Response to the review tc-2019-120-RC2 by anonymous reviewer #2
of Reviewing Satellite Passive Microwave Sea-Ice Concentration Data Set Intercomparison:
Closed Ice and Ship-Based Observations by Kern et al.

Summary:
This paper presents detailed comparison and analysis of several passive microwave sea ice concentrations. A general intercomparison between products is done evaluate biases between products and differences in trends and variability. Then the concentrations are evaluated by comparison with a validation product consisting of high confidence 100% concentration observations, and with ship-based observations. The results showed varied performance by the different products, which depend on regional and seasonal conditions.

General Comment:

This is a very detailed manuscript and will serve as a solid reference for understanding differences in the different passive microwave products. The analyses are logical and thorough. The manuscript is generally well-written, although there are some areas of repetitiveness and verboseness that could be shortened. A main issue of the paper is that it is quite long. In some ways, it almost feels like two or even three papers – each part (the product intercomparison, the 100% validation, and the ship observation comparisons) could be a paper in its own right. However, I can see the value in having all the information available in one document. Thus, much of the length is justified by the content, but I do think some areas could be made more concise, and while there are already substantial supplementary appendices, perhaps more material could be shifted to there.

Thank you very much for your positive opinion of our manuscript. We agree with the view of the reviewer with regard to the length of the paper, shared by reviewer #3 and the editor. We reduced the areas of repetitiveness and verboseness – particularly by shortening description of figures and tables in sections 3 through 5 and by including a lot of the information from section 6 into the respective sections 3 through 5. We note that comments of this reviewer and of the other reviewers triggered the inclusion of additional information, which again lengthened the paper. Overall, the net effect is a shortening by 3 pages.

Another issue is that there are a lot of numbers thrown around – biases, RMS, Rsquared values. These can be hard to read inline in the text and seem to be well summarized in the figures and tables. Thus, I would advise considering focusing less on the numbers in the main text and more on the fundamental behaviors (e.g., lower biases vs. higher biases).

We are grateful for this comment. In the revised version of the manuscript we have avoided to overload the text with these statistical values and tried to concentrate more on the relations between the products.

Overall, I would say minor revisions are required. The biggest effort may be in shifting/cutting some text, but I don't think this would be too difficult. Specific comments are below.

Specific Comments (by line number):

111-112: Important to note here that it is a polar stereographic grid and is not equal area (that's implied with the 70 latitude comment, but should be stated explicitly for clarity)

Thank you for the comment. We agree and added "*which are provided on polar-stereographic grid*" in L111 behind "*For all other products*"

126-176: I know the weather filters are quite critical, but these seems to be algorithm info that might be best shifted to the Appendices with the other algorithm info. Maybe here simply note why the weather filters are important to the study and leave the details to an appendix.

We agree with the reviewer that the information about the weather filters is kind of a detail of the algorithm description. However, our impression gained from our review about how which algorithm / product treats the weather influence and how spurious ice remaining from unaccounted weather influences is filtered (or not) is: This information is not easy to extract and that it might be beneficial to place this information at a more prominent place in our paper than the appendix would be. In addition, the length of sea-ice concentration time series, the requirement for long-term stability across satellite sensors, and the sea-ice concentration threshold used (so far) to compute sea-ice area and extent (which are deemed so important for every years' discussion about potential acceleration of sea-ice cover trends) warrants a closer look to the differences in and the effects of weather filters. This is the second reason why we think that the weather filters deserve to receive more attention in our paper than the general algorithm description.

Therefore, we did not move this part into the appendix but kept it where it is.

233-237, 247-254: an area where things could be shortened. The first part talks about how the Arctic uses a different protocol than ASPeCt, then the part discusses that protocol, ASSIST. These could be combined and shortened so you have: Antarctic, ASPeCt; Arctic, ASSIST.

