Journal: ACPD
Title: Observations and simulations of three-dimensional radiative interactions between Arctic boundary layer clouds and ice floes
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This manuscript provides airborne measurements of Artic cloud reflectivity over heterogeneous surfaces, particularly over the transition from dark ocean water to bright sea ice/snow covered surfaces. The transition from dark-bright surfaces impacts the transfer of radiation from the surface to the cloud such that reflectivity over bright ice surface is reduced and that over the dark ocean is enhanced – when in the vicinity of the ice edge. The impact of enhanced radiation above ocean surface has the potential to bias retrievals of cloud radiation, and this impact has a spatial extent that will depend upon the distribution of the ice-to-water area, cloud height, cloud thickness, etc.

The potential and degree of bias in the cloud properties then depends upon many, variable, factors including the specific surface albedo heterogeneity (amount of water area to ice area, total ice edge length, size/area of sea ice floes, etc.), the height of the cloud above the surface, the geometrical thickness of the cloud. Through a modeling study to simulate the surface and atmospheric conditions of a measurement case during the Arctic VERDI campaign, the authors present measurement support for the alteration in radiation at flight level (above cloud) at high spatial resolution. Through a series of simulations that vary the surface and atmospheric components, the authors then isolate how variations in these components impact the measured cloud reflectivity and their respective magnitudes. The manuscript presents representations of the physical scale over which the biases in radiation would impact a cloud retrieval and a second representation that defines the physical scale where the 3-D radiation differs from the 1-D (IPA) assumption. The incorporation of where the biased radiation (due to the 3-D effect) would exceed that due to the measurement uncertainty is included in the first representation. *However, due to the complexity of these Arctic scenes, and the relative importance of the surface conditions, cloud height, etc., the results in this manuscript are not meant to provide a parameterized correction for these biases, nor are meant to be compared to operational satellite cloud retrievals. The operational cloud retrievals utilize knowledge of the underlying surface albedo to indicate the spectral bands to be used in the cloud retrieval but which do not account for the 3-d effect of horizontal transfer of radiation from different surface type, nor how this horizontal transfer of radiation ultimately is further scattered and absorbed by the cloud before ultimately reaching the sensor. The authors plan future work to investigate these results over a larger number of measurement cases and to airborne-satellite retrieval comparisons.*

The authors have made substantial improvements to the manuscript to clarify the scope and goals of the paper and remove misleading statements in the original version of the manuscript. Some of my original interpretations I can now see were incorrect, while others have led to necessary and important clarifications in the manuscript. In addition, the revised version is more clearly arranged, and shorter in length. What results is a revised manuscript that establishes the importance of airborne measurements in advancing our knowledge of Arctic climate, given the many challenges for passive Arctic remove sensing of clouds, yet establishes the challenges that remain in moving from individual case studies to regional studies that will improve our understanding of the role of clouds in the sensitivity of the Arctic climate. I believe this work is a valuable contribution to the Arctic cloud literature, and I recommend acceptance with minor revision.

Listed now are comments and suggestions intended to improve the manuscript.

Minor Comments

1. Title to subsection 4: Would suggest altering the title to include the 3-d interaction between the heterogeneous surface and the cloud. Other than that, I think the remaining point of confusion regarding the type of 3-D effects you are quantifying could be on page 13, line 6 ("If we compare the 3-d effect for clouds.."
2. Page 8, line 27: I'm curious if you mean reflectance measurements taken at low flight levels (in clear sky conditions) when you measure "surface reflectance". Do you mean that you have removed the atmospheric contribution between the surface and the aircraft (i.e. a modeling component to the study), or have assumed (due to low flight-level) that this contribution is small, and therefore neglected?
3. Page 25, line 12: I would suggest clarifying that the retrieval is based on "the best fit of measurements to" the forward simulations.

Minor Technical Comments (grammar, spelling, comprehension, etc.)

