The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-245-RC1, 2020

The Cryosphere
Discussions
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Interactive comment on "Estimating instantaneous sea-ice dynamics from space using the bi-static radar measurements of Earth Explorer 10 candidate Harmony" *by* Marcel Kleinherenbrink et al.

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Received and published: 26 November 2020

Review: Estimating instantaneous sea ice dynamics from space using the bi-static radar measurements of Earth Explorer 10 candidate Harmony

by Marcel Kleinherenbrink and 8 co-authors

General comments:

Overall, the authors present a very thorough analysis regarding the potential of the

Harmony mission concept for retrieving parameters characterizing sea ice dynamics: short-term ice drift and deformation (here divergence and shear) as well as spectra of ocean waves travelling into sea ice at the marginal ice zone. Equations for calculating the sea ice drift vector from the "double" bistatic configuration are derived and explained; due to the lack of corresponding measurements, bistatic backscattering coefficients are calculated based on a theoretical model; and considering the noise-equivalent intensity, the "velocity noise" is estimated. In addition, a filtering scheme is suggested to reduce noise and preserve discontinuities in the drift velocity field. Finally, a possible methodology for the retrieval of wave spectra from ocean swell in sea ice is sketched. The paper is well written and structured and should definitely be published. Nevertheless, before publication some mostly easy-to-fix modifications are required to make the text easier to understand for readers who are not familiar with the details of this field of application.

Specific comments:

In addition, I think it is also necessary to sharpen the argument for the importance of Harmony in sea ice drift and deformation retrieval. A major argument in this paper for using data of the proposed Harmony mission is the availability of two-dimensional "instantaneous" sea ice drift vectors. What does "instantaneous" mean when linked with the Harmony mission? Why is the instantaneous drift important for understanding sea ice dynamics? In my opinion this requires a more detailed explanation.

The instantaneous ice drift is obtained from two measurements with a time offset Δtb = BATI/2Vsat, equation 2 in the article. With 6.7 km/s (for Sentinel-1) and 300 km ATI-baseline, one obtains 22.4 s. This is a significant difference compared to the sub-seconds "instantaneous" movements from tandem ATI as described by Dammann et al. (The Cryosphere, 13, 1395–1408, 2019) or from Doppler-shift as proposed by Kræmer et al. (IEEE Transactions on Geoscience and Remote Sensing, Vol. 53, No. 12, December 2015) and should be mentioned.

The sea ice model simulations (section 2.1) were carried out with time steps of 200 s (hence larger by a factor of 10 compared to Harmony's temporal baseline). In order to assess how representative instantaneous snapshots are for characterizing sea ice drift and deformation, it would be useful to provide a typical range of time intervals over which sea ice drift can be assumed to be constant. Perhaps this is known from buoy measurements? It is understood that this is dependent on the temporal variability of the external forces and the internal "reaction time" of the ice. And how fast are ice velocities changing in break-up or closing events? It would strengthen the arguments for the need of the Harmony mission if these questions are addressed (e. g. in a discussion section), as well as including brief examples why and how the information about different temporal scales is actually used in the models.

It has also to be considered that there are large time gaps between single instantaneous drift measurements ("epochs" in Fig 7 of the article) – how large are these time intervals for an anticipated mission scenario, dependent on latitude? I assume that a direct comparison between model results and instantaneous observations will not be very useful considering the usual lack of knowledge about short-term spatial and temporal variations of the forces acting on the ice.

Page 16, lines 357-366: The retrieval of feature tracking and pattern matching is not restricted to image pairs acquired with a one day's temporal gap, this depends on the number of available satellites and the latitude. Nevertheless, it is true that the actual drift distance is underestimated at larger time gaps. But also Harmony cannot close this gap, since only short-term (20 s) snapshots of the drift field are available, with larger temporal gaps between single snapshots (and in this case, there is only one passive-active SAR formation, i.e. time gaps between short-term snapshots are the same as for the retrieval of the average drift from an image pair acquired with one satellite). The advantage I see is that we will get a much better picture of possible variations and temporal scaling of the drift velocity (also available from buoys) with high spatial resolution over a large area at a given time (not possible with buoys). Here, both

the traditional tracking methods and bistatic measurements provide important contributions. For the marginal ice zone, the retrieval of ice drift employing feature tracking and pattern matching is indeed often very difficult, this is hence another advantage of Harmony (but still the argument of the long time gaps between snapshots applies).