Thank you for the suggestion. We modified the text as follows:

Added in L229 (after Worby et al. 2008): "*and the IceWatch/ASSIST (Arctic Ship-based Sea-Ice Standardization) protocol (http://icewatch.gina.alaska.edu)*"

Deleted in L233-237: "*Such a protocol was not implemented in the Arctic in the same rigorous way as in the Antarctic. Nevertheless, ship-based visual observations were carried out as well during numerous cruises into the Arctic Ocean and its peripheral seas, using a slightly different protocol, established in the late 2000s. The need for a slightly different protocol can be explained by various forms of melt on Arctic sea ice, which are largely lacking for Antarctic sea ice.*"

Changed in L239/240: "*About ~7000 of these were carried out in the Antarctic under the framework of the ASPeCt protocol.*" into "*About ~7000 of these were carried out in the Antarctic (ASPeCt) and ~8000 in the Arctic (IceWatch/ASSIST).*"

Changed in L242-244: "*Beitsch et al., 2015), merged with the existing ASPeCt data and standardized. Standardization means that the resulting ascii format data file containing all observations uses similar formats for all variables and missing data.*" into „*Beitsch et al., 2015) and merged with the existing ASPeCt data. The majority of the ASSIST data is taken from the data portal http://icewatch.gina.alaska.edu. Additional sources for ASSIST data are PANGAEA (for Polarstern cruises before IceWatch/ASSIST), the Arctic Data Center of the NSF: https://arcticdata.io/catalog/#data, and the data archive of the Bering Sea Ecosystem Study (BEST): https://www.eol.ucar.edu/projects/best/ice.shtml. All data are standardized, i.e. the ascii format data files containing the observations use similar formats for all variables and missing data.*"

Changed in L244-246: "*For the comparison presented in this manuscript, we use all ASPeCt observations from the period June 2002 through December 2015. This data set is available via http://icdc.cen.uni.hamburg.de/1/daten/cryosphere/seaiceparameters-shipobs, last access date: 28/3/2019.*" into "*For the comparison presented in this manuscript, we use all ASPeCt and IceWatch/ASSIST observations from the period June 2002 through December 2015. This data set is available via http://icdc.cen.uni.hamburg.de/1/daten/cryosphere/seaiceparameters-shipobs, last access date: 28/3/2019.*"

Deleted L247-254: "*In the Arctic, ship-based sea-ice observations have been collected under the IceWatch/ASSIST (Arctic Ship-based Sea-Ice Standardization) initiative and are available via http://icewatch.gina.alaska.edu. The majority of the data used in this manuscript for the Arctic is taken from that portal. Additional sources for ship-based sea-ice observations are again PANGAEA (for Polarstern cruises before IceWatch/ASSIST), the Arctic Data Center of the NSF: https://arcticdata.io/catalog/#data, and the data archive of the Bering Sea Ecosystem Study (BEST): https://www.eol.ucar.edu/projects/best/ice.shtml. In total ~8000 observations are available for the Arctic. We prepare these data in the same way as the ASPeCt observations for the Antarctic and use all observations from the period June 2002 through December 2015. This data set is available via http://icdc.cen.uni.hamburg.de/1/daten/cryosphere/seaiceparameters-shipobs, last access date: 28/3/2019.*"

280-281: One area not clearly explained is how the monthly average concentrations were derived. Was it simply the average of the concentration for all days in the month? Was a 15% cutoff used?

The monthly average sea-ice concentration is the average of the concentration for all days in the month over the entire sea-ice concentration range including 0%. We added in L282: "*using data of all days of a month of the entire sea-ice concentration range including 0%.*"

290-310: this section seems either repetitive of early content (weather filters), or what comes later. Figures 6-11 are all introduced here, but aren't discussed until the following sections. That means the figures are referenced twice, which is wasting words.

