Response to Review

Dear Editors and Reviewers:

We would like to thank the reviewer for the detailed and helpful comments, suggestions, and careful checking. We have addressed the comments on a point-by-point basis and implemented the proposed changes in the manuscript. The comments from the reviewer are in black while our responses are highlighted in blue. We also provide a track-change version together with the revised paper.

The authors have presented detailed, proper answers to most of my comments to the original version of the paper, and made corresponding changes and additions to the paper. I think that the paper has improved considerably. Below I have some comments for your consideration for further paper improvements.

We appreciate the time and effort you dedicated to our manuscript. The enhancement of the paper would not have been possible without your valuable suggestions.

From first review: "I think the study set up with data acquisitions and data processing is rather well conducted, and the TIS lead detection method could be generally applicable for a large number of TIS images, but I think it is not sure as it is based on small amount of data. Further, I don't think it is meaningful to develop lead detection methods for the three TIS bands separately, and compare the results. You should develop the best possible lead detection algorithm for the TIS data (having as input all bands or just two/one), and only present this in the paper. In the following I have also some other major comments to the papers and suggestions for possible improvements. These are followed by miscellaneous specific ones."

Response: Thanks for your valuable comment. We agree that it would be better to apply the most appropriate thermal infrared band for lead detection. However, until the cross-comparison experiments were carried out, we found each band has its advantage on ice leads detection.

Taken together, it is necessary to carry out a comprehensive application demonstration of the new on-board sensor. We applied the same method to the three bands of SDGSAT-1 TIS to extract leads, and further conducted cross-comparison to determine their detection performance. The cross- comparison results suggest it is beneficial to combine the lead detection results of the TIS three bands.

I can understand your view here, and you compared lead maps by the three bands and also combine them together in Section 4.3 for comparison the MODIS maps, but it still would be nice see a case study where all three bands, or at least two bands, are used together for the lead detection, and whether this brings any improvements.

Thank you for your suggestion. The point you described is indeed very interesting. However, as the reviewer has mentioned, this study only presents a limited number of case studies, so it may not yet be sufficient to give very convincing results in terms of exploring how the three thermal infrared bands can (or should) be combined for lead detection. As a study applying new satellite data, our main concern here is whether the lead detection methods widely used by previous studies based on thermal infrared data (Willmes and Heinemann, 2015a; Hoffman et al., 2019; Qu et al., 2021) are applicable to SDGSAT-1 TIS data. Our results show that while the temperature anomaly method can segment leads, additional step is needed to filter the sea ice surface temperature variations at high resolution.

As for the use of two or three bands for lead detection, in fact, we are currently exploring sea ice surface temperature retrieval methods based on SDGSAT-1 TIS, which involve the use of different thermal infrared bands such as split-window using the B2 and B3 or triple split-window using the B1, B2 and B3. This approach has the potential to lead to improvements in the further sea ice lead detection. However, regardless of the specific multi-band combination or subsequent lead detection, it would require the development of new methods (e.g., reconsidering appropriate temperature thresholds), which is beyond the scope of this study.

When more SDGSAT-1 data becomes available in the future, we will try to explore the interesting question you have raised. We mentioned this in the appropriate place in Section 6:

"We therefore recommend using the combined results of the leads detected from the three TIS bands and also intend to further explore the adaptability of combining different thermal infrared bands and their potential for improved lead detection in the future.".

The absolute radiometric calibration evaluation by Hu et al. (2022) suggested that the average temperature bias of SDGSAT-1 TIS reached 0.661 K, 1.081 K and 0.426 K for B1, B2 and B3, respectively. This suggests that the B3 band has the best radiometric calibration accuracy. However, B2 and B3 bands are more affected by the strip noise than the B1 band. B1 band is a less common thermal infrared channel with colder temperatures than the other two split-window channels (B2 and B3 bands) due to the absorption effect of ozone However, we do find that using the TIS B1 band can obtain more small leads in the presence of interference in B2 and B3 data.

