in the training set? Please include all the stations in the Fig. 13 and use gradient color scale for the timing of measurements. The same for the spatial distribution of the stations – maybe different point style?

Fig. 11. Please consider revising the Figure as already mentioned. It should be in color, bigger in size and better resolved, use different line colors and styles (if you keep individual years). In the left part of the graphs, especially on c) nothing is visible. Explain x-axis, what is Tr187? Give the direction of the north. An additional map with the location of the shown stations would be useful here.

Fig.12. Please see the comments before. What band do you use or is it a color composite? Also please include coordinates, scale. Please put the labels on the in situ and virtual stations. What is the difference between open circles and squares for the virtual stations?

540-542: where could I see it myself? In the table 2? Then please organize the Table in a clearer way.

Table 2: please organize it in a more understandable way and provide more explanations on how to read it.

555-608: Please include these sections into the Results. This is clearly a continuation of your results, and not discussion.

557: please indicate which parameters did you use, there are many different ones.

562: please include a short explanation how did you choose the window size

Fig. 13: please see comments to this figure above.

569: please change the word “analog”, it is unclear what you mean.

569-576: I think it would make sense to move this paragraph to the beginning of the section, and to describe the ice thickness product after that. Do I understand correctly that you use the second approach to create the ice thickness product?

571: why only four stations if you have five? Please mark on Fig. 1 the clusters of virtual stations attributed to the in situ stations based on their proximity.

571-573: please reformulate sentence, it is unclear. What is main VS? What is time shift?

573: “The performance of the both approaches was evaluated at 11 virtual stations nearest to the location of the gauging stations”. Now I am again confused. These 11 are in the training set? But why?

574-575: how can I see the results of the first approach?

584: “The interannual variability in maximum ice thickness retrieved from altimetric measurements at many virtual stations indicates a clear decrease from 2008 to 2012.” Is this something shown in Fig. 15? Then refer to the figure 15 right there. What means many? Why did you include only 2 of in

situ and 2 of virtual stations in the Figure? Could you show a plot similar to the Fig. 8-9,, which would include all of the stations?

592: please explain what is ridging flag

Figure 14: I suggest to combine the yearly plots into one multiyear plot, and add some vertical lines to mark the timing - to show the interannual variability. Please indicate the north-south direction, add unit on the color scale. Please describe results shown in Figure 14 in the text. Right now, you only mention that you created the product. What is the area we see in this product? What is the extent of it?

600: more disagreement than what? Is this statement shown in Fig. 15? Refer to the Figure.

601: "This does not strongly contradict expectations as for most virtual stations this disagreement lies within estimated RMSE values (0.07-0.18 m)." . Please reformulate and explain what you mean. I cannot follow logics here.

602: "Besides the reasons noted earlier..." – where, what do you refer to?

603: why there is a degradation in the in situ time series? Lower representativeness – lower than what?

604-608: Please explain what are you trying to point out here, it is not clear.

609-610: how do you demonstrate that they are accurate enough?

611-612: do you present this result? Is it something that I can see in Fig. 15?

614: how could the date of first consolidated ice be detected and why then you did not use this approach?

614-616: please reformulate the sentence to support your suggestion

618-623: is this something recommended in the previous studies (then please include references) or this is your own hypothesis?

Figure 15: please see above the comments to this Figure. Why there are two plots for the b)?

The Discussion section has only one subsection which actually discusses the results in the context of the physics of the radar signal return and potential errors related to that. Another subsection considers a study case of an ice road and applies the developed methods to this study case, which again reads more like results. I was missing a discussion of your results in the context of the relevant studies (which are not only methodologically relevant).

I have an impression that the whole section 6.2 would benefit from shortening and compacting. Some of the discussed issues are mere speculations and raise more questions than give answers, and some other points are not really relevant to your study (e.g. layering as you pointed out in 682).

646: "...grows gradually from January until April." – is there no wind redistribution?

649: Please include the figure 4 here if needed

652-653: please explain better what you mean with the ratios and 40%, and 25%.

660: you mean the power relationship becomes weaker? What correlation do you mean?

665: "Further congelation of inter-floes volume as well as ice growth lead to leveling of the ice lower boundary.". Can you support this hypothesis? Do your observations of the decreasing backscatter (669-671) contradict this statement?

668: please explain what do you mean by the first two cycles

669: please explain what do you mean by the note "due to the waveform peak power"?

703: I do not think that we have seen any clear tendencies in the referred section.

705: can changes be robust?

706-707: please provide a reference for this statement

708-709: how do you define an outlier? These are the valid observations, right?

712-721: this part sounds like an outlook to me and should belong to the Conclusions section.

746: please expand on what you mean by a delay. Delay to what? Is it the best term in this case? Please check it further in the text as well.

746-748: this sentence is hard to follow. Exception from what? Why this is an exception? Where is the Salekhard river reach?

751, 754: what is circulation?

754: earlier than what?

762: perhaps, "could be adjusted" instead of "has to be adjusted"?

760-771: this also sounds like an outlook and can be combined with 712-721

Figure 16: You never mention Figure 16b in the text.

778-780: please reformulate the sentence: what is the second record of melt onset?

780: correlations between which dates? Is the information on Fig. 17a similar to the Fig. 16b?

780-783: please explain better what are you doing here. How did you produce a forecast? Is forecast is just the melt onset day derived from altimetry (whatever the second record means)? This is a bit confusing.

789-794: again outlook, can be combined with previous ones and moved to Conclusions

Figure 17: Please explain what ROI are you referring to? In Fig. b) please correct the label of y-axis – the current label is not clear – what is ice road closing delay?

Conclusions: please use this section not only for a dry summary of the results but also for a more general wrap-up (reinforcing the problem importance, filling the knowledge gap, outlook and recommendations etc).