We see the point of the reviewer and changed the text of this introductory part to Section 3. We changed the title of the section to make clear that we treat SIA, SIE and the distribution here. We remove all references to figures and instead refer to the subsections where appropriate. We deleted text.
L279: Changed "*Inter-comparison of sea-ice area and extent*" into "*Inter-comparison of sea-ice area, extent, and distribution*"
L281: Added "*(Subsection 3.1 and 3.2)*" behind "*extent (SIE)*"
L290-293: Deleted: "*The two most relevant filters applied are the open-water filter, and a statistical land spill-over removal filter (Lavergne et al., 2019). In addition, these filtered sea-ice concentrations are truncated to values between 0% and 100%, even though the retrieval naturally provides a sea-ice concentration distribution around these two values (see Fig. 3 and Lavergne et al. (2019)).*"
L293: Changed: "*this truncation*" into "*the truncation*"
L295-297: Deleted: "*In Fig. 6, we present the SIA and SIE time series of months March and September for the Arctic; in Fig. 8 we show the SIA and SIE extent time series of months February and September for the Antarctic. The months chosen reflect the time of the typical minimum and maximum SIA and SIE.*"
L299: Deleted: "*in the Arctic (Fig. 7) and in the Antarctic (Fig. 9 and Fig. 10)*"
L300: Added: "*(Subsection 3.3 and 3.4)*" behind "*September 2011*"
L303/304: Deleted: "*(see map k) in Fig. 7 and Fig. 9 and 10)*" and "*(all other maps in Fig. 7 and Fig. 9 and 10)*"
L305-310: Deleted: "*Finally, we summarize differences between the mean sea-ice concentrations of all products and differences between the mean SIA and SIE values of all products in Fig. 11 and in Appendix G, Fig. G1 through Fig. G6. Similarly to the sea-ice concentration maps mentioned above, we re-grid the monthly mean sea-ice concentration onto the EASE grid version 2.0 with 50 km grid resolution using bilinear interpolation and apply a common land mask (the one of SICCI-50km) to all products. The differences between SIA and SIE values shown in Fig. 11 are computed from these gridded 50 km resolution, common land mask products.*" Note: We put the relevant information in here into the text describing former Figure 11, now Figure 9.

344-352: Outside of 290-310, Figure 11 here is referenced in the text before Figures 8, 9, 10. Taking my suggestion for 290-310, then Figure 11 shouldn't be mentioned until after Figures 8-10. You could split Figure 11 into separate Arctic and Antarctic figures and reference the Arctic here. Or simply wait and add this discussion for both hemispheres at the end of Section 3.

We re-arranged subsections 3.1 to 3.4 and split Figure 11 into an Arctic and an Antarctic part such that we first discuss SIA and SIE for the Arctic (subsection 3.1) and the Antarctic (now subsection 3.2, formerly 3.3) and subsequently discuss the sea-ice concentration distribution for the Arctic (now subsection 3.3, formerly 3.2) and the Antarctic (subsection 3.4). In subsections 3.3 and 3.4 we put the respective parts of the split Figure 11. Note that figure numbers have changed: former Figure 8 became new Figure 7, former Figure 7 became new Figure 8, former Figure 11 a) to f) became new Figure 9, former Figures 9 and 10 became new Figures 10 and 11, and former Figure 11 g) to l) became Figure 12. Note that the number of all subsequent figures increased by one.

354-362: One thing not really discussed in detail is the impact on spatial resolution on the results. At least some of the biases between products – especially for SIE – is due to different spatial resolution (not only gridded by the sensor footprint size), particularly between AMSRE and SSMI-based products. This should be discussed in some detail to put the results in context. As noted, for area, the effect is small because the concentrations tend to be low at the ice edge, but for SIE, even a 25 km resolution effect, summed around Antarctica can be 100,000s of sq km in SIE.

We thank the reviewer for pointing this issue out. The time-series of SIA and SIE are computed at the native grid resolution; here this effect certainly can have a contribution. But also for the SIA and SIE values shown in (old Figure 11 g) to l), new Figure 12), which are computed from 50 km EASE2 grid sea-ice concentrations this possibly has an influence.