Not all this information is in revised Section 2.1, e.g., band-wise accuracy

We have added the accuracy of the TIS three bands into Section 2.1:

"…the analysis shows that the accuracy of the radiometric measurement is better than 0.661 K, 1.081 K and 0.426 K for B1, B2 and B3 bands (Hu Y. et al., 2022)"

Table 1 on currently available lead detection datasets is very good addition to the paper.

You have added some references on previous lead studies which I suggested to the paper, and omitted those which were not relevant. I agree with your decisions.

Thanks for your comment.

On automated SAR lead detection:

Therefore, the automated lead detection algorithm may not be adapted to the scenario we have shown here. In contrast, it is more appropriate to analyze the differences between HH and HV data directly, so we have performed a false-color composite using the dual-polarized data.

Yes, I can agree with this. You could explain in the paper why automatic methods were not applied.

We have carefully clarified this point in Section 5.2.:

"Murashkin and Spreen (2018) developed an automated S1 lead detection algorithm. It should be noted, however, that this algorithm may have limited applicability for complex scenarios that involve a potential transition zone between thin ice and seawater. In contrast, the use of quantitative backscatter data obtained from dual-polarized S1 images has been found to offer improved distinguishability."

Response: In accordance with your suggestions, we amended the data presentation and pre-processing sections (please refer to the revised version if the editor decides the manuscript can be revised). We would like to answer your questions about the TIS data here (and have added these details where appropriate in the revised manuscript).

I think Section 2 is now much better with more information on the TIS data.

The article has been enhanced thanks to the constructive comments provided by the reviewers. We thank the reviewers for their contributions.

For convenient use of the TIS data, the ground segment crops the original TIS data to 300 km in the along-track dimension.

TIS B1 band is a wide channel with a wavelength of 8.0-10.5 μm. It is mainly used in combination with the B2 (10.3-11.3 μm) and B3 (11.5-12.5 μm) bands to obtain a better accuracy in land surface temperature retrieval based on the three-channel split-window algorithm (Liu et al., 2021; Hu et al., 2022).

The quantization bit of the TIS is 12 bit. The TIS radiometric measurement is better than 0.42 K for the three bands, which satisfies the preflight requirements (≤1 K)

Please add these to Section 2.1.

Thanks for the comments. We have added these to the corresponding paragraphs in Section 2.2:

"…with a resolution of 30 m in a swath of 300 km (and the ground segment crops the original TIS data to 300 km in the along-track dimension for convenient use)"

"As a wide channel with a wavelength of 8.0-10.5 μm, the B1 band is commonly used in conjunction with the B2 and B3 bands with the aim of improving the precision of land surface temperature retrieval based on the three-channel split-window algorithm (Liu et al., 2021; Hu Z. et al., 2022)."

"Quantization bit: 12 bit" in Table 2 in the manuscript.

There are currently no TIS-based surface temperature products or cloud mask products available, all of which are under development.

This is very important information and must be added to Section

This has been added into Section 2.2: "Since the SDGSAT-1 was launched in November 2021, the development of TIS-based surface temperature products or cloud mask products is currently under development.".

On the automatic BTA threshold determination:

Response: We did consider using iterative thresholds for the BTA data as well, as Willmes and Heinemann (2015a) did. However, it is hard to argue that automatically selected thresholds are more appropriate than fixed thresholds for few cases in this study. For the three bands lead detection, without the use of a fixed BTA threshold for standard, the comparability of binary segmentation results would be poor, and the further cross-comparisons between the three results would be meaningless.

Yes, you are right here, for your study the use of manually determined BTA threshold is ok.

Thank you!

Although the TIS data used in this study cannot yet include various sea ice and atmospheric conditions, we would like to explain here the soundness of the constant threshold. We tested the results of the threshold values selected by the iterative method. Setting the initial threshold as 1.2 K, the automatically selected BTA thresholds by iterative method for the seven TIS data (for the each of the three bands) were shown in Table R2. The iteration thresholds for the BTA images were relatively close, with the minimum of 1.8 K and the mean of 2.0 K. From this perspective, no large errors can be produced between the segmentation results from iterative selection or from the constant threshold.

