The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-48-RC2, 2020

The Cryosphere Discussions

Interactive comment on "A comparison between Envisat and ICESat sea ice thickness in the Antarctic" *by* Jinfei Wang et al.

Anonymous Referee #2

Received and published: 17 April 2020

Three Antarctic sea-ice thickness data sets are analyzed: Envisat radar altimeter, ICESat laser altimeter, and Upward-Looking Sonar (ULS). The satellite data sets are compared in five regions and three seasons over several years in the early 2000s. In spring, the mean difference between Envisat and ICESat sea-ice thickness is small, but in summer and fall, the Envisat values are much larger than ICESat. Differences are attributed to lack of radar penetration through wet snow, different footprint sizes, and snow depth assumptions. Relative humidity may explain the seasonal differences that arise from wet snow.

In general, the data comparisons in this paper are done adequately, but the analysis of differences is speculative and weak. I think major revisions will be needed.

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Main Comments

The first paragraph of the Introduction discusses the extent of Antarctic sea ice, but it fails to mention the fact that almost all of that sea ice is seasonal – it completely melts away every year, except in a small portion of the western Weddell Sea. Therefore, it's not clear to me why "sea ice thickness is an equally critical component as sea ice extent" (line 33). I understand the importance of sea-ice extent as a barrier between the ocean and the atmosphere that affects albedo and the exchange of heat and moisture, but I think the authors need to explain better why Antarctic sea-ice thickness is so critical, given that almost all the ice melts away every year.

In the comparisons of ULS data with Envisat and ICESat (Section 3.1) there is no mention of the fact that ULS measurements are made at a single point, whereas Envisat and ICESat measurements are made over large footprints or areas. How might that affect the comparisons?

Lines 232-238. The mean sea-ice thickness in both the Envisat and ICESat data increases from spring to summer. The authors call this an "anomalous thickness growth" as if it can't possibly be true, and they attribute it to "limited comparison pairs" and "uncertainties of both data sets". However, isn't it possible that the mean ice thickness could actually be greater in summer, because the thinnest ice melts away, leaving only thicker ice? Antarctic sea-ice extent is about 18 million sq km in spring and 3 million sq km in summer. Suppose the spring ice extent consists of 15 million sq km of 1.3 m ice and 3 million sq km of 3.2 m ice, for a mean thickness of about 1.6 m (matching the actual spring ICESat mean thickness). And suppose that all the ice loses 1.3 m of thickness in the summer melt. Then only 3 million sq km are left, with a mean thickness of 3.2 - 1.3 = 1.9 m (matching the actual summer ICESat mean thickness). I'm not saying that these are the correct numbers, I'm just pointing out the plausibility of the argument that the mean thickness could be greater in summer than in spring. Of course it requires a more careful analysis.

Section 4 discusses the reasons for the differences between Envisat and ICESat sea-ice thickness: (i) if the snow is wet, the Envisat radar does not penetrate all the way to the snow/ice interface; (ii) the footprints of Envisat and ICESat are different; (iii) snow depth is treated differently in the retrieval algorithms. These are all legitimate potential reasons for the differences between Envisat and ICESat ice thickness, but as presented here, they are speculative and qualitative arguments, not quantitative. For example, consider equation (1) for the ice thickness from Envisat, in which F is the measured freeboard and S is the assumed snow depth. If the radar backscatter is from wet snow within the snow layer, rather than the snow/ice interface, then the measured freeboard F is partially ice and partially wet snow. This would lead to a modification of equation (1) and a new ice thickness I' instead of I. Does the difference I-I' account for the bias in Envisat relative to ICESat? Another example: regarding snow depth, how much of a change in snow depth in the Envisat retrieval algorithm would be needed to account for the bias in ice thickness relative to ICESat? Is this change in snow depth within the uncertainty of the snow depth measurements? Another example: Figures 10 and 11 suggest a connection between ice thickness differences and relative humidity. What is the correlation? Have other researchers considered this connection? Another example: a very simple model of ice thickness is based on cumulative freezing-degree-days (FDD), e.g. Lebedev 1938. Using temperature fields from (say) a reanalysis product, how does a simple FDD ice thickness model compare to Envisat and ICESat ice thickness? Would this provide any insight into biases? My overall point is that the analysis in this paper (Section 4) needs to be more quantitative. The authors claim that "without enough observation data and numerical model experiments we cannot quantify the impacts of the uncertainties over the sea ice thickness." (lines 327-328). But my suggestions above for further quantitative analysis do not require any additional ice thickness data or numerical model runs that are not already publicly available. This is not a question of lack of data, it's a question of digging into the comparisons of Section 3 more quantitatively.

