Spaceborne thermal infrared observations of Arctic sea ice leads at 30 m resolution

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General comments

The authors have developed a method to map Arctic sea ice leads using Thermal Infrared Spectrometer (TIS) data onboard recently (Nov 2021) launched Chinese Sustainable Development Science Satellite 1 (SDGSAT-1). TIS has three IR bands: B1 (8.0-10.5 µm), B2 (10.3-11.3 µm) and B3 (11.5-12.5 µm), with 30 m resolution and 300 km swath width. The TIS instrument provides TIR data at much finer resolution than MODIS (1 km) and VIIRS (750 m), and somewhat finer than Landsat 8/9 (100 m). Optical and NIR data at comparable or even finer resolution are available from many sensors (e.g. Sentinel-2, Landsat 8/9), but only TIR data enables to retrieve sea ice properties regardless of daylight conditions.

The method for the Arctic sea ice leads mapping is developed using 11 TIS images acquired over the Laptev and Beaufort Seas in Match and April 2022. The general lead detection method was same for all three TIS bands with some variable parametrization, i.e. all three bands were not used together for the lead detection, but in some cases the resulting three lead maps were combined (if I understood correctly, please see my comment later). The same TIS images were also processed to the leads maps (binary map: lead (open water or thin ice) or sea ice. The leads by the three TIS bands were compared to each other, and to lead detection maps by Sentinel-2 band 2 (green band) data and MODIS daily IST data. The Sentinel-2 lead detection was based on study by Muchow et al. (20121) and the MODIS lead detection to (Qu et al. 2021). A case study was also conducted were a TIS lead map was compared to Sentinel-1 dual-polarization SAR image. Possible atmospheric influences to the TIS lead detection were investigated using ERA5 air temperature and OMI ozone total column data. The TIS band 1 covers the ozone absorption band.

In general, the TIS lead detection seemed work fine, and against the S-2 lead maps there was 96.3% pixel based match (authors used TIS accuracy here). Compared with the MODIS lead map, the TIS map presents more leads with width less than hundreds of meters. All three TIS bands showed similar performances in detecting leads. The B1 band can be complementary to the other two bands, as the temperature sensitivity is different from the other two, benefiting better detection by combining the three bands. Arctic lead maps with fine resolution (e.g. 30 m) allows to observe narrow leads which are undetected in the MODIS/VIIRS products, and estimate their contribution to the overall Arctic lead fraction.

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.

The review and discussion on related previous studies is well conducted, e.g. different methods for lead detection are nicely discussed. However, your review could include also following new study:

Q. Wang, M. Shokr, S. Chen, Z. Zheng, X. Cheng and F. Hui, "Winter Sea-Ice Lead Detection in Arctic Using FY-3D MERSI-II Data," in *IEEE Geoscience and Remote Sensing Letters*, vol. 19, pp. 1-5, 2022, Art no. 7005105, doi: 10.1109/LGRS.2022.3223689.

lead map with 250 m resolution

There are many studies with lead detection using SAR and altimeter data, and it is fine to give only few examples as you have done. Related to (Murashkin and Spreen, 2019) include also reference:

Dmitrii Murashkin, Gunnar Spreen, Marcus Huntemann, and Wolfgang Dierking, "Method for detection of leads from Sentinel-1 SAR images," Annals of Glaciology, vol. 59, no. 76, pp. 124–136, 2018

Could you use their method for automatic lead detection in your S-1 SAR imagery? This would allow better utilization of the SAR imagery as comparison data.

Your review includes only one study where Landsat data are used for the lead detection (Qu et al. 2019). Are there any other Landsat studies? Please check. One relevant study here could be:

Cáceres, A.; Schwarz, E.; Aldenhoff,W. Landsat-8 Sea Ice Classification Using Deep Neural Networks. Remote Sens. 2022, 14, 1975. https://doi.org/10.3390/rs14091975

Sentinel-2 lead study by (Muchow et al. 2022) must be discussed in Introduction, it is now mentioned later in Section 4.1.

You could also summarize currently publicly available Arctic lead products with their time spans, seasonal coverages (full year or only winter season) and spatial resolutions.

Section 2 Data could be changed to "Data and pre-processing", i.e. to include all data processings before analyses and lead detection method development, e.g. move Section 3.1 (Pre-processing of TIS data) to Section 2.

Detailed descriptions of TIS instrument and its data should moved from Introduction to Section 2.1. In the following are some questions on the TIS data:

What is the size of the TIS image along track?

What is the main intended application of the band 1?

What is the resolution of the TIS data in K?

Is there yet IST product from bands 2 and 3? Under development?

Are there any TIS cloud masking algorithms or products?

BTA threshold for the lead detection was manually selected (here 1.8 K). Are you sure this is really applicable for a large amount of TIS images acquired in various sea ice and atmospheric conditions? Why did you not develop an automatic selection method for the BTA threshold, as you did for the BT threshold? I think is rather serious potential flaw in your lead detection method. You should really have an automatic BTA threshold selection method.

In general, we could have better reliability on your TIS lead detection method if more TIS data had been used in its development. Can you add more TIS images to your study?