You could add to the paper a short mention about this automatic BTA threshold study, and that the results were close to the manual BTA.

Thanks for the comment. We have carefully added this into Section 3.1: "In addition to the fixed thresholds, we have also tested the iteratively selected thresholds (Willmes and Heinemann, 2015a) which yielded similar results to the manually selected fixed threshold of 1.8 K".

On adding more TIS data:

Response: Although we would like to carry out more detections, what we have presented in this manuscript is all that can be done in the spring of 2022. On the one hand, the SDGSAT-1 was launched just one year ago, so we can only obtain data after March 2022. On the other hand, the cloud interference is the main limitation for lead detection based on thermal infrared data in the Arctic. Due to the unavailability of simultaneous cloud detection (we are also working on this point), the method proposed in this study is only concerned with clear sky conditions, and therefore the available data is limited.

OK, you could add launch date of SDGSAT- 1 to Section 2.1 (it is now in Section 1, but could be repeated), and that practically you have all available data used in your paper at the time of its writing.

Thanks for the comment. We have clarified these in Section 2.1:

"Since the SDGSAT-1 was launched in November 2021, the development of TIS-based surface temperature products or cloud mask products is currently under development."

"The set of eleven TIS images, presented in Figure 1 and composed of four consecutive scenes, encompasses the majority of the available data up until the time of writing"

Currently, SDGSAT-1 needs to take into account various imaging requirements in different areas, so it is difficult for the satellite to keep observing the polar regions for long periods.

Please add this to Section 2.1.

Done as it suggested: "Considering diverse imaging requirements across various domains, it poses a challenge for SDGSAT-1 to maintain prolonged surveillance of polar regions.".

On the comparison of the TIS lead map against Sentinel-2 lead map:

Response: We agreed with you that it would be more valuable to compare in-situ and airborne measurement.

In terms of validation of the accuracy of lead detection, previous studies based on moderate resolution thermal infrared remote sensing have also used a variety of different methods.

Overall, even with certain errors, it is sound to use S2 data with normalized brightness and objective companions for validation in this study.

Yes, it is ok to use S2 lead maps as validation data, but you should take care of using the results to show accuracy of the TIS lead map, as they more show how two remote sensing products agree. It does not to tell what is the absolute accuracy of your TIS lead map, to my opinion.

Yes, I have understood your point. The comparison between the TIS-detected and S2 lead results are not yet sufficient for the absolute accuracy of lead detection. We have revised the corresponding paragraphs in the manuscript, taking care to avoid any possible misleading reference to "overall accuracy". For example, in the abstract, we have revised:

"…the TIS-detected leads achieve good agreement with Sentinel-2 visible images."

On Landsat vs. TIS data:

Response: Landsat-8 at 100 m resolution is indeed appropriate to be used for comparison with the TIS results. However, we did not acquire the matched Landsat-8 data during SDGSAT-1 TIS imaging. So, So, we only compared with the MODIS data at 1km resolution.

Yes, I understand, and comparison to Landsat can be left for future studies.

Thank you!

In the future, we do plan to develop a long-term lead dataset based on SDGSAT-1 TIS at 30 m resolution to support relevant research about sea ice dynamic, which requires more SDGSAT-1 data accumulation and development of related products (particularly cloud products and surface temperature products).

Please add this to Section 6.

The corresponding sentences have been modified:

"Along with the acquisition of additional TIS data over the course of a year, as well as the development of a near-real-time cloud product, we plan to develop a long-term lead dataset based on SDGSAT-1 TIS at 30 m resolution to support research on the dynamics of sea ice and expect to investigate the lead detection capabilities of this dataset across different seasons."

I don't have any new major comments to the revised paper.

