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Interactive comment on "About uncertainties in sea ice thickness retrieval from satellite radar altimetry: results from the ESA-CCI Sea Ice ECV Project Round Robin Exercise" *by* S. Kern et al.

Anonymous Referee #2

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General comments

The authors present an analysis of the effects of snow depth, snow density and ice density on the retrieval of sea ice thickness from pulse limited radar altimetry. They conclude that the Warren climatology is no longer representative of snow conditions, in line with several other studies. They also make recommendations regarding the sensitivity of ice thickness to ice type dependent sea ice density.

One of the main objectives of the study is to 'characterize the uncertainties in the sea ice thickness product based on the uncertainty of the input parameters'. However, as has already been mentioned by another reviewer, the authors do not present an anal-

ysis of the error on the freeboard retrieval itself. This is not an insignificant source of error or possibly bias and is dependent upon several factors including the radar speckle noise, the local sea level interpolation (the abundance of lead measurements), radar penetration into the sea ice pack, filtering of contaminated waveforms, retracker noise/biases as well preferential sampling of larger (thicker) floes. See Ricker et al, 2014, 'Sensitivity of CryoSat-2 Arctic sea-ice volume trends on radar-waveform interpretation', The Cryosphere, 8 1831-1871 for a more detailed discussion of freeboard retrieval uncertainty. The abundance of lead measurements, and sea level interpolation error, in particular is considered to be a significant source of error even for CryoSat-2, and will be more severe for pulse limited systems. Kurtz et al, have also looked in some detail at the freeboard retrieval (again for CryoSat-2) in their paper "An improved CryoSat-2 sea ice freeboard and thickness retrieval algorithm through use of waveform fitting", The Cryophere, 2014, 8, 721-768. There is also the issue of off-ranging to leads biasing the sea surface elevation low, which was examined for CryoSat-2 by Armitage et al, 2014, 'Using the Interferometric Capabilities of the ESA CryoSat-2 Mission to Improve the Accuracy of Sea Ice Freeboard Retrievals' IEEE Transactions on Geoscience and Remote Sensing. Similarly, this effect can be expected to be more severe for pulse-limited systems. Unless this paper is extended to address the impact of the freeboard retrieval uncertainty I feel that the scope of the study should be limited to 'examining the impacts of snow depth, snow density and ice density on ice thickness uncertainties', or something similar. In effect, what the authors have presented thus far is an assessment of the sensitivity of ice thickness retrieval to snow depth and the density of ice and snow that is somewhat independent of the altimeter measurements themselves.

The manuscript is in general well written and the figures are clear however the discussion section, in particular, is quite long-winded and hard to follow. I feel that this section could be trimmed down to 2/3 or even half of it's current length without a significant loss of content.

Detailed comments

P1519 L16: Given the claim that this is the first time a combined time series of ERS1/2 and Envisat data has been constructed, has an inter-satellite comparison been performed to check for inter-satellite biases? These could arise from e.g. differences in the on-board tracking systems. An inter-satellite comparison could be indicative of the accuracy of the freeboard retrieval algorithm and is fairly standard practice when looking at multi-mission time series.

P1521 L9: What does this stand for?

P1521 L22: The number of freeboard measurements per grid cell affects the thickness uncertainty as well as the use of external datasets like snow depth & density. This should be addressed in this paper.

P1522 L3-13: As has been pointed out by another reviewer, the Warren climatology cannot be considered to be valid in Baffin Bay, the Canadian Archipelago or Hudson Bay (as well as the Fram Strait on P1526 L7, figures 4&5) as the polynomial fits are not constrained by measurements in these regions. See figure 1&3 from Warren et al, 1999, for an indication of where there are observations in their climatology. It is not justified to present comparisons in regions where the data are not valid.

P1523 L10: Provide references for this statement i.e. lab work by Beaven et al 1995. It should also be mentioned that this idea has come under question, in particular by Ricker et al, 2014 (above), and justification for continuing use of this assumption should be made.

P1523 L15,26: Do you use different averaging distances for the different datasets? If so, why? Or is this a typo?

P1523-24: How come airborne Electromagnetic sounding (i.e. EM Bird) data has not been used? This could be a useful comparison as it measures the ice thickness directly.

P1525 L15: Please see my above comments about addressing the freeboard uncer-

tainty. As the paper stands you have not addressed all of the input parameters.

P1526 L9,13: Where are these values taken from?

P1526 L15: Both radar and laser altimetry techniques are sensitive snow depth, snow density and ice density, but in different ways. This is not clear from your statement.

P1527-1528: See above comments on the Warren climatology validity.

P1529: See comments on Warren climatology validity. Also, considering that you have shown the Warren snow depth is about double that of OIB and AMSR-E snow depths, it is rather trivial to say that the altimeter 'snow freeboard' is higher than the campaigns freeboard when you apply the Warren climatology. The rationale for converting altimeter freeboard to a 'snow freeboard' should be clarified anyway, or else left out and focus on the sea ice thickness.

P1531 L5: The seasonal range of ice draft derived from altimetry will also be influenced by the seasonal range of snow depths and densities that are applied, as well as the FY/MY ice densities. Would it be possible to examine the effect of using different snow depth/density values as well as ice density values? If not, this should at least be mentioned.

Figure 9: Whilst these results are not particularly encouraging for RA-2 thickness retrievals, I am still not convinced about your freeboard retrievals and data filtering given that you are reporting such large negative thicknesses. Considering that these are monthly, gridded and smoothed data you would not expect to see RA-2 ice thickness of -2.5m. Negative ice freeboards are understandable from a data processing point of view (and also can occur in reality) but on the spatiotemporal scales that you are presenting the data one would not expect to see these large negative thickness values. This requires some explanation.

P1532 L3-9: In line with the points made by another reviewer, and by myself, I think that any comparison between RA-2 and CryoVEx data in the Fram Strait that uses the

Warren climatology in any way should be left out. This includes the “W99”, “AMSR-E+W99” and “KF11” results.

P1535 L25-P1536 L2: I think this is an important point. It should perhaps be put into the previous section where you talk about the sea ice thickness results, to add some balance to the very negative results that you have presented! I think it is almost certain that OIB is much more sensitive to the small-scale range of ice thicknesses – it will pick up pressure ridges where RA-2 will likely not, and will be sensitive to smaller, thinner floes where RA-2 will not.

P1336 L10-24: I do not understand what you are trying to demonstrate here. You seem to be calculating the sea ice density from the ice thickness equation, using values of ice thickness that already assume a particular ice density? What is the benefit of doing this? The derived ice densities are not meaningful since they depend on the density assumed to derive the OIB ice thickness.

P1538 L18-22: Again, I would emphasize that this over/under estimation of ice thickness does not necessarily mean that either OIB or RA-2 are incorrect. Rather it is probably indicative of the spatiotemporal differences between the two retrieval methods – i.e. OIB being more sensitive to e.g. ridging and smaller, thinner floes, RA-2 measuring over one month.

Interactive comment on The Cryosphere Discuss., 8, 1517, 2014.