Authors' response to the Referee 1 comments on tc-2023-142: Updated Arctic melt pond fraction dataset and trends 2002 – 2023 using ENVISAT and Sentinel-3 remote sensing data

by L. Istomina et al.

The authors thank the reviewer for their valuable comments. We would like to highlight two points we felt were important upon evaluation of the revised manuscript:

1. Many of the reviewer's comments seem to point toward insufficient clarity of the text. We made sure to carefully check the text once again to make sure that all important information, like references to tables, figures, etc, is explicitly included and cannot be missed. We believe that the revised text will therefore be easier to follow.
2. The comments regarding the influence of open water onto the MPD retrieval were addressed in the parallel manuscript by Niehaus et al 2024, which was submitted in The Cryosphere later than the present manuscript, and for this reason was not referred to in the original text, but passed the review earlier and is now published. We now include this important reference and hope that now the present manuscript appears in the correct context, namely, the delivery of the long-term dataset and discussion on the quality of the two-surface (as opposed to three-surface) melt pond fraction retrieval.

In the following text, we address the comments of the reviewer 1 point by point, whereas the reviewer comment is highlighted with bold face font, and the authors' response follows in normal font.

I suggest dividing the results and discussion sections for better organization. Discussions are currently scattered throughout the paper.

We have carefully reconsidered the current organization of the manuscript and concluded that, given the large thematic spread of the aspects discussed in Sections 3.1, 3.2, 4.1 and 4.2, it would not be beneficial to separate the discussions from the section where the topic is introduced. The current paper presentation aims at highlighting the limitations of the MPD retrieval, so that the dataset users have no false understanding regarding its quality. In this context, we feel that separating the discussion into one section would 1) hinder the comprehensive understanding of each of the presented aspects, 2) render the discussion section – being now a mix of separate aspects – largely unusable and hard to follow. That's why we have decided to leave the manuscript structure unchanged, and instead take care to check the language for clarity to ensure better understanding.

I think there are spectral differences between MERIS and OLCI. The sensitive analysis should be done on the same targets (i.e., sea ice, melt pond, lead, and ocean) between MERIS and OLCI. Although MERIS and OLCI don't have same temporal period, similar targets can be used. This analysis will show a good example applying the algorithm for old satellite to a successor satellite.

The spectral resolution of the MERIS and OLCI sensors is summarized in Table 1. While some channels indeed differ, the 9 channels that are used for the MPD retrieval are exactly the same, so we do not expect MPF discrepancies stemming from the spectral resolution issue. As for the intercomparison of MERIS and OLCI on selected targets of given surface types: as the data gap between MERIS data (summer 2011) and OLCI data (summer 2017) is 5 years long, there is no possibility to select exactly the same surface types at a 300m spatial resolution. Should the surface selection be imperfect, any resulting MPF discrepancy cannot be exclusively attributed to the algorithm performance but rather to the difference in the MERIS and OLCI surface type. Thus, the authors refrain from such a comparison.

P4, L118: Multiple satellite have been used for their purpose, but it is hard to follow. It would be good to add a table summarizing satellites used in this paper. Furthermore, a flowchart of this paper would enhance clarity.

The sensors used in this paper have been summarized in Tables 1 and 2. We will add the reference to the Table 1 also in L. 119 to enhance clarity. Table 2 is already referred to in the original version of the text.

P5, L146: In terms of cloud screening, cloud shadows are appeared on the sea ice surface depending on angles. Please describe the cloud shadow removal process if authors did.

The snow/ice flag approach, described in Istomina et al., 2010 and used as a reference cloud mask in the presented approach, is based on locating the spectral behavior of snow and ice surfaces as appearing in the Arctic and screening out all other surfaces. This means, that clouds and cloud shadows are screened out automatically as they do not present the spectral signature of snow and ice. The corresponding clarification has been added to the text.

Figure3 c: Please explain why sentinel-3 OLCI MPF produces 1 comparing to different sentinel-2 MSI MPF.

This explanation is already contained in the original text on P.9, L. 236-239, right after the Figure 3c was referred to. This MPD behavior is caused by the spectral ambiguity of the TOA reflectances shown in Fig. 7, so that two solution families representing the same TOA reflectances equally well are used interchangeably, depending on whether the transport scattering coefficient is limiting the sea ice properties or not. This case highlights the problem of the spectral ambiguity, where ONE set of measured TOA reflectances corresponds to MANY different subpixel fractions of different surface types. Corresponding clarification will be added into the text.

P8, L225: Please justify why the authors select these two cases. I think there are good cases in the 50 scenes. In the 50 scenes, some cases (i.e., leads and small open water) highly affect melt pond fraction showing diverse spectral behavior. Please add more diverse cases.

The selection of the two cases presented in Fig. 2 and 4 stems from the need to illustrate the MPD performance on the entire span of MPF range, from low to very high MPFs of 100%, possibly showing the spectral ambiguity issue without the open water influence, being the simplest case. As can be seen from the text corresponding to Figure 2-5 on PP 8-10, a multitude of factors can affect the algorithm performance. The authors are convinced that the potential data users need to be aware of these details. Regarding the effect of the open water on the MPF: this effect has been illustrated on the entire dataset of 50 scenes in Fig. 6a and even in more detail, with the suggestion on how to improve the performance in the presence of open water, in Niehaus et al., 2024 (see preface to this author response above). The corresponding reference and clarification will be added in the next version of the text.

