Review of The Cryosphere Discuss., 9, 4539-4581, 2015

Late summer sea ice segmentation with multi-polarisation SAR features in C and X-band

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General comments:

The authors have collected three RADARSAT-2 quad-polarization and two TerraSAR-X dual-polarization synthetic aperture radar (SAR) images of a mixture of landfast ice types in the Fram Strait. The collection period is during late summer, an eight day period spanning late August and early September. They use coincident helicopter derived sea ice thickness and surface roughness data, downward looking digital photographs (classified into open water, submerged ice, melt pond, thin ice and thick ice), and the SAR images, to manually select five different regions of interest (ROIs) representing homogeneous zones of 3 types of ice according to the WMO nomenclature. The zones, or ice classes, are medium thick first-year sea ice, thin first-year sea ice, and old ice. From these ROIs they extract sets of polarimetric features, parameters which provide information about ROI scattering properties, qualitatively evaluate their behavior (relative behavior and behavior with time i.e. "temporal consistency"), and test their classification capability across the SAR dataset. Because the RADARSAT-2 images are quad-pol, and the TerraSAR-X are only dual-pol (one is HH+VV and one is VH+VV), not all polarimetric features can be derived from the latter. The choice of polarimetric features is based on a previous study which outlined their utility for classifying winter SAR scenes.

Generally the authors find that by combining their polarimetric features in a supervised classification leads to better classifier performance, i.e. compared to using reduced feature sets. They assert that the increased information (more polarimetric features) available from the quad-pol RADARSAT-2 data leads to a better classifications compared to the dual-pol TerraSAR-X data, though they acknowledge other sensor parameters (e.g. variations in incidence angle) and environmental conditions need to be further considered.

Discrimination of sea ice types in SAR images is difficult during the late summer period, when sea ice is prone to surface melting/freezing, desalination, and variations in melt pond fraction – factors which all affect microwave-ice interactions and the performance of classification techniques applied successfully to images acquired during other seasons. In light of a changing sea ice-associated marine environment and potential for increased marine activity during summer, it is important that new ways to discriminate sea ice types in SAR images are found. Dual-pol and quad-pol data offer improved discrimination potential, making studies like this one important steps in the maturation of the field.

Certainly the paper is relevant to the scope of TC. The paper is generally well structured, and methods and results adequately described. The ideas and tools used in this paper logically follow a previous work (Moen et al., 2013 – also published in TC), but offer new results by extending this line of research into the late summer period. There are some concerns, provided in the specific comments below.

Specific comments:

These are numbered for sake of clarity; they are not necessarily in order of importance.

1. *Use of air temperature data in the analysis*. The authors use air temperature data recorded on the R/V Lance vessel, which appears to have been at sailing within about 100 km of the area under investigation. At this time of year the sea ice cover will be very close to its freezing point and very sensitive to slight changes in its surface energy balance, so that air temperatures recorded at some distance away may not indicate whether or not the ice is freezing or melting at the time of a SAR acquisition. While it is understandable that measurements on the ice could not be made, assertions about the freezing/melting state of the ice cover made on the basis of these air temperature readings, and how this relates to the scattering behavior and classification performance, should be made with caution. The authors should use these ancillary data to guide their analysis and discussion points. Making concluding statements on the basis of these data, however, would not be appropriate.

2. *Selection of polarimetric features*. The authors draw a connection to a previous publication in order to justify the selection of polarimetric features in this study. This seems logical, however not enough information is provided in the current paper about the expected behavior of these features for the varying system and target parameters under consideration. The authors should follow on their descriptions of the expected behaviors of Relative Kurtosis and Geometric Brightness with appropriate background information relating to the other features. While some of the target behaviors are understandably novel, expected system-based behaviors should still be provided. For example, co-polarization ratio and co-polarization correlation magnitude will vary as a function of incidence angle across the 10° range between R1 and R2. Variations in the co-polarization correlation magnitude between R1, R2, and R3 do appear to trace the variations in incidence angle, at least for ROIS 1-4, which somewhat contradicts the assertion made in lines 5-10 on page 4554.

3. *Classification versus segmentation*. The term "segmentation" is used extensively, including the title. Segmentation typically refers to dividing an image into groups of connected pixels. What is being done here is an image classification, the labelling of pixels.

4. *Organization and writing*. The results section includes long descriptions of methods and justifications for investigations that were either previously provided or belong elsewhere. For example see beginning of Section 3.13:the background information on sea ice permittivity is important, but would make sense if it were provided much earlier. As it is, the results section is cumbersome to read. It should be edited so that focus is on key results and discussion points. The paper should also be edited to make sure the correct tense is being used consistently (e.g. line 10 on page 4547, "(ROIs) <u>were</u> chosen" etc.).

