

## Summary

The authors extend an existing unsupervised classification approach for detecting open water targets from radar altimeter waveforms, to include detection of thin-ice. The authors present the classification approach conceptually, apply it to Cryosat-2 L1B Ice Baseline D data waveforms then compare their results to existing thin ice detection techniques from passive microwave radiometry (SMOS sensor) and infrared data (MODIS sensor), as well as Sentinel-1 SAR imagery. A comparison is also made to another Cryosat-2 sea ice product, the AWI Cryosat-2 sea ice product v2.4. The Laptev Sea is the region of focus due to the occurrence of winter period thin ice areas from flaw leads and coastal polynyas. The classification is applied to Cryosat-2 data taken January through March over the 2011 to 2020 period. Overall, the method is promising for detection of thin-ice areas, as a potential improvement over the ESA Climate Change Initiative (CCI) algorithm described in Paul et al. (2018) which does not include this feature. With a better evaluation in comparison to the prepared MODIS thin-ice thickness data (see major comment below), the utility and limitations of the proposed algorithm will be better understood. The work is clearly justified, and as the authors state, knowledge of thin ice areas is important for sea ice mass balance work, and there are limited datasets for remote study of their properties and coupled processes. It should be a good contribution to TC and of interest to the readership after comments here, and in the other reviews, are adequately addressed.

## Major comments:

1. The authors compiled a large number of overlaps between their classification and MODIS TIT information. Despite this, the use of MODIS TIT to understand classifier performance is limited to a brief statement about overall class assignments on lines 267-269. The MODIS TIT data are further used for assessing relationships between ice thickness categories and waveform properties, which adds value to the interpretation of classifier performance. However the paper would be much improved by using the MODIS TIT for more detailed comparisons to the UWC classification outputs, in order to better understand limitations and inform further classifier optimization. The comparison to the CCI data is much more informative.
2. The visual comparisons between the classification and coincident sensor data are helpful, and the authors put together a good summary of relationships between observed conditions in each comparison. The authors should provide a clear rationale for the choices made, in order to add confidence that these are un-biased assessments. It is apparent that the Cryosat-2, MODIS, and Sentinel-1 comparison on 01 March 2018 is chosen due to the short time gap between all three acquisitions. The other comparisons are not as well justified, and it is likely there are several overlaps to choose from.

## Minor Comments (by line number):

L4: clarify that it is a Cryosat-2 based classification here

L6: clarify what linear dependency is found (e.g. “between...x and y...”) or consider re-wording

L22: delete “in their retrieval capabilities as well as” and replace with “and”

L26: comma after “sensors”

L29: delete “are also prone to”

L36: commas after “density” and “cover”

L38: delete “But even when ... classified as sea ice”

L39: change “the later” to “recent” and “over” to “of” (i.e. freeboard *of* ice)

L40: “from” Ku-band radar altimeters

L44: delete “since the range ...depth.”

L48: delete “on”

L49: delete “short comings and”

L51: Make “However, at a lower spatial resolution ...” a new sentence

L58: use “spatial and temporal resolutions” or “spatio-temporal resolution”

L65-68: “This study is structured into the following sections: Section 2 describes the data sets; Section 3 provides details on the unsupervised clustering for CryoSat-2 and the MODIS thin-ice thickness retrieval. Section 4 summarizes and discusses the results and implications on CryoSat-2 surface-type classification, and Section 5 concludes with an outlook.”

L70: “The following sub-sections highlight the data sets used ...”

L74-75: delete “aiming at monitoring ...was placed”

L76: delete “Moreover,”

L79: delete “mainly characterized ... ice cover,”

L80: change “showing” to “with”

L85: “This dataset comprises, ...”

L86: comma after data, and delete “also”, and add “on” after information

L91: delete “As basis” and just use “MODIS” rather than writing it out

L92: delete “MODIS sensors on board the polar orbiting”

L93-94: The MODIS data access information can be moved to the data availability section

L96: delete “In a first step”

L102: Add information about the temporal component, e.g. hourly data nearest to acquisition, daily average, etc.

L110: “and less rough surface under calm, low-wind, conditions.” The possibility of wind-roughened polynya and lead should be mentioned since this would also contribute strong backscatter and bright pixel values.

L112: “e.g. on nilas ice, as they...”

L115-116: move the introduction to Sentinel-1 to beginning of the section

L118-120: Since the Sentinel-1 data are used only for visual assessment, the processing steps are likely straightforward and could be described briefly here.

L123-125: delete the first sentence

L127: change “keeping” to “enabling”

L129: delete “used”

L130: clarify what is meant by a Cryosat-2 observation

L131: sentence “The number of useable ...” is not necessary because of previous descriptions

L139: delete “has”

L143: put a comma after “clustering” and delete “next classification steps consist of an”

L148: delete “so called” and “followed”

L163” here, and elsewhere, just use the abbreviation after it has been defined (i.e. MP)

L167: nilas

L168: delete “of”

L170: also compare to wind-roughened water

L176: as mentioned above for MP, just use “IST” since it was defined earlier

L191: Change text to “The very high spatial and temporal resolution altimetry ....”

Figure 2 caption: use italics for words in quotes (and delete quotation marks)

L199: use “subsets” in place of “zoomed-in snippets”

L200: pluralize to “results”

L207: delete “and, therefore, no truth is available”

L207-209: provide some indication of what is meant by lead or thin-ice surface being very small (how small)

L215: comma after “Northwards”

L216: delete “in ice thickness”

L222: delete “in a quantitative analysis”

L223: change “acquired at” to “from”

L224: delete “from each other”

L229: recommend to change “supposedly” to “likely”

L233: How is thin ice labelled correctly as lead and not thin ice?

L239: change “blended with” to “compared to”

L270: “TIT”

L272: “TIT”

L273: delete “spatiotemporally”

L276: “deviations”

L286: delete “However”

L287: change “this” to “a”

L293: change “Contrariwise” to “In contrast” and use “LEP” only since it is already defined

L304: citation needed

L309: use LEW

L331: delete comma after “both”

L334: “(WMO, 2014)”

L346: delete “in general”

L350: delete “in general” and comma after “both”