

## ***Interactive comment on “Virtual radar ice buoys – a method for measuring fine-scale dynamic properties of sea ice” by J. Karvonen***

**J. Karvonen**

juha.karvonen@fmi.fi

Received and published: 29 October 2015

This manuscript presents preliminary results of a feature-tracking algorithm applied to surface-based radar imagery of sea ice. The high temporal resolution and weather independence of radar makes ship-mounted and coastal systems ideal instruments for operational monitoring of sea ice as well as the study of small-scale ice dynamics. The results described by the author are highly promising and personally I am very pleased to see them, but I feel the value of the work (and its suitability for publication in The Cryosphere) would be greatly improved with an expanded, quantitative discussion of the observed ice kinematics. The results illustrated in the generally well-produced figures indicate the potential to derive some geophysically interesting analysis of small-scale ice kinematics, but unfortunately I feel the discussion of ice motion and deforma-

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tion observed in each of the test cases is too brief and qualitative. In my opinion, the quantification of small-scale ice motion represents the primary scientific contribution of this work and without such I agree with the first reviewer that this manuscript may be more suitable for a technical journal like one of the IEEE publications. I also feel the author may be overstating the novelty of the approach and appears to be overlooking a quite extensive body of literature regarding the use of coastal radar to monitor ice dynamics in Barrow, Alaska

Dear Prof. Mahoney,

Thank you for the comments! I have included more details in the analysis part of the results. However, the main goal of this study was to develop and implement an algorithm capable of continuous stand-alone operational ice drift monitoring.

The method is novel in the sense that it combines existing methodology to implement an operational continuous local ice drift monitoring. Some parts of the algorithm are different compared to earlier systems. However, I have removed the word novel from the manuscript to avoid overstating of the novelty.

Major comments 1. Missing details regarding radar system and data acquisition approach I for one would be interested to know the make and model of the radars used in this study and how the imagery were acquired in the form used for analysis. This information is also a consideration for reproducibility

Most of the Finnish coastal radars are produced by a Finnish company Navielektro. However, the model of the radar is not essential because the image capturing device can be connected to operate with most radar systems, it has e.g. been installed onboard the Finnish RV Aranda (using FURUNO radars) and onboard some Finnish ice breakers (various radar producers). The radars are common surveillance or ship radars. No specific radars for sea ice detection have been used in our studies. A section on the image capturing has now been included in the manuscript.

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- Was the imagery reproduced from the raw video signal, or did the authors use some kind of screenshot of the radar display?

The imagery were produced from the raw radar signal by the radar server. This has now been described in the manuscript.

- In section 4.1, the author refers to 8-bit imagery. Is this the full bit depth of the raw data, or was the dynamic range of the data reduced for analysis?

The original A/D conversion produces 12 bit raw data which is quantized to 8 bits per pixel for the digital imagery. The 8 bpp imagery seems to be adequate for e.g. sea ice monitoring.

- Was any additional hardware necessary to obtain the imagery?

The radar server performs the image acquisition, as described in the manuscript.

2. Missing references to and discussion of other relevant literature The authors make reference to one paper discussing the tracking of ice using land-based radar in Barrow, Alaska (cited at Rohith et al., 2013, but should be MV et al., 2013; please see my minor comment below) but they miss a much broader body of relevant work extending back to the 1970s [e.g., Shapiro, 1975; Shapiro and Metzner, 1989; Mahoney et al., 2007; Druckenmiller et al., 2009; Jones, 2013; Mahoney et al., 2015]. The two most recent of these are probably the most relevant as they use the methodology described by MV et al., which has notable similarities to the approach described in this manuscript. Jones (2013) presents an analysis of landfast ice deformation observed by coastal radar in the context of landfast ice stability, while Mahoney et al (2015) include a discussion of errors and a comparison with independent observations of ice motion.

Thank You! I have added these references.