5. *Sea ice in the Fram Strait*. More background information on sea ice conditions characteristic of the Fram Strait would significantly improve the quality of the paper. It would also make it easier for readers not familiar with the ice conditions in that region to assess the potential utility of the classification approach or individual polarimetric features for sea ice detection and discrimination studies elsewhere.

Technical corrections:

P=Page, L=Line

P4540L6: These remotely sensed data are not *in situ*.

P4540L9: 'temporal'

P4541L7: give the dual polarization combination used by ice services (HH + HV or VH + VV)

P4541L8: swath 'widths'

P4541L14: State the C-band frequency in GHz, as done below for X-band.

P4541L16: 'to investigate' instead of 'in investigating'.

P4541L19: 'platforms'

P4542L9: 'derived from' instead of 'based on'

P4542L20-27: This could be split up into two sentences to improve readability.

P4543L10: 'individual'

P4543L24: delete 'detailed'

P4544L2: '… ship, helicopter, and satellite platforms…'

P4544L6: '…from the scientific vessel R/V Lance provided information …' (delete 'are also available')

P4544L9: delete 'ground based'

P4544L18: '… and the positions…'

P4544L19: ' … scenes were acquired during ascending orbits.'

P4544L22: 'Air- and ship-borne measurements' or 'Airborne and shipborne measurements'

P4545L8: 'From this device …'

P4545L13: How is it known that there is very little or no snow cover? More detail is needed to back up this observation.

P4546L5-18: How reliable are the classified images? Was an accuracy assessment performed?

P4546L22: Provide information regarding the meteorological instrumentation and measurement height.

P4547L10: '…(ROIs) were chosen …'

P4547L19: It would be more appropriate to indicate that the ice types were labelled according the WMO sea ice nomenclature, in addition to providing the reference.

P4547L23-25: '…is smooth with <u>a</u> high melt pond …' ; 'ROI3 and ROI4 <u>represent</u> areas of weathered and deformed old ice …' ; 'ROI3 represents thinner ice with <u>a</u> higher melt …'

P4548L4: delete <u>different</u>

P4548L6: Sentence 'This study investigates … ' should be deleted (stated already).

P4548L18: 'Assuming <u>reciprocity</u> …'

P4550L5: '<u>Bayes'</u> decision rule'

P4550L12: delete <u>hence</u>

P4551L1: pdf should be <u>PDF</u>

P4552L21: <u>PDF</u>

P4552L26: '… is not <u>necessarily</u> a result…'

P4553L4-5: '…evolution of <u>feature means from each ROI are</u> displayed in …'

P4553L13: '…searching for <u>temporally</u> consistent'

P4554L3-9: Did you try subtracting the additive noise from the RS-2 scenes before calculating $R_{VV/HH}$? These data are found in the RS-2 header files. This method has been shown to improve $R_{VV/HH}$ estimates of ocean and ice at the high incidences analyzed here.

P4554L10-15: Did Gill et al. (2013) look at the late summer period? Please clarify.

P4555L8: '…could solely discriminate all ROIs…' (delete '<u>between</u>')

P4556L5: '…helicopter <u>flight</u>…'

P4556L14: '… scenes are small.' (delete '<u>in general</u>')

P4556L18: '… with the full feature set <u>give</u> …'

P4557L3-4: Here the parameters are given in text form when the symbols were previously given. Best to stick with using the symbols.

P4557L13-15: This sentence should be re-written for clarity. The rest is very well described.

P4558L3: '<u>acquisition</u>'

P4558L5-6: As given it is not clear how both of these processes (formation of rime, refreezing of the ice) would lead to a lower contrast between sea ice types. The occurrence of either is plausible and worthy of mention, as per the conditions. However the authors should be cautious attributing these processes to reduced ice type discrimination. Could a refreezing of the sea ice lead to increased microwave penetration depth and enhanced ice type discrimination on the basis of volume scattering differences between ice types?

P4558L20: add a period to the end of the sentence

P4558L24: '… at the time of acquisitions could all contribute to poorer segmentations.'

P4559L3: *in situ* data were not used

P4559L24: Another possible reason would be a higher sensitivity to incidence angle.

P4560L4: '… evaluated visually <u>for</u> its ability …'

P4560L6-7: 'The segmentation in general performed well …'

P4560L16: '<u>temporally</u>'

Figure 9 caption: 'assigned'

Figure 11 caption: 'assigned'