## Assessment of error in satellite derived lead fraction in Arctic

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The Cryosphere Discuss., 9, 6315–6344, 2015

**General comments**

The authors have studied accuracy of an AMSR-E radiometer data based Arctic sea ice lead fraction (LF) product. The LF product is provided by a third party and is publicly available. The product covers winter months of Nov-Apr and has resolution of 6.25 km. The authors discuss in detail importance of sea ice lead information for estimation sea ice heat fluxes and sea ice deformation and drift, and thus, LF data should be assimilated to sea ice models as initial conditions. LF data can be also used for evalution of the sea ice models. The authors point out that for this work also uncertainty estimates of LF data are needed. The uncertainty estimates of the AMSR-E LF product are based here on LF data derived from ENVISAT SAR imagery using a method developed by the authors. The authors found out that the AMSR-E LF data has consistent LF overestimation by a factor of 2-4, and they developed an adjustment for the tie points in the AMSR-E LF algorithm (published in a journal paper). It is not possible to correct LF values in the AMSR-E product, but an user must calculate corrected LF data from the original AMSR-E daily gridded brightness temperatures.

In general, the paper is well written and structured, and easy to read and understand. The data processing and analysis methods are scientifically sound and discussed in needed detail. The authors give an overview of difference satellite data based LF derivation methods, and conclude that microwave radiometer data based method is currenly the best choice (which I agree): daily Arctic coverage independent cloudiness and daylight conditions. The SAR based methods for LF estimation may not yet be suitable for operational applications.

My main critic and concern in the paper is the method used for SAR based estimation of LF:

1) It is very simple, not up to current state-of-art in SAR based sea ice classification. The algorithm is basically a backscattering coefficient threshold method to separate leads with calm open ocean or thin ice (low sigma0) from sea ice (high sigma0). Leads with rough ocean or deformed thin ice are not identified, as the authors point out. The threshold method results a binary mask of leads vs. sea ice at 100 m pixel size which can be aggregated over a larger area to LF estimates. The threshold algorithm uses as input median filtered (5x5 pixel window) sigma0 values, which reduces the effect of radar speckle, but I think that still the radar speckle has some effect on the results if a sigma0 value is close to threshold causing randomness to which class, lead or sea ice, a pixel is assigned.

I suggest that the authors estimate the equivalent number of looks in their SAR imagery rectified to 100 m pixel size, yielding an estimate for radiometric resolution of the sigma0 (~10*log10(1+1/sqrt(ENL))), and study possible effects in the lead-sea ice classification.

The authors claim that no method has so far have been presented in literature addressing automatic LF retrievals from SAR. I would say that this may not be true as recent years papers have published on SAR based sea ice concentration (SIC) retrieval which may also be applied here, see e.g.:

Anders Berg and Leif E. B. Eriksson, "SAR Algorithm for Sea Ice Concentration—Evaluation for the Baltic Sea", IEEE Geoscience and Remote Sensing Letters, Vol. 9 (2012), 5, p. 938 - 942.

Karvonen, J.: Baltic Sea ice concentration estimation based on C-band HH-Polarized SAR data, IEEE J. Sel. Top. Appl., 5, 1874-1884, doi:10.1109/JSTARS.2012.2209199, 2012.

Karvonen, J.: Baltic Sea ice concentration estimation based on C-band Dual-Polarized SAR data, IEEE T. Geosci. Remote, 52, 5558-5566, doi:10.1109/TGRS.2013.2290331, 2014.

Steven Leigh, Zhijie Wang, David Clausi. “Automated Ice-Water Classification Using Dual Polarization SAR Satellite Imagery,” IEEE Transactions on Geoscience and Remote Sensing, vol 52, no 9, 2014.

Liu, Huiying; Guo, Huadong; Zhang, Lu, “SVM-Based Sea Ice Classification Using Textural Features and Concentration From RADARSAT-2 Dual-Pol ScanSAR Data”, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 8(4), pp 1601-1613, 2015.

I suggest that the authors conduct a thorough review of SAR based sea ice classification methods relevant to their study, and see if they can develop or apply a better method for the LF estimation. If you decide to continue use your current method then a firm detailed justification is needed.

2) The AMSR-E LF product accuracy is studied using an another LF product based on satellite data, this case SAR, and further, the SAR based method itself is not fully validated. The authors constructed a manually quality controlled sub-set of SAR based LF data for the AMSR-E LF accuracy studies. I suggest to study if you could add visual spectrum MODIS and MERIS data from March-April to further validate your SAR based LF estimation. At least larger leads should be visible in the optical imagery. During nighttime also 1 km MODIS ice surface temperature data could also usefull (e.g. as by Willmes and Heinemann 2015). My work with these data have shown that manual quality control of cloud masking is unfortunately needed. The authors could also check availability of fine resolution Landsat etc. data over their study area.

In general, I am concerned about validating one remote sensing product with another product, which itself is fully mature and validated. Your study is more about intercomparison of two RS products and finding their differences, and you may not get solid information about the AMSR-E LF product accuracy againts the true (in-situ) lead fraction. You claim that AMSR-E LF product is overestimating LF, but are you sure that your SAR based LF method is not underestimating, and thus, leading to this conclusion?

3) SAR based LF estimation is difficult, especially using single channel SAR imagery as in your case (ENVISAR C-band HH-pol WSM). I propose that you check if finer resolution ENVISAT APP images are available over your study are in Nov 2008 – Apr 2009. If that is the case then use APP based LF estimates to validate those from coarser resolution WSM imagery. In addition, are there any RADARSAT-2 dual-pol ScanSAR images available (through MyOcean or metno’s Ice Service data archive)? Addition of cross-pol data could enhance lead detection.