Page 3, line 13: Spelling error; change to "macrophysical"
Page 9, line 2: Spelling error – change "fulfil' to "fulfill"
page 4, line 4: The "10" in the NOAA-10 satellite is printing out like an "IO" (eye-oh).
page 7, line 1: Suggest replacing "performed" with "taken".
Page 9, line 6: suggest alternate phrasing -replace "how strong" with "the degree to which", or something similar.
page 10, line 22: suggest phrasing change for subject-verb order: "There are two, distinctly separated maxima, which correspond to..."
page 12, line 12: "bright" and "enhanced" are redundant – could use just one of these.
Page 13, line 6: Suggest to begin the 2nd sentence on this page with, " With sea ice in the vicinity, the measured nadir radiance above the cloud parcel…" (ties in with the previous sentence that you are presenting contrasting material).
Page 13, line 7: suggest additions to sentence "…the horizontal photon path…is extended for clouds of higher altitude (compare for cloud A…)
Page 13, line 9: Does "…the distances presented here…" refer to Figure 6? Just a point of clarification.
page 13, line 20: suggest replacing "water covered area" with "open sea".
Page 13, line 26: "independent of" not "independent on"
page 14, line 1: suggest adding "(see red curve in Fig 6)" after "… scene from Fig.4a,.."
page 19, line 9: suggest adding "cases" after "…the following simulations cover two cloud~~s~~ *cases*…" .
page 26, line 12: Suggested wording changes: "For a ~~lower~~ smaller tau, the effect will be ~~lower~~ reduced."
page 27, line 3: Suggested phrasing change: "…was used to distinguish between ~~areas of both surfaces~~ these surface types."
page 27,line 6: Is the word "separated" necessary here? I think you could remove it.
Page 27, line 10: Suggest rephrasing the sentence for higher impact, "To quantify the uncertainties of a cloud retrieval in such areas of open water close to ice floes, reflectance measurements from the VERDI campaign and 3-D radiative transfer simulations were performed with MCARaTS for a clear-sky case and tau=1/5/10 located above various, idealized surface albedo fields."
Page 27, line 14: suggest Moving the position of the ΔL: "..to estimate the distance to the ice edge (ΔL) within which the …"

Page 28, line 2: “are ~~a~~ robust measures ~~to~~ that quantify…”
page 29, line 2: Suggest small sentence structure change for readability "...to airborne measurements taken over ocean areas located close to sea ice edges will result in an overestimate of tau and reff and the overestimation will increase with proximity to the ice edge."
Page 29, line 8: A small point that the 1.5 km is respective to the mean of the results, yet earlier in the paper the 2 sigma std. dev value of 1 km was used. The results support both, but I mention it in case you want to quote consistent value in your summary.
Page 29, line 12: The very last sentence of the manuscript is awkward concluding sentence (the “which dealing” part should be amended.)

Figure Comments
Figure 4: I see a small “ring” of enhanced over ocean radiation around the ice floe. Is your interpretation that the enhancement seen is due only to that from the nearby heterogeneous surfaces (i.e. Jäkel, 2013 findings).
Figure 9: I would ask for added clarification in figure caption. Suggestions are: a). Simulations for varying cloud base, given a fixed geometrical thickness of 500 m. b) Simulations for varying cloud thickness, given a fixed cloud base at 0 m.
Figure 11: I would expect that the 1-d IPA results for tau =1 (cloud altitude = 500-1000 m), would asymptote to the same value (2 km) as shown in Figure 10a (diamond values). Did I misinterpret?
Figure 12/13: I would appreciate further clarification in interpreting the frequency distribution for scenario 4 with respect to the model simulation setup and results in Figure 12. Unless I am not fully appreciating the importance of the scene “averaging”, I would feel that the frequency distribution for scenario 4 would actually be the red line in Fig 13 a (identified as Scenario 2 in the legend), where the over water enhancement is larger than in Scenarios 2 and 3. Is my expectation incorrect, or is there a labeling error in the legend captions for Fig 13?