Authors' response – ACP

Radiative closure and cloud effects on the radiation budget based on satellite and ship-borne observations during the Arctic summer research cruise PS106
by Barrientos Velasco et al.

Response to Anonymous **Referee #2**

We would like to thank Anonymous # 2 for dedicating time and giving suggestions to the improvement of the manuscript by providing us with valuable comments. We have revised the initial submission version and hope that the manuscript is now acceptable for publication.

The point-by-point response to the review comments is written here in italic-grey font. Additionally, in blue is marked the location of the modification of the text in the diff.pdf file.

Overall summary of major changes:

We would like to inform the referee about the following major changes based on the comments of Referee #1 and #2:

- Figure 17 and Table B1 were deleted from the manuscript.

Clarifications for specific comments:

- Ln 49-50: The data sources used by Riihelä et al. were CERES, GEWEX SRB (a separate dataset), and flux components calculated with the FluxNet-Streamer RT code driven primarily by CLARA cloud and surface parameters. Please clarify this point and note GEWEX data.

  This point has been clarified, and the text has been changed to (Page 2):

  'The investigation by Riihelä et al. (2017) presents an intercomparison between ground- based observations and several satellite products of surface radiative fluxes. Downward and upward LW and SW radiative flux observations from the Tara drifting ice camp and long-term observations on the Greenland Ice Sheet are compared to the CERES SYN1deg ed.3A, FluxNet, and Satellite Application Facility on Climate Monitoring cLoud, Albedo and RAdiation (CLARA) data sets (Karlsson et al., 2017), and the Global Energy and Water Exchanges (GEWEX) SRB (Wu and Fu, 2011). This study concludes that CERES SYN1deg has the smallest root-mean-square error (RMSE) compared against in-situ fluxes. This study recommends to further investigate differences in the surface and cloud properties that lead to discrepancies in flux retrievals.'

- Ln 147: Upon first read, I expected to find the specs for the horizontal size and resolution of the "pixel grid", only realizing later that the authors wanted to say that there is only one 'stack' of grid cells in the vertical direction. Please revise to clarify, noting at least the ballpark figure or estimate of the horizontal coverage/footprint of the shipborne measurements.

  The text has been modified and this aspect clarified as follows (Page 6):

  'As a first step, the measurements are averaged onto a common pixel grid with a vertical and temporal resolution of 31.18 m and 30 s, respectively, leaving a total of 595 vertical pixel grids and, in general, more than 2700 time-steps (Griesche et al., 2020)'

- Ln 159: If the QL retrievals are based on training against radiosondes, are you certain that the relationships based on a single source site in Ny-Ålesund are sufficiently robust to work anywhere else over the Arctic Ocean?

  There is no long-term data set of radiosondes profiles within the central Arctic Ocean from which a retrieval can be derived. Given that PS106 covered mostly the Svalbard region, it has been assumed that Ny-Ålesund provides consistent and reliable data set to train the LWP retrieval.

- Ln 165 and 170-172: The impacts of rain and liquid/ice mixtures on QL are noted, but isn't QI affected just as well, as cloud radar reflectivity is a driver for it too?

  Yes, it is. The text has been modified as follows (Page 7):

  'Precipitation conditions compromise the retrieval accuracy of Q_L and Q_I from the MWR and cloud radar, respectively.'

- Ln 183-185: Here it was difficult to follow what it means when "Cloudnet pixel type...(is) assigned value to zero". Does it mean that aerosols and insects are discarded from analysis entirely? Yet the later manuscript estimates CERES aerosol radiative effects, would there have been a chance to analyze similar aerosol effects from in situ data? This is a bit confusing.

  Yes, the pixels classified as "aerosols" or "insects" were excluded from the analysis. As per suggestion of Referee #1, the analysis of CERES aerosol effect has been removed from the paper to avoid distracting the reader from the main focus of the manuscript.

  For clarification, the text was changed as follows (Page 7).

  'Thus, as a first step, any Cloudnet pixel of "aerosols", "insects", and "aerosols and insects" are removed by changing its assigned value to zero to discard them from the analysis.'

  Section 2.2: The CERES data product background is nicely described, but please also state the name of the data product used. Is it SYN1deg?

  Yes. We opted to use the general name for simplicity. Nevertheless, for precision the new version considers CERES SYN1 for precision and consistency with the literature.

- Ln 227 – 228: The text reads like the PS106 radiosonde data was assimilated into ERA5. Was this indeed the case?

  Yes. As mentioned in the paper. ERA5 assimilates the radiosondes launched from Polarstern.

- Ln 242 – 244: The impact of ice crystal habits on RT has been investigated and the effects are not negligible (e.g. Wendisch et al., 2005: https://doi.org/10.1029/2004JD005294). Please provide some consideration for the potential impacts of assuming spherical ice crystals in T-CARS?