We now discuss this in subsection 3.5: "*We note that the grid resolution of the products is not necessarily compatible with the true spatial resolution because the footprints of the satellite sensor channels used in some of the algorithms is coarser (Table 2). This applies to NT1-SSMI, CBT-SSMI, NOAA-CDR, and OSI-450, i.e. the products at 25 km grid resolution based on SMMR, SSM/I, and SSMIS data. For these products, we expect that gradients in the sea-ice concentration are more smeared than for products with a better match between footprint size and grid resolution as, for instance, CBT-AMSRE or SICCI-25km. This is illustrated for OSI-450 and SICCI-25km in Lavergne et al. (2019, Figure 6). For a typical wintertime Antarctic ice edge at 65°S comprising half a compact and half an open sea-ice cover, this difference in the match of true resolution and grid resolution between SSM/I and AMSR-E products would result in a slightly larger SIE (by ~200 000 km²) derived from the SSM/I product. This is because a compact ice edge is smeared more in the SSM/I product, creating more grid cells with a sea-ice concentration > 15%, the threshold used currently to compute SIE. In fact we find that during winter OSI-450 SIE exceeds SICCI-25km SIE by ~100 000 km² in the Arctic (Fig. 9 c) and by ~200 000 km² in the Antarctic (Fig. 12 c). Since the algorithms used for the sea-ice concentration retrieval for these two products are almost identical, the difference in SIE can well be attributed to the above-mentioned impact of differences between true and grid resolution. The second pair of almost identical algorithms is CBT-SSMI and CBT-AMSRE. In the Arctic, for winter, CBT-SSMI SIE exceeds CBT-AMSRE SIE by ~400 000 km² (Fig. 9 c) but in the Antarctic CBT-SSMI SIE is smaller than CBT-AMSRE SIE by ~100 000 km² (Fig. 12 c). Differences in the algorithm itself and/or in the weather filter might be the cause.*"

453-456: I guess a question here is whether the truncation is done intentionally. Setting the tiepoint to get a mode a little higher than 100% does, as the authors note, improve the statistics. It's admittedly for the wrong reason and can result in further problems and it does skew estimation of uncertainty. But I can also see the logic to set things a bit high to avoid underestimation at <100% concentration. I guess one question here is: how much difference does it make? Does setting the mode for 100% at 101% or 102% make a significant difference, e.g., in terms of heat fluxes? This is discussed in another comment further below.

Thank you for this idea. We are happy to include it into our paper – actually in Sect. 6.1.3 – as follows: "*However, one consequence of this (hypothetically) shifted sea-ice concentration distribution with modal values > 100% is that the sea-ice concentration in areas with a true < 100% sea ice concentration, i.e. 99% or even 98%, might be set to 100%. Such areas could contain leads. According to, e.g., Marcq and Weiss (2012) about 70% of the upward ocean-atmosphere heat exchange occur through leads even though these cover only one to two percent of the Central Arctic ocean. Assuming a heat transfer through thick ice of 5 W/m² and through a lead of 400 W/m² (e.g. Marcq and Weiss, 2012, near-surface air-temperature difference of 30K) a heat flux calculation yields 5 W/m² for 100% and ~ 9 W/m² for 99% true sea-ice concentration, an increase by 80%. Using sea-ice concentrations of an algorithm with a modal value at 101% or higher might therefore result in a substantial under-estimation of the surface heat flux. Integrated over the central Arctic Ocean (area ~ 7 million km²) this under-estimation could be as high as 2.4 * 10^12 MJ per day.*"

402-528: This section is quite long and somewhat difficult to read through and keep track of all of the numbers. This is a section that could perhaps be shortened by leaving numbers to figures and tables and focusing on the key takeaways.

Thank you for this suggestion. We have shortened this section accordingly. However, in an effort to reduce redundancy between this section and section 6 we included relevant parts of section 6 in this section.

606-608: But the authors note earlier that these are the concentration ranges where ship-based obs are least reliable. So, are the differences errors in satellite or in the ship obs?