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Minor Comments

Lines 19-23. It's not clear whether the deviations are Envisat minus ICESat, or ICESat minus Envisat.

Line 21. "the large correlation coefficient" – Is this a spatial correlation or a temporal correlation? Please add the word "spatial" or "temporal" as appropriate.

Line 103. Following equation (1), say that rho is density.

Line 104. Give a reference for AMSR-E snow depth climatology.

Line 108. A threshold of 70% is given here, but on line 131 it says 60%.

Lines 125-126. "R is the ratio of sea ice thickness over snow depth, which is a seasonally dependent factor and calculated from ASPeCt observations." I understand that R changes seasonally, but does it also change from year to year based on ASPeCt observations?

Line 139, equation (4). Please provide UNITS for the quantities in this equation.

Line 146. "the deviations." – please say explicitly "the deviations between Envisat and ICESat sea-ice thickness" or whatever deviations are being referenced here.

Lines 151-153. "The seasonal classification is based on the ICESat operating periods... If ICESat data has overlapping time over ten days with respective months, we average Envisat data over the two months." OK, but wouldn't it be better to do a time-weighted average of the monthly Envisat data to match the ICESat period? For example, consider the ICESat period from Feb 17 to Mar 20. Instead of averaging Envisat over all of February and March, consider this: the ICESat period is 32 days long – 12 days in February and 20 days in March. So calculate: (Env. avg.) = (12/32)*(Env. Feb.) + (20/32)*(Env. Mar.) Wouldn't that provide a more accurate Envisat average with which to compare ICESat?

Line 164. For the ULS data, I understand that "207" refers to location #207 in Figure

2, but I don't understand "207-6" – what is the "6"? Please explain your numbering system.

Line 168. "Due to the discontinuity..." – what discontinuity?

Lines 173-174. In Figure 4, where do the error bars come from? What do they represent? One standard deviation? 95th percentile?

Line 190. It would be helpful to indicate on one of the maps the location of the Ross Ice Shelf polynya and the Ronne Ice Shelf polynya.

Line 192. I think "clockwise" should be "counter-clockwise". Please check.

Lines 216-217. "Comparing the values in the eastern Antarctic, ICESat shows some deformed ice up to 3 m while Envisat shows smaller thickness by about 1.5 m." I don't see this in Figure 7. Please give approximate longitudes or otherwise indicate in Fig 7.

Lines 241-242. In reference to Figure 9, "In the western Weddell Sea, the regression lines have large positive intercepts in all three seasons." Yes, this is true for all five regions, not just the western Weddell Sea.

Lines 261-262. "ICESat uses the modified snow-ice density to get rid of the biased snow depth." I don't see how equation (2) would get rid of a biased snow depth. The snow depth S is part of the factor R = I/S.

Lines 295-298. "wet snow caused by melt or flooding could lead to underestimations while refreezing of molten snow could lead to overestimations [of snow depth]. All of the above biases can also cause the differences between Envisat and ICESat." I don't see how underestimates AND overestimates of snow depth can BOTH lead to a positive bias in Envisat ice thickness relative to ICESat. Please clarify.

Lines 300-301. "in underestimations of snow depth... the sea ice thickness deviation presents negative." It's not clear to me whether "deviation" refers to the error in the Envisat ice thickness, or the difference Envisat-ICESat ice thickness. Consider equation

(1). If the snow depth S is an underestimate, then the true snow depth S' > S. If the measured freeboard F remains constant, then the true ice thickness I' > I. The error I-I' < 0 (i.e. negative error in the original estimate I). On the other hand, I'-ICEsat > I-ICESat (i.e. increased bias of Envisat). Please clarify the use of "deviation" and the effect of snow depth on the calculated ice thickness.