How about ICESat data for SAR lead detection validation? ICESat data were acquired in Nov 2008 – Apr 2009?

In summary, I would like to see you study further accuracy of your SAR LF estimation method, as it is new one and presented for the first time in your paper.

In the paper you mention/discuss about thin ice, but you don’t define exact thickness range or WMO ice classes for the thin ice.

**Specific comments**

Page and line numbers refer here to the printer-friendly version of the article.

**Introduction**

Page 6317, line 1: “Model simulations showed that even 1% change in sea ice concentration due to the increase in areal lead fraction can lead to a 3.5 K difference in the surface temperature”

Does this refer to sea ice surface temperature or surface air temperature?

p. 6317, l. 17: “Accurate observations of lead fraction are thus of high importance for model evaluation and for being assimilated into models as initial conditions, or during a simulation.

How about the exact lead locations, especially larger ones, are they imporant?

l. 6318, l. 16: “However, this approach is limited in time coverage because AMSR2 started to deliver the data only in 2012 (http://suzaku.eorc.jaxa.jp), and quantitative validation work is still needed.”

Quantitative validation work is needed - is this your opion or found in a journal paper?

p. 6318, l. 28: “The selected classifier was able to detect 68% of leads correctly, and only 3% of ice measurements were falsely identified as leads.”

Why quite high fraction of leads were missed with CryoSat-2 data? This could be of interest to a reader.

p. 6319, l. 26: “Based on analysis of the errors we introduce a correction factor for the existing dataset and suggest an improvement of the AMSR-E based method itself.”

The AMSR-E LF data cannot be corrected, but you propose a tie point correction to the LF algorithm itself? Please correct me, if I am wrong.

**2.1 The AMSR-E LF dataset**

p. 6320, l. 12: “LF is expressed as the percentage of a grid cell covered by leads, which are represented by either open water or thin ice.”

What is the thickness range of thin ice here?

Please explain shortly in this sub-Section the method for the AMSR-E based LF estimation.

The AMSR-E LF is a daily gridded product? This is not explicitly mentioned.

**2.1 The SAR images**

p. 6321, l. 19: “The SAR images originally provided with spatial resolution of 75m×75m,”

This is pixel size of the WSM images, not the resolution. Provide resolution and noise floor, available from ESA docs. Investigate many equivalent of number looks are in your rectified SAR images, see my comments above.

p. 6321, l. 22: “Calibrated surface backscattering coefficient (ASAR Product Handbook, 2007) normalized over ice was used for this study (we will refer to this value as backscatter).”

Unclear what this normalization means, incidence angle variation compensation?

**3 SAR-based threshold technique**

p. 6322, l. 22: “The threshold was first tried with nd=1 and nd = 2 (dashed red lines), but it was found that an intermediate value nd = 1.5 (solid red line) worked better and therefore was chosen.”

How this was determined? Visually analyzing results with different nd?

p. 6323, l. 3: “This method is developed strictly for the purpose of the AMSR-E LF dataset validation and therefore does not represent an independent LF retrieval method from SAR.”

I don’t understand this, to my opinion your SAR LF should be independent of the AMSR-E LF dataset if you want to validate the AMSR-E LF.

What is the effect of SAR noise floor in your sigma0 threshold based LF method? Measured sigma0 is sum of target true sigma0 and SAR noise equivalent sigma0. Can the threshold in (1) be lower than the noise equivalent sigma0? If so then leads are not detected at all.

### 4.1.1 MQC SAR LF

p. 6324, l. 13: “Defining a threshold locally not only eliminates significance of these effects, but it takes advantage also of less variety of surfaces in general.”

How threshold definition was done, manually?

p. 6324, l. 20: “The classification in each subset was then inspected visually, comparing the three collocated maps: backscatter, MQC SAR LF and AMSR-E LF, in order to make sure it was successful.”

Now your MQC SAR LF dataset is not independent of AMSR-E LF? If so then how this effects your SAR LF vs. AMSR-E LF comparison? I think your SAR LF should be totally independent of AMSR-E LF.

### 4.1.2 SAR LF

p. 6325, l. 5: “The majority of subsets contained leads represented by signatures darker than surrounding background, while if those with brighter signature were present in large amount such images were discarded.”

This is a serious drawback of your SAR based LF method, leads with high sigma0 are not detected. You have circumvented this by discarding SAR images with leads having high sigma0. Another, and better, way would be to further develop your algorithm.

## 5 Discussion

p. 6238, l. 20: “A method to retrieve LF from SAR backscattering coefficient is introduced. This simple threshold technique is only suitable for the purposes of this study, and is thus not universal. However, its potential is shown, and the limitations are identified, which allows further developments of the method.”

It is good that you admit many limitations of your SAR LF method, but I am not very happy about circumventing this by stating that it is still suitable for your study. You could target more universal SAR LF algorithm to increase value of your paper. See my General comments.

p. 6329, l .22: “When the distribution is bimodal (one mode for leads and one for thicker ice), a value between the peaks can be used as threshold, as suggested by Lindsay and Rothrock (1995) for distributions of temperature or brightness. However, such cases were so rare in the selected SAR images that this approach was discarded.”

Yes, also to my experience cases when a sigma0 has a clear bimodal distribution are rare, as there are leads with low or high sigma0, smooth FYI with low sigma0 etc., i.e. the overall sea ice sigma0 distribution can have many local peaks.

p. 6331, l. 2: “For example, it would not be able to capture leads narrower than 3 km due to its resolution,...

This limitation should also mentioned in Introductory and 2.1 The AMSR-E LF dataset Sections.