This is true and it is difficult to come to a concluding statement here. We changed the layout of this paragraph completely because we felt that part of the information given here was not to the point (and partly even not correct) and because we also had a comment from reviewer #3.
We changed:
"*Binning the sea-ice concentrations of one data set, e.g. ship observations, into 10% wide bins and computing the mean sea-ice concentration of the other data set, e.g. here satellite observations, results in the red symbols in Fig. 15; doing the same but exchanging ship- and satellite observations in the blue symbols in Fig. 15. The motivation for such a step comes from the notion in Sect. 2.3 that the average accuracy of the ship-based sea-ice concentration observations is 10%. From these binned values and associated regression lines we find: 1) Ship-based observations in the range 50% to 80% are under-estimated by the satellite-based ones, particularly by the EUMETSAT-OSISAF – ESA-CCI products as illustrated in Fig. 15 e to h): a mean satellite sea-ice concentration of 55% compares to a ship-based sea-ice concentration of 70%. The only product where this is even worse is NT1-SSMI (Fig. 15 a). 2) Red regression line slopes of ESA-CCI products are closer to 1 than the black ones. For most of the other products – except CBT-SSMI and NOAA-CDR – red regression line slopes deviate more from 1 than the black ones.*"
into:
"*We want to better visualize the average distribution of the two data sets and investigate the partitioning of the data into sea-ice concentration bins of 10% width - the average accuracy of the ship-based sea-ice concentration observations. For this purpose we bin sea-ice concentrations of one data set, e.g. ship observations, into 10% wide bins and compute the mean sea-ice concentration of the other data set (Fig. 15, red symbols) and vice versa (blue symbols). The binned values and associated regression lines illustrate even better the above-mentioned asymmetry in the distribution*

of the data pairs. For instance, NT1-SSMI (Fig. 15 a) sea-ice concentrations range between 60% and 100% over a ship-based observations range of 80 to 100%. Consequently, the average NT1-SSMI sea-ice concentration for ship-observation bin 95%-100% is ~85% (uppermost red triangle), while the average ship-based sea-ice concentration for NT1-SSMI bin 95%-100% is ~95% (uppermost blue square). For two equally well-distributed data sets, one would expect that red and blue symbols and regression lines are close to each other. This is not the case and we refer to Sect. 6.1.4 for more discussion of this issue."

694-697: As noted above, spatial resolution of the TB input plays a big role in the location of the ice edge, weather filter, and land-spillover,

We added a discussion of this issue in the manuscript; see our reply to your comment to lines 354-362.

660-882: Section 6.1 is really long and seems to largely repeat the results section before. I think much of this could be shortened or removed completely. I don't think figures should be referenced again – they go with the results. Lines 822-831 are a nice summary and this is what Section 6 should be aiming for, not repeating all the results. Section 6.2 is also good – could almost just do that and remove 6.1.

Thank you for this suggestion. We have shortened this section accordingly. We included relevant parts of section 6.1 into the respective sections 3 to 5 and kept 6.2 as suggested. Hence, section 6 is substantially shorter now.

877: The summer to winter differences in ASI are likely largely due to the atmosphere, right? More moisture in the summer and a bigger effect on TBs. This should be noted here.

It would be obvious to assume that these large differences are caused by the larger atmospheric effect during summer for near-90GHz algorithms. However, there are two issues with that. First of all, this large winter-to-summer difference we only find for the Arctic; it is not present for the Antarctic. Secondly, from winter to summer sea-ice conditions change more in the Arctic than the Antarctic. In the Arctic sea ice is very compact during winter because its mobility is limited; during summer the sea ice cover can be quite open. In contrast, for the Antarctic also in winter the sea-ice cover is more mobile and openings are created year-round; during summer the sea-ice cover might be as open as in the Arctic. We note also that the difference in atmospheric moisture content (water vapor, clouds) between winter and summer can be expected to be smaller in the Antarctic than the Arctic. Therefore, we believe the large winter-to-summer difference in the agreement of ASI SIC with ship-based SIC could only partly be explained with the elevated atmospheric moisture; it is partly also caused by the fact that during the more open ice condition of summer the comparably high-resolution ASI SIC is closer to the ship-based SIC than during winter. Openings during winter are small and cannot be resolved with ASI SIC. Also during winter surface property changes can have a substantial impact on near 90 GHz emissivities and hence ASI SIC. Note that the difference between ASI SIC and ship-based SIC reduces from winter to summer (!). If the elevated summer-time atmospheric influence on ASI SIC would be the cause for the difference in skills between winter and summer than it would be more logical to assume that the difference between ASI SIC and ship-based SIC would increase from winter to summer.
As this is a longer discussion to include, which would touch several issues we will possibly not include this issue in more details into out paper.