Figure5 c: Please explain why sentinel-3 OLCI MPF produces 1 comparing to different sentinel-2 MSI MPF.

Here again, like in the case of earlier mentioned Fig. 3c, two solution families are present due to spectral ambiguity issue, whereas the split between them is caused by the reached boundary criterium on the ice scattering coefficient. The corresponding clarification will be added to the text.

P13, L330: I don't get it how this conclusion was reached.

Due to the ambiguity of the spectral TOA reflectance measured by all moderate resolution spectroradiometers like MERIS, MODIS, OLCI, etc (shown in Fig. 7), the three-surface MPF retrieval will not be able to distinguish whether all 3 surfaces are present, and if, which of the surfaces are present. This is due to the fact, that the TOA measured signal is spectrally ambiguous, meaning, a multitude of surface combinations and fractions give *same* TOA reflectance, making the inverse retrieval from this

TOA reflectances to derive the subpixel surface fractions inaccurate. This means that, given no additional external information is applied, the 3-surface MPF retrieval will be always able to find a suitable combination of 3 surfaces even when only 2 surfaces are present, as the spectral TOA reflectance it obtains from the satellite data does not constrain the surface mixture confidently. Which of this many combinations it then mostly finds, depends on the training and calibration of the algorithm, but since the limited training data presents limited surface conditions, there will always be conditions which the 3-surface MPF retrieval without additional data is not able to retrieve correctly.

Niehaus et al., 2024, presents the 3-surface retrieval with additional data and addresses this issue in detail. This reference and a corresponding clarification have been added to the text.

P13, L357: Open water influence the retrieval of melt pond fraction. The leads and small open water surrounded by sea ice are also influence the retrieval of melt pond fraction. It would be good to mention this.

Indeed, here leads and other open water areas within sea ice are meant. Corresponding clarification will be added into the text.

P14: While there is no map in the figure 9, the part 4 describes geographical information.

Indeed, Figure 9 addresses hemispheric averages and investigates the uniformity of the dataset between the two sensors MERIS and OLCI. The geographical distribution of the melt pond fraction trend is shown in Fig. 10.

P17, 434-435: If sea ice type shift have progressed, it would be good to add melt onset data for this description.

The retrieval of the sea ice type in summer is not a trivial task, as passive microwave ice type retrievals are hindered by open water and melt pond presence. In this context, it is out of scope of the current manuscript to perform accurate ice type or melt onset retrievals to use as an evidence for the observed melt pond fraction trend behavior, where the melt onset data would be of course of importance. Nevertheless, we felt it was important to mention ice type shift as a potential reason already in this manuscript, to establish context for the future studies. Corresponding clarification will be added into the manuscript.

Figure 11: Please demonstrate more about figure 11 in the paper.

Figure 11 is explained on P. 15 L 389 onwards. Indeed, it can be referred more often in the Section 4.1, to point out areas where the MPF trend is significant. This will be done in the next version of the paper.

4.2: The trend of Arctic sea ice concentration and thickness is steeper than long-term melt pond trend due to sea ice type shift above described?

As remote sensing passive microwave sea ice concentration products are unreliable in summer due to the presence of open melt ponds and wet sea ice surface, there is currently no way to prove this fact at a global Actic scale. However, we felt it was important to mention that the thinning of the Arctic sea ice as shown by Sumata et al., 2023; Haas et al., 2008; can potentially cause negative sea ice concentration trend which might affect the MPF trends presented here.

Figure 12: It is difficult to see the many weekly trends. It would be good to show monthly trend instead of weekly with error bars.

The advantage of the daily melt pond fraction product as presented in this paper, in contrast to e.g. MODIS 8-day reflectance product which is also sometimes used for the MPF detection, is the high temporal resolution which is beneficial for both climate model input as well as independent melt pond

studies. While the authors agree that the presented Figure 12 cannot be easily compared to the above mentioned 8-day composites or monthly averages presented in other studies, it is out of scope of this manuscript to perform such comparisons, which will be done in the future. Other than easy comparisons to other MPF products, the authors could not see any advantage of giving up the high temporal resolution in this figure and decided to keep the weekly trends as presented in the original manuscript.

Technical corrections

P9, L239: Figure 2a to Figure 3a?

The reviewer probably suspects a typo here, but no, indeed, the Figure 2a lower square is meant as correctly written in the original version of the text.

P9, L242: level means level ice?

P9 L242 reads: “Here, the sea ice surface is not as level: high fraction of ridges… can be observed”. In this sense, yes, it means the sea ice surface is not level and contains relief in form of ridges. The word “level” will be exchanged by “smooth” in the next version of the manuscript for more clarity.

Figure7: IC means SIC? What stands for OWF?

OWF stands for open water fraction and was defined on P11, before Fig. 7. IC stands for ice concentration and will be specified in the next version of the text.

P13, L352: Please add this reference Rostosky et al., (2023) below.

Here the reference to Rostosky and Spreen, 2023 is meant. This will be corrected in the next version of the paper.

P14, L367: data 2012-2016 not available should be mentioned.

Indeed, it can be mentioned also here, and will be added in the next version of the manuscript.

Figure9: Please add some information about the thickness of blue and red color

The Fig. 9 shows standard violin plots, where the histogram of the data is shown with the color thickness. The corresponding clarification will be added to the next version of the manuscript.