Specific comments

The authors have resolved nicely my specific comments, below are few comments to their responses:

How do you define what is a critical area in the Arctic? Explain in the text.

Response: In the scope of this study, the critical seas refer to areas pervaded by leads with significant sea ice dynamic process.

Thus, the Beaufort Sea and Laptev Sea can be considered to as the critical areas for lead observation

Please add this explanation to the paper.

The corresponding sentences have been modified:

"…the TIS has acquired substantial high-resolution thermal infrared data from the critical seas in the Arctic, including the Beaufort Sea and the Laptev Sea, which are pervaded by leads with significant sea ice dynamic processes (Wernecke and Kaleschke, 2015)."

2. Data

l. 131: "The georeferenced level-4 TIS data"

Level-4 product is based on the Level-1 product after ortho-rectification using ground control points and Digital Elevation Model (DEM) and output with standardized format.

Add this level-4 data description to Section 2.1.

Done as it suggested:

"The georeferenced level-4 TIS data is based on the level-1 product after ortho-rectification using ground control points and Digital Elevation Model (DEM) and output with standardized format (CBAS, 2022).".

5. Discussion

l. 483: "In particular, the B2 band is more sensitive to such surface information because various types of sea ice have different emissivity and produce different BT values."

The corresponding paragraph has been amended: "contours of multiyear ice with high backscatter values that are observed in SAR images are similar to some negative BTA features... This suggests surface temperature variations for different thicknesses of sea ice. Similar surface temperature variations are also found in the 1 m resolution IST data derived from helicopter-borne thermal infrared imaging (Thielke et al., 2022).".

This is very good correction and clarification to the paper.

Thanks for the comment.

Related discussion in Section 1, line 60:

"Essentially, IST data, which are usually retrieved using the split-window technique (Key et al., 1997), are less accurate in the presence of melt ponds and leads because of the lower emissivity (0.96 compared to 0.99) of water compared to sea ice, causing a difference in the retrieved temperature (Hall et al., 2001)."

I don't quite understand this, why IST has less accuracy in melting conditions (melt ponds present)? Does emissivity difference 0.96 vs. 0.99 matter that much? In melting, i.e., warm conditions, we have very little, if any, thermal (IST) contrast between different surface types, is this what you are really meaning?

Thanks for pointing it out. Our statement here may have been misleading. It is not meant to imply limitations of the IST algorithm in melting scenes, but rather to highlight its challenges in scenes that involve both level ice and melting conditions (i.e., melting ponds and leads) due to the presence of mixed pixels.

In fact, this issue has already been mentioned in the "ATBD for the MODIS snow and sea ice-mapping algorithms" (Hall et al., 2001):

"The primary difficulty with surface temperature retrieval occurs when melt ponds and leads are present. The emissivity over water will be somewhat lower than that of snow or ice, say 0.96 compared to 0.99. This will make a difference of a few tenths of a degree (Jeff Key, written communication, 1996). The directional effects are also probably slightly different in melt ponds and leads as compared to snow- or ice-covered sea ice."

"…due to mixed pixel effects... the presence of melt ponds and leads in the summer months will also affect the emissivity of the ice surface and therefore the calculation of ice surface temperature."

We carefully revised the corresponding sentences in our manuscript as:

"Essentially, IST data, which are usually retrieved using the split-window technique (Key et al., 1997), has challenges in sea ice scenarios with the presence of melt ponds and leads. This is due to the lower emissivity (0.96 compared to 0.99) of water compared to sea ice, causing a difference in the retrieved temperature, especially with mixed pixel effects (Hall et al., 2001)."

l. 498: "On the other hand, as the TIS data available within the scope of this paper is relatively limited, these individual case studies presented may be weak in terms of generalizability."

Yes, this is the case, and this must be also emphasized in Conclusion Section.

Thanks for the comment. We had already emphasized this again in Section 6:

"Nevertheless, limited by the imaging time and cloudy conditions over the Arctic region, only individual case studies based on TIS data were carried out, which may result in a weak generalizability.".