  We agreed on the high importance of the selection of the parameterization of the ice-crystals. We revised the text and edited it as follows (Page 9):

  'The parameterization for ice clouds assumes spherical ice crystals with $R_{E,I}$ values with an allowed range between 5.0 and 131.0 µm. Radiative fluxes are known to be sensitive to assumptions about the crystal habit, eg., hexagonal shape (Wendisch et al., 2005). However, the decision was made based on the availability of parameterizations in RRTMG and to be consistent with the Cloudnet parameterization of ice crystals.'

- Ln 289: Please be careful here – the ERA5 underestimation described by Pohl et al. had its roots also in the use of (simple) literature-based constants for the albedo of various ocean/ice surfaces – if SIC and ice albedo were perfectly simulated but melt ponds missing, the resulting albedo should be an overestimation since melt ponds darken the surface relative to snow or bare ice. The text now suggests that missed melt ponds will result in albedo underestimation, which is not generally so.

  After careful consideration and also the suggestion from Referee #1, we have decided to exclude the comparison of surface albedo between ERA5 and CERES since no additional analysis is provided after the comparison.

- Ln 414: The SWU effect is very large, but quite consistent with e.g. radiative kernel calculations for radiative energy balance disturbance following a certain change in albedo (e.g. Bright and O'Halloran, 2019) - you may wish to note this for reinforced belief in the result given.

  Bright, R. M., & O'Halloran, T. L. (2019). Developing a monthly radiative kernel for surface albedo change from satellite climatologies of Earth's shortwave radiation budget: CACK v1. 0. Geoscientific Model Development, 12(9), 3975-3990.

  Thank you for the reference. We consider the citation appropriate to emphasize the finding.

- Ln 432 – Looks like a broken reference here to a scatterplot figure X?

  Yes. Unfortunately, we repeated that text by mistake.

- Ln 581 - 582: A larger negative bias in CERES all-sky fluxes due to "the presence of clouds" seems like a half-formed sentence. Clouds are included in all-sky fluxes in every case, how do they now contribute to bias increases? Please be more specific.

  The clear-sky comparison is based on the Cloudnet classification. There were periods when clouds did not pass directly over the active remote sensing instruments, which is just a point measurement. Thus, no cloud observations were obtained; however, their presence have been captured on the larger spatial footprint by CERES. The text has been clarified to (Page 20):

  'These values confirm that the larger negative bias for all-sky conditions is due to the presence of clouds that were captured within the CERES footprint but did not pass over the shipborne remote sensing instrumentation.'

- Ln 611: Interesting to see a fog case noted, since those would be expected to be the ones where satellite-based fluxes could be very biased since fog conditions are challenging for them. Was this the only case of fog during the cruise?

  In general, the fog events were characterized by the classification of low-level stratus clouds. This suggests that fog events were often present during the PS106 cruise (Griesche et al., 2020). However, the case described was characterized by a dense fog that lasted the longest during the entire cruise.

- Ln 719 – 734: Here the attention seemingly slipped, resulting in broad repetition of content between the two paragraphs and generally hard to follow descriptions. Fig 17c and d are not really "subdivisions" of 17b since the y-axis unit is not the same, but they are the same sample set divided by albedo threshold. Please revise this section carefully for consistency and clarity.

  We agree with the comment. However, the text has been deleted considering the comment from Referee #1 (Page 24):

- Figures 2 to 4: Since you already have the visualization available on Polarstern being in open water, MIZ, or dense ice in Fig 16, why not include the same information here? It is especially relevant for Fig 2.

  Figure 2 to 4 were edited including this recommendation.

- Figures 8 and 10: Please note that light yellow is a color very easily lost during printing, perhaps a shade or two darker would be more apparent.

  The colour followed the standard Cloudnet's colours. Nevertheless, the new color is darker.

- Figure 11: The "pale yellow" shading appeared either red or orange (on screen and paper) – or is it the rectangular regions at ~10Z and ~23Z that you refer to here? Also, on this figure it seems that the Cloudnet-CERES differences in QL and QI are quite stable in time, but the CRE difference fluctuates considerably? I may have missed the explanation in the text, but why is this the case?

  Yes, we referred to the rectangular region at ~10Z and ~23Z. The shading is changed to gray. We explained that the abrupt change of surface albedo was due to the simultaneous rapid reduction of surface albedo from a value of 0.6 to 0.27. The end of section 3.3 explains it (Page 18).

  'The radiative effect of clouds on this day has a strong cooling influence both at the SFC and TOA that is enhanced by the surface albedo. In Fig. 11c. An abrupt change of the CRE at the SFC and the TOA is visible at 05:00Z in Fig. 11c, due to a simultaneous rapid reduction of surface albedo from a value of 0.6 to 0.27 (see also Fig. 2a).'