900-955: The conclusion also feels very repetitive and overly long. Focus not on just restating results, but providing a concise summary and drawing relevant conclusions.

Thank you for this suggestion. We have shortened this section accordingly.

936: They're empirical models, not "geophysical", right? At least in general.

We changed to wording accordingly.

Appendices: Strictly speaking, the algorithms could just be referenced to their primary source material. However, since these are appendices, and the summaries are nice to have accompanying the paper, they are okay. These could be shifted to supplementary material though, as opposed to appendices in the main manuscript.

We have been discussing this issue among the author team with different opinions. The main reason for putting these descriptions into the appendices and not into supplementary material is that we wish to allow the reader to have this information at hand with one download; downloading supplementary material is always an extra step to take and not everybody is doing it already when downloading the paper itself. We find it important to have the material at hands right away and our paper is also structured that way. We therefore thank the reviewer for rising this issue to our attention again because it has strengthened our view that the place where these descriptions are now is the right one; we did not shift the algorithm descriptions to supplementary material.

Minor Comments (by line number):
60: The acronym for "SMMR" should be spelled out here, the first time it is used.

Changed as suggested.

90, 92: "contribution" sounds odd to me. These are manuscripts, so perhaps just say "manuscript" or "paper" or "journal article".

Changed to "paper".

142: replace "roots" with "is based"

Changed as suggested.

147: not sure if this is a typo or intentional "]0.0% to 30.0%]" – the backward bracket is not something I'm familiar with. I don't see the need for brackets at all. This happens elsewhere in the manuscript as well.

The usage of "]" is intentional because it excludes the value 0.0. We did not change it in the manuscript.

158-159: incomplete sentence

We changed in Line 157 "*with*" to "*who found*"

190: replace "comply with" with "be consistent with"

Changed as suggested.

289-290: this sentence isn't clear to me.

These products contain a "nice" fully-filtered version – which looks like all the other nice products – and which is the version of these products which is possibly going to be used be 95% of its users. However, in addition to this fully-filtered version there is also the possibility to use the non-filtered sea-ice concentrations, i.e. those sea-ice concentrations which are naturally derived by the algorithm and which may fall below 0% or may exceed 100%.
We changed
"*Note that we use the fully filtered and truncated versions of these products, i.e. the variables, which are the main entry point to this product files.*"
to
"*As described in Lavergne et al. (2019), these products contain a fully filtered and truncated to the range [0.0% … 100.0%] version and a non-filtered, non-truncated version of the sea-ice concentration. The latter contains the naturally retrieved sea-ice concentrations, i.e., also values < 0% and > 100% (see Sect. 2.1.3) and no weather filters are applied (see Sect. 2.1.3). We use the fully filtered and truncated version.*"

355: "1980s and 1990s" – no need for "ties"

Changed as suggested.

372: "< -20%" – here you mean, e.g., -30%, -40%, etc., right? As written it's correct, but it can be ambiguous because "<" can imply lower in magnitude. So maybe be more explicit here to be clear, e.g., "differences in negative biases even greater than 20% in magnitude".

We checked our manuscript for the occurrence of such formulations and changed them as suggested.

575: "satellite-based"

We checked our manuscript for the occurrence of such formulations and changed them as suggested.

591-593: the phrasing is awkward in this sentence – hard to follow

This sentence has been reformulated.