Technical comments:

(a) "Speckle tracking" requires coherency, and results in sub-pixel accuracies of (slow glacier) ice displacements. However, unfortunately we cannot use this technique for the retrieval of sea ice drift from two overlapping SAR images that were acquired with a time gap of several hours. In this case speckle is NOT correlated, and the methods used for estimating average displacement or drift vectors are either feature tracking or pattern matching (described, e.g. in A. A. Korosov, P. Rampal, "A combination of feature tracking and pattern matching with optimal parametrization for sea ice drift retrieval from SAR data", Remote Sensing 9, 258).

(b) I recommend to include the papers by Dammann et al. and Kræmer et al. mentioned above either in your introduction or in a discussion section and emphasize the difference between their and your "instantaneous" drift field.

(c) A table with numbers for baselines (ATI, XTI, critical) and other Harmony mission parameters would be useful.

(d) Bistatic SAR, "bistatic angle", "bistatic distance", along and across-track baselines for stereo and close-formation mode – since many readers will not be familiar with the concept of bistatic SAR, a drawing showing the major geometric elements used in your text would also be useful (extension of Fig. 1, or addition to it)?

(e) Page 5: At the bottom you refer to the previous section in which you describe orientation and geometry but on page 3 you mention that a detailed overview of Harmony's observation geometry will be discussed in a separate publication (line 80)? Please explain the angles in equation (3).

(f) Page 6: Equations under (5) are central for this paper. This may also include equation (7). In what mostly follows after equation (5), your focus is on the drift field (and not radar intensity). I think one should emphasize this even more strongly than done in the recent text.

(g) On page 7, line 170, you state that you can ignore baseline decorrelation in the Stereo formation because the phase centers are separated by only a few meters. Here you talk about cross-track decorrelation between each of the Harmony satellites and the Sentinel-1 satellite? What about the temporal baseline in XTI-(close-) formation?

(h) You assume that the volume decorrelation can be ignored. You can mention that formally this is not a problem: if the volume decorrelation is < 1, then the total decorrelation in Eq. (8) decreases further. Hence your results can also account for the effect of volume decorrelation, but you can't link its magnitude with specific ice properties (low salinity ice such as multi-year or brackish ice).

(i) Is the description of the Komarov model in such detail necessary, or would it be sufficient to refer to the two referred Komarov papers? If you think that it is necessary to include all equations in the paper you should move them to an appendix.

(j) What are the criteria for selecting a certain scale factor in Eq. (32)?

(k) Page 11, line 271: Edges are kept if they have more than 50 pixels connected together - what is the pixel size (is it 1km x 1km as mentioned one page earlier, line 251)? This means that discontinuities shorter than 50 km are ignored in the further analysis (determination of divergence and shear)? Please clarify and give a reason for this threshold.

(l) Page 12 line 309: Which ICESAR campaign are you referring to (any reference)? Line 327: does it make sense to consider a negative SNR?

(m) Page 13, Fig. 3, caption: These values were "taken" from Komarov et al. (2019) and Landy et al. (2019). ("agree" indicates somehow that these ice parameters are a

result of your calculations). Line 334: "A change of operational mode will therefore be beneficial for sea ice studies" – valid if you focus on the retrieval of instantaneous drift (and for a few other applications), but not necessarily valid in general. This should be noted.

(n) Page 14: the subswath edges can't be recognized in Fig. 5. Perhaps you should add a zoom-in.

(o) Page 15, line 355: It is ROSE-L, not L-ROSE

(p) Page 16: You talk about velocities in leads - do you mean pieces of ice in leads or the surface current of the water surface? In the marginal ice zone, ice floes may rotate more than in closed pack ice. The rotation causes also a phase shift. Any comments on that? Line 386-387: I disagree – we don't see single ice floes in Fig. 8 and 9 but separate regions with different drift velocity vectors.

(q) Fig. 7: the instantaneous velocities were calculated for a time step of 200 s? Figs. 8 and 9: please add the extent of the images in meters or provide pixel size.

(r) Page 19, lines 410-411, sentence: "This allows to infer swell properties in any direction as the gap is typically smaller than this." I don't understand the second part of the sentence, which gap is smaller than what?

(s) Page 20, line 423 "or" => of

(t) Just curiosity: you mention that the Harmony satellites shall be equipped with a TIR sensor- what are its potential applications? Dependent on the position of the target area of the TIR sensors, they could help to detect thin sea ice and open water leads (under cloud-free conditions).

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