3. Sensitivity / limitations of VB identification and tracking The text states that the number of VBs populated in any image sequence can be controlled by the search radius parameter,  $R_s$ , but I feel it would be helpful to have some discussion of the

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limitations of the number of VBs that can be identified and tracked. This important for any subsequent analysis of ice kinematics as it controls the effective spatial resolution with which the ice velocity can be resolved. It would also be important to discuss other factors (such as image quality and atmospheric noise/artifacts) that control the number of VBs can be tracked. In particular, can the author use information from cases where the correlation of a VB was lost to better understand trackability of ice features?

Only the VB's which have higher cross-correlation than  $T_{cc}=0.9$  (the value used here) are tracked and otherwise they are lost. So, only in the areas where there exist such ice features which have high signal-to noise ratio (ice/open water edges, ice ridges, radar shadow areas) can be tracked. In areas with no significant features, VB's can not be assigned and ice can not be tracked, because tracking would not be reliable. In typical Baltic Sea ice conditions there are enough features for VB reasonable tracking, because most of the area is drift ice and the ice is not very thick, the ice drift will produce ice deformation (e.g. ridges) visible by radar. If a VB is lost by the algorithm it has typically drifted so far from the radar that SNR becomes too low for reliable detection. Continuous monitoring is enabled by adding new VB's. Some artifacts can cause loss of VB's, this is at least partly corrected by adding new VB's e.g. if some poor-quality radar imagery appear, the tracking automatically continues after the image quality has improved and new VB's have been generated. The lost targets were typically lost as they had drifted away from the radar and SNR had become lower. In general the number of traceable targets depends on the density of good scatterers (deformed ice, e.g. ridges) within the radar range. The parameters have been selected such that adjacent VB's are not very close to each other, by adjusting the radius parameter more VB's can be generated, but it would not make much sense to track very close VB's because probably their drift is very similar.

There may be periods when there is noise in the radar imagery due to weather conditions (e.g. heavy wet snowfall or radio-frequency interference) and many VB's can then be lost and the tracking is in practice interrupted. However, the system recovers

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automatically by adding new VB's as soon as the radar signal is useful again.

4. Expanded discussion of results required The discussion of ice motion in each of the test cases is highly descriptive. The ice drift data shown in the figures ought to allow the calculation of range of drift statistics such as acceleration, divergence/shear, rotation, dispersion, correlation length, etc, but instead the text contains only highly qualitative descriptions of the ice motion such as “very slow” and “rather coherently”. Tantalizingly, the author states that acceleration could be calculated “if necessary”, but I was disappointed to see that it was not deemed to be so. Figures 10 and 14 provide timeseries of estimated divergence derived from triplets of VBs, but there is only minimal discussion of these results and Figure 10 is not actually cross-referenced in the main text. Moreover, understanding and quantification of errors becomes increasingly important when calculating differential motion and without any such analysis it is difficult to assign significance to these results.

The discussion has been extended, but no more derived quantities have been computed. Estimates of the acceleration can roughly visually be estimated as the slope of the velocity plots, we only give some samples of the largest acceleration in the updated manuscript. A short section on estimation of the estimation errors has also been included. The main goal of this study was to develop a system capable of continuous stand-alone ice drift and testing it with radar imagery time series.

Minor comments.

in typical usage, “landfast” is a single word. Please correct throughout

Corrected.

p 4703, line 15: Please correct “Barrow Sea” to read “the Chukchi Sea near Barrow, Alaska”

Corrected.

p 4703, line 17: Rohith is the first name of the first author of this paper. For publication

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his last name is abbreviated to MV, so this citation should be (MV et al., 2013). Please also correct the full citation in the reference list.

Corrected.

p 4703, line 15-17: I think this section of text could be rephrased to make it clearer to the reader that it was MV et al. who examined radar data in Barrow. To the casual reader, it might appear that Lucas and Kanade did this work.

Rephrased.

p 4712 line 19: please correct “floats” to “floes”

Corrected.

Sincerely, Juha Karvonen, FMI

Please also note the supplement to this comment:

<http://www.the-cryosphere-discuss.net/9/C2016/2015/tcd-9-C2016-2015-supplement.pdf>

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Interactive comment on The Cryosphere Discuss., 9, 4701, 2015.

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