The TIS lead map is evaluated against the Sentinel-2 lead map, and their agreement is very high, 96.3%. You talk about accuracy of the TIS lead map based on this comparison, but this comparison really don't give an absolute accuracy of the TIS map, as I don't think your Sentinel-2 lead map is error free. For determination of accuracy in-situ or airborne data are needed.

TIS strip noise is discussed first time under Results. It should be mentioned when TIS sensor and data properties are described under Section 2.

It would be very interesting see lead map comparison between TIS (30 m) and Landsat (100 m), can you add this to your paper? We could see how much 30 vs. 100 m resolution matters in the lead detection.

Finally, under ‘Summary and conclusion” Section you discuss more about future research goals, and will be there an operational TIS lead product?

Specific comments

Abstract

“unresolvable ice leads”; change to “unresolvable sea ice leads” or to “unresolvable leads”

1. Introduction

line 28: “under wind and water stresses”

better “under wind and ocean stresses”

l. 33: “During winter, newly opened leads are the main source of ice production, brine rejection, and turbulent heat loss to the atmosphere”

Is it leads or polynyas in the whole Arctic scale? Please check. Anyway polynyas could be mentioned in this context.

l. 47: “Other studies also applied active and passive microwave data to lead detection with the advantage that microwave wavelengths are transparent to cloud cover; however, either the data resolution is too coarse”

Too coarse to what? Detect smaller leads? In some application of the lead data?

l. 57: “Essentially, IST data, which are generally retrieved by the split-window technique (Key et al., 1997), are less accurate under the presence of melt ponds and leads because the lower emissivity (0.96 compared to 0.99) can cause a difference in the retrieved temperature”

Lower emissivity of what? Water?

l. 61: “They detected leads for January through April over the period of 2003 to 2018, presenting a lower estimation for the lead area compared with the results in Willmes and Heinemann (2015c); the reason is the difference in spatial resolutions of the lead datasets.”

Give resolutions of these datasets in the text.

l. 67: “Qu et al. (2021) proposed a modified algorithm

Modified from what? From Hoffman et al?

l. 94: “To date, the TIS has acquired substantial high-resolution thermal infrared data from the critical seas in the Arctic”

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

l. 102: “This study is the first to observe Arctic sea ice leads at 30 m resolution”

Table 1 must include references to the data it present.

Figure 1 should include acquisition times for the rectangles 1-4. Describe that visible images come from Sentinel-2.

2. Data

l. 130: “Considering the benefit of incorporating three thermal infrared bands for observation, Thus, the three bands of SDGSAT-1 TIS data are used”

You can remove ‘thus’ from the sentence.

l. 131: “The georeferenced level-4 TIS data”

What do you mean by level-4 data here?

Give some refences to Sentinel-1 and -2 sensors and data.

l. 139: “given that the visible spectrum centered at 560 nm gives a good effect (König et al., 2019) for a scene containing sea ice and seawater.”

What is this ‘effect’? Good discrimination between sea ice and water?

l. 147: “we collected S1A dual-polarization data in the Beaufort Sea on April 3 and 28, 2022 (see Table 2).

Table 2 shows S-1 data only on 3 Apr.

Table 2: S-1 resolution is not 40 m, it is around 100 m, the pixel size is 40 m. Explain what are h07/08 etc. under MODIS column.

l. 163: “air temperature) data available by every 6 hours”

Your ERA5 reference shows that data is hourly.

OMI ozone: give some reference also for the ozone retrieval, in addition to the product reference.

3. Method

l. 195: “In addition to the leads presenting as distinct yellow and red colors on the BT map,

Give also temperature ranges these colors represent.

Give some references to the BTA based lead detection in Section 3.2, as this method has been used in many studies using MODIS and VIIRS data.

l. 208: “By collecting eight TIS data acquired between April 3 and April 28”

There is seven TIS images in Table 2.

l. 222: “Previous methods applied a variety of BTA thresholds”

should be “Previous studies”, and give also references.

Figure 6 and 7: give TIS band used in the figures.

l. 268: “Finally, the binary detection of leads at a 30 m resolution was derived based on SDGSAT-1 TIS in three bands.”

How all three bands were used together in the lead detection? You must explain this in detail.

4. Results

l. 302: spell out TP, FP, FN and TN in the text,

Section 4.2: equation numbers should be (2) and (3).

Section 4.3: again how lead detections by all three TIS bands are combined?

l. 381: “The previously developed method (Qu et al., 2021) was applied to detect the leads based on the MODIS IST data.”

Explain in the text why you selected the method by (Qu et al., 2021).

5. Discussion

You talk in the text about ‘ozone resolution’, what is that? Figure 12 shows ‘best total ozone solution’.

You could add to the discussion here the correlations between different TIS bands.

Section 5.2: Descriptions on S-1 SAR processing should go to Data Section.

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.”

Are the TIR emissivities of different sea ice types really that different? Please check literature, and give variation range in the text. I would say it is more about variation of sea ice/snow surface temperature, e.g. thin sea ice has surface temperature which is a function of freezing temperature and air temperature, but surface of thick ice is fully insulated from ice bottom, i.e. only air temperature matters.

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.

Technical corrections

Many figures are too small, try to increase their sizes. Also colorbars for BT, BTA, are way too small.

References for the same authors and the same year are missing a,b,c, after the year in Reference list.