Figure 2. It would be helpful to outline the zero contour (the coastline) to make it easier to distinguish land from ocean. Also, the caption should say that the background is bathymetry, and give the source of the bathymetry data.

Figure 3. Please add at the end of the caption: "with 50 km grid size."

Figure 4. See comment above for line 164: I understand that 207 refers to a location in Figure 2, but what does "207-6" mean? Also, see comment above for lines 173-174: in the caption, say what the error bars represent. Also, the dates along the horizontal axes should be in a more readable format such as 2008/03 instead of 200803. Perhaps the journal has a standard format for such dates.

Figure 6. Consider rotating the whole figure into landscape mode, which would allow the panels to be larger.

New table. This is just a suggestion, but I found it helpful to create a table for myself of the different data sources, their spatial and temporal resolutions, and their treatment of snow. For example:

Source | Spatial res | Temporal res | Snow

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Envisat | 50 km grid | monthly avg | AMSR-E climatology

ICESat | 100 km grid | see Table 1 | ASPeCt observations

ULS | single point | monthly avg | built into eq (4)

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Typographical Corrections

Line 14. Change "firstly" to "first"

Line 14. After "ICESat ice thickness" add "product"

Line 23. Change "deduce from" to "come from"

Line 47. Change "provides" to "provide"

Line 56. After "ice thickness data" add "set"

Line 96. Delete the URL. It is given in the "Data availability" section on page 11.

Line 98. Change "month" to "months"

Line 100. Delete the word "data"

Line 108. Change "girds" to "grids"

Line 133. Change "provides" to "provide"

Line 135. Delete the word "criterion"

Line 143. Perhaps "for that" should be "because"?

Line 160. Delete "at first"

Line 164. Delete the word "Basically,"

Line 172. Change "Envisat thickness exceeds ULS remarkably" to "Envisat thickness greatly exceeds ULS"

Lines 186 and 188. Change "seems" to "is"

Line 199 and following. "by -0.03" should be "of -0.03". In most of the paper, "by X.XX" should be either "of X.XX" or "at X.XX" depending on context.

Lines 205 and 206. Change "reveals" to "shows". The word "reveals" means that something previously hidden or unknown is now exposed, implying that the revealed value is the true value. But in this case, the "revealed" value may be biased or uncertain, so it's better to say "shows".

Line 207. Change "which can also be reflected from the..." to "which is also reflected in the..."

Line 220. Change "disability" to "inability"

Line 221. Delete the word "from"

Line 227. Change "malposition between two histograms" to "offset between the two histograms"

Lines 230-231. Change "while ICESat during 1.0 m" to "while ICESat peaks at 1.0 m"

Line 231. Change "and a mean thickness" to "with a mean thickness"

Line 231. Delete the word "two"

Line 231. Change "the thin ice smaller than" to "the ice thinner than"

Line 232. Change "smaller" to "thinner"

Line 233. Change "grow" to "grows"

Line 244. Change "The comparison results perform better" to "The results are better"

Line 248. Change "little" to "few"

Line 249. Change "deduce" to "arise"

Line 250. Change "quantity" to "quantitative"

Line 254. Delete the word "that"

Line 255. Delete the words "implementation of"

Line 260. Change "Another one" to "Another difference"

Line 280. What is "shorter" ice? Does this mean "less extensive" in area?

Line 281. Does "wider" mean "more extensive"?

Line 283. Delete the word "loaded"

Line 287. Delete the words "used in the retrieval"

Line 296. What is "molten snow"? Is it "wet snow"?

Line 315. Change "deduce" to "come"

Line 320. Delete the word "affected"

Lines 324-325 and lines 327-328. These sentences say the same thing. It's not necessary to repeat.

Line 331. After "sea ice thickness" add "data"

Figure 5 caption. "first and second rows" (rows – plural) and "the last row shows" (shows – singular). Yes, English is strange.

Figure 8 caption. "red line" should be "red lines"

Table 1 caption. Say that ON is Oct-Nov, FM is Feb-Mar, and MJ is May-June.

Table 2 and Table 3 captions. Spell out "sea ice thickness" instead of SIT. Also say that CC stands for correlation coefficient.

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